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Hydrogeothermics of Slovakia

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ABSTRACT

Hydrogeothermics of Slovakia is based on temperatures from 376 wells and on the heat flow density data determined in 136 wells. It is also based on hydrogeothermal data from 61 geothermal wells and on the data from hydrogeological and geological wells as well. The geologic setting in Slovakia is favorable for the occurrence of geothermal energy resources to the south of the Klippen Belt, i.e. in the **Inner** Carpathians. Heat flow density and geothermal gradient values fulfil economic limits for the geothermal water exploitation. The mean heat flow density is 82 $mW.m^{-2}$ and aquifers can be reached mainly to the 3000 m depth. Mean transmissivity value of the most wide-spread aquifers (Triassic dolomites and limestones) is $3.10^{-3}\ m^2.s^{-1}$.

KEYWORDS

Temperature, heat flow density, aquifers, transmissivity, water chemistry, depth of aquifers

Introduction

In the years 1970 resp. 1974 we submitted a project for fundamental research of spatial distribution of earth heat and geothermal resources of the West Carpathians for 1971-74 resp. 1975-1980 with outlook to 2000. That time we had available 64 data on temperatures in boreholes and 13 data on heat flow density (FRANKO 1971). Similarly we had data on geothermal waters only from 7 boreholes, which were discovered outside the natural discharge areas. In 1991-1994, at compilation of the Atlas of Geothermal Energy of Slovakia we already processed data on temperatures from 376 boreholes, on heat flow density from 136 boreholes and data on waters from 61 geothermal boreholes (FRANKO et al. 1995).

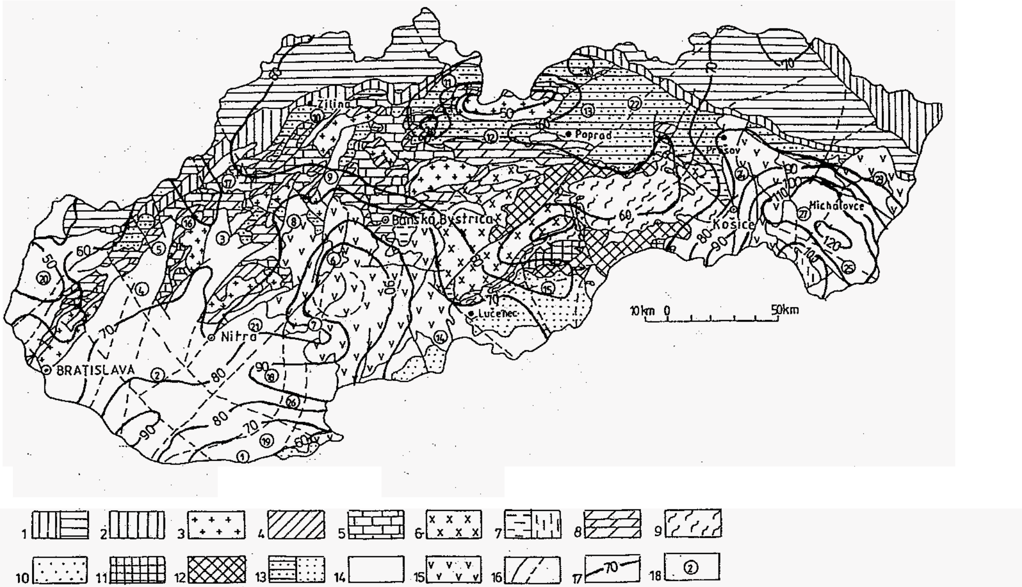


Figure 1: Geothermal activity of Slovakia according to heat flow density (Franko & Král 1999). 1 Outer Flysch belt; Krosmo zone; Magura zone; 2 Klippen belt; 3 Tatricum basement; 4 Tatricum cover unit; 5 Fatricum; 6 Veporicum basement; 7-Veporicum and Zemplinicum cover unit; 8 Hronicum; 9 Gemericum; 10 Meliaticum; 11 Turnaicum; 12 Silicicum; 13 Inner Carpathian Paleogene, Buda basin; 14 Neogene basins; 15 Neogene volcanics; 16 main faults; 17 heat flow density (mW.m-2); 18 number of the prospective geothermal area

Geothermics

The geothermic field is distinctly variable on the territory of the West Carpathians. Its regional character and spatial distribution of geothermal acitivity are mainly determined by FRANKO et al. (1995):

- different depth structure of neotectonic blocks of the West Carpathians, mainly manifested by different thickness of earth crust and non-uniform contribution of the earth mantle
- the course of the main disconformity and fault lines deep-seated in the earth crust
- spatial distribution of Neogene volcanism
- distribution of radioactive resources in the upper parts of the earth crust
- hydrogeological conditions

Temperature

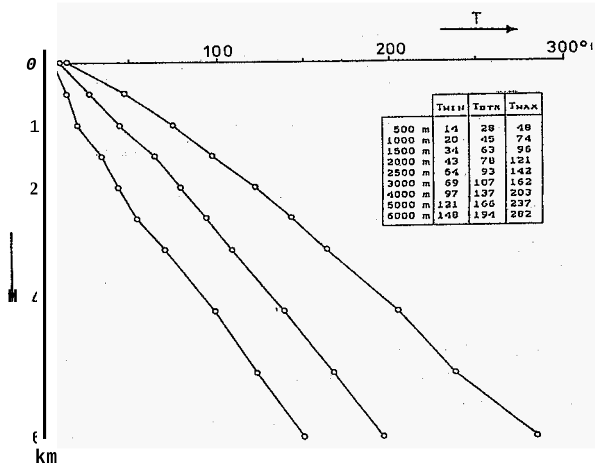
The temperature field at depths to 3000 m is mainly formed in dependence on hydrogeological conditions. Its local variability is also conditioned by the geomorphology of the terrain, local manifestations of natural outflows of geothermal waters and Neogene volcanism and representation of rocks with various heat conductance. The temperature field at depths below 3000 m is, however, a reflection of geothermal activity of deeper morphological structures of the earth crust.

From geothermal point of view we may divide the West Carpathians into two parts (Fig. 1). The relatively low temperatures and values of surface heat flow density are characteristic of the central and northern parts of the Inner Carpathians and of the western part of the Outer Flysch Belt. High temperatures and a high heat flow are typical of Neogene basins and volcanic mountain ranges of tbe Inner West Carpathians. The boundary between these geothermally different regions is formed by the zone of intense horizontal temperature gradients, mainly at the contact of the volcanic-sedimentary complex with pre-Neogene units **of** the West Carpathians. We observe a transitional geothermal activity in the Inner Carpathian Paleogene and in the eastern part of the Outer Flysch Belt.

Vertical distribution of temperatures indicates distinct differences of temperature between these regions and their increase with depth. Maximum temperature differences at depth of 1000 m are around 50 "C, at depth of 6000 m, however, reach 130 to 140 °C. To regional measure the geothermal activity of the West Carpathians sinks in direction from the inner structures towards the outer margin of the Carpathian are (Figs. **2.3).**

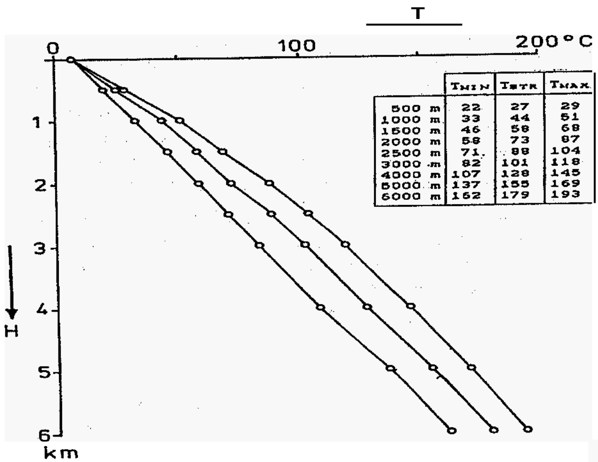
Heat flow

The distribution of heat flow density values is represented by the histogram in Fig. 4. The medium value calculated as the aritmetic mean from all data **is** 82.1 ± 20.5 $mW.m^{-2}$. The data are concentrated into three sets characterized by the average values approximately 65, 80 and 115 $mW.m^{-2}$.



	TMIN	TSTR	TMAX
500 m	14	28	48
1000 m	20	45	74
1500 m	34	63	96
2000 m	43	78	121
2500 m	64	93	142
3000 m	69	107	162
4000 m	97	137	203
5000 m	121	166	237
6000 m	148	194	282

Figure 2 : Geothermogram – Inner West Carpatianr (Král 1996)



	TMIN	TSTR	TMAX
500 m	22	27	29
1000 m	33	44	51
1500 m	46	58	68
2000 m	58	73	87
2500 m	71	88	104
3000 m	82	101	118
4000 m	107	128	145
5000 m	137	155	169
6000 m	162	179	193

Figure 3 : Geothermogram – Outer West Carpattans (Král 1996)

The heat flow density in the West Carpathians is distinctly variable and from regional point of view, similarly as in the temperature, we record its decrease from the Inner Carpathians towards the outer arc.

According to the average value **of** heat flow density (q = about **82** $mW.m^{-2}$) and the geothermal gradient (Gg = about **39** $°C.km^{-1}$) the territory of Slovakia has quite a raised to raised geothermal activity (FRANKO et al. 1995).

Aquifers of geothermal waters

So far we have distinguished 27 (Fig.1) perspective geothermal areas (**FRANKO** 1995). The geothermal area represents a territory, which is characterized by different geological-tectonic and hydro-geothermal conditions. To aquifers of geothermal waters most widely spread Triassic dolomitic-limestone complexes in the Inner West Carpathians in 22 areas belong. In the second place as to extension are Neogene clastic rocks (sands, sandstones, breccias and conglomerates) in **3** areas and in the third place andesites, rhyolites and their pyroclastic rocks in 2 areas.

Figure *4* : Histogram of the heat ***flow*** density data in Slovakia ***(Král 1996)***

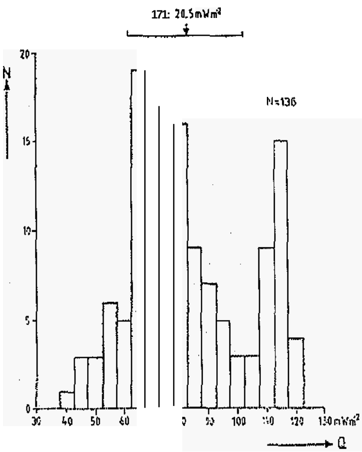
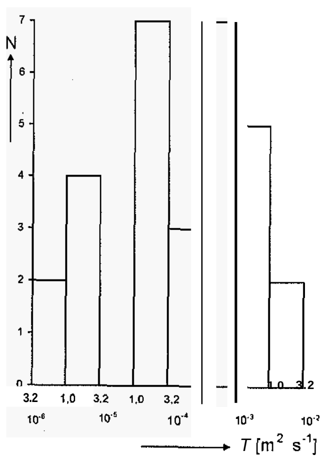


Figure *5* : Histogram of transmissivity coefficient (Franko ***1995)***



Triassic dolomites and limestones (also basal Paleogene conglomerates and breccias are added to them) are found in the Inner Carpathian nappes, envelope units and Eastern Alpine nappes. Their thickness is different in various nappes and envelope units. The most continuous is their extension in the Krízna nappe, with thickness up to 500 m. The aquifers have fissure and fissure-karst permeability. The coefficient of transmissivity T varies within the range of 6.7 x 10^{-6} to 2.3 x 10^{-2} $m^2.s^{-1}$ with an average of 3.1 x 10^{-3} $m^2.s^{-1}$ according to tested aquifers. There is very low to very high transmissivity of carbonates with average high transmissivity. From the histogram of T values (Fig 5) it is possible to mention that highest transmissivity is bound to natural discharge areas of geothermal waters with aquifers in shallow position and lowest to deeply lying and isolated aquifers.

Another significant, but less spread aquifer are Neogene clastic rocks. The aquifers have porous permeability. Mainly the central depression of the Danube Basin is significant (**FRANKO** et al. 1989), in which transmissivity varies within the range of 6.1 x 10^{-5} to 3.6 x 10^{-3} m^2 s^{-1}. In space transmissivity of aquifers generally sinks from the centre to the margins of the depression and from the top to depth.

In the East Slovak Basin according to present-day knowledge andesites, rhyolites an ther pyroclastics belong to less singinificant aquifers of geothermal waters.

Hydrogeochemistry

On the basis of T.D.S. content geothermal waters are divided (Tab. 1) into **4** types (**FRANKO** et al. 1975), low mineralized (up to 5g.l^{-1}), medium mineralized (5-10g.l^{-1}), high mineralized (10-35g.l^{-1}) and very high mineralized (more than 35g.l^{-1}). In the same area several types are found as with depth T.D.S. increase.

According to mineralization and the chemical type of waters with regard to their paleohydrogological development (**FRANKO** and BODIS 1989) their various origin and genesis **of** their chemism may be concluded. Essentially atmospherogenic, thalassogenic and mixed waters are concerned (FRANKO et al. 1995). Waters of atmospherogenic origin contain in the first place petrogenic mineralization with the content of dissolved substances up to 5g.l^{-1}, sporadically also more. They are mainly waters **of** Triassic carbonates, which contain carbonatogenic (A_2) and sulphatogenic ($S_2(SO_4)$). Waters with silicatogenic dissolved solids (A,) are mainly bound to Pontian sands of the Danube Basin and to Ottnangian sands of the South Slovakian Basin. Waters with mineralization more than 5-10 g.l^{-1} contain mainly thalassogenic dissolved solids ($S_1(Cl)$). They are divided into relic waters metamorphosed in the rock-water system, infiltration-degraded waters in various time and space and waters with high content of total dissolved solids.

Table 1: Distribution of geothermal waters according to T.D.S.

T.D.S. ($g.l^{-1}$)	Origin of water	Palmer-Gazda's indices of water chemism	Number of areas
up to 5	atmospherogenic	A_1,A_2, A_2-S_2(SO_4), S_2(SO_4), S_2(SO_4)-A_2	19
	mixed	S_2(SO_4)-S_1(Cl)-A_2 A_2-S_2(SO_4)-S_1(Cl)	2
5-10	mixed	A_1-S_1(Cl)-A_2	1
	thalassogenic	S_1 (Cl)	3
10-35	thalassogenic	S_1(Cl)	5
More than 35	thalassogenic	S_1(Cl)	2

Deep position of aquifers

The geological complexes, which take part in the structure of the territory of Slovakia are of various depth reach (FUSAN et al. 1987). In the Outer Carpathians from the north to south it is the Flysch Belt with assumed depth in the western part 5000-6000 m, in the eastern part 10.000-12.000 m. Then the Klippen Belt follows, of very steep position with reach of more than 10.000 m. In the structure of the Inner Carpathians crystalline-Paleozoic-Mesozoic tectonic nappe units on the one hand and post-nappe formations as the Inner Carpathian Paleogene sediments with very variable thickness in depressions to 1500-3500 m and Neogene formations, mainly in basins, reaching thickness of 5000-7000 m on the other hand, take part. In close connection with them are neovolcanic complexes with thickness to 2500 m (Tab. 2). With regard to the mentioned depth reach of building complexes in the Western Carpathians we mention depth of position of geothermal waters aquifers (Tab. 2). On the basis of knowledge on the Tertiary and its basement in almost all delimited areas are conditions suitable to extension of waters with low temperature, which may be sought for by boreholes with present-day economic depth to 3000 to 4000 m. Middle temperature waters are spread in 11 areas, however, by boreholes to 3000 to 4000 m deep they may be sought for mainly in 3 areas. Waters with high temperature are in 4 areas, but by boreholes to 4000 m it is possible to seek for them in 1 area only (FRANKO et al. 1995).

Table 2: Distribution of geothermal waters according to areas

Temperature (°C)	Type of water	Depth of aquifers (m)	Number of areas
above 150	high thermal	3500-7000	4
100-150	middle thermal	2500-6000	11
below 100	low thermal	100-4000	24

Conclusion

To the end of 1998 geothermal waters were proved by 63 geothermal boreholes in 15 areas. By geological boreholes these waters were proved in further 8 areas. ***So*** far 4 areas have not been proved. The yield of boreholes varies within the range of 5-100 $l.s^{-1}$ and temperature of waters 40-90 °C. At present SLOVGEOTERM Bratislava investigates the geothermal waters in the Košická kotlina Depression with temperatures 120-130 °C and yield of boreholes about 60-120 $l.s^{-1}$. For comparison we mention in the table the yields and temperatures of natural outflows and geothermal boreholes (Tab. 3). When we subtract the yield of natural outflows with temperatures 15-20 °C so the yield of geothermal boreholes is nearly by 370 $l.s^{-1}$ higher in favour of waters with temperatures more than 40 °C.

Table 3: Yield and temperature of waters of natural outflows and of geothermal boreholes

Temperature (°C)		15-20	20-30	30-40	40-70	70-100	Total ($l.s^{-1}$)
Yield ($l.s^{-1}$)	outflows	414	292	182	139		1027
	boreholes	-	9	76	719	268	1072

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