Geothermal Resource Assessment of the Drava Basin

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Geothermal Resource Assessment of the Drava Basin
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Hungary-Croatia
IPA Cross-border Co-operation Programme

A cross-border region where the rivers crosses, not divide

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Geothermal Research in the Drava Basin

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Contents

INTRODUCTION

Introduction in English

It is well known that due to its high temperature gradient the Pannonian basin is a favourable area for geothermal energy production. This natural resource is further enhanced by another advantage of the area; knowledge and experience resulting from decades long geological, hydrogeological and hydrocarbon exploration. This knowledge has special importance as existence of subsurface resources is necessary, but not sufficient condition for providing sustainable energy for the population. This subsurface resource will only convert to useable energy source following adequately planned and executed exploration and exploitation program.

Planning and execution starts with understanding and detailed mapping of subsurface startigraphy, hydrogeology and tectonics. As a first step areas with significant potential for geothermal energy utilization can be selected based on the results of geological and geophysical investigations. Selection of the most suitable technology on the other hand depends not only on subsurface hydrogeology, but also on present day and future geographical and economical considerations. All this is topped with environmental and legal considerations, which provide the framework for sustainable and well controlled energy utilisation.

Subsurface geology is not changing on human timescale, but still it is difficult to reveal and understand it in great details. Technology on the other hand is rapidly developing and the environmental regulations tend to become stricter from year to year. This complexity and variety gives the difficulty and the beauty of geothermal energy utilization.

All these aspects have been considered during the DravaGeo project which evaluated the cross-border area of Drava basin across the Hungarian-Croatian border. Drava basin is not only an excellent study area because of its subsurface geology. Hungarian hydrocarbon exploration started in the Drava basin and the neighbouring Zala basin, which was also part of our study area. A unique geological database resulting from almost 80 years of hydrocarbon exploration is a solid basis for geothermal exploration.

At the same time southern border areas along the Croatian border are primary target areas for development. It is high time to reconsider resources and possibilities in these areas. As part of these reconsiderations both traditional and new areas should be considered. Geothermal energy may become one of the new key areas.

Geology, hydrogeology and geothermal characteristics of the Drava basin is summarized in the first part of this book introducing several maps prepared during the project and never published before. These maps summarize project results and possible geothermal energy resource areas in the Hungarian-Croatian border area in an easy to understand way also for non-technical readers. Next chapters of the book give an overview of the economical, settlement development and legal aspects of the area providing a framework for project planning. Overview of geothermal technologies is presented in a CD-ROM publication of the DravaGeo project.

Hungarian and Croatian translation of this book can be found on the DravaGeo project web site: www.geo.dravamedence.hu

Introduction in Croatian

Često se spominje kao činjenica da zahvaljujući visokom geotermičkom gradijentu u Panoskom bazenu u eksploataciji i iskorištenju geotermalne energije posjeđuje izvrsna svojstva. Ovim prirodnim resursima se pridružuje i druga prednost koja je data akumulacijom znanja koja je najvećim dijelom rezultat istraživanja na području hidrologije, geologije i fosilnih energenta (plin i nafta). Važno je to zato jer sami podzemni geotermički, a i bilo koji drugi prirodni resuri nisu dovoljni da bi doprinjeli održivom razvoju i društvenom blagostanju bilo kojeg geografskog područja.Ovaj energent je društveno a održivo iskoristiv samo nakon jako detaljne i sveobuhvatne plansko-izvršne djelatnosti.

Ove djelatnosti počinju upoznavanjem podzemnih tektonskih, geoloških i hidroloških odnosa. Na temelju rezultata geoloških i geofizičkih istraživanja se mogu odabrati lokaliteti, na kojima sa već postojećim eksploatacijskim i tehnološkim mogućnostima može uspješno iskoristiti geotermalna energija. Pri izboru primjenjene tehnologije eksploatacije važno je poznavanje ne samo pozemnih geoloških odnosa već i društvenih-gospodarskih prilika, kako i definiranje mogućih potreba konkretnog područja. Ovim se informacijama još pridružuju oni ekološki propisi, zakonske, pravne odredbe, koji s jedne strane doprinose održivosti a s druge strane osiguravaju pravilno funkicioniranje. Geološke odrednice su, mada teže upoznatljive, one su stalne i skoro nepromjenjljive već duže vrijeme, tehnologija iskorištavanja je u stalnoj promjeni, razvoju a ekološki zahtjevi konstantno postaju sve stroži. U rješavanju ove raznolike problematike je i težina a i ljepota iskorištavanja geotermalne energije.

Prilikom naših istraživanja dajemo pregled svih ovih zadataka na jednom konkretnom području, u Dravskom bazenu, koji se prostire u pograničnoj zoni Hrvatske i Mađarske. Ovaj je bazen izvrsno područje istraživanja i zbog geoloških prilika, a naročito sa područjem županije Zala koje je isto uključeno u naša ispitivanja, a predstavlja koljevku istraživanja ugljikovodika u Mađarskoj i Hrvatskoj. Rezultati geoloških istraživanja, u prošlih 80 godina čine sigurnu podlogu za geotermalna istraživanja.

Uz spomenute zapadne dijelove, posebno su interesantna i južna i istočna područja Dravskog bazena, jer predstavljaju ključne točke fokusa prostornog planiranja i prostornih razvojnih politika Mađarske a i Hrvatske. Potrebno je ponovno posebno razmotriti svaku mogućnost i potencijal u klasičnim i u novim društveno-gospodarskim sektorima. Takav je sektor i primjena geotermalne energije.

Prvi dio naše knjige pruža pregled geoloških, hidrogeoloških i geotermalnih uvjeta preko brojnih tematskih i stručnih karata, koje su nastale prilikom ovog istraživanja, baš zato sadrže i daju rezime još nigdje ne objavljenih znanstvenih rezultata. Ove zanstvene i tematske karte pružaju uvid i laicima u mogućnosti potencijala i mogućeg iskorištavanja geotermalnih resursa hrvatsko-mađarskog pograničnog područja. Drugi dio knjige daje pregled gospodarskih, razvojnih i pravnih okvira, potrebnih za izradu konkretnih projekata. Mogućnosti tehničkih i tehnoloških aplikacija i realizacija sadrži jedno posebno cd izdanje koje je isto nastalo kao rezultat projekta DravaGeo.

Potpuni hrvatski i mađarski prijevod ove knjige je dostupan u digitalnom formatu na web starnici projekta DravaGeo: www.geo.dravamedence.hu

Introduction in Hungarian

Gyakran emlegetett tény, hogy magas hőmérsékleti gradiensének köszönhetően a Pannon-medence geotermikus energia termelése és felhasználása szempontjából nagyon kedvező természeti adottságokkal rendelkezik. Ezekhez a kedvező természeti adottságokhoz társul a terület egy másik nagy előnye; az a tudás és ismeretanyag, ami az elmúlt évtizedek földtani-, vízföldtani- és szénhidrogén-kutatásai során halmozódott fel hazánkban. Fontos ez azért, mert a felszín alatti természeti adottságok megléte önmagában nem elegendő ahhoz, hogy az itt élő emberek számára fenntartható energiaforrást biztosítson. Ez az energiaforrás csak egy sokrétű és nagyon alapos tervezési-kivitelezési munka elvégzését követően válhat a társadalom számára elérhetővé és fenntartható módon kiaknázhatóvá.

A tervezési-kivitelezési munka a felszín alatti rétegtani, vízföldtani és tektonikai viszonyok részletes megismerésével kezdődik. A földtani és geofizikai vizsgálatok eredménye alapján lehet kiválasztani azokat a területeket, ahol a geotermikus energia felhasználásának valamely lehetséges módja sikerrel alkalmazható. Az alkalmazandó technológia kiválasztásához már nem csak a felszín alatti geológiai viszonyok, hanem a konkrét terület népességi, gazdasági jellegzetességeinek ismerete, sőt várható jövőbeni igényeinek felmérése is szükséges. Ehhez társulnak azok a környezetvédelmi előírások és törvényi, jogszabályi keretek, melyek egyrészt a fenntarthatóságot, másrészt a szabályozott működést hivatottak elősegíteni. A földtani viszonyok hosszú idők óta adottak, de nehezen megismerhetőek, a műszaki megvalósítás lehetőségei folyamatosan változnak és fejlődnek, a környezetvédelmi elvárások pedig jellemzően szigorodnak. Ez a sokszínűség adja a geotermikus energia felhasználásának nehézségét, de egyben a feladat szépségét is.

Vizsgálataink során mindezeket a feladatokat egy konkrét terület, a Dráva-medence országhatáron átnyúló, Magyarországot és Horvátországot érintő példáján tekintettük át. A Dráva-medence nem csak földtani adottságai miatt bizonyult kitűnő vizsgálati területnek. A vele közvetlenül határos és vizsgálatainkba szintén bevont Zala-medencével együtt a hazai szénhidrogén kutatás bölcsője volt. A közel 80 év kutatásának eredményeként előállt földtani ismert a Pannon-medencén belül is kiemelkedő, kitűnő alapot biztosít a geotermikus kutatások számára.

Ugyanakkor a déli, horvát határok menti területek a területfejlesztésnek elsőrendű célterületei. Időszerűvé vált újragondolni a térség adottságait és lehetőségeit. Ezt részben a hagyományos ágazatokban, részben pedig új területeken lehetséges megtenni. Ilyen terület lehet a geotermikus energia alkalmazása is.

Könyvünk első része a terület földtani, hidrogeológia és geotermális viszonyait tekinti át számos olyan új térképet bemutatva, melyek a kutatás során létrejött, korábban sehol nem publikált eredményeket foglalják össze. Ezek a térképek a laikus olvasó számára is érdekes és értékes adatokat szolgáltatnak arra vonatkozóan, hogy a vizsgált magyar-horvát határterület mely részei milyen geotremikus lehetőségeket rejtenek. A könyv további része a gazdasági, településfejlesztési és jogi hátteret tekinti át, megadva azt a keretet, ami a konkrét projekttervezéshez szükséges. A lehetséges műszaki megvalósításokat egy külön CD kiadvány tartalmazza, mely szintén a DrávaGeo projekt eredménye.

A könyv magyar és horvát nyelvű fordítása teljes terjedelemben megtalálható a DrávaGeo project honlapján: www.geo.dravamedence.hu

I. EVALUATION OF GEOTHERMAL RESOURCES IN SOUTHERN TRANSDANUBIA AND THE TRANSBOUNDARY REGION OF CROATIA

1. INTRODUCTION

Somogy Megyei Önkormányzat (SMÖ), Baranya Megyei Önkormányzat (BMÖ), Zala Megyei Területfejlesztési Tanács (ZMTT) and University of Pécs (PTE) have been awarded the project to evaluate the geothermal potential of southern Transdanubia, Hungary, and transborder region of the Drava basin in Croatia. The main geothermal prospects of this area are related to reservoirs in Upper Pannonian sandstones, Lower Pannonian turbiditic sandstones, Middle Miocene Lithothamnium-bearing limestones, Mesozoic (mainly Triassic) carbonates and fractured metamorphic basement rocks.

Geomega Ltd. acquired 2000km of 2D seismic sections and the most important well data from the MBFH (Hungarian Mining and Geological Authority). This was completed by collection of water flow tests and measured temperatures from selected new wells. It was followed by a complex evaluation of this large database. The evaluation was geophysically oriented and consisted of digitalization of paper based well logs, construction of SMT Kingdom seismic project and stratigraphic interpretation of 2D seismic sections. This resulted in good knowledge of the different geothermal reservoirs in southern Transdanubia.

Further interpretation of the seismic data was carried out in order to arrive at a new tectonic map of the study area. The map and the seismic sections show that the main tectonic elements related to the formation of the basin have been the subject of neotectonic reactivation. Active faults exert a major control on the fluid flow and heat transfer systems of the basin. New temperature and thermal gradient maps have been constructed to check this relationship and to outline areas where hydraulically open fault systems are available.

We have arrived at the main conclusion that southern Transdanubia and the adjoining Croatian territories exhibit major potential for geothermal utilization. The main value of this work is given by the acquired knowledge and created database, which together can offer optimal projects for geothermal installations in the study area.

2. FORMATION OF THE PANNONIAN BASIN AND MAIN GEOPHYSICAL FEATURES

The Pannonian basin is located in eastern Central Europe, as part of the Alpine orogenic system (Fig. 2.1). The Alpine, Carpathian and Dinaric mountain belts surround this extensional basin of Neogene–Quaternary age. Its broader geological environ, the Mediterranean region, is a wide zone of convergence between the Eurasian and African plates.

A remarkable feature in this overall compressional setting is the abundance of extensional basins superimposed on former orogenic terranes and associated with orogen-parallel displacement of internal blocks and oroclinal bending (Horváth & Berckhemer 1982). Following the suggestion of Horváth (1988), Ratschbacher et al.(1991) argued that extensional collapse occurs during tectonic escape and suggested the term extrusion to describe these interrelated processes.

The goal of this chapter is to review recent data regarding the formation and deformation of the Pannonian basin system. This can assist the understanding of the Transdanubian part of the basin, which is fundamental to describe the geothermal energy potential in the transboundary territory of Hungary and Croatia.

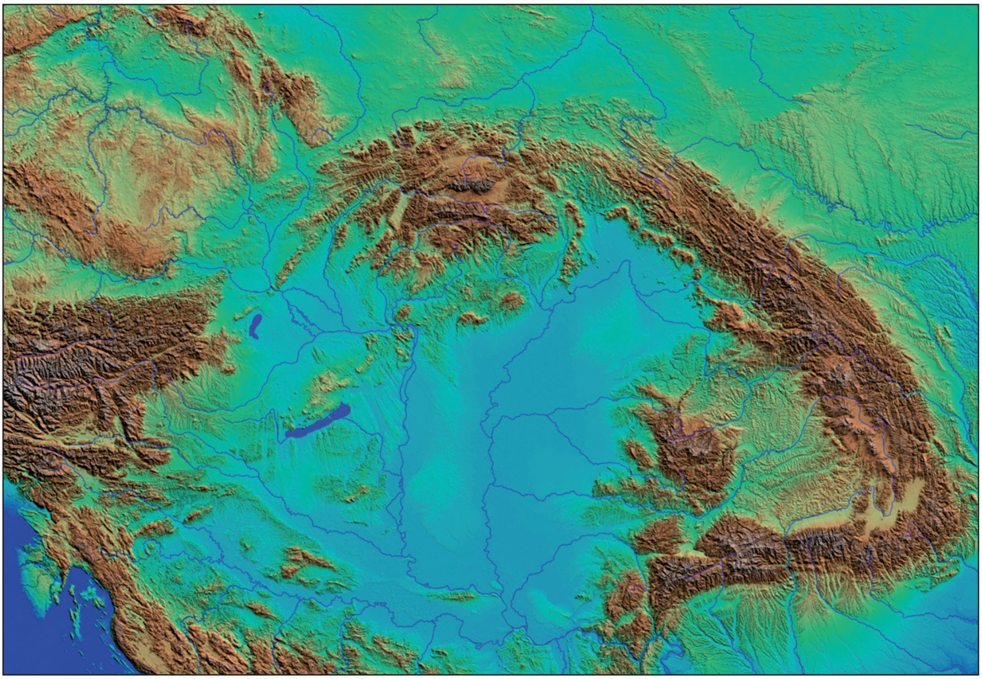


Figure 2.1. Digital terrain model of the Pannonian basin to show its position within the Alpine, Carpathian and Dinaric mountain belt

2.1. Review of tectonic history

The Pannonian basin and its surroundings are characterized by a polyphase deformation history with a sequence of distinct structural episodes. There is a good knowledge of the principal kinematic features, which is the location of major fault zones, the timing and the amount of deformation (Fig. 2.2). A rapid and dramatic change in tectonic style started in the Early Miocene, which initiated the formation of the Pannonian basin. This process culminated in the mid-Miocene (Badenian) and was coeval with a large-scale tectonic transport of the external flysch nappes towards the foreland of the Carpathian arc (Royden et al. 1982).

Kinematic data (Fodor et al. 1999) and numerical modeling (Bada 1999) suggest the predominant role of Carpathian subduction facilitating large-scale lithospheric extension in the Pannonian basin from latest Early Miocene to Pliocene times. Continuous roll-back of the subducting plate along the contemporaneous Carpathian arc exerted trench-pull forces on the upper plate. (Fig. 2.3) The overriding plate in a subduction zone tends to passively follow the retreating hinge of the downgoing lithosphere. This induced tensional stresses and eastward stretching of the ALCAPA and Tisza–Dacia terranes. The upper plate is extending in the direction of maximum gravitational potential energy difference. Trench suction forces acting normal to the curvature of the Carpathian arc, in combination with collisional forces exerted along the Alpine–Dinaric belt, can reproduce well the reconstructed Mio-Pliocene palaeostress pattern (Bada 1999). Because of the finite strength of the Pannonian lithosphere, tensional stresses were transmitted far behind the arc region and, as a consequence, nearly the whole Pannonian basin system extended significantly. It is important to emphasize that there are no remarkable differences in either the style or the amount of extension between the formerly distinct ALCAPA and Tisza-Dacia terranes. There is, however, one obvious exception; the presence of the coeval non-extensional Transylvanian basin in the eastern part of the Tisza–Dacia unit (Ciulavu et al. 2002). The formation of this basin is poorly understood and the original concept of Royden et al. (1982) still seems to be the most plausible. They explained the Transylvanian basin as a continental sag caused by the suction force exerted to the upper plate by the downbending Carpathian slab.

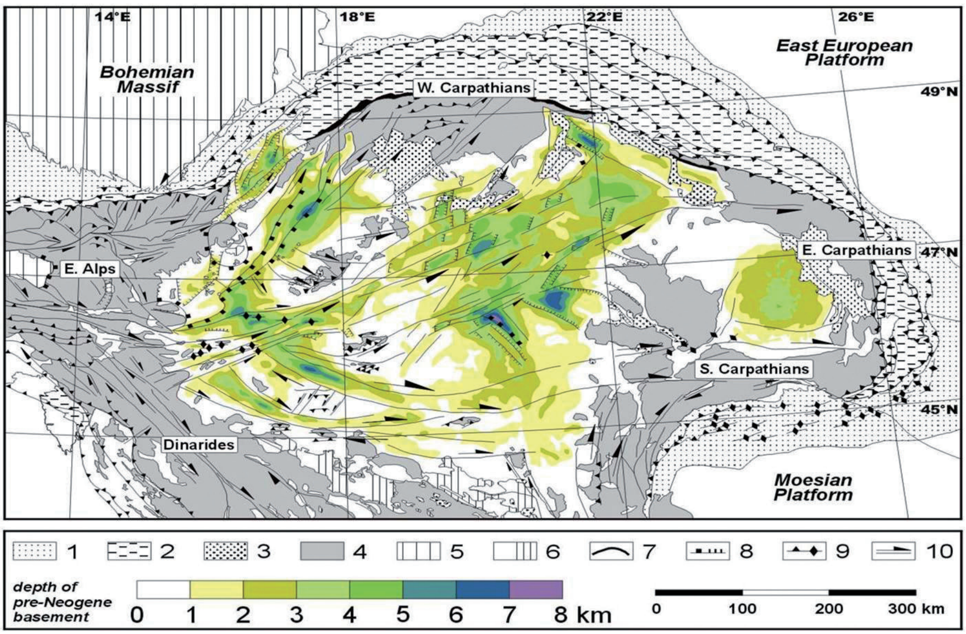


Figure 2.2. Map showing the depth to basement of the Pannonian basin and the main faults controlling the basin formation. Legend:
1 = Foredeeps; 2 = Flysch belt; 3 = Miocene volcanoes; 4 = Inner Alpine, Carpathian and Dinaric mountains; 5 = Bohemian massif; 6 = Dinaric ophiolites; 7 = Boundary of main tectonic units; 8 = Detachment and simple normal faults; 9 = Thrusts and folded anticlines; 10 = Strike-slip faults.

Tension in the Pannonian region caused about 50–120% crustal lithosphere extension and nearly an order of magnitude higher mantle lithosphere extension (Horváth et al. 1988; Lenkey 1999). Occasionally, extension was concentrated in discrete zones where pull-apart basins developed (Horváth & Royden 1981; Horváth 1993; Csontos 1995; Fodor et al. 1999). Heterogeneous extension is reflected by the variation of pre-Neogene basement depth (Fig. 2.2). Elevated basement blocks separate deep sub-basins where the thickness of the Neogene–Quaternary sedimentary rocks can reach 6–7 km. Such irregular basement morphology is mainly the result of strain localization along pre-existing crustal weakness zones inherited from Late Cretaceous thrust and nappe tectonics.

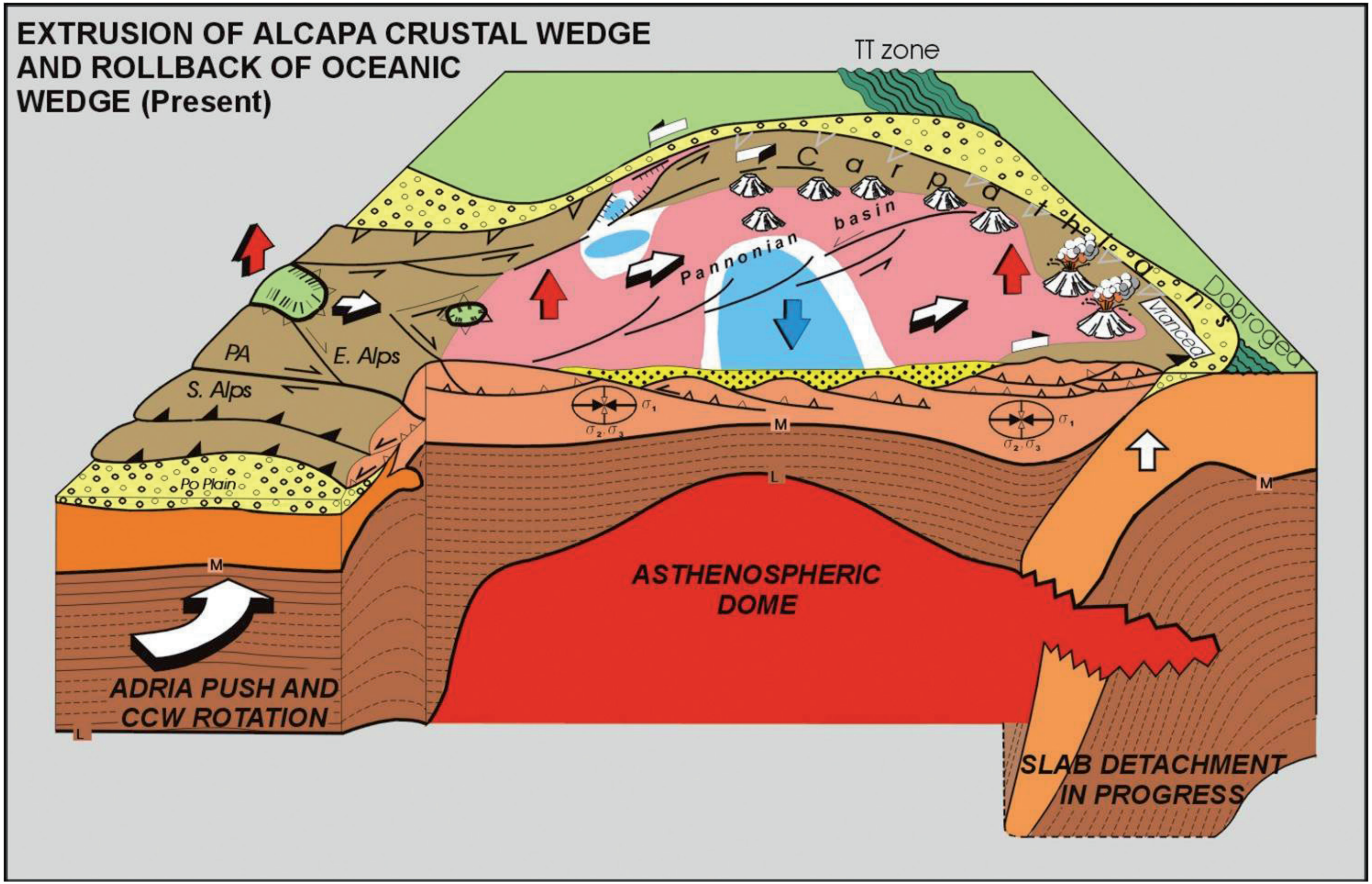


Figure 2.3. Box model to illustrate the formation of the Pannonian basin and the related subducted slab. Arrows indicate the present kinematic pattern of region

Quaternary differential vertical movements, related erosion and sedimentation have significantly influenced the observed thickness of the basin fill. These processes are related to the late stage of basin evolution. Contemporary stress data, seismicity pattern, seismic profiles and Quaternary subsidence history indicate that the Pannonian basin is in the phase of structural inversion (Horváth 1995; Horváth & Cloetingh 1996; Bada et al. 1999; Gerner et al. 1999). An increase of horizontal compression as a result of the changes of boundary conditions around the basin system causes buckling of the Pannonian lithosphere (Horváth & Cloetingh 1996; Cloetingh et al. 2006) manifested in the uplift and subsidence of the basin flanks and centre, respectively (Fig. 2.4). Present-day boundary conditions include active collision along the Alps–Dinarides belt (Adria-push), terminated subduction and continuing continental collision in the SE Carpathians and eastward translation of crustal wedges currently squeezed out from the region of the Alpine orogen (Fig. 2.3).

Stratigraphic data provide important information on the basin evolution in terms of timing and characterization of major tectonic events. Furthermore, the petrological and geochemical analyses of magmatic rocks give further constraints on the composition, thermal state and rheological behaviour of the deforming lithosphere-asthenosphere system.

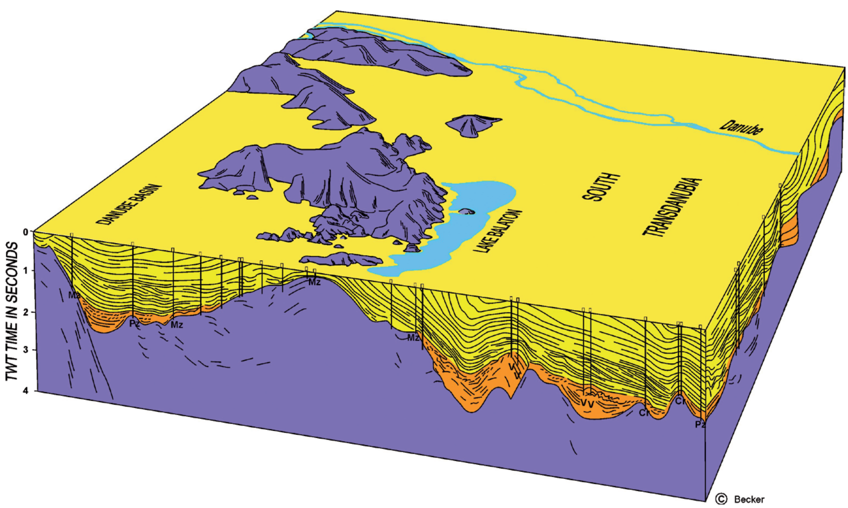


Figure 2.4. Box model to illustrate the Quaternary deformation pattern of the area characterized by subsidence (e. g. axial part of the Danube basin and uplift (e. g. Transdanubian Range)

Volcanic rocks identified in the Pannonian-Carpathian system (Fig. 2.2) show large variation in lithology, geochemical composition, and spatial and temporal distribution (Pécskay et al. 1995; Harangi 2001; Konecny et al. 2002). Silicic volcanism started about 20 Ma ago with the deposition of ignimbritic flow deposits and rhyolitic tuffs. The second main type of magmatic activity during Miocene to Quaternary times (20-0.15 Ma) produced large bodies of calc-alkaline volcanic rocks in the northern Pannonian basin and at the inner side of the Eastern Carpathians. The third main type of magmatic activity in the Pannonian-Carpathian region took place during Late Miocene–Pleistocene times (12–0.5 Ma) with a climax at 3–5 Ma (Balogh et al. 1986; Pécskay et al. 1995), producing mainly alkali basalts and some other mafic rocks. Volcanic products are located throughout the Pannonian and Transylvanian basins and are of much lower volume than the calc-alkaline rocks.

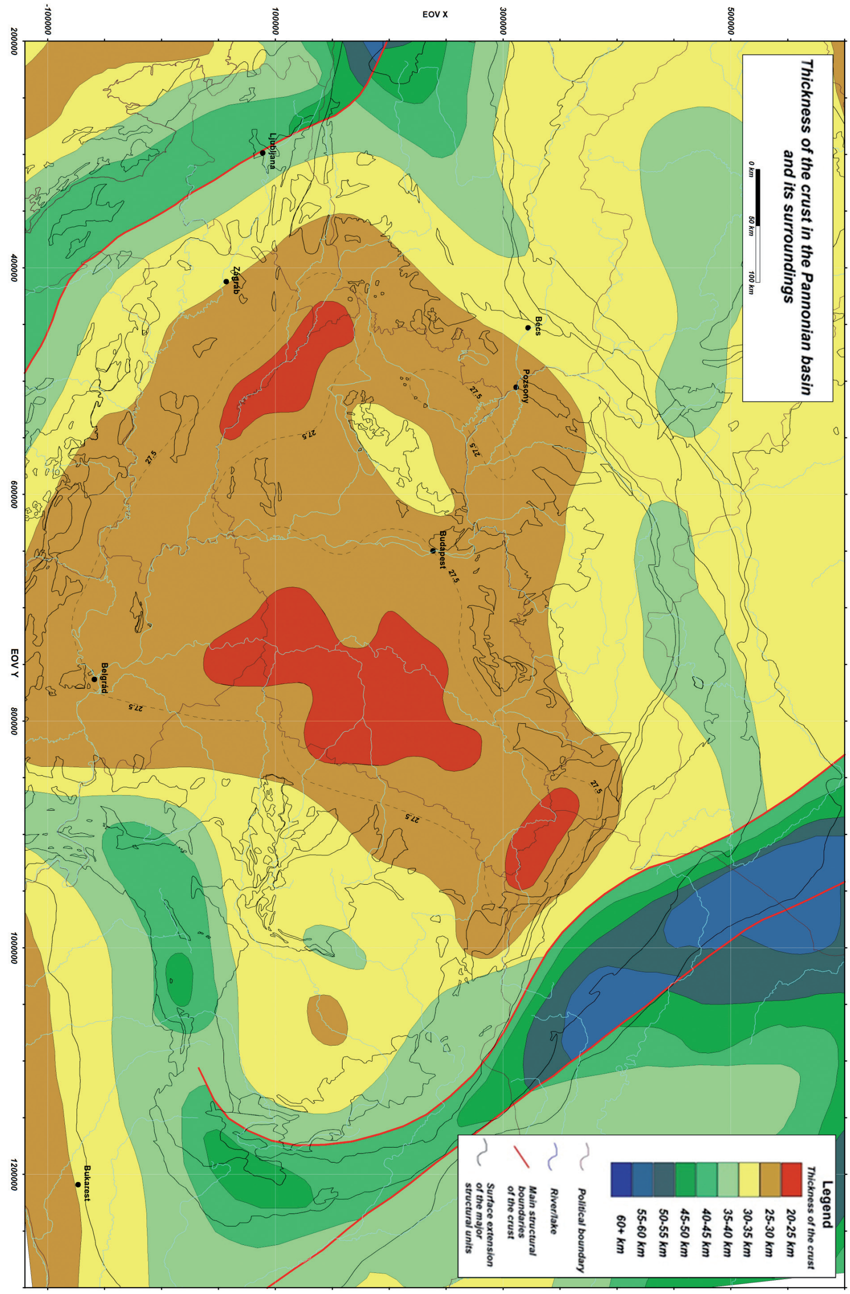


Figure 2.5. Map of crustal thickness in the Pannonian basin and surrounding orogenes showing anomalously thin and thick crust, respectively (OTKA T034928)

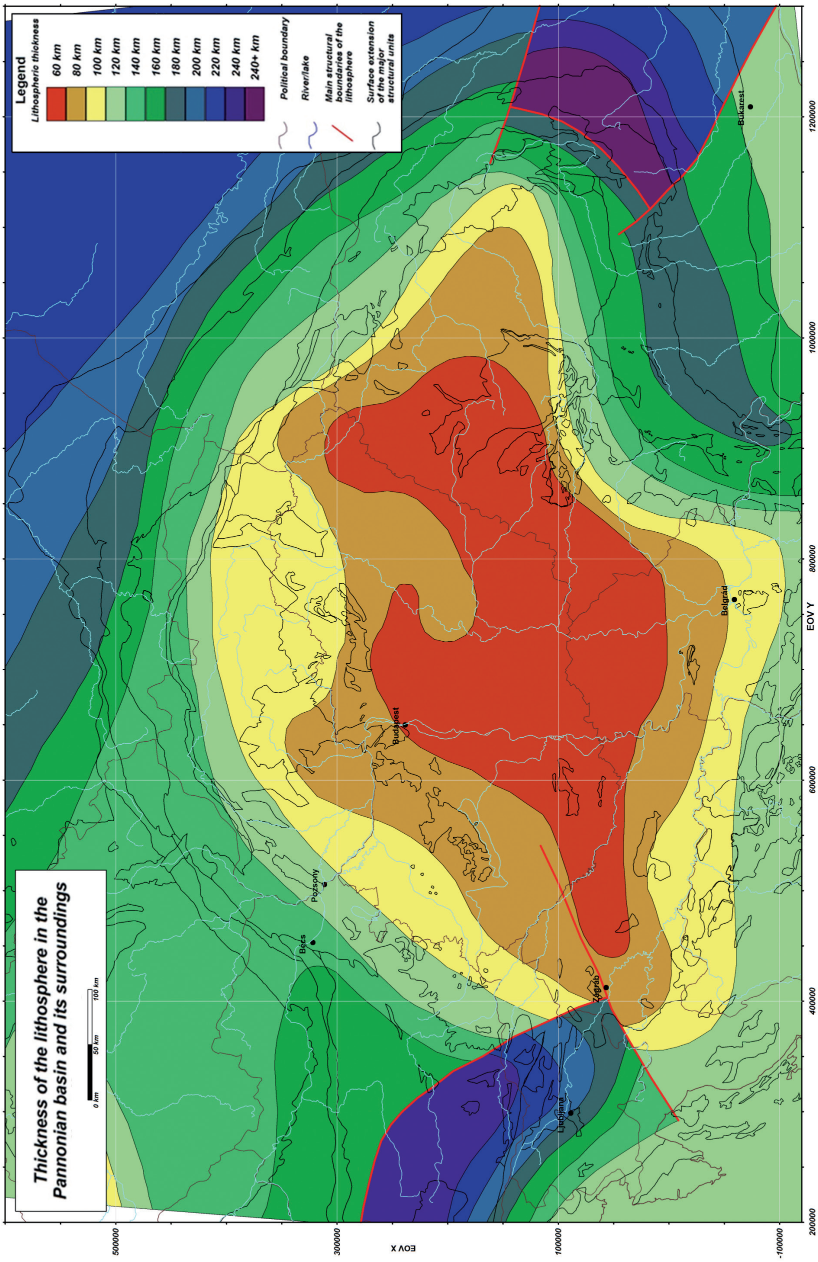


Figure 2.6. Map of lithospheric thickness shoving large updoming of the hot asthenosphere below the Pannonian basin (OTKA T034928)

2.2. Lithospheric structure

Formation of back-arc basins is a lithosphere-scale process (Fig. 2.3). Knowledge of the crustal and lithospheric thickness maps of the Pannonian basin system and the surrounding orogens provides further constraints on the mechanism of their formation and subsequent deformations. The map of crustal thickness (i.e. depth to the Moho discontinuity) is shown in Figure 2.5.

The lithospheric thickness map (Fig. 2.6) has also been improved remarkably in the Pannonian basin as a consequence of new magnetotelluric soundings and sophisticated inversion of all available apparent resistivity and phase shift sounding curves (Ádám & Wesztergom 2001). This shows that the depth to the low-resistivity asthenosphere is on average 60–65 km in the basin, and locally, as the Békés depression, rises to 50 km depth (Ádám et al. 1996). Tomography studies (Weber 2002) revealed the presence of relatively high seismic velocities beneath the Békés depression. Weber (2002) explained this phenomenon by local compositional differences in the mantle as a result of a mafic intrusion corresponding to the continental rift model as indicated by interpretation of gravity and magnetic measurements (e.g. Ádám & Bielik 1998).

Both terranes were characterized by extensive Early to Mid-Miocene silicic volcanism of identical geochemical composition (Harangi 2001). This implies that lower crustal melting and low crustal strength were common features of the two terranes. The anomalously high temperature gradient from the Early Miocene is well constrained by subsidence, thermal and maturation history analysis carried out for Neogene basins on both terranes (Horváth et al. 1988).

2.3. Heat flow

The terrestrial heat flow provides basic information on the geothermal processes at depth. There are abundant temperature and thermal conductivity measurements in the Pannonian basin and the surrounding region, which allow the determination of the heat flow in many locations (Dövényi et al., 1983; Dövényi and Horváth, 1988; Ravnik et al., 1995).

The surface heat flow distribution in the Pannonian basin shows values ranging from 50 to 130mW/m^2, with a mean value of 100mW/m^2. The average heat flow in the basin is considerably higher than in the surrounding regions. The Ukrainian and Moesian Platforms are characterized by low heat flow values of 40–50mW/m^2, which are typical for the stable continental crust (Demetrescu et al., 1989; Gordienko et al., 2001). The Carpathians and the Bohemian Massif show varying heat flow values of 50–70mW/m^2, which are close to the worldwide mean value for continental crust (65mW/m^2) (Pollack et al., 1993). The Outer Dinarides are characterized by extremely low heat flow values (<30mW/m^2). The low heat flow is due to karstic water flow in the carbonatic rocks of the mountains (Ravnik et al., 1995). The Inner Dinarides have heat flow of 50–60mW/m^2. The Adriatic Sea shows varying heat flow of 30–50mW/m^2. The high heat flow in the Eastern Alps is based on a few data. The peripheral Vienna and Transylvanian basins are characterized by lower heat flow values (50–70 mW/m^2 and 50mW/m^2, respectively) than the central basins. The low heat flow in the Transylvanian basin suggests that it was formed by a different geodynamic mechanism than the Pannonian basin.

The Transdanubian Range and some parts of the North Hungarian Mountains (Bükk, Aggtelek-Gemer Karst) are characterized by low heat flow (50-60mW/m^2). These mountains are built up from Mesozoic carbonates, which are exposed at the surface. The fractured and karstified rocks have large permeability, which allows easy infiltration of meteoric water. The downgoing water cools almost the whole area of the outcrops. The water is heated up at depth and returns to the surface at the feet of the mountains in thermal springs. Most importantly, these carbonate rocks at depth in the Transdanubian

Range belt, mid-Hungarian belt and around the Mecsek and Villany Mountains represent a huge, hot water bearing reservoir in Transdanubia and Croatia.

3. HYDROGEOTHERMAL SYSTEMS OF THE PANNONIAN BASIN

3.1. Introduction

The immense heat of the Earth is stored in rocks, as well as in the fluids filling their pores and fractures. The classical utilization of geothermal energy is based on deep circulating *thermal groundwaters from hydrogeothermal systems* (Fig. 3.1). Heating from the Earth interior causes thermal expansion of the subsurface fluids causing lower density, and therefore their rising along suitable pathways, like subsurface conduits and faults. Logically, these hot waters may reach the surface and discharge at thermal springs, or drilled wells. Cold meteoric water from precipitation with higer density and higher hydaulic potential recharge the systems. To avoid overexploitation of geothermal systems extracted thermal water has to be replaced by re-injection, or only that amount of water can be abstracted whose natural recharge is guaranteed. This issue makes a strong link with water management policies (e.g. Water Framework Directive 2000/60/EC).

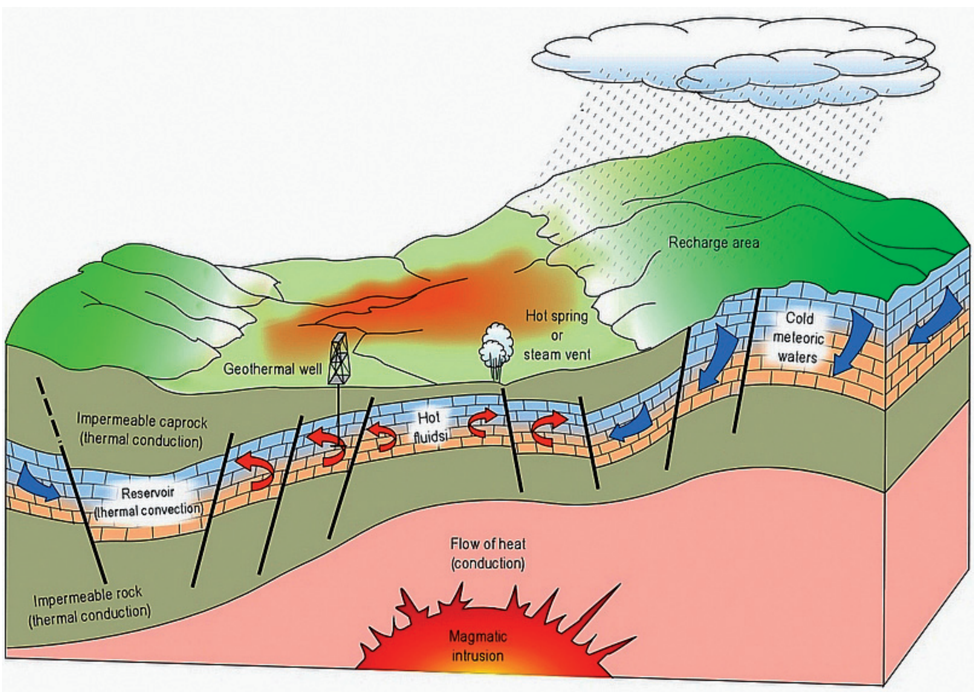


Figure 3.1. Model of hydrogeothermal reservoirs

3.2. Outline of the regional water flow

There are two major types of thermal water reservoirs (aquifers) in the Pannonian basin: (A) the karstified-fissured basement rocks and (B) the porous basin-fill sequences (Fig. 3.2). Although these two major units can be in hydrodynamic connection, they are characterized by different flow regimes, which are summarized below.

The multi-layered flow system of the Pannonian basin (e.g. Erdélyi 1979, Tóth 1999, Rman et al. 2011a) can be outlined on the basis of pressure conditions, the chemical character of the groundwaters, as well as geothermal. The deep groundwater flow systems in the Pannonian basin are maintained by the considerable hydraulic potential between the recharge and discharge areas (i.e. mountain chains and low-lying basin), sufficient recharge (precipitation) and extensive deep-lying permeable formations outrcropping at the surface at large areas (Fig. 3.2).

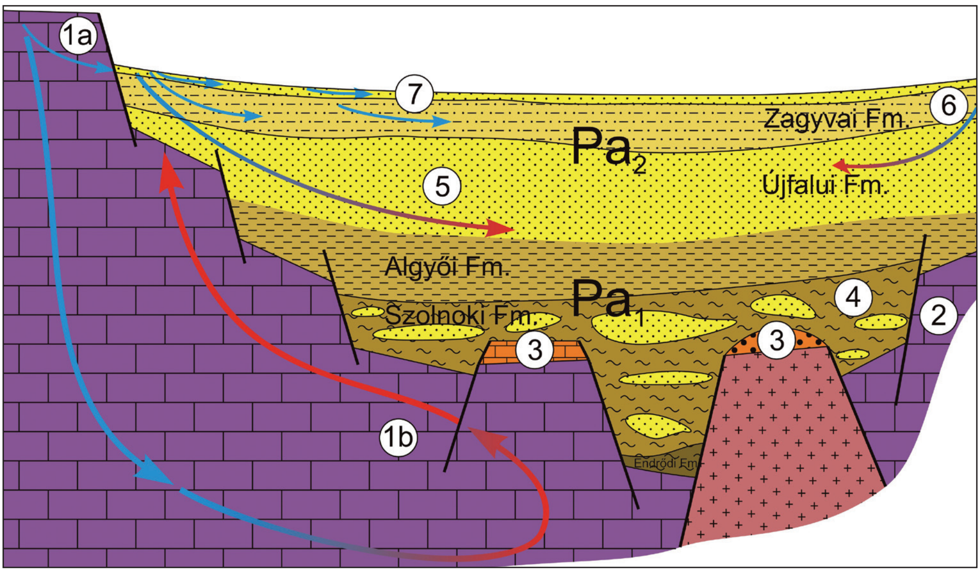


Figure 3.2. Main types of groundwater flow systems in the Pannonian basin. Legend: 1a= gravity-driven cold karst flow system, 1b= mixed gravity- and geothermal (density)-driven flow system (regional karst flow system), 2= deep carbonate rock bodies with fairly stagnant thermal groundwater reserves, 3= sands, gravels, reef carbonates, etc.) directly overlying the karstic basement rocks, 4= overpressured zones, 5= regional flow system in the porous basin fill, 6= intermediate flow system in the porous basin fill, 7= local (shallow) flow system in the porous basin fill.

A. The main aquifer zones of the basement comprise the uppermost weathered and karstified parts of the carbonate rocks. They have two major types.

(1) The *gravity driven flow systems* are supplied by the karstic groundwater table aquifers in the mountainous areas. Gravity-driven flow systems can be further divided:
Simple *gravity-driven cold karst flow system* recharging from infiltrating meteoric water and discharging through the cold water springs at the basin margins or within the mountain area (local or intermediate flow system) (1a in Fig. 3.2). These waters generally

have a $Ca\text{-}Mg\text{-}HCO_3$ character. The cold and lukewarm karst springs discharging at the foot of the karstic mountains represent this simple gravity-driven system (e.g. Erzsébet, János and Festetich springs at the southern margin of the Keszthely mountain, springs at Orfű-Abaliget at the northern margin of the west-Mecsek mountain, Pécs Tettye spring). Mixed *gravity- and geothermal driven flow system (regional karst flow system)* which are supplied by the cold karst water system. The karst water flows under the basin fill sediments, warms up and discharges through lukewarm and thermal springs at the basin margins. They are characterized by relatively lower temperature due to the direct hydraulic connection with the surface recharge. The major outlet of this system in the Zala region is *Lake Hévíz*, one of the largest thermal spring-lakes in the world. In the upwelling path thermal waters cool down to some extent, but still show a 20-40 ºC heat excess, compared to the normal geothermal conditions of the area.
(2) The second major type of the basement reservoirs include *deep carbonate rock bodies with fairly stagnant thermal groundwater reserves* that do not have direct hydraulic connection to the surface karst systems (2 in Fig. 3.2). They normally contain thermal groundwater with higher temperature and higher salinity with rather NaCl type (fossil waters) and may have a restricted recharge from the overlying porous aquifers.When the geometry makes it possible, a *closed thermal convection* may develop, which is known from certain parts of the Zala basin.
The *Middle Miocene aquifers* (abrasional and shore sands, gravels, reef carbonates, etc.) directly *overlying the basement rocks form a joint hydraulic unit* with them (3 in Fig. 3.2). Delineation and selection of the potential basement geothermal reservoirs should consider the areal extent and thickness of these Miocene rocks (especially Badenian and Sarmatian aquifers), as well as their hydrogeological parameters.

B. The gravitational flow systems of the porous aquifers in basin areas can be divided into regional, intermediate and local systems (5, 6 and 7 in Fig. 3.2).

The deepest *regional flow system* penetrates the delta-front and the delta-plain sands of the Upper Pannonian Újfalu formation. Locally, the overlying Zagyva formation can also be a part of this system. A great part of thermal waters with temperatures above 30°C and below 60°C in the Zala (e.g. Gelse, Zalalövő, Zalaegerszeg, Nagykanizsa, Lenti, Letenye, Galambok) and Dráva (e.g. Barcs, Babócsa, Szulok, Sellye) basins discharge from this unit. The sedimentary and post-depositional erosion processes may significantly modify the stratification of these units, and as a result the forced flow paths and recharge/discharge conditions, too. Under favourable conditions the sandy aquifer units of the Újfalu and Zagyva formations are outcropping, or are in direct contact with Quaternary aquifers on the hilly areas with a higher hydraulic potential, therefore providing a fairly quick and direct recharge. The system is characterized by a strong anisotropy at a larger, regional scale due to frequent alternation of the sand-silt-clay layers. Although the permeability of the clayey-marly layers is 1-2 magnitude lower than that of the sands, this is still enough to provide hydraulic connection between the sand layers, thus make the entire sedimentary succession one hydrostratigraphic unit.

The *intermediate systems* encompass the multi-level sandy aquifers of the Zagyva (and to a smaller extent Újfalu) formations in the area. In the Zala basin, the drinking water supply of several larger towns (e.g. Zalaegerszeg, Nagykanizsa and Szombathely) is provided by this intermediate flow system. They also play a role in the recharge of the porous and karstified/fractured basement geothermal aquifers, therefore the drawdown resulting from the drinking water abstraction can significantly affect the geothermal regional flow systems, too.

The *shallowest groundwater (local) flow system* can be divided into two main types. On the hilly areas the precipitation percolating through the pre-Quaternary weathered, or coarse- grained sediments feeds the Quaternary alluvium of the valleys (e.g. Somogy county). Here this local flow often meets the intermediate and regional flow systems. The larger streams and deeper and larger alluvial aquifers form the other type (e.g. alluvial plains of the Mura, Dráva rivers), which is a discharge of the deeper flow systems. This is the most favourable situation for shallow geothermal energy utilization with geothermal heat pumps (GTHP). However, it has to be considered that these aquifers provide drinking water supply. It is also important that the shallow groundwater systems should be jointly studied and evaluated with the surface waters.

The good knowledge of the natural groundwater flow system in a region is most important prerequisite of successful geothermal energy exploitation. Natural discharge of thermal waters at springs is only indication of the presence of hot water below the surface. If a hydrogeological model, like the one in Figure 3.2, is available, deliberate exploration can be devised to find adequate places for drilling to produce the required quality and quantity of hot water or steam. Technology to utilize the geothermal energy and methods to sustain a system in an environmental friendly way are also critical issues of the process.

3.3. Hydrogeological parameters of the main aquifers

The different hydrostratigraphic units have to be characterized by relevant hydogeological parameters (e.g. transmissivity, hydraulic conductivity, anisotropy, effective porosity as well as thermal conductivity). In the follwing we provide a general characterization of the main aquifers of the Pannonian basin and their hydrogeological parameters at a basin scale (Rman et al. 2011a). It is important to note that the provided hydrogeological parameters stand only for a general characterization and cannot be directly used at a local scale for a specific formation/aquifer. That information has to come from specific well-tests and individual measurements.

The pre-Tertiary basement is mainly composed of Paleozoic metamorphic rocks and Mesozoic carbonate rocks (dolomite and limestone) with various lithological features. The Paleozoic rocks have best permeability at their weathered upper parts, or related to larger fault zones. The uppermost 50-100 m thick layer of the basement carbonate rocks is usually a weathered and karstified zone which also has better permeability than the underlying unaltered rocks. The Cretaceous and Triassic carbonate rocks have a transmissivity between 100-2000 m^2/d. Although the hydraulic conductivity is usually low for the unaltered Mesozoic and Paleozoic rocks (0,005-0,01 m/d), it can locally reach higher values because of their weathered mantle, fissures and faults and karstified zones (0,05-0,1 m/d). The anisotropy coefficient (Kh/Kv) of the basement carbonates and crystalline rocks is generally around 10 and their thermal conductivity is about 2,4-2,5 W/m°C.

The pre-Tertiary basement is overlain by the Miocene, Pliocene and Quaternary sedimentary sequences. (1) The middle-upper Miocene limestones (Badenian and Sarmathian reef facies limestones) and lowermost Pannonian conglomerates (Békés Formation) which often form a uniform hydraulic unit with the basement carbonates, especially in those cases where they are capping basement highs. The transmissivity of the Miocene reef facies limestones can be as high as 50-1000 m^2/d, while the effective porosity is 0,03-0,1. Their thermal conductivity is about 2,2 W/m°C. (2) The turbiditic sands of the Szolnok formation (Lower Pannonian) have a transmissivity between 0,5 and 20 m^2/d while the effective porosity around 0,1. (3) The delta-front to delta-plain sediments of the Újfalu formation (Upper Pannonian) are the best geothermal aquifers in the region. In the sandstones of the Újfalu Formation the transmissivity is between 50 in 500 m^2/d and the effective porosity around 0,1. The Újfalu formation is overlain by the Zagyva Formation delta-plain sands, silts and coal-bearing clays with transmissivity between 100 and 500 m^2/d and porosity varying from 0,1 to 0,2 (effective porosity around 0,1). The porosity, transmissivity, hydraulic conductivity and anisotropy of the Tertiary rocks and sediments usually decrease with age which is more or less proportional to the burial depth. The thermal conductivity of the Pannonian sandy-silty sediments varies between 1,5 and 2,1 W/m°C. (4) The uppermost Quaternary sediments of the main river valleys (gravely fluvial terraces and coarse-grained alluvial plains) represents the shallowest aquifer and have the highest transmissivity (conductivity as well). The value for transmissivity varies between 100 and 2500 m^2/d. The porosity is also high and varies from 0,1 to 0,35 meanwhile the effective porosity is around 0,15. Their heat conductivity is in the range of 1,5-1,8 W/m°C.

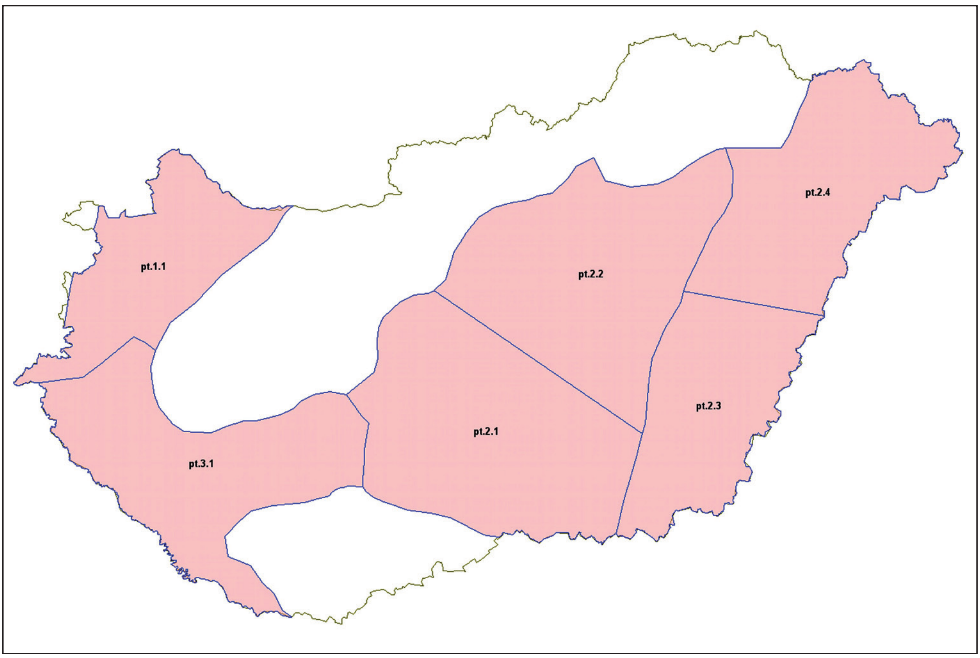


Figure 3.3. Porous thermal groundwater bodies in Hungary

3.4. Definition of thermal Groundwater bodies

Groundwater bodies delineate the major hydrodynamic units which are composed of different rocks with different hydrogeological properties depending on the geology of the given area. In the frame of the integrated river basin management plans related to the implementation of the EU Water Framework Directive, the subsurface area of Hungary has been divided into 185 groundwater bodies. The main aspects of their delineation included the aquifer type, water temperature, recharge areas, major flow patterns. Based on this groundwater bodies are classified into the main types of porous and karstic aquifers. Groundwater warmer than 30° C is considered thermal. The thermal karstic groundwater bodies are typically found within karstified Mesozoic and accompanying younger (Eozene and Middle Miozene) carbonates. The porous aquifers containing thermal groundwater bodies are composed of the thick Neogene basin fill sequences below the 30° C isotherm and are in hydraulic connection with the overlying porous cold water aquifers (Fig. 3.2). The distribution of porous and karstic groundwater bodies are shown in Figs. 3.3 and 3.4.

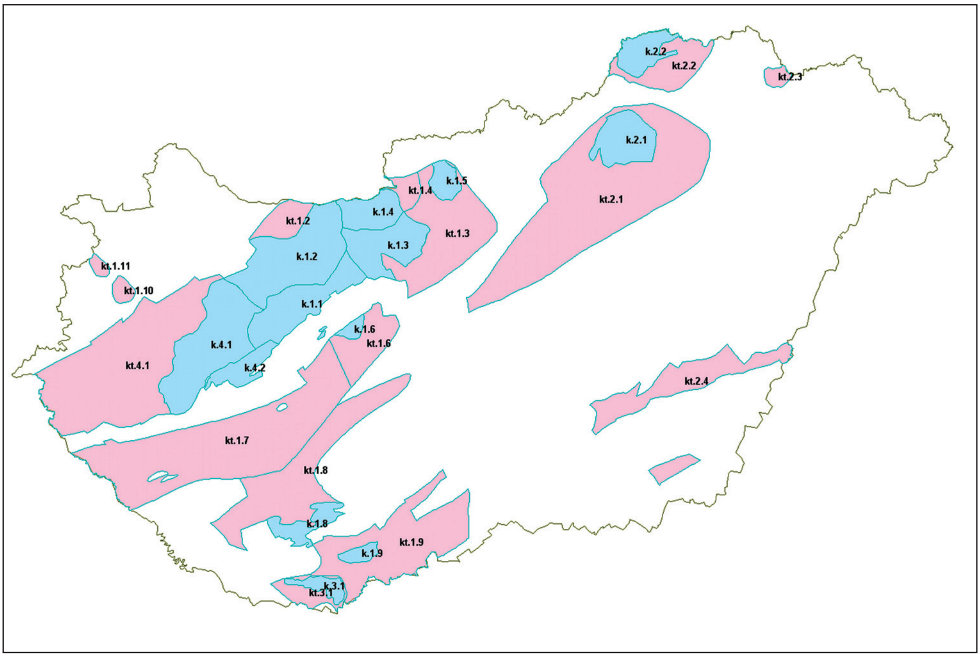


Figure 3.4. Karstic groundwater bodies in Hungary. Legend: blue and pink colour regions depict cold regions of recharge and hot regions of potential discharge, respectively

The detailed geological and hydrogeological characterization of all groundwater bodies of Hungary was performed by the Geological Institute of Hungary between 2005 and 2009. The database consisting of geological and hydrogeological cross sections, theoretical columns showing the geological and hydrogeological buildup of the given groundwater body, as well as their short description is summarized at www.mafi.hu and www.vizeink.hu as well as in Cserny et al. (2006). The following definition of the thermal groundwater bodies of south and southwest Transdanubia is based on these materials. More detailed geological description of the Pannonian sedimentary rocks, the older Cenozoic reservoir rocks and those in the Mesozoic and Paleozoic basement formations is given in the following (Chapter 4, 5 and 6.)

The following thermal groundwater bodies are found in the project area (Zala, Somogy and Baranya counties):
A). porous thermal groundwater body Délnyugat- Dunántúl (HU_pt.3.1.) (HR_pt.3),
B). thermal karstic groundwater body Dunántúl (HU_kt.1.7.) (HR_kt.3.1),
C). thermal karstic groundwater body Mecsek (HU_kt.1.8.),
D). thermal karstic groundwater body Dél-Baranya-Bácska (HU_kt.1.9.)(HR_kt.3.6),
E). thermal karstic groundwater body Harkány (HU_kt.3.1.) (HR_kt.3.5),
F). thermal karstic groundwater body Nyugat-dunántúl (HU_kt.4.1.) (Slovenia-Austria).

In brackets following the name of the water bodies their respective codes in Hungary (HU) and, if available, in the transboundary region of Croatia (HR) are listed (Kolbah, 2010).

The porous thermal groundwater body Délnyugat- Dunántúl (HU_pt.3.1.) partly overlaps with thermal karstic groundwater bodies Nyugat-dunántúl (HU_kt.4.1.), Dunántúl (HU_kt.1.7.) and Mecsek (HU_kt.1.8.), because it represents the porous thermal water aquifer overlying these thermal karstic aquifers in the basement. These groundwater bodies are not separated units, but are in hydrodynamic connections with each other.

A. Porous thermal groundwater body Délnyugat-Dunántúl (HU_pt.3.1.) (HR_pt.3.2)

The groundwater body has a large areal extent therefore its basement belongs to different megatectonic units including the Croatian part of the Drava basin. In its central part the basement belongs to the Mid-Transdanubian megatectonic unit, which is described in details at the thermal karstic groundwater body Dunántúl (HU_kt.1.7.). The basement at northern part of the groundwater body belongs to the Transdanubian Range megatectonic unit and is described in details at the thermal karstic groundwater body Nyugat-Dunántúl (HU_kt.4.1.), while the basement in its southern part falls in the area of the Mecsek megatectonic unit, henceforward its description is provided at the thermal karstic groundwater body Mecsek (HU_kt.1.8.).

The thickness of the Neogene basin fill can exceed 3000 m. The oldest Miocene formation known from almost the entire area of the porous thermal groundwater body is the coarse-grained Szászvár Formation consisting of conglomerates and pebbles, sandstones, mottled clays and marshy aleurolites which deposited in a fluvial environment in a thickness around 1500 m. At some locations few 10 m thick rhyolite intercalations of the Gyulakeszi Rhyolite Tuff may occur, which function as aquicludes. The deposition of clastic sediments mainly in fluvial, subordinately in lagoonal environment continued on the area in the Middle Miocene, represented by the regional deposits of the aleurite, clayes marl, sandstone and conglomerate beds of the Budafa Formation, in a total thickness of about 800 m. Due to the various lithological composition of the Szászvár and Budafa Formations, they have different hydrogeological properties, but from a hydrogeological point of view, this complex can be regarded as a fractured aquitard unit with low hydraulic conductivity.

Due to the transgression in the Middle Miocene, the fluvial sedimentation was replaced by a marine sedimentation, represented by the deposition of the Badenian Tekeres Schlier, which has low hydraulic conductivity ($k<0,1$ m/day) followed by the formation of shallow marine limestones, calcareous sandstones with conglomerates and pebbles at its base. The Leytha Formation can be regarded as a good fractured, karstic aquifer with good to excellent hydraulic conductivity ($k>10$ m/day), especially when it forms a joint hydrodynamic system with weathered-karstified upper zone of the basement. In the deeper open marine environment the Baden Clay Formation deposited. In some sub-basins a sedimentary succession composed of the alteration of brown coal, sand and aleurite was deposited (Hidasi Formation). In the central part of the area the andesite of the Mátra Formation Group is found within the basin fill complex in a few hundreds of meters thickness. The Middle Miocene formations are often intersected by the tuff deposits of the Tar Dacitic Tuff Foramation in a max. thickness of 100 m. In the upper part of the Middle Miocene, open marine sedimentation continued, represented by the deposits of the Szilágy Clay Marl Formation in a total thickness of about 450 m. All these latter formations (clays, Hidas Formation, andesites and tuffs) are regarded as aquicludes.

In some sub-basins, marine sedimentation continued in the Sarmatian. In the shallow marine environment close to the shoreline the coarse-grained limestone of the Tinnye Formation deposited (in a max. thickness of 320 m). This is a good fractured, karstic local aquifers with good to excellent hydraulic conductivity (k >10 m/day). In the deeper parts the clayey marl beds of the Kozárd Formation deposited (in a thickness of about 350 m), which are aquicludes, where hydraulic conductivity is below 0,1 m/day.

The overlying thick Pannonian sedimentary succession is representing the gradual filling up of the basin from deep to shallow water environments by a huge delta system transporting sediments mainly from the NW. Within this basin fill complex the clayey and clayey-marly members (mostly Lower Pannonian formations) are considered as aquicludes, while sandy, aleuritic members (mostly Upper Pannonian formations) are potential aquifers and are parts of the regional groundwater flow system. Their poor to medium transmissivity depends on the sand ratio, the spatial distribution of the sandstone bodies and their hydrodynamic connectivity.

During the Pannonian in the subsiding basin area (Dráva and Zala) the calcareous marl, clay marl layers of the Endrőd Marl Formation deposited first in an open water environment in a total thickness of about 300 m, which can be considered as an aquicludes (with low hydraulic conductivity of k<0,1 m/day). This is overlain by the sandy-clayey turbiditic bodies of the Szolnok Formation, which were once deposited as slumping sediments gravitationally redeposited and accumulated at the bottom of the former slopes of the deep basin. Due to the shallow water depth, this formation did not develop regionally on the entire area, only in the basin areas (Dráva, Zala), where it can be as thick as 650 m. The fine-grained sandstone bodies of the Szolnok Formation can be good thermal water reservoirs. The hydraulic conductivity can be high (k>10 m/day) with medium to good horizontal transmissivity depending on the spatial distribution of the sandstone bodies. It is covered by the clayey-marly deposits of the Algyő Formation, with a thickness up to 900 m on the basin areas, which are aquiclueds(with low hydraulic conductivity of k<0,1 m/day). This is capped by sandstone and aleurolite bodies of the Upper Pannonian Újfalu Formation which is considered as the main porous thermal water aquifer in the area. It has good to excellent hydraulic conductivity (k>10 m/day) with medium to good horizontal transmissivity. Due to the frequent alteration of clay and sand beds, its vertical transmissivity is rather poor. It is covered by the clayey deposits of the Zagyva Formation. The hydraulic conductivity is poor (k<0,1 m/day) with a medium to good horizontal and poor vertical transmissivity.

B. Thermal karstic groundwater body Dunántúl (HU_kt.1.7.) (HR_kt.3.1)

The thermal karstic groundwater body falls in the area of the Mid-Transdanubian megatectonic unit, and its continuation in Croatia, and is composed of Upper Carboniferous to Upper Cretaceous formations. It can be subdivided into the South-Karavanka and the South-Zala-Kalnik sub-units.

In the South-Karavanka sub-unit the Paleozoic basement is poorly known and is built up of Upper Carboniferous schists with aleurite, clay and sandstone intercalations (Tornyiszentmiklós Formation), Upper Carboniferous to Lower Permian clay schist with aleurite, fine-grained sandstone and dolomite intercalations with brecciated limestones (Trogkofel Formation). This is overlain by anchimetamorphic continental, fluvial sequences (Gröden Sandstone Formation). These are aquicludes with low hydraulic conductivity (k<0,1 m/day). The uppermost Permian is represented by brecciated dolomite and aleuritic marl layers of the Tab Formation. Its dolomitic layers can be aquifers, but in overall the Tab Formation is also considered as an aquiclude with low hydraulic conductivity (k<0,1 m/day).

The Lower Triassic is represented by sandy-marly limestones which deposited in a shallow marine lagoonal facies with abundant terrestrial input (Buzsák Formation) in a total thickness of about 100 m. It is considered as an aquiclude with low hydraulic conductivity (k<0,1 m/day). The Middle Triassic is represented by shallow marine limestones and dolomites of the Táska Formation in a total thickness of about 150 m. During the Middle Triassic the platform type sedimentation was interrupted by rifting in the South-Karavanka sub-unit accompanied by basic and intermedier volcanic activity, and pelagic limestones deposited. These are the cherty, clayey limestones of the Sávoly Formation with laminitic marly and volcanic intercalations. This is overlain by the thick (up to 800 m) Upper Triassic platform facies limestones and dolomites of the Igal Formation. The Táska, Sávoly and Igal formations can be all considered as poor- to medium karstified, fractured reservoirs with low- to medium hydraulic conductivity (k=0,1 –10 m/day), with best hydraulic properties related to the Igal Formation, which is the main karstic aquifer of the region.

Jurassic formations are not known from the area, while the Upper Cretaceous is represented by the silicified sandy-aleuritic layers of the Gyékényes Formation, which is an aquiclude.

In the area of the South-Zala–Kalnik sub-unit, the Late Paleozoic – Triassic sequence is built up of anchi–epimetamorphic formations, of which we have a very poor knowledge due to the small number of boreholes crossing them. The Permian is represented by clastic sediments composed of anhydrite, gypsum, sandstones, low-grade meatmorhic limestones and dolomites (Semlyénháza Evaporite Formation). The Middle Triassic is represented by thick-bedded, brecciated limestones (Iharosberényi Limestone Formation). In the Jurassic various schists and radiolarites with limestone olistolithes formed. The youngest Upper Cretaceous deposits are polymict breccias and conglomerates built up of the clasts of the Triassic and Jurassic formations (Inke Formation). All these formations are considered as aquiclueds with low hydraulic conductivity (k<0,1 m/day).

The basement rocks of the thermal karstic groundwater body Dunántúl are covered by Neogene clastic sediments in considerable thickness. As the geological and hydrogeological description showed the thermal karst of the Dunántúl represents basement reservoirs with fairly stagnant thermal groundwater reserves that may not have direct supply from surface karst systems,,but a restricted recharge from the overlying porous aquifers, which also puts restrictions on the exploitable amount of thermal groundwater.

C. Thermal karstic groundwater body Mecsek (HU_kt.1.8.)

The area of the Mecsek thermal karst comprises the basement rocks in the NNE foreland of the Mecsek Mountains. Its recharge area comprises the karstified Middle Triassic blocks outcropping in the Mecsek Mountains (Mecsek karst groundwater body (HU_k.1.8.) (Fig. 3.4).

The basement of the Mesozoic main karstic aquifers are represented by the Paleozic metamorphic and granitoid rocks. These Paleozoic formations all have low hydraulic conductivity (k<0,1 m/day) and can be considered as fractured aquicludes, except for their upper weathered crust with a few tens of meters thickness, or fractured zones related to major tectonic lines, where the hydraulic conductivity may increase (k=0,1-10 m/day).

The oldest member of the Paleo-Mesozoic sequence is the Boda Aleurite Formation composed of aleurite and claystone beds, which is an aquiclude. It is overlain by the conglomerate – sandstone – aleurite sequence of the Upper Permian Kővágószőlős Sandstone Formation which thickness may exceed 2000 m. It is capped by the conglomerate and sandstone beds of the Lower Triassic Jakabhegy Formation. These sandstone formations have low hydraulic conductivity (k<0,1 m/day) and can be considered as fractured aquicludes/ aquitards.

The lower part of the Middle Triassic is represented by the mottled clay deposits of the Patacs Aleurolite Formation overlain by the deposits of the Hetvehely Formation. The Patacs Aleurite and the lower evaporitic layers of the Hetvehely Formation are considered as aquicludes, while the upper fractured dolomites and limestones of the Hetvehely Formation are fractured aquifers with low-medium hydraulic conductivity (k=0,1–10 m/day).

The Hetvehely Formation is overlain by Middle Triassic limetones deposited in an open marine environment, which form a 200-300 m thick karstic aquifer with good to excellent hydraulic conductivity (k >10 m/day). A change in the sedimentary environment is represented by the marls of the Kantavár Formation with altered volcanites and high organic content which is considered as an aquiclude of low hydraulic conductivity (k<0,1 m/day). This is overlain by the fluvial deposits of the Karolinavölgy Sandstone Formation which is a fractured aquifer.

The Lower Jurassic Mecsek Coal Formation with a thickness up to 1200 m has a gradual transition from the Karolinavölgy Sandstone which is overlain by the marls of the Vasas and Hosszúhetény Formations, which are aquicludes with low hydraulic conductivity (k<0,1 m/day). This is followed by clastic and carbonate sedimentation with different deposits in various thicknesses. The isolated Crinoidea-bearing limestones (Pusztakisfalu and Kecskeháti Formations) are not important from a hydrogeological point of view due to their limited extent.

The deposition of limestones continued in the Lower Cretaceous with coeval magmatic activity. The Triassic sequences are cut through by alkali-basalt dykes. The hydraulic conductivity of these dykes is generally higher than their environment, because they are related to major fault zones, so they have an important role in connecting otherwise separated aquifers. West of the Mecsek Mountains in the surrounding of Szigetvár the Middle-Upper Cretaceous Nagyharsány Limestone Formation is known from the basement, which is a karstic aquifer with good to excellent hydraulic conductivity (k >10 m/day).

D. Thermal karstic groundwater body Dél-Baranya-Bácska (HU_kt.1.9.) (HR_kt.3.6)

This thermal karstic groundwater body in Hungary and Croatia is mainly recharging from the Mecsek and Villány Mountains as well as from the Mohács Block (HU_k.1.9.)

which comprises very shallow Mesozoic rocks similar to the Mecsek and Villány Mountains (Fig. 3.4). The Paleozoic basement rocks have low hydraulic conductivity (k<0,1 m/day) and can be considered as fractured aquicludes.

The first sedimentary rocks overlying the metamorphic and crystalline basement are the Lower Permian continental sequences composed of conglomerate, sandstone and aleurite (Korpád Formation) in a total thickness of about 350 m. The rhyolite tuff and agglomerates of the Permian Gyűrűfű Formation can be as thick as 135 m on the area. The Permian sedimentary sequence is finished by conglomerate – sandstone – aleurite sequence of the Cserd Formation in a thickness of 375 m. This is overlain by the Upper Permian Kővágószőlős and the Lower Triassic Jakabhegy Sandstone Formations, described in the Mecsek thermal karst (Chapter 4.3.). These sandstone formations have low hydraulic conductivity (k<0,1 m/day) and can be considered as fractured aquicludes.

The lower part of the Middle Triassic is represented by the aquicludes of the Patacs Aleurolite Formation and the evaporitic members of the Hetvehely Formation, while the upper fractured dolomites and limestones of the Hetvehely Formation are fractured aquifers with low-medium hydraulic conductivity (k=0,1–10 m/day). The Hetvehely Formation is overlain by Middle Triassic limetones, which form a thick karstic aquifer with good to excellent hydraulic conductivity (k >10 m/day).

The end of the Triassic and the beginning of the Jurassic is represented by non-deposition/erosion on this area, and the Jurassic formations are found only in several patches. Close to the Mecsek Mountains the Lower Jurassic marls and calcareous marls of the Hosszúhetény Formation are found in a total thickness of about 70 m, which are considered as aquicludes with low hydraulic conductivity (k<0,1 m/day). In the Middle Jurassic the massive Crinoidea-bearing limestone of the Máriakéménd Formation deposited in a thickness of about 75 m, which can be considered as an aquiclude, however towards the south it is replaced by the Villány Formation which is a karstic aquifer. In the Upper Jurassic the thick-bedded limestone of the Szársomlyói Formation deposited in the zone of the Villány Mountains in a thickness up to 80, which is also a karstic aquifer with good hydraulic conductivity (k> 10 m/day).

The Triassic and Lower Jurassic sequences are cut through by alkali-basalt dykes (Mecsekjános Basalt Formation). The hydraulic conductivity of these dykes is generally higher than their environment, because they are related to major fault zones, so they have an important role in connecting otherwise separated aquifers.

The Lower-Middle Cretaceous thick-bedded limestone of the Nagyharsány Formation is known from a considerable thickness (exceeding 600 m in the S-ern parts) which is a major karstic aquifer with good to excellent hydraulic conductivity (k >10 m/day). In the Bóly basin the Nagyharsány Formation is overlain by Lower Cretaceous marls and turbiditic sandstone. They both are aquicludes, nevertheless some sandstone bodies of the Bóly formation may be local aquifers.

E. Thermal karstic groundwater body Harkány (HU_kt.3.1.) (HR kt.3.5.)

The Harkány thermal karst is found in the Southern foreland of the Villány Mountains in Hungary and Croatia and is characterized by smaller outcropping blocks of the basement. It extends further to the SW till the Dráva valley. The major part of the thermal karst is composed of the Middle Triassic carbonate sequences, which get its major supply from the open karst of the Villány Mountains (Fig. 3.4).

The basement of the karstified aquifers is the Paleozoic rocks. These formations have low hydraulic conductivity (k<0,1 m/day) and can be considered as fractured aquicludes.

Similar to the Mecsek thermal karst, the dolomite and limestone beds of the Hetvehely Formation in a total thickness of about 110 m are fractured, non-karstified aquifers with low-medium hydraulic conductivity (k=0,1–10 m/day), follwed by Middle Triassic with good to excellent hydraulic conductivity (k >10 m/day).

At the end of the Triassic, the Mészhegy Formation, composed of dolomarls, aleurites, sandstones and calcareous marls in a thickness of 40 m, which has much lower hydraulic conductivity, than the underlying karstic rocks.

The end of the Triassic and the beginning of the Jurassic is characterized by non-deposition. In the Middle Jurassic the pelagic limestone of the Villány Formation are overlain by the thick-bedded, ooidal limestones of the Upper Jurassic Szársomlyó Formation in a thickness of 250 m thickness which are both karstic aquifers with good hydraulic conductivity (k> 10 m/day). The Cretaceous bauxite of the Harsányhegy Formation is found in the karstified caverns of the Szársomlyó Formation, which is an aquiclude.

The Triassic sequences are cut through by alkali-basalt dykes (Mecsekjános Basalt Formation). The hydraulic conductivity of these dykes is generally higher than their environment, because they are related to major fault zones, so they have an important role in connecting otherwise separated aquifers.

During the Lower Cretaceous the thick (up to 850 m) thick-bedded limestone of the Nagyharsány Formation deposited, which is a major karstic aquifer with good to excellent hydraulic conductivity (k >10 m/day).

F. Thermal karstic groundwater body Nyugat-Dunántúl (HU_kt.4.1.) (Slovenia-Austria)

The Nyugat-Dunántúl thermal karstic groundwater body is located in the area of Zala county and neighbouring regions in Slovenia and Austria belongs to the Transdanubian Range megatectonic unit It represents the SW-ern continuation of the Transdanubian Central Range in the deep subsurface. The surface of the karstic Mesozoic rocks outcropping in the Keszthely Mountains is downfaulted to the basement, where they can be as deep as 3500 m below the surface.

The main karstic aquifers of the thermal groundwater body are the Upper Triassic and Upper Cretaceous carbonates, with recharge from the cold karts of the Transdanubian Central Range (Fig. 3.4). The pre-Senonian basement – surface of the main karstic aquifer – has a complex pattern and can be divided into four major zones (Jocháné et al. 2005, Cserny et al. 2009):

- In the Nagylengyel area, a NW-SE striking 8-10 km wide zone occurs, built up of Kössen Formation. This zone has a major blocking effect on the karstwater flow perpendicular to its strike, however serves as an excellent conduit zone parallel to it.
- E from the Nagylengyel zone the hydrodynamic unit of the Transdanubian Central Range is found. The infiltrating meteoric water flows towards the marginal discharge areas of the Keszthely Mountains in a shallow depth. The karst water flowing in bigger depths towards the SW and W reaches the Nagylengely area and forced back, and discharges into the Lake Hévíz. The discharge rate of the springs feeding Lake Hévíz before the 1960-ies was over 500 l/s, but the huge karst water abstraction at the nearby bauxite mine at Nyírád decreased this value to approximately 300 l/s (1970-1990). After the mining activities finished some regeneration has occurred and the discharge has stabilized at the 390-420 l/s.

- West of the Nagylengyel zone, and on the southern part, thy syncline structure of the Transdanubian Range can be recognized. In its central part the Dachstein Limestone is found in a 10-15 km wide ENE-SWS striking, while further to the north the Main Dolomite is found. On the S-ern wing of the syncline the Dachstein Limestone occurs with tectonic contacts with the Veszprém Marl and other Lower and Middle Triassic rocks. The southern boundary of these 5-10 km wide zones is the Balaton line.
- Close to the border in a N-S striking 4-5 km wide zone Paleozoic rocks are known which belong to the rocks of the Pohorje Mountains in Slovenia. They have a tectonic contact with the Triassic rocks.

Upper Cretaceous sedimentary rocks are widespread in the Zala region. They are the 200-300 m thick marly beds of the Jákó Marl Formation in the basin interior, and the reef facies limestones of the Ugod Formation. The Jákó Marl and the Ugod Limestone are overlain by the Polány Marl Formation, which is characterized by calcareous marls, marls and aleurites.

In the Zala region the Upper Eocene Szőcs Limestone and the Badenian and Sarmatian limestones are also karstic aquifers, which often form one hydrodynamic unit with the main karstwater reservoirs of the basement.

4. PANNONIAN SEDIMENTARY ROCKS OF SOUTHERN TRANSDANUBIA

The characteristics of the Pannonian (Late Miocene and Pliozene) sedimentary rocks of the study area (Fig. 4.1a-b) are closely related to the evolution of Lake Pannon. It was a long-lived, endorheic lake, which formed as a result of the final closure of the marine connections of Pannonian Basin at the end of Sarmatian (Kázmér 1990, Magyar et al. 1999). This event is marked by a water-level fall throughout the Pannonian basin, therefore the Sarmatian/Pannonian boundary can be commonly observed as an unconformity. Continuous sedimentation took place only in the deepest regions of the basin, where it is very difficult to observe the boundary between the fine-grained pelagic Sarmatian Kozárd Formation and the lithologically very similar overlying Pannonian deposits.

4.1. Lithostratigraphic introduction

During the following 2 million years, the lake level rose and gradually flooded significant land areas. The deposited sedimentary units onlap on the flanks of basement highs. In the meantime, rapid subsidence of the basement began in several places, leading to a formation of deep depressions, like the Dráva Basin. In these deep basins, water depth probably reached 800–1000 m (Magyar et al. 1999). During this period (until about10 Ma) sediment influx was relatively low, which resulted in the formation of calcareous marl and claymarl (*Endrőd Formation*). The thickness of this formation varies between a few and several hundred meters. Coarse-grained bodies with abrasional origin were formed only along the basin margins, with thickness of not more than a few 10 meters (*Kálla and Kisbér Formations*, Csillag et al. 2010). From the viewpoint of the current project, it is more noteworthy that the early Pannonian transgression led to the formation of a base conglomerate or breccia unit with similar thickness. This unit (*Békés Conglomerate Formation*) is widespread on the slopes of the currently buried basement highs, which were islands in the earliest Pannonian.

Lake Pannon reached its largest extent about 9.8 Ma. Then rapid infill started by progradation of huge deltaic systems from two main directions: northwest and northeast. The area of area of Transdanubia was under the influence of the sediment feed from northwest, which formed a sedimentary shelf-slope system (sensu Posamentier & Allen 1999) prograding southeastwards. As shown in Fig. 4.2, the shelf-margin reached the eastern part of Dráva Basin about 5.5–6 Ma. Probably a similar, but smaller shelf-slope system reached the studied area from the west, along the axis of Mura Basin, located in Slovenia (Uhrin, unpublished result).

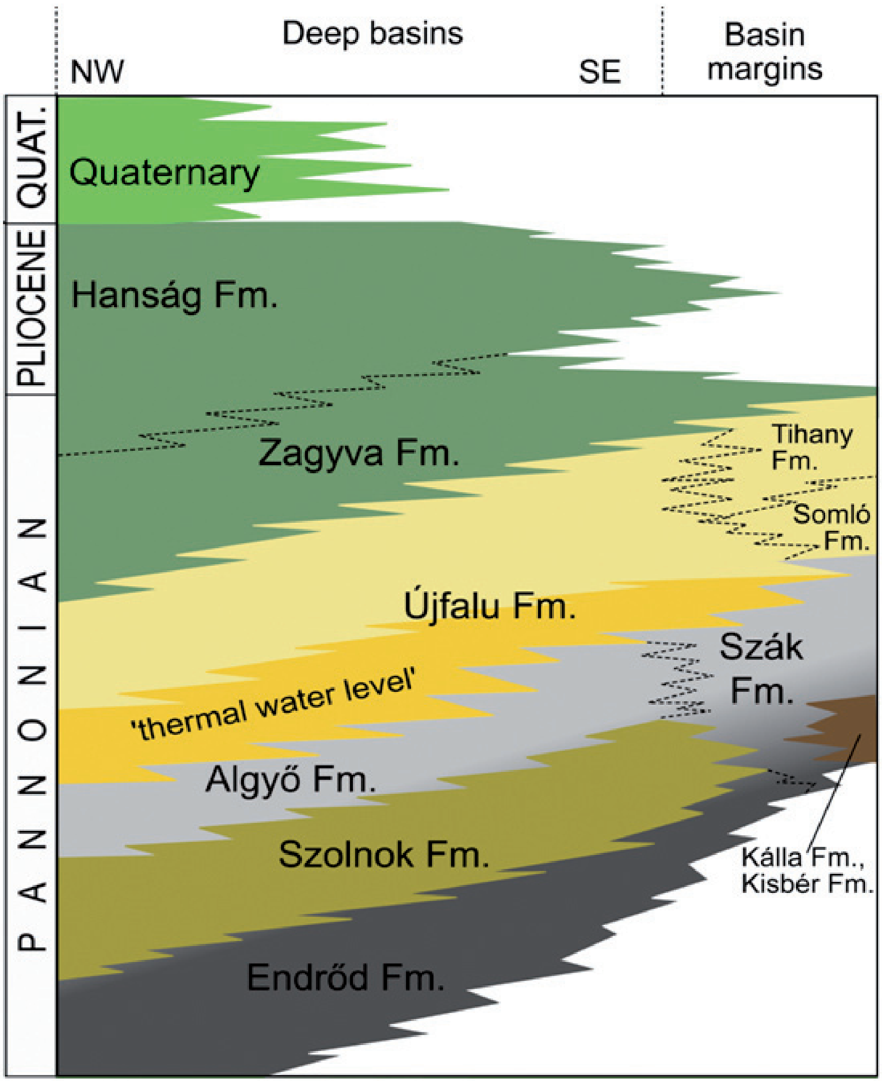


Figure 4.1a. Stratigraphic chart for the main post-rift formations of the studied part of the Pannonian basin (southern Transdanubia)

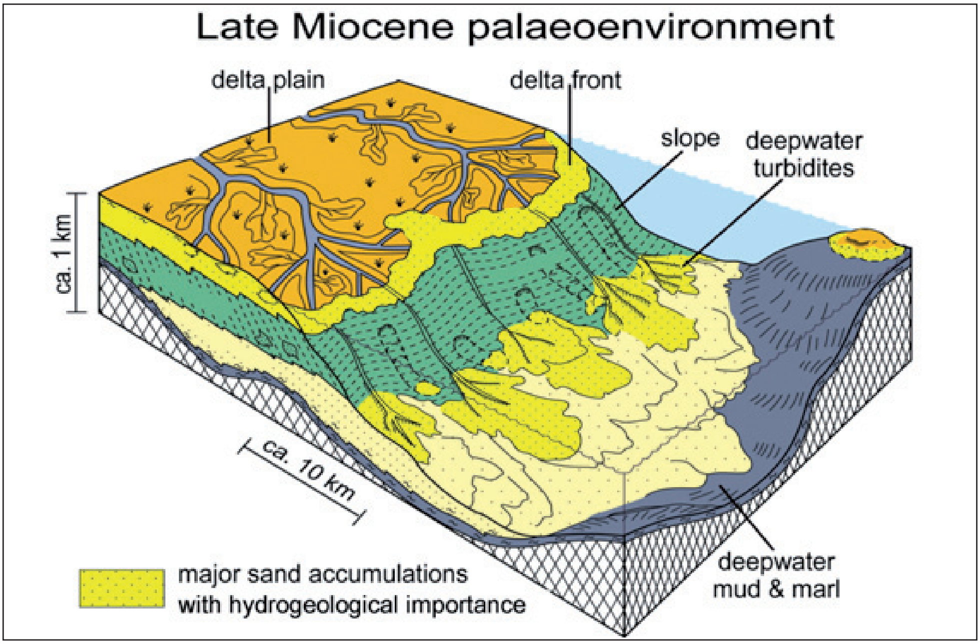


Figure 4.1b. Facies model of Lake Pannon with prograding shelf margin (from Juhász 1992**)**

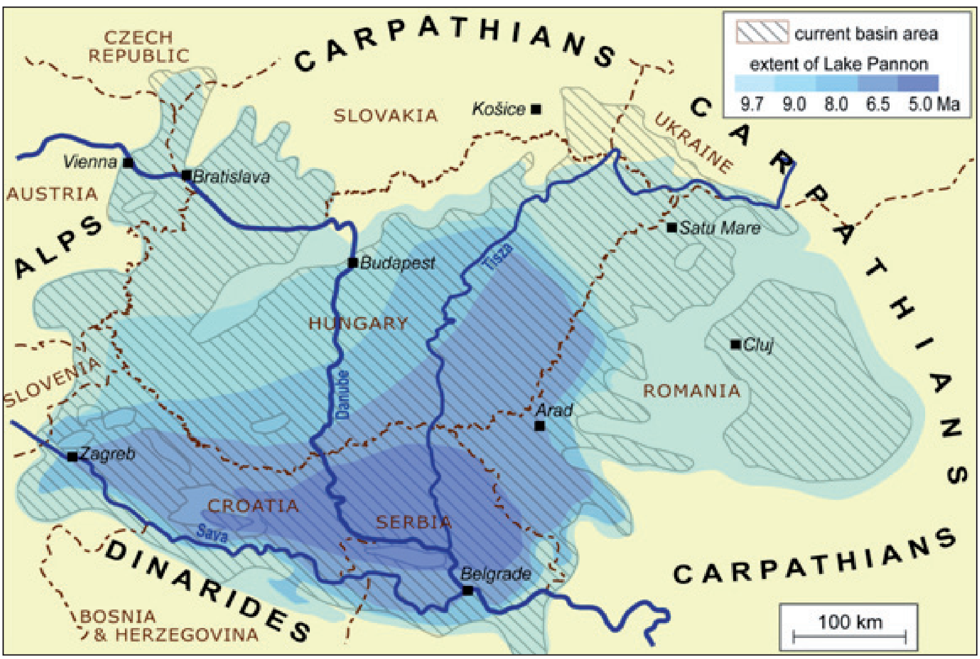


Figure 4.2. Steps of the shrinking of Lake Pannon, together with the main directions of sediment influx (after Magyar et al. 1999, Magyar 2009**)**

As the prograding slope approached a given location in the basin, more and more coarse sediment was carried there by the turbidity currents originating from the slopes. This process led to a gradual transition from the marls of Endrőd Formation to the turbiditic *Szolnok Formation*, which is built up by alternating fine-grained sandstone and pelitic layers. The sandbodies are related to individual turbiditic events, while the pelitic sediments were deposited in the calm intervals between them. The thickness of both the sandy and the pelitic levels generally varies in the range of 3–10 m, but sometimes both can exceed 20 m. Generally, the individual sandbodies can not be correlated between wells located a few kilometers from each other, suggesting that they are laterally confined. In the western part of Zala Basin, an exceptionally thick (50–100 m in average, 200–400 m in the Lovászi area) 'intermediate marl' (*Lenti Marl Member*) divides Szolnok Formation to two, individually mappable levels (Szentgyörgyi & Juhász 1988), of which the upper, thicker one seems to correspond to the uniform turbiditic unit of other regions. Both the thickness and sand content of Szolnok Formation increase towards the deepest zones of the basin, as these basement deeps provided the way for the major turbidity currents. At the same time, the formation gradually thins, then pinches out towards the basin margins and basement highs. Unpublished results of Uhrin show that the most significant sand accumulations commonly gather around or slightly below half-way between the top and the bottom of Szolnok Formation in Zala Basin. A similar tendency has been described in Békés Basin (Southeast Hungary) by Phillips et al. (1994). However, observations by Bérczi & Phillips (1985) and Juhász (1992) from other East Hungarian localities found thicker sandbodies and higher sand ratio in the upper part of the formation.

The sediments of the prograding slope itself are known as *Algyő Formation*, comprising chiefly silt and argillaceous marl, with very subordinate, lense-like sandy intercalations of mass flow origin. The thickness of this formation (generally 150–400 m) more or less reflects the depth of the water body in which the progradation took place. Above the basement highs, where Szolnok Formation is absent, it is difficult to differentiate between the lithologically similar Endrőd and Algyő Formations. In the marginal areas, this difficulty is also reflected by the lithostratigraphical system, applying the term *Szák Formation* for the uniformly pelitic lower Pannonian succession.

Above the slope deposits, there is an abrupt change from pelitic to sandy lithology, marking the base of *Újfalu Formation*. Historically, before recognizing the time-transgressive nature of the Pannonian formations, this surface was defined as Lower/Upper Pannonian boundary; this term is still common in the documentations of exploration wells. The lower part of Újfalu Formation contains thick (up to 20–30 m), coarsening-upward sand sheets representing the ancient delta fronts, which are separated from each other by a few meters thick levels of mud and silt. However, some of the sand sheets are in connection with each other. The latter fact, together with the large lateral extent of the sand sheets (many of them can be traced for some tens of kilometers) makes this unit a very efficient fluid reservoir. For this reason, this part of Újfalu Formation is commonly known as 'thermal water layer' amongst hydrogeologists. The 'thermal water layer' can be 200–300 m in the deepest regions of the sub-basins, while it pinches out along the basin margins.

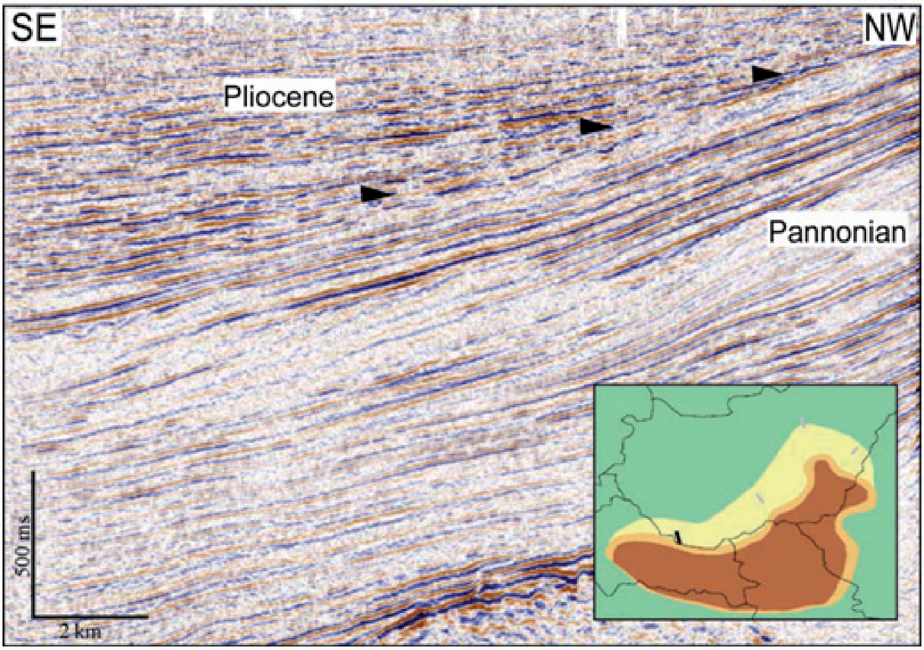
The upper part of Újfalu Formation (reaching a thickness of about 500–1000 m) mainly consists sediments deposited on the wide deltaic plain, which was formed in the background of the delta fronts (Fig. 4.1b). Instead of sand sheets with considerable extent, laterally narrow, fining-upward channel sandbodies are predominant in this unit, which are seldom joined to each other, and are surrounded by a large amount of clay and silt. The corresponding sediments are described as *Somló and Tihany Formations* in the marginal areas, but they are not defined as a lithostratigraphic unit in the deep basins. The so-called 'upper Pannonian' formations (Újfalu, Somló and Tihany Fms.) are more widespread in the study area than the previously discussed ones: along the basin margins, there are relatively wide belts in which they directly overly pre-Pannonian strata.

The uppermost part of the Pannonian succession is characterized by the cessation of the lacustrine influence. As the shelf margin of Lake Pannon moved further southeastwards, the deltaic plain environment was replaced by an alluvial plain across a larger and larger area. From a lithological point of view, the sediments of the deltaic and the alluvial plain are very similar to each other, however, the latter are named as *Zagyva and Hanság Formations*.

The Quaternary succession can be a few hundred meters thick in the central zone of Dráva Basin, where subsidence is still ongoing, and it also reaches a thickness of 70 m in the present valley of Mura. In these regions, Quaternary deposits are mainly fluvial, with significantly coarser grainsize compared with the underlying Pliocene and Pannonian strata (Fodor et al. 2011). In the hilly parts of the study area, the thickness of Quaternary is low and comprises eolic sediments like loess, sandy loess and drift sand (the latter is common in the southern part of the Somogy Hills).

4.2. Sequence stratigraphic approach

In the last few decades, numerous attempts have been made for building a sequence stratigraphic model for the Pannonian strata of southern Transdanubia. Ujszászi and Vakarcs (1993) and Sacchi (2001) recognized several third-order sequence boundaries within this succession using 2D seismic profiles. However, most of the relative water-level drops assigned to these sequence boundaries could not have been revealed in some other studies (Juhász et al. 1996, Magyar 2009, Uhrin & Sztanó 2011). Hence there are only two main unconformities, which are unambigously appropriate for basinwide correlation. The oldest is the Sarmatian/Pannonian boundary the younger one is an angular unconformity appearing within the sediments of the alluvial plain (Fig. 4.3), marking a widespread hiatus between the uppermost Pannonian and the Pliocene strata (Magyar 2009). Certainly, the signs of lower-order fluctuations of the lake level are very common. The repetition of delta front sandbodies above each other in the ‚thermal water level' is resulted by consecutive fourth-order water-level rises and the following refills of the accomodation space on the shelf. However, the amplitude and the period of these variations (30–60 m and several 10 kyr, respectively) is not enough large for resulting a repetition of the formations in the study area, in contrast to some regions of Pannonian Basin in East Hungary (Juhász et al. 2007). Another type of water-level fluctuations have been described by Uhrin & Sztanó (2011): although they have not observed any significant lake-level drop between 9.7 and 6 Ma, they documented the alternation of intervals of quasi-steady and rapidly rising relative lake level with a period of about 250 ky (Fig. 4.4). Notably, both types of water-level fluctuations contribute to the fact that the transition between the ‚thermal water level' and the delta plain sediments within Újfalu Formation is gradual: lake-level rises can make fining-upward sand sheets of delta fronts reappear in the succession even above a thick layer of delta plain sediments.



Fig, 4.3. The Pannonian/Pliocene unconformity on a seismic profile from Dráva Basin (Magyar 2009)

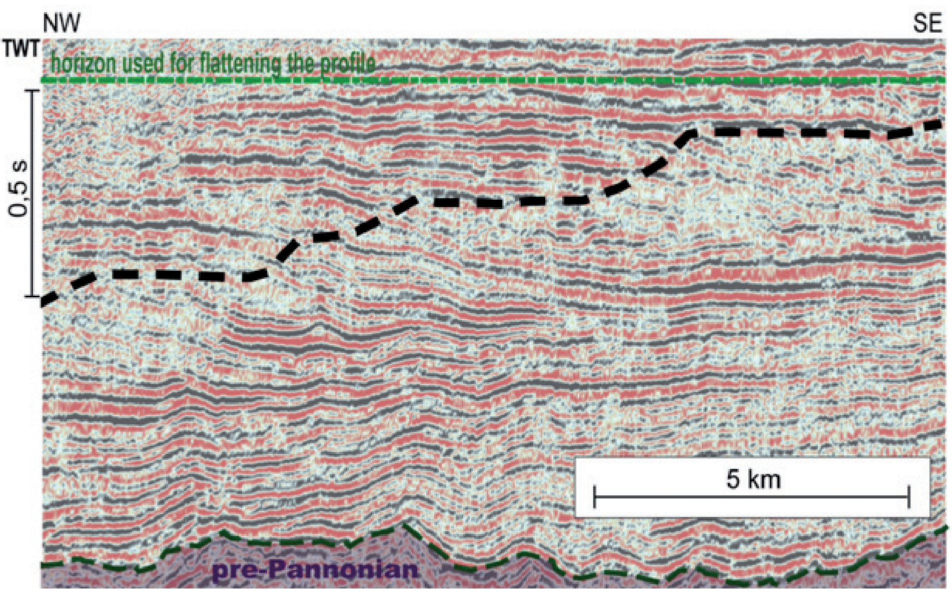


Fig. 4.4. The trajectory drawn by the subsequent positions of the shelf-slope break (i.e. the base of Újfalu Formation, drawn with dashed black line) shows a step-like character due to the alternation of intervals with aggradation and progradation

Between the clinoform foresets of Algyő Formation, a lot of minor unconformities have been identified in different parts of the Pannonian Basin (Mattick et al. 1994, Vakarcs 1997, Uhrin et al. 2009). These unconformities can be tracked only within lateral distances of 20–30 km, and they probably indicate the boundaries of individual sedimentary lobes formed along the prograding slope, of which 9 has been described throughout Zala Basin by Uhrin et al. (2009).

4.3. Seismic mapping

The typical reflection patterns for the seismic facies (Fig. 4.5) related to the Pannonian strata were introduced first by Pogácsás (1984), then the experiences from numerous related works of the last two decades has been summarized by Magyar (2009).

Previous studies have revealed that the reflectors within the lower part of the Pannonian sequence are parallel or slightly divergent to each other, and they commonly show onlaps on the relatively elevated parts of the basement. Identification and connection of these onlaps makes it easy to locate the base of the Pannonian succession on the seismic profiles. The presence of base conglomerate (Békés Conglomerate Formation) the high carbonate content in the lowermost part of Endrőd Formation, and in some regions, the strong lithological contrast between Pannonian and older strata cause that the ‚base Pannonian' horizon usually appears with high amplitude. However, the majority of the Endrőd Formation is characterized by low amplitude reflections, representing the practically homogenous marls. Going upwards, the amplitude increases significantly, due to the strong contrast of acoustic impedance between the sandy and pelitic levels of the turbiditic Szolnok Formation.

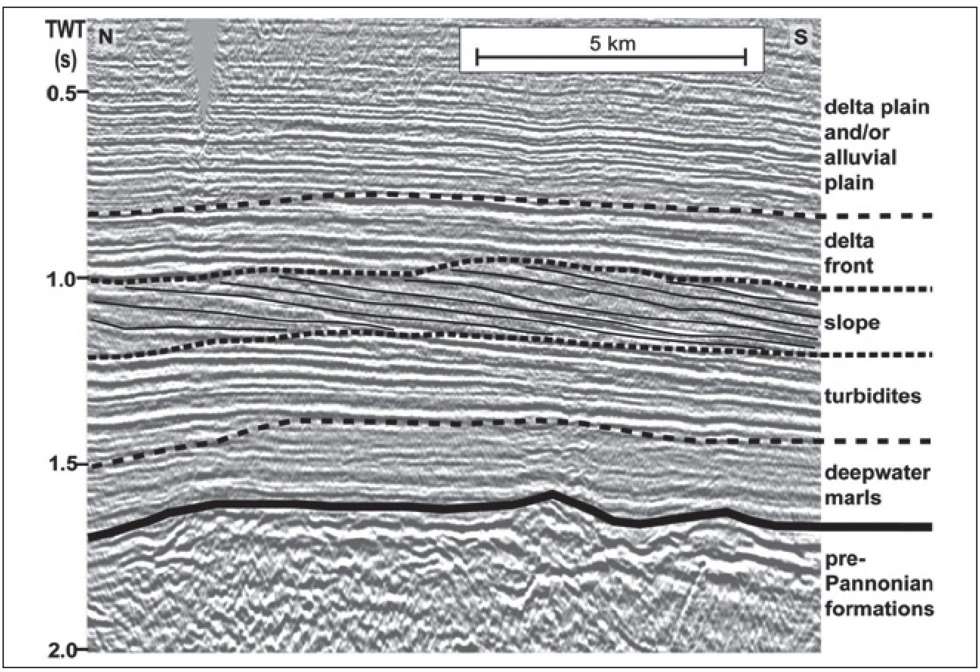


Figure 4.5. Facies interpretation of a typical seismic profile from Zala Basin

Above these strata, the slope deposits (Algyő Formation) appear as an unconformably dipping unit, which is built up by very characteristic, although generally low-amplitude sigmoidal reflections (clinoforms), showing the subsequent steps of slope progradation. Most clinoforms have bottomsets downlapping on the base of this unit. The topsets of the clinoforms can be followed in the overlying unit, which represents the deposits of the shelf. However, a sharp break appears usually at the top of the oblique part of each reflection. This break corresponds to the position of the fossil shelf margin, therefore connecting the subsequent ones on the profiles provides a very good appraisal on the base of delta front deposits (Újfalu Formation), even without using information from wells. However, some spurs of the sandy delta fronts can extend on the slope, what is commonly reflected by higher amplitude along the uppermost part of some clinoforms. If this feature is taken into consideration, it makes the base of the delta front deposits slightly uneven (with 50–80 m deep ‚troughs' on it). The downlapping of the bottomsets is not very sharp, therefore the slope-toe (base of Algyő Formation) can be positioned with a higher uncertainty on the seismic profiles, although the amplitude difference between the turbiditic and slope deposits can contribute to the recognition of this surface.

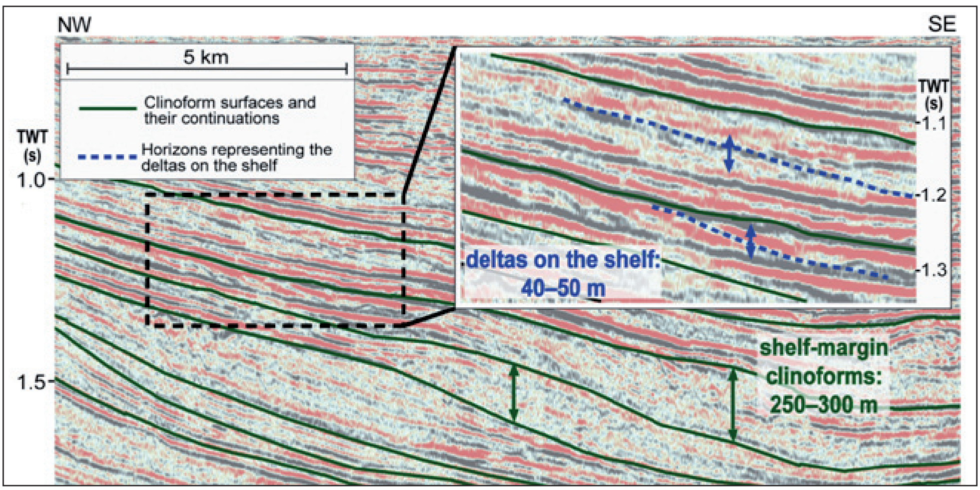


Figure 4.6. Detail of a seismic profile from Dráva Basin (Southwest Pannonian Basin). Note the scale difference between the sigmoidal reflections formed by deltas built on the shelf and by the prograding slope connecting the shelf and the deep basin (after Uhrin & Sztanó 2011).

The deposits of the originally flat sedimentary shelf appear as reflections nearly parallel to each other. In some exceptional cases, the 50 m high prograding deltas are also imaged as small clinoform series (Fig. 4.6). The lowermost horizons of Újfalu Formation generally have high amplitude and strong continuity, underlining the presence of thick, laterally extensive sand sheets intercalating with pelites. Reflections in the overlying, sequence is characterized by medium to low amplitude and medium to weak continuity, indicating that the scale of lithological variability is smaller than the seismic resolution, as it is common in any succession characterized by channel sandbodies and floodplain fines. As a consequence, the lower interval (with reflections of higher amplitude) might be more or less identical with the 'thermal water layer' of Újfalu Formation.

For recognizing the above described reflection patterns (onlaps and clinoforms) more easily, seismic profiles should be flattened (Fig. 4.7) for a palaeo-horizontal. That is necessary because the deformation caused by post-depositional tectonics commonly overprints the original low-angle dips of horizons. After flattening, the original dip of clinoform foresets can be also calculated if measured on two perpendicular profiles, such revealing the directions of slope progradation in Lake Pannon.

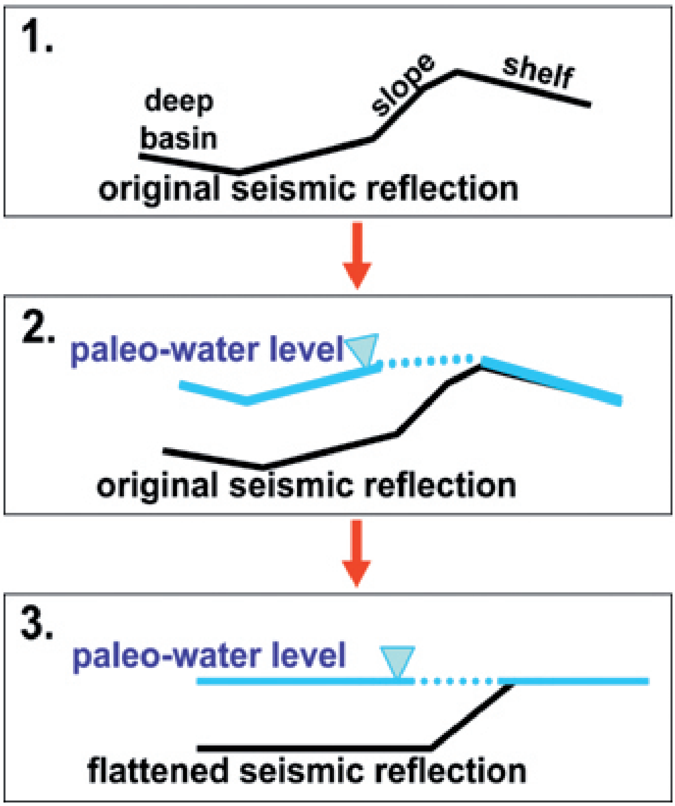


Figure 4.7. Method of flattening the seismic profiles using a palaeo-horizontal level

4.4. Pannonian formations on well-logs

As it has been discussed previously, the main Pannonian stratigraphic units can be distinguished using only seismic profiles, but this method carries significant uncertainty. For this reason, it is worthwile to review the possible methods of the identification of Pannonian formations on the basis of borehole data (Fig. 4.8). Although cores are reliable sources of subsurface lithological information, they are only available from a few, short intervals of the exploration wells, hence focus should be on the interpretation of wireline logs. Based on the experience of numerous previous studies, logs of spontaneous potential (SP), resistivity (R) and gamma-ray (GR) are the most informative for recognizing the lithological trends defining each Pannonian unit.

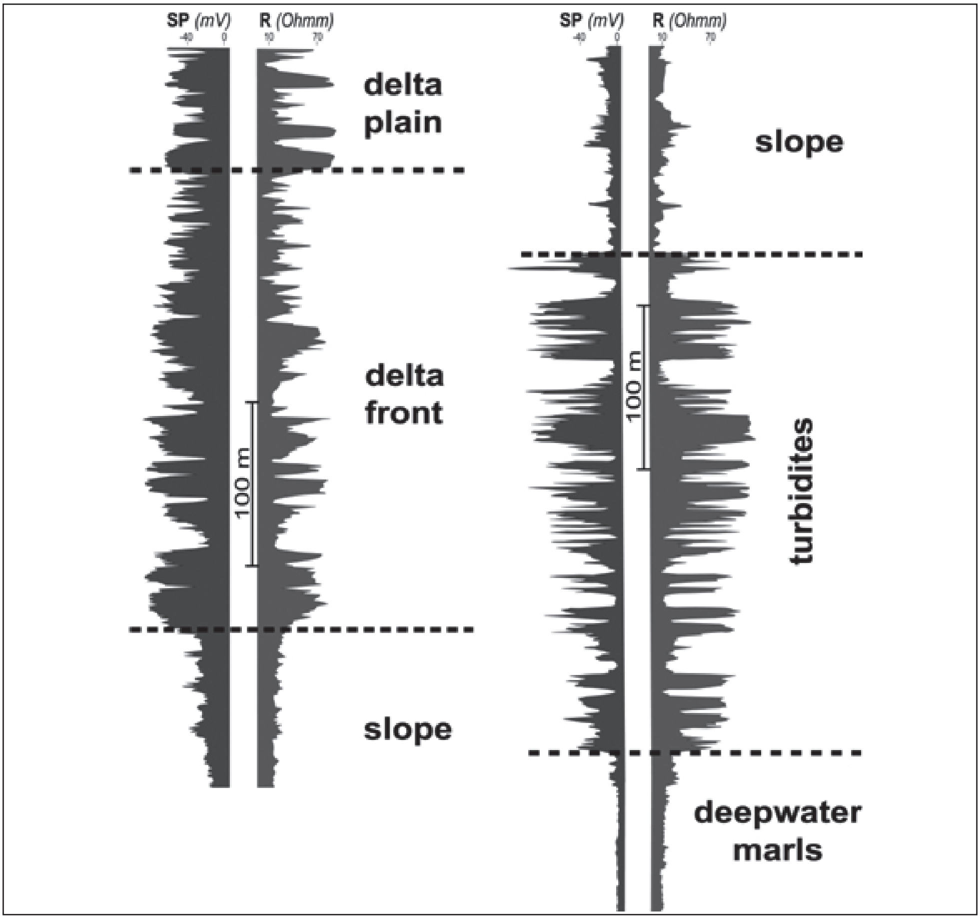


Figure 4.8. Typical well-log patterns for the Pannonian formations

In case of clays and marls with low carbonate content, all three logs show only small deflections, running along the so-called ‘clay baseline’. In case of calcareous marls, SP log is quite similar to the previous type, whereas the resistivity log, compared to the former one, shows higher deflections of random distribution. These two types are characteristic across the Endrőd Formation. In contrast, the wire-line logs of turbidites (Szolnok Formation) are characterized by subsequent cylindrical, bell-shaped or funnel-shaped peaks emerging from the shale baseline on both SP and resistivity logs. This pattern is caused by the presence of thick sandstone intercalations. The boundaries of the turbiditic succession (Szolnok Formation) are generally not difficult to find, as neither the underlying nor overlying units contain such significant sandbodies. The overlying unit represents the sediments deposited on the slope (Algyő Formation), and it comprises chiefly silt, thus the SP–resistivity curve pair generally do not show peaks with notable amplitude. Although some sandy interbeddings with a maximum thickness of some meters can occur in this unit, their signs become characteristic on the logs only in a very few cases.

The major sand sheets deposited by delta fronts (in the ‘thermal water layer’ of Újfalu Formation) are represented by pronounced funnel-shaped peaks on SP, resistivity and GR logs. The base of the lowermost such peak generally coincides with the foreset-topset break of the clinoforms seen on seismic profiles, meaning that it can validate the position of the base of the ‘thermal water layer’. Further upwards in the succession, 5–15 m thick bell-shaped peaks start to appear on the logs, while the above described funnel-shaped ones become less and less frequent. These bell-shaped elements are fining-upward sandbodies formed by the channels on the alluvial plain. Based on hydrogeological properties, the upper boundary of the ‘thermal water layer’ is located close to the base of the lowermost fining-upward sandbody, even if several coarsening-upward sequences are alternating with the channel sandbodies above this layer.

5. PRE-PANNONIAN CENOZOIC FORMATIONS OF SOUTHERN TRANSDANUBIA

5.1. Introduction

This chapter deals with those Eozene and Early and middle Miozene rocks of South Transdanubia which can be characterized by high primary or fractured secondary porosity, thus having the possibility of containing considerably high amount of termal water. Most of these rocks are known only from boreholes, but some formations of the Zala basin are cropping out in the Bakony and the Mecsek Mts.

The chapter is based on a few basic comprehensive papers like: Nagymarosy and Hámor in Haas edit. 2001, Nagymarosy in Haas edit. 2012, Körössy 1988, 1989, 1990.

Tables 1-3 summarize the occurrences of main rock-types and their maximum or minimum thicknesses in the Zala and Dráva basins and southern Transdanubia. In the data sets of the tables we used abbreviations: *lst*- limestone, *sdst* – sandstone and sand, *cgl* – conglomerate or gravel, *br* – breccias or coarse-grained, not-rounded debris. The available well-descriptions did not contain the exact amount of these rock-varieties in the penetrated profiles respectively, so our description refers simply on their occurrences without the thicknesses of the penetrated particular rock-types.

5.2. Eocene

The main high-porosity rock-type of the Eocene in southern Transdanubia is the neritic Szőc Limestone, usually of 100 m average thickness. The typical variety of this purely biogenic limestone contains a huge amount of various shallow marine organisms in a rock-forming quantity: corallinacean algae („*Lithothamnium*”), bryozoans, echinoids, and larger foraminifera such as *Assilina spira*, *Nummulites baconicus*, *Nummulites obesus*, *Nummulites lorioli*, *Nummulites perforatus* and in its higher part rarely *Nummulites millecaput*.

Several further types of the Szőc Limestone occur as well (clayey-marly limestone, sandy limestone, rarely pebbly varieties too). Most of its microfacii belong to grainstones and packstones, while rudestones or mudstones are rare. The fractured prorosity of the rock can be considerably high especially in the case of non-clayey, non-marly varieties.

Zala

The occurrence of the Szőc Limestone in the deep basins of southern Transdanubia is confined to the Zala basin. Its age is Lutetian (early Middle Eocene).

The southwesternmost occurrences of Palaeogene rocks in the Transdanubian Range mega-unit were encountered in the *Zala Basin*. They are covered here by a few 100 to 2,000 m of Neogene (Kőrössy, 1988). The recent shape of the Zala Palaeogene basin is the result of pre-Badenian compressive and erosional events which formed a 30 km-long and 15 km-wide belt of Eocene deposits. The oldest member of the sequence is the littoral to neritic Lutetian Szőc Limestone with a rich fauna of larger foraminifera. Although the available core material is not satisfactory it can be assumed that the Lower Lutetian Darvastó Formation is also present below the Szőc Limestone. The total thickness of the limestone can reach 180 m.

The Szőc Limestone is overlain by a transitional calcareous marly member and then by the sandy-marly beds of the pelagic, epibathyal Padrag Marl, which has no reservoir character at all. In the upper part of this formation the Szentmihály Andesite Complex is interbedded, with more than 1,000 metres thickness near to the centre. Younger Palaeogene formations are unknown in the Zala Basin.

Since the area of the Miocene Zala basin does not coincide with the Palaeogene part of the Zala basin, the Eocene rocks and the Szőc Limestone are confined to the central part of the Miocene basin structure. The northernmost occurrences of Eocene lay along an east-west strike, from Misefa, through Csatár and Nagylengyel to Szilvágy. The line Dióskál-Pötréte-Pusztamagyaród-Ortaháza represents the southernmost occurrences of the Eocene in the Zala basin. After the pre-Badenian compressional event the Eocene sequences have been uplifted, emerged, tilted toward the south and later eroded. This is why the southern Eocene profiles show a more complete sequence containing the Padrag Marl as well (i. e. Pusztamagyaród, Ortaháza wells) and the northern occurrences are more heavily eroded, until the horizon of the Szőc Limestone (i.e. Nagylengyel, Csatár wells). The Eocene limestones of the Zala basin occur along three strikes:

- the Misefa, Csatár, Nagylengyel, Szilvágy belt
- the Pölöske, Zalaszentmihály, Bak, Baktöttös, Pötréte belt
- Ortaháza and surroundings.

Although the thickness of the Eocene increases from the northern belt toward the southern ones, the thickness of the Szőc Limestone does not change considerably.

Mid-Transdanubian mega-unit

From the fifties up to now a number of HC-exploration wells have been drilled south of the Balaton in the Mid-Transdanubian mega-unit. This mega-unit is composed of several further low-rank units. All Palaeogene rocks penetrated in this belt belong to the *South Karawanka unit*. These are Buzsák-8, -13, Táska-1, -4, Nagyberény-I, -2, Lajoskomárom-1 wells.

In all of these boreholes only Oligocene ages have been proved by nannofossil and foraminifera studies, no Eocene rocks have been explored in contrary of the original field-descriptions. All of these Oligocene rocks were of pelitic character, marls, claystones, siltstones, etc., i. e. not relevant from the point of view of our study.

The Ságvár-2 drilling is located in the *Peri-Adriatic Granitoid belt* of the Sava mega-unit. It reached Eocene limestone and conglomerates in a very shallow position according to some older field-descriptions. The repeated investigation of the available core-material did not confirm its Eocene age (Nagymarosy non-published data) or any Palaeogene age at all.

5.3. Pre-Badenian Miocene

The bulk of the territory of southern Transdanubia extends in the area of the Tisza mega-unit, only the northern part of the Zala basin falls into the area of the Alcapa mega-unit.

Although an intensive, multi-cyclic Early Miocene sedimentation went on in the *Alcapa*, the Early Miocene deposits are missing in the *North Zala basin*. If there was any sedimentation in the Early Miocene at all, it might have happened shortly before the Badenian, this is why these deposits are considered as *Karpatian*. Since there are no reliable paleontological data which would confirm their Karpatian age, these deposits of the North Zala basin can be interpreted also as *earliest Badenian.* They transit upwards conformably into the marine Badenian formations.

The Karpatian deposits in the North Zala basin are not widespread, they occur only in the Nagylengyel area in the Csesztreg-3 drillhole and around Kotormány. These three occurrences seem to be isolated from each-other.

In the Cse-3 borehole the Karpatian is represented by some 290 metres of yellow marly sandstone with breccias of Mesozoic limestone and dolomite debris. The Ko-1 borehole comprised a similar rock variety in a thickness of 308 metres.

The Karpatian is more widespread in the Nagylengyel area, it occurs mostly in the northern part. Its relevant rock type is a terrestrial conglomerate cemented by red, green or grey clay. Some rare occurrences of marls and coal-seams were also detected in the Karpatian sequence around Nagylengyel. The total thickness of the Karpatian varies between 0-250 metres here.

In the Miocene sequence of the *Tisza mega-unit* there are fundamental differences with that of the Alcapa mega-unit. The Lower Miocene here is characterised predominantly by continental deposits and the Miocene sedimentation began here somewhat earlier (latest Eggenburgian) as in the Alcapa. However, the “true” Early Miocene deposits are confined to the Drava basin-Mecsek foreland basin-Kiskunhalas belt. Most of the area of the Tisza mega-unit was dryland during the Early Miocene. In a minor part of it a NE-SW striking long basin formed by the end of the Eggenburgian.

In the *South Zala* basin the Karpatian deposits occur only in a few boreholes. They are most widespread around the Budafa-Oltárc structure and the adjoining area of Bázakerettye.

In the Budafa area the Karpatian is represented by coarse grained sandstone, sandy calcareous marl, and breccias of limestone and dolomite debris. Also dolomite and dolo-limestone has been described from the Karpatian sequence, but one can assume that either the breccias were misinterpreted or those dolomites and limestones belong to the underlying Triassic sequence. The thickness varies between 400-1500 metres. In its continuation to the east, in the Oltárc-field, the Karpatian was penetrated in a thickness of 190 to 800 metres, but it may be much thicker. The lower part of the sequence consists of breccias of dolomite, limestone and chert. The upper part consists of sandstone and conglomerates deriving from a metamorphic-cristalline source area.

To the south, around Letenye the Karpatian is 40 to 110 metres thick and consists of dolomite pebbles-bearing conglomerate. In the isolated Pusztamagyaród (Pu)-8 brehole

53 metres of conglomerate represents the Karpatian (from metamorphic source area), but it also can be the basal conglomerate of the Badenian transgressional cycle.

The pre-Badenian Miocene rocks of the *Dráva basin* can be grouped to two major areas: one northern belt in the Gyékényes-Vése-Pat-Bajcsa quadrate and another southern group in the Jákó-Somogyudvarhely-Szigetvár triangle.

In the *northern block* the thickness of the Karpatian increases from the west to the east. For example, its thickness in the Bajcsa and Belezna boreholes ranges from a few tens of metres to 290 metres. More to the east, in Inke it reaches 920 metres and further on, in Vése 1150 metres.

The Karpatian profile here consists of coarse deposits and grey marls. The most relevant rock-types for this study are the sandstone with calcareous cement, conglomerates and breccias. The coarse detrital beds ara concentrated mostly in the lower part of the drilling profiles, while in the Inke area the breccias and conglomerates occur throughout the whole profile.

The pre-Badenian Lower Miocene beds of the *southern block* may be strongly related to those in the Mecsek Mts. In the belt running along the northern foreland of the *Mecsek Mts– Kadarkút Trough–Drava Trough*, the widespread lower part of the *Szászvár Formation* (*Máza Member*) is made up of beds of piedmont alluvial fan and fluvial facies. The lower part of the member is composed predominantly of channel deposits: red (some 50%), subordinately green, greenish-grey and variegated gravel (conglomerate), sand (sandstone), and clayey silt (cobbles – 48%, coarse clastics – 28%, pelite – 24%). The maximum size of the transported boulders is between 30 and 80 cm. Upward and laterally in the flood plain facies the colour of the cyclic succession becomes greener (61%), the psephite content decreases to 23%, sand content becomes predominant (60%) and variegated clays are more frequent (Hámor, 1970).

After the filling up of the basins with coarse detritus, swamps might have been formed in the area. The *Mecseknádasd Member* of the *Szászvár Formation* was formed at this time when the marginal flood plains of river meanders were transformed into paludal-lacustrine facies areas. In the upper part of the member terrigenous influx in the form of yellow, pebbly sand can be observed again, with intra-formational clay boulders.

The area of the Mecsek foreland–South Somogy Trough is filled up asymmetrically by the Szászvár Formation: in the S predominantly by the lower member, developed in a great thickness (800–1,200 m), and northward by the 200–300 m-thick sequence of the upper member, pinching out at the Mid-Hungarian Lineament.

The pre-Badenian Miocene deposits show a decrease in thickness from the southwest to northeast, i. e toward the Mecsek Mts. While in Somogyudvarhely their thickness is 290 metres as a maximum, in Jákó and Szigetvár its thickness varies between a few tens of metres to a few metres. An exceptional sub-basin is the Kadarkút area, where an anomalous thickness of 1615 metres has been observed.

Pre-Badenian Miocene deposits occur sporadically in the wide *belt betweeen the Balaton and the Mecsek Mts.* The coarse-grained sediments resemble to the Szászvár Formation. The conglomeratic-sandy deposits of Kurd-Döbrököz area attaches closely to the Drava basin (290-640 m thickness), while an another belt can be observed from Lajoskomárom to Nikla along a NE-SW strike, comprising the similar deposits around Buzsák, Táska, Igal, Karád, Öreglak (average thickness around 200-300 metres). Extremely thick pre-Badenian Miocene deposits were observed in the Karád area (up to 750 metres).

5.4. Badenian

During the Middle Miocene *continental sedimentation* played a subordinate role. A continuation of the intensive Early Miocene continental–fluvial sedimentation during the Middle Miocene is only proved for the area of the western Mecsek Mts. In the region of the NW–SE-striking Bakóca Trough, which extends toward the northwestern foreland, the *Keresztúr Formation* (Chikán, 1991) deposited, which is made up of poorly sorted and poorly rounded fluvial gravel, sand, and sandstone, of some 100 m thickness. Its Late Karpatian/Early Badenian age is proved by the intercalating “Middle Rhyolite Tuff”. The presence of a similar fluvial formation can also not be excluded within the basal gravel of the Kiskunhalas Formation.

Basal coarse-grained *marine and brackish* deposits of the Badenian, collectively called “*Budafa Formation*” (Hámor, 1970) in Transdanubia, unconformably overlie the Lower Miocene, or the surface of the Palaeozoic/Mesozoic substratum. The Congeria Limestone and Sandstone (*Pécsvárad Member*) is a characteristic marginal brackish water estuary facies. The thickness of the member is 15–30 m. Laterally it interfingers with a lacustrine/deep lagoonal facies, the Komló Clay Marl Member of the Budafa Formation.

Offshore bar, and delta facies constitute the 400–700 m-thick sequence of the *Budafa Sandstone Member*. Upsection the member is made up of cyclically fining, thick-bedded gravel, conglomerate, calcareous sandstone, sand, and clayey sand. The coarse components were derived from various sources. Reworked Lower Miocene fluvial pebbles are common locally, however Mesozoic carbonate rocks (forming the substratum) are the predominant material. The member’s marine facies is proved by marine fossils. The typically cross-bedded sandstone alternates sometimes with turbidite layers.

In the shallower neritic regions with moderated or minimum terrigenous influx the *Leytha Limestone* developed. The Leytha Limestone contains abundant fossils, bivalves, gastropodes, sea urchins and others, but most mollusc shells left only voids, their aragonitic substance having been dissolved during the diagenesis.

The so-called *“Lower Leytha Limestone”* marginal reef facies is represented by fringing and patch reefs, with lithothamnium-, mollusc-, coral-, bryozoan-bearing limestones and calcareous sandstone. Basal abrasion breccia and conglomerate, both containing coarse components with fining-upward, gravel, glauconitic sandstone, sandy, mollusc-bearing, coarse limestone, and bryozoan calcarenite beds, make up the basal part of the formations. It shows sometimes a littoral/nearshore facies with a rich mollusc fauna washed over by wave action. *Lithothamnium*, *Heterostegina*, mollusc-bearing limestone, sandstone, sand, and (rarely) marl, are also typical. All these facies are included into the *Pécsszabolcs Formation* in Transdanubia, with a thickness of the *Pécsszabolcs Formation* is usually 30 to 50 m, rarely 50 to 100 m.

The age of the Lower Leitha Limestone is Early to Middle Badenian. Its separation from the “Upper Leitha Limestone” – because of lithological similarities - is very difficult. The *Rákos Limestone Formation* in the Upper Badenian is represented either by boulder-bearing, coarse gravel formations of an abrasional shoreline, or by porous algal limestone, calcarenite, and calcareous sandstone which deposited in foreshore–reef facies, sometimes cross-bedded. The larger Upper Leitha Limestone reefs can be found in the Mecsek Mts, but also in the deeper Transdanubian basins, for example in the Zala and Drava basins. The thickness of the formation rarely exceeds a few tens of metres. The age of the Upper Leitha Limestone is Late Badenian.

Zala basin

In the Zala basin coarse-grained Badenian deposits (=*Budafa Formation*) occur throughout the area of the whole basin. Their most common rock-varieties are the coarse to fine grained sandstone and conglomerates with a dominance of pebbles and gravels from crystalline source areas. A special sandstone horizon (=”green sandstone”) occurs in the wide-surroundings of Nagylengyel, with first-class porosity parameters. In several wells it behaves as a HC-reservoir. The marine character of these coarse Badenian deposits is proved by a number of molluscs and foraminifers.

The thickness of these rocks ranges usually from a few tens of metres up to a few hundreds of metres. Anomalously thick coarse deposits are known from the boreholes around Újfalu, Lovászi and Csesztreg, where their thickness reaches 800 metres or sometimes more than 1300 metres.

The *Leytha Limestone* is also common in the area, however the limestone facies represents only a minor part of the whole penetrated Badenian profile. Three groups of Leytha Limestone belts can be observed in the Zala basin, all along an east to west strike:

- Vöckönd-Csácsbozsok-Andráshida-Hottó-Németfalu-Salomvár and a little bit further to the west: Kerkáskápolna. The thickness of the total Badenian varies between 20 to 420 metres. An extreme thickness of 500 metres has been observed at Kerkáskápolna.
- Kehida-Misefa-Botfa-Bucsuszentlászló-Csatár-Nagylengyel-Barabásszeg-Gellénháza-Szilvágy-Pusztaapáti. Pölöske and Zalaszentmihály also belong to this belt. In this belt the limestone-part of the total Badenian is much more, than in the northern belt. At Barabásszeg and Szilvágy almost all of the Badenian profile consists of Leytha Limestone, this is the case also in Zalakaros. These thicknesses vary between 90 and 180 metres. In other boreholes, where the ratio of the calcareous beds is lower, the thickness varies between 50 to 460 metres.
- Sávoly-Nagybakónak-Dióskál-Pötréte-Söjtör-Pusztamagyaród-Ortaháza-Zebecke-Bárszentmihályfa belt. In this belt Pusztamagyaród and Ortaháza are those regions, where the whole Badenian is represented by Leytha Limestone, although their thickness is moderate: max 170 metres. In other boreholes the total thickness of the Badenian varies 50 to 630 metres.

Dráva basin

In the Dráva basin the belts of the Badenian reservoir-rocks coincides roughly with those of pre-Badenian age. The main rock-types, sandstone, breccias and conglomerate can be classified as *Budafa Formation*. Its thickness conditions do not show any regularity, except the thickness-maximum in the central zone of the basin, in the surroundings of Vízvár-Somogyudvarhely-Szenta-Tarany-Gyékényes, where the total thickness of the Badenian can reach 1200 metres. The areas with Leytha Limestone also can be grouped into the previous two belts.

- In the north the Bajcsa, Inke, Iharosberény and Zákány boreholes reached the Leytha Limestone. The total thickness of Badenian is 15-550 metres here, but only a minor part of the profile is represented by limestone. Exceptional is the Liszó and Belezne area, where a considerably major part of the Badenian beds consist of limestone.
- In the south the are of the Nagybajom-Berzence-Komlósd-Kadarkút quadrate contains the Leytha Limestone. In the Görgeteg-Babócsa-East – Tarany – Darány areas a major part of the Badenian is of calcareous (limestone, calcareous marl) facies. In the other areas the share of the limestone versus other Badenian rock-types is less. The total thickness of the Badenian in this area varies between a few tens of metres to 1200 metres.

Mid-Transdanubian unit

A wide belt from Nagyszakácsi to Lajoskomárom contains Badenian rocks. Most of the Badenian consists of siliciclastic deposits here, but also Leytha Limestone indications were checked from Nagyszakácsi, Táska, Buzsák, Öreglak, Karád, Lajoskomárom, Mernye, Mezőcsokonya. The average total thickness of the Badenian is around 100 metres, but in Karád and Mezőcsokonya it can grade up to 250-380 metres.

In Buzsák the Upper Leytha Limestone is present. Its thickness reaches 100 metres and has a good porosity to function as HC-reservoir rock.

5.5. Sarmatian

Coarse siliciclastic Sarmatian deposits are not dominant in South Transdanubia, except the conglomerates and sandstones at it transgressive basal beds. The Sarmatian nearshore facies can be characterised also by major coarse limestone bodies. They belong to the *Tinnye Limestone Formation*. The typical variety of the formation consists of *Cerithium*-bearing, oolitic, porous limestone, locally by calcareous sandstone, calacarenite interbeddings and sandy–gravel basal layers. At the top of certain structures smaller patch-reefs were encountered. Their thickness is about 100–200 m In some cases their extent is controlled by the palaeomorphology (margins of the Drava Trough and its branch in Somogy), i.e. they are located at the margins of emerged areas (such as at the margins of the Inke–Igal Island). Their contact with the Badenian deposits is usually conform. In areas the Sarmatian carbonates overlie the basement unconformably.

Zala basin

Coarse siliciclasic deposits are quite widespread in the Zala basin. Their occurrence is more frequent in the northwestern and southern part of the basin. The total thickness of the Sarmatian is usually a few tens of metres, except the area of Lovászi with an anomalistic 410 metres thickness.

The *Tinnye Limestone* is quite rare in the Zala basin. Two isolated patches have been found around Pusztaapáti and Ortaháza. Although the share of the Tinnye Limestone is not too much compared to other sediments, but in Ortaháza is is functioning as HC-reservoir-rock.

Dráva basin

At the end of Badenian or during the Sarmatian the Dráva basin has been uplifted and seriously eroded. Thus, the Sarmatian deposits are missing here, except the northwesternmost part, where at Belezna and Semjénháza 150 metres of sandsone and conglomerates were deposited. Also the *Tinnye Limestone* is present at Belezna.

Mid-Transdanubian unit

Sarmatian reservoir-type rocks occur in this belt only sporadically, in Lajoskomárom, Karád, Mezőcsokonya, and Igal. Typical is the sandstone, in Igal also conglomerate.

The *Tinnye Limestone* occurs in Karád, Lajoskomárom and Mezőcsokonya. In the latter well it is the thickest, reaching 100 metres.

6. GEOLOGICAL FORMATIONS OF THE PRE-TERTIARY BASEMENT

6.1. General overview

In this chapter a brief overview is given on the structural setting and geological architecture of the main pre-Tertiary tectonic units of South Transdanubia. Having a look on the regional geology of the wider surroundings, it is clear that the main geological units discussed below are not restricted to the territory of South Transdanubia, but do continue in the neighboroughing areas in Croatia and Slovenia (Fig. 6.1.). Consequently, the aquifers introduced in this study also occur in the adjoing areas underlining the importance of joint, transboundary thermal water management.

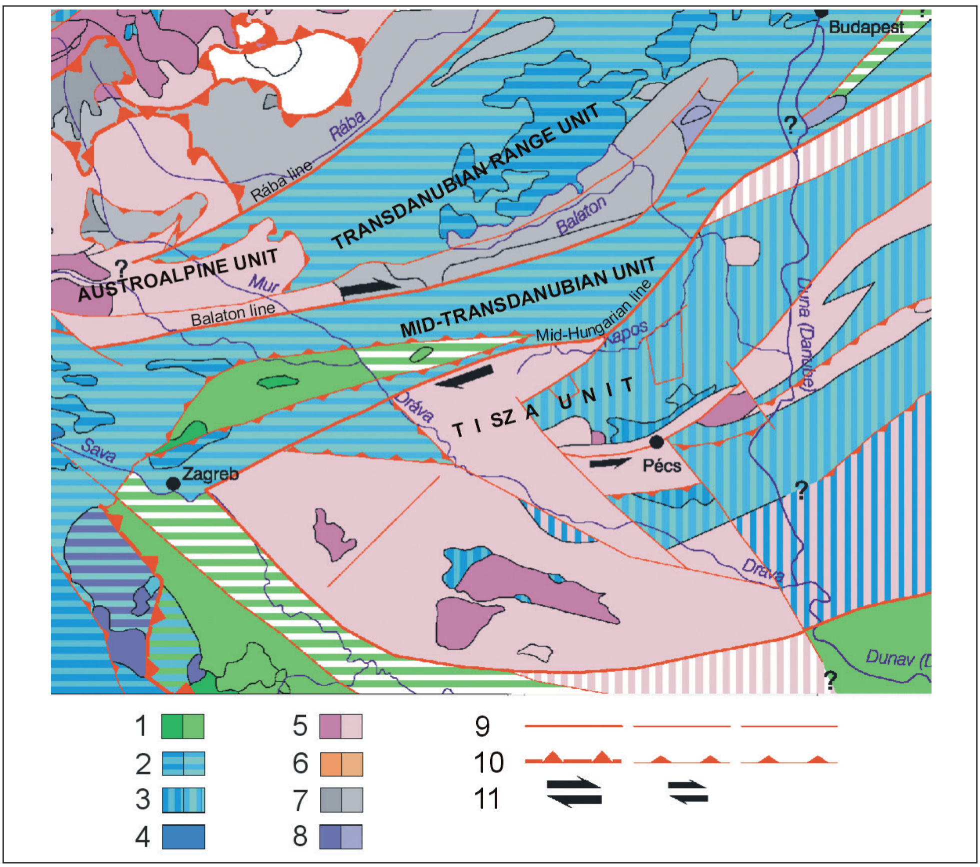


Figure 6.1. Regional-scale, schematic overview on the basement geology of South Transdanubia and adjoining areas referred to the Mid/Late Triassic stage (after Kovács et al. 2010).
1: Magmatic and sedimentary rocks of the Neotethyan oceanic domain, 2–4: Triassic shallow to deep water carbonates, 5: Medium-grade metamorphic rocks (Moldanubian zone), 6: Non- to very low-grade metamorphic rocks (Betic-Serbian zone), 7: Very low- to low-grade metamorphic rocks (Noric-Bosnian zone), 8: Non- to very low-grade metamorphic rocks (Carnic-Dinaridic zone), 9: Tectonic line in general, 10: Nappe boundary/thrust, 11: Sense of strike-slip motion

The pre-Tertiary basement of the sudy area in Hungary can be assigned to four major megatectonic units (Fig. 6.1.):

- Austroalpine unit,
- Transdanubian Range unit,
- Mid-Transdanubian unit,
- Tisza Unit.

The basement rocks in the above units can be divided into two major groups according to their age and origin: (1) magmatic and metamorphic crystalline rocks of pre-Mesozoic age, and (2) overlying mostly non-metamorphic, Permo-Mesozoic (locally also Upper Carboniferous) successions. From a hydrogeological point of view the latter group has a major importance, as the Upper Triassic shallow-water, thick platform carbonates (associated also with Cretaceous reef carbonates locally) within the Mesozoic sequence serve as excellent (thermal) karst aquifers. The thermal water potential of crystalline rocks is generally poor due to their limited hydraulic conductivity.

The *Austroalpine unit* comprises a complex nappe system consisting of metamorphic basement nappes and non- and relatively weakly metamorphic cover nappes formed during the Cretaceous orogeny. The Austroalpine unit is divided into two major parts, namely the Lower and the Upper Austroalpine nappe system (Fig. 6.2.), both of which built up by numerous individual nappes. Elements of the Austroalpine nappe system consisting of medium-grade metamorphic rocks occur only in a very small area within the northwesternmost portion of the study area.

In the northern part of the study area the pre-Tertiary basement is built up by the rocks of the so-called *Transdanubian Range unit.* This unit is separated tectonically by the NE–SW striking Rába line (Figs. 6.1, 6.2.) from the Austroalpine unit in the North(west). The "Rába line" represents actually a complex Miocene normal and strike-slip fault system strongly reworking the primary contact of the Austroalpine and the Transdanubian Range units. The original contact is supposed to be a Cretaceous nappe boundary according to recent interpretations (Tari 1994, Fodor & Koroknai 2000, Haas et al. 2010); in other words the Transdanubian Range unit seems to form an uppermost element (Fig. 6.2.) within the Austroalpine nappe pile (Tari 1994, Fodor et al. 2003, Tari & Horváth 2010). Lithologically the Transdanubian Range unit consists of an Early Paleozoic low-grade metamorphic basement and an overlying, non-metamorphosed Permian–Cretaceous sedimentary sequence. The southern boundary of the Transdanubian Range unit is represented by the Balaton line (Figs. 6.1, 6.2.) that is generally considered as the eastern continuation of the Periadriatic fault system, which represents a Tertiary first-order, dextral strike-slip zone (Kázmér & Kovács 1985, Balla 1988, Tari 1994, Fodor et al. 1998) separating the Southern Alps from the Austroalpine unit.

The next important tectonic unit southeast of the Balaton line is the *Mid-Transdanubian unit,* which is known exclusively from boreholes in the territory of Hungary. The unit has a poorly known internal structure consisting of presumably several nappes and strike-slip duplexes of Cretaceous to Oligocene–Miocene age. The lithological content includes mostly Mesozoic carbonate and siliciclastic sequences with South-Alpine and Dinaridic affinities. The southern boundary of this composite unit is the NE–SW striking Mid-Hungarian line.

South of the Mid-Hungarian line the pre-Tertiary basement is built up by the various crystalline and Mesozoic rocks of the *Tisza unit*. This unit is generally considered as a continental fragment forming originally the part of the ancient European margin. During the Mesozoic times the Tisza Unit splitted from stable Europe and got into its present position due to long-lived and complicated tectonic processes in the course of the Alpine orogeny.

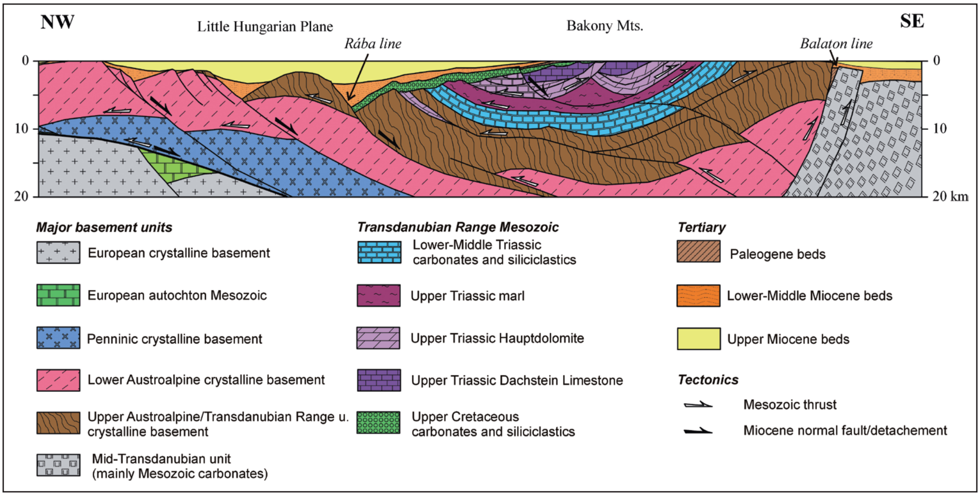


Figure 6.2. Regional-scale, schematic geological cross section through Transdanubia showing tectonic relationships among the Austroalpine, Transdanubian Range and the Mid-Transdanubian units, as well as simplified lithological characteristics (after Tari & Horváth 2010)

6.2. Austroalpine unit

Basement rocks assigned to the Austroalpine nappe system occur only a very restricted area (near the village Bajánsenye) in the northwesternmost portion of the study area (Fig. 6.3., *lithological unit 30*). The Austroalpine unit forms here a tectonic window below the Transdanubian Range unit (Fodor et al. 2003, Haas et al. 2010). Mylonitic micaschists, gneisses and subordinate amphibolites with symplectitic microstructure were transsected by the borehole Bajánsenye–M–1 (B–M–1) in the depth interval 3800–4100 m below Miocene sediments. These rocks — displaying striking similarities to the main rock mass of the Pohorje Mts. in NE Slovenia — are correlated with the crystalline series of the Lower Austroalpine Koralpe-Pohorje-Wölz nappe. A complex, polyphase metamorphic evolution including an early, eclogite facies stage followed by a medium-grade, Eoalpine metamorphism overprinted finally by an Early Tertiary, upper greenschist facies (~450 ºC) mylonitisation was demonstrated for these rocks (Lelkes-Felvári et al. 2002). A flat-lying ductile shear zone of extensional origin related to Late Cretaceous(?) extension of the Austroalpine units was also postulated (Lelkes-Felvári et al. 2002).

These rocks were also reached in numerous boreholes in the pre-Tertiary basement of the Mura basin in Slovenia. Another metamorphic rock suite (Kobansko and Magdalensberg Formation) displaying considerably lower metamorphic grade also occours in several boreholes in Slovenia. These predominantly phyllitic and metavolcanic rocks represent a tectonically higher, Upper Austroalpine nappe unit overlying the Lower Austroalpine Koralpe-Pohorje-Wölz nappe.

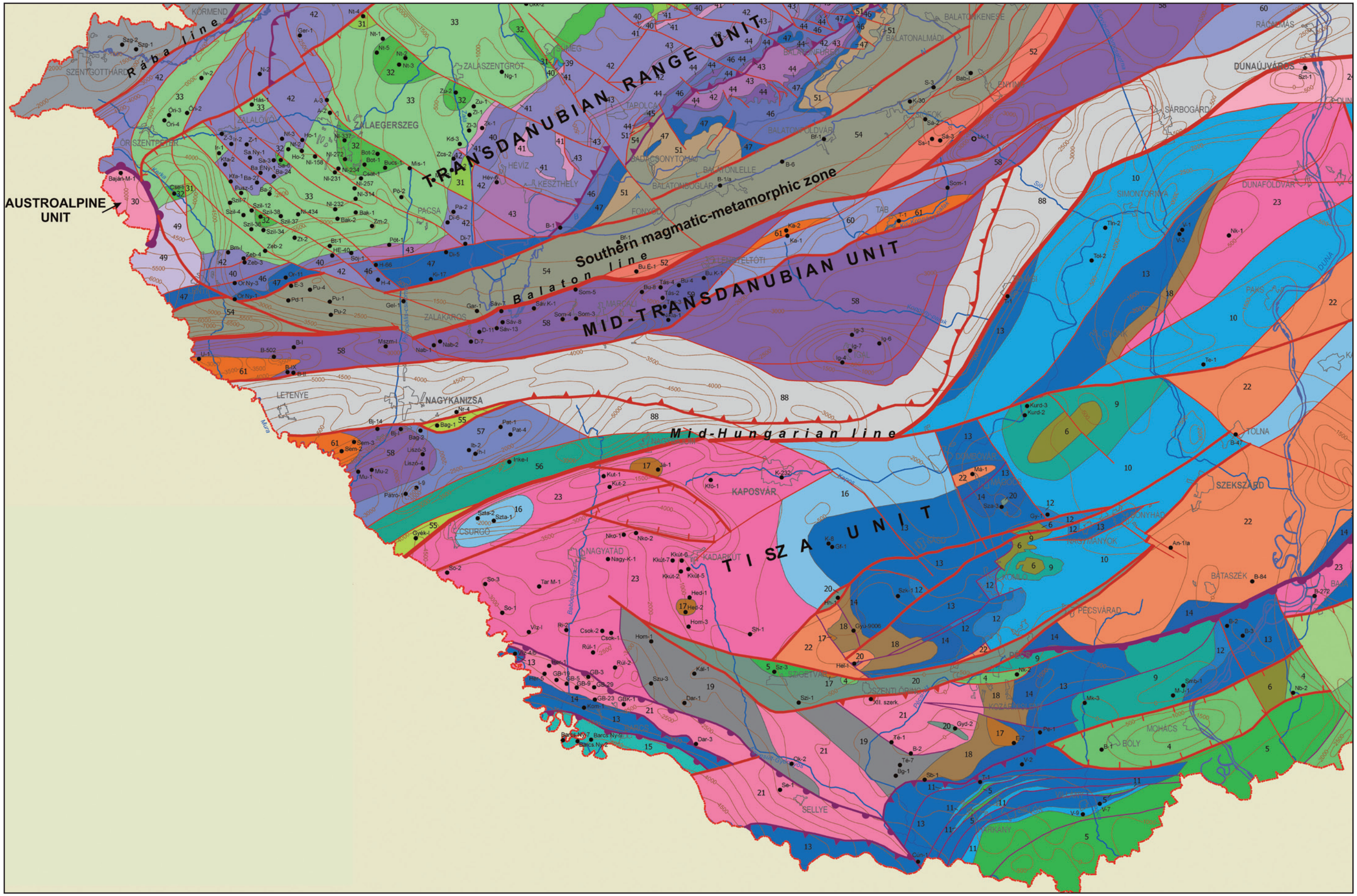


Figure 6.3. Detail of the pre-Tertiary basement map (Haas et al. 2010) showing litho-tectonic subunits in South Transdanubia

Legend:

TISZA UNIT

1-3	Upper Cretaceous shallow and deep marine formations
4, 7	Lower Cretaceous basinal marl, limestone formations
5	Lower Cretaceous shallow water platform limestone
6	Lower Cretaceous basic volcanites
8-9	Jurassic-Upper Cretaceous pelagic limestone, marl
10	Lower-Middle Jurassic pelagic fine siliciclastic formations
11	Jurassic shallow and pelagic, condensed limestones
12	Upper Triassic-Lower Jurassic coal-bearing siliciclastic formation
13	Middle Triassic shallow marine siliciclastic and carbonate formations
14	Lower Triassic fluvio-lacustrine formations
15	Mesozoic low-grade metamorphic formations
16	Mesozoic formations in general
17	Permian continental siliciclastic formations
18	Permian volcanic formations
19	Upper Carboniferous continental siliciclastic formations
20	Lower Paleozoic low-grade metamorphic formations
21, 23	Variscan medium-grade metamorphic rocks
22	Variscan granitoid rocks
24	Variscan metamorphic rocks in general

AUSTROALPINE UNIT

30	Medium-grade metamorphic rocks (with Alpine metamorphism)

TRANSDANUBIAN RANGE UNIT

31	Upper Cretaceous continental siliciclastic formations
32, 33	Upper Cretaceous platform and basinal limestone, marl
34	Lower Cretacecous continental and lacustrine formations
35-37	Lower Cretacecous platform and basinal limestone, marl
38	Lower Cretacecous flysch-like formations
39	Jurassic-Lower Cretaceous pelagic limestone, chert
40, 42	Upper Triassic platform limestone/dolomite
41, 43	Upper Triassic basinal limestone, marl
44	Middle Triassic basinal limestone with tuff
45, 46	Middle Triassic platform limestone/dolomite
47	Lower Triassic shallow water siliciclastics and carbonates
48	Mesozoic low-grade metamorphic formations
49	Upper Paleozoic and Mesozoic formations in general
50, 51	Permian shallow water carbonate and continental formations
52	Lower Permian granitoid rocks
53	Upper Carboniferous continetal formations
54	Lower Paleozoic low-grade metamorphic formations

MID-TRANSDANUBIAN UNIT

55	Upper Cretaceous pelagic marl
56	Jurassic-Cretaceous melange
57	Triassic-Jurassic very low-grade metamorphic rocks
58	Middle-Upper Triassic platform and basinal carbonates
59	Lower Triassic shallow water marl and limestone
60	Upper Paleozoic and Mesozoic formations in general
61	Permian shallow marine carbonate and siliciclastic formations
•$_{Ig-7}$	Borehole reaching the pre-Tertiary basement

6.3. The Transdanubian Range unit

The Transdanubian Range unit, bounded by the Rába line in the NW and the Balaton line in the SE (Figs. 6.1., 6.2.), can be divided into two important subunits based on lithological characteristics: a relatively narrow zone south of the Lake Balaton containing predominantly magmatic and metamorphic rocks (called southern magmatic-metamorphic zone further on), and the the Transdanubian Range unit itself exposed in the Transdanubian Mid-mountains.

Southern magmatic-metamorphic zone

Early Paleozoic low-grade, metasedimentary rocks (Balatonfőkajár Quartzphyllite) prevail in the zone bordered by the Balatonfő- and the Balaton Lines (within the so-called Balaton Zone; Fig. 6.3*., lithological unit 54*). Several boreholes in the Zala Basin also reached similar, very low-grade metasilt- and sandstones in the southwesternmost segment of the zone (e.g. boreholes Pördefölde Pd–1, Eperjehegyhát E–6, Pusztamagyaród Pu–5, Gelse Gel–1). However, some boreholes (Balatonhídvég Hi–1, Hi–2, Sávoly Sáv–7, Garabonc Gar–1) located between these two areas drilled substantially higher metamorphic grade rocks (garnet-bearing micaschist and andalusite-biotite-sillimanite schists; Árkai 1987, Török 1992, 1994) in the pre-Tertiary basement. Beside the various metamorphic complexes magmatic rocks of Permian and Oligocene age (Balogh et al. 1983, Benedek 2002, Jósvai et al. 2005) are also characteristic elements of this zone (e.g. Ságvár, Buzsák, Balatonfenyves; Fig. 6.3*., lithological unit 52*).

Transdanubian Range Unit s.s.

The major part of the pre-Tertiary basement of the Transdanubian Range Unit consists of Permo-Mesozoic sedimentary rocks underlain by a metamorphic Variscan basement. These formations are exposed on the surface in the Transdanubian Range, whereas they occur in the basement of the northern Zala Basin below thick Tertiary sedimentary cover in the southwest. An overview on the litostratigraphy of the Late Paleozoic–Mesozoic sequence of the unit is shown in Figs. 6.4a-c.

The Variscan crystalline basement of the Transdanubian Range unit is built up by the weakly metamorphosed Lower Paleozoic Balaton Phyllite Group consisting of mostly metasiliciclastics (Balatonfőkajár Quartzphyllite, Lovas Slate) and subordinate acidic to basic metavolcanic intercalations (Fülöp 1990, Budai et al. 1999). This rock suite underwent Variscan very low- to low-grade metamorphism (Árkai & Lelkes-Felvári 1987, Lelkes-Felvári et al. 1994) associated with a SE-vergent nappe structure with disharmonic and isoclinal folds (Dudko 1988, Dudko & Lelkes-Felvári 1992, Balla & Dudko 1993).

The Lower Paleozoic succession is unconfomably overlain by the non-metamorphic Upper Permian–Lower Cretaceous sedimentary sequence. This sequence suffered compressional deformation during the Mid-Cretaceous resulting in the formation of a major, first-order syncline structure and associated reverse fault zones on its limbs (Fig. 6.2.). Jurassic and Early Cretaceous rocks were preserved only along the axis of the first-order syncline during the subsequent uplift, whereas Triassic formations were deeply eroded in the limbs. The folded structure is unconformably overlain by Upper Cretaceous sediments (Fig. 6.2.).

The Alpine cycle started with characteristic red, continental sandstone deposits of Upper Permian age (Balatonfelvidék Sandstone; Fig. 6.4a), which — together with the Lower and Middle Triassic rocks — occurs in the southeastern and northwestern limbs of the syncline. The Permian sandstone is locally accompanied by Lower Permian rhyolite (Kékkút Rhyolite) exposed in the basement of the Tapolca Basin (FÜLÖP 1990).

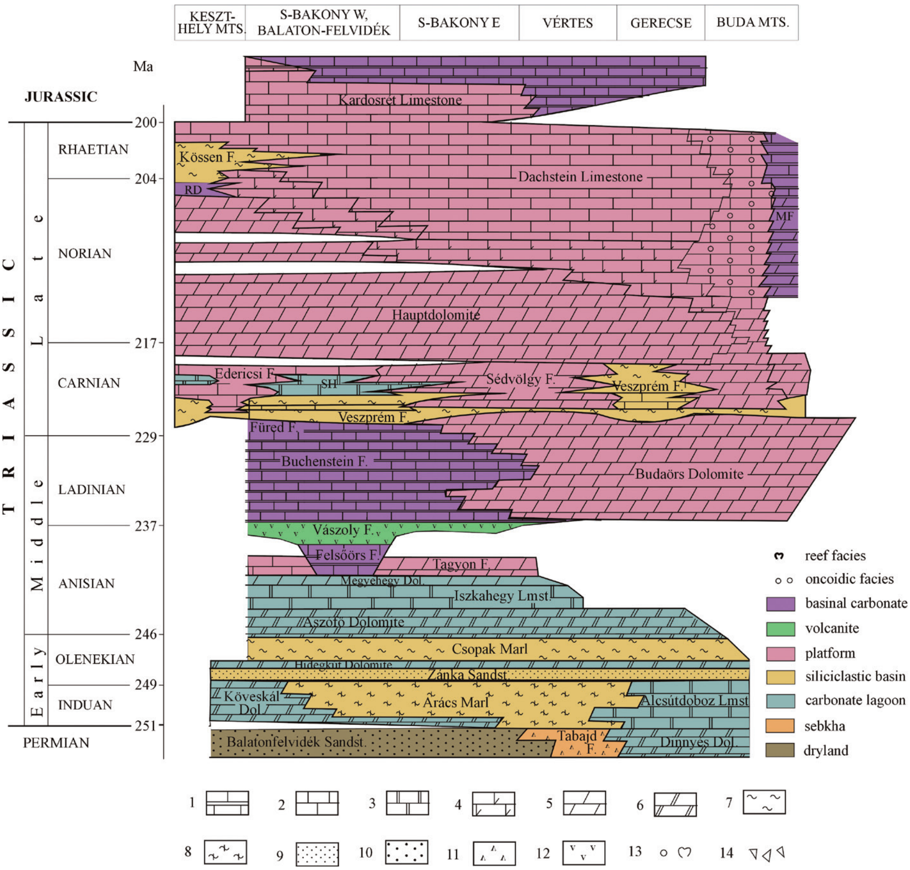


Figure 6.4a. Litostratigraphy of the Late Paleozoic–Mesozoic sequence of the Transdanubian Range unit. Permo-Triassic (after Haas 2001)

1. basinal limestone 2. platform limestone 3. lagoonal limestone 4. limestone–dolomite alternation 5. platform dolomite 6. lagoonal dolomite 7.marl 8. marl 9. marine sandstone 10. continental sandstone 11. evaporite 12. volcanite 13. oncoid Megalodus 14. breccia. MF – Mátyáshegy Limestone, RD – Rezi Dolomite, SH – Sándorhegy Limestone.

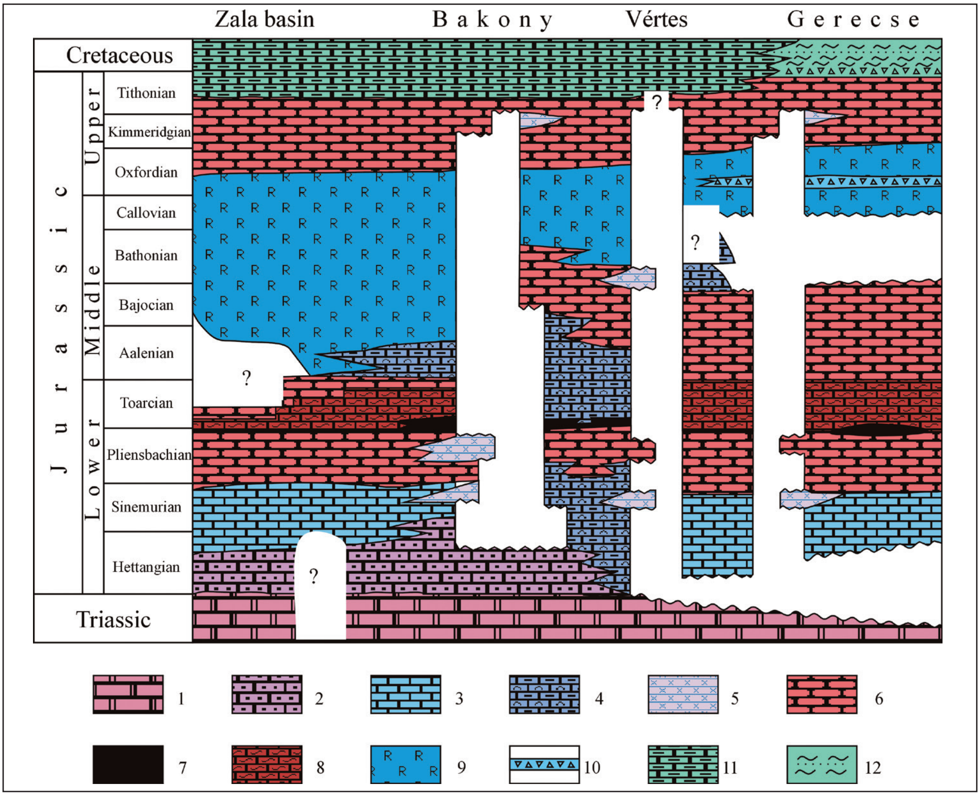


Figure 6.4b. Litostratigraphy of the Late Paleozoic–Mesozoic sequence of the Transdanubian Range unit. Jurassic (after VÖRÖS & GALÁCZ 1998)
1. Dachstein Limestone (uppermost Triassic) 2. Platform carbonate (Kardosrét Limestone) 3. Pisznice Limestone 4. cherty limestone (Lower Jurassic, Isztimér Limestone) and Bosytrian limestone (Middle-Jurassic, Eplény Limestone) 5. „Hierlatz-type" limestone 6. "Ammonitico rosso" Limestone 7. Manganesian shale 8. "Ammonitico rosso" marl 9. Radiolarite 10. „Oxfordian breccia" 11. Calpionella-bearing (maiolica) and Lombardia-bearing limestone 12. marl/sandstone.

The Lower Triassic shallow marine succession — consisting of anhydrite, dolomite and sandstone (Köveskál F.), red silt and cellular dolomite (Hidegkút F.), and marl/limestone (Csopak Marl) — appears in the southwestern segment of the Transdanubian Range (BUDAI et al. 1999) and indicates a marine shallow water, mixed siliciclastic-carbonate ramp environment in the Early Triassic. The marine environment was also characteristic during the Middle Triassic with the formation of a carbonate platform in the Anisian, which was segmented in the late Middle Triassic accompanied by acidic-neutral volcanism (BUDAI & VÖRÖS 1992). The deepest Middle Triassic is composed of mainly shallow marine carbonates: finely laminated, cellular dolomite (Aszófő Dolomite), laminar bituminous limestone (Iszkahegy F.), and dolomite again at the top (Megyehegy F.). The same Early–Middle Triassic sequence is known in the nortwestern limb of the syncline (HAAS et al. 1988). The late Middle Triassic rifting resulted in the formation of smaller intrashelf basins characterized by open marine limestone, marl, tuffite and siliceous sediments (Felsőörs and Buchenstein F.).

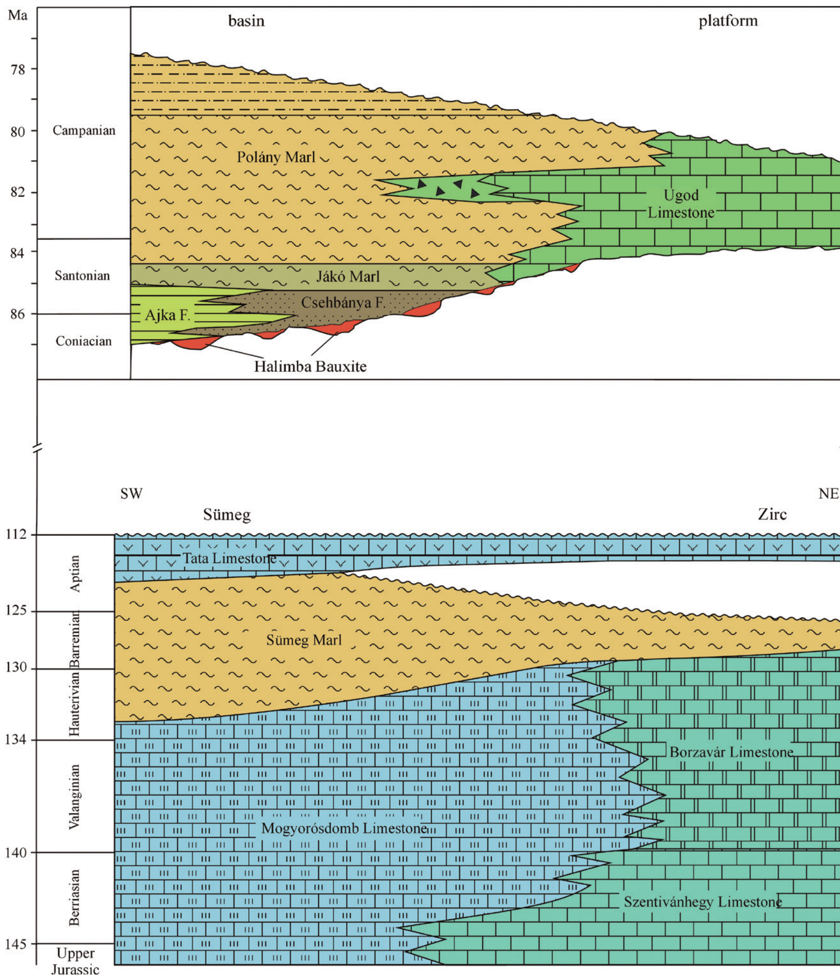


Figure 6.4c. Litostratigraphy of the Late Paleozoic–Mesozoic sequence of the Transdanubian Range unit. Cretaceous (after Haas 2001)

The lower part of the Upper Triassic is composed of intraplatform basin marl and calcareous marl (Veszprém F.) with limestone intercalations in its upper part (Sándorhegy F.). Such basin deposits (Haas 1994) occur also on the surface in the Keszthely Hills, where they interfinger with shallow marine platform carbonates (Ederics Limestone and Sédvölgy Dolomite; Budai et al. 1999). Carnian basin sediments were also drilled at the southwestern margin of the Transdanubian Range and in the Zala basin (Kőrössy 1988).

The upper part of the Upper Triassic is represented by widespread, thick shallow marine carbonates (Fig. 6.4a). The lower part is composed of the thick (~1.5 km) Hauptdolomite F., whereas the overlying Dachstein limestone reaches a thickness of few hundred metres. In the project area the Hauptdolomite crops out in the Keszthely Hills (Budai et al. 1999), whereas limestone occurs only in the vicinity of Sümeg (Haas et al.

1984). Upper Triassic intraplatform basin deposits — bituminous laminar dolomite (Rezi Dolomite) and marl/clayey marl (Kössen F.; Haas 1993) — also occur in the project area. Upper Triassic rocks were also exposed in the basement of the Zala Basin (Kőrössy 1988). Because of their generally favourable hydrogeological features the shallow water Upper Triassic carbonates (Hauptdolomite, Dachstein limestone) are extremely important from the point of view thermal water potential.

The overlying Jurassic sequence indicates first the segmentation of the Late Triassic platforms with differential subsidence of tectonically bounded blocks resulting in the formation of seamounts, deep througs and steep slopes between them (Galácz & Vörös 1972, Galácz 1984, Vörös & Galácz 1998). Jurassic–Lower Cretaceous rocks are known on the surface only near Sümeg in the northern part of the project area. Here the Lower Jurassic is represented by shallow marine limestones (Kardosrét, Pisznice and Hierlatz Limestone; Fig. 6.4b), the Middle–Upper Jurassic by pelagic limestones and radiolarite (Lókút F.; Haas et al. 1984). The uppermost Jurassic–Early Cretaceous cherty biancone type limestone (Mogyorósdomb Limestone) is followed by pelagic Lower Cretaceous marl (Sümeg Marl). The Jurassic–Early Cretaceous rocks of different facies are preserved in small erosional patches in the basement of the Zala Basin. The Mid-Cretaceous limestones are preserved on the surface around Sümeg (Tata Limestone) and reached by boreholes around Nagylengyel.

The Upper Cretaceous sediments were deposited uncomformably on the folded, uplifted and eroded Pre-Senonian sequence. The continental erosional period included intense karstification of the Upper Triassic carbonates and as well as bauxitisation (around Sümeg). In paleo-highs shallow marine reef limestones with Rudists (Ugod Limestone) were formed, whereas pelagic marl sequences dominate in basinal parts (Jákó and Polány Marl; Fig. 6.4c). Senonian deposits are widespread in the basement of the Zala basin as well.

In Slovenia Triassic platform carbonates assigned to the Transdanubian Range unit were preserved only locally as small tectonic fragments above the medium-grade Austroalpine crystalline basement (Murska Sobota Massif). South of the massif the narrow, E–W striking Ljutomer fault zone contains Lower Triassic rocks displaying remarkable similarities to the corresponding series of the Transdanubian Range unit.

6.4. The Mid-Transdanubian unit

The basement between the Balaton line and Mid-Hungarian Line is known exclusively from boreholes, and attributed to the so-called Mid-Transdanubian composite unit (Bérczi-Makk et al. 1993, Haas et al. 2000, 2010).

The Mid-Transdanubian unit consists of predominantly Permo-Mesozoic rocks, but the drilled sequences show significant facies differences suggesting the presence of tectonically juxtaposed blocks in this unit. The original location of these blocks can be restored in the junction area of the Southern Alps and the Dinarides. Considering the main characteristics of the drilled sequences three subunits could be distinguished (Haas et al. 2000): the Julian-Savinja Zone–South Karavanke, the South Zala and the Kalnik subunits.

The northernmost Julian-Savinja Zone–South Karavanke subunit represents practically the eastward continuation of the South Alpine range. It is characterised by Permo-Triassic, mostly non-metamorphic formations with thick Triassic platform carbonates (Haas et al. 1988). The wells drilled in the vicinity of Újfalu, Budafa, Magyarszentmiklós, Nagybakónak, Sávoly, Táska, Buzsák, Karád, Igal, Tab and Lajoskomárom all exposed basement rocks that belong to this subunit (Fig. 6.3., *lithological units 58-61*). The most complete Upper Paleozoic sequence exposing a thick (~800 m) marine Permian shallow water, siliciclastic and carbonatic sedimentary succession (Fig. 6.5) is known from the borehole Újfalu–I (U–I; Bérczi-Makk & Kochansky-Devidé 1981) close to the Hungarian/ Slovenian border. This well exposed dark grey sericite schist (Carboniferous?) below the Lower Permian limestone, dolomite and siliciclastic rocks. The overlying Upper Permian is built of a lower siliciclastic and a thick, upper dolomite member. In other wells of the subunit the Lower Triassic sequence indicates shallow water ramp facies with significant terrigenous influx in its deeper parts. The Middle Triassic is characterised by platform and basinal carbonates with coeval volcanic activity, whereas the Upper Triassic succession generally consists of thick platform carbonates.

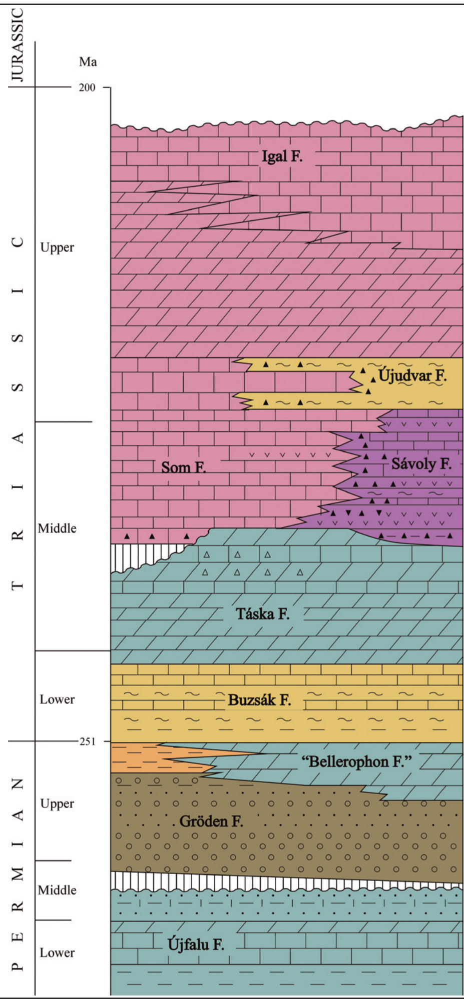


Figure 6.5. Litostratigraphy of the Permo–Triassic sequence of the northern part (Julian-Savinja Zone–South Karavanke subunit) of the Mid-Transdanubian unit (after Haas et al. 2001)

In Slovenia the South Karavanke Palezoic-Mesozoic formations are found south of Periadriatic zone. Only a single borehole reached Middle to upper Triassic carbonate rocks in the project area in Slovenia. In northwestern Croatia outcrops in the Ravna Gora as well as some exploratory wells (near Vuckovec and Vukanovec) exposed Triassic platform carbonates in the basement that can be assigned to this subunit. However, because of the scarce data the geology of the pre-Tertiary basement is rather poorly constrained in this area.

In the southwestern part of the unit (South Zala subunit) strongly tectonised Permian to Jurassic sedimentary sequences occur. The Permian evaporite-bearing deposits are overlain by Triassic carbonates and Triassic–Jurassic slope- and basin deposits that suffered (very) low-grade metamorphism. The age of the low- to intermediate pressure metamorphism is Cretaceous (~96 Ma; Árkai et al. 1991). A key well (Iharosberény–1) transected Middle–Upper Triassic limestone of platform and foreslope facies in a remarkable thickness. Above the Triassic carbonates brecciated limestone, Middle–Upper Jurassic radiolarite (Dosztály, 1994) and shale were encountered. The South Zala subunit and the Medvednica unit in northern Croatia display very similar character and age of metamorphism, therefore they might belong to the same tectonic unit (Haas et al. 2000).

In the southwesternmost part of the unit (Kalnik subunit) a Cretaceous(?) mélange-like, weakly metamorphic (Árkai et al. 1991) succession (Inke F..) consisting of acidic and intermediate metavolcanites, serpentinite, spilite, shallow marine limestone, debris flow breccias and Middle and Upper Triassic dark grey radiolarites (Dosztály 1994, Kozur & Mostler, 1994) is present in tectonized shaly-silty matrix. This succession is covered by the Late Cretaceous pelagic marl (Gyékényes F..) in the key well Inke-I. This zone is considered as the NE continuation of the Dinaridic ophiolites cropping out in the Mt. Kalnik in northern Croatia (Pamic 1997).

6.5. The Tisza unit

The pre-Tertiary basement south of the Mid-Hungarian line is composed of the formations of the Tisza unit (Fig. 6.1.). In the southwestern part of the project area the Mid-Transdanubian Unit is probably thrusted upon the Tisza unit to some extent (Csontos & Nagymarosy 1998).

The geological evolution of the Tisza unit show basic differences in comparision to the previously discussed units that all belonged originally to the “Alpine realm”. This feature is due to its different paleogeograpic position during the Paleozoic and Early Mesozoic times at the southern margin of stable Europe. The pre-Tertiary basement of this unit can be divided into two main groups: Variscan metamorphic and magmatic crystalline rocks and overlying non-metamorphic Late Carboniferous and Permo-Mesozoic sequences.

Crystalline complexes

The crystalline rocks of the Tisza unit (Fig. 6.3., *lithological units 20-23*) are known only from boreholes except the small outcrop of the Mórágy Crystalline Block (Jantsky 1979) in the southeastern hilly foreland of the Mecsek Mts. Crystalline rocks are directly overlain by Miocene sediments in the southwestern segment of South Transdanubia between the western edge of the Mecsek Mts. and the Hungarian/Croatian national border, whereas they are covered mostly by Permo-Mesozoic — locally by Carboniferous — sequences in the middle and eastern portions of South Transdanubia (Fig. 6.3.).

The crystalline rocks of the Tisza unit were grouped into several tectonically bounded subunits (complexes or "terranes", cf. Kovács et al. 2000) according to their lithological characteristics and metamorphic evolution. However, the exact location and nature of the boundaries of these generally deeply buried complexes is poorly constrained in many cases. In the project area four larger and three smaller subunits were distinguished (Fig. 6.6.):

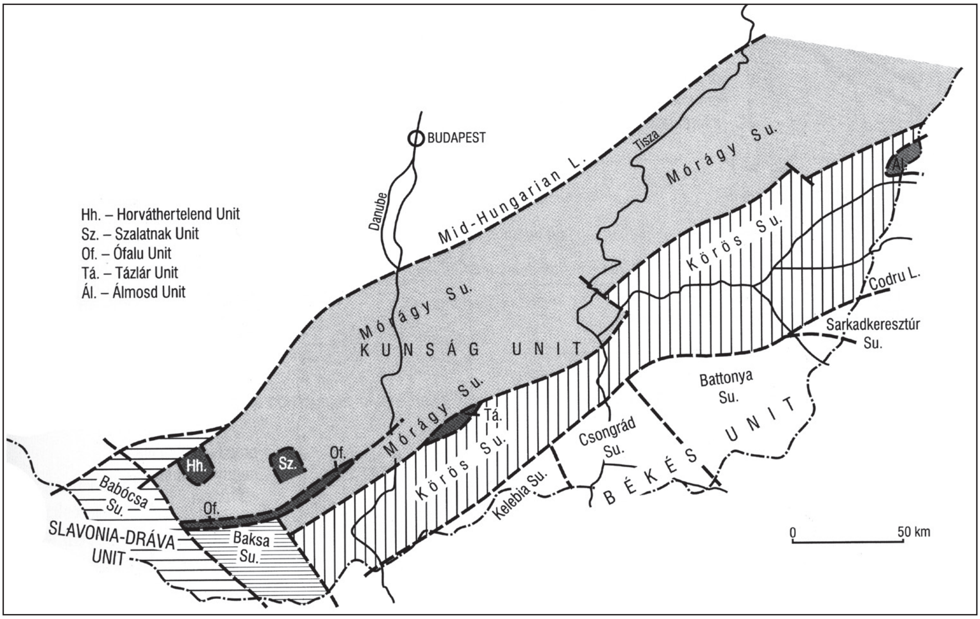


Figure 6.6. Overview of the crystalline complexes in South Transdanubia (for detailed explanation see text). (After Szederkényi 1997)

- Babócsa subunit (or Görgeteg-Babócsa subunit in older literature),
- Baksa subunit,
- Kőrös subunit,
- Mórágy subunit,
  - Ófalu subunit,
  - Szalatnak subunit,
  - Horváthertelend subunit.

The Babócsa and the Baksa subunits form together the so-called Slavonia-Dráva unit, which extends southward over the river Drava to Northeast Croatia (i.e. Slavonia). It crops out in the Papuk and Psunj Mountains, where the formations are characterised by a general (W)NW–(E)SE strike. The same strike was deduced for the Hungarian part of the unit.

The Mórágy and Kőrös subunits form together the Kunság unit that is characterised — in contrast to the Slavonia-Dráva unit — by a general NE–SW strike.

(Görgeteg-)Babócsa subunit

This subunit forms the pre-Tertiary basement of the South Somogy area and the Dráva basin. It consists of mostly medium-grade gneiss with minor micaschist and subordinate amphibolite intercalations. Serpentinite was also mentioned from the Dráva basin (Szepesházy 1958), however, this result was not confirmed up to now. Intense ductile deformation is represented by the frequent appearance of mylonitic zones within these rocks. The protolith of these metamorphites is represented by the alternation of thick greywackes and relatively thin pelites without any carbonate intercalations. Amphibolites lenses are the metamorphosed varieties of mafic lava and tuffs with T-MORB character (Tóth M 1995) intercalated with the sedimentary rocks. In a small area near to Barcs the amphibolite facies crystalline rocks are overlain by very low- to low-grade Mesozoic metasedimentary and metavolcanic rocks (Árkai 1990) forming the Pre-Tertiary basement in this segment of the Drava basin. This sequence might be correlated to the low-grade Mesozoic sequence of the Medvednica unit (Haas et al. 2000) that is exposed by several boreholes in the pre-Tertiary basement of northern Croatia.

Baksa subunit

This subunit forms the crystalline basement of Villány Mts. and its northern foreland up to the Mecsek Mts. In comparision to the Babócsa subunit it displays a much more variable rock assemblage consisting of a folded gneiss–micaschist–marble–dolomitic marble–calc-silicate gneiss rock series. This series shows a remarkable metamorphic zonation from the chlorite zone up to sillimanite zone with a southwestward increasing temperature gradient (Szederkényi 1976). Near the village of Gyód a subvertical, serpentinised ultramafic body is wedged into this complex. North of this body near the village Görcsöny a single eclogite occurrence (Ravasz-Baranyai 1969) is known indicating a high pressure metamorphic event during the Variscan tectonometamorphic evolution. The pre-metamorphic rock assemblage of the Baksa subunit is represented mainly by a greywacke-pelite series associated with well-developed carbonate members and accompanying thick, T-MORB tholeiite lava intercalations.

Kőrös subunit

This subunit forms the pre-Alpine basement of the southeasternmost segment of Transdanubia east of the Villány Mts. up to the river Danube. It strikes ca. NE–SW, similarly to the Mórágy subunit. Lithologically it is characterized by medium-grade gneiss–micaschist–amphibolite association. The pre-metamorphic rock assemblage is represented mainly by a greywacke-pelite series associated with accompanying basic lava and tuff intercalations.

The crystalline rocks of the Görgeteg-Babócsa, Baksa as well as the Kőrös subunits seem to have suffered a more or less uniform metamorphic evolution with the following stages:

1. Traces of a high-pressure eclogite-facies metamorphism preserved only in sporadically occurring, retrograde, symplectitic amphibolites with the characteristic mineral assemblage almandine-pyrope-rich garnet, omphacite, kyanite, phengite, zoisite, and rutile (p_{min}= 15–16 kbar, T= 600–700 ºC).
2. Medium-grade (amphibolite facies), Barrow-type metamorphism characterized by the garnet-staurolite-kyanite±sillimanite index minerals (p= 6–9 kbar, T= 600–650

ºC; Árkai 1984, Árkai et al. 1985; Török 1989, 1990). This event fundamentally determines the main metamorphic characteristics of the crystalline basement of the whole Tisza unit.

3. Low-pressure medium-grade metamorphism characterized by high thermal gradient with andalusite as index mineral (p= 2–3 kbar, T=550–600 ºC). This event is proven to be important in many localities of the crystalline basement (Lelkes-Felvári et al. 1989).

As the stratigraphically overlying Carboniferous and Permo-Mesozoic sequences are practically non-metamorphic, the age of metamorphism is clearly pre-Alpine. Geochronological data (mica K/Ar and Ar/Ar ages) indicate a cooling to ~300 ºC after amphibolite facies peak metamorphic conditions in the range of 320–290 Ma (Balogh et al. 1983, Lelkes-Felvári et al. 2003, Lelkes-Felvári & Frank 2006).

Mórágy subunit

This NE–SW striking subunit forms the pre-Alpine basement of the Mecsek Mts. and its north(east)ern foreland up to Mid-Hungarian line. Its lithostratigraphy strongly differs from all other crystalline subunits as it is composed of granitic rocks. The granite belt can be traced from the western foreland of the Mecsek Mts. to the middle part of the Great Hungarian Plane. In the Western Mecsek Mts. a subvertical, lens-like body of serpentinised harzburgite (Szederkényi 1974, 1977) wedged into the granite. The granite body exposed in the Mórágy Hills is composed of microcline megacryst-bearing biotite monzogranites containing variable sized mafic enclaves of predominantly monzonitic composition. Both of these rock types — formed by the mixing and mingling of a felsic and a more basic magma during the early stage of the magmatic evolution — are crosscut by late magmatic, leucocratic dykes. The age of the intrusion is Lower Carboniferous (~340 Ma; Klötzli et al. 2004, Gerdes 2006, Koroknai et al. 2010). During cooling the already solidified pluton suffered a greenschist facies metamorphic overprint resulting in the formation of ca. NE–SW striking, steeply dipping foliation and furthermore narrow, mylonitic zones.

Ófalu subunit

The Ófalu subunit forms a NE–SW striking, narrow, linear tectonic belt (the so-called Mecsekalja zone) in a length of ca. 40 km located between the Permo-Mesozoic sequence of the Mecsek Mts. in the North and the granite body of the Mórágy subunit in the South (Fig. 6.6.). The Ófalu subunit — exposed at the northwestern margin of the Mórágy Crystalline Block — comprises a Lower Paleozoic, internally heavily folded and mylonitized, greenshist facies rock suite with melange-like character. The predominant rock types of this subunit are various gneisses associated with metasedimentary and metavolcanic rocks. Based on sporadically preserved plant remnants and Conodont fragments a Silurian–Devonian age of the metasedimentary rocks can be assumed (Kedves & Szederkényi 1996, Kovács†, pers. comm.). Near Ófalu a small subvertical serpentinite body (Ghoneim & Szederkényi 1977) is wedged into the metasedimentary rocks with tectonic contacts. This small, rootless serpentised ultramafic body — as well as the other rootless ultramafic bodies preserved in the Baksa, Mórágy and Görgeteg-Babócsa(?) subunits probably represent dismembered fragments of an obducted, Paleozoic oceanic lithosphere (Balla 1981).

The main metamorphic event reached uniformly greenschist facies in the Ófalu subunit, whereas a previous amphibolite facies event was also detected in some gneissic rocks (Lelkes-Felvári et al. 2000). Prominent greenschist facies mylonitic deformation of the Ófalu subunit was dated to be about 300 Ma (Lelkes-Felvári et al. 2000, Tüske 2001) associated with important strike-slip deformation along the zone (Szederkényi 1977).

Szalatnak and Horváthertelend subunits

The Szalatnak and Horváthertelend subunits are located north and west of the Mecsek Mts. (Fig. 6.6.). Both subunits are characterized by the occurrence of (very) low-grade metasedimentary and variable metavolcanic rocks. The occurrence at Szalatnak comprises a more than 1500 m thick sequence. Thin lydite bands are characteristic for the thick, folded metagrauwacke-slate members, containing Silurian Conodont fauna (Kozur 1984) and Graptolite fragments (Oravecz 1964). Several anthracite intercalations also occur. At the base of the sequence a granitic intrusive body (Szalatnak Syenite) is known with a fractured, thin contact aureole. The intrusion age of this pluton is unclear, as controversial age data (Carboniferous?, Triassic?) were published. The described sequence is unconformably overlain by non-metamorphic Permian/Lower Triassic sandstone. The Paleozoic metasedimentary sequence drilled near Horváthertelend is covered by Badenian sediments. The Szalatnak and Horváthertelend subunits were interpreted as remnants of Late Variscan nappes with unknown vergency. The Szalatnak/Horváthertelend subunits sufferred a transitional very low- to low grade metamorphism (~350 ºC; Árkai et al. 1995) with low pressure character, whereas very low-grade overprint (Szederkényi 1974) is characteristic in the upper part of the sequence.

Carboniferous and Permo-Mesozoic sequences

Late Carboniferous and Permian sequences (Fig. 6.3., *lithological units 19 and 18-17*) occur predominatly in the middle part of South Transanubia (surroundings of Szigetvár), whereas Mesozoic rocks prevail in the eastern part of the basement of the Tisza unit (Fig. 6.3., *lithological units 1-16*). A general overview on the litostratigraphy of the Late Paleozoic–Mesozoic sequences is shown in Fig. 6.7.

The Late Carboniferous to Permian molasse-type sequences overlying the crystalline basement of the Tisza unit show important differences in the different crystalline subunits. The oldest overstep formation is the Late Carboniferous Téseny Sandstone F. characterized by a coal-bearing grey sandstone and clay sequence. It occurs both in the Babócsa and the Baksa subunits, but totally missing in the other crystalline subunits. In the Babócsa subunit the Late Carboniferous molasse is overlain by young, Miocene sediments and forms a NW–SE oriented, tectonically bounded narrow depression in the neighbourhood of the villages of Darány, Szulok, Homokszentgyörgy, and Kálmáncsa (Jámbor 1969). In the Baksa subunit the anthracite-bearing Upper Carboniferous rocks (Hetényi & Ravasz-Baranyai 1976) are overlain by the Lower Permian Korpád Sandstone and Gyűrűfű Rhyolite Formations (Fazekas et al. 1987). The thickness of the coal-bearing Carboniferous formation exceeds 1500 m, that of the overlying Permian redbeds and rhyolite also reaches 1000 m. The Lower Permian Korpád Sandstone and/or Gyűrűfű Rhyolite appear in all of the previously introduced crystalline subunits, however, they did not form a uniform, continuous cover over the crystalline basement or the Carboniferous rocks.

In the Mecsek Mts. a ca. 3200 m thick Permian molasse overlies the crystalline rocks of the Mórágy subunit. It consists of a fairly continuous and undisturbed sequence (Korpád Sandstone, Gyűrűfű Rhyolite, Cserd Conglomerate, Boda Siltstone and Kővágószőlős Sandstone) from the lowermost Permian up to the unconformity above the topmost Permian covered by Lower Triassic redbeds (Jakabhegy Sandstone F.). In the southern portion of South Transdanubia (Kőrös subunit) an incomplete Permian sequence is known with thin Korpád Sandstone and Gyűrűfű Rhyolite covered by Lower Triassic redbeds (Jakabhegy Sandstone). Upper Carboniferous sandstone below the Permian formations is also missing here, although it is widespread in the northern foreland of the Villány Hills (Kassai 1976).

Based on the characteristics of the Mesozoic successions three zones — clearly traceable from the Late Triassic — were distinguished within the Tisza unit from the North to the South:

- Mecsek zone (a relatively deeper zone with intense sediment accumulation)
- Villány–Bihor zone (relatively elevated area with respect to its surroundings)
- Békés–Codru zone (not present in the project area)

The Lower Triassic rocks form the overall overstep sequence in the whole Tisza unit (Fig. 6.7.). They comprise continental redbeds in predominantly fluvial facies (Jakabhegy Sandstone F.). This stage was followed by a transgression in the Early Middle Triassic producing fine siliciclastics on a wide tidal flat (Patacs Aleurolite) overlain by evaporites and dolomites (Hetvehely F.). During the next stage of the Middle Triassic the terrigenous influx decreased, and a large, storm-affected carbonate ramp was formed (Török 1997). Different type of carbonates (Rókahegy Dolomite, Lapis Limestone, Zuhánya Limestone, Csukma F.) were deposited on this ramp showing generally an upward shallowing trend from the early Ladinian (Török 1993, 1998). The Middle Triassic of the Villány zone is characterized by a higher proportion of dolomites in comparision to the Mecsek zone.

A definite differentiation of the Mecsek and the Villány zones began in the early part of the Late Triassic when the Mecsek Half-graben (Nagy 1969, 1971) and the Villány-Bihor ridge began to form. In the Mecsek Zone a restricted brackish to fresh water lagoon environment was followed by delta progradation and formation of various fluvial and lacustrine facies (Karolinavölgy Sandstone). At the same time a thin (~30 m) sequence of Carpathian Keuper-type siliciclastics (Mészhegy Sandstone), with peritidal dolomite interlayers at their base, was deposited in the Villány Zone (Rálisch-Felgenhauer & Török 1993).

The facies differences developed during the Late Triassic became even more pronounced in the overlying Jurassic and Cretaceous sequences of the Mecsek and the Villány–Bihor zones. In the earliest Early Jurassic fluviatile–lacustrine sedimentation developed during the Late Triassic continued in the Mecsek zone, and a thick coal-bearing siliciclastic succession (Mecsek Coal F.) was deposited in lacustrine, deltaic and coastal swamp environments. The thickness of the coal-bearing formation may reach as much as 1200 m and several hundred meters in the other parts of the Mecsek Zone. In the next stage of the Early Jurassic as well as in the Middle Jurassic grey, bioturbated shale, marl and sandstone were deposited in an open marine basin with an upward deepening trend indicating gradual transgression in the area. The thickness of this "spotty marl" group (Vasas and Hosszúhetény Marl, Komló Calcareous Marl) may reach 2500 m in the Mecsek Half-graben.

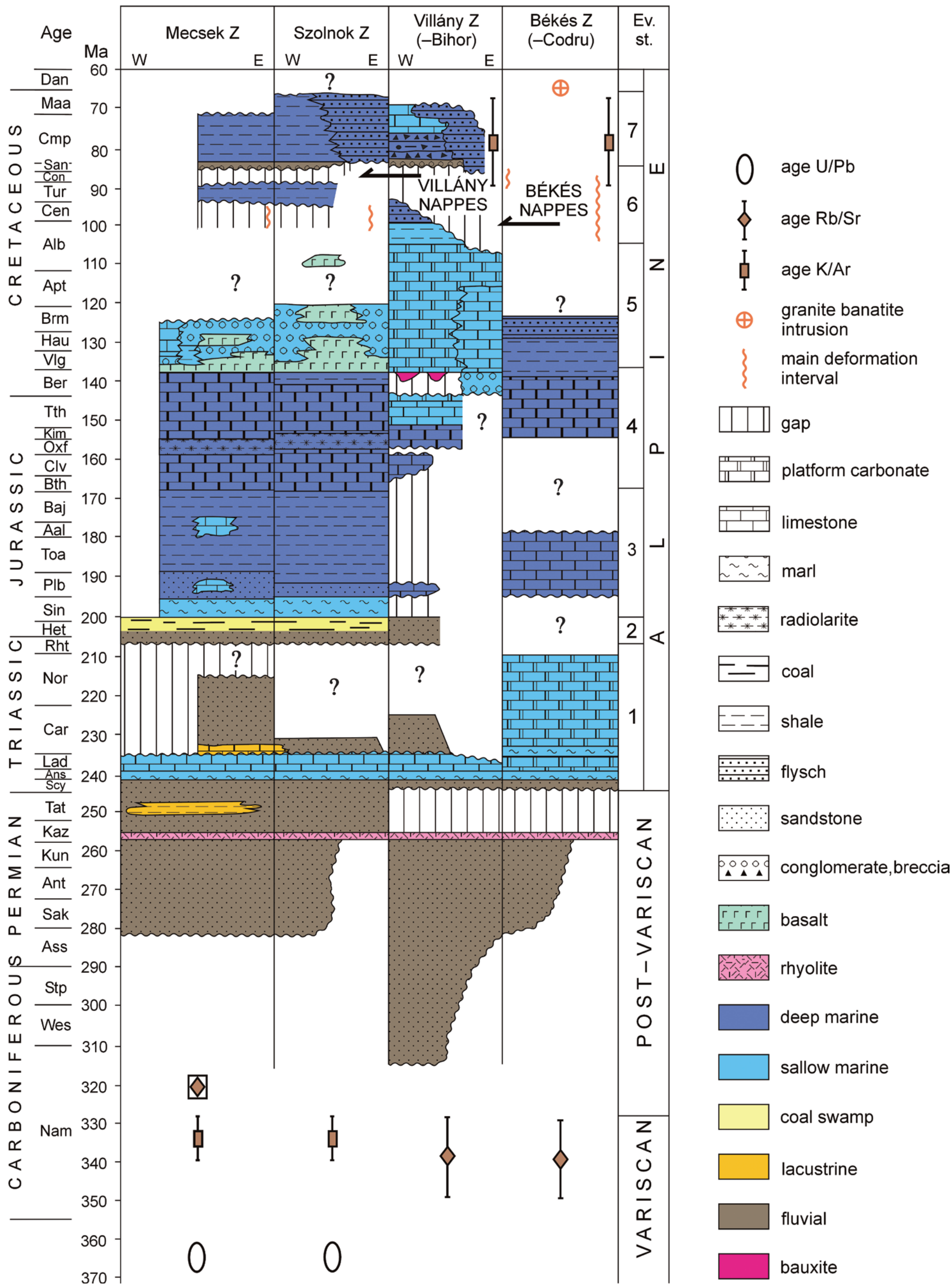


Figure 6.7. Overview on the litostratigrapy of the Late Paleozoic–Mesozoic sequences of the Tisza unit.
For detailed explanation of the distinguished zones see text. (After Haas & Péró 2004)

The large proportion of terrigenous material throughout the whole Early Triassic–early Middle Jurassic interval clearly indicates the proximity of a continental source area. This situation changed basically in the middle part of the Middle Jurassic indicated by the drastic decrease of the terrigenous input and the appearance of the typical "Mediterranean" carbonatic lithofacies. The middle Middle Jurassic–earliest Early Cretaceous interval is represented by a condensed sequence of Ammonitico Rosso-type limestone, cherty radiolarian limestone, siliceous limestone and Calpionella limestone. A significant change could be also recognised in the ammonoid and brachiopod faunas: the Early Jurassic and early Middle Jurrassic faunas show definite European affinity, whereas the Middle to Late Jurassic interval is characterized by Mediterranean elements (Géczy 1973a, Vörös 1988). These changes are considered as indicators of the separation of the Tisza unit by rifting from the southern margin of European continent (Géczy 1973b, Vörös 1993).

The rifting process continued in the Early Cretaceous leading to intra-continental rift-related alkaline basalt volcanism (Harangi 1994, Harangi et al. 1996) that is present over large portions of the Mecsek Zone. The volcanic activity reached a maximal intensity in the early Early Cretaceous, and lasted in the late Early Cretaceous. Intense erosion of the volcanic complex already began in the late Early Cretaceous, when atolls and thick volcaniclastic series were formed containing large amount of shallow marine fossils which were redeposited from the broadened sedimentary zones developed around the volcanic structures (Császár & Turnšek 1996). This marine sedimentation was interrupted by intense tectonics by the end of the mid-Cretaceous. Due to the early Late Cretaceous (tectogenesis and subsequent erosion the early Upper Cretaceous pelagic siliciclastic series with typical red shale was preserved as small remnants only.

A new sedimentary cycle commenced in the late Late Cretaceous. Overlying coarse clastics, pelagic red calcareous marl is known in the central part of the Mecsek Zone grading northeastward into grey silty marl and further on into sandstone-dominated, "flysch"like sequences.

In contrast to the continuous sedimentation of Mecsek zone during the Triassic–Early Cretaceous interval, major gaps do exist in the Mesozoic sequences of the Villány–Bihor zone (cf. Fig. 6.7.). In some areas the entire Late Triassic–Early Jurassic interval is missing, while in others Lower Jurassic thin, sandy, belemnoid-bearing crinoidal limestone may occur (Vörös 1972). A less than one metre-thick Middle Jurassic ferruginous, stromatolitic bank, rich in ammonoids belonging mainly to the European fauna province (Géczy 1973a, 1984) closes the gap. Upper Jurassic thick-bedded, light-coloured pelagic limestones are overlain by bauxite lenses representing again an important gap. Lower Cretaceous Urgon-type (Császár 1992), shallow-water platform limestone with Dinaridic-type dasycladaceans (Bodrogi et al. 1993) is characteristic in the Villány zone. However, the lowermost Cretaceous basaltic volcanics widespread in the Mecsek zone are represented here only by a few sills and dykes. The sequence is terminated by Mid-Cretaceous flysch-type formations (Császár & Haas 1984). The Late Cretaceous overstep sequence consists of mainly marine siliciclastics deposited in the foreland basins of the early Late Cretacous nappe pile. The Villány-type Mesozoic extends to the South and West-Soutwest over the Hungarian/Croatian border and forms the pre-Tertiary basement in northern Slavonia.

7. DATABASE PREPARATION AND REGIONAL MAPPING OF KEY AQUIFER HORIZONS

7.1. Database overview

Four regional aquifers have been identified in the study area, which are proven to be able to provide large water yields for geothermal energy consumption. From top to bottom these are:

1. Delta front sand packages of the Miocene strata and their lateral equivalents. These sandstones belong to the Újfalu Formation in Hungary and the equivalent lower Bilogora Formation in Croatia, are known as the main thermal water bearing layer. Several spas in Hungary, Croatia and Slovenia get their thermal water from this aquifer;
2. Deep-water delta front turbidite and sheet-sand packages (Szolnok Formation (Hungary) and basinal parts of the Ivanić Grad and Kloštar Ivanić Formations (Croatia). These sandstones are well known in the oil industry as hydrocarbon reservoirs but they are also good hot water aquifers in large part of the study area;
3. Badenian-Sarmatian biogenic limestones;
4. Fractured and karstified Mesozoic carbonates in the basement of the Tertiary strata. The volume of water bodies associated with these aquifers are usually large and are supplied by meteoric waters recharged in elevated areas with exposed carbonate rocks (such as Bakony, Mecsek and Villány Mountains).

Detailed geological and hydrogeological characterisation of these formations was given in the previous chapters. In order to fully evaluate the geothermal potential of these strata however, not only their geological-, but also their structural-, thermal and yield characteristics need to be understood and mapped on a regional scale. To do this a comprehensive, integrated geological/geophysical database has been built, which served the basis of the regional structural and thermal mappings. This database can be subdivided into three parts: borehole-, seismic- and published map data.

The borehole part of the integrated database was tailored from various publicly available data sources. The T-JAM project (Thermal Joint Aquifer Management, www.t-jam.eu) borehole database consists of lithological and stratigraphical data of 158 and 99 public boreholes from the Zala basin area and neighbouring Slovenia. This was completed by borehole and formation test data from more than 100 boreholes collected from the Hungarian Mining and Geological Authority (MBFH: Magyar Bányászati és Földtani Hivatal).

Our geothermal database comprises hot water yield-, chronostratigraphic- and temperature data from more than 1000 water- and petroleum exploration boreholes in Hungary. This database was completed by water yield data acquired from the South Transdanubian Water Management Directorate (Dél-dunántúli Vízügyi Igazgatóság).

Borehole geophysical logs, as well as seismic time-depth curves were also acquired for a few selected boreholes in the area with the aim of tying borehole data into the seismic surveys, as well as of depth converting the interpreted seismic horizons.

The second fundamental part of the integrated database is 2D seismic sections, which were used for regional mapping of the key aquifer horizons. Seismic survey were available only for the Hungarian part. The sections were acquired as digital SEGY files from the Hungarian Mining and Geological Authority together with navigation files with the geographic coordinates of the sections.

The third pillar of the database consists of various published geological- and geophysical maps as well as digital topographic data. These maps include the Bouguer anomaly map of Hungary (kinga.elgi.hu), the surface and pre-Tertiary geology map of Hungary (Haas et al. 2010, Gyalog and Budai, 2010), and various subsurface maps published in form of books, report or conference presentations. (Fodor et al. 2011, Putniković and Cota 2010, Horváth & Royden, 1988). Unfortunately for the Croatian side of the study area neither well nor seismic data was available, so here only published maps and literature data were used for the mapping. These data and digitised maps were all used and integrated in the regional mapping of the key aquifers.

The locations of the well and seismic data made available for this study are shown on Figure 7.1.

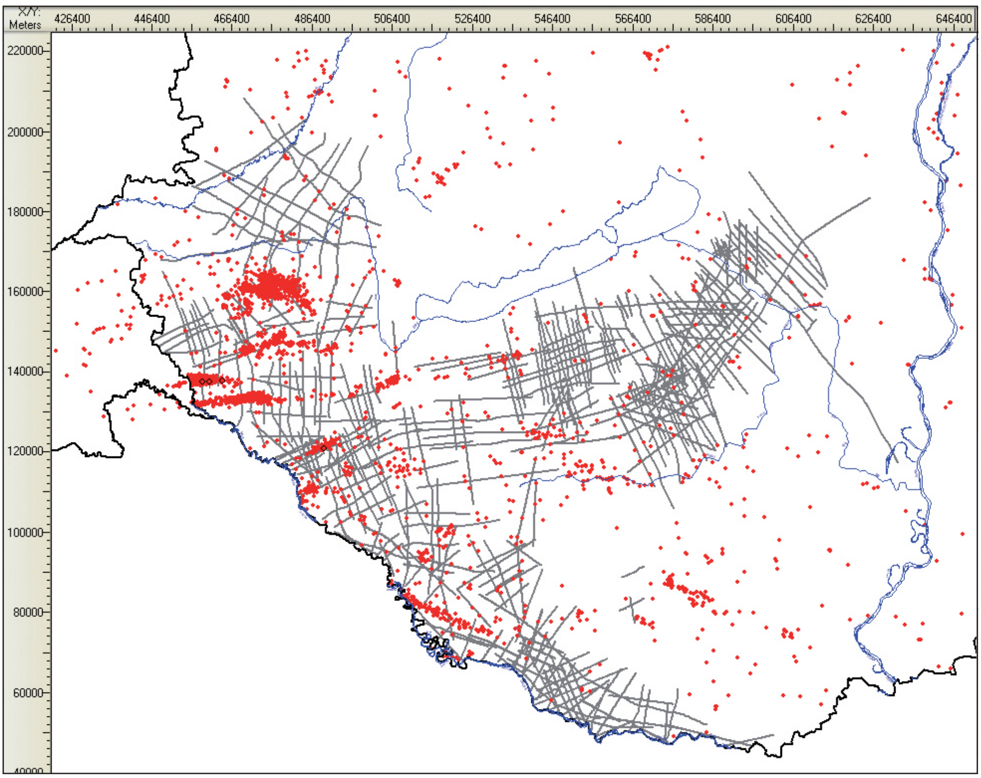


Figure 7.1. Locations of the wells (red dots) and seismic surveys (grey lines) used for the study (Hungarian National Grid (EOV) coordinate system).

7.2. Data integration and preparation

The key for a successful geothermal evaluation of an area is a well-established, integrated geological/geophysical/geothermal database. For rapid and convenient work it is essential for the database to be in digital format. Prior to any interpretation work significant efforts were placed on the establishment of a regional digital database.

As a first step of this process all boreholes and other geology-related data needed to be digitised. This included the digitisation of basic well-, formation- and water yield data as well as published subsurface geological maps. Part of these datasets was available digitally for the project, however, the newly acquired data needed to be digitised and organised into Excel tables suitable for integrating into the interpretation software.

As the final step of the database building, all digital data relevant for a regional evaluation was integrated with the interpretation software (SMT Kingdom Suite). This software package among many others provides excellent tools for seismic interpretation and geological correlation. The following datasets were integrated into the Kingdom project:

- Borehole data
- Basic well data of all available wells,
- T-D curves of selected wells,
- Geophysical logs of selected wells,
- Seismic data
- 2D surveys,
- Geological and geophysical maps and grids
- Bouguer anomaly map,
- Pre-Tertiary basement depth (2010 edition),
- Pre-Tertiary geological map (2010 edition),
- Surface geological map of Hungary,
- Other published subsurface maps from Hungary and Croatia,
- Topographic data

7.3. Regional structural mapping of key aquifer horizons

As mentioned before, four regionally important aquifer horizons were identified in the study area. In order to fully understand the geothermal potential of these aquifers their structural setting as well as subsurface morphology needs to be mapped on a regional scale.

The deepest of the four aquifers represents the fractured/karstified carbonates below the Tertiary strata of the Pannonian Basin. In the Hungarian part of the study area detailed structural mapping of the pre-Tertiary strata has recently been conducted by the Hungarian Geological Institute based mainly on well and seismic data. Results of these mapping were published by Haas et al. (2010), and were digitised at the onset of this study. Also, within the framework of the T-JAM project (Fodor et al. 2011) a detailed and up-to-date pre-Tertiary depth map is available for the Zala Basin and Mura Depression areas, which partly overlap with the Haas et al. (2010) map. Becasue of the geological and structural complexity of the pre-Tertiary strata the time consuming complete (re) mapping of the pre-Tertiary basement in our study area was not conducted. Instead, it was decided that only a compilation (i.e. merging) and update of the various input maps would be performed using the extensive set of well data collected for the present study. For example, it was discovered that many of the wells that reached the basement and are available in our database was not used during the construction of the Haas et al. (2010) basement depth map, resulting in as high as 200-300 meter discrepancy between the well data and the map. During the construction of the regional pre-Tertiary depth map first the various basement maps were merged into a sigle map (Haas et al. 2010, Fodor et al. 2011 and Horváth & Royden, 1988) and then it was locally adjusted to the well data. In areas with no well control (e.g. large part of Croatia) the compiled map was left unchanged.

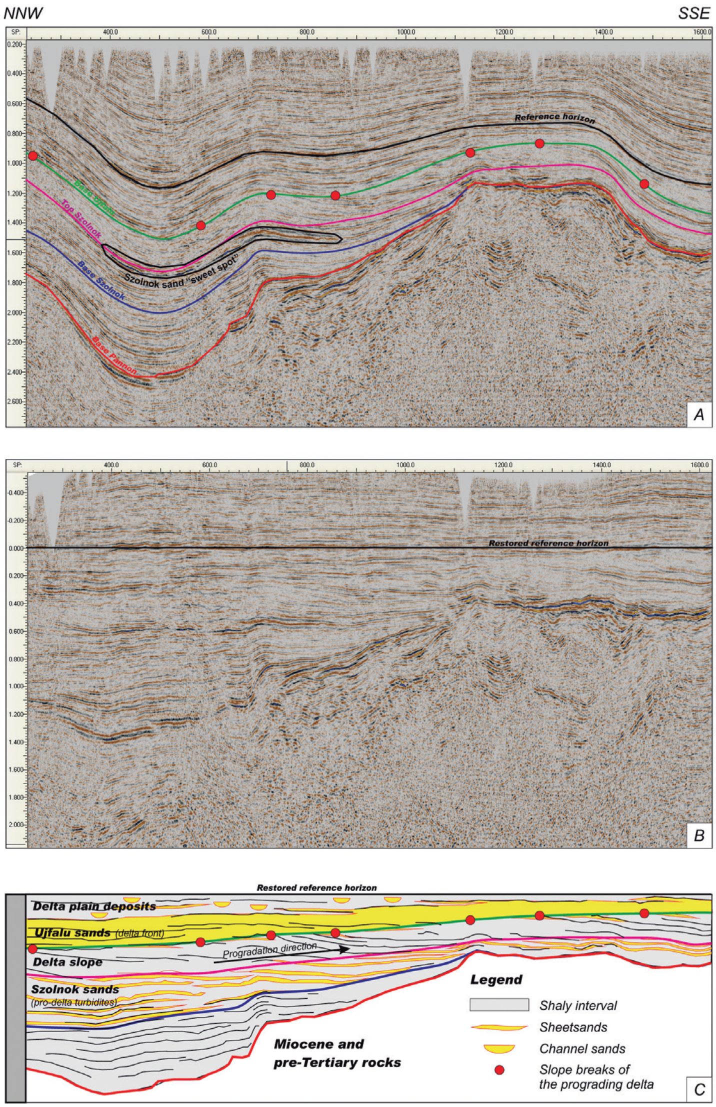


Figure 7.2. A) Interpretation of the Base Pannonian, top Szolnok and base Újfalu horizons on the Na-69 2D seismic sections. B) Tectonically restored (undeformed) seismic section demonstrating the internal stratigraphic structure of the prograding delta sequence. Note the characteristic seismic facies of the prograding sequence, which helped the identification of the delta front and pro-delta turbiditic sand bodies on the seismic surveys. C) Simplified geological model of the prograding (shelf) system constructed base of the restored seismic sections showing the Újfalu and Szolnok aquifers.

For mapping of the three Neogene aquifer horizons 2D seismic sections were also used. An integrated mapping using not only well but also seismic data provides a much better structural constraint on the final maps. The first step of mapping these horizons was their interpretation on the available 2D seismic sections. Identification of these events on the seismic surveys was based on their distinct seismic facies patterns. The base Pannonian (top Miocene) is usually a strong seismic event resulting from the generally higher acoustic impedance of the Miocene compared to that of the Pannonian (Fig. 7.2). Also, the top Miocene clearly marks a regional unconformity as demonstrated by the truncations and onlaps associated with this seismic event.

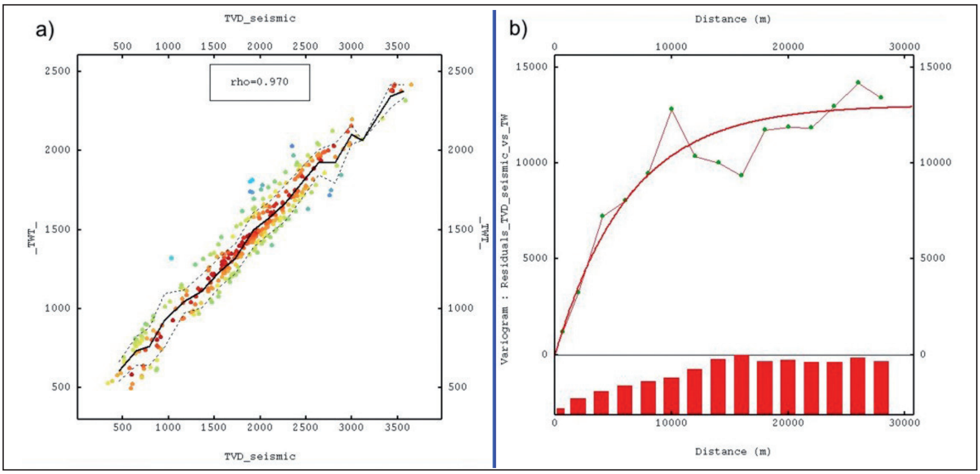


Figure 7.3. Depth conversion of the interpreted seismic horizons using external drift kriging (KED). A) correlation of true vertical depth observed in wells vs. the seismic TWT interpolated into the well locations in order to define global trend and residuals. Residuals (i.e. distance from the trend) are colour coded. B) Experimental variogram and fitted variogram model of the residuals. Histogram of the variogram pairs is shown in the bottom.

The Szolnok and Újfalu formations represent respectively the excellent quality sand sequences deposited on the distal slopes and fronts of the deltas filling the Pannonian basin during the Pliocene. The prograding delta sequence, which generally contains only silt and poor quality sands, can be easily identified on the seismic surveys based on their characteristic sigmoid internal reflection pattern (i.e. clinoforms, Fig. 7.2). Based on this pattern the base Újfalu horizon was identified and interpreted as a line connecting the shelf breaks (i.e. top clinoform), while the Szolnok formation as the strong reflection package at the base of delta slope (i.e. base clinoform).

The second step of map construction was the depth conversion of the interpreted horizons. Analysis of available time-depth curves from various parts of the study area demonstrated that the average velocity of the Pannonian (i.e. post-rift) strata can change significantly across the area. On the flanks of the basin, where only thin post-rift strata has been deposited (preserved), the average velocity is significantly lower than in the deep basins. For this reason performing the depth conversion using a single time-depth curve would have resulted in a significant discrepancy between well data and the final map. Therefore the depth conversion was performed using a geostatistical approach called kriging with external drift (KED).

During KED a loosely-defined primary parameter (i.e. TVD in well data) is estimated with the help of a spatially densely-defined external parameter (secondary variable or external drift, i.e. seismic data). This technique utilises the exellent correlation between the TVDs (true vertical depth measured from seismic reference datum) of a given formation observed in the boreholes and the seismic (two-way travel time) interpolated into the well locations using the interpreted seismic horizons (Fig 7.3a). During the depth conversion process first the global trend of the depth converted horizon as well as the residuals are calculated. The residuals represent the error between the global trend and the real depth (color coded on in Fig 7.3a). As second step, the residuals are spatially analysed in form of experimental variograms, which is used to describe the spatial variability (and possible anisotropy) of the input data. Detailed analysis of the 2D variogram reveals tectonic-related spatial trends within the data. This is followed by the variogram modelling where (combination of) simple variogram functions are fitted to the experimental variograms (Fig. 7.3b). This is one of the most important part of the gridding, since the choice of variogram model has a major impact on the accuracy of the depth conversion far away from the well control. The final depth of the seismic horizons was calculated by the KED procedure using the global trend as well as the variogram of the residuals.

The third and last step of the depth map construction was the compilation and interpolation of the various input data into a single regular grid. Using regular grids is essential for later map manipulations, temperature interpolation and visualisation. The inputs of this step were the well data, the depth converted seismic horizons, as well as the data points of the corresponding subsurface maps from the T-JAM project area and Croatia. One problem we faced during this process is that the spatial density of the input data (wells + seismics) is not uniform across the study area. In the deep basin areas of Hungary for example, which were the focus of extensive hydrocarbon exploration in the past, the available data density is much higher compared to the flank areas, where practically there is no deep well or seismic control (see Fig 7.1, e.g. foreland of the Mecsek, Villány and Bakony Mountains). Similarly, data availability for the Neogene aquifers from the Croatian side was restricted to a published map of the base Pannonian horizon (Putniković and Cota, 2010) and due to the lack of available seismic surveys the top Szolnok and base Újfalu horizons could not be constrained properly. Using a mapping system like this would have resulted in a geologically inconsistent result in areas with poor data control. This was especially true for the base Pannonian and base Újfalu horizons.

Therefore, instead of simply interpolating the input well-, seismic- and map data over the whole study area a KED system similar to that described above was used. As external drift a regionally available parameter (i.e. map) was needed, which shows adequate correlation with the depth of the Pannoian strata. This parameter is the gravity anomaly, which is known for a long time to excellently represent the thickness of the Neogene strata in tectonically uninverted areas. For the construction of the base Pannonian map therefore the gravity anomaly map of Hungary was used as external drift, which helped constraining the map in areas with poor data control. For constraining the top Szolnok and base Újfalu horizons the finalised base Pannonian map was used relying on the very good correlation between the depth of these horizons and the depth of the base Pannonian. With this trick we were able to estimate the top Szolnok and base Újfalu horizons even in the Croatian side of the study area. Bare in mind however, that in Croatia these maps are reflecting the global trends established by the correlation with the base Pannonian and are not constrained by hard data (well or seismics). For this reason the top Szolnok and base Újfalu maps in the Croatian side of the project should be used with reservations.

The final subsurface depth maps of the 4 aquifer horizons are shown in Figs. 7.4-7.7. The maps are quality controlled and locally corrected for any crossovers resulting from differences in the interpolation techniques and the amount of input data. One exception to this is the base Pannonian vs base Tertiary map in the Drava Basin and Bjelovar Depressions areas, where crossovers do exist between these two maps. The reason behind this is that in these areas the two maps are based on published maps with markedly different scale and resolution. The Horváth & Royden (1988) map, which was used to constrain the base Tertiary map, is a regional map with contour intervals of 500m, while the map of Putniković and Cota (2010) is a detailed, high resolution map based on proprietary well and seismic data.

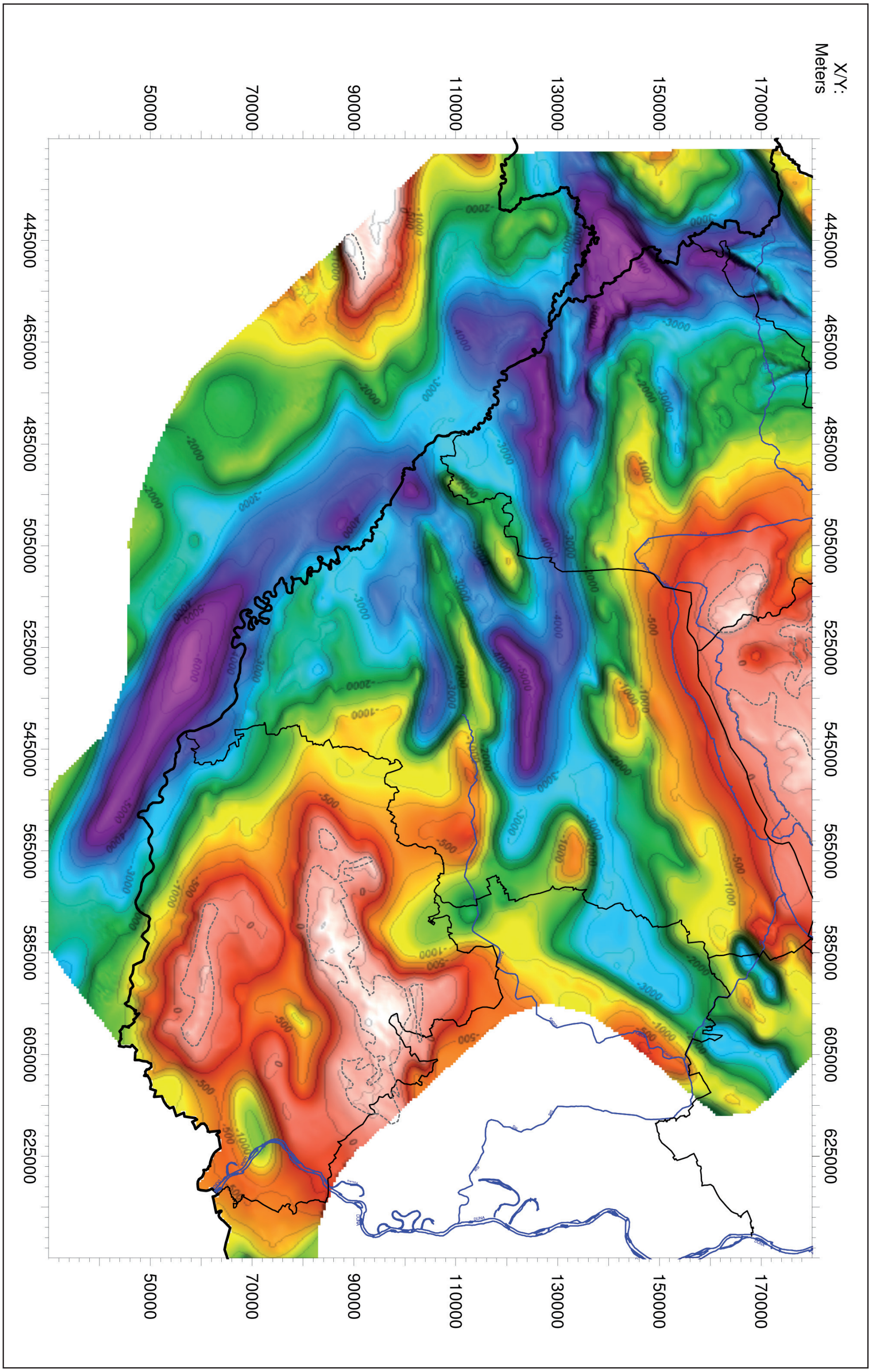


Figure 7.7. True vertical depth (TVD) map of the pre-Tertiary basement in the study area (m below sea level). Areas with outcropping basement are shown by the dashed polygons. See text for discussion.

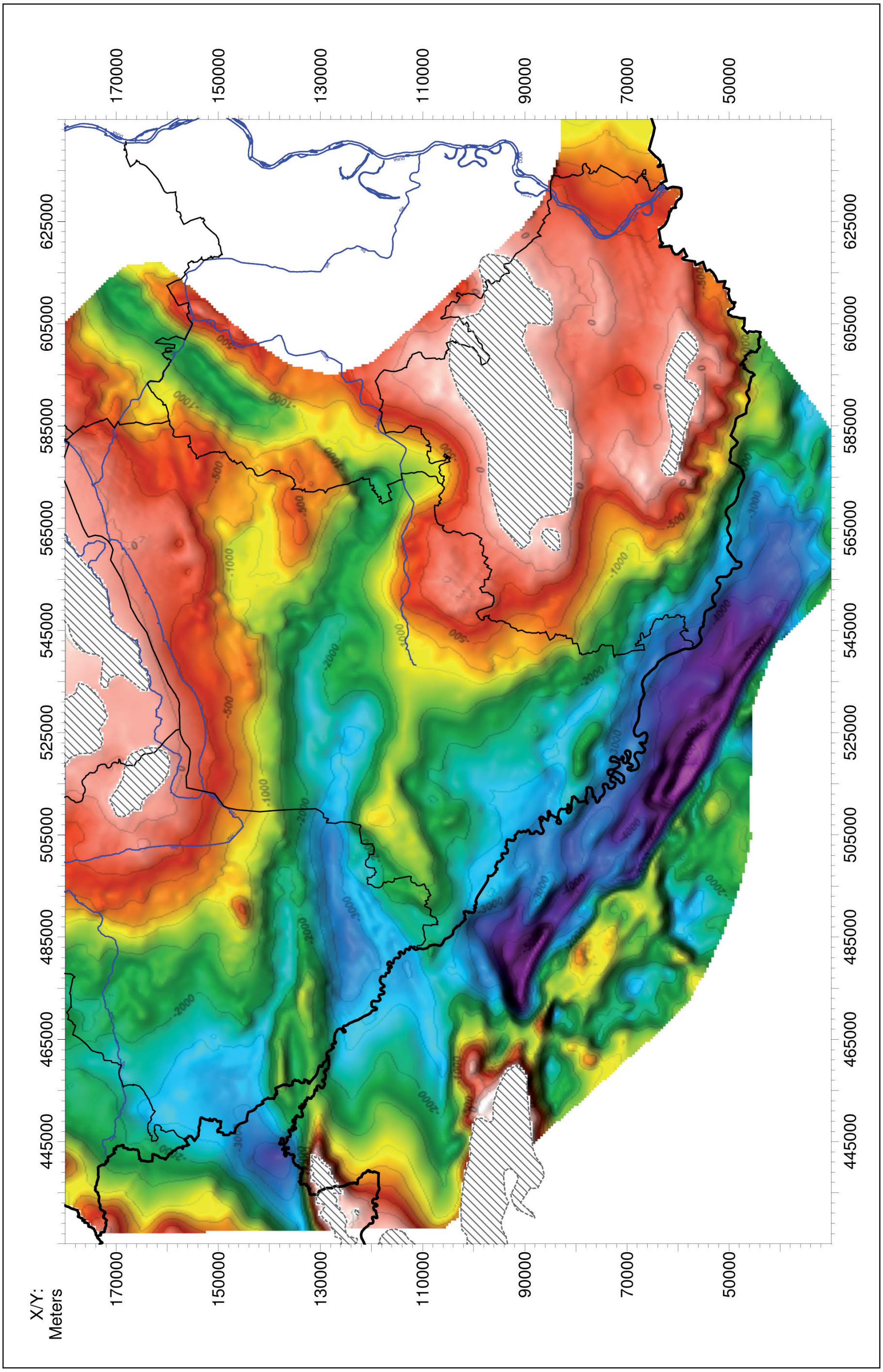


Figure 7.6. True vertical depth (TVD) map of the base Pannonian (top Miocene) horizon in the study area (m below sea level). Areas with missing Pannonian sediments are shown by the hatched polygons. See text for discussion.

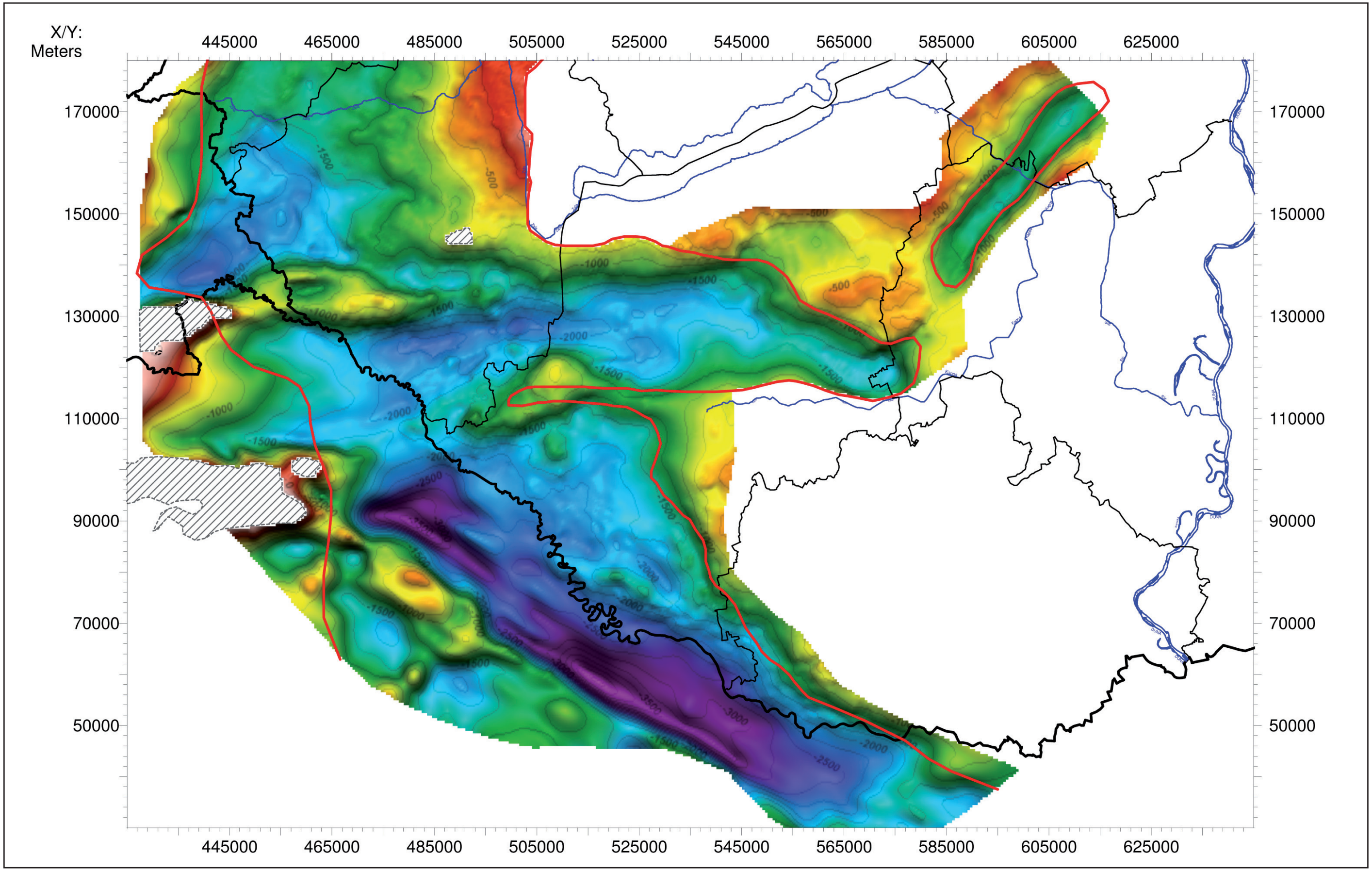


Figure 7.5. True vertical depth (TVD) map of the top Szolnok horizon in the study area (m below sea level). Outside the red lines the Szolnok Formation is poorly developed with thin or no sands at all (modified after Fodor et al 2011). Areas where the Szolnok formation is missing are marked by the hatched polygons. See text for discussion.

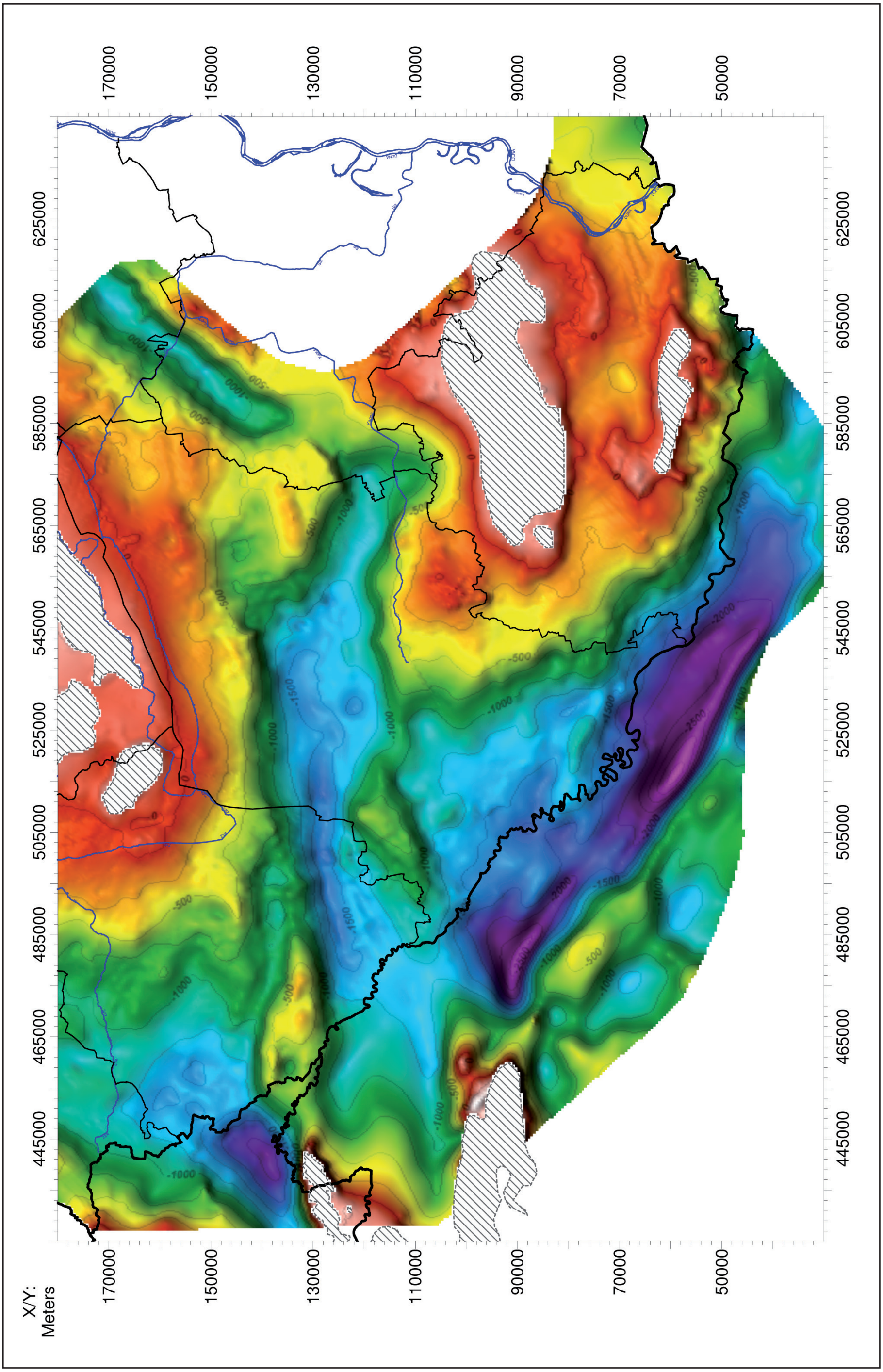


Figure 7.4. True vertical depth (TVD) map of the base Újfalu horizon in the study area (m below sea level). Areas with missing Pannonian sediments are shown by the hatched polygons. See text for discussion.

The maps are referenced as true vertical depth below seal level. From a structural point of view there are several structural features which can be identified on all four maps. The Transdanubian Range and the Mecsek Villány area represent the structurally highest positions where the pre-Tertiary rocks are exposed on the surface. The Mecsek-Villány area from the West and South is bounded by the deep Drava basin where the thickness of the Neogene sequence exceeds 5000m. Even the shallowst aquifer horizon (base Újfalu) exceeds the depth of 1500m in this area. Another important depression identified in the area is the Zala basin located West of the Transdanubian Range, where the average thickness of the Pannonian strata is ~2000m reaching as high as 3000m in the southern part. In this basin the Szolnok and Újfalu formations are at ~1500 and ~1000m depth respectively.

The Transdanubian Range and the Mecsek-Villány areas are separated by an E-W oriented elongated basin and ridge system, which is associated with the Mid-Hungarian tectonic zone. The deepest part of this zone is located near the western border of Hungary (Letenye-Nagykanizsa trough) where the depth of the pre-Tertiary basement exceeds 5000m. In this zone even the shallowest of the four identified aquifer horizons are deeper than 1500m. The eastern continuation of this zone is the Mezőcsokonya basin, which further continues to the NE-SW oriented Northern Somogy or Ozora trough. The Mezőcsokonya and Ozora deeps are separated by the Igal high, where the depth of the pre-Tertiary basement is only 1000m, while the three other horizons are at a depth of 300-500m.

Several other smaller tectonic high can be identified on the maps. The Drava and Nagykaniza basins are separated by the Inke high, while north of the Nagykanizsa basin the Budafa and Lovászi anticlines can be identified. In these folded areas the depth the Pannonian aquifers are at 1000-1500m.

7.4. Regional temperature mapping of key aquifer horizons

Thermal characterisation of the mapped aquifers is the most important factor in evaluating the geothermal potential of the area. Since the depth of the aquifers changes significantly within the study area, their temperatures also show large variations. For this reason the thermal characteristics of the aquifers can be best demonstrated with temperature maps.

The temperature maps were constructed using temperature data from the GTERM temperature database. This database contains measured temperature data from more than 1000 water and hydrocarbon exploration boreholes in the area. As first step, the temperatures of the given aquifer were estimated in all boreholes in the area at the depth taken up by the structure maps shown earlier at the location of the given borehole. This interpolation/extrapolation is performed by using the measured temperatures, the reliability parameter of the measurements, the thermal conductivity of the succession, and the calculated heatflux across the penetrated strata. A quality parameter is assigned to each calculated temperatures representing the reliability of the calculated value. For example, in case of poorly constrained, unreliable input temperature data or in case of extrapolation of temperatures into depth much deeper than the deepest temperature measurement in the borehole, the quality parameter shows a large uncertainty of the calculated value.

As second step the interpolated temperature data exported from the GTERM database were quality controlled and filtered. Obviously errorous data and data points with very large uncertainty parameter were removed from the dataset. Temperature data calculated for a depth value being more than twice as deep as the total depth of the given borehole („relative distance" > 1, see Fig. 7.8) were also removed from the dataset and were not taken into account during the temperature map construction. As seen on Fig. 7.8 this data cleaning process significantly reduced the standard deviation of the data cloud, increased the correlation coefficient and helped constraining a reliable temperature trend.

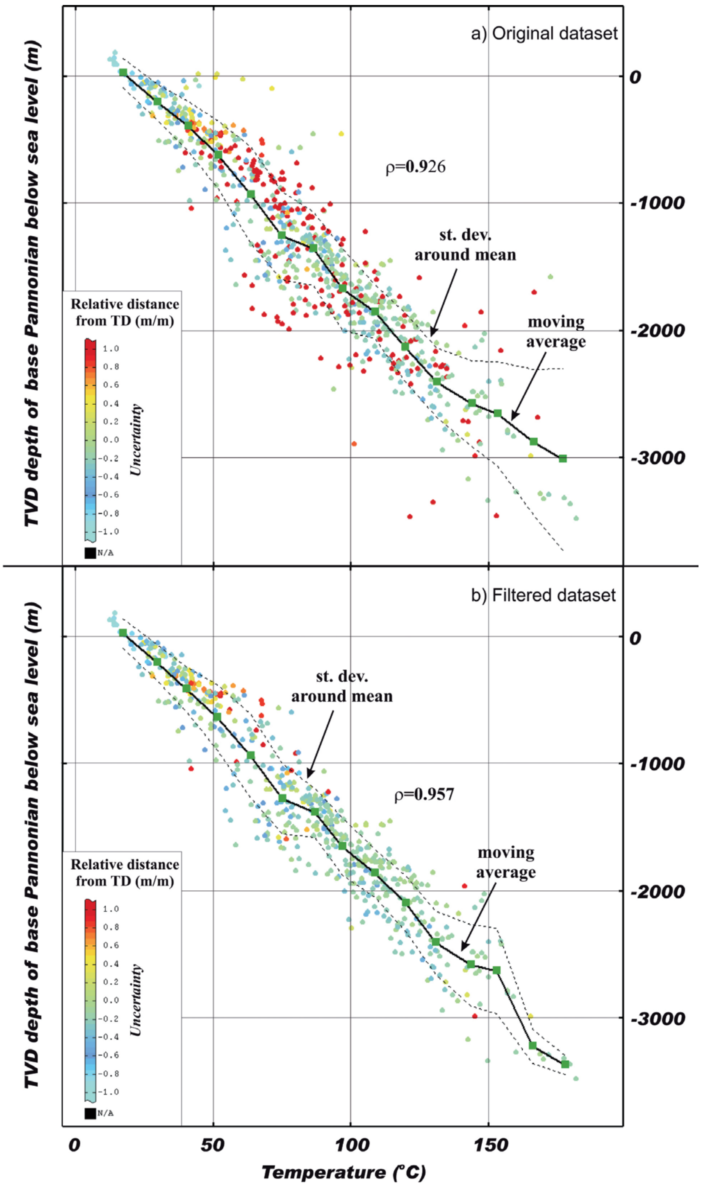


Figure 7.8. Temperature vs. Depth data pairs used for the temperature map construction of base Pannonian. See text for further discussion.

As final step of the temperature mapping the quality controlled temperature data were interpolated into regular grids for each aquifer. For interpolation technique a KED system described earlier was used. As external drift the TVD depth of the given aquifer was used (see very good correlation on Fig 7.8b), which help constraining the temperatures even in areas with no available well control (i.e. Croatia). As surface temperature, 11.5 °C was used, which is the yearly average temperature in this region. The goal was to produce realistic looking, smooth temperature maps, therefore the uncertainty parameters were fully taken into account during kriging. This means that in the course of interpolation data points with larger uncertainty were taken into account with smaller weights compared to those with smaller uncertainty.

The temperature maps for the four aquifers are shown in Fig. 7.9-7.12. Bear in mind that the temperature maps shown are referenced to the depth of the horizons shown in Figs 7.4-7.7. Three of these horizons (top Miocene, top Szolnok, top basement) represent the *top* of the given aquifer, which can have thickness over few hundreds of meters. Consequently the temperatures shown represent the *minimum temperature* of the water bodies in these aquifers. The shallowest aquifer represents the *base* of the Újfalu formation, meaning that the corresponding temperature map represents the *maximum temperature* of the associated water body.

Also bear in mind that these temperatures are *static equlibrium* temperatures of the aquifer. Temperature anomalies associated for example with upwelling hot fluids along fracture zones (like the Harkány thermal bath with 62 °C water from only 50m depth!) are not or only suppressedly represented by these maps.

As expected, the maps indicate steadily increasing temperatures with depth. The inferred average geothermal gradient varies between 4-5 °C/100m and is clearly showing a decreasing trend with depth: while the gradient for the Újfalu horizon is 5.11 °C/100m as average, for the top Szolnok, base Pannon and top basement it is 4.95, 4.64 and 4.17 °C/100m, respectively.

It can be seen on the maps, that the elevated areas near the Transdanubian Central Range, the Mecsek, Villány and Kalnik mountains represent the coldest places in all four aquifers. These are the recharge areas of the kartic reservoirs. In contrast, the hottest places (discharge areas) are seen in the Drava basin where the depth of the pre-Tertiary basement reaches 7000m. Here the temperature of the pre-Tertiary aquifer exceeds ~300 °C. Generally, the hottest places of the pre-Tertiary aquifer are found in the deep parts of the Drava and Zala basins, where the temperatures are around 250-270 °C. The corresponding top Miocene maximum temperatures are between 200-220 °C, and it can be concluded that they are over 100 °C for large part of the study area.

Because of the smaller structural relief, the temperatures in the Szolnok and Újfalu aquifers show less variations. As the Szolnok formation was deposited only in the deep grabens its temperature is rather uniform everywhere. It is usually around 100 °C, however if one takes into account that this aquifer is often several hundred meter thick, static temperatures being well over 100 °C can be considered in these turbiditic sands almost everywhere in the study area.

Being the shallowest the Újfalu aquifer is characterised by the smallest temperatures. Temperatures are usually above 50 °C in the depressions, which can reach as high as 80-90 °C or even over 100 °C in the deepest parts of the area (Zala and Drava basins). These temperatures are really appealing for geothermal applications since the flow rates are usually very good from these sands, and the water chemistry of these waters are also preferable to waters from the deeper aquifers.

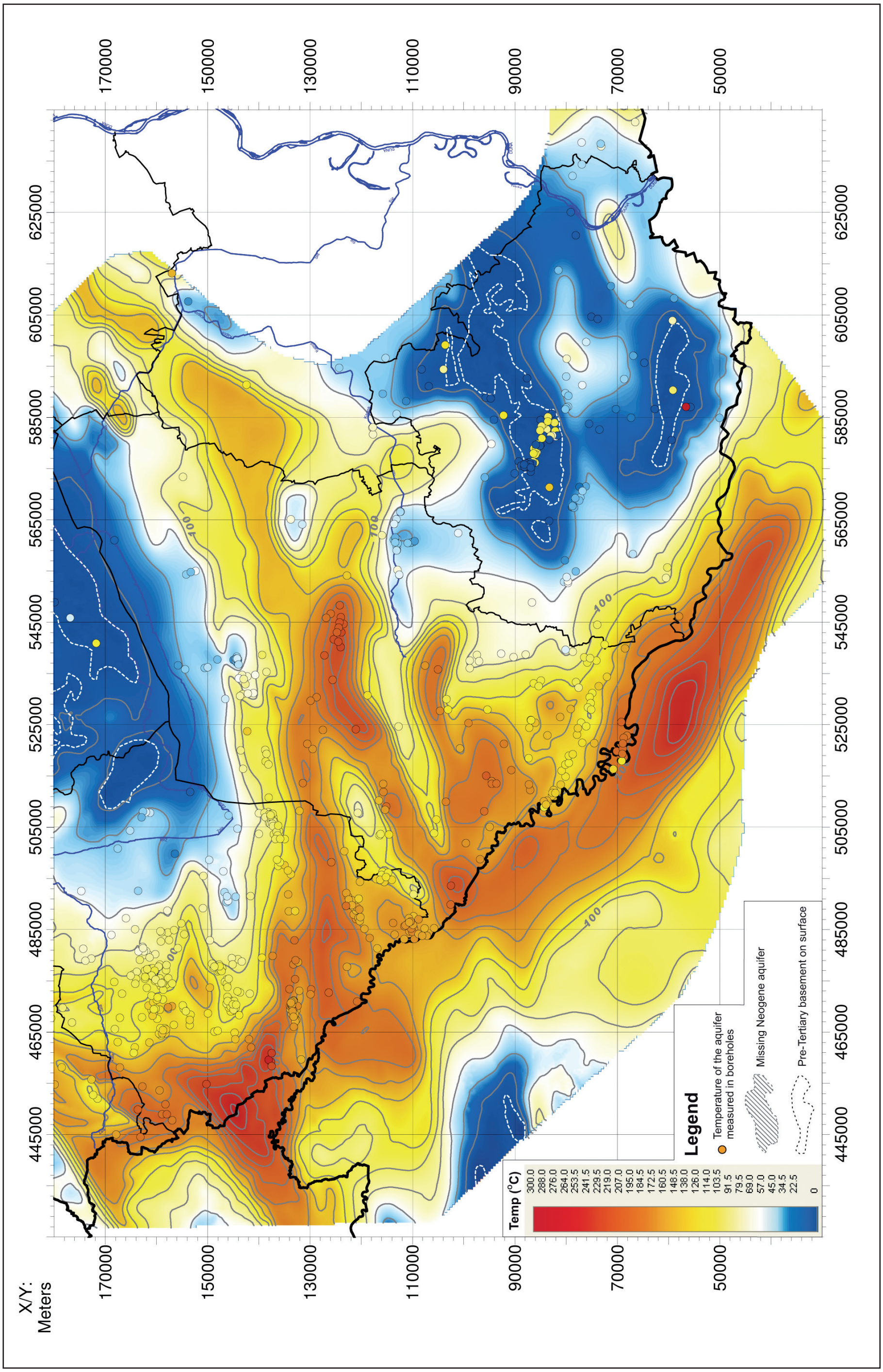


Figure 7.9. Static equilibrium temperature at the pre-Tertiary basement. For reference depth see Fig. 7.4.

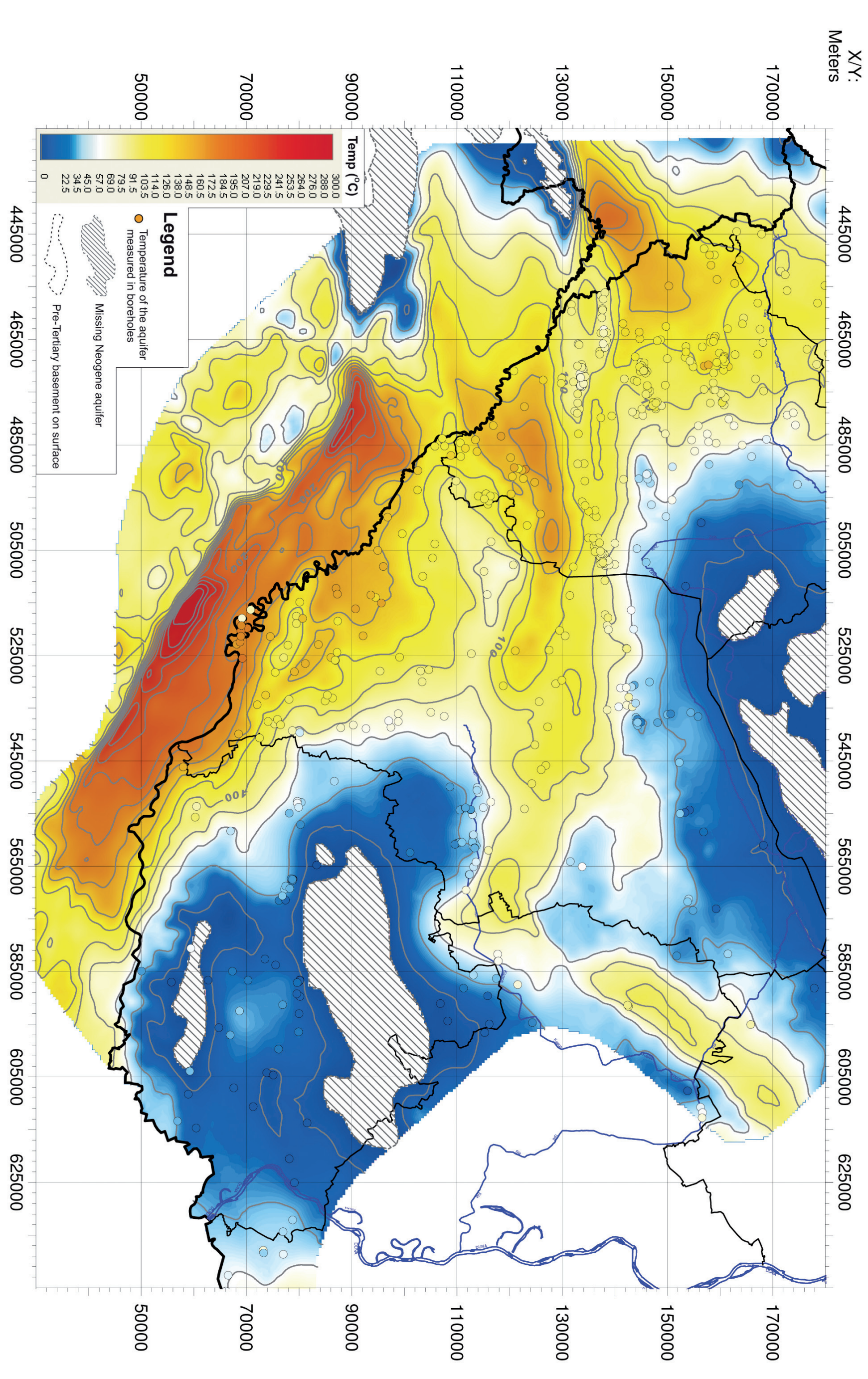


Figure 7.10. Static equilibrium temperature at the base Pannonian. For reference depth see Fig 7.5.

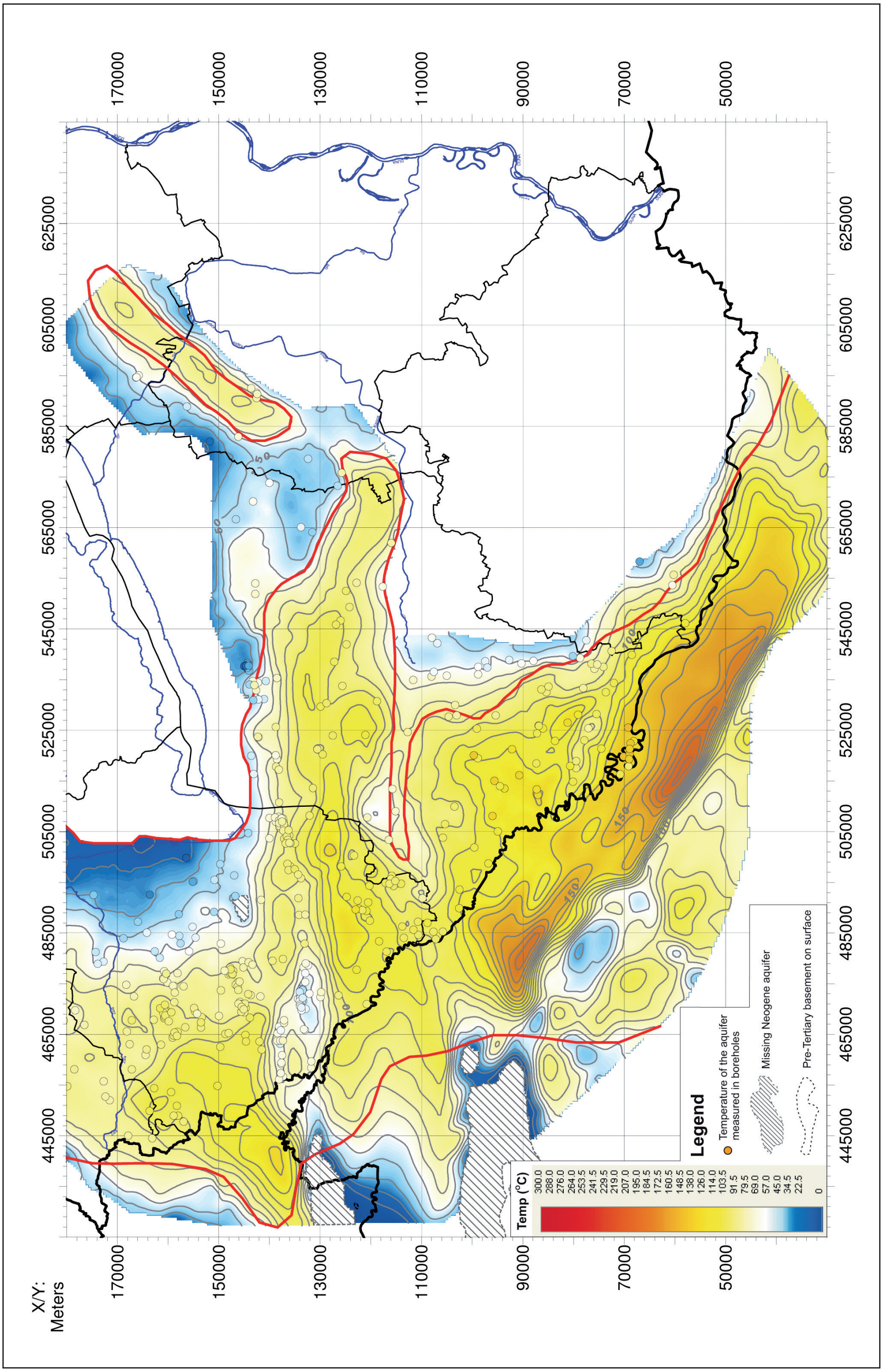


Figure 7.11. Static equilibrium temperature at the top Szolnok horizon. For reference depth see Fig 7.6.

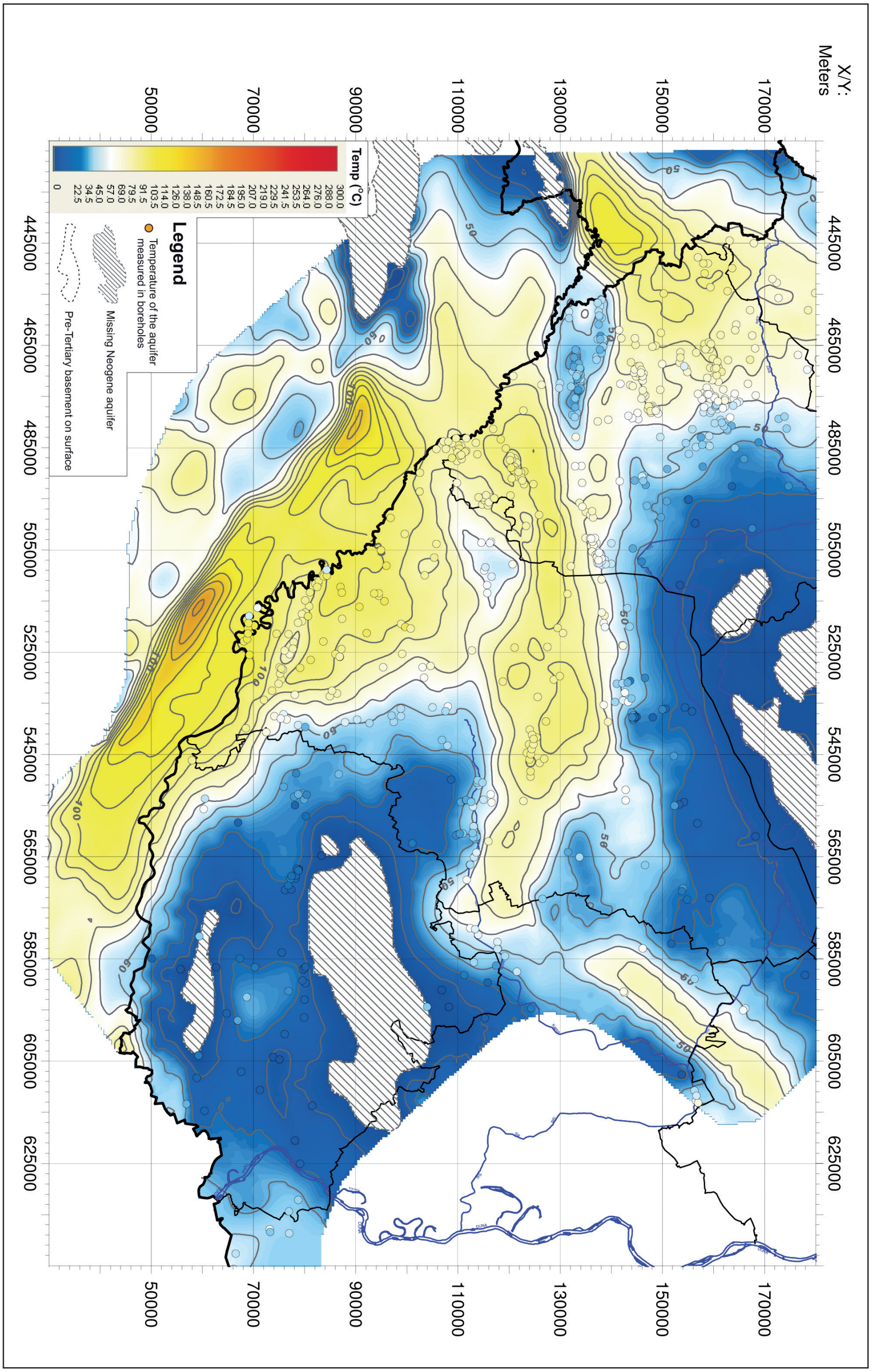


Figure 7.12. Static equilibrium temperature at the base Újfalu horizon. For reference depth see Fig. 7.7.

8. WATERBODY CHARACTERISATION

For geothermal applications it is crucial to have local and regional information about the waterbodies being targeted. These informations include the outline-, depth- and static temperature of the aquifer, as well as the typical/expected drainage area and expected wellhead water temperatures of a producing well. Expected water rate is also very important, however it is (as the wellhead temperature) largely depending on the well completion parameters (e.g. length of screened section, length and size of tubing etc).

In the following, characteristics of the waterbodies identified in relation to the four regional aquifers are discussed. This is done by integrating geological-, structural-, thermal- and well test data.

8.1. Upper Pannonian delta front sands (Újfalu/Bilogora Formation)

The Újfalu Formation is the best known and most extensively exploited thermal aquifer in the region dominated mainly by spa, wellness and balneological applications. Several national and international thermal baths in Hungary, Croatia and Slovenia are acquiring their thermal water from this aquifer.

Typical thickness of the aquifer is ~200m, which can increase upto ~400m in the depositional centers (Fodor et al, 2011). The sequence is dominated by sands with very good interconnectivity (amalgamation) resulting in excellent permeability, flow rates and drainage area. Calibrated regional hydrogeological studies suggest that the whole aquifer can be considered as a single waterbody with regional flow patterns and drainage areas/communication as large as 30-50km (Tóth et al, 2011).

Thermotectonic characteristics of this waterbody are shown in Figure 8.1. The map combines the depth and static temperature map of the waterbody as well as the outflowing water temperatures measured at the wellheads. Only those water temperature data are used for this map, which (1) are warmer than 30°C; and (2) either are known to be coming from this aquifer, or are coming from a depth range defined by the depth map and a [-400m, 100m] bounding interval (i.e. 400m upward and 100m downward). Bear in mind that the static aquifer temperatures represent the *maximum* expected equilibrium temperature of the aquifer because the reference depth of the temperature map is the *base* of the Újfalu formation. Becasue of this the outline of the thermal waterbody could be easily determined by the line, where the aquifer temperature exceeds 30 °C. The waterbody is named pt.3.1.UP.THERMAL-SPA reflecting the official code used by the Hungarian authorities (**p**orous-**t**hermal, pt.3.1), the stratigraphic age (**U**pper **P**annonian, UP) of the aquifer and a common name for easier reference.

At the edge of the waterbody, which corresponds to ~180-200m depth below sea level (bsl), the outflowing water temperatures are just slightly lower than the aquifer temperature indicating only small degree of cooling. This is attributed to the shallow depth and the usually high flow rates. In these bluish areas of Fig. 8.1 the outflowing wellhead temperatures are 30-40 °C. One exception is the Héviz area, where 37-41 °C waters are coming from a depth of only 20m bsl. This region however cannot be considered as static, as it represents the discharge area of a local flow system originating from the Keszthely Mountains (the sandy upper pannonian sequence is overlaying the karstified Mesozoic carbonates, resulting in crosscommunication with the deeper karstic aquifer).

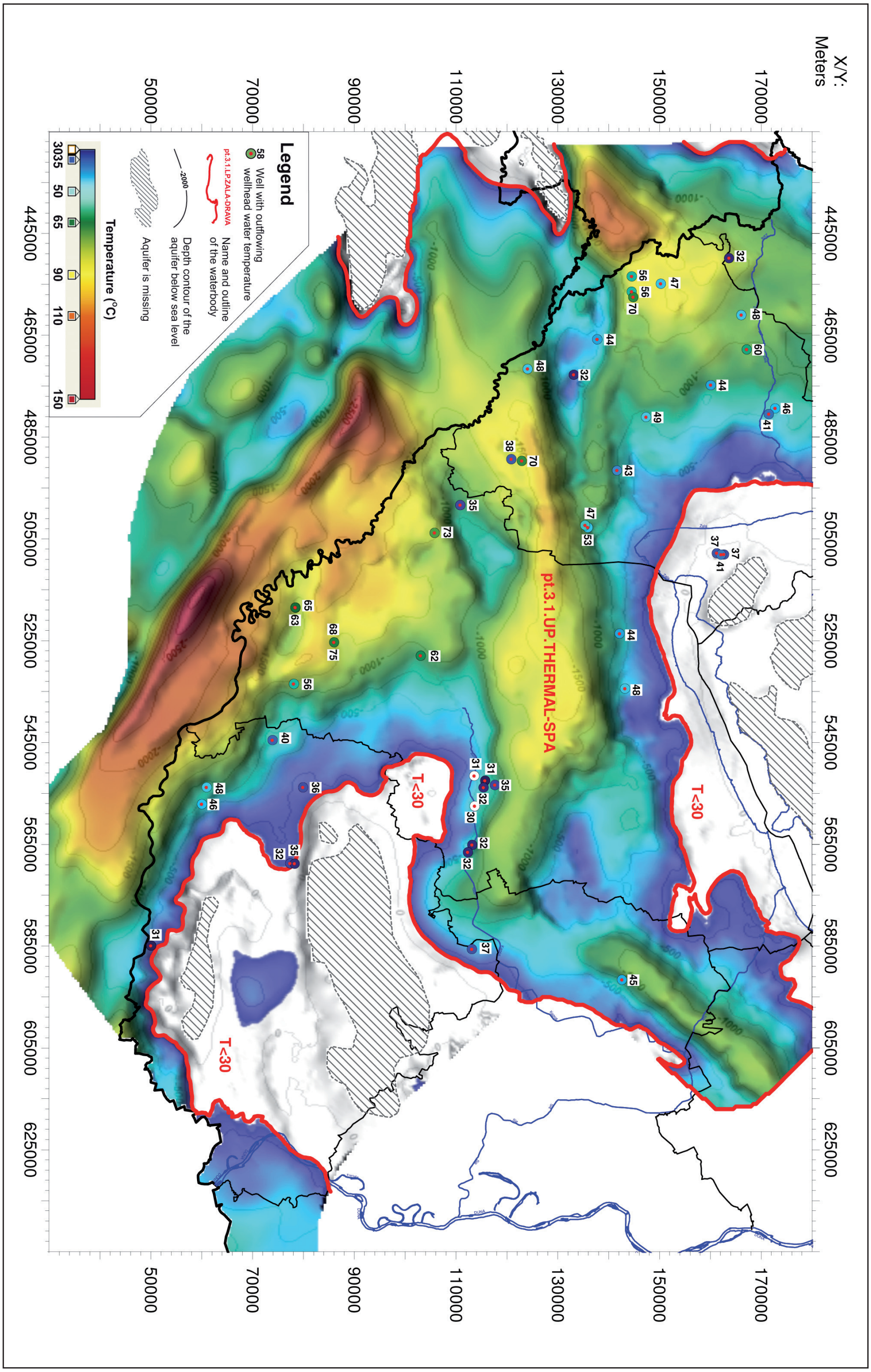


Figure 8.1. Waterbody identification and thermotectonic characterisation of the Upper Pannonian delta front sands (Újfalu Formation). Temperature and depth values are referenced to the base Újfalu Formation, therefore they should be considered as maximum.

The flanks of the deep basins (Zala-Mura, Mezőcsokonya, Nagykanizsa, Drava) represent an intermediate zone. Here the maximum static aquifer temerature is 60-70 ^{o}C (~ 1000m bsl depth) resulting in 40-50 ^{o}C outflowing water temperatures. The gap between the static and outflowing temperatures further increases in the deepest parts of the basin due to the larger depth and consequently larger cooling as the water travels up the wellbore. Available data from the deeper parts of the Zala and Drava basins indicate that wells screened for the THERMAL-SPA aquifer in the 1200-1500m depth range are able to produce waters as warm as 65-75 ^{o}C, albeit the static reservoir temperature at this depth is 90-100 ^{o}C. Considering this trend outflowing water temperatures as high as 90-100 ^{o}C is expected from the center of the Drava and Mura depressions, where the depth of the waterbody is the largest (~2000-3000m bsl depth, ~120-140^{o}C static temperature).

8.2. Lower Pannonian pro-delta turbiditic sands (Szolnok/Ivanić Grad Formation)

The Lower Pannonian Szolnok Formation is well known in the hydrocarbon industry because many oil and gas fields in the region were accumulated in the sand layers of this formation (e.g. Petisovci, Dolina, Lovászi, Budafa, Újfalu, Bajcsa etc). Its geothermal exploitation however is rather limited and is lagging behind that of the Upper Pannonian sands. Reasons of this include the larger depth, poorer porosity, lower flow rates (max 300-400 m^3/d) and the increased salinity compared to the shallower sands. Most of the wells utilising this aquifer were completed in the beginning of thermal-water utilisation by sectional perforation of unproductive oil-drillings.

Typical thickness of the aquifer sequence is ~400-600m, which can increase upto ~1500m in the depositional centers (Fodor et al, 2011). The sequence is dominated by sands in the basin centers and becomes pelitic on the flanks of the depocenters. The sequence consists of ~5-20m thick turbiditic sheetsands separated by 20-100m thick marls and claymarls. Extent and vertical amalgamation of the individual sand layers is controlled by the orientation and vicinity of the feeding submarine channels. Generally, the lateral extent of the individual sands is limited (~5km), however thicker, amalgamated sandy intervals can be correlated at distances over 20km.

Considering the depositional setting of these sands, one could consider individual/stacked, uncommunicating waterbodies for the Szolnok Formation aquifer, which are hydrodynamically isolated from the shallower pannonian waterbody. This is supported by hydrogeological studies, which suggest stagnant waters in these sands being not part of the regional flow systems (Rman and Tóth, 2011). On the other hand, petroleum industry data clearly indicate that in certain areas the individual sandy intervals do communicate through fault systems, which also played key roles in the migration of hydrocarbons into many of the the oil and gas fields of the region. Becasue of this the pore waters in the Szolnok Formation can be considered as part of a single waterbody, but hydraulically separated from the shallower Pannonian waters. The extent of the waterbody is determined by the lateral distribution of the turbiditic sands and is mainly concentrated to the central regions of the depocenters.

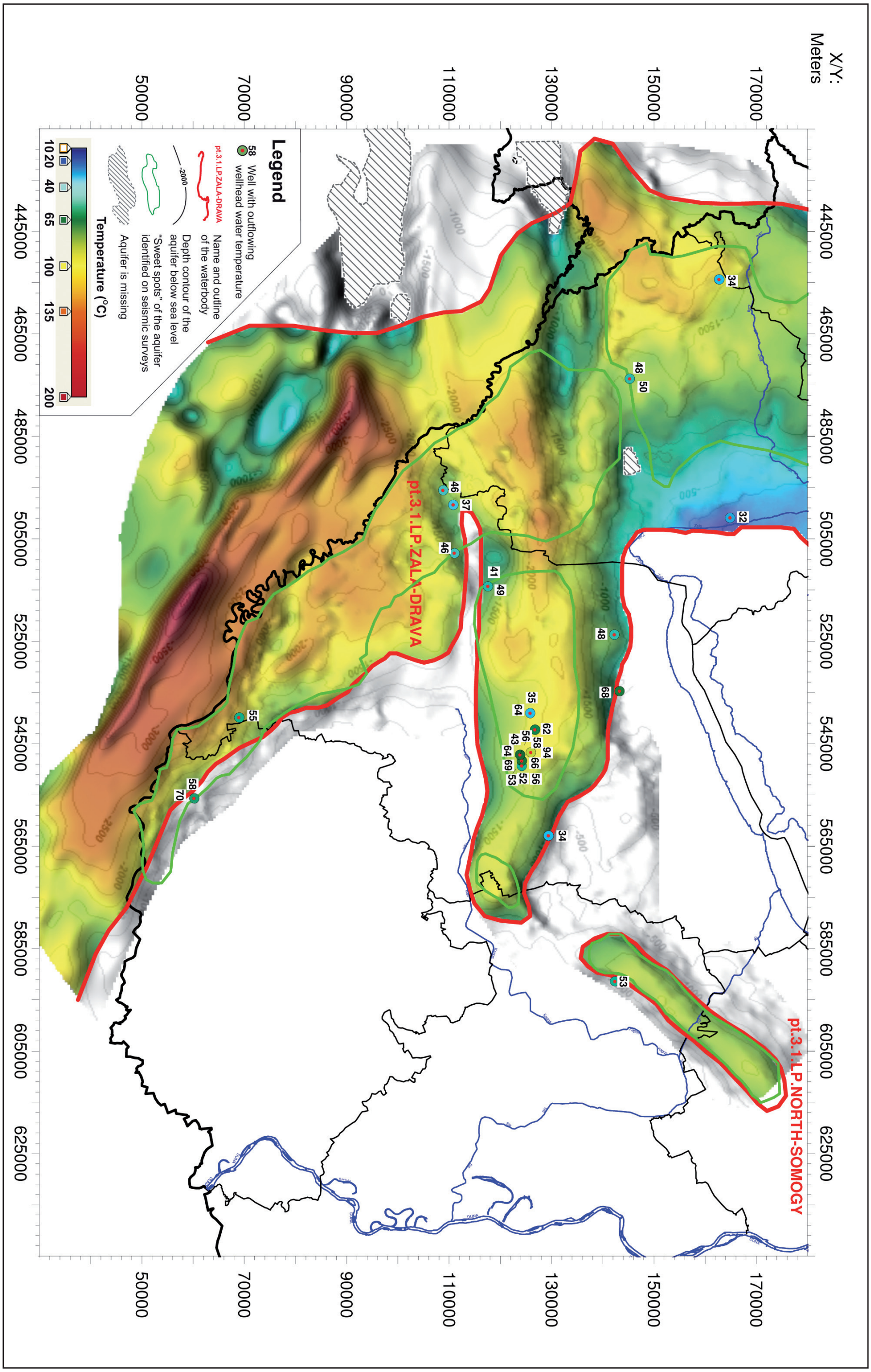


Figure 8.2. Waterbody identification and thermotectonic characterisation of the Lower Pannonian pro-delta sheetsands (Szolnok Formation). Temperature and depth values are referenced to the top Szolnok Formation, therefore they should be considered as minimum.

Thermotectonic characteristics of this aquifer are shown in Figure 8.2. The map combines the depth and static temperature map of the aquifer as well as outflowing water temperatures data measured at the wellheads. Only those water temperature data are used for this map, which (1) are warmer than 30°C; and (2) either are known to be coming from this aquifer, or are coming from a depth interval 100m above the top Szolnok depth down to the base of the Pannonian. Bear in mind that processing and compilation of our test database is still in progress, so not all tests are shown on the map. Also bear in mind that the static aquifer temperatures represent the *minimum* expected equilibrium temperature of the aquifer because the reference depth of the temperature map is the *top* of the Szolnok formation.

Two waterbodies have been identified in the area named pt.3.1.LP.ZALA-DRAVA and pt.3.1.LP.NORTH-SOMOGY (LP stands for **L**ower **P**annonian). They are both part of the generic pt.3.1 neogene waterbody used by the Hungarian authorities. The boundary of these bodies reflect the lateral extent of the thick turbiditic sand sequence, which were drawn using well, literature (Fodor at al., 2011, Vrbanac et al., 2010, Saftić et al. 2003) and seismic data. On the seismic sections namely, the thick sand bodies at the base of the prograding delta system appear as a package of strong reflectors (see Fig. 7.2). Locations on the flanks, where these reflectors loose their amplitude are coinciding with areas of a poorly developed Szolnok Formation with only thin or no sand at all. In addition, based on seismic attributes the so called „sweet spots" within the aquifer could also been identified, where the sand sequence is the thickest and best developed (green outlines on Figure 8.2). These polygons stop at the Hungarian border because of the lack of available seismic surveys from Croatia. Literature data however indicate that well-developed, thick turbiditic sands exist in the central parts of the Drava and Mura basins as well (Vrbanac et al., 2010, Saftić et al. 2003). Of course in relaity the transition between the perspective aquifer sands and the pelitic areas is not a sharp line, therefore some uncertainty should be considered for the locations of these lines.

The ZALA-DRAVA and the NORTH-SOMOGY waterbodies are hydrodynamically isolated from each other by the Igal-high where the Szolnok Formation is restricted only to a few thin sand layers, as evidenced from well data. The outline of the ZALA-DRAVA waterbody marks the „valley" where the prograding delta system progressed from NW to SE during the Pannonian (Magyar, 2010). Static aquifer temperature in this zone is around 100 °C (1500-2000m bsl), which goes up to over 150 °C in the deepest part of the Drava basin (3000-3500m bsl). The maximum outflowing wellhead temperature data available in our database is 94 °C in the Mezőcsokonya basin, but generally they are significantly lower than the minimum static aquifer temperature. The reason behind this is the significant amount of cooling during water production from this aquifer due to the lower flow rates compared for example to the Upper Pannonian THERMAL-SPA waterbody. The scatter of wellhead temperatures is also relatively high indicating that the flow rates from this aquifer is largely depending on the well completion (amount and total length of screened sand, aquifer depth, length and size of tubing etc). In fact, because of this some wellhead temperatures are as low as or even lower than the wellhead temperatures from the THERMAL-SPA sequence in the same area.

Two important things should be mentioned regarding the Szolnok waterbodies. Firstly the aquifer sequence is very thick (600-1500m) and typically contains more than 20 individual sand layers. Completing a waterwell for multiple sands could significantly increase the flow rates and consequently the wellhead temperature. Secondly, because of the large thickness 30-50 °C static temperature difference exists between the top and base of the Szolnok sands. The wellhead temperatures shown in Fig. 8.2 are referrig to sands screened at various depths within the reservoir, which also contributes to the large scatter of the data.

8.3. Middle Miocene carbonates

The top Miocene horizon marks a regional tectonic event in the Pannonian Basin (see Chapter 2). As the result of regional uplift, erosion and reactivation of former Miocene faults, a characteristic unconformity surface has been developed. Directly below this various Miocene formations with different lithology and age are found. In the deepest parts of the subsiding basins, where only minor or no uplift occured fine clastics were deposited, which are not perspective aquifers for geothermal exploitation. On the paleo-highs on the other hand calcareous sands, and biogenic limestone reefs were formed during the Badenian and Sarmatian (Leytha and Tinnye Limestone Formations), which are excellent aquifers.

Unfortunately however, these formations do not form a large regional aquifer, and faults further compartmentalise them into waterbodies of local importance. Regional mapping and correlation of these tectonically often complex waterbodies could only be done with detailed core, log and seismic analysis, which is beyond the scope of this study.

For this reason only a generic thermotectonic characterisation is given (Fig. 8.3) without delineating the Miocene carbonate waterbodies. As earlier, only those water temperature data are used for the map, which (1) are warmer than 30^{o}C; and (2) are coming from a depth interval between the top Miocene and 300m below it. Bear in mind, however, that based on the available data we were not able to specify the exact formation where the water test is referring to, so it includes Miocene limestones, but also sandstones or other lithologies. Further studies are needed on a local scale to provide a more precise geothermal characterisation of the Miocene aquifers. Also note that, as for the top Szolnok maps, the static aquifer temperatures represent the *minimum* expected equilibrium temperature of the aquifer because the reference depth of the temperature map is the *top* of the Miocene.

Similarly to the Szolnok aquifer the outflowing wellhead water temperatures show a large scatter even in case of wells close to each other. The reason behind this is the highly variable flow rates in the various wells. Wells with higher flow rates can produce warmer waters at the wellhead compared to the wells where the rate of waterflow is lower resulting in larger degree of cooling. The largest observed wellhead tempearatures from the Miocene aquifers are 94 and 96 ^{o}C.

8.4. Mesozoic carbonates

Several lukewarm and warm natural springs and spas are associated with fractured/karstified Mesozoic carbonates in Hungary (e.g. Héviz, Harkány, Igal, Budapest). These waters are usually produced from a shallow depth, where the expected static aquifer temperature is much lower than the temperature of the produced water. This is becasue these locations represent the discharging areas (springs) of a water flow system, which flow-lines penetrate much deeper than the depth of the discharge area. In other words these waters are warm becasue they are originating form a much greater depth. Geothermal exploitation of the Mesozoic carbonatic waterbodies in a static, basinal setting however is rather limited.

Three large and two smaller karstic waterbodies have been identified in the area (see Fig 8.4). The outlines compiled for Hungary and Croatia represent areas in the pre-Tertiary basement, where carbonatic rocks prone to karstification and fractures are present either directly below the pre-Tertiary unconformity or below an overlying (non-karstic) Mesozoic succession. The outlines in the Hungarian part of the project were constructed using the pre-Tertiary geological map of Hungary (Haas et al. 2010) and can be considered as a modified versions of the waterbodies officially used by the Hungarian authorities (see Chapter 3). In the Croatian part of the study area the map publised by Kolbah (2010) were used, which show very good correlation with the Hungarian ones across the border.

Similarly to the waterbodies discussed earlier, Fig. 8.4 combines the depth and static temperature map of the pre-Tertiary horizon (i.e. top of the aquifer in largest part of the study area) as well as outflowing water temperatures data measured at the wellheads. Only those water temperature data are used for this map, which (1) are warmer than 30°C; and (2) either are known to be coming from this aquifer, or are coming from a depth interval between the pre-Tertiary and 500m below it. Bear in mind however that based on the available data we were not able to specify the exact formation where the water test is referring to, so it include Mesozoic carbonates, but may also include other lithologies. Processing and compilation of our test database is still in progress, so the number of tests referring to this aquifer may change in the future. Also bear in mind that the static aquifer temperatures represent the *minimum* expected equilibrium temperature of the aquifer because the reference depth of the temperature map is the *top* of the pre-Tertiary (which not always coincides with the depth of the karstic aquifer).

kt.ZALA-BAKONY waterbody

This waterbody coincide with the kt.4.1, k.4.1 and k.4.2 waterbodies of Hungary (kt = **k**arstic **t**hermal). The aquifer is outcropping in the Keszthely and Bakony Mountains, which are recharge areas of the aquifer. The top of the waterbody is steadily deepening towards the west where its maximum depth is over 3000m bsl. This is also reflected in the static temperatures and the outflowing wellhead temperatures, which also show a westward increasing trend (Fig 8.4). In the eastermost part, close to the foothills of the Keszthely Mountains several positive temperature anomalies can be observed, where the outflowing water temperature is larger than the static aquifer temperature relating to the top of the waterbody. As mentioned earlier these anomalies can be explained by upwelling waters from a greater depth.

Generally, the wellhead temperatures are only few degrees smaller in the shallow regions than the static aquifer temperature, and they are still only 10-20 °C colder than that in the deeper parts. This indicates that the water yield and permeability of this aquifer is very good. The maximum measured wellhead water temperature from this waterbody is 80 °C.

kt.MID-TRANSDANUBIAN waterbody

The MID-TRANSDANUBIAN karstic waterbody is the largest reservoir identified in the Mesozoic basement stretching from the Medimurje region of Croatia towards NE along the mid Hungarian fault zone (Nagykanizsa, Marcali, Igal, Tamási areas). It also includes the karstic aquifers of the Mecsek Mountain and its northern foreland: it compiles the kt.1.7 and kt.1.8 waterbodies of Hungary as well as the HR_kt.3.1 waterbody of Kolbah (2010).

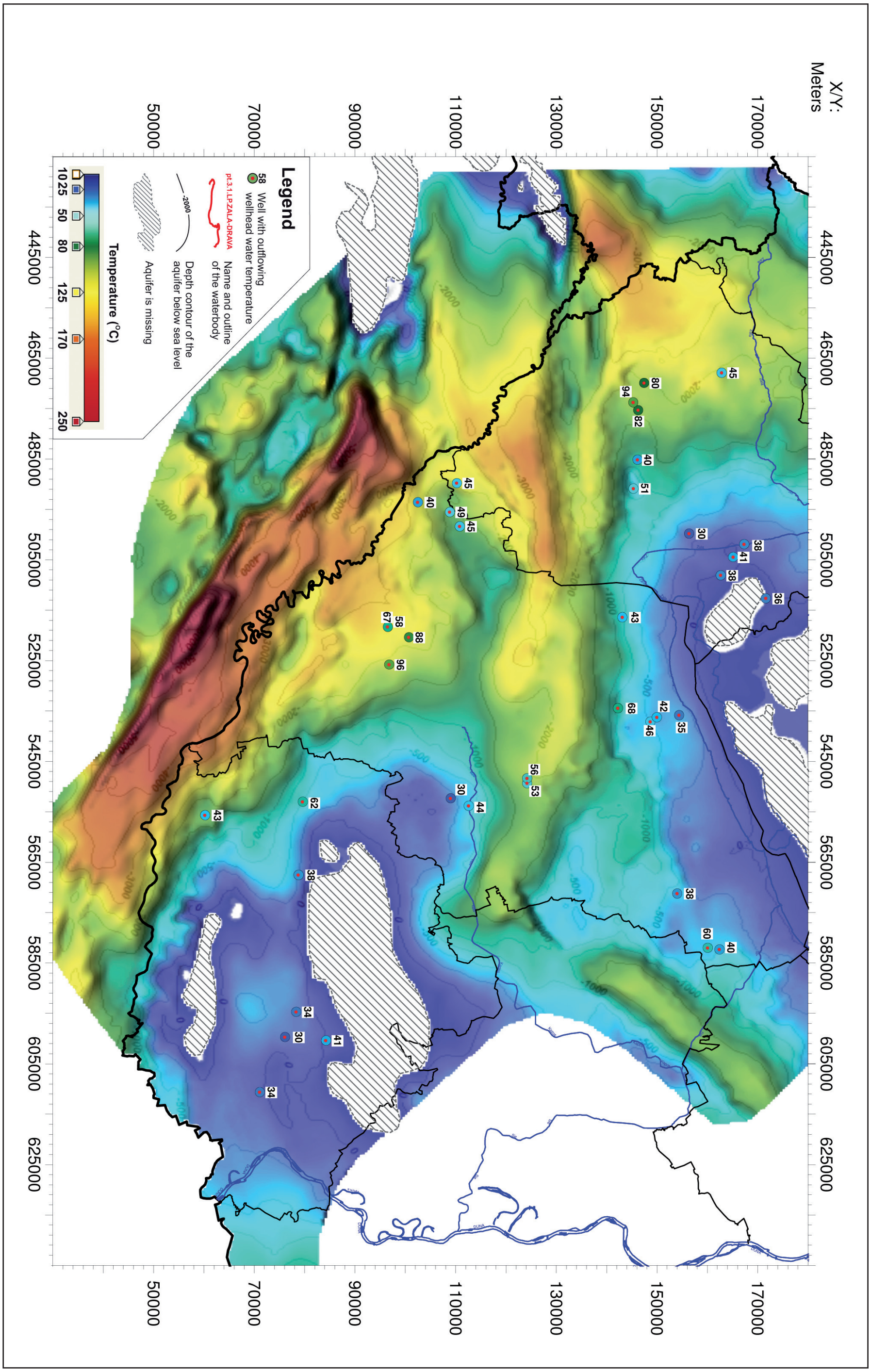


Figure 8.3. General thermotectonic characterisation of the Miocene. Temperature and depth values are referenced to the base Pannonian level, therefore they should be considered as minimum.

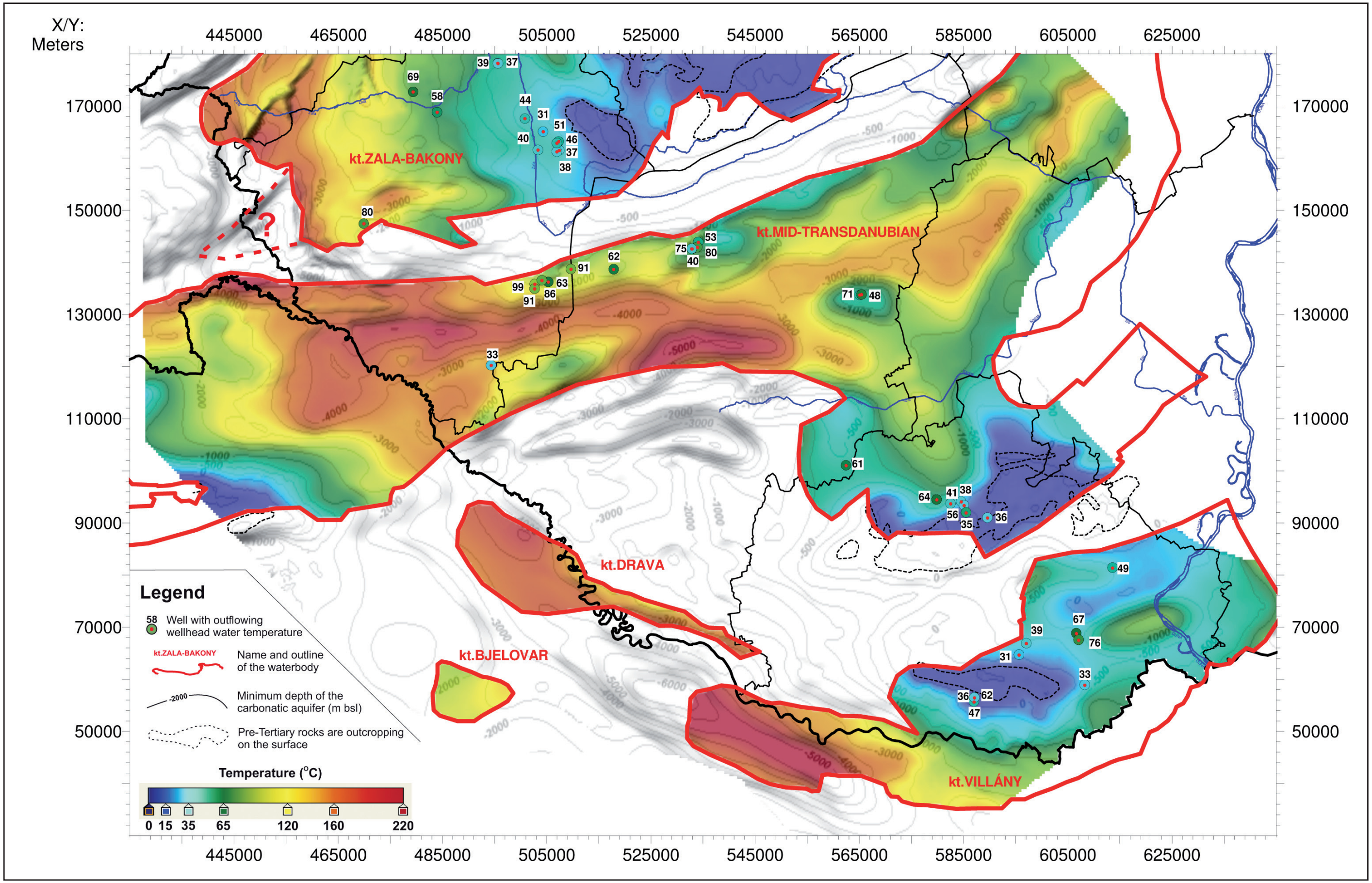


Figure 8.4. Waterbody identification and thermotectonic characterisation of the Mesozoic carbonates. Temperature and depth values are referenced to the top of the pre-Tertiary basement, which not always coincides with the top of the aquifer. Both temperature and depth values therefore should be considered as minimum.

Although considered as a single waterbody, it is likely that this area consists of many smaller waterbodies hydrodynamically isolated from each other. This is concluded firstly from the geotectonic location of the area, which lies along one of the most tectonised areas of the Pannonian Basin (Mid-Hungarian fault zone). Secondly, the basement rocks in this area are geologically very variable and the exact tectonic position and connectivity of the carbonatic rocks is poorly constrained. In fact, in the deepest part of this zone (Nagykanizsa-Mezőcsokonya trough) the pre-Tertiary basement is not known exactly.

This is one of the major drawbacks of this waterbody: in large part of this area the basement (althought being hot, 140-220 ^{o}C) lies in the 3000-5000m depth range, which makes the geothermal exploitation difficult both from a technical and an economical point of view. Easily accessible areas include the flanks and the elevated blocks like the Inke- and Igal-highs. In these areas the static aquifer temperature is 90-120 ^{o}C, at 1500-2000m depth. The hottest outflowing wellhead temperatures are found along the northern margin of this zone, with 99 ^{o}C being the maximum. Genereally, the wellhead temperatures are only slightly cooler than the static aquifer temperature in this region, indicating excellent water transmissibilities and flow rates from this aquifer.

In the southern part of the waterbody the basement is dominated by Middle Triassic shallow marine carbonate formations, which are outcropping in the Mecsek Mountains. This region serves as a recharge area for the regional waterflow system.

kt.VILLÁNY waterbody

The VILLÁNY karstic waterbody stretches from the SE part of the Drava Trough, through the Villány Mountains to the Danube river and beyond. In the catalogue point it comprises the kt.3.1 and kt.1.9 waterbodies of Hungary and the HR_kt.3.5 and HR_kt.3.6 waterbodies of Croatia (Kolbah, 2010). The aquifer rock consists of Middle Triassic shallow marine carbonate formations as well as Cretaceous platform limestones.

The Villány Mountains, which serves as the recharge area of the flow system divides the waterbody in half. Waters entering the karstic system on the southern slopes of the Villány continue their path southwards, while meteoric waters from the northern slopes travel in the direction of North or NE. Local discharging areas of this waterflow system includes the Harkány thermal bath, where 62 ^{o}C water is produced only from 40m depth.

Generally the static temperature of the top of the aquifer in the Hungarian part of the VILLÁNY waterbody is relatively cold due to the shallow depth. One exception is the Mohács depression where the pre-Tertiary basement is found at 1000-1500m depth. In addition, in this area the aquifer is found burid below a series of Cretaceous basinal marls, resulting in 60-70 ^{o}C outflowing wellhead temperatures.

South of the Villány Mountains and in Croatia the top of the aquifer shows a steadily deepening trend towards the South. Its depth reaches 2000-2500m South of the border and drops below 5000m in the Drava Trough. The corresponding static aquifer temperatures are ~100 and 220 ^{o}C respectively. Unfortunately no well data is available from this region, which could constrain the outflowing wellhead temperatures.

kt.DRAVA and kt.BJELOVAR waterbodies

Kolbah (2010) has identified two smaller waterbodies in the Croatian part of the Drava Basin (coded as HR_kt.3.2 and HR_kt.3.3). They are much smaller than the earlier discussed waterbodies, and they are also isolated from the large karstic aquifers of the region. The average depth of the DRAVA waterbody is ~3000m bsl, while the top of the BJELOVAR waterbody is found ~ 2000m bsl. The corresponding minimum static aquifer temperatures are 150-180 °C and 110 °C respectively.

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II. LANDSCAPE AND SETTLEMENT GEOGRAPHY OF THE DRAVA REGION, FUNDAMENTALS OF ITS CULTURAL GEOGRAPHY

1. LANDSCAPE GEOGRAPHY

1.1. Geological, geomorphological features

The area – considering its geological structure – is part of the south-eastern large-scale structure of the River Tisza, which is one of the two large rock slab blocks comprising the Carpathian basin. This large-scale structure used to be situated in the northern part of the former Tethys Ocean, on the edge of the European continent. The mid Hungarian large-scale structural line – also called Zagreb-Kulcs-Hernad line denoting its direction -, which divides the ALCAPA and Tisza-Dacia slab blocks, touches on the north-western part of the area. In its composition, structure and rock material, the area is related to the Transsylvanian Inselberg, the basin-bed strips of the southern Great Hungarian Plain, and the Transdanubian Hills and inselbergs (Mecsek, Villány Mountains). The relation is not only genetic but also visible since crossing the Drava to the south you can find young hills, basins, plain-like territories, river valleys similar to the South Transdanubian region. The inner ranges of the Dinaridas with a strike direction from north-west to the south-east spread along to the south of the structural line denoted by the downstream of the river Sava (Varga G. et al 2012).

The Miocene era had a crucial role in the structural evolution of the Carpathian basin: at that time the uplifting of mountainous areas began together with the sinking of basin parts, the sinking of the Drava, Sava trenches as well. The substratum in the Drava trench has already sunk to 3,500-4,000 meters deep. Significant part of the trench is filled with clayey, muddy, sandstone, sandy sediments from the Pannonian and Pleistocene epochs. The morphological evolutionary progress of the Drava trench began after the Pannonian epoch. The largest sediment-collecting basin was the Slavonian Inland Lake which was a residue of the Pannonian Inland Lake in the area between the Sava and the Drava. The rivers Mura, Drava, Sava also belonged to the catchment of this lake. The river Drava appeared through the filling up of this lake and the periodic sinking movement, which determined later surface evolutionary processes. In this way the river Drava and the Plain along the Drava is not a trench with a homogeneous structure but a combination of smaller basins. This area was an accumulative area of streams running from the north at the beginning and mid Pleistocene. The last provable period of the sinking of the Drava trench and its partial basins is the Würm glacial of late Pleistocene, when wind-blown sand, warp, sand and infusive loess settled on the thick stream Pleistocene strata rows. Most of the surfaces and forms of Ormánság - which turned into sediment catchments again due to the sinking and used to be covered with loess and wind-blown sand – were destroyed by the Drava that changed its direction to the north. That is, the Drava flew in a more northern place compared to where it flows now. A whole set of partial basins evolved due to the sinking of the Drava trench at the end of the Würm (Varga G. 2009, Dövényi Z. 2010).

The basement for the present hilly territories is provided by the clayey and sandy sediments of this Pannonian Sea, on which Pliocene (Csarnotanum) brick clay and 10-20-meter thick Pleistocene loess are settled in many places. In general, this is typical of the whole area. Apart from these, the surface is covered with sand in the right-bank continuation of the Drava on the alluvium surface of Somogy. Mesozoic, mostly limestone inselbergs elevate from the level of the young basin hills (Ivanščica 1061m, Kalnik 643m). Older inselbergs of Variscan origin comprised of crystal rocks are Papuk (953m), Psunj (985m) and Medvednica (1035m) on the edge of the Zagrab basin. Fruska Gora (539m) rises in the east, which is also of Paleozoic slate material, in Szeremseg between the Danube and the Sava (Varga G. et al 2012).

As a result of the bed changes due to Holocene structural movements, the river Drava drifted to the south, its present place. Holocene fluvial, mainly muddy sediments settle on the surface and near the surface, as well as loess sediments in certain places (e.g. NW Ormánság) (Varga G. 2009, Dövényi Z. 2010).

1.2. Present topographical picture

The flat along the Drava is a heterogeneous plain-like landscape that is gradually widening to the east.

Heading from the west to the east on the Hungarian side, the Kerka region (Hetés), the southern part of the Egerszeg–Letenye Hills, Mura-left-bank Flat, Mid Drava Valley, Drava Flat, Fekete Brook Flat and Nyárád–Harkány Flat small regions belong to the examined area.

The **Kerka region (Hetés)** is the least dissected erosive hilly landscape of the Western Zala Hills. The average relative relief is 26 m/km^2. Its area is covered by the lower Pleistocene alluvium of the Ancient Mura and Kerka, it is dissected by structural movements and erosive processes to different extent. Lenti basin, an upper Pleistocene sediment area, lies between block-like residuals. Due to the significant old Pleistocene arching of the SW part of the **Egerszeg Letenye Hills** small region, the area between Lower Valicka and Mura (on the Letenye Hills), heavily accentuated rows of hills evolved between the valleys following the NS structural lines. These rows of hills were characterized by asymmetric ridges and crests rising like islands. The relative relief is the largest here on the whole of the Zala Hills. The **Mura-left-bank Flat** small region is the left side edge of the wide structural trench of the river Mura in Hungary. The substratum is comprised of New Paleozoic and Mesozoic formations. Eocene subvolcanic formations can be found in the Letenye region. The older terraces of the river are only preserved by pebble fragments at a height of 30-40 m above the river level, while the valley flat in the western part of the small region is dominated by the New Pleistocene and Old Holocene alluvial flat of the Mura. The **Mid Drava Valley** small region is dominated by the 1-4 km wide and 50-60 m long low and high alluvial flat levels. Numerous meander curves, end-of-Pleistocene – Holocene lateral erosion of a middle-stretch type river, watery bogs, New Holocene levels, low meander terraces in their corners line up. The **Drava Flat** accompanying the Drava is a perfect plain with a height of 89.5-110 m above sea level. The average relative relief is 2m/ km^2, with a slightly higher value to the west. More than 50% of the surface is alluvial flat (mainly in the east), 35% is low flood free flatland, which is dissected by slightly wavy flat parts covered with wind-blown sand. The most typical forms are the deserted meanders up to the northern boundary which is of a sharp terrace-like form. The northern continuation of this small region is the **Fekete Brook Flat**, which is at a height of 96-212 m above sea level, mostly terraced alluvium covered with wind-blown sand in the southern part. The average relative relief is 4 m/ km^2. The surface is a low-lying, slightly dissected plain in the northwest, while in the south-west it is a slightly wavy plain. The Fekete Brook Flat covered with cutoff meanders of the Drava is separated from the western part covered with high-lying loess with a steep slope. Accumulations of wind-blown sand in the direction of west-east are typical. There is a high threat of inland waters (Varga G. 2009, Dövényi Z. 2010). **Nyárád-Harkány Flat** small region with a height of 89-162 m is a terraced alluvium, which turns into a hillfoot surface in the direction of north-west. The surface slightly slopes down to the south, south-east, it is slightly dissected vertically, the average relative relief ranges between 2 and 30 m/km^2. Most of the small region is a low flood free plain, whereas the area situated to the west of the Karasica is a wavy plain. The surface is heavily dissected by valleys running north-south and north-west, especially in the middle part of the small region. Its forms are partly connected to the loess surfaces and partly to the river erosion action. Derasion valleys of south-east direction further modified by erosion are common (Dövényi Z. 2010).

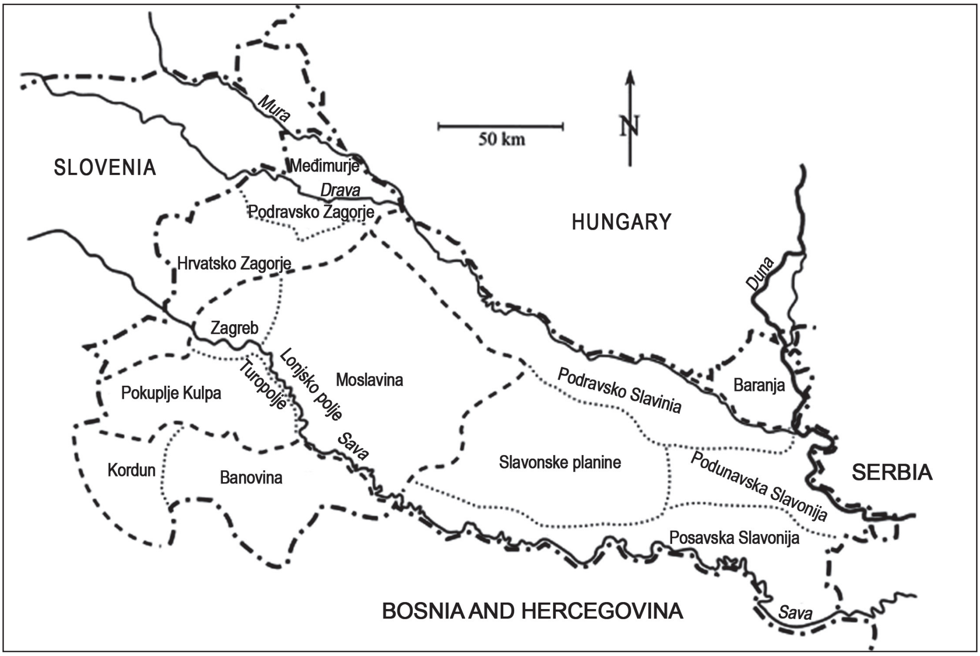

Figure 1. Landscapes of Pannonian Croatia (Source: Varga G. 2011)

Two distinctive morphological landscapes can be differentiated in **Slavonia along the Drava**, that is, on the right side of the Drava: sandy land along the Drava, which is genetically the continuation of the alluvium of Inner-Somogy (”Croatian Sahara”), and the landscape ranging from Kapronca to the river mouth of the Drava, which comprises a river plain. **Danubian Slavonia** is more dynamic in its relief than the part along the Drava (Erdőd Dálya loess plateau, Western Szerémség loess plateau, Dakovo loess plateau). Low and medium height mountains that stand out and are of different heights belong to the *Slavonian Inselberg.* In the composition of the mountains there are, on one hand, crystal rocks such as granite and fillits, mica slates in the connecting metamorph mantle, on the other hand, Neocene overburden sediments (sandstone, limestone, marl) can be traced in significant spread. Dilj is of distinctive appearance, which is comprised of Tertiary period sediments mostly covered with loess. The ellipsoid-shaped Pozsegai basin is a special morphological unit of the Slavonian Mountains. The left side plain of the river Sava belongs to **Slavonia along the Sava**, its eastern wing is Búzaköz, its western wing is narrower, and is lined with the alluvia of the streams running down the Slavonian

Inselberg. The **Baranya** triangle (Dravaszög) is comprised of three morphological units: the alluvium of the Danube and the Drava within which the Meadow of Kopács represents a special natural value; Baranya loess plateau, which is in its greater part connected with the area south of the Vörösmarty block (Bansko brdo), to a lesser extent to the eastern part of Nyárád Harkány flat stretching across from the Hungarian territory. The typically island-like tectonic block, the Monoszló Mountains, or Bilo Gora, the broken structured mountainous region around Pakrac can be found **along the Lónya and in Moslavina** of Mid Croatian Pannonia to the north of the Sava. Many thermal springs can be found on its territory around Lipik. Depressed areas are the Bjelovár basin and the Daruvár basin. Lónya Field (Lonjsko polje) following the Lónya current is the longest and also the lowest part of the area. Its central part is adjusting to the tectonic axis of the Sava trench, which has reserves of crude oil and natural gas around Struzsec. The Marcsa forest here is mostly known for its alluvial oak forests. **Zagreb and its region** focuses on the foreground of Hegyalja (Prigorje) which touches on mountainous and flat areas. On the northern frame mountains of **Croatian Zagorje**, which plays a central role in closing the western frame, mostly a karstic form variety of medium-height mountain ranges appear, since in their material composition Triassic limestone and dolomite, furthermore Cretaceous limestone can be detected, but basically it is a heavily dissected hilly landscape consisting of Neocene sediments (Miocene, Pliocene), its seismicity is especially strong. The Bednja catchment, the Varasdi basin and the connecting erosive hilly area to the south belong to the **Drava region of Zagorje. The Drava Valley** flows in a structural trench at this stage, it has a large fall, that is why barrages (of Varasd, Perlak) reservoirs have been built. The **Muraköz** flat from Légrád to Perlak has a quite even surface, however it shows an imperfect character close to Csáktornya, and finally it quickens, it acquires a hilly form towards the Slovenian border, and it continues further in the territory of the latter (Varga G. et al 2012).

1.3. Climate

The climate of the examined domestic area is significantly influenced by its location occupied in the Carpathian basin. This is manifested in the mean annual temperature and the amount of precipitation and its annual distribution as well. The area lying north of the Drava belongs to the hottest areas of Hungary due to its low flat location. The examined area is moderately warm, moderately wet, and moderately dry in its eastern part, in the western parts it has a moderately cool – moderately wet climate, but in the south west it tends to be of wet climate.

The number of sunny hours increases when heading from the west (1850) to the east (2080). 720-820 hours of sunshine can be expected with similar distribution in the summer annual quarter. The number of sunny hours in the winter period is 190-210. The **average annual temperature** is 10.5-10.8 °C in the east, 10.4-10.6 °C in the middle areas, whereas it is around 9.2-9.8 in the west. Similarly to the number of sunny hours, the average annual temperature also rises from the west to the east. In the west 15.8-16.5 °C, in the east 17.4 °C can be expected in the vegetation period. The non-freezing period lasts about 200 days in the east, and about 195 days in the west (from 5-7 April to 26-28 October). The daily average temperature exceeds 10°C on 182-204 days (from the last days of March to 20-22 October). The highest summer temperature has averaged for many years around 32.5-34.0 °C, while the lowest minimum temperatures are between -16.5- -18 °C. The amount and annual distribution of **rainfall** is determined by the south-west location.

The yearly rainfall amount, which exceeds the country average in Hungary, is caused by the Mediterranean cyclone activity strengthening in this area in the autumn period. Thus in the yearly distribution of rainfall a specific autumn secondary maximum appears. Contrary to the mean annual temperature, the annual amount of rainfall increases from the east to the west, on average it is around 630-680 mm (in the east), 700-720 mm (in the middle), 760-780 mm (in the west). The distribution of rainfall is similar in the vegetation period, the values range between around 380 mm, 380-400 mm and 400-420 mm. The 24-hour maximum of rainfall is 118 mm. The **number of snow-covered days** decreases heading from the west to the east from 42 to around 30 days. The average maximum thickness of snow is 20-28 cm. The **aridity index** shows values between around 1.0-1.1 in the east, 0.98-1.0 in the middle, 0.86-0.98 in the west. The most frequent **wind direction** is north-west, but in the autumn months eastern and south-eastern winds are common too. The average wind speed is around 2.5-3 m/s. Since it is a moderately wet and wet region, the climate is favourable for hydrophilic plants as well (Dövényi Z. 2010).

Temperate-zone continental features prevail in the climate of Pannonian Croatia, it belongs to the long-summer, short-winter variety of continental territory. This primarily refers to the basic territory between the Drava and the Sava, however from the right bank of the Sava submediterranean effects prevail as well. The **annual mean temperature** is around 10-11 °C. The hottest month is July with no exception, which rises somewhat above 20 °C. The coldest month is January, whose temperature shows values between -0.6- -1.6 °C. Exceptions are the higher-lying areas of the Slavonian inselbergs (Papuk, Krndija, Psunj, Dilj and Medvednica), where the temperature is much lower, and the mean temperature in January might as well sink to -4 °C. This is also true in the hottest summer months, as the mean temperature in July does not reach 20 °C in these mountainous areas (Varga G. et al. 2012).

1.4. Hydrogeology of the area

In terms of hydrogeology, Pannonian Croatia wholly belongs to the catchment area of the Black Sea. Its dominant and largest watercourse is the Danube which is the main hydrogeological axis but it has a peripheral position. Its two significant feeders, the Drava and the Sava, join it on the right side. The Drava has its source in Southern Tirol, crosses Austria and Slovenia, then it flows on domestic territory, then its a boundary river from the Mura mouth to lower Mihojlac – with the exception of Répássy projection –, following this it reaches the Danube at Almás (run-off: 653 m^3/s) at its lowest Baranya and Slavonian stages on Croatian territory. The water levels are the highest at the end of spring and the beginning of summer, but due to the secondary rainfall maximum of the catchment area, an autumn flood wave also stands out in the regimen. Low-water is typical of the end of summer and in the winter months. The Drava has a big fall, as a boundary river it is less regulated, that is why its bed mostly evolves freely (Varga G. et al 2012).

The **Kerka region (Hetés)** is the catchment area of the Lendva stream and the right side of the Kerka. Lateral waters of the Lendva: Kebele Stream, Szentgyörgyvölgyi Stream, lateral waters of the Kerka: Little-Kerka, Cupi Stream. It is an area with abundant flowage. The water quality is of 1st class. Subsoil water is almost everywhere reachable between 2-4 m, the amount of layered waters is average. There are few artesian wells, their depth exceeds 100 m, with an average run-off. The southern part of the **Egerszeg Letenye Hills** small region flows through the Alsó-Válicka and the Kerka, as well as the Principális channel towards the Mura. The annual run-off is substantial, it decreases heading from the south to the north. Even the little streams rarely dry up. It has little continuous ”soil water”, its level stands between 4-6 m even in the valleys. The amount of soil and layered waters is not significant. The depth of the layered waters is between 100-200 m, with substantial run-off in some places. Thermal water of 60°C has been explored in Pusztaszentlászló. The valley flat to the left of the Mura is called **Mura-left-bank Flat,** its important tributaries are: Lendva–Adovány Channel, Szentadorján Stream, Béci Stream, Borsfa Stream, Újkút Stream. It is an area with abundant flowage. The water quality of the Mura is of II class, at low water it is of III class, the subsidiary streams are clean. 6 out of its seven lakes are of natural origin. Subsoil water is everywhere reachable between 2-4 m, its amount is considerable. In spite of its peripheral location it is a water base. The amount of layered waters is little, populous settlements have artesian wells, whose depth varies between 50-150 m. **Mid Drava Valley**: Zsdála Stream is parallel to and lateral water of the Drava, it has a substantial flowage surplus. Subsoil water is everywhere reachable between 2-4 m, the amount of layered waters is not significant. The depth of the artesian wells is generally less than a 100 m. The 38°C-hydrogen-carbonated thermal water of Barcs supplies a spa. The **Drava Flat** is the narrow valley flat on the left bank of the Drava from Drávagárdony to Old. This reach of the Drava is 75 km long, to which a catchment area of 37,863 km^2 belongs. 1,143 km^2 out of this is Hungarian territory on this reach. Korcsina Channel, Gürü of Sellye, an 18-km reach of the Fekete Brook, Gordisa Channel, Lánka Channel flow into the Drava on the left side of this reach. The area has moderate rainfall, it has surplus water. The flat of **Fekete Brook** is netted by the branches and subsidiary streams of the Fekete Brook (the stretch above Baranyhídvég) such as the western branch of the Gyöngyös, the main branch of the Gyöngyös, the Sikota Brook, the Somogy–Baranya Borderlands, the Almás Stream, the Körcsönye Channel, the Okor Channel, the Pécs Brook, the Egerszeg Channel. Mostly the lower, mouth reach of these watercourses belong to this landscape. The eastern part of the ***Nyárád–Harkány Flat*** belongs to the subsidiary streams of the Borza Stream (Versend Stream and Majs Stream), its middle part belongs to the catchment of the Karasica, its western part belongs to the catchment of Tapolca Channel. It is a moderately dry area with moderate flowage. There might be floods on the Drava and its lateral watercourses early in spring, at the beginning of summer and also autumn, whereas low waters occur mainly in winter when there is a break in the run-off of river-heads in the high mountains. Local streams yield a lot of water mainly at the beginning of summer but they may flood at other times as well. The left side alluvial flat of the Drava is wholly protected from floods by dikes. Inland waters of the protected areas are channelled by a 400-km drainage (*Drava Flat*), a 600-km drainage (*Fekete Brook Flat*), and a 260-km drainage (*Nyárád-Harkány Flat*).

The water of the Drava is of class I quality, the Fekete Brook is of. Class II quality, but below the mouth of the Pécs Brook it is polluted to class III. ”Subsoil water” can be found 2-4 m deep everywhere. Chemically it is of calcium-magnesium-hydrocarbonated character. Its hardness is of 15-25 °dH, (Nyárád-Harkány Flat: 25-35 °dH, to the north of Csányoszró it is over 45 °dH), its sulphate content is 60-300 mg/l. In some places a high nitrate content also appears (e.g. the middle reach of the Fekete Brook).

In some places artesian wells supply a runoff of over 500 l/m from depths below 100 m. Their use is often limited by the high iron content. Several thermal waters have been discovered in the area, e.g. Felsőszentmárton (hotter than 40°C), Okorág (hotter than 35°C), Sellye (hotter than 48°C), Harkány (4 wells with sodium carbonated water hotter than 60°C, 2 wells are over 40°C), Pusztaszentlászló (60°C), Barcs (38°C) (Dövényi Z. 2010).

The area has moderate rainfall, it has surplus water. The Hungarian territory gets significantly more rainfall compared to the rest of the Great Hungarian Plain, and accordingly it is more abundant in surface waters as well. The dragging of the river mouth to the south- east is typical of the lateral waters of the Drava. This phenomenon is caused by the alluvium of the Drava which diverts the coming streams on a long stretch (Varga G. 2009).

The most significant tributary of the Drava is the **Mura** coming from the Alps, with which it has a common regimen, furthermore the Plitvica, Bednja, Valpó. The **Sava**, which rises in the Julia Alps, is the second longest (944 km) tributary of the Danube which has the largest runoff (Zagreb: 255 m^3/s, Belgrade: 1,780 m^3/s). It mostly runs in a structural trench in its stretch here in whose axis it often changes its stretch character. Its catchment touching on the area definitely shows an asymmetric image. In terms of navigability, apart from the Danube (137 km), the Sava (446 km), the Drava (151 km), and the Kulpa – whose navigable stretch is only 4 km) can be mentioned.

There are relatively few **stagnant waters** in Pannonian Croatia. Most stagnant waters are connected to the Sava, the Drava, the Baranya stretch of the Danube as gemmation mortlakes. In Kuplamező the dying, marshy lakes of Fekete Marsh and Blatnica are typical. Artificial lakes are the Varasd and Perlak Reservoirs, and the fishponds in the Končanica and Kaniška Iva regions along the Ilova (Varga G. et al 2012).

1.5. Vegetation

Fresh deciduous forests are the climatozonal vegetation type of the **Kerka region (Hetés)**: beeches, hornbeam groves, sessile oak woods, Hardwood groves can be found along the Kerka, there are alder groves around smaller streams, there is a considerable spread of calciphobic oak woods mixed with pinewood. Its vegetation is transformed to a significant degree, mainly in the central flat areas. **Egerszeg-Letenye Hills** are a potential forest area (hornbeam oak groves, alder groves). The forests of the hills are of a good natural state today too, though intensive silviculture and non-indigenous tree species pushed into the front has transformed the original forest communities. Typical natural habitats on the territory of the **Mura-left-bank Flat** are willow-poplar groves, oak-ashen-elm groves farther from the river, shrub willows on the river bars. Along cutoff meanders, low waters there are alder groves. Extensive golden rods, tree plantations can be seen on active flood plains. Forest flora is dominated by elements of gallery forests. Uniquely in Hungary, Illyrian beeches, hornbeam groves have evolved on the territory of **Mid Drava Valley**. It is typical of the **Drava Flat** vegetation that the waterwashed, primeval alluvial flat of the Drava famous for its Slavonian oaks has significantly transformed since the river regulation and anti-inundation work. The larger forest blocks that have remained in its fragmented natural vegetation are comprised of oak-ashen groves and hornbeam oaks rich in submontanic-submediterranean mixes (thin spiked wood edge, Ruscus aculeatus, black bryony). These hardwood forests are primarily typical of the protected side. Plantations (poplar, willow, acacia) are common. Natural-state willow groves (summer snow-flake, sweet flag), white poplar groves (bunchy marigold, crown imperial, horse-tail) can be found in some places on the active flood plains and along the cutoff meanders, however only fragments of black poplar groves can be detected. The **Fekete Brook Flat** is a ”wild waterland” system of the Fekete Brook and Pécs Brook which used to be a continuous area together with the Drava. Today it is an area protected from floods and inland waters, it is a cultivated area to a significant degree, where the size of acacia plantations is increasing. The few remaining forest blocks among ploughlands are dominated by hornbeams-oak roburs. The **Nyárád-Harkány Flat** is a heavily transformed agrarian landscape covered with ploughlands. Its original vegetation is hornbeams-oak roburs, which is getting a more loess-oak character heading from the west to the east. Forest vegetation has only remained on isolated spots, impaired forests are common as well as acacia, poplar and pine plantations.

The number of species on these areas are 800-1,000, the number of protected species is 40-50, invasive species are: Acer negundo, tree-of-heaven, false indigo, common milkweed, non-local aster species, **Fraxinus pennsylvanica**, Fallopia japonica species, acacia, golden rod species (Dövényi Z. 2010).

The eastern, smaller part of **Pannonian Croatia** belongs to the Pannonian flora sector, the larger western part belongs to the western Balkan flora sector. The area is covered by the floristic region of the Great Hungarian Plain (Eupannonicum) from the floristic regions of the Pannonian sector, and the Slavonian (Slavonicum) and the Croatian (Croaticum) floristic regions within the western Balkan sector. In terms of cenology and ecology, primarily the oak forests from the forests of the region are worth mentioning. These occur on mountains, hilly and flat territories as well. They can be found from the lowest lands (low and high alluvial flats) to the altitude of 400-500 m (oak robur, sessile oak, tomentose oak, Austrian oak), above these oak mixes appear in which the main components are beech, silver linden, hornbeam, flowering ash, field maple. Parallel with rising altitudes hornbeam oaks, then beeches mixed with hornbeams and oaks, mixed beeches, finally homogeneous beeches comprise the forest. Pines in natural state are not typical, they only appear in patches on the western mountains reaching a height of 1,000 m. Other communities are rock grasses, which appear as silicate rock grass on crystal base rock, and as limestone and dolomite rock grasses on carbonated base rock, there are loess-lowland grasses as well as the typical sand vegetation that are characteristic of the ”Croatian Sahara”. There are gallery forests (hardwood and softwood) of different types on the alluvial flats. Due to the effect of edaphic factors, moor and hair-weed vegetation can be observed as well. Traces of point management can be found in areas that used to be reeds, swamps and moor meadows.

Some special areas with unique features of plant geography in Pannonian Croatia are Kopács Meadow (4,000-11,000 ha), on whose territory Lake Kopács (170-230 ha) never dries up. The meadow is almost in an intact state, there are parts which are free from human intervention, disturbance, where many herbaceous plants, rare birds, fish and amphibian fauna live. Marcsa forest, which is in the Šumećani district, is also a special area which is presumably an alluvial-flat oak forest due to the Csázma watercourse nearby (Varga G. et al 2012).

1.6. Soils

Two soil types are typical of the erosive hilly small region of the **Kerka region (Hetés)**: pseudogley brown forest soil and alluvial meadow soils along the Kerka Valley and other streams. Brown forest soil with clay washed in and pseudogley brown forest soil are the typical basic types of the **Egerszeg-Letenye Hills** small region. Meadow, moorish meadow, drained and parcelled flat moor soils that have formed on the alluvium of the rivers are also significant. Pebbles and different alluvium from clay to sand can be found on the residue of terraces of **Mura-left-bank Flat**. Pseudogley brown forest soil has formed on loess sediments of higher ground surfaces. Brown forest soils with clay washed in have formed on sandy sediment. Soils of the river valley are comprised of meadow, mainly younger alluvial meadow soils formed on the alluvial substances. Brown forest soils with clay washed in can be found on the periglacial sandy sediments of higher ground surface in the **Mid Drava Valley**, there are pseudogley brown forest soils in its western part. Dominating soil type of the small region is alluvial meadow soil, but the regional proportion of raw alluvial soils is also significant. Soils of the **Drava Flat** have mostly formed on alluvium sediments. Brown forest soil with clay washed in and brown soils that border the small region formed on periglacial sediment with sand as mechanical component. Carbonated meadow soils can be found on alluvial substances richer in humus with mechanical components of mud or clayey mud. The alluvial soil of the Drava flood plain is the major type of the small region.

The **Fekete-víz Flat**: forest and chernozem have a considerable role in addition to meadow and alluvial meadow soils. Brown forest soils with clay washed in can be found on periglacial sandy sediment and loess, brown soils and chernozem brown forest soils can be found on sand and loess. Soils of the **Nyárád-Harkány Flat** formed mainly on alluvial soils of Drava origin in the western part of the small region, and on loess sediments in the east. Meadow and alluvial meadow soils with mud as mechanical component can be found on the Drava flood plains that have a lower calcite content than the Danube flood plains. Meadow and alluvial meadow soils comprise a third of the small region's soils. Brown soils with mud as mechanical component can be found on the loess of the prominent terrace residues. The most extensive soils of the small region are chernozem brown forest soils on the loess sediments of the hillfoot areas that line the Villány Mountains and stretch into the small region. Lime-furred chernozem soils around Bóly are of good fertility (Dövényi Z. 2010).

Brown forest soil is the most common soil type on mountainous and hilly areas of **Pannonian Croatia**. Its version with clay washed in also develops depending on how much rain falls on the territory. Grey forest soil also forms in the west and on the Slavonian Inselberg where the most rain falls, proving the increased lixiviation. Chernozem soils formed on flatlands where the soil-forming parent rock is mainly loess or loess-like sediment. Two versions are known depending on the loess type and thickness. Lime-furred chernozem formed on the Djakovó loess plateau, lime accumulation is not common on infusive (having a larger clay content) loess territories or territories mixed with other sediments, on these territories chernozem is typical.

Due to the frequent water cover, alluvial soils formed along the Sava, the Drava and the Danube and mosaic-like in the basins. In accordance with the base rock, sandy soils were formed around Gyurgyevác and Molva. Stony-rocky skeleton soils formed due to periglacial effect on montanic areas of near or over 1,000 m height.

Distribution of intrazonal soils is also mosaic-like, which is explained by water cover or its lack or an effect of a lithomorph (rock-like) soil-forming factor. Moorish soils developed along the larger rivers or in the basins fixed to moor vegetation. You can see traces of salinization which shows lime-salt saline (pedocal) soil genetics – adjusting to the alpine reservoir – near Slatina. Different types of black turf soils, fixed to rock quality, appear on limestone. One of these is larger and more extensive black turf soil which got its name for the high content of 0-type humus in it. The other is red-clayey turf soil which has better water management due to its clay content. The former mainly occur on limestone islet blocks or on the finely fragmented islet blocks of Kordun, the latter occur on the territory of Petrova gora and Žumberak.

Table 1: Proportion of soil types in the individual small regions
(Source: Varga G. 2009, Dövényi Z. 2010)

Kerka region (Hetés)		**Egerszeg–Letenye Hills**		**Mura-left-bank Flat**		**Mid Drava Valley**	
Soil type	*Area share (%)*	*Soil type*	*Area share (%)*	*Soil type*	*Area share (%)*	*Soil type*	*Area share (%)*
Pseudogley brown forest soil	83	Brown forest soil with clay washed in	45	Pseudogley brown forest soil	40	Brown forest soil with clay washed in	24
Alluvial meadow soil	16	Pseudogley brown forest soil	42	Brown forest soil with clay washed in	25	Pseudogley brown forest soil	7
Earthen barren	1	Earthen barren	3	Meadow soil	2	Alluvial meadow soil	57
		Brown soil	1	Alluvial meadow soil	33	Raw alluvial soil	12
		Meadow soil	1				
		Moorish meadow	3				
		Flat moor soil	5				

Drava Flat		**Fekete Flat**		**Nyárád-Harkány Flat**	
Soil type	*Area share (%)*	*Soil type*	*Area share (%)*	*Soil type*	*Area share (%)*
Brown forest soil with clay washed in	2	Humous sandy soil	1	Meadow soil	5
Brown soil	5	Brown forest soil with clay washed in	6	Alluvial meadow soil	29
Meadow soil	8	Brown soil	6	Brown soil	8
Alluvial meadow soil	83	Meadow chernozem	3	Chernozem brown forest soil	45
Raw alluvial soil	2	Lowland lime-furred chernozem	1	Lime-furred chernozem	12
		Chernozem brown forest soil	6	Humous sandy soil	1
		Meadow soil	33		
		Alluvial meadow soil	44		

2. SETTLEMENT NETWORK

2.1. Legal regulation of the settlement system

The Constitution of 1991 contains the fundamentals of the Croatian public administration system. Many new statutes concerning public administration issues have been made by legislators since then. The općina system used to be the public administration level below the state level until 1992, which was transformed by the county system in December. Most duties of the općinas were taken over by the counties, but self-government of općinas did not cease to exist. Thus at present there are two public administration categories that have self-government – the county and the općina – between the state level and the level of settlements. De jure both of them are actors having self-government in regional public administration, however, de facto the county is more of a local representative of state administration (the county unites local public administration and self-government on the basis of the Constitution), thus it is closely controlled by the state. (Ivanišević et al., 2001).

The level below the county, which is called " local self-government units" in legislation, falls into two types. One of them is the općina ("community" might be the Hungarian translation, this resembles what used to be the district in Hungarian public administration), the other one is the town. They are differentiated according to their organizational set-up and scope of activities in statutes, however in practice there is very little legal-regulatory difference between them. Both of them belong to a county, and are under the supervision of county authorities. The main difference is of a settlement geographical character, namely, općinas are organized in rural areas, whereas towns (grad) are logically typical of urbanized areas. Several settlements which can be considered as connected in terms of physical geography, social, economic aspects, and their people have common interests, belong to the same općina or grad.

The law allows for establishing towns in urbanized areas. This legal status can be achieved in several ways. Every county town and town with a population of over 10,000 is automatically raised to the rank of town. It is possible for every settlement to become a town when there is a reference to special importance (which may be economic, historical, geographical …). Due to this latter possibility, the number of towns in Croatia is rapidly increasing. While their number was 38 in 1991, this rose to 123 by 2001 (among them, apart from Zagreb, there are 19 county towns, 52 have a population of over 10,000, 51 became a town due to a special reason (Ivanišević et al., 2001). The number of settlements that became towns due to a special reason is the largest on the seaside, the islands and the core area (surroundings of Zagorje) of the Croatian state (e.g. 5 out of 7 in Krapinsko-zagorska County, 5 out of 6 in Zadarska County, 11 out of 14 in Primorsko-goranska County. It is the lowest in Slavonia e.g. there is none in Osječko–baranjska (Eszék–Baranya), Vukovarsko–srijemska (Vukovar–Szerémség), Brodsko–posavska.

Obviously this is explained by the different population density in the areas that are different in their conditions. These have partly natural causes (accentuated – not accentuated surface) and partly social causes (Turkish subjection – undisturbed development of settlements). In the centres of smaller attraction zones (determined by physical geography factors) that developed on accentuated surface (mountains, archipelago) there is a rightful claim to obtain the title of town (functions exist), whereas more extensive but smaller attraction zones developed in the eastern part (less accentuated surface) of the country, therefore it is logical that there are fewer central places which have central functions and which could potentially qualify for the title of town.

Contrary to this, settlement and self-government are more or less overlapping institutions in Hungary inasmuch outer built-up areas are not taken into account. Thus in Hungarian-Croatian relation, the settlement network in Croatia (also true of Slavonia) is more fragmented than community self-governments in Hungary. In terms of development it means that infrastructure and community claims are more scattered spatially while self-government decision-making is more concentrated in Croatia, whereas it is contrary to this in Hungary where infrastructure and community claims are more concentrated and self-government decision-making, assets and finances are more fragmented. Public administration is being reformed at present, which is aimed at changing this fragmentation.

2.2. Statistically-based – quantitative – analysis of the settlement network in the examined area

Public administration units of the area included in the examination are organized in a similar way but have typically different basic statistics. The Hungariancounties of the subsidized area are home to slightly more than one million people on a territory of slightly more than 14,000 km^2, whereas the Croatian counties have a territory of slightly less than 17,000 km with a population of slightly less than 1.26 million. While these statistics and the area indices based on them such as population density (the Hungarian County average is 70.38, the Croatian County average is 74.83, the common average is 72.79 people/km^2) are commensurable, the county level data show a more mixed picture due to the higher degree of fragmentation of the Croatian territory.

The average size of the Croatian counties is less than half of the Hungarian ones, at the same time the differences in size of Croatian counties are a lot bigger (more than five and a half times) than in Hungary (less than twice). The same can be seen with regard to the number of inhabitants where the average population of the Croatian counties is also less than half of the Hungarian counties. Our second statement is also true which says that differences in the number of inhabitants among Hungarian counties are substantially smaller than in Croatia. (Table 2)

Thus since the Croatian system is much more fragmented than the Hungarian, moreover it has bigger inner differences, furthermore they have differing licences, possibilities and finances, the practice-oriented planning concerning them (e.g. use of geothermal energy among others) has to have differing starting points as well.

In terms of the settlement network, the examined area has several common features but there are several factors which strengthen the differences more. The main features of the Drava region are fragmentation (networks consist of a great many elements), the relatively low average number of inhabitants on one settlement and lack of towns. However, the settlement networks, which developed in similar natural environment and had a similar history of development, are regulated in different legal frameworks which have a different effect on their self-government, legal status, political, economic, developmental independence as well.

Table 2: Basic demographic and community data by counties in the examined area. Source: national central statistical offices 2010

	area	Population	Number of towns	Number of settlements	Population density
Baranya	4429,6	393758	14	301	88,89
Somogy	6035,86	320578	16	245	53,11
Zala	3784,11	288591	10	257	76,26
Average of surveyed Hungarian counties	**4749,86**	**334309**	**13,33**	**267,67**	**70,38**
Average of all Hungarian counties	**4868,68**	**436461,5**	**17,21**	**165,84**	**89,65**
Varaždinska	1261	183730	6	301	145,70
Koprivničko-križevačka	1746	124467	3	264	71,29
Bjelovarsko–bilogorska	2652	133084	5	323	50,18
Virovitičko-podravska	2021	93389	3	190	46,21
Požeško-slavonska	1823	85831	4	277	47,08
Osiječko–baranjska	4155	330506	7	263	79,54
Vukovarsko–Srijemska	2448	190404	4	85	77,78
Međimurska	730	118426	3	129	162,23
Average of surveyed Croatian counties	**2104,5**	**157479,6**	**4,38**	**229**	**74,83**
Average of all Croatian counties	**2696,33**	**204314,9**	**6,3**	**321,86**	**75,81**
Average of surveyed area	**2825,96**	**205705,8**	**6,82**	**239,55**	72,79

Table 3: Population density data by counties in the surveyed area. Source: national central statistical offices 2010

	Number of settlements per 100 km^2	Number of towns per 100 km^2	Number of towns per 100,000 people	Proportion of towns as percentage of all settlements
Baranya	6,80	0,32	3,56	4,65%
Somogy	4,06	0,27	4,99	6,53%
Zala	6,79	0,26	3,47	3,89%
Average of surveyed Hungarian counties	**5,64**	**0,28**	3,99	**4,98%**
Average of all Hungarian counties	**3,41**	**0,35**	3,94	**10,38%**
Varaždinska	23,87	0,48	3,27	1,99%
Koprivničko-križevačka	15,12	0,17	2,41	1,14%
Bjelovarsko–bilogorska	12,18	0,19	3,76	1,55%
Virovitičko-podravska	9,40	0,15	3,21	1,58%
Požeško-slavonska	15,19	0,22	4,66	1,44%

Osiječko–baranjska	6,33	0,17	2,12	2,66%
Vukovarsko–Srijemska	3,47	0,16	2,10	4,71%
Međimurska	17,67	0,41	2,53	2,33%
Average of surveyed Croatian counties	**10,88**	**0,21**	2,78	**1,91%**
Average of all Croatian counties	**11,94**	**0,23**	3,08	**1,96%**
Average of surveyed area	8,48	**0,24**	3,31	**2,85%**

The difference between plains and hilly areas, which can be seen in Hungary as well, stands out concerning the number of settlements per 100 km^2, population density of plain-like Osijek and Vukovar counties lags far behind that of other Croatian counties. However, the picture is different if they are compared with Hungarian counties, Osijek-Baranya shows the Southern Transdanubian average, while Vukovar is nearing the total Hungarian population density, and it is definitely higher than the 1.3-1.4 average of the Great Hungarian Plain. This also implies that the settlement density of the other Croatian counties included in the survey is much higher. All this is partly consequence of the legal regulations, however, as it was mentioned before, not every place that is regarded a settlement has self-government in Croatia. Its significance in developmental policy is that infrastructure and community claims are spatially fragmented due to the fragmented settlement structure, however local decision-making shows higher concentration.

The picture is also highly polarized in the case of settlements that have the legal status of a town, however in this case the crucial role is played by the differing historical developmental paths. Above-average town density of Muraköz and Varasd Counties is a consequence of a more undisturbed development and partly the more accentuated vertical surface in their physical geography. The Hungarian counties and Pozsega are spread around the area average while the town density of the rest of the Croatian counties shows a picture of underurbanization. On the other hand, interesting anomalies can be noticed too. While the area-related town density in case of Pozsega and Somogy is not especially high, the population-related town density is the highest in these two public administration units.

Basically towns have a greater role within all settlements in Hungary, but for example Vukovar County performs outstandingly on the basis of these statistical figures, that is, a relatively high proportion is represented by settlements which have the legal status of a town within the few settlements. On the other hand, it is true for both the Hungarian and the Croatian area that quantitative statistics of all towns lag behind the national averages (substantially in case of Hungary), that is, certain parts of the supported area are considered to be underurbanized in their own country.

Table 4: Basic data of population on the settlements of the surveyed area. Source: national central statistical offices 2010

	Average settlement size (capita)	Average town size (capita)	Number of town-dwellers	Proportion of urban population
Baranya	1308,17	18478,6	258700	65,70%
Somogy	1308,48	10442,9	167087	52,12%
Zala	1122,92	16339,6	163396	56,62%
Average of surveyed Hungarian counties	**1248,98**	**14729,6**	**196394**	**58,75%**
Average of all Hungarian counties	**2631,82**	**21243,6**	**275485**	**69,50%**
Varaždinska	610,40	9242,5	55455	31,50%
Koprivničko-križevačka	471,47	13831,0	41493	35,90%
Bjelovarsko–bilogorska	412,02	9034,6	45173	37,72%
Virovitičko-podravska	491,52	9573,0	28719	33,95%
Požeško-slavonska	309,86	8129,0	32516	41,67%
Osiječko–baranjska	1256,68	19863,9	139047	45,60%
Vukovarsko–Srijemska	2240,05	20137,0	80548	44,72%
Međimurska	918,03	7661,0	22983	20,09%
Average of surveyed Croatian counties	**687,68**	12741,0	**55742**	**35,40%**
Average of all Croatian counties	**634,80**	17426,1	**76327**	**51,58%**
Average of surveyed area	858,73	13801,6	109271	45,75%

As to population concentrated by the settlements, it can be stated that the average settlement size and average town size of the Hungarian counties concerned – though both, less than half of settlements, two thirds of towns, are below the national average – exceed the related data of the Croatian counties concerned. The difference is significant in the case of settlement size, it is nearly double, it is less regarding town size but it exceeds 10 %. The data on the Croatian side show a mixed picture in national comparison: the average settlement size of the area is slightly bigger, but its town size is smaller than the Croatian average. Again large inner differences are hidden by the averages. While the average settlement and town sizes of Vukovar and Osijek exceed those of Hungarian counties (both indices in case of Vukovar, and Osijek exceeds even Baranya that has the highest figure in terms of town size), the lowest values are only half or a quarter of the Hungarian values. It is typical that the population data of the Hungarian counties show less spread than the Croatian side where there are significant inner differences, that is the Hungarian side is of a much more homogeneous character in this respect.

There are also significant differences in terms of urban population of individual counties in absolute values. Whereas on the Hungarian side urban population by counties is on average near 200,000, which means over 52% even with the lowest index, on the Croatian side this value is 55,000 people on average, that is slightly more than its quarter, which is a proportion of urban population between 20(!) and 45%. By this the difference between the least (Muraköz) and the most (Baranya) urbanized county is more than threefold.

Hence it follows that when developmental programs are made the following has to be taken into account: not only the distribution of infrastructure and decision-making competences are different but there are differences in demand and economy caused by different sizes of population concentration on the settlements. That is, there is a substantially higher concentration of population on average on the Hungarian side and in the eastern counties of the Croatian areas than in the more western Croatian counties. All things being equal, implementation of investments based on community demand may be more profitable in these areas.

2.3. Qualitative analysis of the settlement network in the examined area

Croatia has a monocentric settlement network, in whose centre Zagreb, the country's capital and largest urban centre can be found. Another three regional centres (Split, Rijeka, Osijek) can be found in the country, all three (and also the capital) are situated on peripheries due to the special form of the country. There are agglomerations of settlements around the regional centres – especially around the capital –, which are functionally connected to them. The territory between the regional centres are organized by meso- and microregional centres. (Figure 2)

The distribution of mesoregional centres is highly disproportionate in the examined area. Central areas are rare in the area of the Slavonian inselbergs (Papuk, Bilo) because of the rare urban network, it is hard for mesoregional centres to develop. There is a similar situation along the Drava where the relative lack of towns is caused by the state-border character rather than natural conditions. On the middle run, the deficiencies of regional centres are planned to be overcome by accentuated support and development for the Verőce-Daruvár-Kutina axis according to Croatian development documentations.

Lack of towns in the middle and northern parts of the supported area goes together with lower population density and unfavourable income levels as well. In contrast to that, a significant urban area has developed in the eastern and western peripheries of the area, where it is not only the population density (in Croatian relation) that is significant but also above-national average income and developmental indices can be seen.

The urban core of the examined area in the west is no other than the western – north-western section of the Zagreb agglomeration and its loose attraction zone outside the supported area. This is the largest agglomeration of towns in the country but only a section of it falls under our examination. Its major centres are Varasd, which constitutes a section of the most dynamically developing axis of the country, as well as Kapronca and Belovár, which belong to the less developed settlements of the Zagreb agglomeration but they have to be developed on long term.

The other agglomeration of towns consists of Osijek and the towns belonging to its attraction zone in the western part of the area. The southern elements of this group (e.g. Slavonski Brod) are already outside of the examined area. Its major members are situated to the southwest of Osijek (Vukovar, Vinkovci). The natural development of the urban region is severely limited by the state borderline to the north and east, which can be an area for active border-region co-operations of settlements in the future, of which there have been examples – in both relations – in the history of the area. However, it must be added that Osijek and its area turned into a disadvantageous position after the break-up of Yugoslavia in several respects, one of whose elements is the eastern location bordering on Serbia, while the country's orientation was changed from former eastern to north-western. The northern agglomeration is also deficient in the west, which cannot be explained by the above mentioned, and real mesoregional centres have not developed here. The allotted settlements (Dakovo and Nasice) can be seen on the level of development documentation, but they are far from the development level expected of a medium-degree centre.

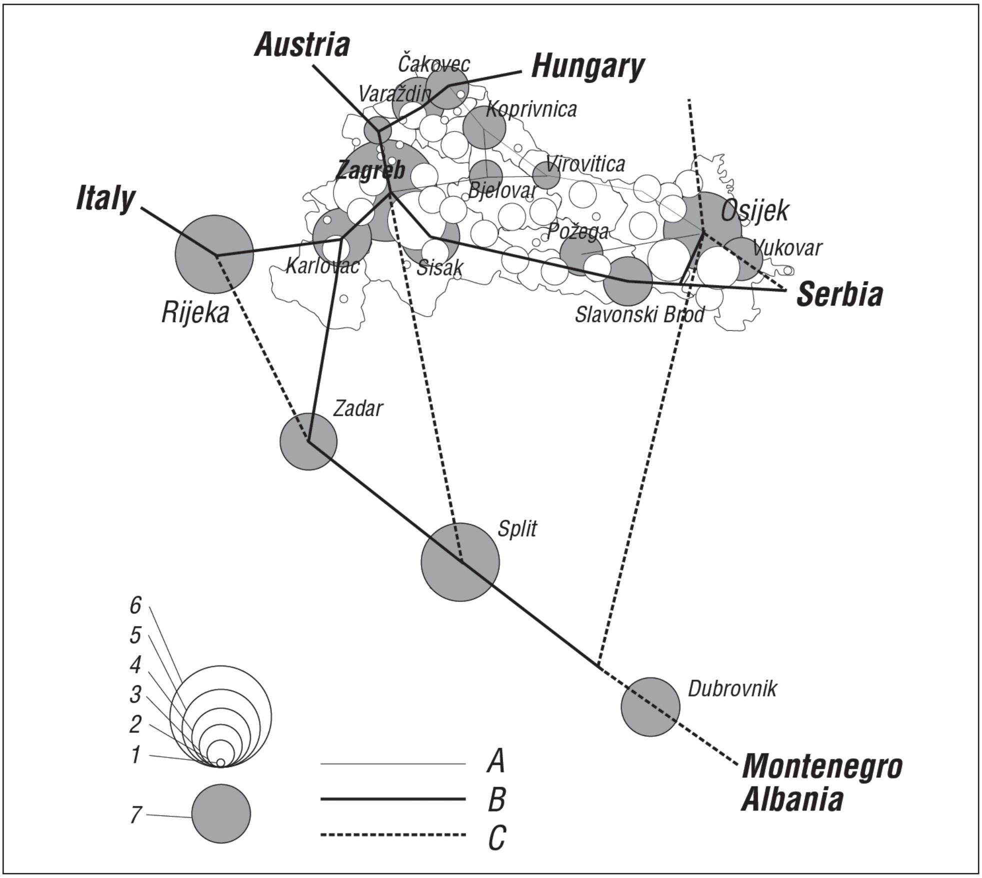

Figure 2. Urban network and spatial structure lines in Pannonian Croatia VÉGH A. ed. (2011)
Legend: 1: 1–10 (thousand people), 2: 10–25, 3: 25–50, 4: 50–100, 5: 100–250, 6: over 250 ,
7: county town, A: Secondary spatial structure line, B: Primary spatial structure line,
C: Potentiall spatial structure line

On examination of the settlement network of Hungarian counties, it must be highlighted that it is better balanced not only in terms of quantitative aspects but also in its spatial location and functional conditions. Key elements in the spatial structure of the area are the cities of county status (Pécs, Kaposvár, Zalaegerszeg, Nagykanizsa), four of which can be found in the surveyed area.

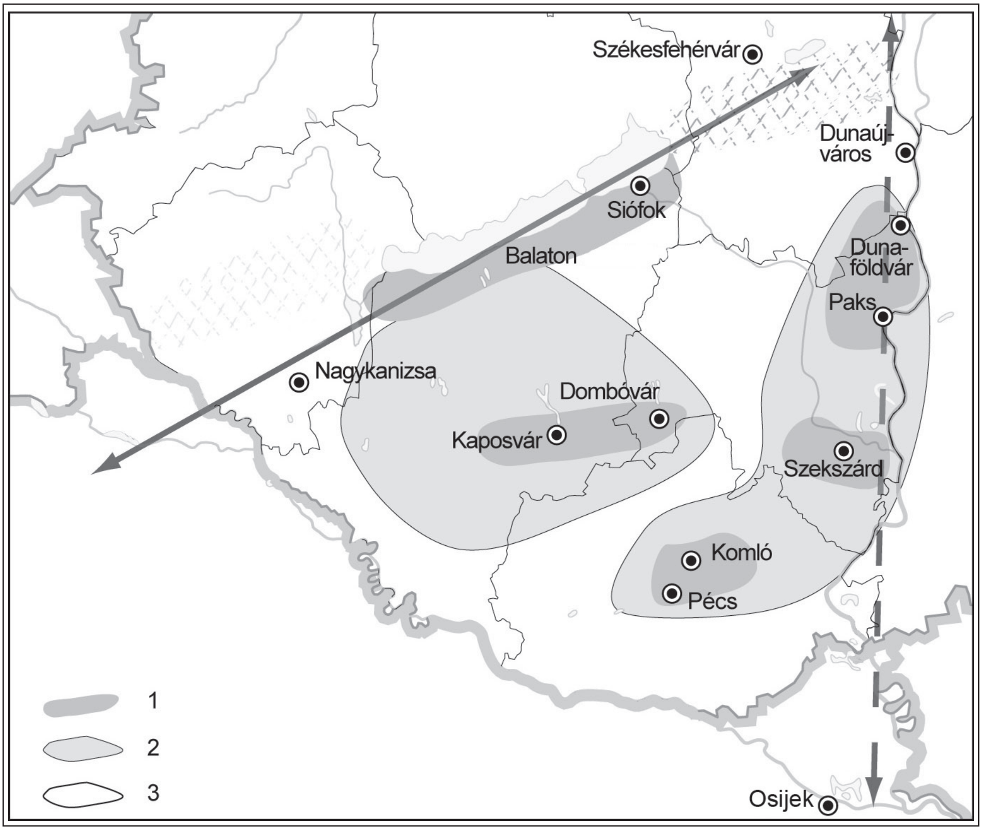

Figure 3. Spatial structure of Dél-Dunántúl (Southern Transdanubia). (Source: Pap N. 2006)
1. Urban areas
2. Transitory areas
3. Near-border and inner peripheries
4. axis
5. resort area

A large part of the urban population of the area is concentrated in the urban zones which developed around them and in the connecting string of towns to the south of Lake Balaton. Similarly to the Croatian situation, the Drava region in Hungary is also a backward and underurbanized area, like the inner periphery of Somogy and Baranya border region, which belongs to the Zselic regional unit. One of the obstacles to the regional and local co-operation of the two countries is this, namely, the directly adjoining territories are backward and lack towns.

With regard to town size, a further consequence can be drawn, that is, there is only one, namely Pécs, which is a city according to Central European measures. The second largest is Osijek with slightly more than half the population of Pécs. Typically, there are more Hungarian towns with a population of over 50,000, whereas the 25,000-50,000 category is dominated by Croatian towns. The proportions are balanced below this.

Table 5: Towns of the area with a population of more than 15,000 (source: central statistical offices, 2010)

Town	County	Population (capita)
Pécs	Baranya	157 721
Osijek	Osiječko–baranjska	83 496
Kaposvár	Somogy	67 979
Zalaegerszeg	Zala	61 970
Nagykanizsa	Zala	49 850
Varaždin	Varaždinska	38 746
Vinkovci	Vukovarsko–Srijemska	31 961
Bjelovar	Bjelovarsko–bilogorska	27 099
Vukovar	Vukovarsko–Srijemska	26 716
Komló	Baranya	25 299
Siófok	Somogy	24 347
Koprivnica	Koprivničko-križevačka	23 896
Keszthely	Zala	21 047
Požega	Požeško-slavonska	19 565
Đakovo	Osiječko–baranjska	19 508
Mohács	Baranya	18 884
Čakovec	Međimurska	15 185

2.4. Summary

There is a fragmented settlement and urban network in the area with a low number of inhabitants and a high number of settlements. Urban centres are evenly distributed on Hungarian territory, whereas they are positioned in a polarized way in the area in Croatia, leaving significant territories town-deficient (which will increase if their functions are examined instead of the legal town category, and ”hardly towns” (CSAPÓ T.–KOCSIS ZS. 2008, PIRISI 2009) are left out of the examination).

The settlements on the Hungarian side have a greater average population concentration (though they lag behind the national average), the proportion of big cities is greater here too. Undersized towns can also be found in significant numbers in the area, which could be rural areas according to their population (36 towns with less than 5,000 inhabitants), 21 Hungarian, 15 Croatian).

In terms of development, the most favourable conditions are provided by the island-like urbanized areas and the public administration centres (county, zupanjas) due to the allocation of developmental resources and decisions.

3. HISTORICAL, CULTURAL, ETHNIC BACKGROUND OF THE SUPPORTED AREA

The total expanse of the supported area is 31,000 km^2, has a population of approximately 2.2 million[1], and it covers the southern and western parts of Transdanubia in Hungary and the northern and middle parts of Pannonian Croatia in the case of the southern neighbouring country of Hungary.

The area, which is the ”touching surface”, the contact zone of the Hungarian and Croatian dwelling-places, is culturally and ethically multi-coloured, heterogeneous as a result of different historical-economic causes. This partly correlates to the fact that there are several regional units in the area that have independent character, marked history, and regional identity in some places. With this latter it is enough to think of Slavonia which had double, Hungarian-Croatian ties for centuries, but there is also a strong local identity in Muraköz and the Baranya triangle whichused to be parts of Zala and Baranya Counties until 1918.Of course, this can be seen in their architectural heritage, their culture. The same applies to Croatian Podravina and the Drava region, a match in every respect, but also the Mura region and Ormánság. Another duality is, which is also a very important division in identity and culture in the Croatian area, the differentiation by dialects - which can be attributed to partly historical reasons and migratory processes. Accordingly, the kajkav dialect is dominant in Međimurska, Varaždinska and Koprivničko–križevačka zsupanjas (districts), and it is the crucial dialect in Bjelovarsko–bilogorska County. This dialect, which used to be the language of medieval Slavonia, and only appeared in Croatian literature in the late renaissance period, is different from the official štokav in many aspects. The kajkav centre is Zagreb, and the mentioned territory is gravitating towards it, that is, the capital not only for economic but also for historical and identity-related reasons. Štokav, which is the standard language of Croatia, is the dialect in Virovitičko–podravska, Osječko–baranjska, Vukovarsko–srijemska and Požeško–slavonska zsupanjas that are situated to the east of the kajkav area. A major role in its spread was played by the population who moved in from Bosnia when the Osmanli Empire grew and settled down here.

The Turkish occupation mentioned before had a major effect on the ethnic re-arrangement of the area, partly due to that, a great many Croatian appeared in the Hungarian Kingdom first as refugees, then as organized or spontaneous settlers after the reoccupation wars. The proportion of Hungarians on certain territories (Muraköz, Baranya triangle) was significantly decreased by their migration, meanwhile their groups developed in the 16th-18th centuries by which Croatians in Hungary can still be differentiated. The Croatians of the Mura region[2], who are ”relations” of those from Muraköz and speak the kaj dialect, are present in our counties concerned, also the Croatians of the Drava region[3] on the territory historically ranging from Őrtilos to

[1] The population in the narrower, primarily supported area is half a million less, that is, it is only approximately 1.6 million.

[2] Their settlements, among others, are Fityeház, Bajcsa, Molnári, Murakeresztúr, Kollátszeg, Petrivente, Semjénháza, Tótszentmárton and Tótszerdahely.

[3] Most works dealing with Croatians of the Drava region include the history of 8 settlements, Felső-szentmárton, Dravasztára, Révfalu, Dravakeresztúr, Potony, Tótújfalu, Lakócsa and Szentborbás, but it must be highlighted that there also used to be villages with greater numbers of Croatian population to the west of the Drava.

Dravasztára who speak the kaj and štokav dialects, and the Croatians of Somogy[4] who do not really preserve their identity nowadays, and the Croatians of Baranya who can either be bosnjak or sokac. Hungarian population, as well as other indigenous ethnic groups, can be found on the Croatian side of the border, partly as remaining medieval population (Szentlászló, Kórógy, Haraszti), and partly as descendants of settlers from Transdanubia and Bácska who were migrating first sporadically from the end of the 18th century, then in greater numbers after 1848. Nearly 52% of Croatians in Hungary[5] are concentrated in the three counties on the Hungarian side, while almost 83% of the 16,595 Hungarians recorded in 2001 lived on the supported area. Most of them lived in Osječko–baranjska County (9,784 people), and – for historical reasons – on the territories beyond the adjoining counties: Bjelovarsko–bilogorska (1,188 people) and Vukovarsko–srijemska (2,047 people). Apart from the Croatian ethnic group, the German ethnic group represents a significant proportion and cultural weight on the former ”Schwäbische Türkei” territory in Baranya on the Hungarian side. The size of the Gipsy population is the greatest in Somogy County (9,440 people), which is followed by Baranya County (8,552 people) and Zala County (4,039 people). In the case of the Croatian partner, quite a large share of the total Gipsy population (9,463 people) – partly because Muraköz and the Baranya triangle belonged to Hungary and not to the Independent Croatian State in the Second World War – is concentrated in Osječko–baranjska and Međimurska zsupanjas, and the number of Serbian people is the highest in Osječko–baranjska County (28,866 people), and Vukovarsko–srijemska County (31,644 people).

The Croatian and Hungarian minorities that can be found on both sides and the ethnic self-governments make it easier to maintain contacts, they constitute a kind of bridge between the two countries. Knowledge and networking of Croatian experts, researchers and artists living in Hungary, and knowledge and networking of Hungarian experts, researchers and artists living in Croatia are used extensively by the governments, chambers, self-governments and associations. Hungary has tried to create as strong cultural connections as possible with the Croatian-side partner organizations since Croatia became independent.

Koprivničko–križevačka County, Bjelovarsko–bilogorska County and Virovitičko–podravska County belong to the twin counties of Somogy County. The parties concerned regularly attend each other’s cultural programmes (”Motives of the Drava region” in Koprivnica) (Royal Cooks’ Meeting in Nagyszakácsi etc.), agricultural fairs, while there is a close co-operation between the county libraries, associations of the disabled and pensioners and between the Hunters’ Chambers of Virovitičko–podravska County and Somogy County. Koprivnica and Kaposvár have been maintaining a multi-faceted relationship since they signed a twin-town contract.

Leaders in the two Baranya Counties of Hungary and Croatia signed an agreement of mutual co-operation in which the two counties dedicated themselves to building stronger relationships in hospitality-tourism, education and sport beyond the economic and transportation relations. Pécs on the Hungarian side of the Baranya area is the educational and cultural centre of Croatians in Hungary, you can find here Miroslav Krleža Nursery, Primary School and Dormitory which provides education and training from the nursery to secondary-school final exams, there is graduate training in the Croatian department of

[4] Settlements mentioned most often included Buzsák, Táska and Varjaskér.

[5] In 2001 the number of people who considered themselves Croatian in Hungary was 15,620, out of whom 720 lived in Somogy, 2,734 lived in Zala, while 4,608 lived in Baranya.

the University of Pécs, and the only ethnic Croatian Theatre can be found in this city too. The Croatian Consulate General of the county greatly contributed to the success of the programme series of the Cultural Capital of Europe in 2010 by mediating approximately 70 programmes for the town in total. An active participant in this work was Osijek which has been a twin town of Pécs since 1973 and which settlement has similar conditions and weight on the other side of the border to that of the Baranya County town. It is an interesting parallelism that Pécs is one of the ”citadels” of the Croatian culture in Hungary, and Osijek – corresponding to the large numbers of Hungarian population in Croatian Baranya – is a prominent centre for Hungarian education in Croatia.

Efforts have been made in Zala County to establish stronger relationship with, understandably, Muraköz that once belonged to its territory, and Varaždinska zsupanja due to its geographical location. The twin town of Nagykanizsa is Čakovec, centre of the Zrinyis in the 16th–17th centuries, and the twin town of Zalaegerszeg is baroque Varaždin which once functioned as a capital. Sponsored by Croatians, a Croatian library is functioning in Nagykanizsa, the twin towns send and host Croatian and Hungarian guests every year (Croatian Choir of Kanizsa, Meeting of Croatian-Hungarian Florists etc.). Music and secondary-school sport connections have been established among others in Zalaegerszeg- Varaždin relation, while in 2010, as a result of co-operation with several Croatian settlements, programmes were organized on several occasions where the partner sent their representatives too (VII. National Pottery Festival – Zalaegerszeg, Hungarian-Croatian Family Whitsun – Zalaegerszeg, Renaissance Festival – Koprivnica, Traditional Christmas Fair – Čakovec).

In summary, it can be stated that the Hungarian and Croatian ethnic dwelling-places coloured with other ethnic groups do not follow the rivers, the Trianon borders closely, which occasionally slowed down migration and the spread of culture but could not stop them. As it has been mentioned, the bilateral Croatian-Hungarian minorities are suitable for fulfilling the role of a bridge. Contrary to the fact that the Hungarian Croatian interstate relationships are definitely good due to this and the supporting character of the minority policy, the intensity of the cultural relationships is medium, it is stronger between schools, associations, professional institutions, while it is formal, protocol-like between local governments.

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III. PUBLIC ADMINISTRATION, REGIONAL DEVELOPMENT, REGIONAL POLICY

1. PUBLIC ADMINISTRATION AND REGIONAL DEVELOPMENT

It is essential to examine some characteristics of the systems of public administration and self-government in the two countries with a view to developing and buiding up cross-border relationships. These organizations are the main actors of co-operation at present. Both the Croatian and the Hungarian public and self-government administrations are in a state of continuous change. Below we would like to show the factors and features essential for the co-operation.

After the political changes, the first democratic government of our country decided to wind up the whole of the council system with all its positive and negative motives. Thus the county lost all of its regional administrative and regional planning functions, districts also disappeared from the scene in the same way. However, it must not be forgotten that the county did not use to be a bad by-product of state socialism[1], it, called vármegye at that time, existed in a legally continuous way as regular part of the Hungarian public administration and regional organization for a 1,000 years except for the past 60 years. It is also important that it has a strong territory-related sense of identity connected to it.

A region/county dichotomy can be observed in the present Hungarian public administration system being reformed at the moment and in the establishment of cross-border co-operations. Regions do not have self-government, they are headed by a regional development council which only takes part in the division of development funds, and the majority of its members are delegated by the government. It has become clear in the past two decades of the self-government system that some settlements, due to the overfragmented settlement network, could only function efficiently if they managed their institutions and provided services jointly. The right for free association included in the law on self-governments made it possible to establish small region associations. This is only working more or less at present because the intention for association is not controlled by rationalism but by local, casual interests.

The Hungarian regional development and planning system has not had an efficiently working regional level up till now. This left a significant stamp on the organization of cross-border connections. For the vertical Croatian public administration system, in which there is clear hierarchy, it is not possible to properly interpret and comprehend the Hungarian system. This makes the quality of co-operations highly complicated, creates a special financing system in which democratic institutions only have limited supervisory rights.

The present Croatian public administration system/county system was created when the country separated from Yugoslavia and it is built on historical traditions before the Yugoslavian era. The former regional administrative system of the one-time Hungarian Kingdom was restored with some modification of public administration borders. It must be noted that the Croatian-Hungarian border in the Austrian-Hungarian Monarchy was only a totality of administrative, in fact, cross-county borders according to the XXX. Law of 1868 (Compromise-Nagodba). The public administration legacy on the two sides of the border is shared, the roots are the same.

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[1] The county was the main actor in regional planning in state socialist Hungary as well. Besides, the county party secretary used to have a key position in the state party hierarchy, which meant, in terms of regional planning, an almost unlimited control over development funds. Partly due to this, the functions of the county were emptied by the regime-changing anticommunist parliamentary forces.

„Županija" (county) on the territory of the Croatian Republic is on the middle level of the hierarchy in the public administration and self-government system and it is empowered with state administration and economic means. The basic level of the public administration is the općina, which constitutes a socio-economic-territorial unit according to the Croatian approach. The Croatian self-government system shows great differences from the Hungarian one. The most important of these is the clear subordinate and superordinate relations, while there is still a horizontal system in Hungary at present with territorial local governments that have no jurisdiction. The Croatian system is of a vertical construction, and the government has total control and supervision over the local authorities. The planning-statistical regions have been established according to the EU requirements, however these do not possess public administration functions or regional development funds (Lugarić Rogić, T. 2005, Mezei C. 2010).

The "Hungarian" County in Hungary struggled with an average of 160 co-ordinated local governments to organize and implement regional development and cross-border co-operation. This is made even more difficult by the incomprehensible decree-based regulation of the voluntarily established small region associations. The small-region level is functioning at the moment but its existence is not properly supported in the constitution.

The present government has scheduled several measures to eliminate the Hungarian public administration problems discussed so far. The first and most important is that it co-ordinated the institution of the government office with the county local governments. The government office practically embodies government control, and it took over, as a deconcentrated factor, the functions of a number of public institutions which have territorial competences. It is not yet clear how but it is planning to eliminate the regional development councils which are at the head of the planning-statistical regions, their task will be fulfilled by the county regional development council. The district system will be restored too, where the governmental legal control will also prevail. The present cabinet is also planning to enhance economies-of-scale in the divided and fragmented self-government structure. Maintaining an office or institution would only be possible with a larger population. It promises to take concrete measures in 2012.

It has come up during the interviews with local governmental leaders several times that lack of resources is an everyday occurrence, small regions are incompetent, and there is a lack of regional level that has decision-making frameworks and constitutional background when cross-border co-operations are established. It has been brought up that small regions are defenceless against the leading town several times, or the particular town does not have the power to organize the economic area due to the horizontal frames.

In terms of cross-border co-operation, the županija-općina system of our southern neighbour is more comprehensible when public administration and self-government are examined, because co-operation, which goes together with a lot of difficulties and non-understanding, is feasible in a more comprehensible way; an unambiguous hierarchical level has been created with clarified subordinate and superordinate relations. As it has been dealt with already, Hungarian public administration is at the beginning of a transformation process, which is essentially aimed at establishing a vertical system with comprehensible subordinate and superordinate relations. This new Hungarian public administration construction shows more and more similarities to our neighbour's system, in terms of spatial planning the domestic system converges with the Croatian one. Spatial organization of the countries that used to have a uniform system of public administration and spatial organization (in the Hungarian Kingdom) will apparently be similar again. There are several questions being formulated concerning the CBC co-operation. The structures that become similar might as well help co-ordination between public administration units that have the same competences and are of the same level of hierarchy. However, a weakened self-government may also weaken the efficiency of cross-border connections.

2. REGIONAL DEVELOPMENT STRUCTURES OF THE CROATIAN-HUNGARIAN BORDER AREA

2.1. Basic conditions of regional development in the border area

Spatial connections are strong primarily with the Hungarian core area around the capital, secondly in the direction of the Southern Great Hungarian Plain. Its traditional spatial structure role is of a mediating character in the direction of Western Balkan and the Adriatic and Italian areas. On the other hand, it is a special contradiction of the area that beside the mediating role there is an also traditionally existing isolation which is decreasing primarily towards the south.

The road network transformed many times due to changes in domination spaces (Hóvári J. 2006). There is a description of the ethnic, social, cultural content of the established structures in János Hóvári's study. Starting from Budapest and heading along the shores of Lake Balaton, Nagykanizsa is the last mediating town in the south-western direction. From there the road runs towards Zagreb–Károlyváros–Fiume, and Ljubljana–Koper to the sea, or through Triest towards the Italian territories. Another less significant way out towards the Adriatic also starts from Budapest but this runs along the Danube through Szekszárd and the mediating towns of Pécs and Osijek on the Slavonski Brod, Sarajevo, Mostar, Metković, Ploče line. The gateway function is also supported by railways on parallel routes which are slightly different from road routes.

The spatial structure skeleton is constituted by the urban areas which are not independent of transit roads. A polycentric agglomeration which is united by tourism and recreational function developed on the southern shore of Lake Balaton, the urbanized axis of Kaposvár-Dombóvár, the agglomeration of Pécs which became great on industrial base and is transforming today, the southern bridge-town of Osijek which has multifaceted functions, the series of towns along the Danube which used to be market towns (with the function of bridge towns), and Nagykanizsa to the south-west, a traditional commercial city with some industry. Inner peripheries have developed in the inter-territories and they are surrounded by narrow or wide interim zones. Tiny villages, dead-end settlements, town-deficient areas can be found on the hilly areas, occasionally with ceremonial ”almost” towns. They are typically found along the county borders, in the zones between the county towns, which refers to the fact that their character did not develop independently of the specific features of spatial organization of public administration either.

An outer periphery also developed along the state border, this is mostly explained by the opposition against the Yugoslavia of the 1950s. This is experienced on both sides of the border. The southern Slavonic war conflicts of the past decades worsened the situation in the borderline area. This is a zone which is becoming deserted, there are demographic and employment crises due to the long relative isolation and investments that did not take place. Only some border crossing points stand out. The mine fields, destroyed infrastructure on the settlements, destruction of industrial plants, fleeing population etc. in the eastern part of the Croatian side have given tasks in effect today for development policy.

The area in Hungary is unfavourably divided in terms of regional organization. Nagykanizsa and its environs – it used to have an important role in the south-western mediation towards Italy, and it could potentionally have it today too – is part of the Western Transdanubian region that has developed on the Austrian border. After 1921 the Baranya triangle was part of the SCS Kingdom, then of the first and the second Yugoslavia, today it is part of Croatia. Nowadays break-away and dropping behind is not caused primarily by the existence of the state border but it is a consequence of sinking into the morass of the southern Slavonian war conflict (Serbia is to the east across the Danube, the problems are the destruction by the war, mine fields, the refugee problem, impossibility of economic activities in its area).

The county structures on the Hungarian side of the area are strong, their inheritors are primarily the historical county seats, towns with a legal status today (Pécs, Kaposvár, Szekszárd and Zalaegerszeg to the west). Regional development processes are determined by their population and economic weight and by the political power of their leaders. Nagykanizsa which also has the legal status of a county only contributes to the formation of processes with a significance of a small town.

Rivalry between towns and counties of varying intensity in the Hungarian areas is typical, and complementary co-operation in addition to that are the determining features of the area processes. The mediating role of the area is shown by the connection to the metropolitan areas.[2] Nagykanizsa could connect more to Zagreb regarding the two-hour travel time than to Budapest, the rest of the bigger towns belong more to the perimetropolitan area of Budapest. Efficient connection to the metropolices is hindered by the significant lag behind in terms of infrastructure development.

In the next 20 years, Hungarian population will drop by about a hundred thousand to 850,000 according to the EUSTAT forecast, although tens of thousands of international migrants may arrive here. The area is losing part of its population, and its relative *(inside the country)* demographic and political weight is also decreasing. The migration taking place inside the area is also massive. Population insignificance of inner peripheries is of an increasing intensity, at the same time there is an increase in social and cultural tensions (e.g. Ormánság). In accordance with that, the central places in the rural areas are being revalued (due to the concentrations of services needed for a liveable life, of market economy actors, and together with that of employment). The proportion of the Gipsy population is increasing, their demographic (juvenile) characteristics are different from that of the majority and other ethnic groups. Numerous issues are raised concerning their social integration, segregation tendencies, if not general, are also present here. Some of the most backward areas in Hungary can just be found here in the border area, considerable efforts have already been made for their development in the framework of the National Development Plan (2007-2013).

Changes can be measured in the urban areas as well. Kaposvár has gone through an impressive development in the past more than ten years. However, its ambitions to become a regional centre are not proportionate to the achievements. There is a strong suburbanization process in Pécs, the west-east division of the town has strengthened. The change of function (from mining-industrial centre to a modern service-industrial centre) has taken place partly through spontaneous, partly planned processes. On the other hand,

[2] Metropolitan – part of the global metropolitan network (Budapest and Zagreb here), perimetropolitan towns – settlements (towns) that are of a maximum two-hour travel time from the metropolitan centre and which are closely connected to that (PN).

the lost industrial jobs and functions could not be replaced by the new ones entirely, which is the main cause of the present sense of crisis and crisis situation. Developmental tasks of the Cultural Capital of Europe 2010 event constitute a large-scale culture-based town development programme. The completed M6 and M60 motorways are the most promising on the long run. The most criticized investments have not brought a break-through as yet. New possibilities opened for Szekszárd through the building of the motorway and the new bridge on the Danube, however the processes in the town through which these favourable changes could bring about their positive effect have not started yet.

The following could place the area on the European and world maps (Pap, N. 2006, and 2007):

- Mediating border area of the European Union towards the Balkan areas,
- Nuclear industry centre in Central Europe,
- Highly significant geothermal conditions
- Background area of Lake Balaton which is experiencing a change in the structure and character of its tourism,
- Pécs was the Cultural Capital of Europe in 2010,
- University of Pécs is one of the largest universities in Hungary,
- Some agrarian conditions (e.g. wines of Villány, Szekszárd, Balaton),
- It touches on the European Corridor V, the stretch to Pécs of the V/c Corridor is complete already, V/B has been built across the border as well,
- It is along the Danube which is the basis for European Corridor VII.
- It is one the regions struggling with the most severe social problems.
- Alps-Adriatic oil pipeline
- Northeast-Southwest gas pipeline

2.2. Fundamental development and spatial structure issues of the border area

There is a highly varying spatial structure and system of connections in the Croatian-Hungarian border area. A west-east slope can be observed on the 355-km stretch with regard to development. Before they are described it is important to list the spatial structure features of the border area concerned according to the NUTS II division used in the EU.

Two regional development (planning-statistical) regions on the Hungarian side touch on Croatia: The Western Transdanubian region and the Southern Transdanubian region; it is necessary to discuss the problems on the territories in the south of Zala, Somogy, Baranya counties. This is a rural, town-deficient area, only Lenti, Letenye, Csurgó, Barcs and Mohács stand out, but they lack attraction, or an attraction zone going further than the neighbouring villages. They are unable to generate a cross-border attraction of any kind.

Transportation connections of the near-border small regions are greatly influenced by the distance from the main roads starting from Budapest and the traffic generated by them. Southern Baranya and Somogy, the Drava region are weakly provided for in this regard. Examining the accessibility and approachability of small regions, it can be stated that significant areas on the Hungarian side of the Croatian-Hungarian border area count as isolated areas. Even the county town cannot be reached in 60 minutes in large areas due to the underdeveloped road network, let alone road or railway border crossing points. An external, badly approachable frontier zone along the Danube is standing out near the border. For those living on the isolated territories it is hard to have access to different services due to the unfavourable approachability, and it also slows down the flow of innovation. Small regions of Sellye and Barcs are extremely hard to approach inland. The lack of medium-sized towns and the fragmented settlement structure give a highly rural character to the area on the Hungarian side of the Croatian-Hungarian border area. Centres of small regions are towns in every case, however they can only fulfil their "urban role" to a limited degree, they do not have possibilities for innovation. This is added to the totality of ethno-integrational problems accompanying the frequent occurrence of Roma population.

There is a partly similar situation, but differing problems in Croatia. At present the three-region[3] version is being implemented concerning the Croatian NUTS II division (Lőrinczné Bencze E. 2009, Lovrinčević, Ž.–Marić Z.–Rajh E. 2005).

The Croatian-Hungarian border area on the Croatian side is located in the north of Sjevernozapadna (northwestern) and Središnja i Istočna (Pannonian Croatia) regions. There is also a west-east developmental slope from Čakovec through Varaždin–Koprivnica towards Beli Manastir. In fact, only Osijek has regional roles, there is an actual "spatial structure gap" between Koprivnica and Osijek, where Virovitica does not possess any significant central functions that would advance it to a regional centre, its position may be compared to that of Szekszárd on the Hungarian side.

The Čakovec–Koprivnica–Varaždin triangle located in the north-western part of the country is the most developed area of the country after Zagreb, and it has the most possibilities for innovation. This can be explained by the fact that the capital is close and it lies favourably close to the main transportation routes. Most of the Podravina area is influenced by two negative factors, one of them is the high proportion of agricultural workers, the other is the fact that young people continuously migrate to bigger towns, first of all to Zagreb. There was a significant population loss in the time period after the political changes (1991-2001), not aiming at completeness: in Gola (-13.2%), in Legrad (-13.8%), in Novo Virje (-11.8%) and in the war-struck Baranya triangle (Matica, M. 2005).

The other problematic point is the structure and build-up of the transportation network. The primary task of the motorway and road network inherited from former Yugoslavia was to ensure the traffic between the member republics. That is why and also due to the varying, occasionally not too friendly relationship with the neighbours, and the proximity of the border, the development of the Drava region was of secondary importance. At present, a freeway covering the whole of Podravina does not exist, though it was included in the plans but it was not implemented (Matica, M. 2006. p. 6.). However, other investments concerning the area are being implemented. The A12 motorway is being built and is planned to be completed as far as Berzence after 2011, and the A13 as far as Barcs. These will only be freeways with two double lanes.

If we examine the Croatian-Hungarian border area in the narrower sense and consider the above mentioned spatial structure problems, then it can definitely be stated that heading from the Koprivnica-Nagykanizsa line to the east we find ourselves in a rural

[3] The three regions are: Sjevernozapadna (North-west with six counties: Grad Zagreb, Zagrebačka, Karpinsko-zagorska, Varaždinska, Koprivničko-križevačka, Međimurska), Središnja i istočna (Pannonian Croatia, middle and eastern parts of the country with 8 counties: Bjelovarsko-bilogorska, Virovitičko-podravska, Požeško-slavonska, Brodsko-posavska, Osječko-baranjska, Vukovarsko-srijemska, Karlovačka, Sisačko-moslavačka) and Jadranska Hrvatska (the seaside with 7 counties: Primorsko-goranska, Ličko-senjska, Zadarska, Šibensko-kninska, Splitsko-dalamtinska, Istarska, Dubrovačko-neretvanska)

area. The transportation network opens up the area more poorly than the average of the given country. Every freeway on the Hungarian side is perpendicular to the border, and this disadvantage is even worsened on the Croatian side by the high migration and the high proportion of agrarian population Gola (70), Novo Virje (61.3%), Pitomača (42.5%). Segregation and integration problems of the Roma population in Hungary are also present just like in Medimurska County. It is only the Letenye-Lenti district in our country where a more dynamic development is possible if the positive effects from the relatively developed Međimurska County and Koprivničko– križevačka County will be felt (Matica, M. 2003.).

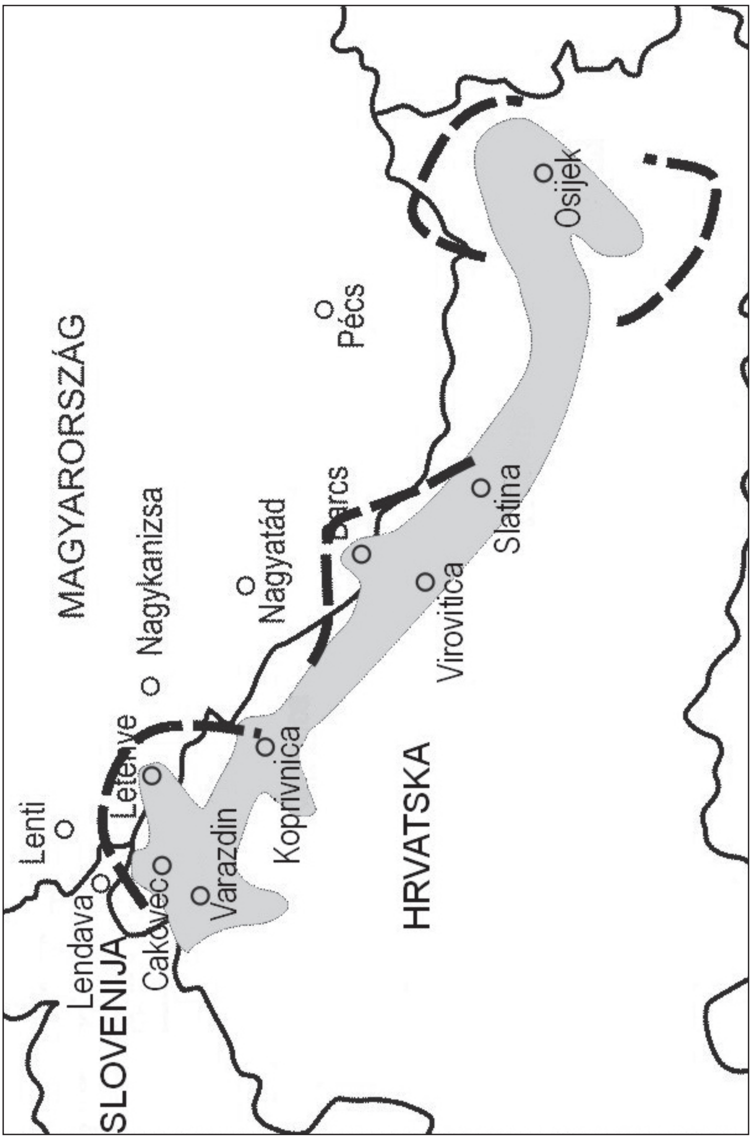

Figure 1. Some possible areas for the establishment of border-area connections (Bali L. 2009)

In summary, it can be stated that there is a chance for further mutual cross-attractions in the border area at only a few points. This is greatly influenced by the spatial structure gap near the border with our southern neighbour, and there is only one spatial structure axis relevant in terms of border-area relationships and it is on the Čakovec (Csáktornya)–Koprivnica (Kapronca)–Virovitica (Verőce)–Slatina (Szlatina)–Osijek (Eszék) line. This, practically Čakovec (Csáktornya)–Koprivnica (Kapronca)–Varaždin (Varasd) triangle, can generate cross-attraction, and co-operation may intensify in the direction of Barcs in the future *(Figure 1).* This situation will probably be conserved because territories near the Hungarian border are not classified into one spatial structure unit by the Croatian regional policy. Verőce-Dravamente County and Osijek-Baranja County are part of the Pannonian region, while Muraköz County and Kapronca-Körös County are included in the North-Western region which has much better development indicators. This will further increase the difference in the quality of co-operations in the individual border area zones in a way that only the western Berzence-Letenye, and Koprivnica-Légrád stretches will have chances for the establishment of border-area connections, while cross-border co-operations originating from the regional centres (Pécs, Osijek) and their narrow attraction zones will only take place on the eastern territories.

2.3. Corridors influencing the development of co-operation

The accessibility of the seaside, which is its primary tourist attraction, is almost of a hundred per cent for Croatia. The Split–Zagreb–Letenye–Budapest–Vienna and the Zagreb–Ljubljana-Triest motorways ensure the connection with the core areas of Europe. The transportation-geographical significance of the Zagreb-Belgrade motorway along the river Sava must not be disregarded, it indirectly meets the needs of Bosnia-Herzegovina as well.

The situation is different with a view to Hungary. The Pannonian-Balkan region has priorities for Hungary. The traditional Hungarian transportation axes traditionally follow west-east, northwest-southeast, and northeast-southwest directions.

In terms of the examined area, the following communication axes are noted in the present Hungarian literature (Erdősi F. 2005, Pap N. 1999):

- south-western ”Adriatic” Corridor
- south-eastern ”Pontus-Levante”
- southern ”Suez”
- south-western ”Slavonian”

With a view to border-area co-operation, it is worth examining the south-western ”Adriatic” Corridor and the development possibilities of the ”Slavonian” axis.

Corridor V/B has almost entirely been built up towards the sea in the direction of Rijeka and Venice, only some constructions have not been finished yet. It was among the utmost priorities for Slovenia, Croatia and Hungary. In terms of our examined problem, it is the most important that the M7 motorway reached the Croatian border, and the M70 reached the Slovenian border. A significant railway development has also taken place, the first railway connection of Hungary towards Slovenia has been built (Pirisi-Reményi 2005). In the present situation it seems that it has not finally been decided yet whether the primary direction should be towards Koper or Rijeka (Fiume).

Seeing the above mentioned developments, a multicultural area that is on the periphery of the state territory practically found its way back to the mainstream economy and society. Peripheral features can still be seen since both the Croatian-Slovenian Muraköz and the Hungarian Muramente were places from which capital was withdrawn, and few extra investments were made in the 1990s compared to how much they lagged behind.

Examining Corridor V/C, the ”Slavonian” axis, there is a different picture. The section from Budapest to Ploće is a main line for Bosnia-Herzegovina, but a secondary line for Croatia and Hungary (Pirisi-Rényi 2008), although it is a secondary line on the country level, it is a main line on the mesoregional level. It is essential to develop and build completely the Corridor for the Transdanubian Region, Eastern Slavonia and Tuzla Canton. This makes it possible to use and exploit their comparative economic advantages as widely as possible.

The level of preparedness of Corridor V/C is at its beginning stage as yet. The plans are available in all three countries. Preparations are the best in Hungary at present, where the first section of the motorway that is part of the Corridor is ready, the planning-licencing processes are ready for each section, and construction is being carried out, and there is a realistic chance to modernize the Budapest-Dombóvár railway section. The Croatian partner says that complete build-up of the section in Croatia is dependent on the Hungarian investments.

2.4. Influence and throughput of border crossing points

Transportation infrastructure and problems of border crossing points are a regional policy issue, the latter also includes foreign and internal political challenges. The above mentioned two factors represent a complicated issue both in inner-country terms and with regard to the Croatian-Hungarian border section, which significantly influence the character of the present and future connections. Several compromises have to be made with local and state leaders in our home country as well as in the neighbouring country for the development of border crossing points and the PanEuropean transportation corridors.

In our case, Croatia and Hungary have to make an agreement too. The Hungarian-Croatian bilateral development of border crossing points is considerably influenced by the fact that Hungary joined the ”Schengen Area”, practically we are the outer, southern border of the Union. Outer border control was included in the first pillar of the Amsterdam Treaty, the content of the treaty was included in the common legal material for the member states and for those who wish to join, thus it is a requirement of membership and accession as well.[4] The guarding bodies (Customs and Excise Office, Police) must stop inward immigration, which is an issue of outstanding importance for the EU these days. Patrolling activity must be carried out on a 5-km-wide territory near the border, which is complemented by in-depth checks.

Traffic at the crossing points is basically determined by the transportation demand, technical capacity is only a secondary factor. Traffic over the nominal capacity can simply be handled through organizational methods. The structure of crossing traffic in Croatian-Hungarian relation is primarily formed by the following factors:

- The function and status of the crossing point. In the above mentioned relation, international railway crossing points, with passenger and goods traffic, are in Gyékényes, Murakeresztúr and Magyarbóly; international road crossing points,

[4] Hungary became a fully entitled member of the EU on 1 May 2004. Croatia will, in all probability, be a member of the organization in 2013, and the Schengen Treaty will come into force with our southern neighbour even later.

with passenger and goods traffic, are in Letenye, Barcs, Dravaszabolcs and Udvar. In addition to that, it is important to mention Tornyiszentmiklós towards Slovenia with a view to the Croatian-Hungarian-Slovenian triple border. Berzence fulfils the function of handling international road passenger and also bilateral goods traffic.

- Special features of traffic structure and composition within the possibilities ensured by the status are important, as well as the rank and technical build-up of the tracks connecting to the crossing points. What economic potential the areas have which are connected by the crossing point, and what central functions settlements possess nearby.

In the Croatian-Hungarian border relation, it is necessary to mention that there are only six road and three railway crossing points on the 355-km long section. Crossing is possible per 60 km on average. There is an even more unfavourable situation on railway, there is not a single crossing point between Magyarbóly and Gyékényes.

Goods traffic has a typically low share on the whole of the border section, this is a consequence of the fact that only two, V/B and V/C of the international Corridors pass through. A more significant passenger and goods traffic is undoubtedly handled by V/B – which includes M7 as well. In addition, traffic on Corridor V/C was considerably reduced by the southern Slavonian Civil War, it only restarted towards Udvar in 1997. Out of all the crossing points Letenye handles the largest traffic, which, however, shows a significant transit character. The crossing point of Dravaszabolcs is used by those who come from the areas between the Papuk and the Drava, and the one in Barcs is used by those who come from the areas between the Papuk and the Bilo Mountains. Bjelovar, Virovitica (Verőce), Daruvar belong to its attraction zone. The attraction zone of Berzence is the narrowest, most people come from the environs of Hlebine, Virje and Đurdevac.

Gyékényes is the most significant out of the three railway crossing points, which has several causes. The first is that it is lying on Corridor V/B, the second is that the connecting Koprivnica-Zagreb section is one of the relatively fast sections of the Croatian railways which is also in the best state. International passenger traffic in Murakeresztúr stopped according to the latest timetable of MÁV (Hungarian State Railways), and there is only one passenger train pair apart from the Sarajevo international express train in Magyarbóly. There has been a rather light traffic since the reopening of the railway crossing point on 4 September 1997, and it is like that nowadays as well.

2.5. Development (IPA) programmes in the Croatian-Hungarian border area

The following factors have a decisive influence on the Croatian-Hungarian cross-border relationships and the socio-economic development of the near-border zone on the Hungarian side: distance from the individual Corridors, distance of county towns and towns with a larger population than 20,000 from the border, the intensity of twin-town connections, the presence of the Croatian ethnic group, the west-east slope coming from the national level, as well as the rurality of the border areas of Southern Transdanubia.

These problems have been recognized on both sides by regional policy actors, and efforts have been made to remedy the anomalies caused by the above factors when national programmes were set up. Accessibility and approachability potentials are an issue on both Croatian and Hungarian sides, which are still rather weak today. It is the most significant obstacle to more intensified micro-regional connections, that is, it is one of the main hindering factors in the actual cross-border socio-economic co-operations. The other important recognitions are remedy of rurality, development of human infrastructure, job creation, strengthening the positions of functional towns (Nagykanizsa, Čakovec, Koprivnica, Virovitica, Kaposvár) and regional centres (Pécs, Osijek) and facilitation of their agglomerations.

These processes and initiatives are also supported by measurable data such as the spatial concentration of winning IPA projects. The most potent are primarily the county towns and the settlements that have the legal status of a town on the Croatian side.

There is the same territorial tendency concerning the settlements which show intensity in the data of the latest IPA rounds *(Fig 2.)* Pécs bears the palm together with Kaposvár and Zalaegerszeg, and Čakovec (Csáktornya), Virovitica (Verőce) and Osijek (Eszék) on the Croatian side. Concerning the smaller settlements there is only one grouping of small settlements forming a definite axis (Muraszerdahely, Lenti, Csáktornya, Letenye, Tótszerdahely, Kotoriba, Kapronca, Križevci) concerning Zala County and Međimurska County in the Croatian-Hungarian-Slovenian triple-border zone where there is intensive co-operation. Kaposvár and Nagykanizsa also show continuous activity, however with Kanizsa the willingness to co-operate is not exclusively the achievement of the town. As to IPA projects, it is clear that the organizations of the University of Pannonia in Veszprém contributed to the success, and not, in fact, the Nagykanizsa Campus[5] *(Figure 2.)*.

A special situation was shown in the results of the first round, most of the successful projects were made in the field of research-development, education-training, and in relation to ”people to people” connections. It is interesting in the field of research that a local government or development agency is the lead beneficiary in half the cases, this may primarily be explained by the practice-orientation of scientific examinations (possibilities of geothermal energy, unemployment, biotechnology). There is a wide scale of participating settlements in connection with education such as Murakeresztúr, Čakovec, Marcali, Slatina, Szigetvár, Osijek, Pécs. Existing and working twin-town connections served as basis in fifty per cent of the cases, as well as in the field of people to people connections where the border area Croatian and Hungarian small towns (Virovitica, Čakovec, Križevci, Letenye, Szigevár) were successful.

There were few projects that served to deepen actual economic co-operative activity under the topic of co-operative economy (finding cross-border business partners)[6] with one beneficiary per county: Somogy County Enterprise Centre Public Foundation (Kaposvár), Southern Transdanubian Regional Association of Employers and Manufacturers (Pécs), Zala County Enterprise Development Foundation (Zalaegerszeg). Only two projects have been worked out and are being implemented for the set-up of Drava-related disaster recovery and other information networks under the measure ”Joint Local Planning, Strategies, Programmes”.

There were sixty successful projects in all in the second round, which is a rise of 50%. Composition share of the winning projects did not change, the tendency experienced before continued. There is an almost one-and-a-half increase in the first priority, this is

[5] The Nagykanizsa Campus is a branch campus of the University of Pannonia, it does not have an independent faculty. There are seven senior lecturers, fewer than half of them have relevant area-related social and economic expertise.

[6] Although there were eight successful projects under 2.1.3. Joint Research, Development and Innovation (R+D+I), none of the lead beneficiaries were from the business sector (e.g. Somogy County Local Government, PTE (University of Pécs), Local Government of Križevci, Integrational and Development Agency of Balaton Public Benefit Non-profit ltd. etc.)

made subtle by the fact that there was not a single project under the measure Sustainable Tourism in the Mura-Drava-Danube River Area. With the second objective there is an increase of 25-50% in seventy per cent of the cases. In the Co-operative Economy measure there is an average increase, the only decrease is of 25% in ”Joint Research, Development and Innovation”. There is a more than 50% increase in the number of winning projects with some topics of the measure ”Intercommunity Human Resource Development”, and there is a more than twofold increase in ”People to People Connections” (there is a decrease only with activities relating to bilingualism).

Figure 2. Spatial distribution of supported projects of the Croatia-Hungary Cross-Border Co-Operation Programme, source: Bali L. 2011. (1 project, 2-3 projects, 5-10 projects, 10-30 projects, Over 30 projects)

Looking though the winning topics of the second round, a past tendency is again standing out: local governments fill the resource gap from funds intended to be used for cross-border co-operation. Some examples of this are the projects under the 1.1.1 and 1.1.2 priorities: ”Development of the Waste Water Treatment Plant in Letenye and the sewage system of the south-western part of the town of Prelog, and ”Technical documentation for sewer system Bázakerettye, Donja Dubrava, Donji Vidovec and Kotoriba”, and ”Technical documentation for sewer system Őrtilos and Goričan”. The increased socio-economic cohesion of the border area is doubtful in each case, especially with Bázakerettye. There are no such tendencies in the second priority. Most of the successful projects were under ”Joint Research, Development and Innovation (R+D+I)”, ”Cross-border Educational, Training and Exchange Programmes”, and ”People to People Connections”, and ”Actions connected to Bilingualism”. Spatial heterogeneity is also the highest in these cases: Sopje, Slatina, Beremend, Marcali, Kaposvár, Osijek, Pécs.

Thus what has been experienced so far is the fact that density of cross-border interactions is primarily determined by the spatial, transport and ethnic relations. There has been a rare occurrence of–co-operation that can interpreted as an exclusively cross-border co-operation e.g. in the case of Letenye (HUHR/1001/2.2.2/0012), Tótszerdahely (HUHR/1001/1.1.2./0004), Gradina (HUHR/1001/2, Lakócsa (HUHR/1001/2.2.1/0016). The ethnic aspect has a strong influence in each mentioned case, the micro-regional contacts from before the state socialism have practically been revived through the powerful help of the EU.

Table 1: Priorities/Areas of Intervention/Actions
Hungary-Croatia IPA Cross-Border Co-Operation Programme
(A summary survey of the first and the second rounds)
Source: edition by Lóránt Bali based on the reports of www.hu-hr-ipa.com. 2011.

Priority 1. : Sustainable Environment and Tourism	Number	
1.1. Sustainable and Attractive Environment	1st round	2nd round
1.1.1. Development of landscapes in the Mura-Drava-Danube area	2	3
1.1.2 Environmental planning activities and minor public actions to improve the quality of the environment in the natural areas; habitat reconstruction	4	6
1.2. Sustainable Tourism in the Mura-Drava-Danube River Area		
1.2.1. Elaboration of a regional tourism product plan	1	0
1.2.2. Development of infrastructure for active and ecotourism: visitor centres, forest schools, water sport infrastructure, bicycle tracks, hiking paths, rentals	0	0
1.2.3. Development of thematic routes of cultural heritage	0	0
1.2.4. Promotion of the river area as a single touristic product	0	0
1.2.5. Private investment attraction	0	0
Priority 2: Co-operative Economy and Intercommunity Human Resource Development		
2.1. Co-operative economy		
2.1.1. Cross-border business partner finding	3	6
2.1.2. Cross-border labour market mobility promotion	2	3
2.1.3. Joint research, development and innovation (R+D+I)	8	6
2.1.4. Joint local planning, strategies, programmes	2	5
2.2. Intercommunity Human Resource Development		
2.2.1. Joint cross-border education, training and exchange programmes	7	12
2.2. 2. People to people connections	7	16
2.2.3. Bilingualism actions	4	3
Total of supported projects	**40**	**60**

As to the results, there is not a very positive picture in terms of the spatial structure of the border area. The slogan of the programme ”A cross-border region where rivers connect, not divide” did not come true. This is also shown by the table above. The fewest joint projects can be found under the priorities (1.1, 1.2) where an actual, regional, if you like, co-operation, approach would have been needed. In addition, the picture is made extremely subtle by the fact that there was low activity under the priorities of private investments (1.2.5.), business partner finding (2.1.1.) and cross-border labour market mobility promotion (2.1.2.). These would have been the break-through points that would have contributed to laying the foundation for a Croatian-Hungarian border area functioning as a united socio-economic area again.

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IV. GENERAL SURVEY OF ENERGETICS

1. CHARACTERISTICS OF THE ENERGETIC SECTOR OF HUNGARY, FOCUSING ON GEOTHERMAL ENERGY

Hungary is highly dependent on the energy import (mainly from Russia) since the domestic production of nuclear energy, gas, coal and oil can only partially cover the needs. Primer energy production is based on gas, oil and nuclear energy, the share of renewables are below the EU average.

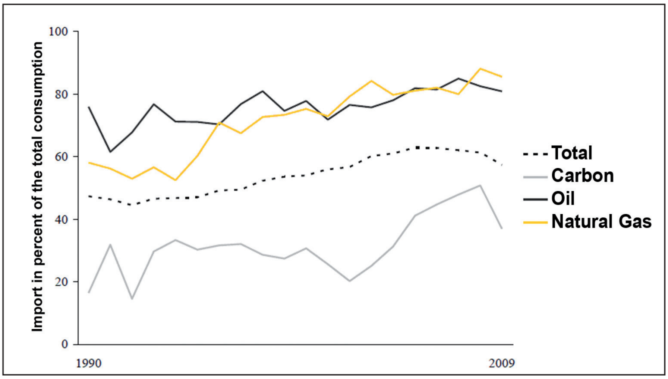

Figure 1. Energy import dependency of Hungary (Source: Nemzeti Energiastratégia 2030[1] National Energy Strategy 2030)

The primary energy intensity in Hungary, the total primary energy demand of the domestic production of the country was 2.4 times higher in 2007 than the EU average (based on nominal GDP), which rate is considerably lower if PPP GDP is taken into account (1.22). On the other hand electricity intensity is even lower on PPP GDP (97%-a), than EU average. All this means that Hungary is characterized simultaneously by very low per capita energy consumption and relatively high energy intensity.

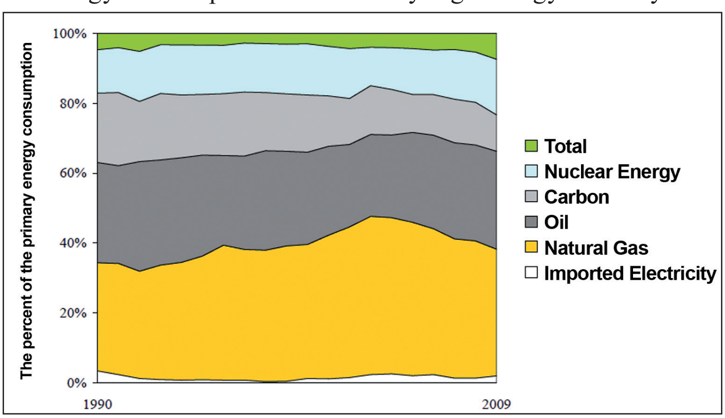

Figure 2. Primary energy consumption in Hungary (Source: http://www.terport.hu/webfm_send/244)

[1] http://www.kormany.hu/download/3/58/30000/ESTRAT2030%2020110513.pdf

The share of renewables from total final energy consumption was 6.6% in 2008 (7.3% in 2010), which positioned the country into the lower third among the EU member states (EU-27 average in 2008 was 10.3%), and Hungary is also behind the countries with similar level of economic development (Bulgaria 9.4%, Czech Rep. 7.2%, Poland 7.9%, Romania 20.4% and Slovakia 8.4%). The difference can be explained partially by the more favourable and better utilized hydropower potential and higher forest coverage of the neighbouring countries as well as by the more efficient regulation systems of the latter. According to the 2009/28 EC directive this indicator should reach 13% by 2020.

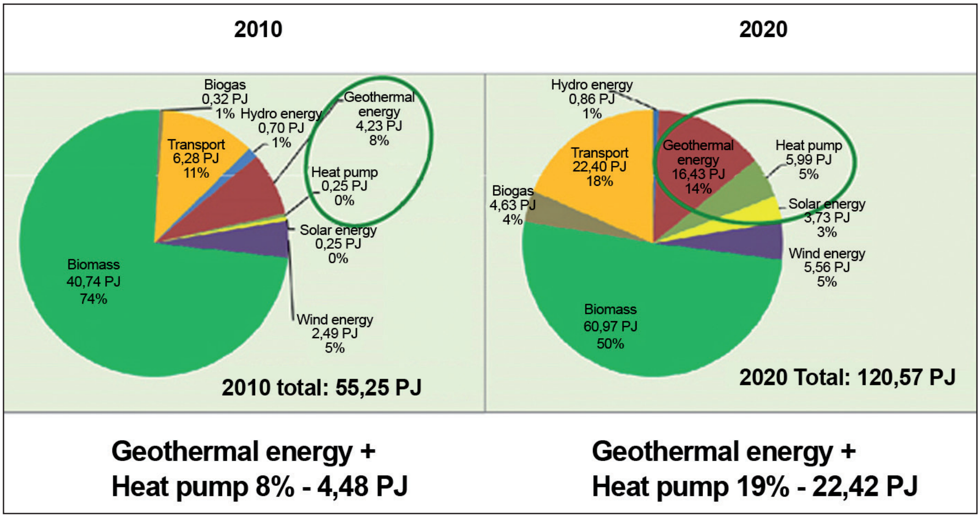

Figure 3. Distribution of renewables used in electricity and heating-cooling sectors. (Source: http://ec.europa.eu/energy/renewables/transparency_platform/doc/national_renewable_energy_action_plan_hungary_hu.pdf)

The proportion of geothermal energy utilization in the energy balance of Hungary, despite the significant proven resources, is low (0.16%). In addition, Hungary has no geothermal power generation facilities.

After joining the European Union (EU) renewable energy utilization started to grow intensively in Hungary. While before 2004 green electricity production amounted to only 0.5% of the total electricity production, by Q1 2009 it reached 4.3%, and renewables (RES) around 5.1% in total primary energy supply (TPES). This growth represents a fivefold increase in electricity production compared to 2001. At present biomass represents almost 90% and geothermal 8.2% of renewable energy use. Hungary is rich in renewable energy sources. Pellets and other solid biomass are the most widely used resources in line with present renewable generation ratio.

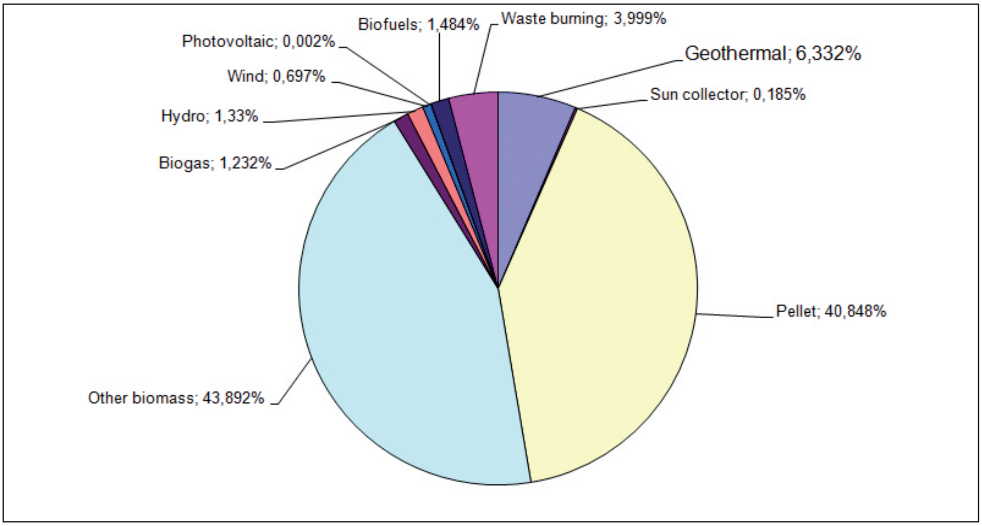

Figure 4. (Source: Energy Centre, 2008.)

In 2008, the government approved the Renewable Energy Strategy for 2007-2020. The policy targets the increase of RES production to 15% by 2020. The strategy will favour decentralized energy production, the cogeneration of heat and power and the establishment of small power stations utilizing renewable sources locally. The strategy forecasts a substantial amount of new investments by 2020, in the field of biomass, wind, solar and geothermal energy. Electricity generation from RES will grow faster than heat generation.

2. THE ENERGETICS SECTOR BY SMALL REGIONS IN SOUTHERN TRANSDANUBIA

Pipeline energy carriers have a decisive role in energy consumption in Southern Transdanubia, along the Drava as well as in other places in Hungary. As a basic energy carrier, natural gas is used by the population, public institutions and companies of the area. It is used by connecting to the pipeline directly as individual consumers or in groups (organized into small or big district-heating networks). Apart from that, electric power needs are also met by connection to the public network.

Besides the Paks Nuclear Power Plant plc., which has an outstanding performance on national level, there is Pannonpower plc. of Pécs, which is a decisive actor in energetics in several respects in the Southern Transdanubian Region. With the former it is interesting to note that in connection with the technological processes of nuclear energetics utilization, the possibility to generate electricity was enhanced by smaller water turbines. Taking into account the extended life span of the power station, a small but not insignificant increase in electricity performance is made possible by this extra potential not utilized previously. It is also almost totally free of greenhouse-effect gas emission.

Apart from the two big electricity-generating power station premises, there are several, a lot smaller gas engines which produce electricity for the companies and institutions of Southern Transdanubia. Favourably, power generation is connected to heat energy supply for example through meeting district-heating needs or technological heat needs of companies. Energy needs of populous settlements, institutions are (also) met by heat power station capacities, their role is to supply housing estates and large institutions with heat energy (e.g. Kaposvár, Szekszárd, Mohács). Power stations in Southern Transdanubia (they are only heating power stations except for the nuclear power station of Paks and the power station of Pécs):

Table 1: Power stations of the Southern Transdanubian Region.
Source: Gálosi-Kovács B. 2011

Name	**Fuels**
Nuclear power station of Paks *(Paksi Atomerőmű Zrt)*	Uranium
Thermal power station of Pécs *(Pannon Hőerőmű Zrt)*	natural gas, biomass
Heating power station of Komló *(Komlói Fűtőerőmű Zrt)*	Biomass
Szigetvár – heating power station (*EFC Szigetvár Kft- Ligna-Therm Kft.*)	natural gas,(biomass)
Kaposvár – heating power station *(Kaposvári Fűtőerőmű Kft)*	natural gas
Mohács – heating power station *(Mohácsi Hőszolgáltató Kft)*	natural gas
Szekszárd – heating power station *(Alfa-Nova Energetikai Fejlesztő, Tervező Kft.)*	natural gas
Dombóvár – heating power station *(Dalkia Energia Zrt)*	natural gas
Bonyhád – heating power station *(Fűtőmű Szolgáltató és Kereskedelmi Kft)*	natural gas
Szentlőrinc – heating power station *(Szentlőrinci Geotermia Zrt.)*	terrestrial heat

Thermal water is utilized for heating in the buildings of the local government in Bóly, in some blocks of flats in Nagyatád. Certain plants with a large energy need have their own energy-generating base, e.g. Cement Works of Beremend. Smaller enterprises have also thought of establishing a decentralized energy source but their primary energy source is still gas coming into the region through pipelines.

Due to the price increase of energy carriers and unstable market supply, more and more consumers are urged to look for other solutions which offer marketable energy carriers instead of natural gas coming from great geographical distances. Simple energetics solutions, mostly supported investments, have already appeared in the Southern Transdanubian Region, they are organized as autonomous systems and provide energy relying on local possibilities. These are smaller systems utilizing the local primary energy sources and generating only thermal energy, but the possibility to produce electricity is not excluded on a technical-technological level. Relying on biomass, smaller-capacity power stations may also be able to generate electric current, but the area can also count on wind energy and especially thermal energy though only in a smaller quantity in the beginning.

Differences in the consumption of gas and use of electricity by settlements indicate clearly where mixed modes of heating have a greater role already, and where the actual shift to the comfort of pipeline gas and electricity has been made. *(Where the energy for heating, cooking and water heating are wholly provided through pipelines.)*

Biomass is utilized in various "home-made forms" and quantities in many places in the examined area. It is especially present in places where the gas pipeline has not been built yet or, due to lack of income, people living there cannot afford modern heating modes and their continuous maintenance. Because of the full comfort provided by the use of pipeline gas heating, people gave up regarding waste, which used to be burned, as a material that can be utilized for energetic purposes. It seems natural that people start to recycle parings, the by-product of grape-growing and fruit-growing, to utilize heat energy locally where it is possible and where there are a great many privately-owned farms. In this case it is desirable to facilitate more and more modern and efficient burning methods.

From further energy sources **geothermal energy** has a potential in a greater area, within it especially thermal heat by its volume, but the utilization of terrestrial heat may be significant on community level too. Heat energetic use of thermal water primarily occurs in district-heating systems of bigger cities, but secondary use is also possible in bigger institutions and thermal spas of the area. The use of terrestrial heat can be expected in newly-built houses or in the energy supply of some industrial parks, however its spread may be limited due to the high costs of both the soil-collector and the heat pump solution.

There are outstanding geothermal conditions in Southern Transdanubia. Thermal water resources are utilized in spas – for balneological purposes – in many places, but there are great possibilities in multi-stepped use on the energetic side too. However, the present environmental and public health regulations do not help but hinder energetic utilization to some degree. Although the conditions are favourable in many places, the costs of energetic utilization of thermal water are high, and gas heating is used because of its low price for the community and its consumption can also be planned in the usual, convenient way. There is only some hope for this new type of energy to spread in a greater degree due to the advance of the ecological approach and the expected increase in the price of hydrocarbon.

Regarding the conditions of our area, if thermal waters are used for energetics, it is highly recommendable to use heat pumps to utilize heat energy because in this case only “waste heat” is used, and water does not have to be pressed back to the ground because it was not brought to the surface for energy generation.

Geothermal energy has been gained from the used hot water using heat pump technology in the Spa Baths in Harkány. Similarly, modernization of district-heating is based on terrestrial heat using heat pump technology in Szentlőrinc. Such system is used in Bóly too to heat local government buildings.

There is thermal water in the Mohács small region too that can be used for energetic purposes. However, it is not planned to use geothermal energy, but solar collectors are being installed on some continuously operating buildings handled by the local government, and domestic hot water is produced.

At present the simplest and cheapest way of using **solar energy** is through solar collectors. At present, these systems can primarily be utilized the most economically for domestic hot water production. There would be many more forms of the use of solar energy in the examined area, and it can be an outstanding form of utilization together with the geothermal conditions in the examined area.

Electricity generation by **wind power plants** is blooming in western Europe at present. Its effect on Hungary can only be measured through the increase in the number of wind power plants in Northern Transdanubia at present. The rate of progress reaches Southern Transdanubia only nowadays because wind conditions are not so favourable in this region as they are to the north and north-west. The local power supply company and system management are neither interested nor aiming at facilitating developments because extra work is needed for them and they would mean an uncertainty risk in terms of continuous power supply. Smaller-capacity wind power plants could be considered because they can be operated as island-type powerhouses, and could provide for the local needs using an autonomous system and battery-storing. Moreover, solar panels could be connected to the supporting pillars of these apparatuses rotating only at a height of some tens of meters, through which their performance could be enhanced.

There is no plan for the utilization of **water energy** in traditional ways, maybe smaller, new technologies could be used for gaining energy from the Danube, the Drava and tributaries with a big run-off. There are not many possibilities of this today, and plans for bigger facilities are not being made at the moment.

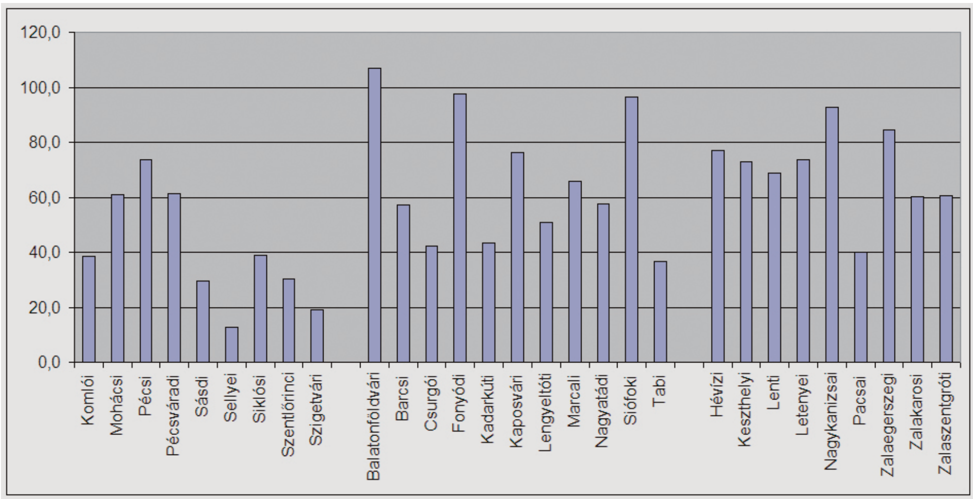

Figure 5. Households using pipeline gas heating per percentage of total flats in small regions of Baranya, Somogy and Zala Counties (Source: KSH 2011. Statistical Yearbook of Baranya, Somogy and Zala County)

2.1. Mohács Small Region

Pipeline energy carriers, community energy use

The proportion of flats in which pipeline gas is used in the Mohács Small Region is almost complete, and the proportion connected to the network is 60%. Connection is lower than that in the less populous villages that are on the north-western, western periphery of the small region, where burning wood and agricultural waste has always been a natural energy source. Traditional heating is a way of saving money for people living in villages with a low number of population.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

A well-managed grain sector and livestock-farming were coupled with excellent agricultural conditions in the small area. Joining the EU changed the conditions of agricultural efficiency in many respects. The people living here realized that they should adapt to new challenges, the state farm, which was outstanding on a national level earlier too, could only preserve its good positions if agricultural specialists were responsive to novelties. Bóly for example is one of the most outstanding examples of the usability of renewable energy sources in the region.

Relying on the excellent local conditions, the people in Bóly have further plans to produce and utilize biomass and biogas from community waste. Important achievements have been made by the town especially in grass energy production and in getting people to produce it, as well as in its processing and burning. The thermal water heating system started in 2008, it is used for heating the old people's homes, the school, the nursery school and the swimming pool.

The solar energy utilization program through solar collectors is supported by the local government of Mohács, works were in progress in 2006 (dormitory, home for the aged), and the use of thermal water is also continued as much as possible. The spa based on the thermal water of Mohács opened in 2007.

Energy rationalization, energy efficiency

Developments that started here indicate that the life of people living in the small region will preferably be changed by small or large-scale local projects which have innovative elements, and use renewable energy sources. Out of these, those conceptions may have a powerful effect on economic development that rely on local agricultural production and make use of biomass. These are primarily connected with the activities of Bóly Agricultural Producing and Commercial Company plc. at present. The geothermal projects in progress and the application of solar energy both contribute to this area being able to produce part of its present energy needs from local sources.

2.2. Siklós Small Region

Pipeline energy carriers, community energy use

Pipeline gas is used by 38.8% of households in the small region. Out of the more than fifty settlements, typically and primarily the ones with a higher population are connected to the country's gas supply network system. Most of the settlements that do not have a gas network have a population of 200-400 people.

Out of the settlements connected to the gas network, Harkány has a very high number of households consuming pipeline gas, while the average gas use is rather low here, not medium. The average gas consumption of households is almost the double in Beremend which has a much lower proportion. A much lower gas consumption of the properties not used by their owners the whole year is shown by this big difference.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Two heat pumps of 1.1 MW capacity each, which need restoration, have been operating in Harkány on the territory of the spa for several years. They ”recycle” the energy of the used hot water of the pools for the spa and some other nearby institutions. The new thermal spa has been operating in Siklós since 2010.

Heating and cooling needs, as well as hot water needs of the reception building is done through a geothermal heat pump system without auxiliary heating in the Mohács Historical Memorial Park.

The Croatian-Hungarian border area has significant renewable energy resources primarily biomass. Considering the unfavourable economic position of the area, the utilization of renewable energy could mean a cost-efficient energy source for the region, and additional employment opportunities could be ensured.

Energy rationalization, energy efficiency

Up-to-date utilization of renewable energy sources can often be made continuous through additional solutions.

2.3. Csurgó Small Region

Pipeline energy carriers, community energy use

There is an 83.3% proportion of settlements that are connected to the pipeline gas network, while only 42.2% of small regional households have joined this mode of energy consumption.

Among the settlements which are supplied with gas, there is a higher proportion of connection, more than 50%, in the case of settlements situated along the Drava. The spread of this rate is only between 10-20% even in the relatively more populous villages (with over 1,000 inhabitants) in the northern, north-western ground surface of the area. There is a restricted use of both gas and power in the households of the Csurgó Small Region. Higher figures are again shown by Csurgó, Berzence and Somogyudvarhely. In the smaller villages even if gas heating is installed by a small proportion of the population, it is not used. Mixed waste heating connected to gas heating and wood heating are also common in community heating.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Biomass has a primary role within renewable energy sources but it is utilized with traditional methods, and there are a lot of reserves in this as to energy efficiency.

The investing firm of Nagykanizsa would like to use a new solution to utilize thermal water in the small region. There is a plan to build a small power plant generating electricity as well with geothermal heat in Inke. The project included the build-up of the complete vertical set of economic units for the utilization of thermal water from multi-stepped energetic use through baths and gardening to fish-farms.

They also want to deal with energy tree plantations using the experience gained in forestry and timber industry. They also consider it important to develop further the energy management of the small area also by starting producing oil-yielding plants (rape).

Energy rationalization, energy efficiency

Local governments are the major actors in it, who supported, as much as their scarce funds made it possible, the population in their effort to insulate houses and replace doors and windows.

2.4. Barcs Small Region

Pipeline energy carriers, community energy use

There is a 44% proportion of settlements that are connected to the pipeline gas network while 55% of small regional households have joined this mode of energy consumption. The territorial appearance of this situation is special since there is a surprisingly high proportion of households which use pipeline gas supply in the western part of the small region while there is no pipeline gas supply at all in the tiny villages on the eastern periphery and in the south-eastern corner.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

The area is suitable for production and utilization of biomass coming from energy tree plantations. There is no programme for the utilization of energetic possibilities of thermal water, though geothermal conditions are excellent here too. Gas use could be reduced by heat-pump energy utilization.

Energy rationalization, energy efficiency

The most useful would be to burn biomass using much more up-to-date technologies. The gas bill could be reduced by using geothermal energy both for the households and the community buildings.

2.5. Szigetvár Small Region

Pipeline energy carriers, community energy use

There is an only 21.7% proportion of settlements that are connected to the pipeline gas network while the proportion of households consuming gas is 19.2% in the small region. The settlements where there is pipeline gas are typically very near each other.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

A small wood-burning heating plant has been built and is operating more or less continuously in Szigetvár. It seems to be a very good effort to utilize the conditions of the small area.

Thermal water and geothermal energy could also be utilized for energetic purposes but it could only be implemented and also maintained through supports.

Energy rationalization, energy efficiency

If efficient, small-sized wood-fired or biomass-fired block heating was implemented instead of the present mixed heating, then jobs and income could be insured locally for those living on small settlements.

2.6. Sellye Small Region

Pipeline energy carriers, community energy use

Pipeline gas can only be used on 16 settlements out of the 35 of the Sellye Small Region. There is also a very low number of connected households, which makes it even less sensible to have pipeline gas locally. Their proportion is only 12.4%. Gas consumption also greatly differs among connected households depending on whether it is also used for heating or only for cooking. Most settlements are not connected to the public utility gas network, the proportion of those who heat with wood and coal during winter is high, therefore smoke pollution can cause a problem.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

The area is rich in natural resources, whose preservation and further development are essential. It would be efficient to start transformation (forestation, energy tree plantations) along the low-productivity soils using suitable methods and extra funds in the southern, south-western parts of the small area.

Energy rationalization, energy efficiency

Help for the population of such a disadvantaged area is possible through modernization and targeted support policy. For this, it is necessary to renew the technics and technology of heating.

2.7. Szentlőrinc Small Region

Pipeline energy carriers, community energy use

There is a 21.7% proportion of settlements which are connected to the pipeline gas network while the proportion of households consuming gas is 19%. The territorial appearance of pipeline gas use is definitely focused on the central settlement of the small region, gas use is typical on settlements with a population of over 1,000.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Relying on the significant renewable energy sources of the Szentlőrinc Small Region, the following things have to be encouraged and supported: different modes of their use first of all in the field of energy utilization, the development of connecting technologies and the strengthening of industrial enterprises dealing with it.

There are good conditions for exploitation of biomass, solar, wind and geothermal energy carriers in the Szentlőrinc Small Region, conceptions of development have emerged through local initiatives, which were also good on the national level. The use of geothermal energy in the district-heating plant and its extended use for other purposes are examples of a concrete project in Szentlőrinc.

Energy tree plantations help to supply fuel for biomass power stations which utilize biogas for energetic purposes. Sort-term plans for establishing a biogas power station have been made by the Bicsérdi Arany-Mező Agricultural plc. and Szabadszentkirály

Agricultural plc. Agricultural by-products, wood chips, sawdust are used in the less than 5 MW equipment, and individual settlements are primarily supplied with heat energy.

The small region has extremely good conditions in the field of geothermal energy exploitation. There are two possibilities for geothermal energy utilization, one is the 36°C-degree thermal water of Szentlőrinc, the other is rock-heat. The geothermal indicators of the southern – lowland – areas of the small region reach or exceed the national average. According to the data of the relatively large number of deep drillings, a hot arching anomaly can be found on the south-eastern borderline of Szentlőrinc in the formation of a near-surface old-Palaeozoic mica, gneiss, where the geothermal gradient can reach the value of 80-85°C/km. A temperature of 120°C was verified at a depth of 1,200-1,300 m by measurings. Such a high value substantially exceeds even the outstanding national data. Geothermal energy can directly be used to replace gas used in district-heating, and the energy remaining in the ”cold” water after it was used in district-heating can be used in agriculture (greenhouse gardening) and in baths as well. The number of buildings connected to the district-heating system in Szentlőrinc can be increased due to the large amount of geothermal heat energy available.

For further profitable utilization, it is essential for the geothermal energy that can be gained to reach or exceed 100°C, and newer investment elements are also needed. Geothermal energy can be used to generate electricity in special small power stations. If a sufficient amount of geothermal energy of 100°C can be ensured (rock exceeding 100°C can be ensured at a drilling depth of 1,300-1,500 m), then a 2.15-MW-capacity, ORC-system small power station can be planted on this heat. It will be possible to sell a considerable amount of electricity in addition to providing for the complete system's self-consumption. In this case, generation of electricity is a priority, and only the ”remaining” heat is used for heating. If feasibility is possible, then not only financial support for projects but also serious investors' interest is ensured.

Wind energy utilization and a Wind Power Plant Park consisting of 24 units are planned by the local government of Bicsérd. The plan to plant 2.5-MW-capacity wind power plants and the selected premises were found suitable according to the results of wind measurings. The capacity of the wind power park – according to present conceptions – approximates 50 MW.

One of the possible developmental directions is organic farming based on natural ecological conditions primarily through the increasingly marketable organic-farming cultures. In addition, it is also necessary to develop the traditional intensive gardening cultures. Suitable energetics can be provided by the thermal and geothermal bases of the area for the development of intensive gardening cultures (greenhouses).

By-products of agricultural activity and forestry, which arise in traditional agrarian production sectors, energy tree plantations, and energy plants can be considered in the utilization of biomass for energetics. Energy plants are increasingly grown and used on arable lands as an alternative way of using these lands, which also takes places on good-quality but not cultivated lands.

Energy rationalization, energy efficiency

The fuel need of the Pécs biomass power plant of Pannonpower has created the possibility of the energetics use of forest utilization, which can create demand for state forest areas and privately owned forests as well but only through the application of a rationalized forest management.

2.8. Pécs Small Region

Pipeline energy carriers, community energy use

There is a 92.3% ratio of settlements which are connected to the pipeline gas network while small regional households show a 73.7% ratio. There is no gas network on only three settlements. The higher connection rate is coupled with above average gas use too, while lower gas consumption can be coupled with smaller connection rate.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Burning biomass with up-to-date technology, an increasingly efficient conversion of solar, wind and water energy, and utilization of waste heat and geothermal energy which is not accompanied by using subsurface water. Most of these renewable energy sources are some by-products or waste whose neutralization is in our interest, the balance can also be positive in terms of energetics.

Energy generation relying on biomass may receive special emphasis because it is possible, in co-operation with agricultural plants, to elaborate a programme which makes it possible to use the biomass produce of production to generate energy.

Energy rationalization, energy efficiency

Efforts have to be taken to replace obsolete heating equipment with more effective ones. Local governments should also make an effort to introduce innovative solutions on their properties.

2.9. Nagyatád Small Region

Pipeline energy carriers, community energy use

The proportion of settlements with gas supply reaches 55% in the Nagyatád Small Region and the figure is similar as to connection to the gas network. Nagyatád is the primary centre in the spatial structure of the small region, where for example 85% of households consume pipeline gas.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

There are definite plans to utilize thermal water, but problems with income generation hinder the social acceptance of these projects.

2.10. Lenti Small Region

Pipeline energy carriers, community energy use

There is a high proportion, 96.08%, of settlements supplied with pipeline gas in the Lenti Small Region. This type of energy consumption is available on 49 settlements with the exception of two settlements. The rate of households consuming gas is lower, it is

68.73%. Lenti is the primary centre in the spatial structure of the small region, where for example a high proportion of households consume pipeline gas but also the two more populous settlements e.g. Gutorfölde, Lovászi.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

The small region has very good conditions for the utilization of geothermal energy. There were plans to build the first geothermal power station of Central Eastern Europe in Iklódbördőce, but the project stuck at the preparatory stage. The temperature of the thermal water proved suitable but the quantity was insufficient. This would not have made the project profitable with the present Hungarian tariffs of green power transmission, therefore Mol plc. cancelled it temporarily, the project was suspended. The aim of geothermal energy utilization was to generate electricity which would be fed into the national network by connecting to the 20 kV mains nearby. The secondary utilization of the returning 70-80°C thermal water is planned by using it for heating in the village. There is a model project being prepared for the utilization of geothermal energy source in the village in Szécsisziget.

Developmental objectives based on renewable energy sources in the small regional integrated project package until 2013 are: creation and expansion of possibilities for fruit, plant and flower growing by using geothermal energy; utilization of renewable energies, energy plant growing, geothermal heat energy use – can be connected with the implementation of energy rationalization in the public institutions of Lenti and other settlements; Barlahida – establishment of Barlahida Leisure Centre, thermal water utilization.

2.11. Letenye Small Region

Pipeline energy carriers, community energy use

The proportion of settlements supplied with pipeline gas in the Letenye Small Region is 74%, 8 out of the 27 settlements of the small region do not have pipeline gas network. The proportion of households consuming gas shows a similar value, it is 73.5%. Letenye is the primary centre in the spatial structure of the small region, where for example nearly 70% of households consume pipeline gas.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Natural and economic (agricultural and forestry) conditions of the small region are suitable for the energetic utilization of renewable energy sources and biomass, but the conditions are also good for the utilization of geothermal energy. The considerable thermal resources of the region have thoroughly been opened up but exploited to a low degree: thermal baths with a small regional attraction zone opened in the past few years in Bázakerettye and Letenye. Thermal water wells can be found in Bázakerettye, Kiscsehi, Lispeszentadorján, Borsfa, Zajk, Letenye, Kistolmács, Bánokszentgyörgy, Oltárc and Pusztamagyaród.

Elements of the application of renewable energy sources within the ”GREEN HEART OF ZALA” small regional integrated project package until 2013 are: developments based on alternative utilization of electricity and heat energy, introduction of environmentally friendly, gentle technologies (utilization of primarily biogas, biomass, wind, solar, geothermal and small-scale water energy), e.g. development of the industrial park and the village biomass district-heating station – in Pusztamagyaród; use of geothermal energy for heating in Borsfa, utilization of alternative energy, non-touristic utilization of thermal water.

2.12. Nagykanizsa Small Region

There is a significant proportion, 96.6%, of settlements supplied with pipeline gas in the Nagykanizsa Small Region, only one of the 27 settlements has no pipeline gas network. The proportion of households consuming gas shows a similar value, it is 92.6%.

Local renewable energetics potential and initiatives, plans aimed at utilizing it

Main characteristics of the small region: favourable geothermal conditions, the average geothermal gradient is 5°C/100 m, thus rock heat is 60°C at a depth of 1,000 m, and it is 120° at a depth of 2,000 m. There are significant reserves in renewable energy use but utilization is of low level at present; alternative solutions are offered by the agricultural utilization of thermal water, and the use of forests in order to gain energy. A small regional integrated project package has been made which is primarily organized around the biodiesel product line, and the utilization of geothermal conditions. The integrated character of the project is shown, on one hand, by the agricultural developmental elements in connection with biodiesel base material production and geothermal energy (seeds production, larger sowing areas, agricultural tools, road developments, trainings for farmers, heat utilization), on the other hand it includes insuring the industrial background of processing as well as the logistical network of product utilization and selling.

There is a plan for building the geothermal small power station of Bajcsa. Growing energy-utilizing plants and development of the agricultural infrastructure: growing rape on a regional level, insuring other biodiesel base materials (e.g. collection of used cooking-oil). The creation of the necessary agricultural infrastructure (tools, agricultural and forest path development) and also insuring the conditions for organic farming (organic gardening, herbs growing and collection etc.) can be connected here. A good example for the integrated character of the project is the possibility to use renewable energies, especially geothermal energy in early vegetable growing in polythene greenhouses, in hothouses.

In the microregion where the level of gas consumption is lower the usage of biomass is higher. The forests of the given territory, the potential amount of biomass, provides the possibility of its energetic use. The exploitation and complex usage of the geothermal energy should be planned to those areas, in case of the presence of the natural endowments, where there is no possibility to produce and use biomass.

Table 2: Electricity and gas consumption of small regions as of 2009.
(Source: based on KSH (Central Statistical Office) data eds. Gálosi-Kovács B. 2011)

Name of small region (by county)	**Population (capita)**	**Total number of flats**	**Households consuming electricity**	**Electricity sold to households (MWh)**	**Electricity consumption per household (MWh)**	**Households consuming gas**	**Pipeline gas sold to households (1000 m^3)**	**Proportion of households consuming gas as % of flats**	**Pipeline gas consumption per household (1000 m^3)**	**Proportion of settlements supplied with pipeline gas (%) small region =100**
Mohácsi	49675	21529	26913	52297	**1,943**	13103	20 888	**60**	**1,59**	**95,35**
Pécsi	186800	80128	100816	220110	**2,183**	59048	59120	**73,7**	**1,00**	**92,31**
Sellyei	13340	5594	5727	14269	**2,49**	713	995	**12,4**	**1,39**	**45,71**
Siklósi	36711	14783	21346	47689	**2,23**	5748	7999	**38,88**	**1,39**	**81,13**
Szent-lőrinci	15112	5547	6783	15757	**2,32**	1682	2013	**30,3**	**1,19**	**35**
Szigetvári	26261	10311	12542	29291	**2,33**	1978	3446	**19,18**	**1,74**	**21,73**
Barcsi	24235	10364	11547	22582	**1,95**	5728	5592	**55**	**0,97**	**44**
Csurgói	17061	7269	8443	16615	**1,96**	3071	2402	**42,24**	**0,78**	**83,33**
Nagyatádi	26380	10858	11851	21705	**1,83**	6238	5263	**57,45**	**0,84**	**55**
Lenti	21338	10190	12677	20888	**1,64**	7004	4996	**68,73**	**0,71**	**96,08**
Letenyei	16645	7056	8360	14626	**1,74**	5191	3864	**73,56**	**0,74**	**74,07**
Nagy-kanizsai	65647	27801	38336	53544	**1,4**	25754	22906	**92,63**	**0,89**	**96,3**

3. FUNDAMENTALS OF ENERGY MANAGEMENT IN CROATIA

The energetics sector of Croatia is based on water power plants but the rivers in the Pannonian area are only partially exploited (Drava: water power plants of Varasd, Csáktornya, Dubrava) or not exploited at all (e.g. the Sava). The two big rivers mentioned above are boundary rivers, which can be a problem when water energy is exploited, which already caused a conflict in Hungarian-Croatian relation, and although it seems that Croatians gave up building the Drava water power plant system as far as Osijek, the plan is not completely abandoned. The National Development Plan also denotes possible water power plant sites on the Mura (Mursko Središče, Podturen, Goričan Kotoriba), on the Sava (Podsused, Prečko, Zagreb, Drenje) and on the Drava (Alsómiholjác, Osijek).

Half of the nuclear power station of Krško, which is situated close to the border in Slovenia, is owned by the Croatian state (it was a joint, Slovenian-Croatian project built at the time of Yugoslavia), this means an annual 332 MW energy for Croatia.

In renewable energy, Croatia introduced obligations to purchase all electrical energy output from privileged energy producers and aims to increase the share of renewable sources (without large hydro-electricity plants) from 0.8% to 5.8% of total electricity consumption from 2004 to 2010. Including large hydro, renewable energy in 2006 was 34.7% of consumption.

4. POSSIBILITIES, PLANS TO UTILIZE GEOTHERMAL ENERGY AND CLAIMS OF CERTAIN SETTLEMENTS IN PANNONIAN CROATIA

In the following chapter I would like to describe the settlements and areas that are potential users of geothermal energy in Croatian Podravina (the Drava Region) and in Muraköz, and also outline the possibilities and limitations of local utilization. I will give an overview of the location of known sources on the territory of Pannonian Croatia. Using the questionnaires and the information gathered in the institutions concerned (PORA, REDEA, EIHP) I have separated a couple of relevant settlements which have suitable claims and plans for future utilization. However, these have several limitations according to the examination experiences.

The decision-making scope of settlements is limited due to the verticality of the public administration system. Initiatives preferably start on the county or state level but those have priority even among these which are subsidized by the state such as model projects. At present the position of Croatia is similar to that of Hungary to a significant extent, but it lags behind the Hungarian position in several respects. Scope and quality parameters of sources show a wide spread, however their socio-economic utilization is rather narrow (Figure 6.). They exclusively serve tourism (Varaždinsko Toplice, Bizovac etc.), whereas there are sources similar to the Hungarian conditions and quality. Going a bit forward in this topic, this may be explained by two things, the lack of resources and the geopolitical problems of the 90s.

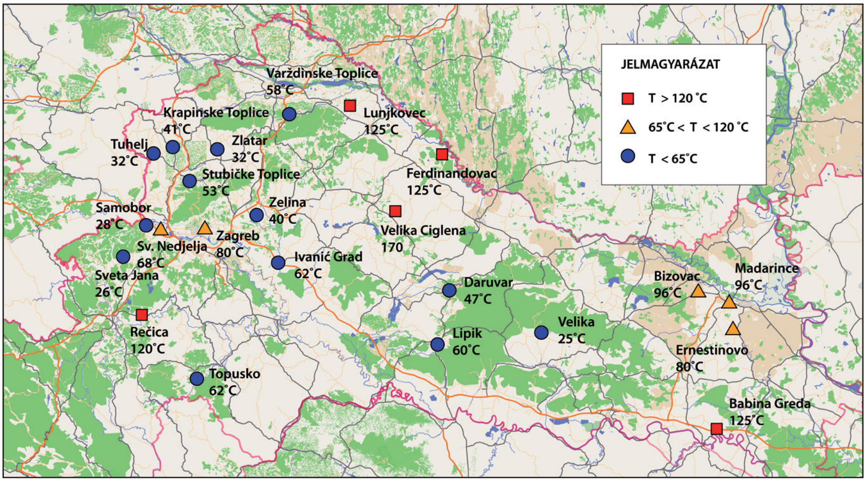

Figure 6. Location of geothermal sources in Croatia. (Source: www.eihp.hr)

Separation of settlements that are potent in terms of geothermal energy utilization is done on the basis of the location of sources and the realistic size of the settlements. The smallest possible users were the settlements where there is at least a population of 500. We had several difficulties during the survey. Settlements have little independence in terms of developments due to the special features of the Croatian općina system. The picture is made even more subtle by the fact that the county can only deal with regional planning. Thus we were able to really examine primarily the developmental conceptions of the county.

Developmental conceptions and claims are not parallel with the available resources in many cases, thus the utilization of thermal water for almost exclusively touristic purposes was implemented. There is no complex utilization conception other than one or two model projects that will be presented later.

Geothermal energy has been utilized for decades with our southern neighbour too. Several sources have been opened in connection with gas and oil exploration since the 70s. Geothermal energy is a special resource on which several profit-making investments can be based. There have already been several only touristic investments: Varaždin, Daruvar, Stubičke Topolice, Lipik, Topusko etc . Historically, the first sources were natural extrusions in several cases, whereas today they are results of the above mentioned other mineral explorations *(Figures 6 and 7)*

Widespread use of geothermal energy in Croatia[2] was in its infancy after the Second World War. This is proved by the fact that complex technologies of exploitation and exploration were only elaborated in 1976, and they were implemented by the INA-Naftaplin company. This can be explained by the industrial and economic structure of the former Yugoslavia where energy-intensive investments were not primarily concentrated on the territory of Pannonian Croatia. National hydrocarbon explorations in Croatia could most probably start after the changes in the constitutional system. As a result, several geothermal sources have been opened. The explorations aimed at finding, opening more and more reserve energy sources. The most significant source can be found on Bizovac, further relevant sources are: Koprivnica, Légrád.

[2] Within Yugoslavia

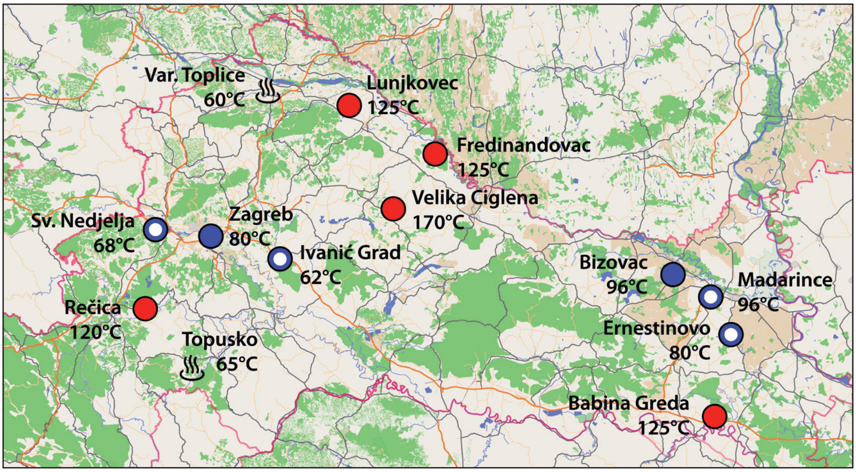

Figure 7. Functioning geothermal investments and the ones to be established in Pannonian Croatia. (Source: Maljković, D., Bosnjak, R., Matijašević N., Kulišić, B. 2008. Legend: Blue spots – a functioning bath; half-filled blue spots – potential source according to geological conditions; red spots – potential heat source over 100°C)

4.1. Major projects

Fundamentals of geology

Lunjkovec–Kutnjak

The source has two banked-up drillings. In terms of solute it has the following components: it has a total of 5g/l solute, three milligrams of dissolved gas per cubic meter 85% of which is CO^2 and H_2S. The bearing rock is carbonated breccia, its porozity is 7-8%, from which it comes to the surface at a pressure of 10 bars. The amount of the outflowing thermal water is 58 l/s and about 120-130°C.

Velika Ciglena

Thermal water comes from gneiss and sand strata, its temperature is 172°*C,* and it contains 24 g/l solute, it comes to the surface at a pressure of about 20 bars, the runoff of the tap is 115 l/s. The water contains a significant amount of H_2S.

Bizovac

The water can be found in a two-layered gneiss-sand format, and breaks to the ground at a pressure of 30 bars, which significantly helps economic exploitation.

Major projects and key areas, primary developmental conceptions

Kutnjak–Lunjkovec

Implementation of the Kutnjak–Lunjkovec programme was announced by the government of the Croatian Republic in November 2006. The aim is to implement a model project through which special features of geothermal energy use would be modelled, and its sector possibilities would be presented. Possibilities of future use are modelled, or would have been modelled, analysed in the programme based on the following aspects: transmission of electricity, testing technological developments in the field of energy supply, especially the implementation of high-temperature air and water with heat communication (Bruketa, N., Komerički Z., 2010).

The geothermal programme falls into two main segments. The first part includes the programme itself and the presentation of the structure of the planned economic zone. The second includes the subprojects in which a significant part of the geothermal energy will be used in production and services. The following organizations are going to take part in implementation in the future: INA d.d., HEP d.d., Podravka d. d., Croatian Privatization Fund, Kapronca–Kőrös County. The most important step at the beginning of the first phase was to summarize the contents of the available feasibility studies, by which investment contracts were established. The following fundamental objectives concerning implementation are formulated in the programme:

- efficient use of available geothermal energy
- utilization of the most modern technological systems in the use of geothermal energy taking environmental aspects into account
- implementation of subprojects of major public utility
- economic efficiency of partial projects has to be kept in view
- it must have a significant socio-economic gain

The water that comes to the surface at a temperature of above 100°C will greatly help to utilize geothermal energy in an economically efficient way. In addition, efforts will be made to make the investment as environmentally friendly as possible through the use of modern technologies:

- through the use of environmentally friendly technologies
- application of flexible patterns which can easily be transformed
- to reduce the precipitation of materials from water which are dangerous for the environment by shortening the process of use.

The subprojects themselves will provide the actual development for the local community, the općinas and the wider environment.

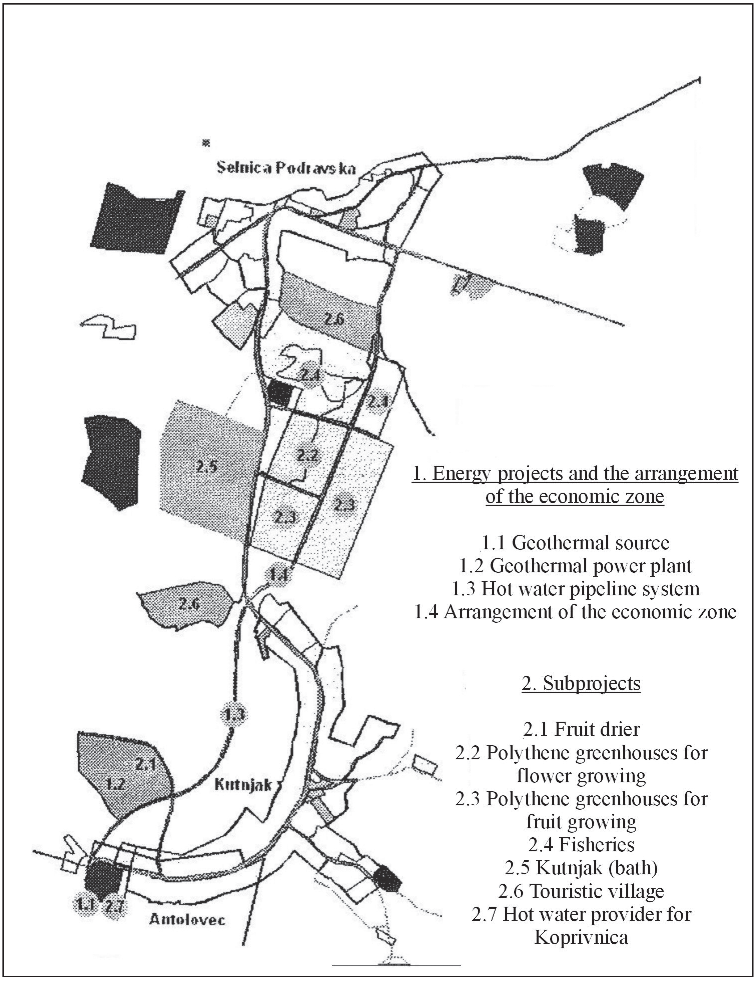

Figure 8. Overview plan of the Lunkovec–Kutnjak investment.
Source: Bruketa, N., Komerički Z., 2010

Implementation of the economic zone

The investment will be implemented in Kutnjak, Antalovec and Selnica Podravska of the Légrád općina according to the preliminary plans. An area of 142 ha is necessary to fully implement both geothermal phases. Project-related uniformity and replotting of lands will be done through expropriation and buying up in the future. However, this process has stuck at the present stage, my interviewees said this was due to the unsettled property relations.

As it is shown in the figure below, the programme includes eleven partial target areas. It is important to highlight in terms of infrastructural conditions that accessibility is insured by the LC 25102 state highway to which the project territory will be connected by an ”industrial” road. Another 720-cadastral-acre area of private property is planned to be included in the implementation of the planned complete economic zone. A firm called Geopodravnia d. d. o. has been set up to direct the investment, which holds the proprietory rights.

Koprivnica

Marked conceptions on the settlement level are only possessed in the county by Koprivnica which is one of the major centres of the border area. This is also shown by the IPA programme in which they are planning to utilize geothermal energy together with Csurgó. Csurgó and Koprivnica received a support of 436.900 euros to implement the project called Innovative Geothermal Energy Research surrounding Csurgó and Koprivnica within the framework of the Hungary-Croatia IPA Cross-Border Co-Operation Programme 2007-2013.

The co-operation is aimed at identifying subsurface geothermal sources near the two settlements, exploring the most suitable places for the geothermal wells. Two feasibility studies as a result of the geotechnical examinations, and the licencing planning documentation of the wells have been made, which will serve the utilization of the geothermal energy in the future. This shows that Koprivnica is committed to geothermal energy use. Thus the town is the second factor in the narrower border area which has visions for the future.

Muraköz County

Just like a large part of Pannonian Croatia, Muraköz County also has a significant geothermal energy potential. The first explorations started in 1911, they have had 15 drillings since then, only five out of which have parameters suitable for economic utilization: Vučkovec, Draškovec, Mačkovec, Hodošan, Merhatovec. None of them possesses calculations necessary for economic utilization in the present situation. Furthermore, geological explorations have not made it clear fully what geothermal parameters the area, and the environs of the mentioned settlements have exactly. According to the reports of the development agency (REDEA), the settlements of the county are waiting to adjust to investment possibilities depending on the county plans, as well as the opening of state resources and EU financial possibilities. They did not regard themselves competent in the subject of utilization issues during information gathering. I was directed to the county level in each case if they bothered to answer the interviewer’s question.

The county itself does not have a concrete plan of utilization of geothermal energy, only the potential together with other green energies has been surveyed in a study financed and presented in an INTERREG III. program in 2008.

Bjelovar (Velika Ciglena)

As I have already mentioned above, significant investment conceptions have arisen in Velika Ciglena near Bjelovar. The masters and managers of the project were INA, HEP (Hrvatska Elektro Privreda–Croatian Electricity Works), and the town of Bjelovar. Unfortunately, they could not start the investment due to the recession. In spite of this, I think it is worth looking at these plans more carefully despite the fact that the mentioned area is situated on the peripheral area of the Croatian-Hungarian border area.

The initial conception constitutes the first step of a multi-functional multi-part investment. The total value of future investments is estimated at 120 million euros. Several smaller geothermal power plants will be set up to utilize this renewable energy source during this program. Several relevant institutions will also take part, as it can be seen above, in the project.

According to the calculations of the Croatian Electricity Works, about 500 million euros had to be invested at the initial stage of planning and implementation, which will be followed, according to the plans, by several millions after the recession. It would be a complex programme where thermal water would be used in a multi-functional way. The water leaving the geothermal power plant will be nearly of 175°C, and 83 litres per second, such output will make it possible for the well to insure supply for other functions.

The investment will most probably take one and a half years to be built, after this it will be one of the most significant investments in Europe, which will be helped by the American Ormat Company's financial and professional contribution. According to preliminary plans, construction would have been finished by 2012, but it will be finished by 2013 because of the recession. It is interesting to note that a very short payback period is calculated (4-12 years). This can be explained by the extremely high producer price of electricity, it is 191 euros, in comparison with the European megawatt prices. The economic potential of Belovar and its environs will appreciate with this investment, and it will also create jobs.

4.2. Conclusions based on the surveys and developmental plans

Utilization of geothermal energy is influenced by several factors on the territory of the Croatian Republic, in Pannonian Croatia and Slavonia. The legal background only became stable in 2003 when the law on mining was passed giving more detailed regulation as to the use of mineral resources lying deep in the ground and that of geothermal energy.

On the other hand, suitable public administration competences are missing on the settlement and općina levels, and as recruitment of state administration experience of several decades, the proper initiatives on small settlements, in villages are missing. This can be explained by several factors apart from special features of the public and state administration environment. If you look at the location of the potential sources and the exploited sources and claims for utilization, you can see a strong correlation concerning the spatial structure of Croatia. The sources that have been functioning for decades are mostly baths, which are situated in the powerful vicinity of the capital. Drillings that are on the peripheral parts near the border are unused and closed yet, and areas that are near big cities have concrete developmental plans and investments for example Bizovac.

Developmental plans concerning this field are very rudimentary (Maljković, D., Bosnjak, R., Matijašević N., Kulišić, B. 2008.). There are references to technologies and methods used in Western Europe in them, and the itemized lists of existing sources. You can see the indication of supposed developmental resources, however concrete plans are rare. Although the Kutnja-Lunjkovec investment is contrary to what has been experienced so far, Kapronca-Körös County has only plans related to the state investment plans, it has no concrete project conceptions apart from that. There is a similar situation in Osijek-Baranya County. Similarly to the other regional administrative units, it has detailed developmental conceptions, but there is hardly anything about renewable energy sources or within that about possibilities of geothermal energy utilization. There is only one chart-like presentation of future plans. These and scattered developmental conceptions in the developmental plans of the other counties turn up in the future visions of local government leaders and regional policy actors: heating of public buildings, agricultural utilization, electricity generation for other market actors. There is a similar situation in Verőce-Dravamente County, only Slatina and Virovitica have visions, Slatina has a statement of intention aimed at preparing a 30-million-euro investment with a company called ENEX.

The picture which you get after questionnaires have been filled in and personal interviews have been made has specific features. It surprises the Hungarian specialists despite the fact that they are quite familiar with the special features of the Croatian public administration system. I consider it highly important to publicize this knowledge because this will provide exact information for future investors and actors of joint investments when they look for partners and start the first steps of future investments. The first important statement is that most local government leaders do not interpret their own settlement as an independent socio-economic unit, but only as a subpart of the općina (a smaller district). Due to this, the developmental innovative potential will be extremely low on the settlement level. Some basic signs of initiatives only appear on the općina level, and most settlement leaders do not consider it a primary task to improve the economic environment and make investments.

These initiatives appear primarily on the county level. In addition to that, county developmental agencies and state companies have concrete conceptions, project plans. In general, local government leaders adjusted to these conceptions in the course of interviews and questionnaires. Generally, energy generation for agricultural purposes and for public buildings as well as market actors is visualized everywhere.

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Županijska razvojna strategija Koprivničko–Križevačke županije za razdoblje 2011–2013., PORA, Koprivnica

V. RENEWABLE ENERGY SOURCES, WITHIN THIS UTILIZATION OF GEOTHERMAL ENERGY – RECOMMENDATIONS

Extra claims for energy that accompanies consumption and economic growth can be met through saving and more efficient use as well as increased resources and the use of local resources. It is highly important to create energy supply security, which is possible through the use of local energy sources and secondary raw materials. Thus energy dependence can be lessened through their use, less money flows out of the area, and jobs are created locally. Renewable energy sources are solar energy, wind energy, biomass in different forms, water energy and geothermal energy. There is a possibility to utilize primarily biomass (on low quality arable lands not suitable for competitive agriculture), geothermal energy and solar and wind energy in the examined area. At present the share of renewable energy sources within total energy use is quite low. It is justified to increase their share in every aspect.

Geothermal energy is one of the most inexpensive renewable energy sources which are economically the most efficient. Hungary and the examined area have outstanding conditions in terms of heat energy flowing from the deep ground. Heat supplies of Hungary are at least 500 billion m^3, out of which approximately 50 billion m^3 can be exploited. More than 9,000 flats on forty settlements of Hungary are heated with geothermal energy. Its inbuilt power of 118.6 MW means 1,162 TJ/year energy, 80% of which is utilized in district-heating systems, 20% is utilized in individual heating systems. Using geothermal energy in heating investments, if conditions are good, may mean a five-year payback period for the investment. In a successful program the basis for a decentralized energetics system can be established – on middle term too -, but it needs decision-making on the national level and raised finances.

Energy of the Earth heat can be utilized in two ways:

1. The most common form of application is to use **heat energy for cooling, heating and to produce domestic hot water,**
2. the other less common application possibility is to **transform the energy of above 100^{0}C- water and steam into electric current and use the leftover heat as in point 1.**

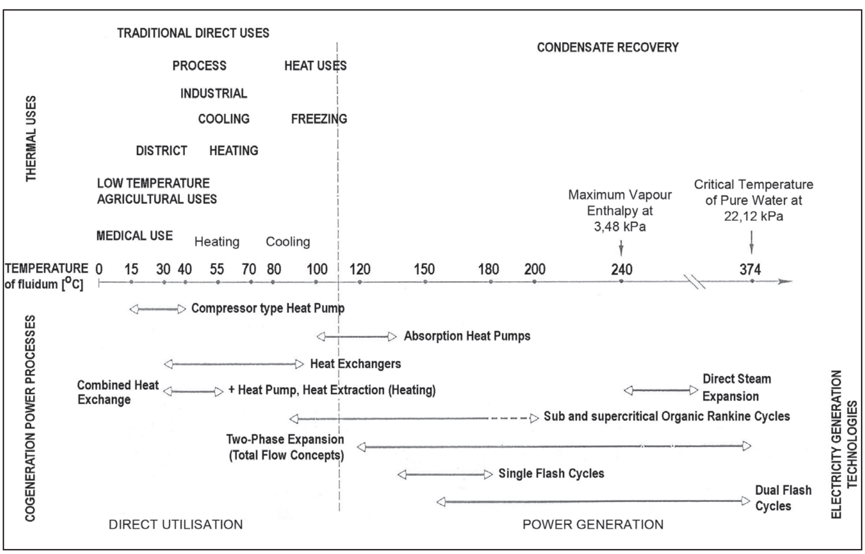

Figure 1. P. Ungemach's diagram describing the utilisation of geothermic sources, depending on temperature (Source: P., Ungemach 1987)

Geothermal energy is not only an alternative but also an additional energy source, which can be utilized together with other energy carriers. It cannot practically be depleted, but it is only concentrated in certain places, it is a local energy source with us.

Terrestrial heat can be exploited and utilized at any place and at any time. It is an advantage when not only hot rock at small depth but also substantial amounts of hot water can be found. Present technics make it possible to exploit or absorb heat using the known technologies (soil collectors, soil samplers etc.). If it is of low temperature, it is used to heat and cool buildings, make domestic hot water with a heat pump.

1. SOURCES SUITABLE FOR DIRECT UTILIZATION

Wet steam or hot water are suitable for domestic, leisure and industrial utilization at a certain temperature range. Lower-temperature and lower-pressure energy sources can be found in sedimentary basins than in hot steam fields, and usually pumps are needed to be applied to bring the liquid to the surface. It is suitable to be used for traditional radiator or floor heating in domestic application.

Division of direct utilization of geothermal energy according to its temperature is the following:

20°C Fish breeding 30°C Swimming-pool heating, biodegradation, fermentation 40°C Soil warming 50°C Mushroom growing, balneology 60°C Livestock farming, heating air and hotbeds in greenhouses 70°C Low-temperature cooling 80°C Heating, air heating of greenhouses 90°C Intensive de-icing, drying of fish stocks	100°C Dessication of organic materials 110°C Cooling, drying tiles 120°C Distillation, complex evaporation 130°C Distillation in sugar refining, extraction of salts, condensing, crystallization 140°C Drying of agricultural products 150°C Alumina production with the Bayer method 160°C Drying fishmeal and lumber 180°C Distillation of highly concentrated compounds

2. ELIGIBLE ACTIVITIES:

Development of a system that is based on geothermal energy and may be used in combination, suitable for supplying some facilities, settlements or groups of settlements.

Multi-stepped complex utilization based on geothermal energy.

3. UTILIZATION MODES OF GEOTHERMAL ENERGY:

- electricity generation
- **heating:** usually below 100°C temperature. The larger part of our possibilities is unused yet. Investment claim is not too expensive for the community. Thermal water use is economically efficient only with large capacities (e.g. blocks of flats)
- **cooling:** The thermal water cooling of buildings happens with absorption cooling systems (Iceland, USA, Japan), with the inclusion of an outside energy source, where the cooling fluid is always different, depending on the demand for cooling.
- **hot-water supply:** it is especially important to maintain on the long term the capacities of thermal water wells for the thermal water heating and water supply of houses, housing estates, public institutions, healthcare institutions, schools. If

the thermal water is of low temperature (e.g. 60°C), then floor or wall heating may be advantageous. Coursing in larger thermal water networks has to be insured by pumping, trying to minimize heat loss.

- **industrial purposes:** energy supply of industrial parks
- agricultural utilization:
  - heating of greenhouses, polythene greenhouses, poultry farms, stables, calf stables
  - drying produce, hot-air hay drier
  - fish breeding.
- **terrestrial heat waste:** it can bring a significant economic gain in the environs of facilities which operate thermal water wells – it may as well be 1-2 km far. The possibility to have healthcare, technical, economic co-ordination with purposes of medicinal baths, wellness, heating, cooling and other energetic purposes: e.g. the exploited water first heats (or cools) the facility first, produces domestic hot water, then it is used for bathwater. Its remaining heat content can be gained then for low-temperature heating through heat pumping. A suitably large and beautiful healthcare/touristic complex with its own park, ornament fish pond, water games, garden may be connected to the heat chain.

The advantage of thermal water with these applications is the concentration and the varied usability, which provides opportunities for setting up enterprises, starting commercial activities, it contributes to the complex development (production, communal supply, thermal spa, sport swimming pool) of an area.

4. UTILISATION TECHNOLOGIES USING GEOTHERMAL SOURCES, THERMODYNAMIC METHODS FOR ENERGY TRANSFORMATION, THE INTRODUCTION OF FOUR BASIC AND THREE COMBINED VARIATIONS

1. In the case of relatively low temperature brine the recommendation is: The ORC (Organic Rankine Cycle, Clausius-Rankine organic fluid cycle) system

Binary thermodynamic cycles – ORC, KALINA are composed of two cycles/cyclical processes; in the primary cycle the hot geothermal fluid (brine) rushes up from the well, giving the heat energy to a working fluid, that of the secondary cycle, through a heat ex-changer.

2. The physical properties of a selected organic working fluid, the working agent of the Kalina system: ammonia plus water

For a given brine temperature, the choice of an adequate working fluid will depend upon a number of criteria with various properties it has to comply with.

- Efficiencies of the ORC cycle technology are between 8-max. 10%,
- with the Kalina cycle technology on the pressure 40 bar the efficiencies are 11-max. 21%, as well as
- with the Kalina cycle technology on the pressure 70 bar the efficiencies are 11-max 23%.

3. Direct Steam Expansion and Flash Cycles, technologies for High Brine Temperature

In a direct expansion cycle, the superheated steam from the reservoir is piped directly, after cleaning and scrubbing into the turbine inlet where it is expanded to produce shaft power.

In a single flash cycle, FC, the fluid flowing from the reservoir to the wellhead is isenthalpic, assuming no conductive heat loss into the surrounding formations.

This fluid then undergoes the procedure of isothermal flashing in a pressure-controlled separator. Steam is further piped into the turbine inlet, where it is expanded and condensed.

4. Single, Dual and Multi-Stage Flash (FC) Cycles

The most favourable way to utilise wells producing geothermal energy with a significantly big enthalpy is, if the produced high-pressure hot fluid can be flashed in a multi-stage cycle. In order to operate the so-called flashing cycles, saturated steam is produced with various pressures, in this way a multi-input turbine can be operated.

4.1. FC and ORC Systems, as combined Technologies of the Basic cycles, in order to increase Conversion Efficiencies

From most geothermal sources two-phase (steam plus water) geothermal fluid is produced. If geothermal power-generating units are installed on these sources, then usually the Flash Cycle system is realised. However, the energy content of the geothermal fluid (between 140^0-180^0 temperature) after the Flash Cycle conversion is still significant. Therefore it is useful to combine the utilising unit with the ORC system. The combined Flash Cycle ORC systems produce 13-28 % power than systems with Flash Cycle only, and the former are also more economical (the specific cost of power generation is lower).

More analysis and research is needed to enable the selection between the different technologies. According to preliminary estimates the proposed efficiency of the above mentioned combined system could reach ηeff = 21% – max. 30% rate of the power plant system capacity.

4.2. FC and ORC Systems, as combined Technologies of the Basic cycles, in order to increase Conversion Efficiencies

Adding up the outgoing performance of the two cycles, for the combined cycle the optimal separator pressure is significantly higher than in the case of the simple Flash Cycle. This makes it possible for the fluid agent of both Flash Cycle parts and those of the ORC parts to enter their own turbines with a low specific content; therefore this means that turbines necessary for the combined cycle can be relatively smaller and more solid as well.

5. Combined cycles technologies, producing maximum efficiency and electricity conversion, based on the Total Flow Concept (TFC)

Technology based on the Total Flow Concept (TFC) thermodynamically means that the expansion happens in two phases utilising the total energy content of the fluid.

6. Innovative Method: Total Flow Concept Cycle (TFC) - Two phase expansion Cycle - combined with Flash Cycle (FC): TFC plus FC

The TFC and FC cycles conversion system includes a liquid-steam separator unit, the multi phased turbine-generator unit, the condensing section and the gas separation section where gases do not condense.

7. Multistage-multiphase-integrated electric power generation with ORC Binary system with different turbo generator units

In the integrated geothermal combined co-generational power plant the system has been extended with the described special elements and multistage power generation units thus increasing the number of these elements/equipment and their costs, too.

5. CONCLUSIONS FOR BETTER EFFICIENCY

Well known from the technical literature, among different existing geothermal power plants with special and favourable efficiency, those integrated and combined technologies can be found, the exergetic efficiency of which exceeds 40 % in several cases.

It is only after detailed analytical technical – economic calculations that it can be decided if the main aim is to increase efficiency resulting in the increase of larger electrical power capacity, or to establish a construction which can be maintained more easily and with moderate investment costs.

Decision makers have to get clear calculations that are based on technical, economic calculations and proven results. According to preliminary estimates η = 32 - max. 38% efficiency values can be achieved through the combined and integrated systems.

Existing geothermal power plant technologies, with favourable efficiencies (%) utilising the maximum benefits of combined technologies (Unk J. 2011).

Technology	Plant Name	Specific exergy input (kJ/kg)	Exergetic efficiency (%)*	
Binary	Brady	36.70	16.3	
Binary	Brady botteming	49.86	17.9	
Binary: recuperated	Rotokawa	227.96	18.7	max. 23%
Binary	Nigorikawa pilot	92.77	21.6	
Binary	Kalina Husavik	81.49	23.1	
Double flash	Beowawe	205.14	26.0	
Binary: simple	Rotokawa	646.71	27.8	max. 35%
Single-flash	Blundell	278.67	35.6	
Binary two phase	Pico-Vermelho	219.65	40.8	
Hybrid flash – binary	Rotokawa	461.45	42.0	
Binary: dual – level	Heber SIGC	125.84	43.0	max. 54%
Binary: flash evaporator	Otaka pilot	126.65	53.9	

Figure 2: Geothermal Power Plant Exergetic Efficiencies (in order of increasing efficiency) (Source: R. DiPippo/Geothermics 2004); Source: Uri Kaplan (ORMAT, USA-Reno)
***Where the exergetic efficiency means the theoretically maximum load rate of the power plant, under local conditions**

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VI. DECISION TREE IN SEQUENTIAL DECISION MAKING

1. INTRODUCTION

If making of investment decisions is not observed as an isolated time commitment, but rather as a link in the chain of the current and future commitments, then a method should be applied that takes various factors into account. The decision tree concept is an efficient way of doing this and its application in sequential analysis and investment evaluation will be analyzed in this article.

Analysis of how investment decisions are made under conditions of uncertainty has attracted attention among the authors in the field of finances. Among the most significant contributions in that field are risk analysis (Frederick S. Hillier 1963, 1965), mathematical programming and decision theory model. Although different in terms of analytical techniques, what these three models have in common is that they observe current investments as an isolated decision making period which can be optimised without taking into account decisions in the following periods.

2. MULTIPLE STAGE DECISION MAKING – DYNAMIC PLANNING

Results of decision making often establish data for future decisions. For example, today's extensive investment decisions affect the decision space (action programme) of the decision maker and prejudice his or her future decisions in the long term. In today's microeconomic practice of decision making **interdependencies between the current and future decisions** are given in multiple ways. For example, the decision about whether new tyres should be put on a car depends, among other things, on the information whether the car will be discarded in the forthcoming period or not. As a rule, one should not be satisfied with the thinking about reducing decision making to a **single stage** (period) for the following two reasons:

(1) Decision 1 made at the time t_1 establishes information that affects decisions 2 and 3, etc. at the times t_2 and t_3;

(2) Relationships at stages (times) 2, 3, etc. also contribute to the output of the decision 1 at the time t_1.

As opposed to static models of decision making there are models of decision making that take such interdependencies **(temporal-vertical interdependencies**) into account. Such models are called dynamic models of decision making. **Dynamic models of decision making** follow the goal of expressing **the optimal sequence of decisions.** Formally, it is always possible to reduce a **multiple stage decision making model** (imprecisely called **multiple period decision making problem**) to a single stage decision making by introducing suitable terms (frequently called decision making functions, strategies, policies). For computational and technical reasons it usually makes no sense translating a multiple stage decision making model to a single stage model. There is an attempt to use **dynamic planning** (or **dynamic optimisation**) to replace simultaneous optimisation of a sequence of decisions with **gradual optimisation along particular stages of decision making**. **Dynamic planning method** is not a calculation method, but it is a mathematical concept which reduces decision making processes (multiple stage decision making) to a form that is easier to solve. Optimisation does not take place simultaneously for all variables, but in **several steps following one after another**. Decision making process is also conducted backwards (**"Roll-back-Analysis"**). The alternative promising the best results is chosen among possible decision alternatives in the **last stage** (period), and backward induction is used for that alternative to find the starting point (at the first stage) of that **decision making sequence**.

In addition to **obvious presentation of a problem, dynamic planning method** is primarily used to facilitate **calculation and technical process**. It is applicable to a wide array of problems, such as problems related to storage, investments, introduction of a new product, maintenance.

Decision making process is observed throughout its time course from the starting point t_0 until the final point in time t_k (in decision making processes taking place in the field of economy this is described as the final point in time, so-called **planning horizon**). The observed time period from t_0 to the final point in time t_k is divided into k "temporal stages". Optimal sequence of decisions $v^{(j)}$ (j =1,2,.., k) is sought along the stages, which means that the end result should be expressed in extremities:

$$\text{Maximize, i.e. minimize} \quad E = \sum_{j=1}^{k} E^{(j)} (Z^{(j-1)}, v^{(j-1)})$$

Here E stands for the end result, and $E^{(j)}$ for results, i.e. $Z^{(j)}$ conditions (future conditions) in temporal stages j (j=1,2,...,k)

This type of management is called **optimal sequence of decisions (optimal policy or optimal strategy)**.

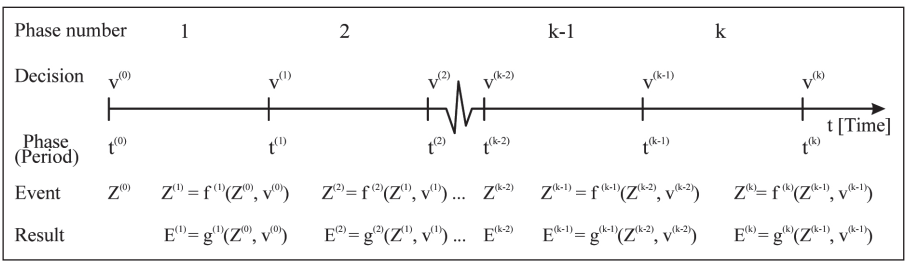

Figure 2.1. Presentation of the sequence of decision making

It should be noted that in practice only decision $v^{(0)}$ for the zero point should be realised. Following the expiry of one period (stage), dynamic programming is applied, taking into account new information obtained until that moment. This is done according to all rules by setting up a new business programme ("rolling" plans). The decision made under the given circumstances will not correspond to the decision that had been previously made for that point in time. Simultaneous making of decisions which follow one after another within multiple stage (multiple period) planning serves the purpose to properly include **temporal-vertical interdependencies** that are relevant for the decision $v^{(0)}$, that is, for construction of a (binding) action plan. Actually, determining the sequence of **binding** decisions for the following period already at that point in time is not a general tendency.

Not all interdependencies are hereby taken into account. In addition to **temporal-vertical interdependencies** among activities there are also **temporal-horizontal interdependencies**. If such temporal-horizontal interdependencies (relationships among programme actions realised simultaneously) are available, then the amounts of gain or risk values cannot be attributed to **particular** business **alternatives** (individual decisions). This is possible only for alternative business programmes. Temporal-horizontal interdependencies can also be taken into account by providing a suitable **combination** of possible (higher risk / higher profit and lower risk / lower profit) **individual decisions** in **the business programme (decisions about the programme – risk policy**). For example, **portfolio selection theory (**Blohm, H., Luder, K. 1995**)** offers principles for solving these problems of interdependence.

2.1 Presentation of the decision tree method

A sequence of decisions can be presented by means of a decision tree (Bodo Runzheimer, 1989). When one of these decisions has been made, a certain prognostic result is produced. When results are known, further decisions can be made. When applying the **decision tree method** to an investment problem – one proposal (J.F. Magee 1964) – a disctinction can be made between single decisions (single stage decisions) and sequential decisions. The latter can again be investment decisions (for example, expanded investments), disinvestment decisions, or other kinds of decisions (for example, decisions about price, sales, promotional measures, production programme) that affect the advanatages of initial investment alternatives.[1] It is investment decisions that often have to be made within a time period in such a way that a series of decisions rely one on another. With full information (full prediction) available, only one decision would be planned, the one having the greatest priority in the sequence. Different decisions in the sequence can be made due to uncertain future, depending on the circumstances in the "environment". For this purpose, alternative sequence of decisions (investment sequence) has to be taken into account for all probable states of the environment that are being observed (the purpose of this limitation is to avoid making the decision tree too complex). Such decision making sequences can be clearly presented by means of a decision tree.

Decision tree – connected and directed graph (Runzheimer, B. 1995) – comprises **decision nodes (behaviour nodes) V** – represented by rectangular shapes, **chance nodes (situation or event nodes) Z** – represented by circles, **end nodes E** – represented by diamond shapes – and **arrows (edges**, **branches**). Decision nodes represent **the initial decision**, chance nodes represent possible **state of the environment,** and end or terminal nodes represent an outcome as a combination of decisions and states of the environment at the end of each stage. **"V" arrows (branches of decision making)** represent **alternative possibilities** (decision making alternatives, action space) starting from the decision node, and **"z" arrows (branches of state)** represent **possible alternative states of the environment** (event space) which can result from an event (state of the environment). This is not applicable to decision making under certainty (see Figure 2-2).

There is a partial difference between the terms **decision tree** and **event tree**.[2] The purpose of both event tree and decision tree is representation and clarification of **the problem of decision making or seeking**. Each node in the event tree represents a certain state (a certain event). These event nodes are connected only by state arrows. As opposed to decision tree, an event tree shows no decision nodes, no end nodes and no operation arrows. Since business operation possibilities and end prospects at a certain point in time do not depend only on the given state, but also on actions in the previous period (stage), these states by themselves provide incomplete description of a decision making situation. If representation in form of an event tree is expanded with available business activities in any period (stage), and if it is taken into account that choice must be made among a set of mutually exclusive business alternatives, an event tree then develops into a decision tree.

Compared to an event tree, a decision tree provides a more complete account of the decision making situation. It is much more extensive and under given circumstances it provides a less clear layout than an event tree. As the differentiation between the event tree and the decision tree is not of key importance here, this difference will not be taken into account in further text.

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[1] Compare Blohm, H., Lüder, K., 1995, p. 280

[2] Compare e.g. Bamberg, G., Coenenberg, G., 1994, p. 16

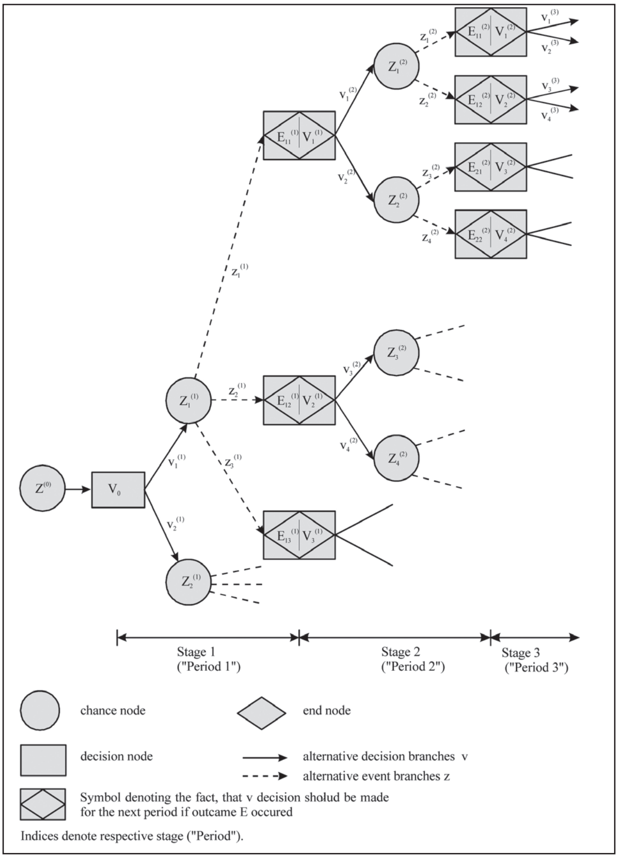

Figure 2.2. Decision tree applied to a multiple stage decision making problem

3. AN EXAMPLE OF A MULTIPLE STAGE DECISION MAKING PROBLEM IN THE CASE OF VARIABLE INFORMATION STRUCTURE – APPLICATION OF THE DECISION TREE METHOD

An oil company has drilling rights on a particular piece of land. As concession period will expire after some time period, the oil company needs to make the following decision: should they start drilling on their own with costs (K) in amount of DM 1.5 million ($v_1^{(2)}$) or not ($v_2^{(2)}$)? If drilling is successful, the company will be able to sell their drilling rights immediately for DM 8 million (without taking DM 1.5 million of drilling costs into account). The probability of finding oil in the process of drilling was estimated by geologists at 0.4.

This is an example of a **decision making situation with the possibility of obtaining information (variable information structure).** Decision maker's information situation (information = knowledge relevant for the decision) is variable. Decision maker can use **additional sources of information**. In addition to the above problem of making a choice (sell drilling rights or undertake drilling on their own), there is also a problem of using **additional information sources**. As acquiring additional information generates costs, these disadvantages should be compared against the benefit gained from the additional knowledge that is relevant for the decision. In literature this principle is known as **sequential analysis**. The decision whether to obtain further information or not is called **sequential decision making.**

This problem is very important in practice, because this question arises in multiple forms in the process of preparing a decision. The question whether additional information should be obtained or not is, of course, asked only when the use of additional information can result in changed future state based on "expert decision making" compared to "making decision without additional information" in at least one case.

The oil company in the above example has to be able to obtain a relatively good idea about soil properties by carrying out seismic testing by means of sound waves which costs DM 150,000 (including opportunity costs arising from, for example, hesitation). There are three possible test results (I = 1, 2, 3) **(three-value method)**. The index denotes a corresponding "stage":

$z_1^{(1)}$: soil structure is good for oil extraction
$z_2^{(1)}$: soil structure is of moderate quality
$z_3^{(1)}$: soil structure is poor

Based on the undertaken research the company reaches a calculation that seismic test provides $p(z_1^{(1)}) = 0.23$ probability for $z_1^{(1)}$, $p(z_2^{(1)}) = 0.5$ probability for $z_2^{(1)}$, and $p(z_3^{(1)}) = 0.27$ probability for $z_3^{(1)}$ (all *a priori* probabilities). Further, based on experience, it is known that probability for finding oil ($z_1^{(2)}$) for $z_1^{(1)}$ test results is 0.95; for $z_2^{(1)}$ it is 0.4, and for $z_3^{(1)}$ it is 0.15 (conditional probability - $z_1^{(2)}$ result is labelled "oil", and $z_2^{(2)}$ "no oil" in "stage 2":

Table 3.1:

Conditioned probability First stage possible results $z_i^{(1)}$	$p(z_1^{(2)}/z_i^{(1)})$	$p(z_2^{(2)}/z_i^{(1)})$
$z_1^{(1)}$	0.95	0.05
$z_2^{(1)}$	0.40	0.60
$z_3^{(1)}$	0.15	0.85

Should the oil company conduct seismic test first ($v_1^{(1)}$) or not ($v_2^{(1)}$)? (In order to eliminate differences in the vaue based on different points in time, coumpound interest was calculated for all payments and payouts according to the starting point). Optimal **policy** of the oil company is determined for the case that the company behaves in a **risk-neutral way.** The solution arises from the following decision tree – amounts are in million DM – (compare Figure 3-1). J.F. Magee (1964) suggested the so-called "r**ollback analysis**" ("backward induction") to determine **maximum expected values of a decision**. The issue of sequential decisions on risk, presented in a decision tree, can be **rationally** solved by means of a rollback analysis, according to the principle of **dynamic planning.** Optimal solution is here found backwards (**recursive, reverse direction**), as one steps back, stage by stage, toward the root node ("root of the tree"). **Expected value** for every given business alternative (v) at the beginning of the last stage (period) is provided first. Maximal expected value of the alternative for each decision node is then determined by means of comparison. In this tree there is $v_1^{(2)}$ for favourable or average seismic test results, which means that the company should undertake independent drilling in both cases. If the result of seismic test is unfavourable, the oil company should choose behaviour alternative $v_2^{(2)}$ – no drilling. Finally, $v_1^{(2)}$ – the company performs drilling on its own – is the best business alternative, if there is no seismic test. (In Figure 3-1 optimal alternatives are represented by thick arrows). These (optimal) alternatives are interesting for further observation, because the decision maker determines his *v* behaviour. Therefore for any given decision making alternative the expected value should be determined at the beginning of the penultimate stage from the **maximum expected value** of the last stage. The alternative with the largest expected value for each decision node is obtained by repeated comparison. This procedure continues until root node is reached with maximum expected value. **The main idea** is that only **optimal results** in event nodes are of interest. In other words, it makes no sense to follow the events that are not optimal for one stage of decision making. Therefore, the following can be concluded: if **optimal solution** is to be reached within the **system,** then **every partial solution** has to be **optimal** as well. **Any partial path of optimal path** (or partial path) **is optimal**. This is the **optimal principle:**[3]

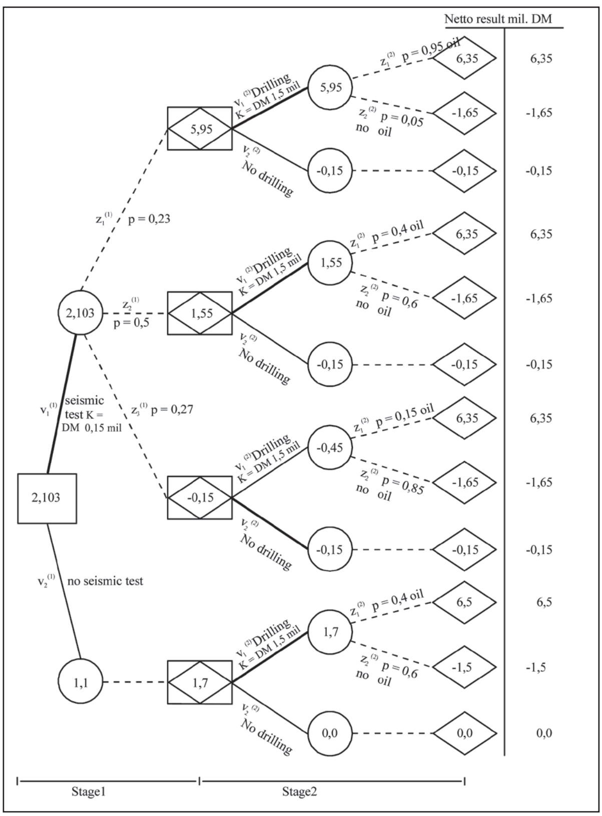

Figure 3.1. Two-stage decision tree on the "oil company" example

[3] Dynamische Programmierung und selbstadpassende Regelprozesse (German translation), München/Wien, 1967, p. 88

"The property of optimal decision making policy is that, regardless of the initial position and the first decision, the remaining decisions represent an optimal decision making policy in relation to the position resulting from the first decision".

The **optimal principle** is proved by contradiction. The starting point in the argument is the assertion that total policy cannot be optimal if the remaining decisions are not optimal.

In the example below (Figure 3-1) the following **optimal strategies** were found by applying the optimal principle**:** seismic test is carried out first, good result -$Z_1^{(1)}$ or moderate result $Z_2^{(2)}$ mean that the oil company should carry out drilling on their own, poor result - $Z_3^{(3)}$ means that drilling should not be carried out. The expected value of this business programme is DM 2.103 million. In the event that the oil company does not carry out the test, the expected value with given data would be lower, i.e. DM 1.7 million. In that case, additional costs in the amount of DM 150,000 for acquiring and evaluation of additional information (seismic test results) are obviously justified. How is this result explained?

3.1 On the problem of determining the value of additional information

According to the prevailing opinion, the value of additional information is determined according to the value gain of expected value of decision, which is calculated on the basis of improved knowledge, compared to expected value of using additional information of the best decision. This attitude, which measures value of additional expected information by calculating the difference between expected values of respective optimal decision making alternatives before and after processing of additional information, is based on **Bayes'** analysis **(Bayes' theorem**).

It should be noted that Bayes' analysis in general relies on expected values, primarily on expected values of success. One extension of the expected value of benefit (risk-benefit), which has not been undisputed, has appeared recently, making Bayes' analysis more realistic. The problem is how to measure risk-benefit of additional value of information and additional costs of information. This is where criticism comes in: values of information and costs of information are mutually independent only in the case of risk-neutral behaviour (making decisions according to expected value).

In general, risk-benefit of information costs, e.g. DM 150,000 DM, depends on business capacities and expected value of additional information. Risk-benefit of costs of additional information cannot be separated from risk-benefit of additional value of information. This can be explained as follows: As opposed to a decision made without any additional information, the use of additional information affects future events in business activities and at the same time it reduces costs of information for successful gains in all the groups in future that will remain after additional information is used. The literature suggests that consequences of wrong decisions should be first included in a "damage function", and that this function is then compared to the function of costs of obtaining information. "The good old dilemma, degree of reality of the decision making model, is in positive correlation with the possibility of obtaining information, here quite clearly". If we are working only with expected values (of success), in terms of usefulness theory, this means that we are dealing with a special case of risk-neutrality, and a linear function of usefulness is assumed. Decision making rule that any information for which value of information exceeds the cost can be explained only in the case of risk-neutral behaviour. The problem of decision making is undisputable in the case of risk with objective probabilities. Reliance on Bayes' strategies of certainty (Raiffa, H., Schlaifer, R, 1961) provides the simplest way for determining the largest sum that can be spent by a rational manager on measures for information improvement. This amount is generally known as full value of information (value of perfect information). It can be interpreted as opportunity cost of wrong decision in case of incomplete information. Full value of information is the largest amount that a decision maker can spend. Full value of information is obtained as expected value of one (hypothetical) Bayes' strategy in the case of full information (certainty) from which maximum expected value of incomplete information is subtracted.

By means of Bayes' strategy of certainty it can be at least calculated whether and to what extent costs for additional information should be included. This involves only a single framework calculation because corresponding amount for full value of information can be spent only for full (certain) information (perfect information). This means that some extensive additional information should be obtained for this amount so that risky information could be translated into certain information. Additional information which does not allow exact predictions (incomplete information) is in any way less valuable than the amount corresponding to full information. Bayes' strategies of certainty are always interesting when it should be determined whether and to what extent (which, of course, assumes knowledge of possibilities for obtaining information) costs of additional information should be taken into account.

It has to be decided whether a market research institute should be hired to conduct statistical research. Costs of additional information – which can be expressed *ex ante* – must not in any case exceed the expected value of full information.

The exact value of incomplete additional information cannot be determined by Bayes' strategy of certainty.

A. Bayes' strategies for incomplete additional information

Calculation of incomplete information by means of Bayes' strategy first requires a presentation of Bayes' rules. These will be explained on a simple example:

An entrepreneur evaluates introduction of a new product (or a new product variety – product differentiation) in Germany. His or her prior expectations about possible sales in the first period (three-value method) are as follows:

z_1 (low demand) 400,000 units (KJ); $p(z_1)$ = 0.3
Probability of occurrence
z_2 (average demand) 900,000 komada (KJ); $p(z_2)$ = 0.5
Probability of occurrence
z_3 (high demand) 1,400,000 komada (KJ); $p(z_3)$ = 0.2
Probability of occurrence

Profit per unit amounts to DM 8, and necessary costs of introducing the product (promotion, organisation of sale, etc.) amount to DM 5 million. The following result matrix with elements $E(v_i,z_j)$ (in million DM) can be produced:

Table 3.2: Result matrix

Condition z_j / Business alternatives v_i	z_1	z_2	z_3	Expected values μ
v_1	- 1,8	2,2	6,2	1,8
v_2	0	0	0	0

Business alternatives are:
v_1 = "Introduction of a new product "
v_2 = "Introduction of a new product is abandoned"

If the entrepreneur would make a decision based only on *a priori* probabilities, then he or she would have to choose v_1. The entrepreneur could hire a market research institute to conduct the research, i.e. he or she could buy additional information. Additional information could change *a priori* probabilities.

The problem is that entrepreneur has to provide expectations on possible results before conducting market research. This possibility of estimating information results *ex ante* is a problem. In addition, even if market research results were known, they would not predict with certainty (incomplete information) "real" total demand. Thus the only occurrence that can be concluded with high probability from occurrence of research results (indicators) T_1 is that of z_1. The same research results correspond to "real" situation z_2, and z_3.

Before asking a market research institute to conduct market research, the entrepreneur estimates the following **conditional probabilities** p (T_k/z_j). These conditional probabilities are marked according to R. A. Fisher as "likelihoods". They provide the probability that T_k will be observed, if z_j would be "true":

Table 3.3: Conditional probabilities

Conditional probabilities / Condition z_j	$p(T_1/z_j)$	$p(T_2/z_j)$	$p(T_3/z_j)$
z_1	0,80	0,15	0,05
z_2	0,10	0,85	0,05
z_3	0,05	0,15	0,80

3.2 Identifying a posteriori probabilities

A posteriori probabilities $p(z_j/T_k)$ can be calculated by means of Bayes' formula by using **anticipated *a priori* probabilities** and conditional probabilities. The definition of conditional probabilities (Runzheimer, B., 1989): "and" represents linking "not only, but also", which means intersection:

$$P(A/B) = \frac{P(A\text{" and" }B)}{P(B)} \quad \text{i.e.} \quad P(B/A) = \frac{P(A\text{" and" }B)}{P(A)}$$

Combined with the principle of total probability (Runzheimer, B., 1989, p. 100) it gives the **Bayes' formula**:

$$P(A_k/B) = \frac{P(A_k \text{"}i\text{"} B)}{P(B)} = \frac{P(B/A_k) \cdot P(A_k)}{\sum_{i=1}^{n} P(B/A_i) \cdot P(A_i)}$$

Translated into symbols applied in the example of introducing a product, the **Bayes' formula** is:

$$p(z_j/T_k) = \frac{p(T_k/z_j) \cdot p(z_j)}{p(T_k)}$$

$$= \frac{p(T_k/z_j) \cdot p(z_j)}{\sum_{j=1}^{n} p(T_k/z_j) \cdot p(z_j)}$$

Combined probabilities $p(T_k$ "i" $z_j)$ should be calculated first, which means probabilities that one state z_j and one indicator T_k occur together. They are calculated from $p(T_k/z_j)$ $p(z_j)$; they are given in the 3rd column of the Table 3.4. The sum of combined probabilities

$\sum_{k=1}^{3} p(T_k$ „ i " $z_j)$ produces total probability $p(T_k)$, with which occurrence of T_1, T_2 and T_3 can be expected:

$$p(T_k) = \sum_{k=1}^{3} p(T_k \text{ „ i " } z_j) = \sum_{k=1}^{3} p(z_j/T_k) \times p(T_k)$$

(for j = 1, 2, 3)

A posteriori probability $p(z_j/T_k)$ which can lead to occurrence of indicator T_k is produced as a quotient of combined probabilities $p(T_k$ "i" $z_j)$ and total probability $p(T_k)$ (Bayes' formula).

A posteriori probability is the probability of occurrence of z_j, on condition (hypothesis) that indicator T_k has occurred. Therefore it shows probability of the event z_j after observation T_k and that is why it is denoted as ***a posteriori* probability**. *A posteriori* probability takes into account *a priori* probability of indicator occurrence (test result, result of additional information) and its certainty of occurrence. Hereby it contains full information which is available to the decision maker regarding the occurrence of z_j, if test result (additional information) would be T_k.

The relation between the original (a priori) and corrected (a posteriori) probability of events can be concluded from Table 3.4.

Table 3.4: Calculating a-posteriori probability

State of environment	a priori probabilities	Conditional probabilities			Combined probabilities (probabilities of product)			a-posteori probabilities		
(1)	(2)	(3)			(4) = (2) □ (3)			(5) =		
z_j	$p(z_j)$	$p(T_1/z_j)$	$p(T_2/z_j)$	$p(T_3/z_j)$	$p(T_1$ „i" $z_j)$	$p(T_2$ „i" $z_j)$	$p(T_3$ „i" $z_j)$	$p(z_j/T_1)$	$p(z_j/T_2)$	$p(z_j/T_3)$
z_1	0,3	0,8	0,15	0,05	0,24	0,045	0,015	0,8	0,09	0,075
z_2	0,5	0,1	0,85	0,05	0,05	0,425	0,025	0,167	0,85	0,125
z_3	0,2	0,05	0,15	0,8	0,01	0,03	0,16	0,033	0,06	0,8
	□ = 1,0				$p(T_1)$=0,3	$p(T_2)$=0,5 (Total probabilit ies)	$p(T_3)$=0,2	□ = 1,0	□ = 1,0	□ = 1,0

In summary, the following steps are required to calculate *a-posteriori* probability:

The starting point are the determined *a priori* probabilities $p(z_j)$ for states of environment z_j. Conditional probabilities T_k are determined based on expected results of additional information (for example, test results), if there is z_j – $p(T_k/z_j)$ –. After that combined probabilities (probabilities of multiplication product) – $p(T_k$ "i" $z_j)$ are calculated, the sum of which gives total probability $p(T_k)$. All $p(T_k$ "i" $z_j)$ are then divided by $p(T_k)$. (Rows) results are probabilities p(zj/Tk).

3.3 Selection of the optimal way of doing business

If the result of additional information (T_k) is taken into account, **expected value** (□) for any business alternative (v_i) can be calculated:

$$\mu(v_i/T_k) = \sum_{j=1}^{n} E(v_i, z_j) \cdot p(z_j/T_k)$$

(in this example k = 1, 2, 3   and   i = 1, 2)

If T_1 would be a realised test result, the following successes (in million DM) could be then expected from product introduction (business alternative v_1)

$$\mu(v_1/T_1) = \sum_{j=1}^{n} E(v_1, z_j) \cdot p(z_j/T_1)$$

= (- 1,8) × 0,8 + 2,2 × 0,167 + 6,2 × 0,033
= **- 0.868 million DM**

Accordingly, if test results would confirm poor demand, entrepreneur would not choose action (business alternative) v_1, but v_2 instead, whose expected value is zero. However, if test results would be T_2, for business alternative v_1 entrepreneur could male calculation with expected value

v_1/T_2) = (- 1,8) × 0,09 + 2,2 × 0,85 + 6,2 × 0,06 =
= **2.08 million DM**

v_1 would then be the optimal business alternative. In case of test result T_3 it would be possible with

$\mu(v_1/T_3)$ = (- 1,8) × 0,075 + 2,2 × 0,125 + 6,2 × 0,8 =
= **5.1 million DM**

to count with business alternative v_1; v_1 should then be preferred to v_2. This second step in the way toward Bayes' strategy is to always choose the optimal business alternative that has been evaluated on the basis on *a priori* probabilities. These are so-called "Bayes' actions". Optimal strategies in the above example would be v_2, or rather v_1, in case T_1, or T_2, or T_3 happened to be test results.

3.4 Calculating the full value of information

Expected values of Bayes' actions (optimum business alternatives) can be evaluated with total probabilities $p(T_k)$ for included results of additional information (test results) T_k. This results in **optimum Bayes' strategy** (S) with expected value

$$\mu(S) = \sum_{k=1}^{3} \mu(v_i^{opt}/T_k) \cdot p(T_k)$$

= 0 × 0,3 + 2,08 × 0,5 + 5,1 × 0,2
= **2.06 million DM**

The value of full information for additional information (e.g. market research results) W(I) is the difference between the expected value of the Bayes' strategy μ (S) and expected values of Bayes' actions without additional information μ:

W(I) = μ(S) - μ = 2,06 - 1,80
= **0.26 million DM**

If costs of additional information are taken into account – K(I) –, which can be included in addition to real costs of obtaining information (for example, hiring a market research institute) and opportunity costs entailed due to hesitation, estimation can be made whether obtaining of additional information makes sense. In the above example market research should be recommended only if its costs would not exceed DM 260,000. The described procedure can be visually presented in the form of a decision tree (in million DM) – compare Figure 3.3.

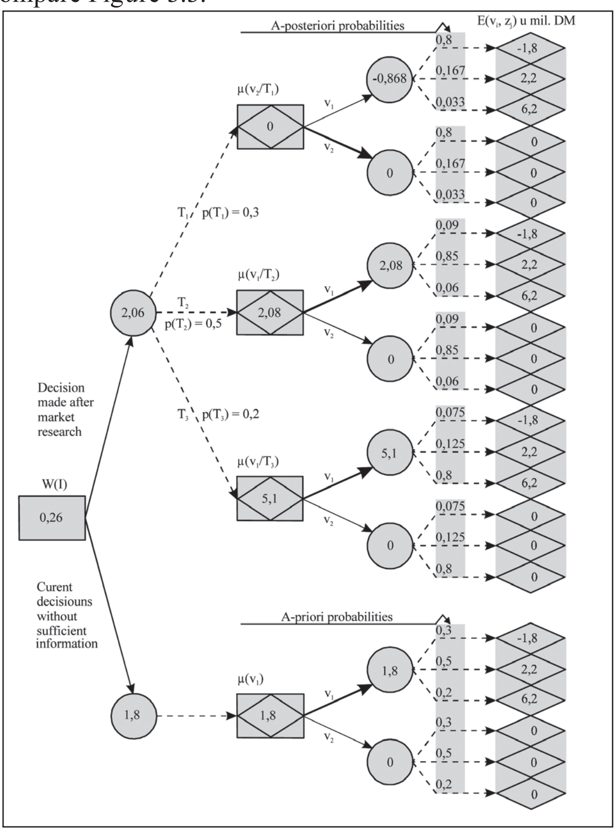

Figure 3.3. Decision tree for calculation of full value of information W(I)

This could be used to evaluate the question whether additional information could have any purpose at all. In **multiple stage (sequence) information process** through Bayes' strategy it is possible to apply pooling of gradually obtained additional information in the sense that input information is not observed as being fully overrun by additional information, but they are accordingly further taken into account (changed). In this way it can be decided at each level of information process whether obtaining of additional information should be recommended or not. Thus the analysis strives to answer a very important question, namely, **how much additional information** would make sense before making the real decision. This issue of optimal amount of information does not raise any new questions in relation to the procedure used in the analysis. If positive decision is reached about the first possibility of obtaining information, the second one could be examined. Bayes' strategy can hereby be interpreted, if time is taken into account, as **the stopping rule** in multiple stage information process. Further management of information process may have sense only if at the end of the period t – 1 the full value of information for acquired additional information in the next period t is higher than corresponding costs of obtaining additional information. The solution is again found in gradual reverse steps (Roll-Back-Analysis) in the decision tree. Finally, let it be emphasized again that the decision making criterion in Bayes' strategy is full value of information W(I) and therefore one speaks of a **calculation.**

4. POSSIBILITIES FOR APPLICATION OF BAYES' STRATEGY

Despite problems related to the Bayes' strategy, where results of additional information have to be evaluated ex ante, and in addition to computational effort in multiple level information processes, this method has found broad application in the past few years, especially in marketing literature and practice.[4]

Bayes' strategy is, as it is correctly claimed in literature[5] "the first concept of managing to accept given information in economic problems of making a choice".

However, questions are raised whether additional information should be acquired or not, then about assumed content of information and about assumptions regarding its occurrence. The decision maker establishes **expectations in advance** as to what additional information, which is still unknown in its real content, will really bring. Possible future states resulting from acquiring additional information should be perceived by decision maker as expected future states before making a decision about obtaining information.

In the field of geothermal projects, a decision tree is primarily applied to economic issues. In certain cases the most favourable options have to be identified. For example, during gas and oil exploitation a company has to decide whether to invest its resources in one gas field rather than in another one (Juan De Dios Ocampo-Dias, 2005). Such a problem may be qualified as a risk situation. When selecting a location for drilling and its production potential in practically uncertain or risky situations, the structured approach by using the decision tree method is useful, as in the course of problem solving it relies on the probability of a certain event within a developed network of a decision tree.

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[4] Very broad literature can be found in Bodo Runzheimer, Dražen Barković (editors): Investitionsentscheidungen in der Praxis, Quantitative Methoden als Entscheidungshilfen, Gabler, Wiesbaden, 1998, p. 115

[5] ibidem, p. 115

5. CONCLUSION

Decision tree requires from a manager to conduct an explicit analysis of conditions related to a future decision and to determine results of various alternatives. Decision tree is a flexible method that can be applied in many situations focused on sequential decision making, probability of various conditions or exploration of alternatives. When planning geothermal potential, the decision tree method is most often applied to economic evaluations of risk situations.

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VII. THE LEGAL FRAMEWORK OF GEOTHERMAL ENERGY USAGE IN THE EUROPEAN UNION, CROATIA AND HUNGARY

1. INTRODUCTION

1.1. International context

In the past fifty years, the international regulation of the interconnected areas of environmental protection and energy usage has seen a never before witnessed intensification. States have established a significant number of intergovernmental and non-governmental organizations[1] with goals connected directly or indirectly to the protection of the environment and the usage of various types of energy resources. Programmes, research studies, impact assessments and comparative analyses have seen the light of day both at the global and the European level, resulting in a large number of international treaties and various other documents. International cooperation regarding energy policy and environmental protection are fields which can and do interconnect on many levels, even though the aims of these two fields also show distinct differences, especially concerning expectations of financial return.

In the framework of this study – in line with the main goals of the project – we will primarily focus our attention on the Hungarian and Croatian legal approach to energy usage, using the relevant legal norms of the European Union as a starting point.

One of the defining characteristics of energy-related problems is that they arise in varied and complex ways, thus predestining the complexity of the legal and administrative responses to these issues. The fact that energy policy is so closely connected with environmental protection is in fact a manifestation of this complexity, with climate change being a prime example – the international community has been struggling to react to this problem via a universal international treaty for quite some time now. The emphasis is on maintaining (or, if necessary re-establishing) the balance between economy, society and the environment. There are system wide issues at stake both at the national and international level, raising interconnected fundamental questions of economic, technological, societal and cultural relevance – issues that manifest themselves in the administrative and the legislative spheres.

1.2. Terminology

For the international and national lawmaker, the terminology used by the legal acts establishing the legislative and administrative framework is of defining importance – in most cases, legal acts themselves enumerate and explain the concepts and expressions used by them. The secondary sources of the law of the European Union (regulations, directives, decisions) do so on every occasion – this is also the case regarding legal acts directly or indirectly regulating geothermal energy.

We would like to refer to the following examples of concepts currently defined by EU law:

- 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases (Article 2 a) of Directive 2009/28/EC);
- 'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth (Article 2 c) of Directive 2009/28/EC).

[1] See for example PÁNOVICS Attila, Az „Európa Környezetéért" folyamat. In: Ünnepi tanulmánykötet Bruhács János professzor emeritus 70. születésnapjára. Studia Iuridica Auctoritate Universitatis Pécs Publicata, PTE ÁJK, Pécs 2009, 286-302.

It can generally be stated that these definitions are often not sufficiently precise or detailed. It is unavoidable however to refer to and use these definitions, even if they are in some cases disputed by the academic sphere or judicial practice.

2. THE LEGAL FRAMEWORK OF GEOTHERMAL ENERGY USAGE IN THE EUROPEAN UNION

In European Union law, numerous legal acts (both general and specific) regulate activities connected to geothermal energy, and impose rules on the natural and legal persons (companies) practicing these activities.

2.1. The powers of the European Union – empowerment by the founding treaties – Policy fields of relevance from the point of view of geothermal energy

The Member States have signed the Treaty of Lisbon on 13 December 2007, which has entered into force on 1 December 2009. This treaty has established a new legal basis of energy policy in primary EU law, defining the aims of the energy policy of the Union, expressly mentioning tasks associated with renewable energy resources:

'In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to:

a) ensure the functioning of the energy market;
b) ensure security of energy supply in the Union;
c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and
d) promote the interconnection of energy networks.' (Article 194 TFEU)

When Directive 2009/28/EC was adopted on 29 April 2009, the EU could not yet rely on the aforementioned legal basis as it was not in force before 1 December of the same year, however, the phrasing of the Directive already was already brought in line with the scope and wording newly formulated legal basis. The aforementioned Article 194 of the TFEU furthermore stipulates that these measures do not affect the Member State'ss right to determine the conditions for exploiting their energy resources. The choice between different energy sources and the general structure of the energy supply also remains in the competence of the Member States.

The Member States have empowered the European Parliament and the Council by means of Article 194 TFEU (previously Article 175 ECT) to establish the measures necessary to achieve the objectives mentioned above via the ordinary legislative procedure (previously: co-decision procedure). Measures relating to energy policy that are primarily of a fiscal nature shall however be adopted unanimously by the Council according to paragraph (3) of the same Article.

In EU law, legal acts adopted in the framework of environmental policy and energy policy contain the most important rules concerning geothermal energy. In the following we aim to give a schematic overview of norms relating to energy policy, while presenting a more detailed outline of the legal acts specifically regulating renewable energy sources.[2]

[2] The complete list of legal norms pertaining to non-renewable energy sources can be found at http://ec.europa.eu/energy/doc/energy_legislation_by_policy_areas.pdf (25 July 2011)

Summaries of EU legal norms can be found in numerous documents. These enumerations and overviews all indicate that the integrated regulation of geothermal energy usage was and still is lacking. Such an overview may be read in the relevant background study prepared for the Hungarian Academy of Sciences.[3]

The list of the most important legal acts relating to geothermal energy is as follows:

a) Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (OJ L 327., 22.12.2000, p. 1) – the so called water-framework directive[4] – bearing in mind that heat of the earth can only be utilized by means of the groundwaters and thermal waters, geothermal energy usage is also a question of water management. The main goal: good quality and quantity of surface waters and groundwaters by 2015 – a good balance between sustainable usage / extraction and resupplyment is a fundamental question that reaches beyond borders.
b) Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast) (OJ L 153., 18.6.2010, p. 13) – this legal act has repealed the first Directive on the energy performance of buildings (2002/91/EC), having regard inter alia to Directive 2009/28/EC on the promotion of the use of energy from renewable sources.
c) Directive 2009/125/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-related products (recast) (OJ L 285., 31.10.2009, p. 10) – replacing the earlier Directive (2005/32/EC) regulating the same subject.
d) Directive 2006/32/EC of the European Parliament and of the Council on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC (OJ L 114., 27.4.2006, p. 64)
e) Directive 2009/72/EC of the European Parliament and of the Council concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC (OJ L 211., 14.8.2009, p. 55) – the repealed Directive contained the definitions commonly used in the electrical industry. In the interest of legal security and unambiguity, it seemed desirable to use these definitions with similar or identical content in Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

A number of soft law documents also deserve mention:

a) Opinion of the European Economic and Social Committee on the use of geothermal energy (OJ C 221., 8.9.2005, p. 22)
b) European Parliament resolution of 25 September 2007 on the Road Map for Renewable Energy in Europe (2007/2090(INI)) (OJ C 219.E, 28.8.2008, p. 82) – the resolution also contains a detailed enumeration of documents relating only indirectly to geothermal energy.

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[3] „A geotermikus energiahasznosítás nemzetközi és hazai helyzete, jövőbeni lehetőségei Magyarországon", study overseer: Mádlné Dr. Szőnyi Judit, Budapest, 31 March 2008. (http://www.geotermika.hu/portal/files/mta-geotermika.pdf)

[4] The list of Hungarian implementing measures relating to the Directive is available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:72000L0060:HU:NOT#FIELD_HU

2.2. Directive 2009/28/EC – the place of the renewable energy sources Directive in the context of other policy areas and goals of the Union

[Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (OJ L 140, 5.6.2009, p. 16)]

The Directive is in conformity with the policies of the European Union regarding the fight against climate change, the reduction of greenhouse gas emissions, achieving sustainable development and ensuring energy securityand also in line with the aim of realising the Lisbon Strategy. The Directive – at least according to the intentions of the Commission as demonstrated in its legislative proposal (COM(2008) 19 final) – will form part of a legislative package that establishes commitments for all Member States in connection with greenhouse-gases and renewable energy. The subject of the planned legal acts: a Regulation updating national greenhouse gas emissions targets and a Directive to improve and expand the EU emissions trading system. The three goals of the legislative package are interlinked and complementary: the EU emissions trading system will facilitate growth in renewable energy; the renewable energy Directive will create conditions enabling renewable energy to play a key role in reaching the greenhouse gas reduction targets.

The external energy policy of the Union should ensure the common voice of the EU in support of intensifying its relationship with its energy partners, with a view to further diversifying sources and routes. Third countries should be able to benefit from the promotion of renewables in the EU through the supply of energy from renewable sources. As a general rule no trade restrictions apply to renewable energy imports or exports. However, the Union must ensure that a level playing field is afforded to all renewable energy producers, in and outside of the EU – thus the Directive addresses the issue of legal framework of third countries as well.

The Directive is also consistent with the European Strategic Energy Technology Plan (COM(2007) 723 final), which emphasises the need to bring the next generation of renewable energy technologies to market competitiveness. Information and communication technologies will play a vital role in achieving this.

2.3. The adoption of Directive 2009/28/EC

In 2006 and 2007, consultations have taken place with Member States, citizens, stakeholder groups, civil society organisations, NGOs and consumer organisations. Public consultations (via the Internet) have also been held, inter alia on heating and cooling in renewable energy, and on administrative barriers. Following the collection of expert opinions and the conducting of impact assessments, The Brussels European Council of March 2007 reaffirmed the Community's long-term commitment to the EU-wide development of renewable energies beyond 2010 and at the same time invited the Commission to submit a proposal for a new comprehensive Directive on the use of renewable resources. The European Council stressed that the proposal for the Directive should include legally binding targets for the overall share of renewable energy and the share of biofuels for transport in each Member State.

The Commission has adopted its proposal on 23 January 2008 (COM(2008) 19 final), which has reached its final form following the necessary hearings and the submission of written opinions by the consent of the European Parliament on 23 April 2009. It has entered into force on 25 June 2009, leaving one and a half years for national implementation: every Member State was obliged to achieve the goals of the Directive by 17 December 2010.[5]

2.4. The main elements of the Directive

The Directive establishes a common framework for the promotion of energy from renewable sources, in the aforementioned scope. It sets mandatory national targets (taking year 2005 as the starting point of the indicative trajectory) for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport.

It lays down rules in the following fields:

- statistical transfers between Member States,
- joint projects between Member States and with third countries,
- guarantees of origin,
- administrative procedures,
- information and training, and
- access to the electricity grid for energy from renewable sources.

It furthermore establishes sustainability criteria for biofuels and bioliquids.

Certain provisions of the Directive are detailed further in the annexes attached to it:

- Annex I – National overall targets for the share of energy from renewable sources in gross final consumption of energy in 2020 (In the case of Hungary: 4,3% for 2005, target for 2020: 13%)
- Annex II – Normalisation rule for accounting for electricity generated from hydropower and wind power
- Annex III – Energy content of transport fuels
- Annex IV – Certification of installers (lays down detailed rules regarding qualification schemes: *inter alia* stating that shallow geothermal and solar photovoltaic and solar thermal installers shall be certified by an accredited training programme or training provider; accreditation is the competence of the Member States)
- Annex V – Rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators

In the Member States of the European Union, a veritable system of non-cost administrative barriers exists.[6] These barriers formed and partly still form obstacles to the proliferation of renewable energy usage. The provisions of Article 13 of the Directive (entitled Administrative procedures, regulations and codes) aim to counterbalance these negative experiences to some extent in the following way:

According to paragraph (1) of Article 13, 'Member States shall ensure that any national rules concerning the authorisation, certification and licensing procedures that are applied to plants and associated transmission and distribution network infrastructures

[5] The list of Hungarian legislation modified in order to implemnt the Directive is available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:72009L0028:HU:NOT#FIELD_HU

[6] See „Assessment of non-cost barriers to renewable energy growth in EU Member States – AEON" (DG TREN No. TREN/D1/48 – 2008), final report published on 10 May 2010 by ECORYS Research and Consulting tasked by the Directorate General for Energy of the European Commission.

for the production of electricity, heating or cooling from renewable energy sources, and to the process of transformation of biomass into biofuels or other energy products, are proportionate and necessary.'

Paragraph (1) of Article 13 furthermore requires the Member States to take the appropriate measures to ensure the following:

a) '[…] the respective *responsibilities* of national, regional and local administrative bodies for authorisation, certification and licensing procedures including spatial planning are *clearly coordinated and defined*, with *transparent timetables* for determining planning and building applications;'
b) 'comprehensive *information* on the processing of authorisation, certification and licensing applications […] and on available assistance to applicants are made available at the appropriate level';
c) 'administrative procedures are *streamlined and expedited* at the appropriate administrative level';
d) 'rules governing authorisation, certification and licensing are *objective, transparent, proportionate, do not discriminate between applicants* and take fully into account the particularities of individual renewable energy technologies';
e) '*administrative charges* paid by consumers, planners, architects, builders and equipment and system installers and suppliers are *transparent and cost-related*;
f) '*simplified and less burdensome authorisation procedures*, including through simple notification if allowed by the applicable regulatory framework, are established for smaller projects and for decentralised devices for producing energy from renewable sources, where appropriate'.

3. THE LEGAL FRAMEWORK RELATING TO THE USE OF GEOTHERMAL ENERGY IN CROATIA

3.1. Basic information[7]

In Croatia traditions relating to the medicinal use of thermal waters coming from natural resources go back several hundred years (e.g. the thermal baths of Varazdin, Daruvar and Lipik). The use of deeper layers of geothermal waters for energy production purposes was rendered possible by the mining activity directed at the extraction of crude oil and natural gas. The first steps in the exploration of geothermal potentials were taken by INA Naftaplin in the 1970s after the company had been assigned the task within the framework of a medium-term energy development plan to explore potential geothermal reserves and assess their exploitability. They elaborated the division of the territory of Croatia into geothermal regions based on the temperature gradients measured in the test wells made for the exploration of crude oil and natural gas. According to this, three characteristic areas were distinguished:

- Pannonian Basin — gradient of 40 – 50^{0}C/km
- Dinarides — gradient of 10 – 15^{0}C/km
- the subsurface layers of the Adriatic Sea — gradient of 20 – 25^{0}C/km

[7] During the working on the study the interpretation of pieces of legislation and sources of professional literature written in the original Croatian language was carried out with the help of a native Croatian lawyer colleague.

Based on the above, exploration work began in the territory of the Pannonian Basin. Geothermal fields located in Croatia can be classified in two categories:

- water temperature above 100^0C – for the production of electricity by binary procedure and use of heat through cascade utilisation,
- water temperature below 100^0C – to be used for heating purposes and during various technological processes.

However, the legislative environment relating to the use of renewable geothermal energy for economic purposes is extremely ramifying and difficult to survey and cannot by any means be considered of stimulating nature. The main cause of the low degree of exploitation of geothermal potentials in Croatia lies – similarly to the Hungarian conditions – in the fact that exploitation would require substantial investment and for the time being its profitability is rather low. Based on the available professional opinions (essays, presentations, reports – see: the list of sources consulted at the back), such complex projects as the utilization of geothermal waters require government support (e.g. through ensuring exemption from duty and VAT). It is a generally-held opinion that the financing of projects is not feasible without financial support provided jointly by private investors, the Environmental Protection and Energy Efficiency Fund and EU Funds.

3.2. The foundations of statutory regulation – the Act on Mining[8]

The question constituting the subject-matter of the present report is based – although not exclusively - on two important Acts of Parliament in Croatia. One of them is the Mining Act, which lays down a rather complicated procedural order, and the other is the Water Act.

The Mining Act classifies among mineral raw materials mineral and geothermal waters from which mineral raw materials can be extracted or accumulated heat used for energy purposes, except the mineral and geothermal waters used for healing, balneal and recreational purposes or as drinking water and for other purposes, which are covered by regulations on waters (§ 5). *Therefore, the provisions of the Mining Act regulate use solely for energy purposes.*

A holder of a right to explore mineral raw materials or of a concession for exploitation of mineral raw materials may be a natural or legal person seated in the Republic of Croatia or in any European Union Member State who has been granted permission by the competent authority to perform such activities.

A natural or legal person that has outstanding public fee or tax payment obligations on the basis of a previous permission to explore mineral raw materials or a concession for exploitation of mineral raw materials, or on the basis of illegal exploration or exploitation of mineral raw materials, or that has not fulfilled obligations with regard to restoration and environmental protection, may not be a holder of a right to explore mineral raw materials or of a concession for exploitation of mineral raw materials.

The right to explore mineral raw materials may only be exercised within the area approved for exploration. The right to explore mineral and thermal waters is granted within the framework of a public procurement procedure by the ministry in charge of mining subject to approval by the ministry in charge of water management.

[8] *Zakon o rudarstvu NN75/09*

The right to explore mineral raw materials may be granted for a maximum period of three years. The holder of a right to explore mineral raw materials is obliged to pay an exploration fee. Prior to the commencement of the exploration a mining plan is required. It is prohibited to sell mineral raw materials extracted in the course of exploration.

For the extraction of mineral raw materials a concession is required. Concessions relating to mineral and thermal waters are issued by the ministry in charge of mining subject to prior approval by the ministry in charge of water management. Prior to the submission of the tender for concession, participants are to submit documentation on the quantity of the mineral raw materials and a recommendation about their classification. A concession may be granted to a person that is licensed to perform the activity, that is the owner of the land within the exploitation field concerned or that has building rights, or a lease, or a right of use over the premises and possesses a mining project. The concession grantor must evaluate the technical, professional and financial capability of the tenderer to realize the concession. The concession for exploitation of mineral raw materials may be awarded for a maximum period of 40 years. The concessionaire shall pay a concession fee in consideration of the mineral raw materials exploitation.

The Act prescribes the obligation of rational mineral raw materials exploitation.

For the construction of mining facilities and installations, a building permit is required, which is issued by the ministry in charge of mining. Participants in the construction of mining facilities and installations are: the investor, designer, contractor and supervisory engineer. The application for the issuance of a use permit is to be submitted by the investor. Prior to the issuance of the use permit the competent ministry must carry out technical inspection of the facilities and installations.

3.3. The Water Act[9]

The scope of the Act covers mineral and thermal waters, except for waters from which mineral raw materials can be extracted or accumulated heat used for energy purposes, which are covered by the Mining Act (§ 2 (4)).

The Act lays it down as a main principle that water does not constitute a product for commercial purposes but it is a heritage to be preserved, protected and used rationally. It is a further principle that for water use exceeding general, everyday use a charge is payable for the deterioration of the status of waters.

Surface waters and groundwaters cannot be subject to ownership or other property rights, they constitute public property. Public property is not negotiable, over waters solely easement and building rights may be acquired. Facilities constructed on waters constituting public property form appurtenances of the public property except for facilities established on the basis of a building right valid at the time of establishing them, and for facilities established on the basis of an easement right.

The following, among others, are considered as water use by the Act: withdrawal of surface and groundwaters, including natural, mineral, thermal and thermo-mineral waters for various purposes (provision of drinking water, market realization in natural or processed form in bottles or in other form of packaging, hygienic needs, healthcare and balneal needs, heating, irrigation etc) (§ 74 (1)); as well as the use of water for sport, bathing, recreation and other similar purposes (§ 74 (6)).

Water – pursuant to the Act – must be used rationally and economically.

[9] *Zakon o vodama NN153/09*

For any use of water exceeding the extent of general water use as well as for free water use a concession contract or water licence is required. The quantity of the water extracted must be recorded by the authorised persons.

The use of groundwaters is permissible only if it has been preceded by water exploration work. Water exploration work is aimed at establishing the existence, distribution, quantity, quality and mobility of groundwaters. Prior to applying for a water licence, the person carrying out water exploration work is obliged to prepare a study on the original status and the method of its restoration after the closing of the well.

§ 94 of the Act lays down that water facilities and instruments used for the exploitation of water energy shall be designed and constructed in a way so as to preserve the possibility of returning the water into streams or other water resources (§ 94(1)).

Owners of land and other authorised persons are prohibited from changing or cutting the flow of groundwaters or from using these waters to an extent that would endanger the supply of drinking water to other persons, or any other use of the waters, mineral and thermal resources or the stability of the ground or the facilities.

The legal person who uses water, which forms part of public property, for relaxation and recreation purposes against the law or who fails to keep a record of the withdrawn water is punishable by a fine between 20 to 100 thousand Croatian kunas.

For the withdrawal of mineral, thermal and thermo-mineral waters a concession is required.

The National Water Council was set up in order to monitor the system of water management, to harmonise various needs and interests, and to make recommendations about measures relating to the development and improvement of the water system. The president and the ten members of the Water Council are elected for a four-year term by the Croatian Parliament.

The National Water Protection Plan[10], as it is referred to, was drawn up in the interests of the protection of waters and the sea from pollution coming from the mainland and the islands. *The plan does not contain provisions relating expressly to thermal waters.* An annex to the Water Protection Plan contains the Programme of water quality monitoring on transboundary waters based on the *Agreement on water management between the Government of the Republic of Croatia and the Government of the Republic of Hungary signed on 10 July 1994 in Pécs*.[11] The scope of the provisions of the agreement covers all economic-related issues, measures and works relating to transboundary water courses and river basin areas or those forming a boundary which, from the aspect of water management, could have an effect on the waters concerned and on waterworks, their use and protection and structures built to prevent water-damages.

3.4. Strategy for Energy Development of the Republic of Croatia[12]

The Strategy created in 2009 is for a period lasting until 2020, its main aim being harmonization with the objectives and time frames of the EU's strategic documents. By the signing of accession documents, Croatia agreed to undertake obligations relating to the energy sector as well. These obligations primarily mean the adoption of EU rules

[10] *Državni plan za zaštitu voda NN 8/99*

[11] Government Decree No.127/1996. (VII.25.)

[12] *Strategija energetskog razvoja Republike Hrvatske NN 130/09)*

relating to energy production, the opening up and development of the Croatian energy market as well as its integration into the EU's energy market.

The Strategy emphasizes that Croatia is a country with good natural potentials and possibilities for the use of renewable energy sources. Croatia undertakes to maximally support renewable energy sources, but only insofar as the social costs of their use are acceptable. In this field Croatia's strategic aims are as follows:

- to meet her obligations contained in EU Directive (2009/28/EC) on renewable energy sources that the rate of use of renewable energy sources, including large hydroelectric power plants, shall make up 20% of the total direct energy use
- in the transportation sector this rate should attain 10% of the directly used energy by 2020
- the rate of use of renewable energy sources in the production of electricity, including large hydroelectric power plants should attain 35% of the total energy use by 2020 (wind power plants, biomass plants, small hydroelectric power plants, solar energy, power plants using municipal solid waste, geothermal power plants)

3.5. Objectives and activities relating to geothermal energy to be implemented by 2020 are as follows:

Based on the present situation, geothermal water is exploited from shallow wells. As a result of the extraction of crude oil and natural gas, Croatia has at her disposal the developed technique and technology enabling her to extract geothermal energy from deeper layers as well. Aims to be achieved include the economically justified use of existing geothermal wells and the economically reasonable design of wells as well as the exploitation of the medium-temperature layers for the sake of development.

Apart from the purpose of energy production, Croatia will support the use of geothermal energy also for touristic-recreational purposes as well as for the purposes of heating, supply of hot water, agricultural production, the industrial processing of agricultural products, the fishing industry etc.

Rules relating to renewable energy sources, energy efficiency and the coupled production of electricity and heat energy are contained in the following pieces of legislation:

- Energy Act[13]
- Electricity Market Act[14]
- Act on the Environmental Protection and Energy Efficiency Fund[15] and the implementing legislation relating to them.

3.6. Summary of the Croatian legislative background

As it is conspicuous from the above discussion, the regulation of geothermal energy is not without antecedents in Croatia. At the same time, similarly to most countries in the region, including Hungary, she does not have an independent legislative background. Some aspects appear in provisions at the level of Acts and also as parts of future governmental and other strategic plans, suggesting that although the intention and, in

[13] Zakon o energiji NN 68/01, 177/04, 76/07, 152/08

[14] Zakon o tržištu električne energije NN 177/04, 76/07, 152/08

[15] NN 107/03

some cases, also the technology are given, the complicated legal and administrative frames accompanied by uncertain, but rather high extraction costs do not render fast and well-rythmed utilisation possible.

The present study has aimed to review the main content frames and principles of the relevant primary sources of law, and although lower-ranking sources of law and legislation specifically applicable to individual Croatian regions may highlight further questions of detail, they do not genuinely affect provisions applicable to the whole territory of the country.

During the compilation of the study, the interpretation of legislation and sources of professional literature in the original Croatian language was assisted by a native Croatian lawyer colleague.

4. THE LEGAL FRAMEWORK RELATING TO THE USE OF GEOTHERMAL ENERGY IN HUNGARY

4.1. Basic information[16]

In legal regulations relating to earth's heat three definitions are used in substantive law (geothermal energy, thermal water and thermal spring). Their management and the licensing procedure are determined by the purpose for which the natural energy source is utilized.

4.2. On legal regulations and the institutional background relating to geothermal energy in general

Geothermal Energy means the inherent energy of the earth's crust stored in the form of heat. Carriers of geothermal energy mean substances in various states (e.g. groundwaters, steams), which allow exploitation of the inherent energy of the earth's crust for the purposes of the generation of thermal energy through exploitation or through the application of another technology.[17]

Thermal springs (thermal water) have probably been present in Hungarian social and historical thinking since our arrival in the Carpathian Basin. As early as then the Gesta Hungarorum by Anonymous mentions Attila (King of the Huns), who "came to the territory of Pannonia with a huge army, and […] took possession of the country. Then he set up his royal seat by the Danube over the thermal springs."[18]

Therefore, the examination of the legal frames relating to earth's heat covers several branches of law and institutions (environmental protection and water management, mining, energy). Harmonisation should extend, apart from management, also to the institutional and legal frames. Besides the Act on Mining already referred to above,

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16 Mádlné Szőnyi, Judit (theme-leader): A geotermikus energiahasznosítás nemzetközi és hazai helyzete, jövőbeni lehetőségei Magyarországon. [The international and national situation and future possibilities relating to the use of geothermal energy] Commissioned by: the Presidential Secretariat of the Hungarian Academy of Sciences, Budapest, 31. 03. 2008, p. 79

17 Act XLVIII of 1993 on Mining, Section 49, Points 11 and 12.

18 Cited by: Nagygál, János in his presentation entitled: The utilization of thermal waters and relating difficulties in the mirror of 50 years – Conference on Renewable Energy Sources, Miskolc 28. 04. 2011.

geothermal energy is regulated by numerous other sources of national law as well. The substantive legal framework relating to geothermal energy comprises six Acts of Parliament, a dozen government decrees and numerous ministerial decrees. Among the legal regulations there is an obvious preponderance of implementing decrees. It is basically the Acts of Parliament that define the legal frames and ensure the elements of guarantee, the implementation of which is provided for by government decrees, while the most detailed regulations are laid down by ministerial decrees. One is to agree with the statement that the national legal regulatory framework is made up of three well distinguishable branches: energetics, mining, environmental and water management.[19] In the opinion of other authors as well, the exploitation of geothermal energy may be evaluated from different aspects, including: energetic, agricultural, environmental protection (water protection) and other aspects.

The diversity of classification itself also suggests that the exploitation of geothermal energy takes place in a complex and ramifying legal environment covering several branches of law, which does not promote transparency or the conduct of simple and fast procedures.

As for the institutional background, we have proceeded from licensing authorities, since the utilization of geothermal energy is an activity that is characteristically subject to licensing. Out of the areas of responsibility falling within the scope of authority of the Hungarian government, energy management is the responsibility of the Ministry of National Development and environmental protection is the responsibility of the Ministry of Rural Development. The institutional background, therefore, consists of the said two ministries and the organs subordinated to them and run by them, as well as the Hungarian Energy Office, a government office functioning as a central administration organ. Central authority decisions in the branch of energetics are taken by the Hungarian Energy Office (MEH) and the Hungarian Office for Mining and Geology (MBFH), and in the branches of environmental protection and water management by the National Inspectorate for Environment, Nature and Water (OKTVFV).

Apart from the MEH, central organs act through their territorial organs organized on a regional basis typically. District mines inspectorates proceed under the MBFH and regional inspectorates (organized on a territorial basis) proceed under the OKTVFV. The MEH, as an organ of central administration with national competence, does not have territorial divisions.

The institutional system is also characterised by the presence of background institutions of high scientific and professional level. In the branch of mining such institutions are the Eötvös Lóránd Geophysical Institute of Hungary (ELGI) and the Geological Institute of Hungary (MÁFI). Both institutions constitute independent budgetary organs, which through their expert activity provide assistance in legislation, public administration and to local governments, and both organizations are under the management and supervision of the State Secretariat for Energy of the Ministry of National Development. The MÁFI,

[19] Mádlné Szőnyi, Judit (theme-leader): A geotermikus energiahasznosítás nemzetközi és hazai helyzete, jövőbeni lehetőségei Magyarországon. [The international and national situation and future possibilities relating to the use of geothermal energy] Commissioned by: the Presidential Secretariat of the Hungarian Academy of Sciences, Budapest, 31. 03. 2008, p. 78. For a similar opinion, see: Farkas Csamangó, Erika: A geotermális energia hasznosítása jogi aspektusból. [Legal Aspects of the Use of Geothermal Energy] In: Agrár és Környezetjog [Agrarian and Environmental Law] 2007/3. p.3.

Hungary's oldest scientific research institute still in operation, was established in 1869 under the name of Royal Geological Institute of Hungary.[20]

A scientific research institute operating in the branch of environmental protection and water management is the Environmental Protection and Water Management Research Institute Nonprofit Ltd (VITUKI). Its main task among others is to study the science of environmental protection and water management and to collect data relating to water management.

4.3. Regulations relating to the research and exploitation of geothermal energy from the aspect of mining.

Geothermal energy basically and primarily falls within the scope of the Mining Act. The starting point is the provision of *Act XLVIII of 1993 on Mining (hereinafter: Mining Act)* in accordance with which mineral raw materials and geothermal energy are state-owned in their natural place of occurrence. The mineral raw materials extracted by the mining entrepreneur and geothermal energy obtained for energy purposes shall become the property of the mining entrepreneur with the utilization. The following activities are classified as mining activity: exploration, exploitation and utilization of geothermal energy, as well as the management of waste resulting from the above activities. With regard to the exploited geothermal energy, the state is entitled to a share, mining royalties, the rate of which in the case of geothermal energy constitutes 2 % of the value of the exploited geothermal energy. In case of a concession, the rate of the royalties is determined by the minister for each site of exploitation based on criteria defined by the Act.

No mining royalty is to be paid in relation to geothermal energy extracted from energy sources the temperature of which is lower than 30 C° or in relation to the amount of extracted energy more than 50% of which has been utilized. The mining royalty, as a matter of fact, constitutes the consideration for the extracted geothermal energy, by which the energy passes from the ownership of the state into the ownership of the mining entrepreneur.[21] In the present structure of costs relating to geothermal activity, mining royalty constitutes 4%.[22]

The licensing of geothermal activity also falls within the scope of the Mining Act basically. The Act provides an answer to the question in which layer of the earth's crust and by which method it is permitted to extract geothermal energy:

A.) No permit is required: for the extraction and utilization of geothermal energy from the earth's crust not deeper than 20m measured from the natural surface.

B.) A water licence is required: in open areas with a depth between 20-2500 m if the utilization of the geothermal energy is accompanied by water abstraction. The permission of the Mining Supervision Authority is needed for closed-system probing wells without water extraction.

[20] https://www.mafi.hu/intezmeny

[21] Szabados, Gábor: A bányatörvény változásairól, annak a geotermiára való hatásairól c. előadása. [Presentation entitled "On the Changes to the Mining Act and Their Impact on Geothermal Energy" Nemzetközi Geotermikus Konferencia [International Conference on Geothermal Energy] 2010.

[22] Nagygál, János: Presentation on "The utilization of thermal waters and relating difficulties in the mirror of 50 years" – Conference on Renewable Energy Sources, Miskolc 28. 04. 2011.

C.) Closed areas: in the part of the earth's crust deeper than 2500 m measured from the natural surface, permission is granted through concession.[23]

By a concession agreement the minister may lease for a definite period the exploration, extraction and utilization of geothermal energy in a closed area *(Mining Act, §8 Points a and ac).* A concession tender is announced based on the decision of the Minister for National Development, who is in charge of the management and supervision of mining. During the implementation of regulations, the basic rules of Act XVI of 1991 on Concessions are also applicable. The general rules relating to concessions are contained in the Act on Concessions, while specific rules are laid down by the relevant provisions of the Mining Act. A concession can be awarded by way of public tender; the details of the call for tenders are not discussed in the present study.

4.4. The use of geothermal energy from the aspect of environmental protection and water management, with special attention to re-injection.

The extraction of the earth's heat is characteristically carried out by the extraction of the thermal water carrying it. The extraction of thermal water, on the other hand, is a question relating to environmental protection and water management.

In accordance with *Act LVII of 1995 on Water Management (hereinafter: Water Act):* thermal water means all waters of subsurface origin (coming from subsurface aquifers), the temperature of which at their well-heads (measured at the ground surface) is 30'C or more. The Act referred to distinguishes between mineral water, medicinal water and thermal water. M*ineral water:* water coming from a natural subsurface reservoir or aquifer, the mineral content of which is characteristically different from that of the drinking water used for regular human consumption, and the composition of which meets the relevant (e.g. biological, chemical) standards set in the relevant legal rule. Medicinal water: mineral water with proven curative effect, the use in therapeutics of which is licensed in accordance with separate legal rules.

The scope of the Act on Water Management extends to surface waters, the natural aquifers of subsurface waters, and the channels and beds, banks and shores of surface waters. Groundwaters and their natural aquifers are owned exclusively by the State. Groundwaters may only be utilized to an extent, taking into account the provisions of this Act, that the balance between water withdrawal and recharge shall be maintained without any adverse effect to groundwater quality and that the requirements laid down in a separate legal rule guaranteeing the achievement of objectives relating to the good status of waters shall be complied with. In view of the protection of both the quantity and quality of available water resources, the water demand may be primarily met from the water resources not yet committed for water use. When using mineral, thermal, and medicinal water resources, use by therapeutics and convalescence recreation shall be preferred *(Water Act, § 15 (3)).* The Act distinguishes between water use for medicinal, thermal and exclusively energy purposes *(Water Act, § 15 (3)).* Thermal water withdrawn

[23] Dr. Tamaga, Ferenc: A geotermikus energia kutatását és kitermelését szabályozó jogszabályok változásai c. előadása. [Presentation entitled "Changes in Regulation relating to the Exploration and Exploitation of Geothermal Energy" VII. Nemzetközi Geotermikus Konferencia Budapest, [Seventh International Conference on Geothermal Energy] 16 June 2011 and Section 22/B (6) (7) and (8) of the Mining Act

exclusively for energy purposes shall be recharged in accordance with the provisions laid down in a separate legal rule *(§ 15 (3))*.

A re-injection obligation has been prescribed by the Water Act only since its amendment of 2003. In the beginning the regulation did not grant any exemptions, then as a result of the 2009 amendment of the Act the existing situation was relaxed by the granting of exemption from recharge in the case of already existing thermal wells being transferred to the competence of the authority. A basic statutory condition for granting exemption from recharge is, on the one hand, that the applicant shall have held a valid operation permit on 30 September and on the other hand, that thermal waters may only be utilized to an extent that the balance between water withdrawal and recharge shall be maintained without any adverse effect to water quality and that the requirements laid down in a separate legal rule guaranteeing the achievement of objectives relating to the good status of waters shall be complied with. Other detailed conditions relating the granting of exemption are laid down in a government decree. It formed part of the relaxation that the amendment rendered it possible for the water user to deduct the expenses arising in connection with the setting up of a well for recharge – in the case of water used for exclusively energy purposes – from the water resource charge.[24]

These provisions – the re-injection obligation and the right to deduct expenses from the amount of the water resource charge – are applicable exclusively to water use for energy production purposes and they have been in effect since 1 January 2010. Pursuant to the Government Decree[25] that entered into force in the meantime – in the year of 2010 – operating permits granted for an indefinite period of time or those granted for a definite period of time and expiring after 22 December 2012 will become ineffective on 22 December 2012. These permits are applicable, on the one hand, to groundwaters extracted for energy production purposes and on the other hand, to irrigation works.

The person who exploits thermal water exclusively for energy production purposes is exempted from the obligation of recharge until 22 December 2014 or 22 December 2020 depending on the status of the water body concerned. In the river basin management plan, in the case of water bodies classified as being of low or deteriorating quantitative status, this exemption is granted until 22 December 2014, while in the case of water bodies classified as being of good quantitative status, it is granted until 22 December 2020.

The person using thermal water not or not exclusively for energy purposes has no re-injection obligation. However, the above water users are required to pay *water pollution penalty also pursuant to separate legal rules* in relation to the thermal water running off and leaking away into the environment – because of the usually high-level salt content and the relatively high water temperature compared to the surrounding environment.[26]

[24] Comments attached to §§ 1-2 of Act XCIX of 2009 on the Amendment of Act LVII of 1995 on Water Management.

[25] Government Decree 147/2010. (IV. 29.) on general rules concerning activities and facilities of water utilization, protection and damage control

[26] Decree 27/2005. (XII.6.) KvVM on the detailed rules of the control of used and waste water, Government Decree 220/2004. (VII. 21.) on the rules of protecting the quality of surface waters, Joint Decree No. 10/2000. (VI.2.) KöM-EüM-FVM-KHVM of the ministers of environmental protection, public health, agriculture and regional development, and of traffic, communication and water management on the limit values necessary to protect the quality of groundwater and the geologic medium.

Consequently, the water pollution penalty and the water resource charge are intended to encourage the person using thermal water not or not exclusively for energy purposes to re-inject the water quantity that would not endanger groundwater into the aquifer layer specified in their water licence.

A water resource charge is payable by the water user in relation to the water quantity committed in the establishing and operating permit, or used without licence, and by the industrial consumer in relation to the actually used quantity of water. The Act defines the terms of water user and industrial consumer, the extent of use of the corresponding water quantity and the calculation of the amount payable as water resource charge (WRC).

No WRC is payable in case of the withdrawal of groundwater based on the amount of water re-injected into the aquifer layer specified in the water licence that does not endanger groundwaters. With regard to the use of thermal water extracted solely for energy purposes, the water user may reduce the WRC payable by him – up to the amount of the WRC – by the amount of justified costs incurred in the tax year in connection with the construction of the well and the modernization of equipment ensuring the recharge of thermal water and approved by the water management authority *(Water Act, §15/C(8)).* The above provision is intended to provide compensation for the costs of re-injection by allowing the offsetting against the WRC the amount approved by the water management authority relating to the construction of the well and the modernization of equipment. The extraction of the earth's heat is mostly carried out by the extraction of thermal water. The construction of thermal wells is subject to licensing. A water licence is required for carrying out operations on waters or for the construction, reconstruction, and decommissioning of hydraulic facilities (establishing permit), furthermore, for the commissioning and operation thereof, as well as for all water uses (operating permit) *(Water Act, §28(1)).* For technical planning a water licence in principle may be applied for *(Water Act § 28 (2)).* In the event that the water operations and the construction or reconstruction of the hydraulic facility were carried out without a permit or not in accordance with the permit, the operating permit may be refused.

Act LIII of 1995 on the General Rules of Environmental Protection (hereinafter: Environment Act) mentions among its aims the preservation and conservation of natural resources, and their rational, economical management ensuring the renewal of the resources *(Environment Act, § 1 Point c)).*

The scope of the Act extends to the whole of the environment and the individual components thereof, including the protection of the earth and water as well. Water conservation covers among others surface and groundwaters, the reserves, the quality (including temperature relations) and quantity thereof. The utilisation and use of the environment must be organized and carried out in compliance with the environmental objectives relating to the status of waters, namely:

a) the status of surface and groundwaters shall not deteriorate,
b) the good status of surface and groundwaters shall be conserved through compliance with environmental requirements specified in a separate piece of legislation.

The conditions of the extraction and use of water - as a vital element and as a resource whose availability is limited - shall be established for each type of the water resources in accordance with the local conditions and by taking into consideration the utilization standard.

Waters may be utilized and loaded, as well as used water and sewage may be discharged into waters – following appropriate treatment – in a way that does not pose hazard to the natural processes and to the renewal of the quantity and quality of waters *(Environment Act § 21 (1)).*

Prior to commencing activities with significant impact on the environment, an environmental impact assessment shall be carried out *(Environment Act, §68 (1)). The environmental impact assessment and the unified environmental permit are regulated by a separate Government Decree.*[27]

Activities falling within the scope of environmental impact assessment may be commenced upon the granting of an environmental licence, while activities falling within the scope of unified environmental licensing may be commenced based on a unified environmental permit.

Activities subject to prior environmental impact assessment:

- the use of groundwaters from a water extraction facility or group of water extraction facilities reaching or exceeding the quantity of 5 million m3/year,
- water re-injection into groundwater reaching or exceeding a recharge of 3 million m3/year.
- Activities subject to unified environmental licensing:
- facilities for the extraction and utilisation of geothermal energy from a capacity of 20 MW,
- in the protected zones of mineral, medicinal and drinking water bases and in Natura 2000 protected areas regardless of size,
- water re-injection into groundwater (unless it falls within Annex 1) in the case of thermal water regardless of size.

4.5. Closing remarks

Legislative frames relating to the use of geothermal energy cover several branches of law. The legal environment cannot be considered either simple or easy to survey. Apart from the high number and complexity of sources of law, the institutional background is also ramifying and it is supervised by different ministries. Laws prescribe various substantial payment obligations under different legal titles (mining fee, water resource charge, wastewater penalty) for persons using geothermal energy.

At present there is no clearly-defined institutional system that would ensure a predictable environment for investors. There is a need for the consolidation of provisions relating to renewable energy, which justifies the adoption of a separate Act on renewable energy.[28]

In Hungary the resolution on the National Energy Strategy for the period until 2030 was passed by Parliament in September 2011.[29] The new strategy replaces the energy strategy of 2008-2020 adopted in 2008. By adopting the new energy strategy Parliament, among others, called upon the Government to “develop a new transparent and accountable governmental energy and institutional-instrumental system in conformity with European regulations that would ensure a predictable environment for investors and also have

[27] Annexes 1-2 of Government Decree No. 314/2005 (XII. 25) on the environmental impact assessment and the unified environmental permit

[28] Bencsik, János: A geotermia szerepe a Kormány energia stratégiájában [The role of geothermal energy in the Government’s energy strategy] 16. 06. 2011, www.kormany.hu

[29] Proposal H/3839 about a Parliament Resolution on the National Energy Strategy – submitted in August 2011

regard for consumer interests." A more detailed examination of the document may reveal to what extent or rate and under which conditions support for geothermal energy figures among the strategic objectives of Hungary. However, this task falls outside the scope of the present study.

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EGEC – European Geothermal Energy Council, Research Agenda for Geothermal Energy. Strategy 2008 to 2030. www.egec.org

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