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Geothermal energy of Slovakia

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Abstract. The geologic setting of Slovakia is favourable for the occurrence of geothermal - energy sources to the south of the Klippen Belt, i. e. in the Inner Western Carpathians. 26 areas or structures with geothermal waters have been outlined in this zone. Temperatures at a depth of 1000 m average 46 °C (ranging from 20–72 °C) and at 2000 m 87 °C (46–120 °C). The mean value of heat flow density is 81.8 ± 20.6 mW/m^2. The total thermal – energy potential of geothermal waters in all prospective areas amounts to 6608 MWt. Geothermal waters are used for space heating, recreation and swimming pools in 35 localities. Their combined discharge is 601 l/s and recoverable thermal power 83 MWt.

Key words: hydrogeothermal conditions, geothermal areas, geothermal waters, boreholes, geothermal - energy potential

Fig. 1, Table 2

The Western Carpathians, which occupy the territory of Slovakia, consist of an Alpine folded mountain system and Tertiary basins. The mountain system is divided lengthwise by the Klippen Belt into the Outer (Flysh Belt – Paleogene sediments) and Inner Western Carpathians. The Inner Western Carpathians are characterized by abundant pre-Upper Carboniferous crystalline schists, Variscan granitoids, Late Paleozoic sediments and volcanics, largely carbonate Mesozoic, pre-Senonian nappe structure, Alpine metamorphism, formation of granitoids, post-Cretaceous vertical movements which modified basins of deposition, and tectonics which gave rise to morphostructural elevations (mountains) and depressions (basins) with widespread post-nappe Paleogene and Neogene sedimentary and volcanic formations.

The geologic setting is favourable for the occurrence of geothermal energy sources only to the south of the Klippen Belt, i.e. in the Inner Western Carpathians. 26 areas or structures with geothermal energy have been distinguished in this zone. These include mostly Tertiary basins and intramontane depressions, namely Komárno high block (1), Danube Basin central depression (2), Bánovce Basin (Topoľčany bay – 3), Trnava bay (4), Piešťany bay (5), NW tract of the Central Slovakian Neovolcanics (6), SE tract of the Central Slovakian Neovolcanics (7), Upper Nitra Basin (8), Turiec Basin (9), Žilina Basin (10), Skorušina Mts. (11), Liptov Basin (12), W and S expases of Levoča Basin (13), Upper Strháre – Trenč graben (14), Rimava Basin (15), Trenčín Basin (16), Ilava Basin (17), Levice block (18), Komárno marginal block (19), Vienna Basin (20), Zlaté Moravce bay (21), NE tract of Levoča Basin (22), Humenné Ridge (23), Košice Basin (24), structure Beša- Čičarovce (25) and Dubník depression – 26 (Fig. 1). The combined area of the 26 hydrogeothermal areas or structures covers more than a quarter (27 %) of Slovak territory. Geothermal waters in the hydrogeothermal areas or structures are largely associated with Triassic dolomites and limestones of the Krížna and Choč nappes (Fatricum and Hronicum), less frequently Neogene sands, sandstones and conglomerates (Danube Basin central depression, Horné Strháre – Trenč graben, Dubník depression) and Neogene andesites and related pyroclastics (structure Beša – Čičarovce). These rocks – geothermal aquifers occur at depths 200–5000 m (outside spring areas) and contain geothermal waters 20–240 °C hot.

The temperature pattern in Slovakia is known fairly well. 376 temperature sections based on deep drilling have been compiled. They represent all major structural-tectonic units of the Western Carpathians. Both the vertical and areal distribution of temperatures indicates major differences between individual units and great variability of the thermal field in Slovakia. Temperatures at a depth of 1000

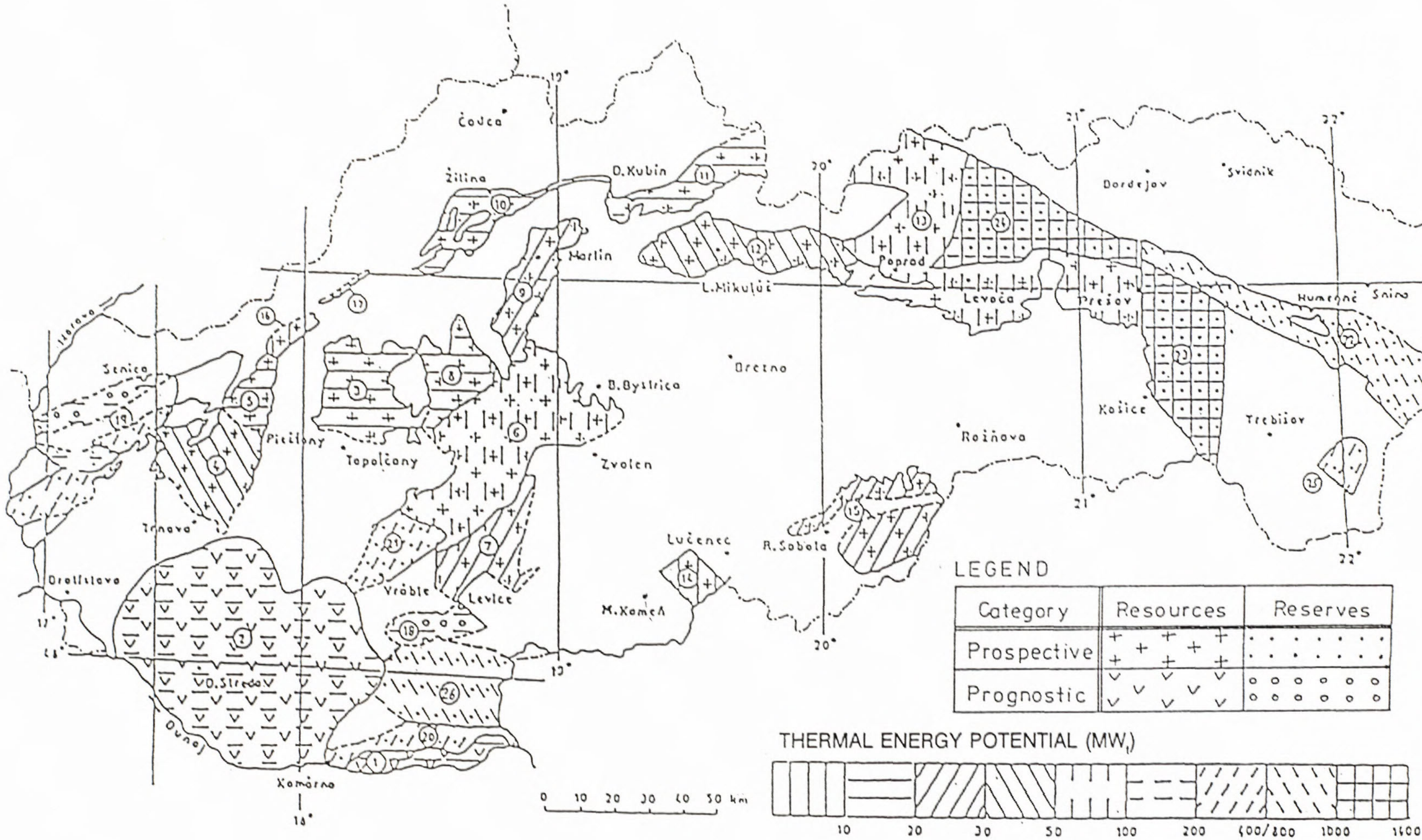

Fig. 1 Map of prospective geothermal water areas or structures in Slovakia and their thermal energy potential (REMŠÍK and FENDEK, 1994)
1 – Komárno high block, 2 – Central depression of the Danube Basin, 3 – Bánovce Basin, 4– Trnava bay, 5 – Piešťany Bay, 6 – Central Sllovakian neovolcanics (NW part), 7 – Central Slovakian neovolcanics (SE part), 8 – Upper Nitra basin, 9 – Turiec basin, 10 – Žilina basin, 11 – Skorušina Mts., 12 – Liptov basin, 13 – Levoča basin (Wand S part), 14 – Horné Strháre-Trenč graben, 15 – Rimava basin, 16 – Trenčín basin,, 17 – Ilava Basin, 18 – Levice block, 19 – Vienna basin,

m average 46 °C (ranging from 20 to 72 °C) and at 2000 m 87 °C (46–120 °C). The mean thermal gradient in the depth interval 0–2000 m in major Western Carpathians units varies from 23.5 to 46.0 °C/km.

The lowest mean temperatures at 1000 m (below 30 °C) and at 2000 m (below 50 °C) have been recorded in the central sector of the Inner Western Carpathians. On the other hand, the highest temperatures typically occur in the southern tract of the Central Slovakian Neovolcanics and Eastern Slovakian Neogene Basin which is a part of the Pannonian Basin. Temperatures here at a depth of 1000 m exceed 70 °C and at 2000 m attain 100 – 120 °C. In the Western Carpathians intramontane basins there is a multitude of local low- as well as high-temperature anomalies caused by convective heat transfer by waters circulating in subsurface reservoirs which reflect hydrogeologic conditions in these structures.

Temperature patterns allow to divide the Western Carpathians into two parts which differ from one another in geothermic activity and spatial distribution of the earth's heat. Fairly low temperatures are characteristic of core mountains in the central and northern sectors of the Inner Western Carpathians and of the western tract of the Outer Flysh Belt. In contrast, high subsurface temperatures typically occur in Neogene basins and volcanic mountains with adjacent intramontane basins. Thermal activity generally decreases from the inner to outer tectonic units.

Heat flow density has so far been measured in 137 boreholes throughout Slovakia. The mean value calculated as an arithmetic mean of all data is 81.8 ± 20.6 mW/m^2 and the same value adjusted to paleoclimatic conditions amounts to 84.4 ± 20.2 mW/m^2. Heat flow densities in the Western Carpathians are highly variable, and regionally fall from the inner structures towards the outer Carpathian arc.

The highest heat flow density (over 100 mW/m^2) has been recorded in the Eastern Slovakian Neogene Basin. Heat flow density distribution reflects the deep structure, thinned earth's crust in this area and increased heat transfer from the upper mantle. High heat flow density values (80–110 mW/m^2) are also typical in the Central Slovakian Neovolcanics. Increased geothermic activity here is directly related to extensive Neogene volcanism, while increased transfers from the upper mantle play only a minor role. Heat flow densities over 90 mW/m^2 have been calculated in the central and eastern Danube Basin (within the proximity of the neovolcanics). Heat flow densities in the Western Carpathians core amount to 50–60 mW/m^2.The Central-Carpathian Paleogene typically displays 65–75 mW/m^2 and the Outer Flysh Belt around 70 mW/m^2. Very low heat flow densities (50–55 mW/m^2) have been noted in the Vienna Basin.

Maximum differences between mean surface heat flow densities in major structural-tectonic units of the Western Carpathians attain as much as 55 mW/m^2. They result from different deep structures and dynamics of basic neotectonic blocks. High heat flow densities occur in areas of Miocene volcanism and thinned crust, whereas low heat flow densities typically occur in areas underlain by a thick crust.

As far as temperature is concerned, geothermal waters in Slovakia (Table 1) are dominated by low-temperature ones (T < 100 °C) while medium-temperature sources (T = 100–150 °C) are rarer and high-temperatures (T > 150 °C) are least frequent.

Research, prospecting and exploration of geothermal waters has so far been carried out in 13 prospective areas in Slovakia (Fig. 1 – areas 1, 2, 3, 8, 9, 11, 12, 13, 18, 19, 20, 21, 26) and in one unprospective area (southern part of the Eastern Slovakian basin – a unsuccessful well).

In 1971–1994 (Table 2) a total of 61 geothermal wells were drilled (only 4 of them were unsuccessful) which verified 900 l/s of waters whose temperature varies from 20 to 92 °C. Thermal capacity of these geothermal waters amounts to some 184 MWt (water temperature will be reduced to 15 °C during exploitation). Geothermal waters were captured by wells 210 to 2605 m deep, and their free outflow mostly ranged from 5 to 40 l/s (Remšík, 1993). Chemically, the waters are represented by Na-HCO3-Cl, Ca-Mg-HCO3-SO4 and Na-Cl types, their T.D.S. is 0.7–20.0 g/l.

In the other 13 prospective areas, geothermal waters have not been verified by wells (Fig. 1 – areas 4, 5, 6, 7, 10, 14, 15, 16, 17, 22, 23, 24, 25), but seven of them (Fig. 1 – areas 4, 5, 10, 16, 17, 21, 23) have been geologically assessed for the purpose of prospecting and exploration for geo-thermal waters. The evaluation of these areas, based on earlier geological information, results of oil wells and geophysical measurements, allowed us to propose wells for geothermal waters in the individual areas.

The evaluation of the thermal-energy potential (TEP) of geothermal waters in Slovakia's individual prospective areas is given in Fig. 1. The total TEP

Table 1 Distribution of low- to high-temperature geothermal waters (Remžík and Fendek 1994)

Type and temperature of geothermal waters	Defined geothermal water structures or areas	Number of geothermal water structures and areas
Low-temperature T < 100 °C	Komárno high block, Central depression of the Danube basin, Bánovce basin, Trnava bay, Piešťany bay, Central Slovakian neovolcanics (NW part), Central Slovakian neovolcanics (SE part), Upper Nitra basin, Turiec basin, Žilina basin, Skorušina Mts., Liptov basin, Levoča basin (W + S part), Horné Strháre – Trenč graben, Rimava basin, Trenčín basin, Ilava basin, Levice block, Komárno marginal block, Vienna basin, Komjatice depression, Levoča basin (N part), Humenský chrbát Mts., Košice basin, Beša – Čičarovce structure, Dubník depression	26
Medium-temperature T = 100 - 150 °C	Beša-Čičarovce structure, Central depression of the Danube basin, Košice basin, Humenský chrbát Mts., Levoča basin (N part), Liptov basin, Turiec basin, Central Slovakian neovolcanics (NW part), Bánovce basin, Žilina basin, Ilava basin, Trenčín basin, Piešťany bay, Trnava bay, Vienna basin, Komárno marginal block	16
High-temperature T > 150 °C	Beša-Čičarovce structure, Žiar basin (part of Central Slovakian neovolcanics – NW part), Košice basin, Vienna basin, Central depression of the Danube basin	5

of geothermal waters in all prospective areas amounts to 6608 MWt (FENDEK, 1993), of which the nonrenewable thermal-energy potential of geothermal water reserves accounts for 6008 MWt and renewable thermal-energy potential of geothermal water resources for 600 MWt.

Geothermal waters (apart from thermal mineral waters used for medical purposes in spas) in Slovakia are an auxiliary energy source. Given the lack of energy, rising energy prices, necessity to protect the environment – mainly the atmosphere – geothermal energy may be successfully and effectively exploited as an available local source of heat or even electricity.

Hydrogeothermal investigations have revealed that Slovakia is particularly rich in low- temperature geothermal resources (water temperatures below 100 °C). The extent and technology of geothermal-energy exploitation are inadequate. Recovery rate of the currently exploited geothermal resources is only about 20 %.

Geothermal waters are used for space heating, recreation and swimming pools in 35 localities. Their combined discharge is 601 l/s and recoverable thermal power 83 MWt. Buildings in three towns are partly heated in this way, and so are greenhouses covering 20 hectares in ten localities. About 80 thermal pools whose total area exceeds 50 000 m^2 serve for swimming and recreation. Thermal spas and swimming pools can admit 75 000 visitors a day. The majority of exploited sources of geothermal energy are situated in southern Slovakia (Danube Basin), primarily in the Danube Basin central depression. At Vrbov in the Vysoké Tatry area, geothermal water is used not only for recreation but also for fish farming. In the Liptov Basin, geothermal water is used for recreational swimming in one thermal spa (Bešeňová).

Essential preconditions to geothermal-energy exploitation have already been created in Slovakia. A project to heat 1300 flats, a city hospital and a pensioners hostel in the town of Galanta in the Danube Basin is under preparation. Another project is the construction of a reinjection station at Podhájska (to heat greenhouses and houses through thermopumps and swimming pools). Geothermal water will also be used to heat 500 flats and an indoor swimming pool in the town of Poprad (Vysoké Tatry area).

Approximately 800 MWt of geothermal resources will presumably be exploited by 2005. At 45 % recovery rate they yield 360 MWt of thermal power which in turn corresponds to 2160 GWh of

Table 2 Results of geothermal wells drilled in 1971–1994 in Slovakia (REMŠÍK and FENDEK, 1994)

Structure area	Number of geothermal wells	Drilling period	Aquifers	Depth of perforated intervals (m)	Discharge (l/s)	Water temperature (°C)	Heat power (MW_t)	T. D. S. (g/l)	Chemical type of waters (over 20 eq. % of 100 % ion sum total)
Komárno block	6	1972–1990	Triassic dolomites, limestones, Neogene sands, conglomerates	77–1761	5.5–70.0	20.0–56.0	0.12–7.33	0.7–90.0	Ca-Mg-HCO_3-SO_4 Na-Cl mixed type
Central depression	34	1971–1990	Neogene sands, sand-stones, conglomerates	276–2487	0.3–25.0	23.0–91.5	0.13–6.80	0.5–8.3	Na-HCO_3 Na-HCO_3-Cl Na-Cl
Dubník depression	2	1989–1990	Badenian sandstones, conglomerates	745–1905	1.5–15.0*	52.0–75.0	0.25–2.40	10.0–30.0	Na-Cl Na-SO_4-Cl
Levice block	2	1973–1986	Badenian clastics, Triassic dolomites	995–1740	28.0–53.0	69.0–80.0	6.30–14.42	19.2–19.6	Na-Cl
Komjatice depression	1	1989	Pannonian sands, sandstones	1509–1700	12.0	78.0	2.50	20.1	Na-Ca-Cl-HCO_3
Bánovce basin	2	1984–1985	Triassic dolomites	1512–2025	2.0–17,0*	40.0–55.0	0.33–1.78	0.7–6.0	Na-HCO_3-SO_4 Ca-Mg-HCO_3
Vienna basin	2	1982–1984	Triassic dolomites, limestones	1242–2570	12.0–25.0	73.0–78.0	2.91–6.59	6.8–10.9	Na-Ca-Cl-SO_4 Na-Cl
Upper Nitra basin	1	1979–1980	Triassic limestones, dolomites	1677–1851	26.0	66.0	4.85	0.93	Ca-Na-Mg-HCO_3-SO_4
Liptov basin	4	1976–1991	Triassic dolomites, limestones	1315–2486	6.0-31.0	32.0–62.0	0.43–5.89	0.5–4.8	Ca-Mg-HCO_3-SO_4 Ca-Mg-HCO_3
Levoca basin	3	1981–1994	Triassic dolomites	835–1983	20.0-33.0	46.0–59.0	2.58–6.08	3.0–4.0	Ca-Mg-HCO_3-SO_4
Skorusina Mts.	1	1990–1991	Triassic dolomites	950–1565	100.0	54.0	16.3	1.2	Ca-Mg-HCO_3-SO_4
Turiec basin	1	1989–1990	-	2461**	-	-	-	-	-
Ilava basin	1	1989–1990	-	1761**	-	-	-	-	-
Eastern Slovakian basin	1	1973	-	1001**	-	-	-	-	-

* pumping discharge; ** well depth

energy. Geothermal energy will be used for space heating, greenhouses, water for households, for drying, fish farming and for recreational as well as balneologic facilities. It can even be harnessed to generate electricity in the Košice Basin.

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