New findings in the Walbrzych-Klodzko geothermal subregion (Sudetes, Poland)

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Abstract

The subregion concerned forms the south-eastern part of the Poland's Sudetic Geothermal Region. Warm springs up to 29°C.are known at Ladek At Duszniki some springs and shallow boreholes produced or produce carbonated water, its temperature close to, or slightly exceeding, 20°C is lowered by CO_2 expansion The existence of a positive geothermal anomaly was assumed in this area

A 1695 m. deep borehole has been recently carried out at Duszniki with the purpose to supply thermal water for medical treatments and space heating. Below the Quaternary (6m. thick) the drilling pierced micaschists and gneiss of Proterozoic (Lower Palaeozoic?) age. In zones of tectonic disturbances water inflows and strong CO_2 eruptions were observed.

The results are less positive than expected. Water flowing free (yield $24m^3/h$) has the maximum temperature of 35.8°C while the amount of CO_2 produced is $160m^3/h$. The average thermal gradient does not exceed 2°C/100m and the estimated heat flow density is less than $50mW/m^2$.

As no positive heat flow anomaly has been found the explanation for water temperature is its deep circulation through fault zones. Its recharge area may be as elevated as 850m (in the Bystrzyckie Mts), while stable isotopes measurements suggest an altitude of 1000m (Orlickie Mts).

Keywords: thermal water, Duszniki, Sudetes, Poland

Introduction

The Walbrzych-Klodzko subregion forms the SE part of the Sudetic Geothermal Region of Poland [Fig.1] It has been distinguished by [8] because of its typical features, both geological (metamorphic complexes of the Orlica – Klodzko Dome occupying large parts of the land's surface along with the sedimentary series of the Intra - Sudetic Trough) and hydrogeological (presence of lukewarm and warm waters emerging in natural springs and many springs of CO_2 – rich mineral waters. The thermal waters occur in the crystalline formations of the Klodzko-Orlica Dome and are either simple acratothermae (Lądek) or carbonated waters (Duszniki). The subregion seems to be geothermally promising, in particular as regards the Intra-Suidetic Trough. It is suggested [9] that the post-Laramian mobilization and migration of basic magma which may be observed in other parts of the Sudetes in the form of basaltic volcanism could not reach here the surface because of compressional stress typical of the synclinal tectonic forms. This means that some magma centers could be preserved at depths. Their possible indicators are strong manifestations of CO_2 observed both within the Trough (e.g Szczawno, Jedlina) and in the Nysa Graben (Długopole. Especially numerous are the CO_2 occurrences along the Pstrażna - Gorzanów fault being the tectonic border between the Intra-Sudetic Ttrough and the crystalline formations of the Bystrzyckie and Orlickie Mts.[11].

Fig. 1. Geological sketch and cross-section of the Duszniki area (J.Fistek)

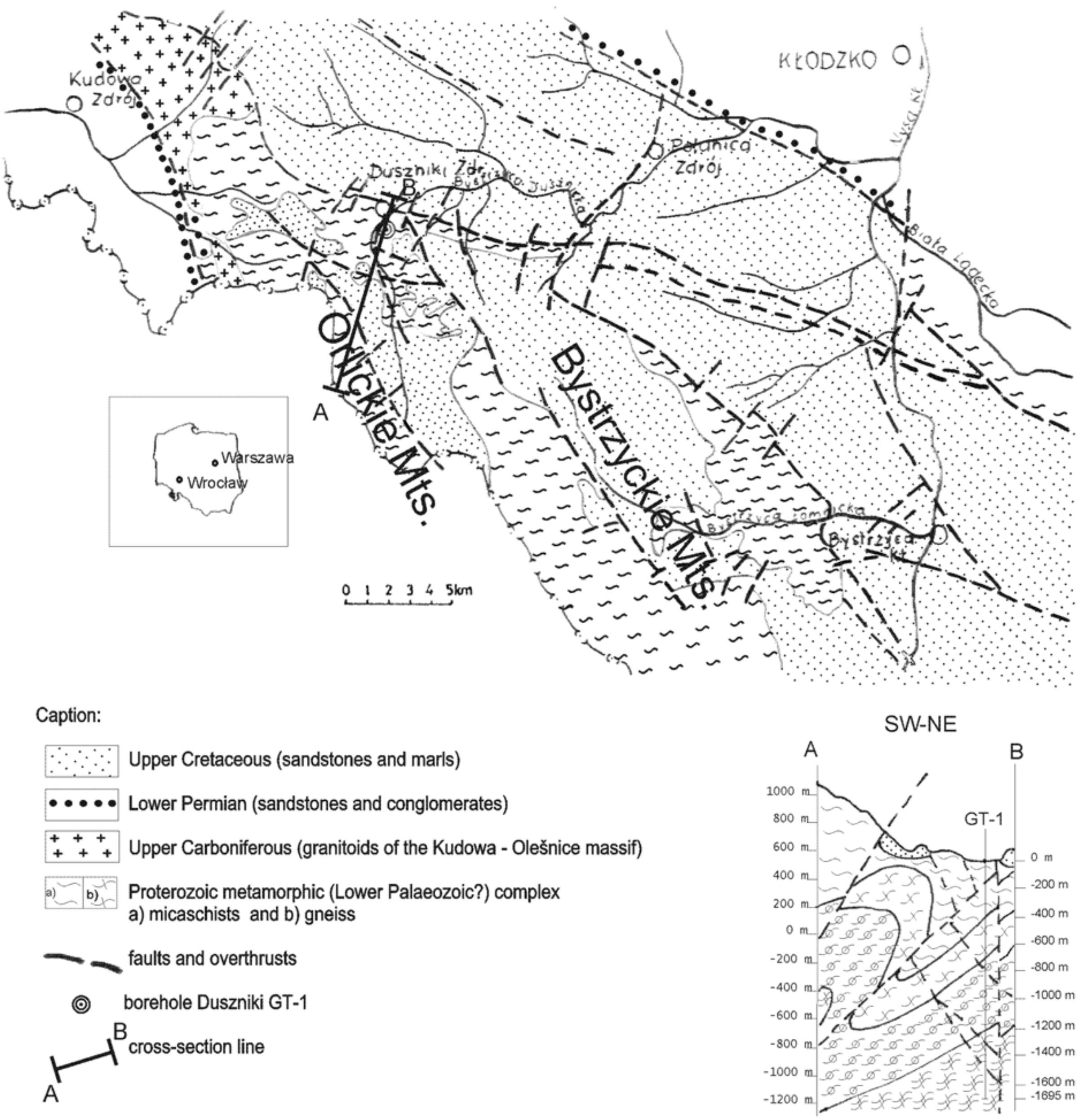


Fig. 1. Geological sketch and cross-section of the Duszniki area (J. Fistek)

Geothermal investigations performed so far in the area under consideration did not reveal distinct anomalies in heat flow density [3].The only exception is Lądek where measurements performed by V. Cermak and published in [6] gave as result 70mW/m^2. Otherwise values between 50 and 62 mW/m^2 were found .It has to be stressed, however, that the borehole network is not dense enough and that the precision of temperature measurements was not always granted as recently pointed out by [16].

The question of supplying the health resorts of the Walbrzych – Klodzko subregion with thermal waters was raised by numerous authors, e.g. by [11], [12] The need for substituting fossil fuels by clean energy sources does not require substantiation. This is particularly important in spas where climatic treatment is equally important as the use of curative waters.

Duszniki Spa was chosen for the prospection drilling as there were prerequisites for optimism. Existing data analyzed by [7] suggested that a positive heat flow anomaly does exist in the

area. Both the presence of lukewarm natural springs in the past and thermal profiles of boreholes up to the depth of 160m corroborated this hypothesis.
The project of the drilling was prepared by the second author and the National Fund for Environmental Protection and water Management decided to finance the undertaking. The works started in October 2000 and came to the end in January 2002. The depth of the borehole reached 1695m.

Outline of geology and hydrogeology

The Duszniki area has a complicated geological setting On one hand we have here to do with the complex crystalline structure of the Bystrzyckie and Orlickie Mts belonging to the mega-unit called the Klodzko – Orlica Dome, on the other with sedimentary rocks of the Upper Cretaceous.The latter are linked to the Intra –Sudetic Trough, the Nysa Klodzka Graben and to the Orlickie and Bystrzyckie Mts block, where they form fragments of the non – eroded, former sedimentary cover of the crystalline. Cretaceous sediments consist of alternating sandstones and silicic or clayey mudstones. Larger tracts of this formation appear mainly within tectonic depressions.
The Duszniki town is crossed by an important fault running WWN – EES, called the Duszniki marginal fault. (Fig.1) It is the structural border between the Intra – Sudetic trough and the Bystrzyckie and Orlickie Mts block. With this dislocation are directly connected the appearances of carbonated waters at Duszniki and its neighbourhood (Stare Bobrowniki and Gorzanów). Indirectly the fault is responsible for the presence of carbonated waters at Kudowa, Polanica and Dlugopole [11].
Along the line Podgórze – Graniczna – Zieleniec, at the foot of the Orlickie Mts there is another important fault running NW – SE. The area situated between the two faults is a tectonic depression, within which the spa has developed. A dense net of dislocations may be observed here. They cut the area into tectonic blocks displaced against each other and stepwise sinking towards the North.
The metamorphic rock complex includes a variety of Algonkian or Lower Palaeozoic gneiss and schists, in particular micaschists, quartzite- graphite- albite – epidote- chlorite – biotite and phengite schists with intercalations and lenses of crystalline limestone in the upper parts of the series. The foliation of these rocks hades mostly towards N and NW. N and E of Duszniki. At Bobrowniki Stare there occur microcline gneisses defined also as mylonitic ones, of a veined, rod and even eye texture.
Within thee described crystalline series, in particular along the line of the Duszniki marginal fault quartzic porphyry intrusions may be found. They belong to the Variscan (Upper Carboniferous) tectonic–magmatic cycle. They are sometimes accompanied by tectonic breccias, highly quartziferous, abundantly impregnated with hematite.
As reported in [5] a spring of acidulous water (Cold Spring) was known at Duszniki (the then Reinerz) already in 1468, while the the Lukewarm Spring (now Chopin,s Frothing Spring) was first mentioned by [2].This is the first published indication of the spring water's temperature deviating from normal. Such indications do not exist in earlier publications mentioning the presence of carbonated waters at Duszniki [1], [18], as well as in some later ones [17]. This confirms the obvious fact that the water's temperature was not high enough to attract the writers' attention
Some of the natural mineral water springs at Duszniki were later deepened by drilling (Chopin's Frothing Spring – 78m, Jan Kazimierz – 165m.).They yield $15m^3/h$ and $3m^3/h$ respectively, of carbonated water flowing free. Several new boreholes have been also drilled up to the depth of 90m [18]. Natuiral springs disappeared along with the growing size of the drawdown cone.

The Duszniki carbonated waters are of the HCO_3-Ca-Na and/or –Mg types with a high con tent of iron (8 – 20ppm). Their TDS is from 1500 ppm to 2800 ppm. The highest temperature (18^0C) is typical for the Chopin's Frothing Spring (the former Lukewarm Spring). Water from other wells has the temperature from 12 to 16^0C.

Drilling results

The results of the Duszniki GT-1 borehole drilling have been summarized on Fig. 2. Its schematized geological profile is as follows:

0 – 6m soil, peat gravel, clay (Quaternary)
- 390m micaschist
- 808m muscovite – biotite paragneiss with intercalations of micaschist
- 1255,5m gneissose granite
- 1695m thinly laminated gneiss with intercalations of micaschist and amphibolite

Beneath the Quaternary the drilling pierced metamorphic formations of Proterozoic (Lower Palaeozoic?) age. They belong to the Stronie schist series and the gneissic series of the Bystrzyckie and Orlickie Mts. The latter is the SW part of the Klodzko – Orlica Dome.

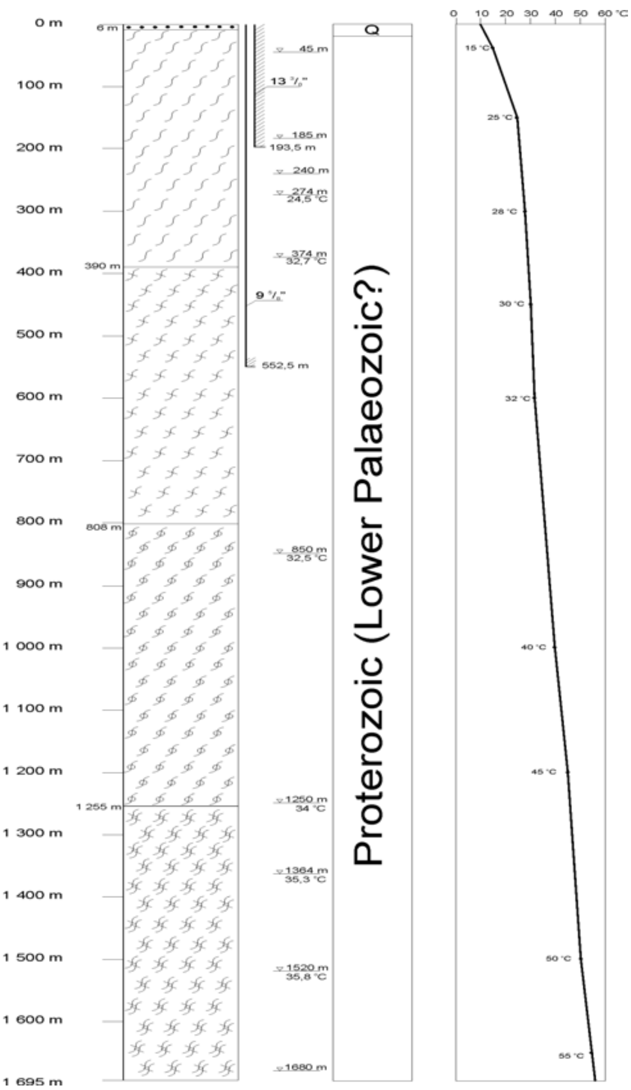


Fig. 2. The simplified drilling profile with hydrogeological, geothermal and technical information (J. Fistek)

During drilling several tectonically disturbed, water-bearing zones were met [Fig.2]. Some of them have been located basing on drilling mud escapes and geophysical logging. Others are typical of artesian outflow of CO_2 –oversaturated water and strong gas eruptions. The most distinct tectonic zones exist at depths: 224-240m, 274-284m, 1345-1346m. [Fig.2].

Two main water-bearing zones have been distinguished and made available for exploitation:

I. Depth 193,5 – 534m. Water may be extracted from the space between $13^{3/8"}$ and $9^{5/8"}$ casing. The spontaneous yield is $20m^3/h$, the water temperature is 29^oC, its chemical type may be characterized as HCO_3-Ca-Na-Mg,Fe with TDS amounting to $3200mg/dm^3$ and free CO_2 to $2200mg/dm^3$.

II. Depth 552,5 –1695m – borehole not cased. Spontaneous yield depends on the production pipe diameter and depth of sinking of production pipes. Without these pipes the yield of the pulsatory outflow (the volume of CO_2 7 – 8 times exceeding the volume of water) exceeded $30m^3/h$. The water temperature was $34,7^0C$, its TDS amounted to $3450mg/dm^3$ and the water type was HCO_3 – Ca – Mg, Fe

Both intervals collect water originating from numerous fissures and most probably are interconnected. The lower one produces water of higher temperature, slightly higher TDS and a slightly more pronounced content of Mg. Water from both intervals is chemically very similar to that from shallow boreholes.

Geothermal considerations

Thermal logging has been done several times at different depths of the borehole both cased and uncased. Because of technical problems connected with the eruptive character of CO_2 discharges the thermal equilibrium has not been attained and the obtained gradient figures not exceeding $2^0C/100m$ are probably lower than the real ones. The temperature measured at the depth of 1640 in water-flowing conditions when the drilling was finished was 55.8^0C (Fig. 2). For thermal equilibrium conditions this temperature would mean that the geothermal gradient amounts to about $3^0100/m$. However the factual situation suggests that this temperature is due to water flowing from greater depths.

A regional geothermal picture for the Sudetic region was presented by [3]. According to this synthetic presentation the mean temperature gradients determined in boreholes closest to Duszniki (Dlugopole and Stary Waliszów: 24km and 27km, respectively, SE of Duszniki) are 3,13 C/100m and 3.51 C/100m, respectively and the heat flow density calculated for these boreholes is $54,5mW/m^2$ and $63,5mW/m^2$, respectively. The heat flow density in the Duszniki area is accordiong to the map (3] below $50mW/m^2$.

Results of isotopic measurements

Tritium and stable isotopes of hydrogen and oxygen were dete4rmined in water samples taken during drilling and after its completion.

The tritium content (Table 1) allows us to distinguish 3 groups of water flowing from the Duszniki GT-1 borehole.

I. Above 10 TU.(sample 1). The content of tritium testifies to a very high proportion of recent infiltration water. The water-bearing zone is recharged by close-to-surface water. Maybe, there is also some influence of water from well B-1 (8,2 TU) which was used to prepare the drilling mud.

II. 4.1 – 5 TU (samples 4 and 5). The admixtures of drilling mud in the non-cased section of the borehole (193.5 -.560m) and maybe also inflows of shallow circulation water are still observable.

III. 0.5 – 3.1 TU (samples 3, 6 – 12). The inflows of groundwaters containing tritium is possible although looks less probable. The low content of tritium in sample 3 is enigmatic. A well-marked drop in the admixture of close-to-surface water in samples 6 – 12 shown by the low tritium content in samples seems to be linked with the casing reaching the depth of 552,5m.

Table 1 Results of tritium determinations

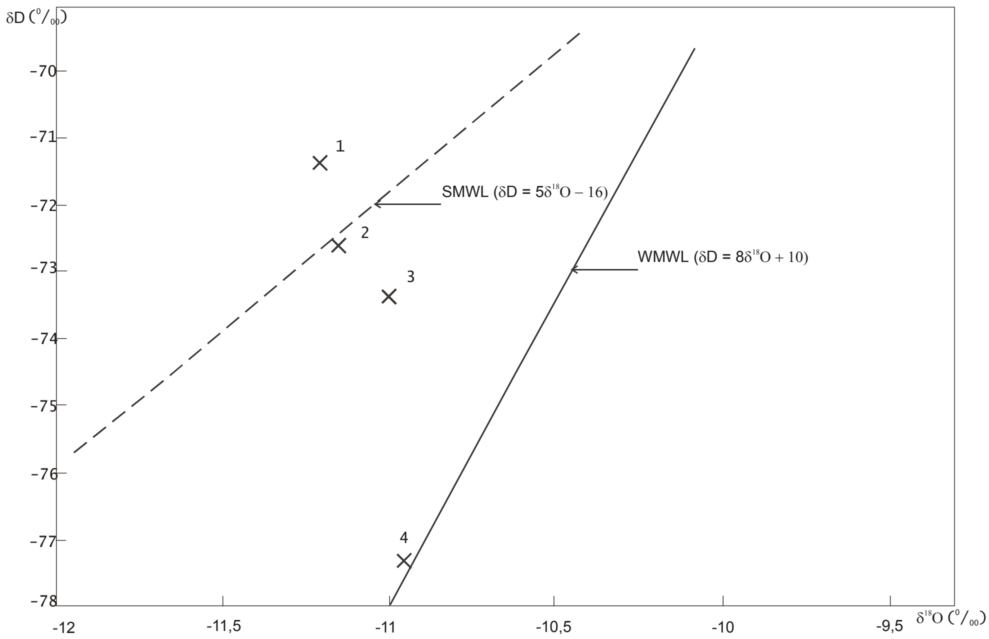
Sample No	Sampling date	Inflow depth (m)	TU	Remarks
1	8.12.2000	198	10,5±0,5	-
3	27.12.2000	193,5-218	1,8±0,2	Easing to the depth of 193,5 m
4	20.3.2001	193,5-560	5,0±0,13	
5	21.3.2001	193,5-560	4,1±0,23	
6	4.4.2001	552,5-796,5	2,8±0,5	
7	7.6.2001	1100-1220	2,1±0,44	Production pipe at 1100 m
8	18.9.2001	1400-1500	3,1±0,5	
9	4.2.2002	1500-1695	0,5	Production pipe at 1500 m
10	9.2.2002	552,5-1695	1,8±0,45	
11	14.2.2002	552,5-1695	1,7±0,42	Production pipe at 850 m
12	14.2.2002	552,5-1695	2,2±0,33	

The results of stable hydrogen isotopes and oxygen isotopes determinations are listed in Table 2. and on Fig. 3 These results are shown against the background of the World Meteoric Water Line (WMWL) and the Sudetic Meteoric Water Line (SMWL), the equation of which was proposed by [4]. The distribution of points on the graph (Fig. 3) suggests that:

1. With increasing depth the content of deuterium in water is dropping. This means that the deeper is the water-bearing zone, the higher is the proportion of distant circulation water recharged at higher altitudes.
2. The picture of ^{18}O content is opposite: with increasing depth the content of heavy oxygen is also increasing. This phenomenon may occur due to the isotopic exchange of oxygen between water and rock-forming minerals containing heavy oxygen. This process may be intensified by temperature increase with depth. Also slower water movement at depths and its longer contact with rocks may result in the picture observed on Fig 3.

Table 2 Results of stable hydrogen isotopes and oxygen isotopes

Sample No	Sampling date	Inflow depth (m)	$\delta^{18}O$	$\delta D \pm 0,8$
			(‰ V - SMOW)	
1	19.01.2001	193,5-374	-11,4	-71,4
2	4.04.2001	552,5-796,5	-11,3	-72,6
3	7.06.2001	1100-1220	-11	-73,9
4	14.02.2002	552,5-1695	-10,96	-77,4



(*)1-4 - sample numbers as in table 2

Fig. 3. Oxygen and hydrogen stable isotopes copmposition in waters from Duszniki GT-1 borehole (J. Dowgiallo)

According to [5] the altitude effect for shallow groundwaters in the Klodzko region may be estimated for ^{18}O as –O.17%0/100m and for deuterium as -1.15%0/100m. Taking into account the possible modifications of oxygen isotopic composition in thermal water due to water-rock interaction only deuterium may be considered as possible altitude indicator. According to various estimates the recharge area altitude for the deepest water with delta D = -74.4%0 may vary between 970m a.s.l. and 700m a.s.l. Both values are admissible taking into account the real altitudes occurring in the Orlickie and Bystrzyckie Mts. It should be, however, stressed that these estimates cannot be considered as exact ones. Supposed mixing of water in the whole profile of the GT-1 borehole allows only to use them as indicatory figures.

The question of water – rock thermodynamic equilibrium

To analyse the question of the extent to which thermal water at Duszniki has reached the equilibrium with rock – forming minerals a diagram has been constructed according to the method proposed by [15] (Fig.4). Waters from both exploitation horizons (A and B) of the GT-1 borehole have been compared with other carbonated waters at Duszniki (Jan Kazimierz-DJK, B-4 borehole –DB=4, Chopin's Frotting Spring – DPC) and with thermal waters at Ladek (the L-group) and Cieplice (the C-group). The conclusions which may be drawn from the graph are as follows:

1. Both thermal and cold waters at Duszniki are situated in the field of immature waters which means that even partly they did not reach equilibrium with the rock
2. Thermal waters from the GT-1 borehole are situated in one point on the graph which testifies to a homogeneous groundwater environment and to the interconnection of all water-bearing zones from the top to the bottom of the hydrogeological system. Chopin's Frotting Spring seems to a local exception.

3. The fast circulation of water in the system does not allow it to reach the temperature corresponding to the thermal conditions occurring at the bottom of the system

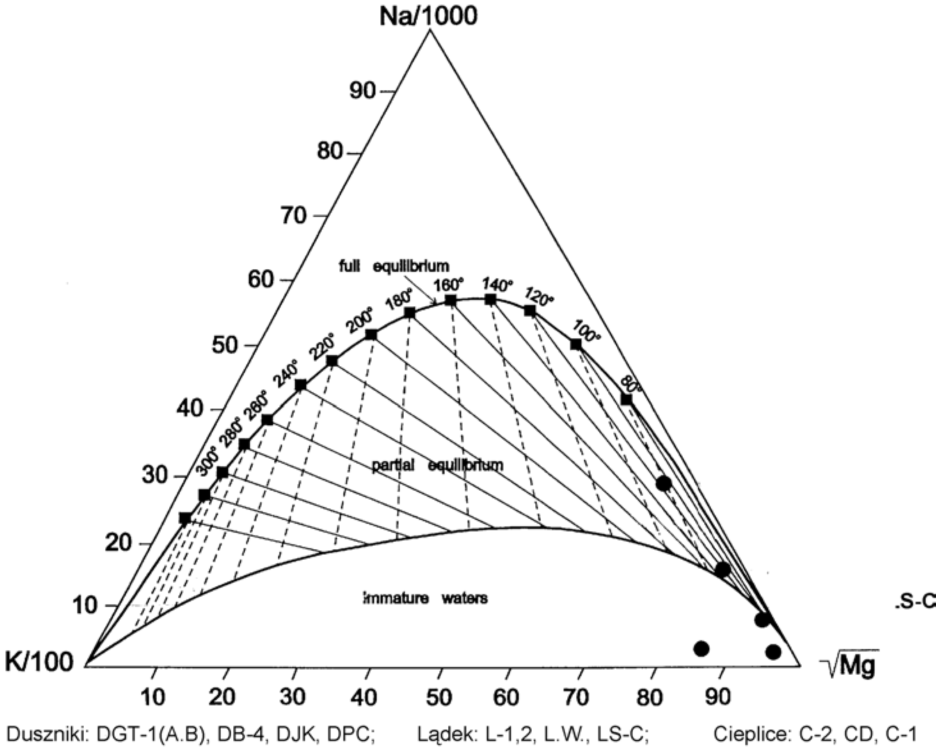


Fig. 4. Na-K-Mg diagram for Duszniki cold and thermal waters compared with Ladek and Cieplice waters

Conclusions

Although the borehole Duszniki GT-1 did not corroborate the hypothesis suggesting the existence of a positive heat flow density anomaly the results are positive both from the scientific and practical point of view. The zone of the Pstrażna – Gorzanów fault (10) has been confirmed as a deep water circulation area and a possible source of considerable thermal water amounts. The recharge area for these waters as suggested by isotopic measurements may be as high as the top parts of the Bystrzyckie Mts (850m a.s.l.) and even the Orlickie Mts (1000m.a.s.l.
The borehole supplied thermal mineral water for medical purposes and recreation swimming pools. Some space heating with water used in swimming pools (possibly with the application of heat pumps) may be also considered.

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