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Geological framework of the Tatra Mountains-Podhale geothermal system (Carpathians)

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ABSTRACT

The Podhale (Western Carpathians) region lying between the Tatra Mts. and the Pieniny Klippen Belt is known as an area rich in thermal water exploited for heating purposes as well as recreation (swimming pools). The thermal springs at the foot of the Tatra Mts. (Jaszczurowka, Oravice) are the surface manifestations of an active geothermal system. Numerous drilling data have confirmed the existence of low-enthalpy geothermal reservoir under the entire Podhale basin. The thermal waters are associated with carbonates of highly fractured Nummulite Eocene and with Mesozoic rocks (carbonates of Middle Triassic, sandstones of Lower Jurassic). Two geothermal doublets were completed for thermal water exploitation in the northern part of Podhale basin where thermal waters of 80-90°C occur at the depth – 2000-3000m.

KEYWORDS

Thermal waters, geothermal system, geology, Carpathians

1 Introduction

The Podhale (Western Carpathians) region lying between the Tatra Mts. and the Pieniny Klippen Belt is known as an area rich in low-enthalpy thermal water (SOKOLOWSKI, 1992, CHOWANJEC & POPRAWA 1998). The Tatra Mts. massif elevated in Miocene and mainly in post-Miocene period form a recharge area of 350 km^2 however, the Pieniny Klippen Belt is considered an impermeable barrier for fluid flow.

The Tatra Mts.-Podhale segment of the Inner Carpathians form an alpine-type artesian geothermal system, which is only a part of a much larger Inner Carpathian geothermal region, situated on both sides of Poland-Slovakian border around the Tatra Mts. massif (figure 1).

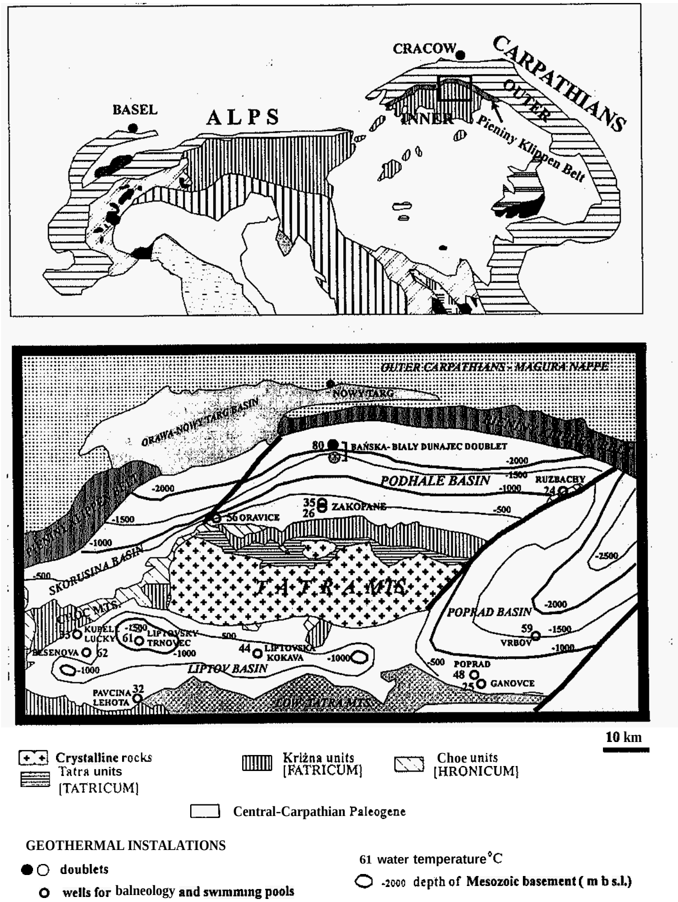


Figure 1 Localization of the Inner Carpathran geothermal regıon (partly after ATLAS OF GEOTHERMAL ENERGY OF SLOVAKIA 1995)

2. Geological structure of the Tatra Mountains-Podhale region

The Tatra Mts., which provide the highest relieves of the Western Carpathians are elevated up to ~*2500* m above sea level and up to ~1500-1800 m above the Podhale surface. The core of the Tatra Mts. is formed by the Hercynian crystalline massif which is covered by a thick pile of Mesozoic sedimentary rocks. Generally, the massif is tilting towards the North.

The sedimentary cover of Hercynian crystalline massif is locally undetached, but mostly it is built of several tectonic slices of different dimensions, generally dipping towards the North. It is possible to recognise (see figure *2* and NEMCOK et al. 1995) units belonging to the High-Tatric (Tatricum), Krizna (Fatricum) and Choc (Hronicum) tectonic nappes transported from the South during post-Lower Turonian movements.

The Tatricum succession is formed by ~2000 m thick complex of Triassic to Lower Turonian rocks. The thickness of Anisian to Ladinian sequence of carbonates reaches up to **600** m while Upper Jurassic-Lower Cretaceous sequence of shallow water limestones attains ~150m. These complexes are karstified and fractured.

The Fatricum succession is formed by ~2000 m thick complex of Triassic to Aptian rocks. The Anisian-Ladinian carbonate sequence which attains ~1000 m in thickness is highly fractured but rarely karstified. The Jurassic sequence is lithologically more variable, but not as thick. The Lower Jurassic sandstones and marls (Fleckenmergel) are locally highly fractured.

The Hronicum succession is formed by ~1000-1500 m thick, mainly carbonate complex of Triassic to Lower Jurassic rocks. The Wetterstein dolomites are usually porous, while the Haupdolomite complex is non-porous but highly fractured.

Some of tectonic units which occur in Tatra Mts. were recognised also in deep geothermal wells reaching the basement **of** the Paleogene Podhale basin (figure 2).

In spite of numerous wells and **2D** seismic profiles the real structure of the Podhale basement is quite well known only on one cross-section (figure 3, see also WIECZOREK & BARBACKI 1997). The geological structure of the remaining area of the Podhale region is highly speculative (figure **4).** To recognise better the mosaic of the numerous units of the Podhale basement, we need 3D seismic data. It is likely that the Mesozoic basement of the Podhale basin is cut by some generally north trending faults (figure **4)** which are recognised in the structure of the Tatra Mts. or can be interpreted from the structure of the Pieniny Klippen Belt and the Paleogene fill of Podhale basin (BAC-MOSZASZWILI 1993, MASTELLA 1975). Moreover, two E-W trending deformation zones are recognised at the foot of the Tatra Mts and in the contact between the Podhale Basin and Pieniny Klippen Belt (figure **4).**

These Mesozoic rocks are unconfonnably overlain by Palaeogene (middle Eocene-Oligocene) sedimentary succession (basal conglomerates, Nnmmulite Eocene and Podhale Flysch) **up** to 3000 m thick (OLSZEWSKA & WIECZOREK 1998).

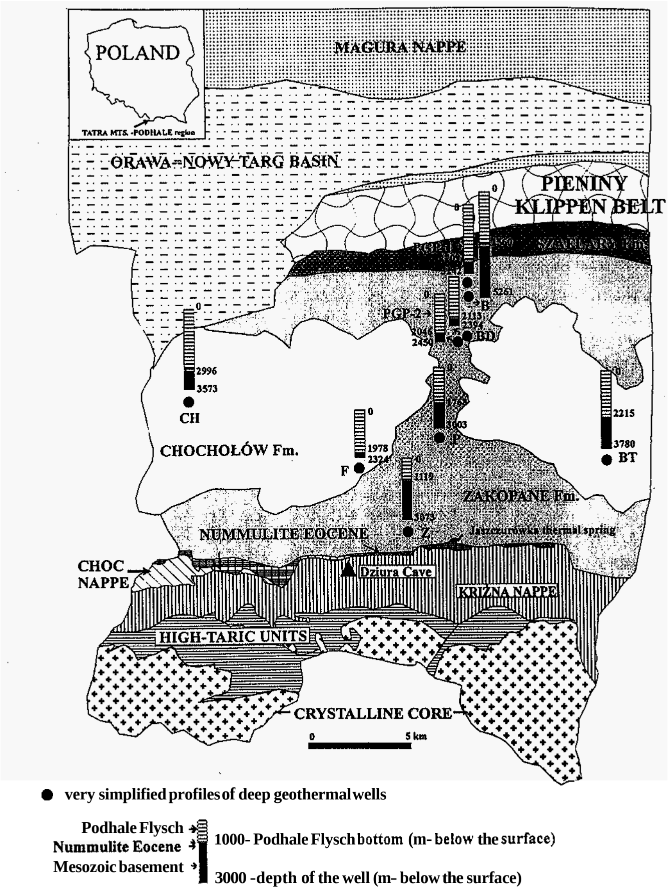


Figure 2: Localization of deep geothermal wells on the geological map of the Tatra Mountains – Podhale region (some data are from PEC Geotermia Podhalanska. and Polish Geological Institute documentation).

The present structure of the Tatra Mts. - Podhale region is a result of:

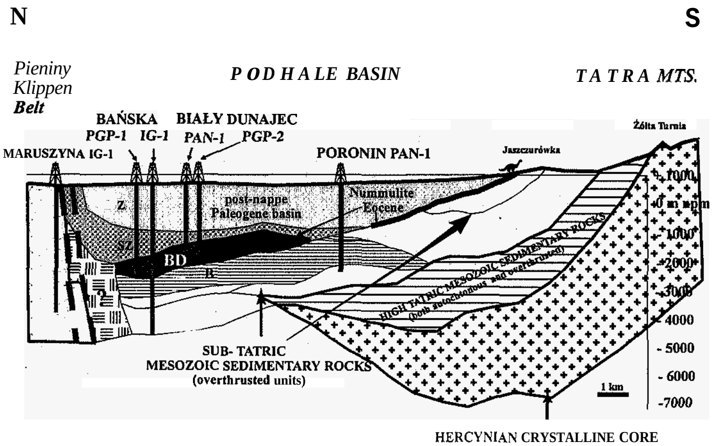
Mesozoic development of the northern margin of Apulia (Adria) (WIECZOREK 1995, DUMONT et al. 1995).

Mainly post-Lower Turonian north directed overthrust of basement and sedimentary nappes at the beginning of collision between Apulia (Adria) and European plate (PLASIENKA et al. 1997).

Early Eocene extension leading to the development of Podhale Palaegene Basin as a part of Central-Carpathian Palaeogene **Basin.**

Early Miocene oblique collision of the Western Carpathian orogen with the North European platform (PLASIENKA et al. 1997) leading to:

- shortening and emersion **of** the Podhale basin,
- the development **of** tectonic contact between Podhale and Pieniny Klippen Belt,
- Miocene and mainly post-Miocene elevation and exhumation of the Tatra Mts.

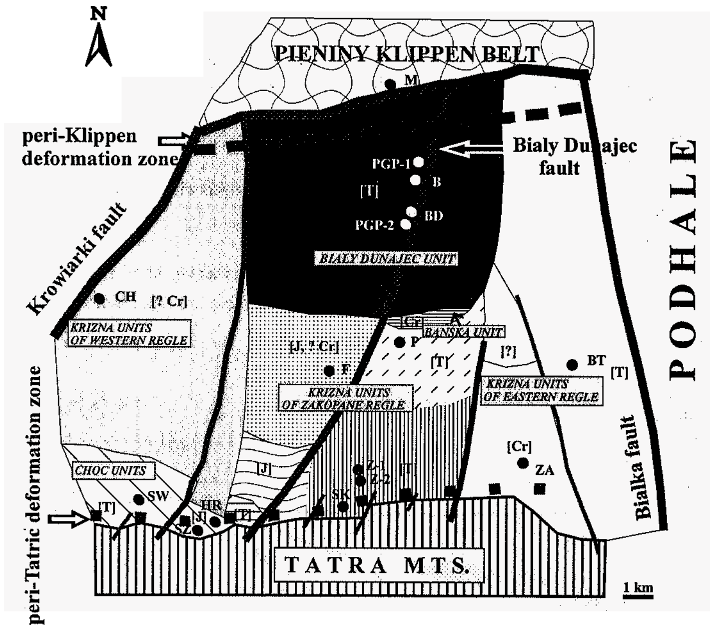


Z - Zakopane Fm., SZ - Szaflary Fm.

BD - Bialy Dunajec unit - main reservoir of thermal water

B - Banska unit

Figure 3: simplified geological cross section from the tatra mountains to Pieniny Klippen Belt (after WIECZOREK & BARBACKI 1997).



● - wells [T] - TRIASSIC [J] - JURASSIC [Cr] - CRETACEOUS

Figure 4: Mesozoic basement of the Podhale basin. A very speculative subcrop map (without the Paleogene cover) Different hachures are used for different tctonic units or groups of units

3. Conceptual hydrogeological model

The conceptual model of **the** Tatra Mts.-Podhale geothermal system which guides exploration of thermal waters is shown on figure **5**. This system is located outside the young volcanic **area** known fiom Slovakia **(ATLAS** OF GEOTHERMAL ENERGY OF **SLOVAKIA** 1995).

The Tatra Mts. massif is a recharge area of 350 km^2 The fractured rocks of sub-tatric zone and its Eocene cover are the most important medium for downward fluid flow. The thermal springs at the foot of the Tatra Mts. (Jaszczurówka, Oravice) with a discharge temperature of 16-20' C are surface manifestations of an active geothermal system. Moreover, not far from the northern Tatra Mts. border, there is a cave (Dziura) whose origin is probably connected with thermal karst processes (BAC-MOSZASZWILI & RUDNICKI 1978). Numerous drilling data have confirmed the existence of a low-enthalpy geothermal reservoir under the entire Podhale basin.

The Podhale thermal waters are associated mainly with carbonates of highly fractured Nummulite Eocene and with Mesozoic rocks (carbonates of Middle Triassic, sandstones and marly limestones of Lower Jurassic).

The water temperature rises towards a northern direction, which is in direction of the general tilt of the Podhale Flysch basement (figure 3). The generally low mineralization of thermal waters also rise from –300 mg/l on the peri-Tatra zone, up to –3000 mg/l in the peri-Pieniny zone.

The artesian condition of the thermal water occurrence is documented by well-head pressure, which rise from 4,6 bars on the peri-Tatra wells (Skocmia, Zakopane), up to 27 bars on the peri-Pieniny wells (Banska).

The absence of thermal springs along the tectonic contact between the Podhale basin and the Pieniny Klippen Belt indicates that vertical permeability of the Podhale flysch sediments is generally low. However, measurable thermal anomalies occurs in this contact (POMIANOWSKI 1988). The Pieniny Klippen Belt is considered an impermeable banier for fluid flow.

The good results of exploration drilling undertaken during the last 20 years in the Podhale indicate that the best region for thermal water exploitation for heating purposes is restricted to the Bialy Dunajec-Banska area, which is situated closely to the Pieniny Klippen Belt. Thermal waters of 80-90°C occur (DLUGOSZ & NAGY 1994) at the depth ~2000-3000m, in the Podhale Flysch basement which is build by mainly carbonate complexes.

Highly variable in thickness (IO-loom) and in facies (limestones, marls, conglomerates) so called "Nummulite Eocene" is regarded a secondary reservoir which provides about 20% of thermal water reserves. The underlay's Bialy Dunajec tectonic unit, composed of about 600 m thick complex of Triassic carbonates (alternating limestones and dolomites) form the main reservoir of thermal water in this region.

Two geothermal doublets (Banska PGP-I and Banska IG-1- as exploitation wells and Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 as injection wells) completed for thermal water exploitation are situated closely to north trending Bialy Dunajec fault. Probably, the high discharge of the wells (200 m^3/h and more) is related to high fracturation of the reservoir rocks in the vicinity of this fault. The temperature of the water is higher than previously estimated (KEPINSKA 1994) hence, the up-flow of the heat along faults has to be taken into account.

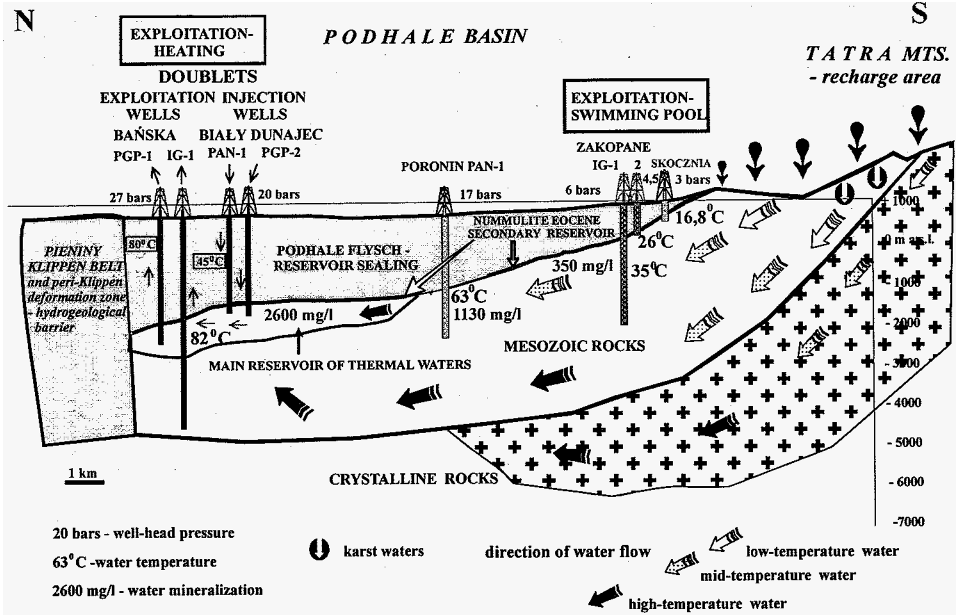


Figure 5: Conceptual model of the Tatra Mountains – Podhale geothermal system (some data are from PEC Geotermia Podhalanska documentation).

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