GEOTHERMAL ENERGY EXPLORATION IN SLOVAKIA

Ondrej Franko

Dionyz Štúr Institute of Geology, Bratislava

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Abstract. Distribution of boreholes after the length of time of their realization and depth, debit, water temperature, water T.D.S. and heat power of the wells is analyzed. Realization of geothermal boreholes in the frame of the programme "Geothermal energy"(GE) started in the year 1971. For the prospection for geothermal resources 25 areas are delimited. In the years 1971-1991 in 14 areas 61 boreholes were realized. From 61 boreholes 5 were negative so that there is roughly 92 % successfulness. Further 2 boreholes are reinjecting and 1 is for observation. Together about 176 MW_t were proved by 53 boreholes, representing roughly 900 l/s of geothermal water with temperature 20 - 91.5 °C, using the temperature difference from surface temperature down to 15 °C.

1. INTRODUCTION

In Slovakia we know around 30 areas of natural issues of geothermal waters (GTW). Around 1000 $l.s^{-1}$ of thermal waters with temperature 15 - 70 °C are issuing there. The majority of natural issues are already captured by boreholes. Drilling of geothermal waters outside these areas had already been known in the last century. As the first "geothermal" borehole Ill. drilling of the Viennese firm Trausl may be considered, which was drilled in 1899 at Kováčová in the Zvolenská kotlina depression with exploration for coal. From the borehole 412 m deep, from Triassic dolomites, 30 l/s water of temperature 45 °C were flowing out. On the basis of this water the spa has been built up. Further 3 "geothermal" boreholes are from the year 1951 (miocene sands, depth 520 m, debit 5-6 l/s, temperature of water 25 °C), from 1967 (Triassic dolomites, depth 1688 m, debit 13.5 l/s, temperature of water 62 "C) and from 1968 (Triassic limestones, depth 1221 m. debit 17 l/s, temperature of water 54.5 °C). The geothermal boreholes in the frame of the geothermal programme started to be realized in the year 1971.

2. WLORED AREAS

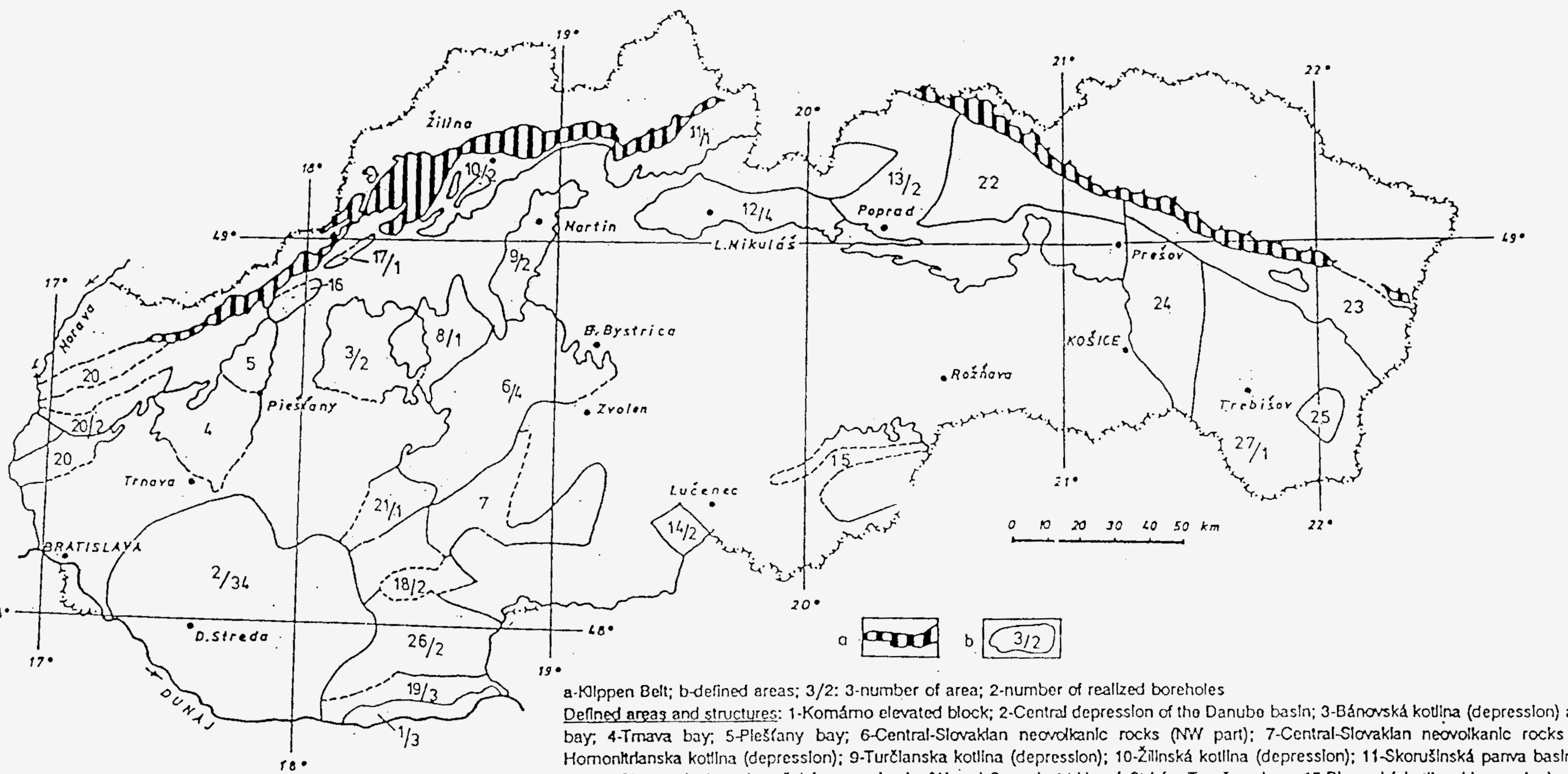
In the years 1971-1991 GTW were proved by 61 boreholes in 14 areas from 25 delimited areas. In 3 further areas GTW were proved by nongeothermal boreholes. 8 areas remain to be proved for GTW by boreholes. A survey of the areas with the number of boreholes, which were realized in them, is represented in Figure 1 and mentioned in Table 1. Evaluation of borehole results is presented in the regional works from the Central depression of the Danube basin (Franko et al., 1989), from the Vienna basin (Remšík et al., 1989), the Komarno block (RemHik et al., 1992) and partly from the Skorušinská panva basin, Liptovska kotlina and Popradská kotlina depressions (Franko et al., 1993). The results of boreholes from other areas are found in partial works and manuscript reports. Shortened results of investigations from the Danube basin, Central depression, Vienna basin and other areas are also mentioned in the works published in the Geothermal Resources Council TRANSACTION from the year 1990.

The result of regional investigations is the valuation of the geothermal potential of Slovakia in the categories of probable and prognostic reserves at the level of 5800 MW_t. In sorting the reserves into individual categories we used the McKelvey diagram as mentioned in the Atlas of Geothermal Resources of the European Community, Austria and Switzerland (Haenel and Staroste, 1988). The prognostic reserves for an area are valuated on the basis of boreholes results. In boreholes alone proved resources are concerned (Table 2). Also in Table 2 further categories of reserves are mentioned, based on renewability and the ways of exploitation. It is necessary to stress that reserves of GE are concerned, which are valuated from GTW.

3. REALIZED BOREHOLES

In the years 1971 - 1991 61 geothermal boreholes were realized (Tab. 1). The fundamental graphical statistical processing of boreholes and data obtained by these boreholes is shown in Figs. 2 and 3a-f. Fig. 2 contains 3 distinct sections in its curve. The first section represents 23 boreholes drilled in 11 years, the second section 26 boreholes drilled in 8 years and the third section 12 boreholes drilled in 2 years (Tab. 3). It is visible from the table how the number of boreholes are gradually increased yearly in the mentioned periods from 2.09 through 3.25 to 6 boreholes or the number of years necessary for realization of 10 boreholes decreased from 4.6 to 3.1 and 1.4 years at the end. On an average, 61 boreholes realized in 21 years or 2.9 boreholes per year. In the course of the curves first section practically only investigation boreholes (besides first 3 exploratory-exploitation wells) were realized by 1 rig, in the second section boreholes of prospecting exploration (1 rig) and in the third section exploitation wells (1 rig) were added. In 21 years 112.131 m were drilled altogether, an average of 1838.2 m per borehole and 5339.58 m per year were drilled on the whole.

In Fig. 3a a histogram shows the distribution of depth of boreholes. From 61 boreholes 38 are 1500 - 2500 m, representing 62.3 %. In the second place there are 13 boreholes 1000 - 1500 m deep, representing 21.3 %. The remaining 16.4 % are boreholes down to 1000 m and below 2500 m.



a-Klippen Belt; b-defined areas; 3/2: 3-number of area; 2-number of realized boreholes

Defined areas and structures: 1-Komárno elevated block; 2-Central depression of the Danube basin; 3-Bánovská kotlina (depression) and Topoľčany bay; 4-Trnava bay; 5-Piešťany bay; 6-Central-Slovakian neovolkanic rocks (NW part); 7-Central-Slovakian neovolkanic rocks (SE part); 8-Hornonitrianska kotlina (depression); 9-Turčianska kotlina (depression); 10-Žilinská kotlina (depression); 11-Skorušinská panva basin; 12-Uptovská kotlina (depression); 13-Levočská panva basin (W and S part); 14-Horné Strháre-Trenč graben; 15-Rimavská kotlina (depression); 16-Trenčianska kotlina (depression); 17-Ilavská kotlina (depression); 18-Levice block; 19-Komárno marginal block; 20-Vienna basin; 21-Komjatice depression (Zlaté Moravce bay); 22-Levočská panva basin (N part); 23-Humenský chrbát (ridge); 24-Košická kotlina (depression); 25-Beša-Čičarovce structure; 26-Dubník depression; 27-East Slovakian basin

Fig. 1 GEOTHERMAL AREAS WITH THE NUMBER OF REALIZED BOREHOLES

Table 1 Geothermal wells realized in the years 1971-1991

Area	Number of boreholes	Depth of boreholes from - to (m)	Age of aquifer lithology	Discharge (l/s) from - to totally	Temperature from - to (°C)	Heat power (MW_t)	Remark
1	2	3	4	5	6	7	8
Central depression of the Danube basin	34	500 - 2800	Dacian, Pontian, Pannonian sards	3.0 - 25.0 400.3	24.0-91.5	88.05	1 negative 1 for observation 1 reinjecting
Zlaté Moravce bay	1	1830	Pannonian sands, sandstones	12.0	78.0	2.5	
Dubník depression	2	916 - 1928 916 - 1928	Badenian cardstones, conglomerates	1.5 - 15.0 16.5	52.0 - 75.0	2.65	
Komárno block	6	210.5 - 1764.5	Triassic, Jurassic dolomites, limestones	5.0 - 70.0 92.5	20.0 - 56.0	10.1	1 negative
Levice block	2 1	1470 - 1900 1001	Badenian, Triassic clastics, dolomites, quartz.	53.0	80.0	14.42	1 reinjecting
East Slovakian basin	2	2025 - 2106	Permian clastics	-			negative
Topoľčany bay and Bánovská kotlina depression		2025 - 2106	Triassic limestones, dolomites	2.0 - 13.0 15.0	46.0 - 55.0	2.02	
Vienna basin	2	2100 - 2605	Eggenburgian, Triassic clastics, dolomites, limest.	12.0 - 25.0 37.0	73.0 - 78.0	9.50	
Hornonitrianska kotlina basin	1	1851	Triassic limestones, dolomites	20.0	66.0	3.76	
Turčianska kotlina depression	2	1458 - 2651	Triassic, Cretaceous, Permian, crystalline rock: dolomites, limestones, marlstones, conglomerates, granitoids	12.0	52.0	1.85	1 negative
Liptovská kotlina depression	4	1987 - 500	Triassic dolomites, limestones	6.0 - 31.0 84.0	32.0 - 62.0	13.58	
Skorušinská panva basin	1	1601	Triassic dolomites, limestones	100.0	56	17.16	
Ilavská kotlina depression	1	1761	Middle Albion sandstones, marlstones, conglomerates, limestones				negative
Levočská panva basin	2	1742 - 2502	Triassic dolomites	28.3 - 33.0 61.3	56.0 - 59.0	10.94	
Total	61	210.5 - 2800	37 Miocene, Pliocene 23 Triassic 1 Permian	903.6	20.0 - 91.5	176.53	1 for observation 2 rrinjecting 5 negative

Tab. 2 Division of GE reserves

AFTER GEOLOGICAL ASSURANCE		
Prognostic (for area) Proved (for wells)	Probable (for area)	Possible (for area)

Renewable (dynamic)	Unrenewable ((static)

Exploitable by single wells	Exploitable by reinjection

Tab. 3 Division of boreholes after the length of time of their realization

Years	Number of years	Number of the wells	Number of the wells /year	Period of realization 10 wells			
				Years	Number of the years	Years	Number of the years
1971-1981	11	23	2.09	70-74.6	4.6	82.4-85.5	3.1
1982-1989	8	26	3.25	74.6-79	4.4	85.5-89.1	3.6
1990-1991	2	12	6.00	79-82.4	3.4	89.1-90.5	1.4

I remark that in Figs. 3b and 3c the discharge for various aquifers is valuated separately. In Fig. 3a they are mainly sands of the Danube (Pannonian) basin and in Fig. 3b Triassic carbonates (dolomites and limestones). When also these carbonates are proved in various areas (Fig. 1, Tab. 1), the results from them are comparable as the same aquifer is concerned in intramontane depressions. Other parameters (depth of boreholes, temperature and T.D.S. of water, heat power of boreholes) are comparable from both aquifers.

Fig. 3b is the distribution of debit of boreholes from the Miocene. Most frequent are boreholes (10) with debit of 10 - 15 l/s, representing 27.8 % from 36 boreholes. In 7 boreholes (19.4%) the debit varies up to 5 l/s; in another 7 boreholes within the range of 5 - 10 l/s. In 6 boreholes (16.6 %) the debit varies within the range of 15 - 20 l/s and in another 6 boreholes within the range of 20 - 25 l/s. Essentially there is a symmetrical distribution of frequency, possibly as a result of pore permeability of the aquifers or homogeneity of rock environment.

In Fig. 3c debit distribution of boreholes from the Triassic is shown. Most abundant are boreholes (4) with debit of 25 - 30 l/s, representing 21 % from 19 boreholes. In 3 boreholes (15.8%) the debit varies within the range of 5 - 10 l/s and in another 3 within the range of 10 - 15 l/s. In 2 boreholes (10.5%) the debit varies up to 5 l/s, in further 2 within the range of 30 - 35 l/s and in further 2 within the range of 50 - 100 l/s. The frequency distribution is asymmetrical, suggesting joint and joint-karst permeability or inhomogeneity of rock environment.

Fig. 3d is a frequency distribution of surficial waters temperature from boreholes. Most frequent are boreholes (16) with water temperature within the range of 50 - 60 °C, from 55 boreholes representing 29 %. In the second place are boreholes (13) with water temperature within the range of 60 - 70 °C, what is 23.6% and in the third place boreholes (12) with water temperature 70 - 80 °C, being 21.8 %. Altogether in 41 boreholes (74.5%) water temperature varies within the range of 50 - 80 °C. It is in agreement with the prevailing number of boreholes (38 = 62.3%) with depth of 1500 - 2500 m.

Fig. 3e is the distribution of T.D.S. of waters from boreholes, Most frequent are boreholes (11) with T.D.S. of waters within the range of 2 - 3 g/l, from 55 boreholes representing 20 %. In the second place are boreholes (9) with T.D.S. of waters within the range of 1 - 2 g/l, what is 16.4% and in the third place boreholes (8) with T.D.S. of waters up to 1 g/l, being 14.5 %. Altogether in 28 boreholes (50.9%) T.D.S. of waters are varying up to 3 g/l. In further 12 boreholes (21.8%) T.D.S. of waters are varying within the' range of 3 - 5 g/l. As visible in 40 boreholes (72.7%), from 55 T.D.S. of waters are varying up to 5 g/l. Waters exploited for heat with such T.D.S. are released into surface streams, in waters with higher T.D.S. prevailingly already reinjection is necessary.

Fig. 3f shows distribution of heat-energetic power of boreholes. Most numerous are boreholes (11) with power up to 1 MW_t, from 52 boreholes 21.2% and further 11 boreholes with power within the range of 2 - 3 MW_t. Among them are 7 boreholes (13.5%) with power within the range of 1-2 MW_t and after them other 7 boreholes with power within the range of 3-4 MW_t. Altogether in 36 boreholes (69.2%) the power varies up to 4 MW_t. In other boreholes the power is gradually increasing to 8 MW and in 2 boreholes it is varying exceptionally within the range of 14 - 15 MW, (Podhájska) and 17 - 18 MW_t (Oravice).

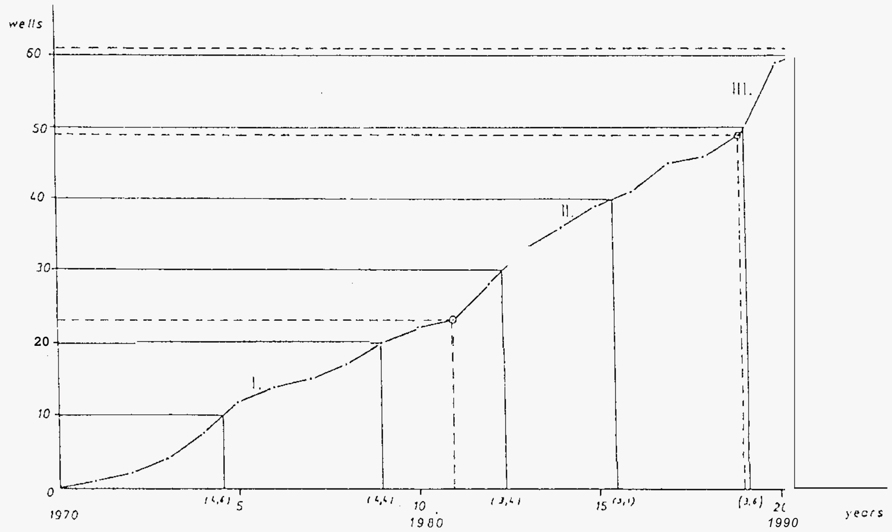


Fig.2 Cummulative distribution frequency of 61 geothermal boreholes after the years

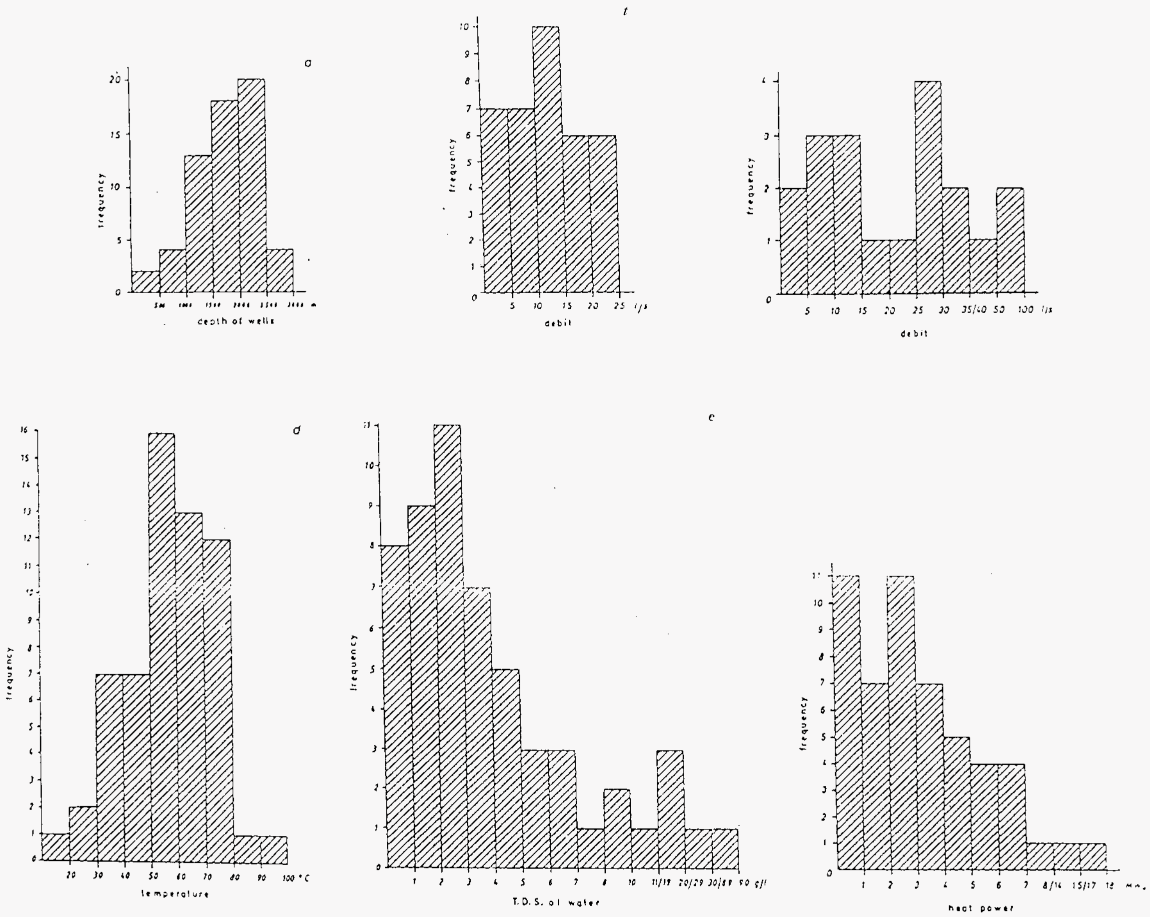


Fig. 3 Histogram; of distribution frequency : a-61wells after depth; b-36 wells (sands and clastics of the Miocene) attcr debit; c-19 wells (dolomites and limestones of the Triassic) after debit; d-55 wells alter surface temperature of water, e-55 wells after T.D.S of water; f-52 wells after heat power

4. CONCLUSION

A survey of the areas in which geothermal boreholes were realized, is mentioned in Tab. 1. It is visible from the table that most boreholes (34) were realized in the Central depression of the Danube basin. In the Komarno block 6 boreholes and in the Liptovska kotlina depression 4 boreholes were realized. In other 11 areas 1 - 2 boreholes were realized. From 61 geothermal boreholes 5 were dry resulting roughly in a 92 % successrate. Of the 61 boreholes 2 were reinjection wells and 1 was an observation well. Altogether the 53 boreholes proved about 176 MW, **of** reserves, representing roughly 900 l/s GTW with temperature of 20 - 91.5 °C and exploitation of the temperature difference from surface temperature of waters down to 15 "C. The GE reserves proved by boreholes as well as prognostic and probable renewed and unrenewed reserves valuated by geothermic balance and volume method are mentioned in Tab. 4.

Renewed (MW,)			Unrenewed (MW)		
proved	prognostic	probable	proved	prognostic	probable
147	85	321	29	445	4511
Total: 553			Total: 4985		
Total 5538					

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