Evolution of selected geochemical and reservoir factors influencing the exploitation of the Podhale geothermal system, S-Poland

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Abstract

The Podhale system was the first in Poland where geothermal space heating and other uses were initiated in the 1990's. In 2001 the main facilities of a regional heating system were started. It will be one of the largest in Europe in its capacity and heat production. Water discharged from Mesozoic and Eocene carbonates, has a temperature of 76-86°C at the outflows, and forms a good basis for multipurpose uses. To assure proper current production and project development, the investments have been accompanied by research and monitoring of the system. Recently, a study was done using selected methods (X-ray analysis, fluid inclusions, geothermal geochemistry) including those used to analyse thermal evolution of sedimentary basins (e.g. Oxyreactive Thermal Analysis, for the first time applied for Podhale). They combined cognitive and practical aspects to define factors controlling processes crucial for geothermal evolution, exploitation and use. The paper presents some results of the mentioned research and monitoring of the Podhale system in reference to sustainable longterm production for space heating and other uses. It focuses on such issues as water-rock equilibrium, secondary mineralization, scaling, corrosion, and results of almost 10-years of hydrodynamical and chemical monitoring. Considering curative features of geothermal water, the prospects of extending uses applications by balneotherapy and recreation are presented. These services should be widely developed in Podhale – the main tourist area in Poland. The subject is supplemented by a brief paleohistory of those components of the system, which are essential for its understanding, optimum exploitation, and use.

Keywords: *Podhale**,** geothermal system, geochemical and reservoir factors, direct uses.*

1 Introduction

The Podhale system was the first in Poland where geothermal space heating and other direct uses were initiated in the 1990's. Water produced from Mesozoic and Eocene carbonates has a temperature of 76-86°C at the outflows and forms a good base for multipurpose applications. There, one of Europe's larger regional geothermal heating project has been under realisation (target capacity 50 MW_t, heat production ca. 600 TJ/y; Dlugosz, 2003). In 1990-2001 one doublet of wells was in operation. In late 2001 the heating system was expanded considerably by two new wells, other facilities and linking some part of receivers in Zakopane – the main city of the region (population 30,000, over 3 million tourists/y). Until 2005 geothermal will supply a prevailing number of buildings in this city and the whole region. Simultaneously, the PAS MEERI Geothermal Laboratory has conducted R&D works on cascaded uses (Bujakowski, 2000). These activities have been accompanied by basic research and new methods were introduced recently, the results of which are presented in this paper. Some studies were carried out within the framework of a Research Grant No. 5T12B00822 financed by the State Committee for Scientific Research (Poland).

2 Geological and geothermal setting

The Podhale system is located within the Inner Carpathians – a part of alpine orogene (Figure 1). It is one of the systems of similar origin, which surround the Tatra Mts. The main geothermal aquifer occurs in the Middle Triassic limestones and dolomites and Middle Eocene carbonates (depths up to 2.5-3.5 km). The reservoir temperatures vary from 20 to 90°C. The water flowrates from the wells amount to 55-150 l/s. The static wellhead artesian pressure is up to 26 bar. A caprock for geothermal aquifers is built by the Paleogene (Late Eocene-Oligocene) flysch (up to 2.5-3.2 km thick). Over ten geothermal wells were drilled within this area (Kepinska, 2000). The rocks, which built the Podhale system, underwent long and complex geological evolution. The Middle Triassic rocks are ca. 235 Ma, while the sedimentation of the Middle Eocene carbonates started ca. 50 Ma ago, and the Podhale flysch45 Ma ago. Their common history as a geothermal system began after the flysch had been deposited, ca. 22 Ma ago.

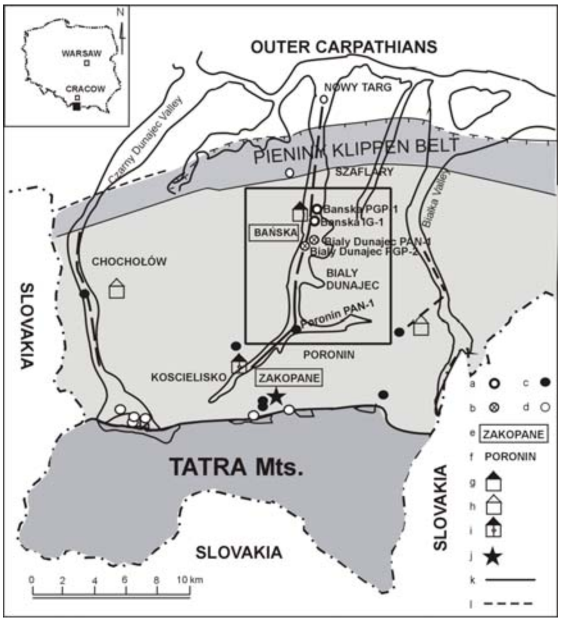

Figure 1: A sketch of the Podhale geothermal system. a-c geothermal wells: a. production, b. injection, c. not in use, d. other wells, e. locality with geothermal space heating system on-line (2003), f. localities planned to be geothermally heated (by 2005), g. geothermal base load plant, h. geothermal heating plants planned, i. central peak heating station, j. geothermal bathing centre under construction (2003), k. main transmission pipeline, l. transmission pipelines planned. Framed is the area of study presented in this paper.

3 Methods and area of study

To assure proper geothermal water production and project development, investments have been accompanied by investigation and monitoring of the Podhale system. Recently, there have been introduced some methods of geothermal geochemistry, X-ray analysis, fluid inclusions microthermometry and also methods of studying thermal evolution of sedimentary basins, e.g. the thermal transformation of illite/smectite and the evaluation of organic material maturity. The latter involves a new type of thermal analysis, the Oxyreactive Thermal Analysis, OTA (Cebulak et al., 1999). These researches combine both cognitive and practical aspects to learn factors crucial for the evolution of the geothermal system as well as its current exploitation and field development planning. The issues presented in this paper are based on the data and investigations made for several geothermal wells. All the wells but one (Poronin PAN-1) are located within the exploitation sector of the system (Figure 1). High reservoir temperatures up to 80-90°C, high water flowrates up to 150 l/s, and high total and effective thickness of reservoir formation (up to 800 and 100 m, respectively) characterize it. Moreover, this sector is affected by deep faults, which favour intense fluid circulation and hydrothermal processes.

4 Selected factors controlling the Podhale geothermal system

4.1 Temperatures

The present reservoir temperature reaches 80-90°C at a depth of 2-3 km within the discussed sector. Figure 2 shows the present deep temperature in the vicinity of the Bialy Dunajec PAN-1 well (line a), the paleotemperature derived from the fluid inclusion microthermometry (that was made for very small but abundant calcite crystals, sometimes quartz), as well as degree of thermal transformation of illite/smectite group (lines b and c).

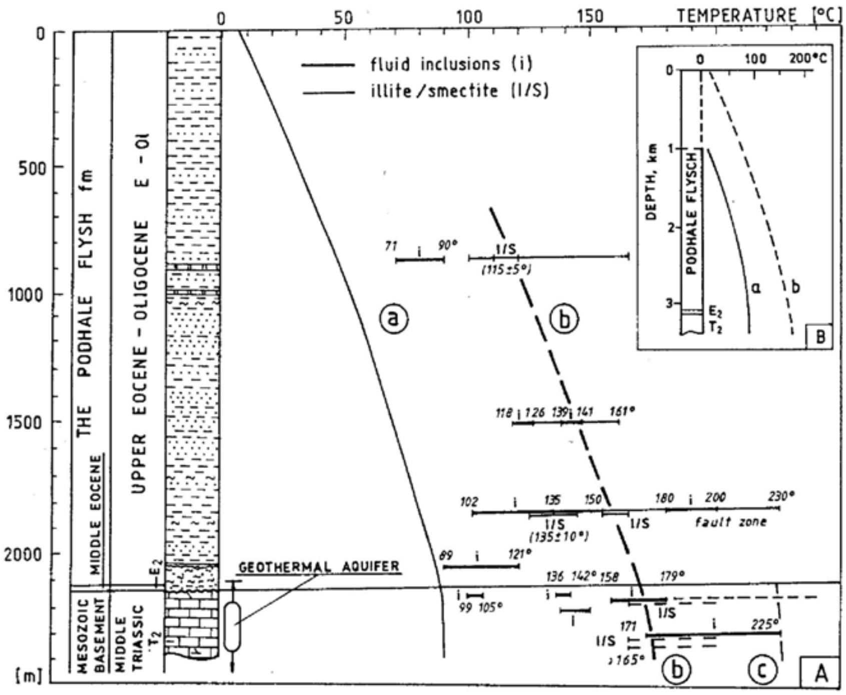

Figure 2: The Podhale geothermal system - present and past subsurface temperatures in the area of study. Case of Bialy Dunajec PAN-1 well (based on Kepinska, 2001) A. Temperatures shown against geological profile: a - present, b - presumed maximum paleotemperatures (after Oligocene), c - approximate paleotemperatures within the Middle Triassic rocks before the Upper Cretaceous orogenic movements. Figures mark the ranges of the fluid inclusion homogenisation temperatures (bolded are more frequent intervals); I/S - temperature ranges according to the illite-smectite group thermal transformation study, intermitted line shows temperature range in the Middle Triassic rocks (before alpine orogeny). B. Temperatures shown against geological profile before erosion of ca. 1–2 km of flysch cover: a - present temperatures, b - presumed paleotemperatures (as shown at A).

In the Podhale flysch case, the maximum temperature of rocks and fluids amounted to 100-165°C. These values occurred in the early stage of the system lifetime, when the complex of the youngest flysch sediments, being at least 1-2 km thick, was not yet eroded. Then the geothermal gradient reached 3-4°C/100 m, while at present it is ca. 2°C. Locally, in the nearfault zones (at a depth of 1850 m), the inclusions recorded temperature up to 230°C. Chlorite and illite are also observed there. Similar effect is known from the Paris Basin, where the higher fluid inclusion homogenisation temperatures and more advanced illite/smectite thermal transformation occur in the fault zone rather than in the area more distant from the faults (Bril et al., 1994).

The maximum paleotemperatures of reservoir rocks and fluids reached a level of 200-230°C in the Middle Triassic. It concerns a period of their maximum burial before thrusting to the present location in the Late Cretaceous and before the sedimentation of the Podhale flysch. After the Oligocene, i.e. after the Podhale system had been formed, the maximum temperature decreased to 165-170°C (Figure 2). Such geothermometers as secondary quartz and dolomite, as well as the examination of the organic matter transformation degree including OTA also confirmed these ranges of the paleotemperature.

Following from the above the Podhale geothermal system has cooled down by at least 70-80°C during its lifetime (about 22 Ma). Fig. 3a shows a sketch scenario of the thermal history of the Middle Triassic and Paleogene formations.

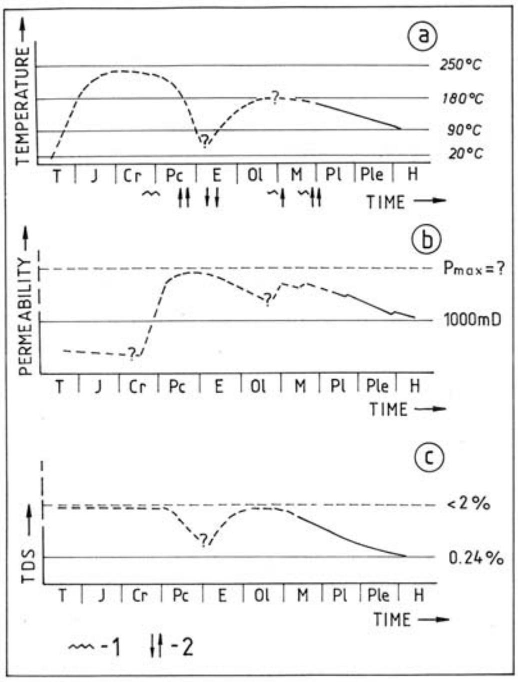

Figure 3: The Podhale geothermal system, area of study - sketch scenarios of changes of the main parameters of the Middle Triassic reservoir rocks vs. geological time. a. temperatures, b. secondary permeability, c. TDS of geothermal fluids. Presumed intervals of maximum temperatures and recorded present values are given. 1 - main stages of alpine orogeny, which affected the Middle Triassic rocks, 2 - lowering and uprising movements, respectively.

4.2 Secondary mineralization

The secondary mineralization in the flysch caprock results mostly from diagenesis, while that in the Middle Triassic reservoir formation from hydrothermal processes.

Secondary minerals, which fill veins and pockets, occur in the clay interbeddings, and replace primary minerals in the matrix. The secondary mineralization in the fractured Triassic rocks developed in greater degree than that in the weakly permeable flysch. Thermal transformations of illite/smectite and organic matter, which happened in the parent rocks of both formations, were independent from the rock permeability. The qualitative composition of the assemblages of secondary minerals within the veins both in the Paleogene and Middle Triassic formations does not differ essentially. Secondary calcite (sometimes dolomite) predominates both within the Paleogene flysch and the Middle Triassic rocks. Quartz, plagioclases, illite/smectite mixed-layers group, illite, Fe-chlorite, and pyrite occur as admixtures. In the Middle Triassic formation galena, gypsum, celestine and sylwine are found in very minor amounts, too.

The illite/smectite mixed-layers serve as an important geothermometer for the Paleogene and the Middle Triassic rocks. The high degree of order (R1) and low content of the smectite layers in the flysch show that these rocks were affected by the paleotemperatures of 100-165°C. In the Middle Triassic rocks, lack of the expending packages indicates the transformation being influenced by hot solutions or the temperature being higher than 165°C. Illite and chlorite might also precipitate directly from the solutions (Kepinska, 2001).

Generally, the secondary mineral assemblages confirm the regularity (Browne, 1984), that the type of the hydrothermal mineralization in low–temperature systems is mainly controlled by the composition of parent rocks. In the case of Podhale system, the predominant component of reservoir rocks-calcite, sometimes dolomite, also forms secondary mineral assemblages.

The secondary mineralization results in decrease of permeability of the reservoir rocks. In the past the rocks passed through the periods of higher permeability with its probable maximum in Paleocene-Early Eocene. It was after their thrusting in the Late Cretaceous, when they were uplifted, unstressed, outcropped, and affected by the karst processes. The second minor permeability maximum but concerning the geothermal system being already formed may have occurred in the Miocene and was favoured by alpine vertical movements. Following this period, the progress in the secondary mineralization probably resulted in the decrease of permeability. Nevertheless, this process weakly or not at all influenced some fractures and breccia zones. The present permeability amounts to a maximum value of 1000 mD in the discussed sector, where the reservoir rocks are considerably fractured. A sketch scenario of permeability changes with time for the Middle Triassic rocks is given in Figure 3b.

4.3 Chemistry and thermodynamics of geothermal water

In the discussed sector, the total dissolved solids of geothermal waters amount to 2.5-3 g/dm^3. Waters are of Na-Ca-SO_4-Cl type. There are young meteoric waters, washed many times, with freshening tendency. The calculations of thermodynamical water-mineral equilibria (using i.e. WATCH-programme; Bjarnason, 1994) showed that these waters are not in equilibrium with the reservoir rocks. They are slightly oversaturated with calcite and dolomite, as well as clays (smectites and chlorites). In contrary, they are close to equilibrium with chalcedony and unsaturated with other minerals. The waters are slightly corrosive against steel elements.

In the course of their evolution, reservoir rocks contained both seawater (Middle Triassic-Cretaceous, Middle Eocene-Oligocene) and meteoric water (Late Cretaceous-Early Oligocene, Oligocene to the recent). Predominant content of calcite in veins of all origins proves that the past waters were also oversaturated with this mineral. Rough examination of the separate fluid inclusions revealed the paleofluid concentration not exceeding the concentration of the seawater. A sketch history scenario of the mineralization of the geothermal fluids for the Middle Triassic reservoir rocks is given on Figure 3c.

5 Production history

From 1990 to 2001 the Podhale system was exploited by one doublet of wells: Banska IG-1 (production) and Bialy Dunajec PAN-1 (injection). Water flowrate varied from 8-16 l/s while outflow temperature was 76-80°C. The maximum capacity reached 1,8 MW_t, heat production ca. 40 TJ/y. As already mentioned, in late 2001 the system was expanded by two new wells and other facilities. The doublet Banska IG-1 and Bialy Dunajec PAN-1 has been monitored since 1990 (flowrate, temperatures, pressures, TDS). Until 2001, before two new wells started the flowrate and temperature of the produced water was observed as being stabilised. However, some slight pressure drop at production well and pressure increase at the injection well was recorded. Among others, the reason for this may be the slight decrease of permeability of the reservoir rocks, due to precipitation of secondary minerals and introducing products of corrosion of the transmission pipeline into the reservoir. Monitoring showed also some decrease in TDS of the produced water – from 2.9 to 2.5 g/dm^3 while the type of water did not change.

In general, monitoring of the wells Banska IG-1 and Bialy Dunajec PAN-1 in 1990-2001 showed the stability of the basic operation parameters of the exploited system. The recovery features of the reservoir are maintained. In reference to sustainable longterm production, the further monitoring of the system and keeping stable level of the parameters are essential for the water production to be considerably increased in relation to 2001.

6 Implications for exploitation

For the last decade the Podhale geothermal was exploited for space heating and some other uses. Extension of the heating network requires the increase in output of geothermal water (up to about 180 l/s) and probably the joining of a new injection well. Therefore, the above-described factors have practical aspects for stable longterm exploitation.

In particular, the scaling trend of calcite and dolomite exists. With time, the secondary minerals proceed in filling up fractures and fissures. Water is also oversaturated with smectites and chlorites. Though clays are found in small amounts, they may silt both the reservoir and in the surface equipment. This effect may decrease the permeability of reservoir rocks. From the other hand, reciprocal processes, i.e. washing out and dissolving of rock components by water, occur. In spite of this, at the present stage of evolution, the Podhale system is still capable to discharge large amount of water, especially in the zones affected by tectonics (the most perspective for siting new wells). The calcite scaling and corrosion tendency involves geothermal exploitation in the closed system. The precipitate scaling due to the secondary mineralization has also a positive effect, which may protect pipes decreasing their corrosion.

In order to maintain stable production and injection capability of the reservoir rocks for a long time with scaling tendency being present, it is very advisable to perform periodical soft acidizing treatment to mitigate for that effect. This has been successfully implemented in the Paris Basin (Ungemach, 1996). It may limit scaling of carbonates and other components. This option is considered in the Podhale field, as it is more simple and cheaper than routine acidizing of the carbonates for increasing their production and injection capacity.

7 Further prospects of geothermal uses

Apart from the district heating, which has been essential for the ecological reasons, the other important applications of geothermal waiting for realisation for many years are balneotherapy and recreation. Due to chemical composition (i.e. H_2S, sulphides, bromium, iodium, potassium, silica) the Podhale geothermal waters have curative properties in the case of dermatological, rheumatic, endocrinological and contagious diseases. Until 2001 only one geothermal bathing pool operated in Zakopane – the main city in the region. There are exceptionally great possibilities to build healing and recreation centres in this region. There are two projects, one of which is just being realised in Zakopane at the site of the existing pool. It includes the construction of the full range healing and recreation complex. This is a long expected project, indispensable to increase the tourist offer and to improve the quality of recreation in this important tourist centre. For Podhale, geothermal balneotherapy and bathing appear to be a very important chance for sustainable development of tourism and economics.

8 Conclusions

The age of the Podhale geothermal system was estimated to be about 22 Ma. The thermal apogee was in its past, when the temperature of rocks and circulated fluids reached at least a value of 165-170°C. With time, during evolution the system was cooled down to a level of 80-90°C. Certainly, the permeability of the reservoir rocks reached its maximum value in the past, too. Since the Late Miocene filling of cracks and fractures has proceeded due to the secondary mineralization. Despite this the system is still active, producing water at high flowrates and temperatures. For maintaining its stable long-time operation, proper current exploitation and development planning is most important. The system offers very favourable conditions for space heating and other multipurpose uses that give the Podhale region the opportunity to introduce an ecological and sustainable development strategy.

The complementary application of both standard methods and those serving the study of geological and thermal evolution of sedimentary basins shown in the present paper is important for the recognition and management of this complex geothermal system. They all enable to reveal various aspects of this interesting geothermal system and provide the information essential for its optimum exploitation and use.

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