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The Geothermal Resources of Southwest Poland

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ABSTRACT

Geothermal and hydrogeological investigations have shown that the Sudetes and the fore-Sudetic monocline are the most promising regions of Poland as far as the development of geothermal resources is concerned. The heat flow recorded in the southwestern part of the monocline attains and sometimes even exceeds 1.7 HFU, which is almost the highest value found within the Polish territory. Some values known up to now from the Sudetes do not exceed 1.7 HFU; however, morphological and tectonic features of this range favor particularly deep circulation of ground water and its considerable heating.

Drillings performed in the last years in Sudetic areas, where warm springs have been known for centuries, have shown that at depths of 600 to 750 m considerable amounts of thermal waters are stored within crystalline formations (granites and gneisses). The yield of spontaneous outflows sometimes exceeds 100 m^3/h and the temperatures may range from 45°C to above 60°C.

The analysis of infiltration conditions based on isotope and geochemical data leads to the conclusion that in other points of the Sudetes, and probably at somewhat greater depths, important resources of thermal waters might be found. Their temperature, which may amount to 70°C or even more, could allow their use for energetical purposes.

Favorable prospects for locating thermal water sources seem also to occur within the fore-Sudetic block, especially within the area of the Strzegom-Sobótka granitic massif. The whole fore-Sudetic block is characterized by comparatively high heat flow values as well as by the occurrence of young (Tertiary) basalts and hydrothermal phenomena of the same age.

The Mesozoic (especially Jurassic) strata of the fore-Sudetic monocline contain considerable amounts of restrainedly concentrated Cl-Na warm waters with temperatures at the spontaneous outflow often exceeding 40°C. These resources are very promising, especially in the northeastern part of the monocline, where the Jurassic sequence attains considerable thickness.

Aside from ground waters, warm air pumped during ventilation of coal mines in the Upper Silesian Coal Basin and from copper mines of the fore-Sudetic monocline seems to be usable for space heating.

INTRODUCTION

Against the background of somewhat unfavorable geothermal characteristics of the Polish territory, the southwestern part of the country distinguishes itself by comparatively high heat flow values. At the same time in several geological units of this area there exist conditions enabling deep and intensive circulation of ground waters. In crystalline formations as well as in sedimentary series thermal waters of comparatively high temperature and low mineralization may be found now and again; these are often under artesian pressure and boreholes are of considerable yield (Dowgiałło, 1970, 1975; Dowgiałło, Płochniewski, Szpakiewicz, 1974; Fistek and Młodzianowski, 1974). From the viewpoint of geothermal resources utilization this area is thus worthy of particular attention, these resources being up to now utilized to a minimal degree. Besides the traditional use of thermal waters for balneotherapy and recreation pools, there are large possibilities for using them in agriculture, horticulture, animal husbandry, and in processing industry (Lindal, 1973).

A separate problem, which will not be considered here in detail is the possible utilization of the warm air exhausted from coal mines in the Upper Silesian Coal Basin (Kowalczuk and Pałys, 1967) and copper mines in the Legnica-Głogów Copper Region, where copper is exploited from Permian deposits of the fore-Sudetic monocline (Downorowicz, 1971). This heat, now uselessly dispersed into the atmosphere, might be used for space heating and other purposes.

GEOLOGICAL STRUCTURE

The area concerned contains the Polish part of the Sudetes together with the fore-Sudetic block, the fore-Sudetic and Silesian-Kraków monoclines, the Silesian-Kraków basin as well as a part of the West Carpathians and of the Carpathian foredeep (Figure 1).

The kernel of the Sudetic structure which composes the northeast margin of the Bohemian massif are Precambrian metamorphic formations (gneisses and schists), among which Paleozoic granitoids and effusive rocks of Permian, Tertiary, and perhaps even Quaternary age occur. The Precambrian is here and there covered by a lower Paleozoic, sedimentary, less metamorphosed series and, in intermontane depressions, is also covered by Mesozoic sediments.

The fore-Sudetic block situated northeast of the Sudetic marginal fault is also composed of Precambrian and Paleozoic metamorphic rocks, Paleozoic granitoids and Tertiary basalts. It is in its main part covered by Kainozoic (Cenozoic) loose sediments.

The metamorphic formations of the fore-Sudetic block dip southeast and in the middle Odra zone sink under the

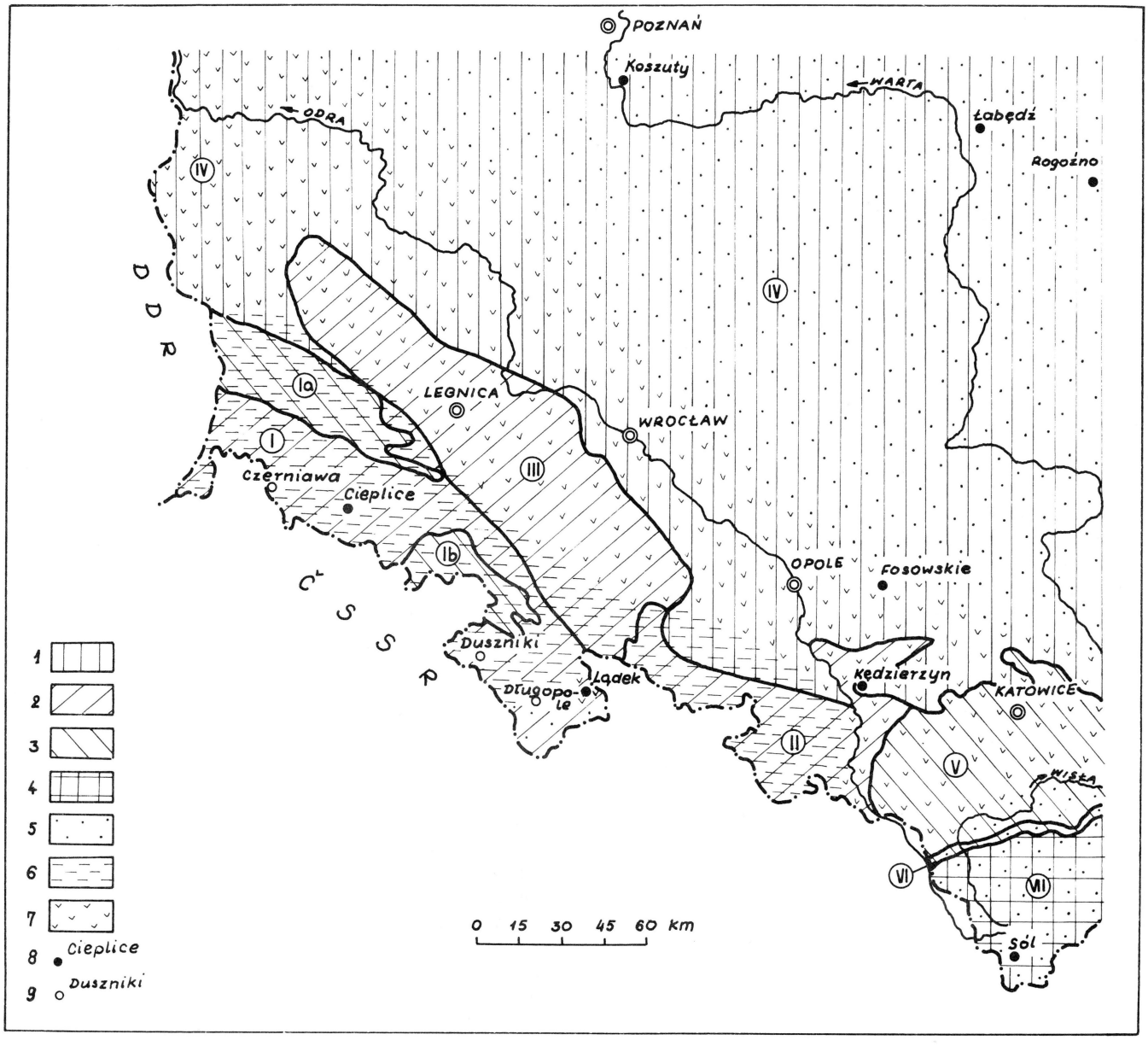

Figure 1. Thermal waters in southwestern Poland. (1) Paleozoic platform; (2) Sudetes and the fore-Sudetic block; (3) Intermontane depressions and foredeeps; (4) Alpides—heat flow distribution (according to Hurtig and Schlosser, 1975), somewhat modified; (5) 1.2 to 1.5 HFU; (6) about 1.6 HFU; (7) 1.6 to 2 HFU; (8) Point of stated occurrence of thermal water; (9) Point of occurrence of cold acidulous water with considerable silica content. (I) Western Sudetes; (Ia) North Sudetic trough; (Ib) Intra-Sudetic trough; (II) Eastern Sudetes; (III) Fore-Sudetic block; (IV) Fore-Sudetic monocline; (V) Upper Silesian trough; (VI) Carpathian foredeep; (VII) Flysch Carpathians.

formations of the Paleozoic platform which dip evenly in the same direction. The platform is covered discordantly by Permian and Mesozoic sediments forming the fore-Sudetic monocline. The Mesozoic series, which grow thicker to the northeast, are a vast reservoir of ground waters. It is supplied mainly in the southwestern part of the monocline, where Triassic and Jurassic sediments crop out to the sub-Kainozoic surface.

The Silesian-Kraków basin is developed in the foreland of the East Sudetes. The main sedimentary series are here Carboniferous deposits with the coal-bearing upper Carboniferous series. They overlie discordantly the folded Devonian. To the northeast the Carboniferous is covered by Permian and Mesozoic sediments, forming the Silesian-Kraków monocline. This unit is separated from the Sudetes by the Opole synclinal basin filled with Cretaceous deposits and to the northwest it passes into the fore-Sudetic monocline.

The Silesian-Kraków basin is separated from the western Carpathians by a narrow zone of the Carpathian foredeep (exogeosyncline), filled with Miocene sediments. The Carpathian nappes composed of Cretaceous and Paleogene flysch are overlapping to the north on the foredeep.

DISTRIBUTION OF HEAT FLOW

The zone of the highest values of heat flow (1.6 to 2 HFU) takes the shape of a belt running from southeast to northwest, approximately parallel to the Sudetic marginal

fault (Fig. 1). It includes the fore-Sudetic block and the foreland of the East Sudetes as well as the southwestern part of the fore-Sudetic monocline. To the southeast it extends over the Silesian-Kraków basin and the southwestern part of the Silesian-Kraków monocline. From the Silesian-Kraków basin a narrow branch of this zone runs to the southeast along the east margin of the Bohemian massif (Hurtig and Schlosser, 1973).

The fore-Sudetic geothermal zone is characterized by almost the highest values of heat flow within the Polish territory. Only within small local positive anomalies connected with Permian salt plugs occurring farther to the northeast of the Paleozoic platform have somewhat higher values been recorded (Majorowicz, 1975, oral commun.). The zone concerned extends eastward in the Carpathian foreland as well as up to the Berlin area to the northwest and seems to belong to the Holland-Altmark-Sudetic foreland geothermal zone.

The zone of lowered heat flow values (1.2 to 1.5 HFU), including the whole remaining part of the Paleozoic platform with the exception of the abovementioned salt plugs, extends to the northeast from the fore-Sudetic zone.

The Polish part of the Sudetes (aside from the southern part of the Kłodzko basin) has been concluded by Hurtig and Schlosser, 1973) to be a zone with normal heat flow values (about 1.6 HFU). The only heat flow measurement performed up to now in the Polish Sudetes (Lądek) has given a value of 1.69 HFU ± 20% (Čermak, 1974 written commun.; Dowgiałło, 1975). To the southwest of the Sudetes there again extends a zone of lowered heat flow values (1.2 to 1.5 HFU).

The existence of the fore-Sudetic geothermal zone may be explained by a comparatively shallow occurrence of crystalline rocks, including Paleozoic granitoids and Kainozoic basalts. The heat flow here may thus be increased by radiogenic as well as by magmatic heat. These formations, covered by Tertiary and Quaternary sediments, are not intensely eroded and only a slow circulation of infiltration waters is possible here. A convectional migration of heat to other areas is, therefore, also difficult. Contrary to the fore-Sudetic block, the Sudetic crystalline rocks which were uncovered during the Pleistocene period were more intensely cooled. Hypsometric differentiation of the surface and a dense network of tectonic fissures cause an intensive circulation of ground waters, which also contributes to the cooling of this area. Moreover, the erosion of the external (rich in radioactive elements) parts of granitic intrusions was probably conducive to the lowering of heat flow values.

OCCURRENCE OF THERMAL WATERS

Sudetes

Thermal waters (warmer than 20°C) within the Polish part of the Sudetes have only been known up to now at Lądek and Cieplice. In these localities they have been used for therapeutic purposes for centuries.

Cieplice lies in the western Sudetes, within the Jelenia Góra valley, north of the granitic Karkonosze range (the highest peak is Śnieżka, 1602 m). Thermal waters occur within fissured Karkonosze granite (upper Carboniferous), covered by several meters of Quaternary deposits. Faults running northwest-southeast and northeast-southwest seem to be the main zones of thermal water circulation. The recharge zones may be situated on the northern slopes of the Karkonosze range or in the Izerskie Mountains, west of Cieplice. In any case infiltration as well as underground circulation are limited to crystalline rocks.

The thermal waters that have been exploited up to now came from springs or shallow wells situated a score of meters from one another. Recently two bore-holes have been drilled at a distance of several hundred meters from the springs. Their depths attained 660 m (Cieplice 1) and 750 m (Cieplice 2). They yield considerable quantities of thermal water (artesian flow)—the borehole Cieplice 2 carrying more than 50 m^3/hr, which exceeds several times the total yield of the springs. Its exploitation, however, causes a decrease of the springs yield.

The content of dissolved solids in the waters considered is 600 to 700 ppm, exceptionally amounting to 1000 ppm. They are of the SO_4—(HCO_3 + CO_3)—Na type except for the stronger mineralized water, which is of the Cl—(HCO_3 + CO_3)—Na type. All thermal waters contain considerable amounts of H_2SiO_3) sometimes exceeding 100 ppm and of fluoride (up to 12 ppm). The α-radioactivity of waters seldom exceeds 3 nCi/l.

Lądek is situated in the eastern part of the Central Sudetes, within the Biała Lądecka valley, at about 450 m. The surrounding mountains are composed predominantly of gneisses and crystalline schists of Precambrian age. The highest point of the drainage area is Śnieżnik (1425 m).

Thermal waters circulate in fissured Precambrian rocks (the Gierałtów gneisses) and flow out from several springs characterized by an almost constant yield and chemical composition of water. Results of drilling recently performed suggest that a fault zone of southeast-northwest direction is the main zone of thermal water circulation.

The content of dissolved solids in the thermal waters of Lądek is very low—160 to 280 ppm, with Na^+ prevailing among cations. The pH values are 8 to 9; the content of H_2S and HS^- together attains 2.5 ppm; of F^-, 11 ppm; of H_2SiO_3, 70 ppm. The α-radioactivity amounts to 40 nCi/l.

Two boreholes have been lately drilled at Lądek. The deeper of them (Lądek 2—700 m) yields more than 10 m^3/hr of thermal water (spontaneous outflow). Although it is situated more than 600 meters to the northeast from the springs, its exploitation causes a certain decrease of their yield.

The temperature of spring waters ranges from 20°C to 29°C. The highest temperature measured at the outflow of the borehole Lądek 2 was 46°C.

The gas content of thermal waters at Cieplice as well as at Lądek is characterized by a considerable prevalence of N_2 (more than 85 percent by volume). The amounts of Ar and CO_2 are comparatively high, although not exceeding quantities which may be found in simple infiltration waters. The N_2/Ar ratio is not considerably lowered in relation to the atmosphere (taking into account the solubility of both gases), while the He content is relatively high. This fact may be explained by high uranium content both in the Karkonosze granite and in metamorphic rocks of the Lądek area.

Determinations of the oxygen and hydrogen isotope composition of the Sudetic thermal waters have shown unequivocally their atmospheric origin (Dowgiałło, 1973), δD ranging from $-75.6‰$ to $-65.5‰$; δO^{18} from $-10.6‰$ to $-9.7‰$. Warmer waters are isotopically lighter than the colder ones, which is in good agreement with their tritium

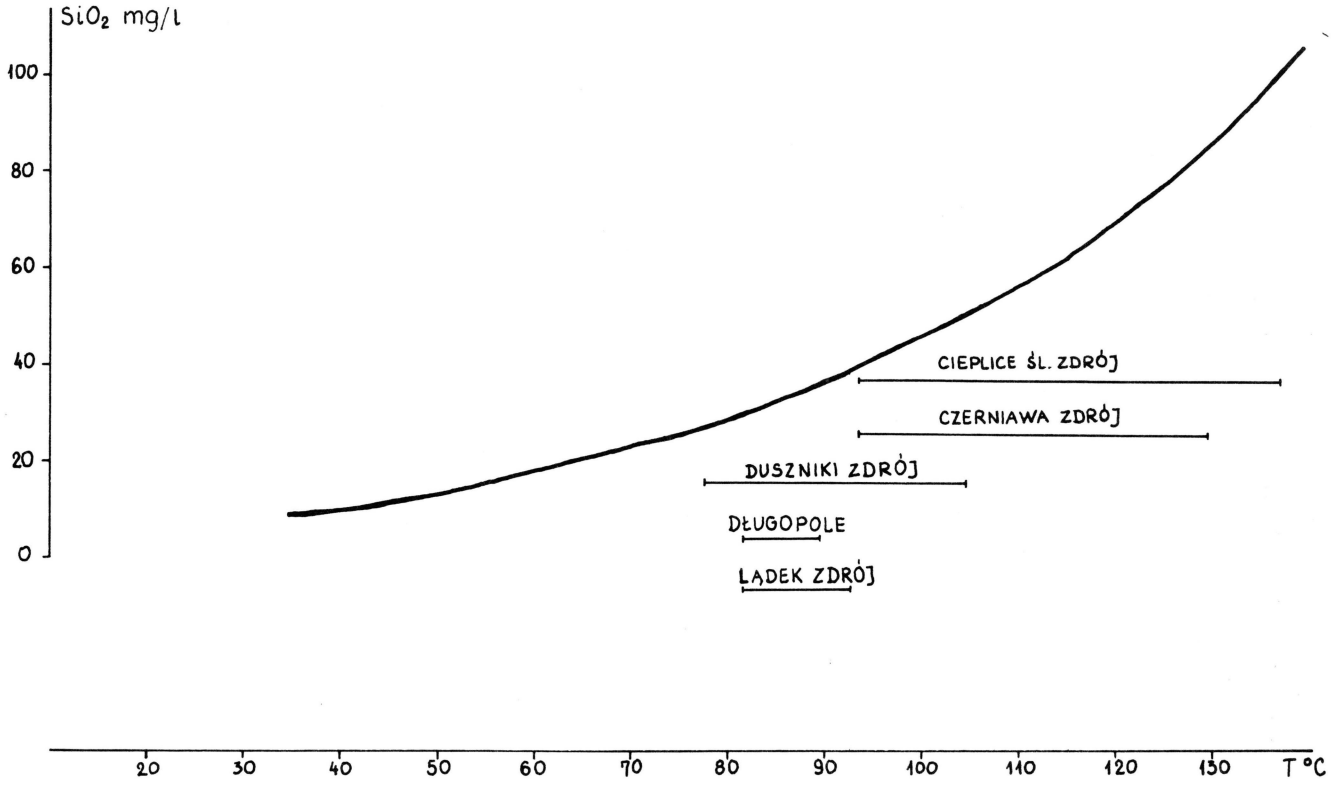

Figure 2. Estimated temperatures of Sudetic waters based on their silica content.

and C^{14} dating (Dowgiałło, Florkowski, Grabczak, 1975). The latter investigations have shown that the age of the warmest waters may go back to the early Holocene or even late Pleistocene (up to 28 000 years at Cieplice). In the period of infiltration the climate of the Sudetes was much colder than at present and the "oldest" waters obviously contain less of the heavy isotopes than the "younger" ones. Moreover, they probably infiltrated at greater heights than local precipitations, which influence the temperature and head of the colder waters.

Using the reference graph presenting the relation between the water's temperature at depths and its silica content (Fournier and Truesdell, 1970), an approximate evaluation of water temperatures at the bottom of the circulation system could be done. As shown in Figure 2, waters at Lądek never attained 100°C, while almost all waters at Cieplice had, at a given moment, temperatures exceeding 100°C. The question of whether this fundamental difference results from different heat flow values in both areas, or from a deeper circulation at Cieplice than at Lądek must remain unanswered until detailed investigations of the geothermal parameters in these areas and in other parts of the Sudetes are performed.

The silica content is often considerable not only in thermal waters but also in various Sudetic cold mineral waters, containing large amounts of CO_2 (Długopole and Duszniki in the central Sudetes and Czerniawa in the western Sudetes). Some of these waters have probably also attained considerable temperatures at depths and have later been strongly cooled as a result of the CO_2 expansion. Thus, the silica hydrogeothermometer shows that surveying prospects for thermal waters do not exist only in areas where such waters have been previously known. Other areas, where crystalline formations are not covered by younger sediments are, therefore, also promising insofar as the exploitation of slightly mineralized thermal waters is concerned (Dowgiałło, 1975). Their resources exceed probably many times the quantities recorded up to now at Lądek and Cieplice.

Extra-Sudetic Area

Besides the Sudetes, thermal waters have been discovered by drilling within the Paleozoic platform (the fore-Sudetic monocline and, further to the northeast, the Szczecin-Łódź trough). Such waters have been found at numerous points; in this paper, however, we are dealing with those which are not strongly mineralized and flow out spontaneously from boreholes, and thus are especially convenient for exploitation.

Thermal waters occurring in Mesozoic deposits of the fore-Sudetic area are of the Cl-Na type, their total dissolved solids content ranging between less than 1 g/l to several tens of g/l. With the increasing thickness of Mesozoic deposits toward the northeast, one may observe an increase in the salinity of deep ground waters in the same direction, although it is not always the rule because of the existence of tectonic disturbances (for example, Łabędź). As shown by isotopic investigations (Dowgiałło and Tongiorgi, 1972), waters occurring in Mesozoic sediments of the Paleozoic platform contain an admixture of relict, marine waters, probably of Mesozoic age. The percent of the relict component grows in substance together with the growing salt content of the waters concerned and with the depth of their occurrence. Although the salinity may also originate from the lixiviation of Permian rock salt, this phenomenon seems to be limited to areas where salt plugs occur.

Within the Opole basin on the west border of the Silesian-Kraków monocline the occurrence of slightly mineralized

thermal waters in Triassic deposits has been determined to be at comparatively unimportant depths at Fosowskie and Opole (Fistek and Młodzianowski, 1974). This fact is easily explained; this area is lying within the zone of somewhat increased heat flow values (Hurtig and Schlosser, 1973; Majorowicz, 1973). The influence of this fore-Sudetic geothermal zone seems to reach the western Carpathians, where at Sól important resources of thermal brine have been discovered (Table 1).

CONCLUSIONS

An attempt to quantitatively evaluate the geothermal resources of southwestern Poland would be premature. Further, many-sided investigations including geothermics as well as hydrogeologics are needed. Table 2 shows that the total yield of spontaneous outflows recorded up to now in the area considered, the surface of which is about 60 000 km^2, does not exceed 200 l/s, while the average temperature of these waters is somewhat less than 40°C. Thus, the temperature of the thermal waters average about 32°C higher than the mean annual temperature of 8°C. The total quantity of heat extracted up to now from the area with waters warmer than 8°C may be estimated as 6.4×10^3 cal/s, which corresponds to about 1.1×10^{-5} cal $\times$ s^{-1} cm^{-2}. If we cautiously assume that the heat flow density in this area is 1.2 cal $\cdot$ s^{-1} cm^{-2} it may be stated that, from the point of view of geothermal balance, the extraction of thermal waters might be increased here about 10^5 times. Obviously, such intensive extraction of deep ground waters requires a previous detailed estimation of their resources to avoid the disturbance of their hydraulic and chemical equilibrium.

As far as the energetic use of thermal waters is concerned, the slightly mineralized waters of the Sudetes and of the Opole basin seem to be the most promising up to now. The next area, where investigations will probably show the existence of considerable geothermal resources is the fore-Sudetic block. The exploitation of thermal waters from the Mesozoic sediments of the fore-Sudetic and Silesian-Kraków monoclines may encounter technical difficulties due to their salinity; however, these waters may still serve for the large development of health resorts.

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Table 1. Selected analyses of thermal waters from the fore-Sudetic platform and the West Carpathians.

Location	Koszuty		Łabędź		Sól	
Age of aquifer	Jurassic		Cretaceous		Tertiary	
Depth (m)	1020		1120		1300	
Temperature at the outflow (°C)	40.5		59		35	
	ppm	% mval	ppm	% mval	ppm	% mval
Na	2950	92.20	2750	92.39	16 200	93.33
K	24	0.44	26.5	0.53	91	0.31
Li					20	0.38
NH_4					19.5	0.14
Ca	125.69	4.51	160.6	6.20	383.16	2.54
Mg	41.64	2.46	6.8	0.43	232.50	2.54
Ba					146	0.28
Sr					149	0.48
Fe^{2+}	3.12	0.09	16.5	0.45	7.13	0.03
Mn	0.3	0.01			tr.	
Cl	4690.96	95.10	4070.46	88.69	26 192	97.87
Br	4.0	0.04			133.2	0.22
J	0.4	0.0			15.8	0.02
SO_4^{2-}	1496	2.24	151	2.43	16.6	0.05
$HCO_3^- + CO_3^{2-}$	222.11	2.62	401.77	9.32	848.15	1.89
HBO_2					98.8	
H_2SiO_3	22.1				20.8	
Total dissolved solids	8241.2		7583.37		44 573.71	

Table 2. Spontaneous outflow of thermal waters in southwestern Poland.

Locality	Depth of captures (m)	Age of the aquifer	Yield (l/s)	Temperature (average)	Total dissolved solids (g/l)
Koszuty	1020	Lower Jurassic	11.1	40.3°C	8.0
Łabędź	1780	Lower Cretaceous	19.4	59.5°C	7.4
Rogóźno	260	Lower Jurassic	31.7	32°C	1.5
Cieplice	0–750	Upper Carboniferous	16	20–63°C (55°C)	0.6–1
Lądek	0–700	Precambrian	40	24–46°C (41.5°C)	0.2
Opole	600	Lower Triassic	13.8	26°C	0.7
Fosowskie	500	Lower Triassic	5.5	24°C	0.8
Sól	1300	Tertiary	41.6	35°C	44

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