## Hydrogeological characteristics of thermal water bearing Plio-Pleistocene basin sediments in Hungary

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In Hungary 1323 thermal-water wells were drilled until 2003. (The Hungarian standard term “thermal-water well” refers, that the surface water-temperature of the well is at least 30 $^{o}$C degrees.) About 85% (1123) of these thermal wells were screened for young sediments of the Pannonian basin. 90,4 percent of the actually working 851 thermal water wells (769) are yielding the examined Pliocene and Pleistocene aged layers The ***Fig. 1*** shows the Carpathian basin areas covered by Pliocene (Pannonian s.l.) formations, together with the earliest wells of this kind.

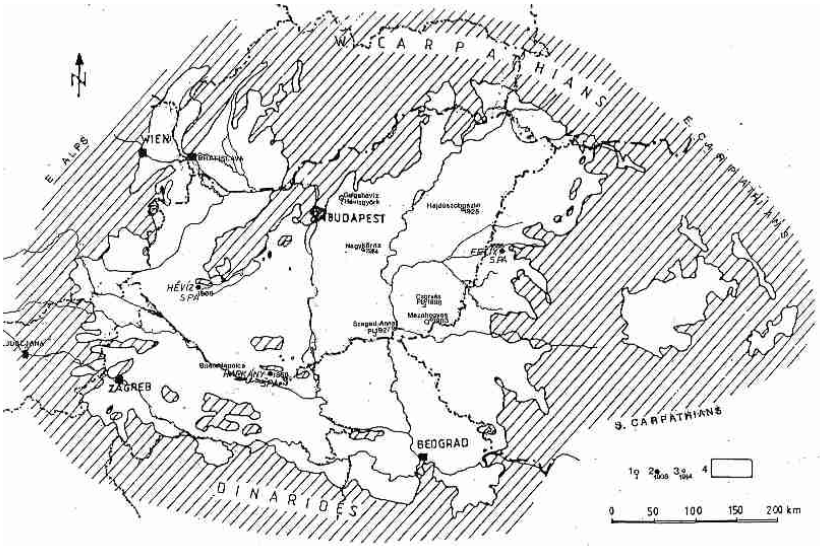



*Fig. 1:* The area covered by Pannonian s.l. sediments in the Carpathian-basin (Juhász Gy. – Magyar I. 1992)

Each thermal water occurrence of these young basin sediments are artificial ones. The geographical terms in the Carpathian basin, such as “hévíz”, “tapolca”, “toplica” etc. are usually deceptive, i. e. inside the basins only cold and luke-warm springs occurred on the surface. But on the boundaries of the mountains, hot karstic springs flows through these overlying young sediments. The first shallow thermal wells of Hungary were screened on Pannonian sandstones and conglomerates next to these thermal karstic springs. (*Harkány: 1866, Félix spa: 1888 and Hévíz: 1908*). The deeper, karstic origin of these springs was not known for a long time. The lake Hévíz was verified to be a karstic spring only in 1943!

The first thermal wells in the basin-areas were drilled for water supply (*Lower Pleistocene: Mezőhegyes 1903., Upper Pliocene: Csorvás 1898., Upper Pannonian: Nagykőrös 1914*).
The balneological usage had begun in the 20’ies parallel with the first oil-exploratory drillings in the Great Hungarian Plain. (*Pannonian: Hajdúszoboszló 1925-27., Upper Pliocene: Szeged, Anna-well 1927*) The more intensive utilisation of geothermal energy for agricultural, communal, and industrial heating had begun in the 60’ies. Most of these thermal wells were drilled with the financial support of the National Technical Development Committee (OMFB) between 1965-1985.

The geology of Pliocene / Pannonian formations was examined mainly by the oil industry. The litostratigraphic units of these sediments were renamed several times in the last 70 years. The ***Fig. 2*** shows the final sequences from 1997.

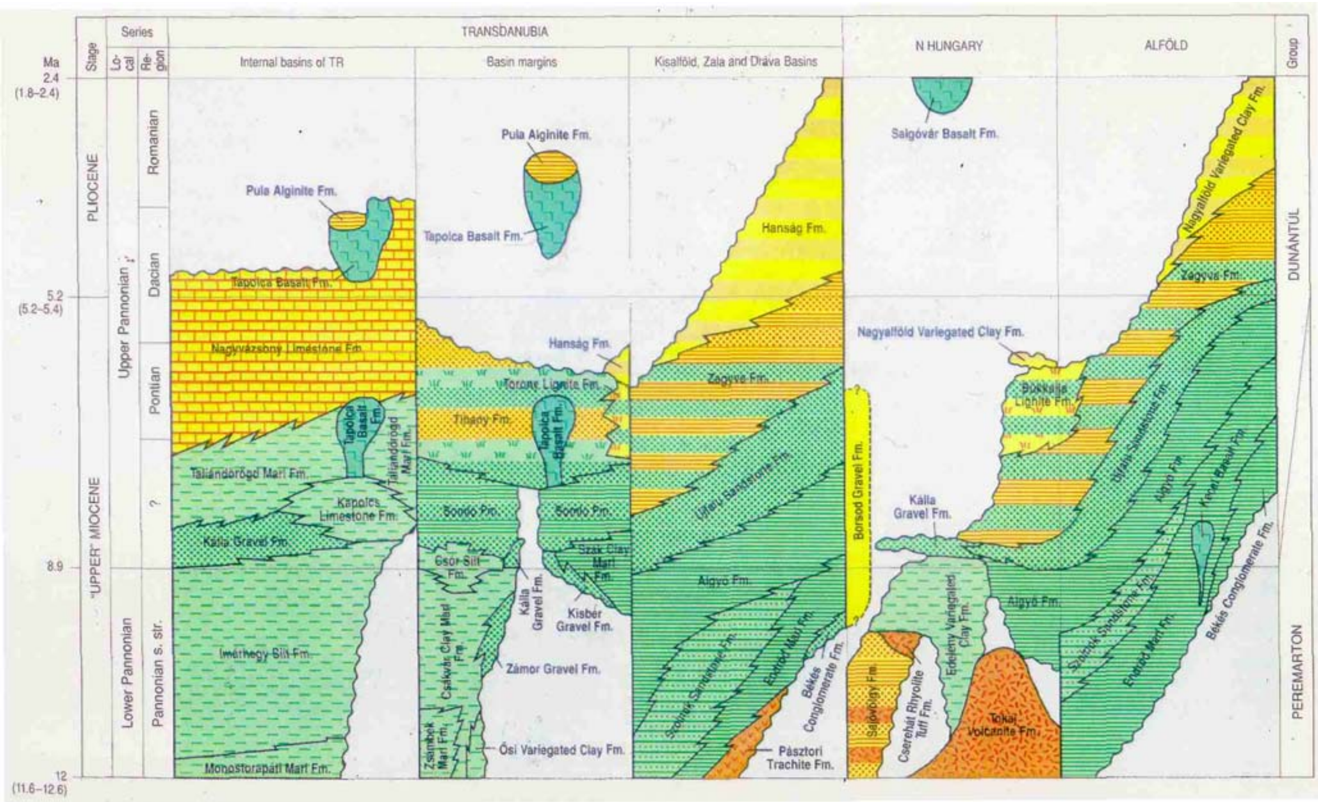


Fig. 2.: The Pannonian s.l. litostratigraphic units of Hungary (Császár G. et al. 1997)

*Table 1:* Summarised data of the wells, screened on Upper Pannonian aquifers

| Surface water temperature (°C) | Utilization | | | | | | | | | | Nr. of wells | Pct. % | Producing wells | Pct. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WS | SPA | AGR | IND | COMM | MULT | REINJ | OBS | CLOS | ELIM | | | | |
| 30 - 39,99 | 70 | 37 | 26 | 20 | 1 | 5 | | 22 | 53 | 42 | 276 | 34.94 | 159 | 28.8 |
| 40 - 49,99 | 25 | 76 | 15 | 8 | 2 | 12 | | 5 | 27 | 22 | 192 | 24.3 | 138 | 25 |
| 50 - 59,99 | 7 | 35 | 11 | 9 | 2 | 11 | 1 | 3 | 14 | 7 | 100 | 12.66 | 75 | 13.59 |
| 60 - 69,99 | | 23 | 15 | 5 | 1 | 22 | 4 | 2 | 10 | 9 | 91 | 11.52 | 66 | 11.96 |
| 70 - 79,99 | | 7 | 15 | 5 | 5 | 10 | 1 | 3 | 4 | | 50 | 6.33 | 42 | 7.61 |
| 80 - 89,99 | | 2 | 20 | 3 | 1 | 4 | | | 6 | | 36 | 4.56 | 30 | 5.43 |
| 90 - 99,99 | | 1 | 33 | 1 | 5 | | | | 3 | | 43 | 5.44 | 40 | 7.24 |
| >100 | | | 1 | | | 1 | | | | | 2 | 0.25 | 2 | 0.36 |
| Summarised | 102 | 181 | 136 | 51 | 17 | 65 | 6 | 35 | 117 | 80 | 790 | 100 | 552 | 100 |
| Percantage % | 12.91 | 22.91 | 17.22 | 6.45 | 2.15 | 8.23 | 0.76 | 4.43 | 14.81 | 10.1 | | 100 | | |
| Producing well% | 18.48 | 32.79 | 24.64 | 9.24 | 3.08 | 11.77 | | | | | | 70.27 | 552 | 100 |
| Production ($10^6$ $m^3/y$) | 6.25 | 13.88 | 26.22 | 2.73 | 3.9 | 10.62 | | | | | 60.87 | | | |
| Prod. Rates% | 10.27 | 22.8 | 43.08 | 4.48 | 6.43 | 17.45 | | | | | | 100 | | |

WS: water supply; SPA: thermal spas and hospitals; AGR: agricultural; IND: industrial; COMM: communal space heating; MULT: multiple-purpose; REINJ: reinjection wells; OBS: observation boreholes; CLOS: closed; ELIM:eliminated

In the beginning of the Pannonian sedimentary cycle mainly grey silt, clay, and marl was deposited (Lower Pannonian, "Mio-Pliocene" phase, Peremarton Group). The Upper-Pannonian ("Pontian", Dunántúl Group) sediments consists of sandstone, clayey marl, and aleurite. The sedimentation was continuos between them only in the deepest parts of the basin, a recognisable discordance is more common. The Upper Pannonian sediments cover a larger area, transgressing into all type of older sediments. In the Transdanubian basins, the sedimentation had begun earlier. This delta-type sedimentation was quite similar in all basins due to the quick deepening of the whole area. The so called *Zagyva Formation* is the final unit of the Upper Pannonian in the western region. In the Great Hungarian Plain the same formation was deposited mainly in the Upper Pliocene (Dacian) era and have different hydrogeological characteristics. In the following, the aquifer characteristics will be presented according to the geological age, from the oldest Pannonian layers till the Lower Pleistocene formations.

The ***Lower Pannonian*** sediments consists only thin sandy layers in the clayey material. The porosity is low, and the salt and gas-content of the groundwater is much higher than the overlying sequence. Because of this, the boundary between the Upper and Lower Pannonian sediments (between the *Algyő and Újfalu Sandstone Formations*) is equal to the lower boundary of the economical thermal water exploitation (***Fig. 3***). Only a few wells were screened for Lower Pannonian sediments (***Fig. 4***). Most of these wells were completed in the beginning of thermal-water utilisation by sectional perforation of unproductive oil-drillings. In some of these wells different Miocene and Upper Pannonian layers were screened together. Their maximal yield is about 200-300 L/minute. The groundwater is of sodium-chloride type, with 2,5-6,5 g/L TDS. Their surface water-temperature ranges between 40 and 70 $^{o}$C. There are two new wells, screened for coarse boundary facies of this sequence in Fonyód, and Fertőd. Their groundwater-characteristics are very similar to the underlying Miocene aquifers. At present, only one single Lower Pannonian thermal water well is working in Ráckeve. One well is used for groundwater monitoring in Hegyháthodász.

The thickness of the ***Upper Pannonian*** thermal-water bearing sediments is more than 2,5 km in the centre of the Great and Little Hungarian Plain. The wells are screened for sand and sandstone layers with different depth. ***The first Table*** represents the distribution of these wells according to their water-temperature and utilisation. The hottest surface water temperatures (100$^{o}$C) were producing from the 2000,5 m deep well K-18/a.of Szentes-Cserebökény and the 1800 m deep well K-271. of Székkutas-Kakasszék in the S$^{rn}$ part of the Great Plain.

The maximal outflow water-temperature of the Upper Pannonian aquifers and the localisation of thermal baths, utilising this aquifer is shown in the ***Fig. 5.*** This water is (Na, K)-$HCO_3$ type mineral water with low or medium dissolved material content (TDS = 1 – 4 g/L). Some of the deepest wells can be sodium chloride type mineral water with salt-content higher than 10 g/L. Upper Pannonian aquifers contains dissolved gas almost everywhere, while the scaling tendency occurs locally. (***Fig. 6***) This phenomenon related to the most saline groundwater and to the highest $HCO_3$ equivalent percent. In the Southern part of the Great Hungarian Plain some wells, producing hotter than 65$^{o}$C thermal waters form the Pannonian aquifers contain a great variety of naturally occurring polycyclic aromatic hydrocarbons (PAH). These waters are not known to be connected with oil fields.

Upper Pannonian wells are used for communal water supply mainly in the northern border of the Great Hungarian Plain. In this area, drinking water cannot be received from the overlying Pleistocene sediments, so they use this 30-35 $^{o}$C warm water.

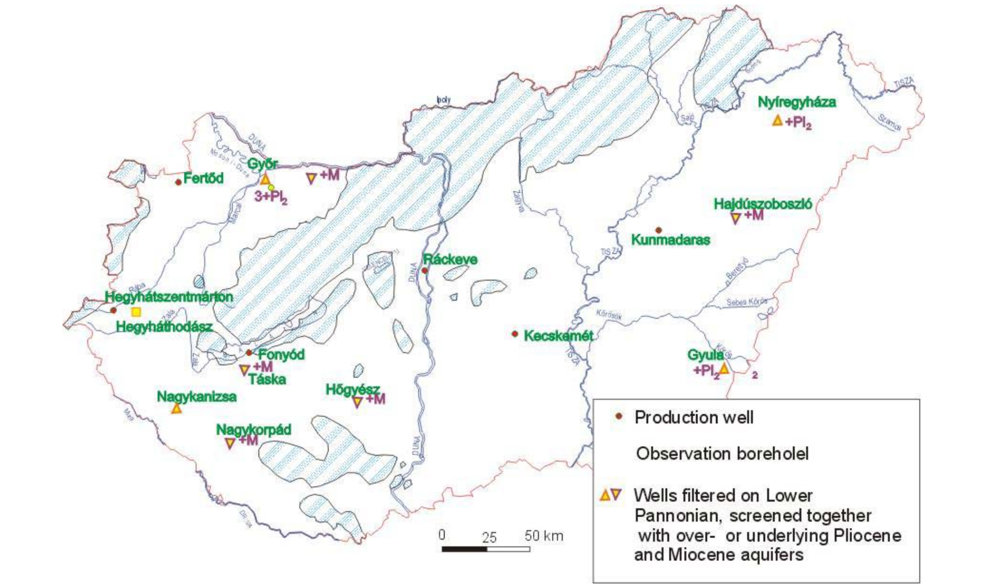



*Fig. 3:* Thermal water wells screened on Lower-Pannonian aquifers

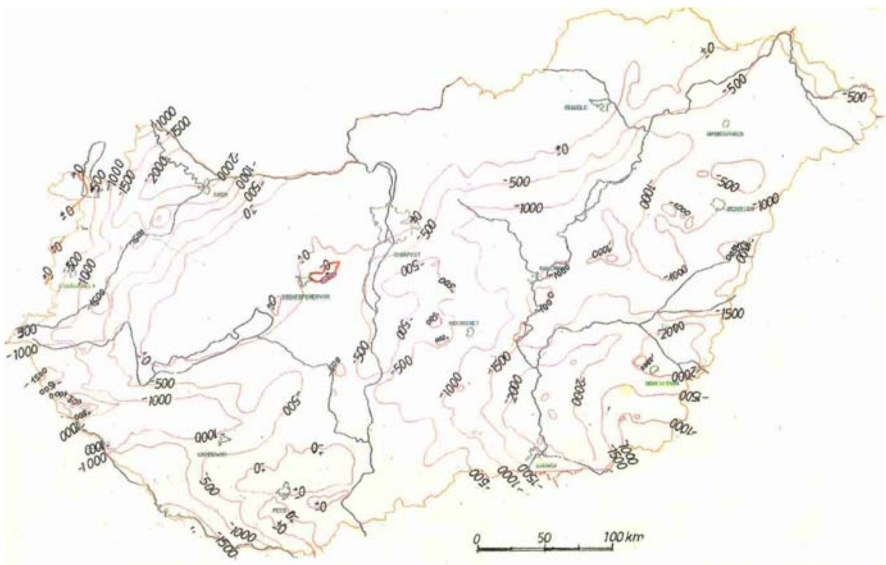



*Fig. 4:* The boundary surface between Lower and Upper Pannonian sediments

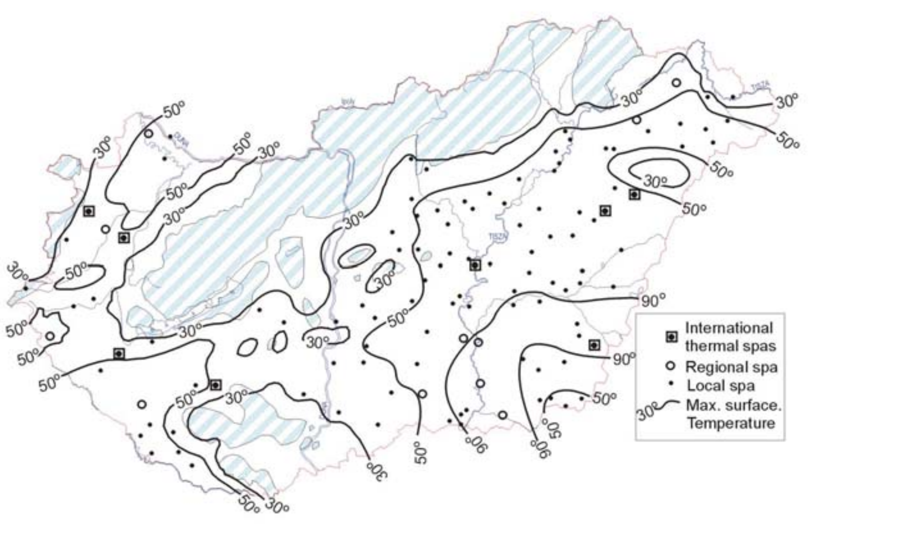



*Fig. 5:* The maximal outflow water temperature of the wells, screened on Upper Pannonian layers and the localisation of thermal baths, utilising this aquifer.

Regional continuos groundwater flow-systems exist from the surface down to the Lower Pannonian aquiclude-type layers. The groundwater is coming from the infiltration of the hills and mountain-margins. The discharge areas are near the largest rivers of the Pannonian region (Danube, Rába, Tisza, Raba, Drava, Sava). Most of the natural groundwater-flow occurs only in the upper parts of the basin-filling sequences. The flow of thermal water, stored in the deeper Pannonian layers, is not so intense.

The geological features of the basement that cause high heat flow in large areas of the Pannonian basin (80 – 110 mW/m$^2$). The temperature-distribution of the basin-areas is related not only to this phenomenon, but also with the heat-convection of the groundwater-flow. In the central basins, the pore-pressure increases downward, while the thermal gradient is decreasing, because both changes are caused by the upward-moving groundwater. In the edge of the basins, the opposite tendencies can be found. The recharge areas are characterised by low dissolved material content even in the deep aquifers. In the discharge areas the TDS-content of the higher aquifers is nearly as high as in the deep layers.

Most of the warmest wells were drilled in the Southern part of the Great Hungarian Plain. The most important geothermal energy utilisations are also situated here. (***Fig. 6, Table 2***) In the beginning, all wells of the deep basins have higher water level than the surface. Only outflow water was used. Due to the increasing use of thermal-water, the pressure decreased, and now pumping, or gas-injection technologies necessary in many areas. In the hilly area of SW-Transdanubia, the water level of the pumped wells are often lower than 80-100 meters below surface, and their temperatures are usually lower, so these wells can be used mainly by spas.

*Table 2:* The main geothermal energy utilizations from the Upper Pannonian aquifers in Hungary (Data of 1998 y.)

| Rank | Locality | Yearly heat-intake (TJ/y) | Average output (MW) |
|---|---|---|---|
| **1** | Szentes | 740,5 | 53,3 |
| **2** | Szeged | 294,4 | 18,3 |
| **3** | Csongrád | 138,1 | 7,2 |
| **4** | Fábiánsebestyén | 80,4 | 3 |
| **5** | Hódmezővásárhely | 73,7 | 3,3 |
| **6** | Debrecen | 69,1 | 2,9 |

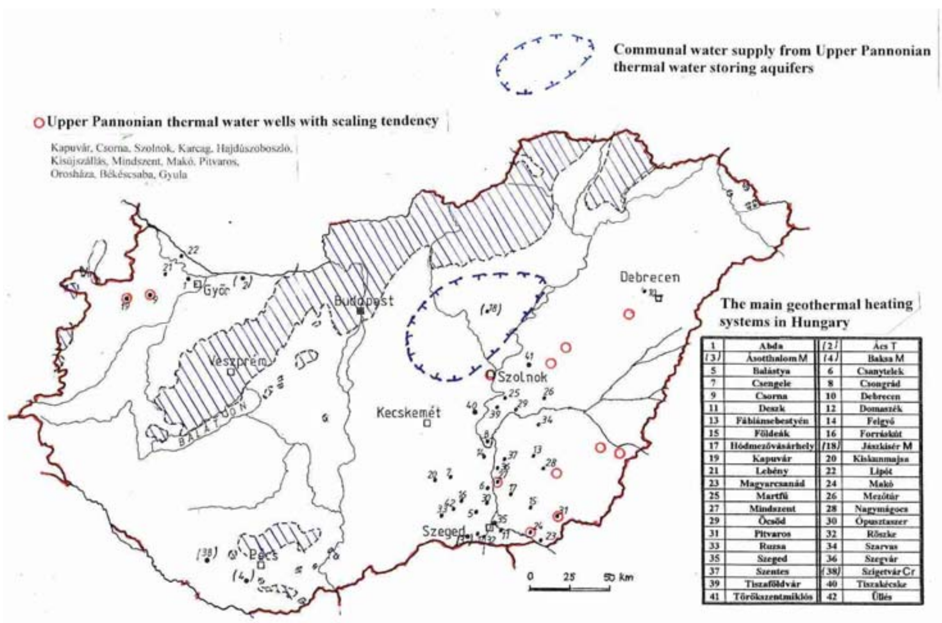



*Fig. 6:* The areas of drinking-water supply and energy utilisation from Upper Pannonian. Thermal water wells with scaling tendency

The ***Fig. 7/a*** shows the thickness of those layers of the Újfalu sandstone formation, storing thermal water warmer than 50 $^{o}$C. The ***Figs. 7/b-c*** shows the changes in pressure till 1990. Since that the energetic utilisation of the Upper-Pannonian layers had decreased to 80 %. Most of the new wells were drilled for balneological purposes, in the hope of thermal tourism.

Environmental problems related to the thermal-water had been known after the 70'ies, especially in the Southern part of the Great Hungarian Plain, where the thermal water is widely used. The utilised warm water was left to flow into surface waters. In these streams and small rivers, the high temperature and salt-content of the incoming groundwater caused recognisable environmental changes. To solve this problem, water-storing reservoirs were built, and there were several different experiments about thermal water re-injection. Although the high cost of this research, this problem could not be solved till now. There is only one example for a well-working geothermal doublet in the Újfalu sandstone formation at the city of Hódmezővásárhely.

The ***Fig. 8*** shows the bottom contours of the ***Upper Pliocene***, and the maximal outflow-temperatures of the wells, screened for this sequence. The 150-600 meter thick *Zagyva Formation* represents the fluvio-lacustrine part of the basin-upfilling. The ***Table 3*** represents the boreholes, screened for this formation, according to their temperature and usage-distribution. These thermal waters have transitional chemical character between the underlying thermal waters and the shallow fresh groundwater. Their gas and dissolved material content is lower than the alkali-bicarbonate type water of the underlying sandstone aquifers. Most of the Upper Pliocene aquifers are used for agricultural, communal or industrial water supply, but some of them have been certificated as "medicinal water" or "mineral water".

*Table 3:* Thermal water wells tapped Upper Pliocene (Dacian) aquifers in SE-Hungary - State 01.01. 2002

| Surface water temperature ($^{o}$C) | Utilization | | | | | | | | Nr. of wells | Pct. % | Producing wells | Pct. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WS | SPA | AGR | IND | REINJ | OBS | CLO | ELIM | | | | |
| 30 - 39,99 | 17 | 2 | 12 | 5 | | 4 | 14 | 17 | 71 | 65.74 | 36 | 63.16 |
| 40 - 49,99 | 4 | 9 | 2 | 1 | | 5 | 1 | | 22 | 20.37 | 16 | 28.07 |
| 50 - 59,99 | | 1 | 2 | 2 | 4 | 2 | | | 11 | 10.19 | 5 | 8.77 |
| 60 - 69,99 | | | | | 3 | | | | 3 | 2.78 | | |
| 70 - 79,99 | | | | | | | 1 | | 1 | 0.93 | | |
| Summarised | 21 | 12 | 16 | 8 | 7 | 11 | 16 | 17 | 108 | 100 | 57 | 100 |
| Percentage % | 19.44 | 11.11 | 14.81 | 7.41 | 6.48 | 10.19 | 14.81 | 15.74 | | | | |
| Producing % | 36.84 | 21.05 | 28.07 | 14 | 12.28 | | | | | 52.78 | 57 | 100 |
| Production ($10^{6}$ $m^{3}$/y) | 1.88 | 2.29 | 0.9 | 3.39 | | | | | 8.46 | | | |
| Prod. Rate % | 22.22 | 27.07 | 10.64 | 40.07 | | | | | | 100 | | |

WS: water supply; SPA: thermal spas and hospitals; AGR: agricultural; IND: industrial; COMM: communal space heating; MULT: multiple-purpose; REINJ: reinjection wells; OBS: observation boreholes; CLOS: closed; ELIM:eliminated

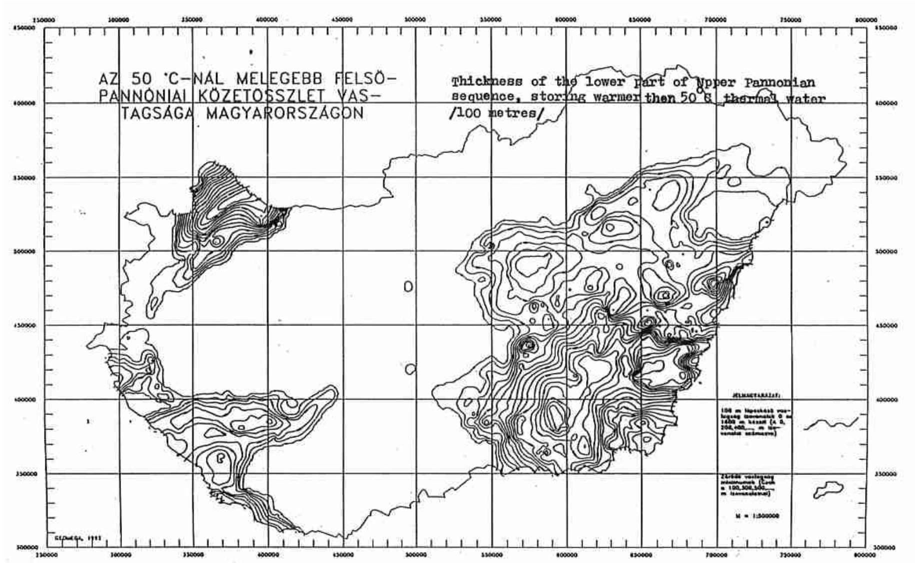



*Fig. 7/a:* The thickness of the Upper Pannonian sediments warmer than 50 °C

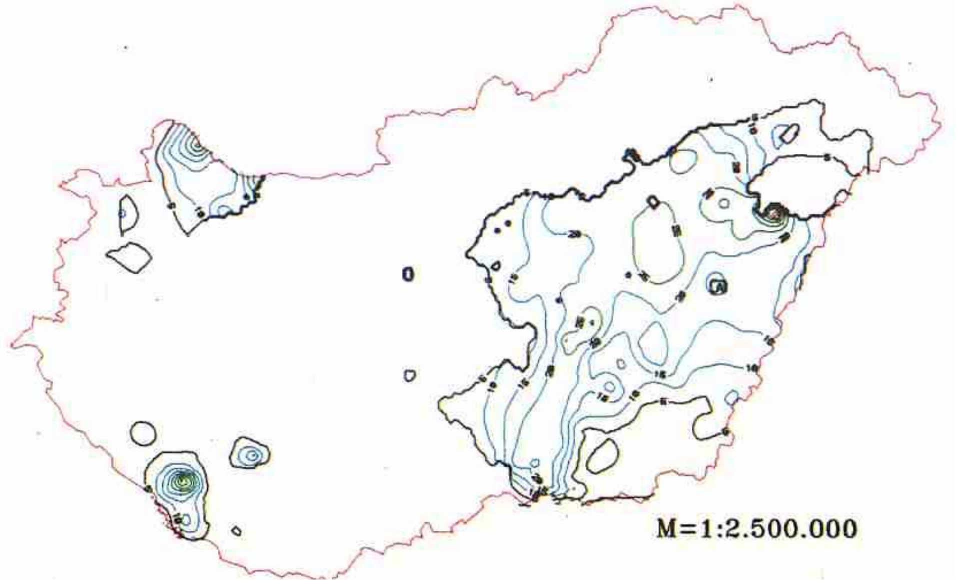



*Fig. 7/b: :* The pressure depression until 1990 (m), at the 50 °C temp.level

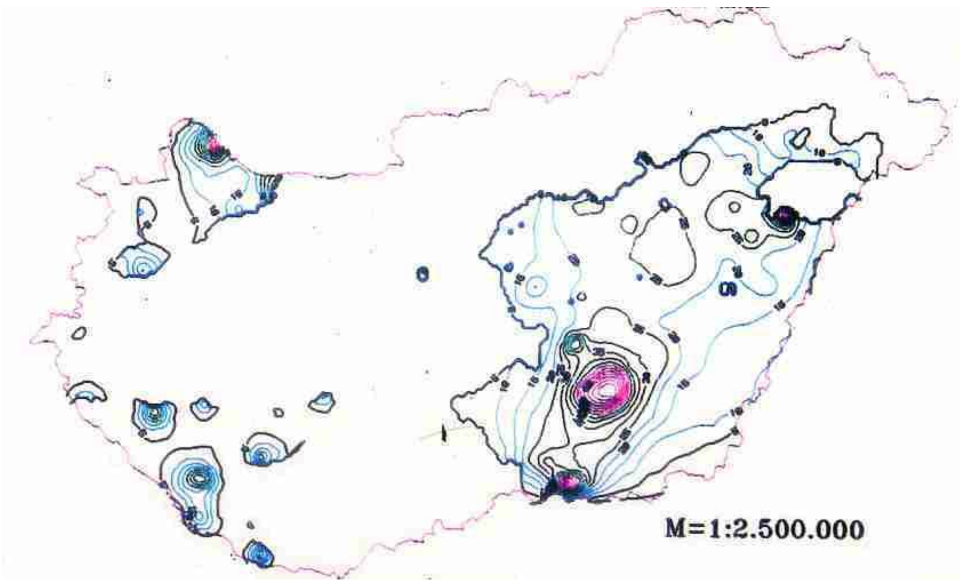
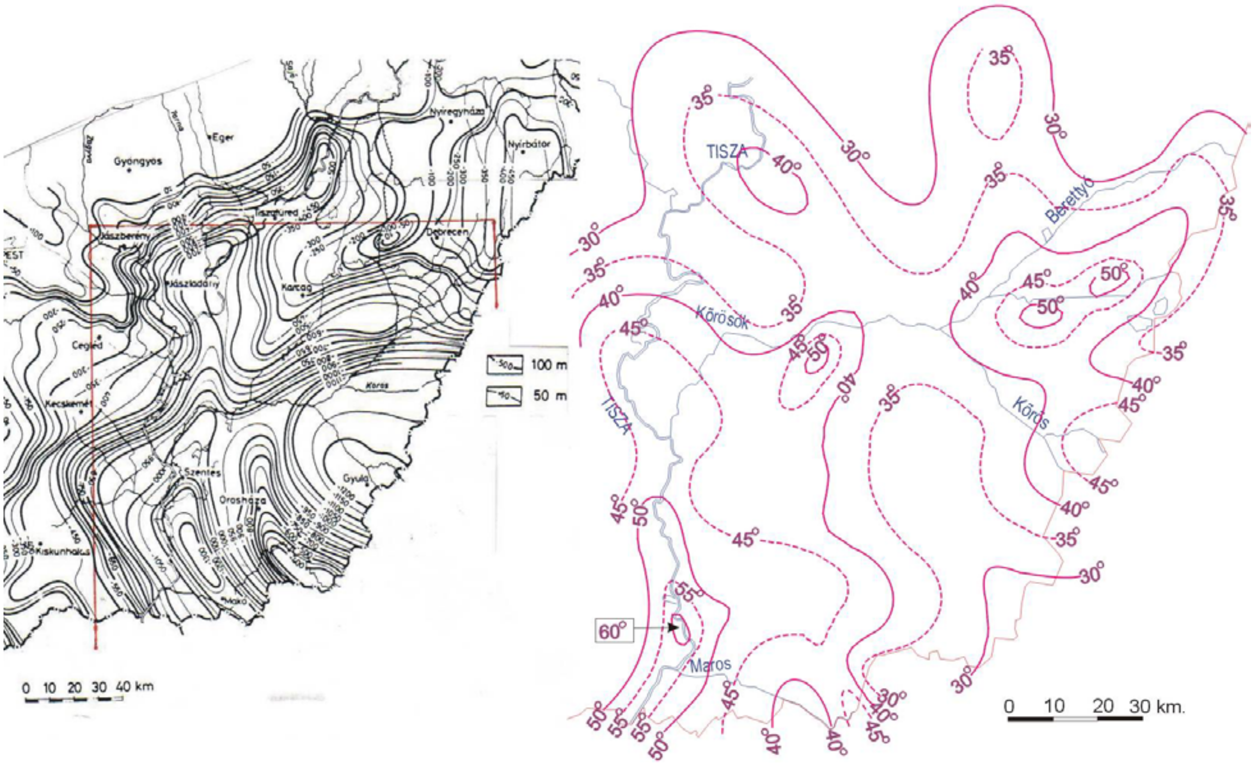



*Fig. 7/c:* The depression until 1990 (m), in the bottom of the aquifers



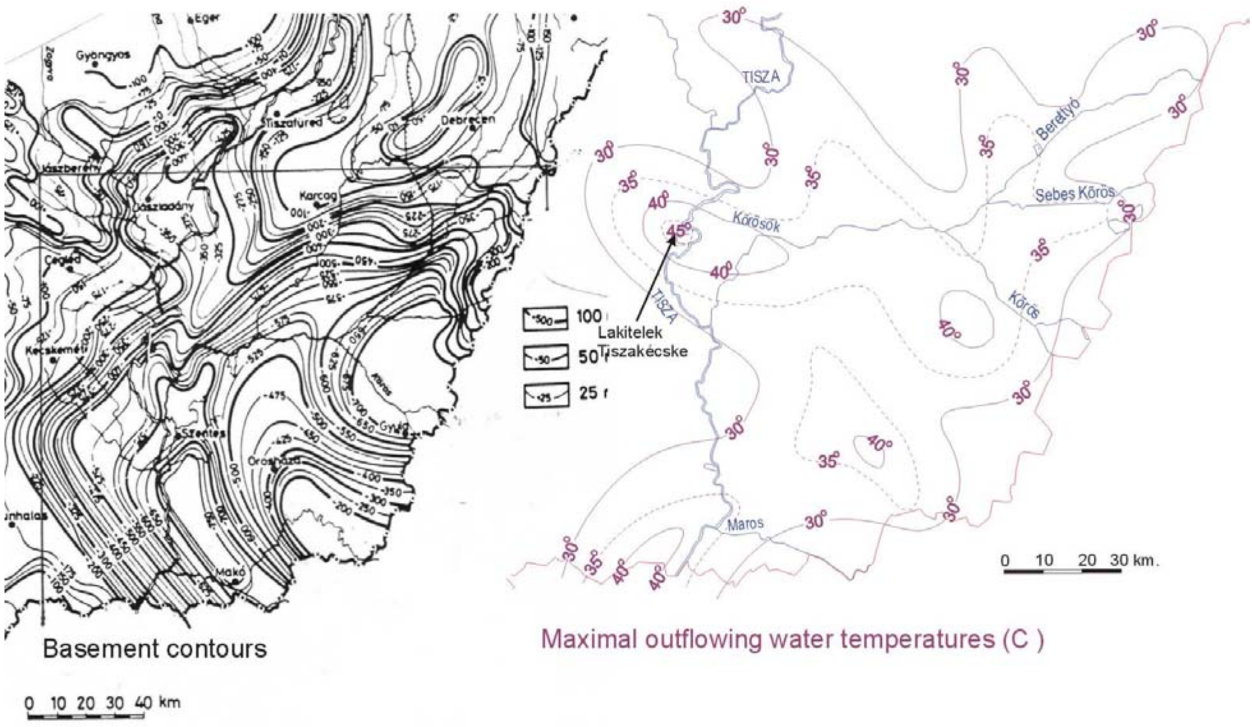




*Fig. 9:* The bottom contours of the Pleistocene in the Southern part of the Great Hungarian Plain, and the maximal outflow-temperatures of the wells, screened for this sequence ($^{o}$C.)

The summarised data of thermal-wells, screened for ***Lower Pleistocene*** alluvial sediments are shown in the ***Table 4***. The bottom contours and the maximal outflow water temperatures of these wells in the Southern part of the Great Hungarian Plain are shown in the ***Fig. 9.*** Nearly all of these thermal-waters satisfy the drinking-water requirements. Their TDS is low, and their temperature changes only between 30-45 $^{o}$C. Lately some of them were drilled for table mineral-water production.

*Table 4:* Thermal water wells tapped Lower Pleistocene aquifers in SE-Hungary - State 01.01. 2002.

| Surface water temperature ($^{o}$C) | Utilization | | | | | | | Number of wells | Pct. % | Producing wells | Pct. % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | WS | SPA | AGR | IND | OBS | CLO | ELIM | | | | |
| 30 - 39,99 | 101 | 6 | 35 | 12 | 3 | 22 | 32 | 211 | 98.14 | 160 | 98.16 |
| 40 - 49,99 | | 1 | | 2 | | 1 | | 4 | 1.86 | 3 | 1.84 |
| Summarised | 101 | 7 | 35 | 14 | 3 | 23 | 32 | 215 | | 163 | 100 |
| Percentage% | 46.98 | 3.25 | 16.28 | 6.51 | 1.4 | 10.7 | 14.88 | | 100 | | 75.81 |
| Producing % | 61.96 | 4.29 | 21.47 | 8.59 | | | | | | 163 | 100 |
| Production ($10^6$ $m^3$/y) | 13.95 | 0.65 | 1.48 | 1.02 | | | | 17.1 | | | |
| Prod. rate % | 81.58 | 3.8 | 8.65 | 5.96 | | | | | 100 | | |

Near the Tisza river, in the area of Lakitelek and Tiszakécske, a pair of a positive and a negative geothermal anomaly is known near the surface. A local circular groundwater-flow is working in this area. According to the latest results, this circulation is related to the upward-coming flow of warm and saline waters from the deeper Pannonian aquifers too.

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