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MAIN FEATURES OF THE PODHALE GEOTHERMAL RESERVOIR: AN ALPINE ARTESIAN GEOTHERMAL SYSTEM

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ABSTRACT

The Tatra Mts.-Podhale geothermal system situated in the Carpathian chain could be considered as an alpine-type, non-volcanic, artesian geothermal system which developed in post-Miocene period. The Tatra Mts. massif built by crystalline and sedimentary rocks constitute a recharge area of the Podhale thermal waters reservoir exploited for heating purposes as well as recreation (swimming pools).

The Podhale thermal waters reservoir is associated with Mesozoic and "Nummulite Eocene" rocks, which are covered by up to 3000 m thick complex of Paleogene flysch.

The geological structure of Mesozoic substratum of Podhale region is composed of a pile of several small tectonic slices imbricated from the south to the north. The best parameters of the thermal waters show the Biały Dunajec unit built by Triassic, highly fractured, carbonate rocks about 600 m thick. Two geothermal doublets (Banska PGP-1 and Banska IG-1- as exploitation wells and Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 as injection wells) were completed for thermal waters exploitation from this aquifer. Thermal waters, slightly mineralised and with temperature of 80-90^0 C occur there at the depth ~2000-3000m. The high discharge of the wells (200 m ^{3}/h and more) is related to the high fracturing of the reservoir rocks in the vicinity of north trending fault.

Other deep wells (Zakopane IG-1, Poronin PAN-1, Furmanowa PIG-1, Chocholów PIG-1, Bukowina Tatrza1ska PIG-1) confirm the existence of low-to-mid-temperature geothermal reservoir under the entire Podhale basin.

At the foot of the Tatra Mts. in Zakopane (Poland) and in Oravice (Slovakia) the thermal waters are exploited from the wells for the swimming pools. The natural thermal springs (temperature up to 20^{0}C) at the northern margin of the Tatra Mts. (Jaszczurówka, Oravice) and a cave (Dziura), whose origin is probably connected with thermal karst processes are the surface manifestations of an active geothermal system

The artesian condition of the Tatra Mts.-Podhale geothermal system is proved by observation in the wells. The well-head pressure is rising from 3 bars in the wells situated on the foot of the Tatra Mts. up to 27 bars in the area situated closely to the Pieniny Klippen Belt - an effective barrier for thermal water flow.

1. INTRODUCTION

The Podhale region is located between the Tatra Mts. and Pieniny Klippen Belt in the Western Carpathians. (Fig.1). This is one of the richest in thermal waters basins surrounding the Tatra Mts. (Franko et al.1993, Atlas, 1995).

The Tatra Mts. massif elevated from 900 m up to 2500 m above see level (up to 1600 m above surface level) is built by crystalline Paleozoic rocks and Mesozoic sedimentary (mainly carbonate) rocks. The thermal springs at the foot of the Tatra Mts., known for 150 years, are surface manifestations of an active geothermal system. Numerous wells completed by Polish Geological Institute, Polish Academy of Sciences and lately by Geotermia Podhalanska S.A. have confirmed the existence of a low-enthalpy geothermal reservoir under the entire Podhale basin (Długosz & Nagy, 1995, Chowaniec & Poprawa, 1998).

Good results of exploration drilling undertaken during the last 20 years in the Podhale region indicate that the best region of thermal water exploitation for heating purposes is restricted to the Biały Dunajec-Banska area, which is situated closely to the Pieniny Klippen Belt.

Two geothermal doublets (Banska PGP-1 and Banska IG-1- as exploitation wells and Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 as injection wells) were completed there for thermal water exploitation.

2. GEOLOGICAL STRUCTURE

The Podhale Basin is filled by up to 3000 m thick sequence of Palaeogene Flysch deposits, underlain by up to 300 m thick complex of Eocene carbonates and conglomerates (see Olszewska & Wieczorek, 1998). They cover the Mesozoic rocks, which are exhumed in Tatra Mts.(see Nemcok et al. 1995) as a result of Miocene-post-Miocene uplift. The Hercynian crystalline massif of the Tatra Mts., tilting towards the North, is covered by a thick pile of Mesozoic sedimentary rocks (Fig.2). In the sedimentary cover of the crystalline massif it is possibly to recognise undetached complexes and several tectonic slices, of different dimensions, belonging to the High-Tatric and sub-Tatric (Krizna and Choc) tectonic nappes overthrusted from the South during post-Lower Turonian movements. The maximum summary thickness of theses sedimentary cover could be

estimated as about 5000 m or more, however, it is highly variable laterally due to tectonic reasons.
As the sedimentary cover dominated are carbonate rocks, frequently fractured and karstified (High-Tatric units). Also the crystalline massif is fractured (magmatic-tectonic jointing) and cut by faults-network.
The large part of Tatra Mts. is considered as a recharge area reaching 350 km^2. Some of tectonic units which occur in the Tatra Mts. were recognised also in the deep geothermal wells reaching the Mesozoic substratum of the Podhale basin. In the present state of our knowledge, the Mesozoic substratum of the Podhale region is built of numerous tectonic units generally gently dipping to the North (see Wieczorek & Barbacki, 1997 and Fig.2). Generally they form a pile of tectonic units of Tethyan passive margins origin (Wieczorek, 1995), which were transported to the north during long-time overthrust movements related to the early phases of Adria (Apulia)-European plate collision. The main overthrust movements took place during Late Turonian time, but younger Late Cretaceous/Early Paleogene movements are very likely.
The most important structure for thermal water exploration and exploitation is Bialy Dunajec unit (Wieczorek, 1998). This unit built by Triassic carbonate rocks were recognised in 4 wells:Bialy Dunajec PGP-1, Bialy Dunajec PAN-1, Banska IG-1 and Banska PGP-1 (Fig.2 and 3). Its thickness attains 600 m. It is underlain by Banska unit (Sokolowski, 1992) built by some hundred meters thick Cretaceous impermeable marls and unconformably overlain by Palaeogene (middle Eocene-Oligocene) sedimentary succession ("Nummulite Eocene" and Podhale Flysch) up to 2800 m thick.
It is likely, that the Mesozoic substratum of the Podhale basin is cut by some, generally north trending faults, which are recognised in the structure of the Tatra Mts. or can be interpreted from the structure of the Pieniny Klippen Belt and of the Paleogene fill of Podhale basin. Moreover, two E-W trending deformation zones are recognised at the foot of the Tatra Mts as well as in the contact between the Podhale Basin and Pieniny Klippen Belt.

3. MAIN FEATURES OF THE RESERVOIR

The Podhale thermal waters are associated with carbonates of highly fractured "Nummulite Eocene" and mainly with Mesozoic rocks (carbonates of Middle Triassic, sandstones and marly limestones of Lower Jurassic). The Tatra Mts. massif constitute a recharge area of Podhale thermal waters reservoir. The fractured rocks of sub-tatric zone and its "Nummulite Eocene" cover are the most important medium for downward fluid flow.
The natural thermal springs (temperature up to 20 ^{0}C) at the northern margin of the Tatra Mts. (Jaszczurówka, Oravice) and a cave (Dziura), whose origin is probably connected with thermal karst processes (Bac-Moszaszwili & Rudnicki, 1978) are the surface manifestations of an active geothermal system. At the foot of the Tatra Mts. in Zakopane (Poland) and in Oravice (Slovakia) the low-temperature thermal waters are exploited from the wells for the swimming pools.

The temperature of water rises northwards, which is in the direction of the general tilt of the Podhale Flysch basement (Fig.2). In peri-Pieniny region the temperature of thermal water riches 90^0 C at the depth of 2700-2900 m. In Bialy Dunajec area, there exists the small geothermal anomaly, which can be explained as up-flow of thermal fluid along deep fault (Kepinska, 1994).
Generally low mineralization of thermal waters also rises from ~300 mg/l in the peri-Tatra zone, up to ~ 3000 mg/l in the peri-Pieniny zone.
The artesian condition of the thermal water is documented by well-head pressure, which rises from 3-4 bars in the peri-Tatra wells (Skocznia, Zakopane), up to 27 bars in 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.

Highly variable in thickness (10-100m) and in facies (limestones, marls, conglomerates) so called "Nummulite Eocene" covers a large part of the Podhale region. In the peri-Tatra zone it represents a thin aquifer which provides low - temperature thermal waters exploited for the swimming pool, however, in the peri-Pieniny zone it forms up to 100 m thick aquifer, which provides about 20% of thermal water reserves exploited for heating purposes.
Among the tectonic pile of Mesozoic units forming the substratum of the Podhale basins, the Bialy Dunajec tectonic unit form the best aquifer of thermal water in this region (Table 1). The lithology and porosity analysis, the examination of cores and the fractures logs as well as the CAST images show that some horizons of a thick Triassic complex composed of alternating limestones and dolomites, are highly fractured (Fig. 3 and 4). It is possible to distinguish minimum 2-3 phases of fracturing. The oldest fractures are usually filled by calcite and locally also by pyrite. The youngest fractures are open or partially open, and their walls are encrusted by calcite. The thickness of the fillings (opening) is generally of about 1mm, however some calcite veins reaches 10 cm in thickness. Open spaces occur also locally along the stylolitic networks, which cut the calcite veins.
Generally good correlation between theses geological and geophysical data and production log (Fig.5) show that fractures are the main path of fluid transfer.
The high discharge of the wells (200 m^3/h and more) is related to the high fracturing of the reservoir rocks in the vicinity of north trending fault.
The geothermal gradient in this area is about 3^0 C /100 m and heat flow density (HFD) is estimated as 65-75 mW/m^2 (Remsik et al.1995).

4.CONCLUSIONS

The Tatra Mts. -Podhale geothermal system represent an alpine type system which is fed by water in high mountains. This is non-volcanic geothermal system located outside of the young volcanic belt (see Nemcok et al.1998) and the rise of temperature is only a result of the reservoir depth related to normal geothermal gradient. Permeable stratigraphic horizon tilted to the north and overlain by impermeable cap rock form the artesian condition in Podhale basin.

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Table 1. Main features of the main aquifer of Podhale thermal waters

tectonic unit	Biały Dunajec unit (sub-tatric unit)
max. thickness	up to 650 m.
depth of the top	2000-2809
area	~. 30 km^2
age, lithology	Triassic, dolomites, limestones
porosity	generally low, 0-.8%
fracturing	locally high
temperature	~90^{0}C in reservoir, ~80^{0}C on well head
mineralization	up to 2700 mg/l
overlying beds	Nummulite Eocene - up to 100 m thick , locally good reservoir parameters, in hydraulic connection with Triassic reservoir Paleogene Podhale Flysch- up to 2700 m thick, **sealing complex**
underlying beds	Banska unit - Cretaceous marls **- sealing complex**
well head pressure	24-27 bars

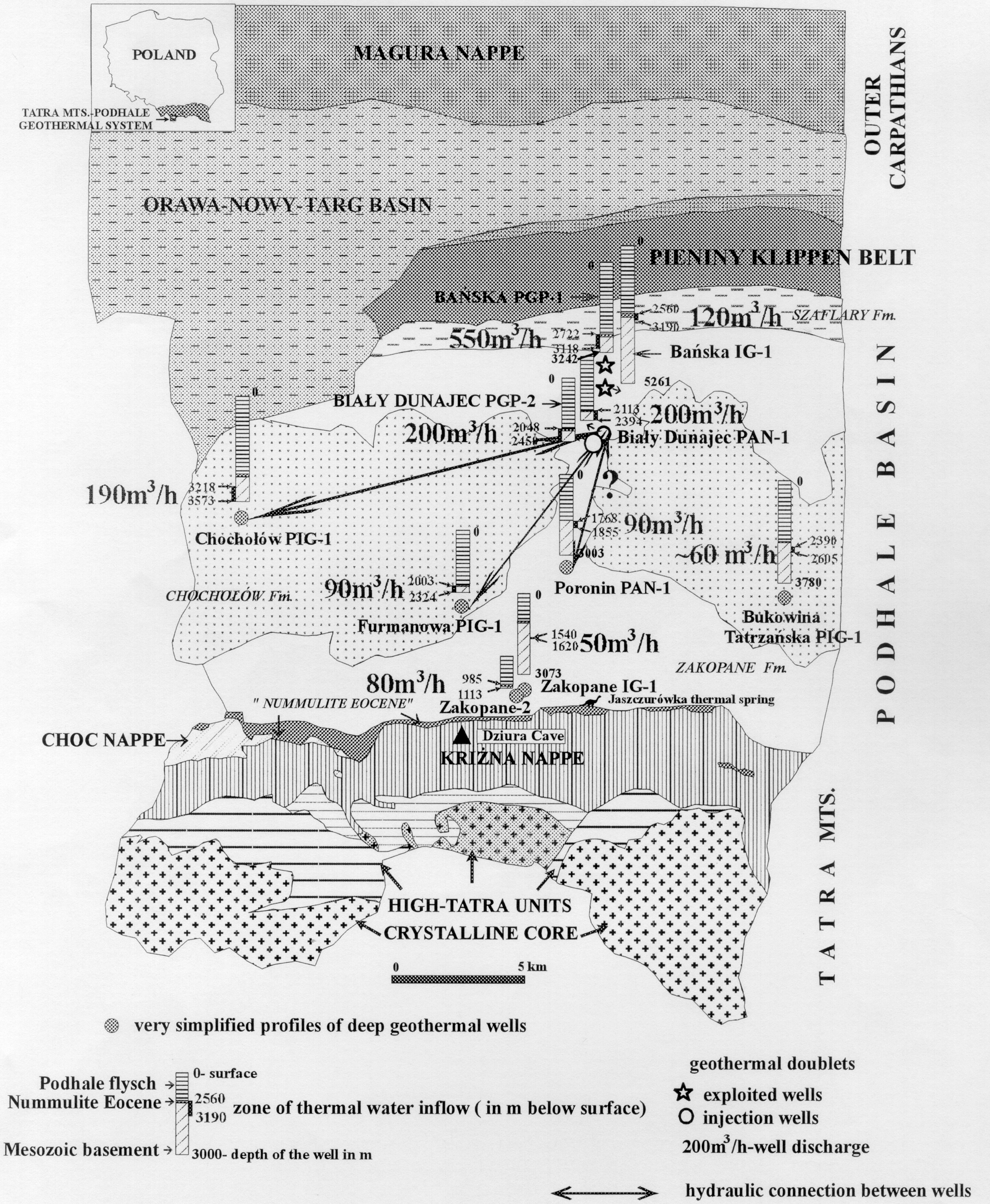


FIG. 1 The geological map of the Podhale region and the main parameters of deep geothermal wells

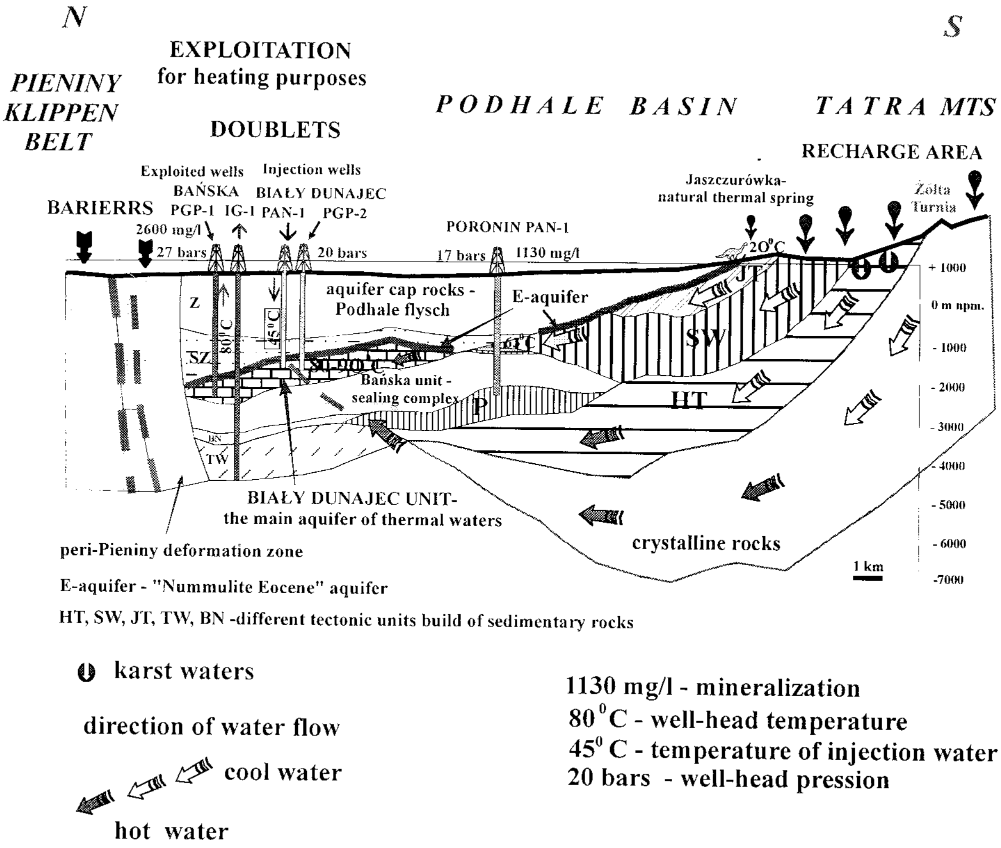


FIG. 2 Hydrogeologic cross-section through Podhale region
(between Tatra Mts.-recharge area nad Pieniny Klippen Belt - hydraulic barrier)

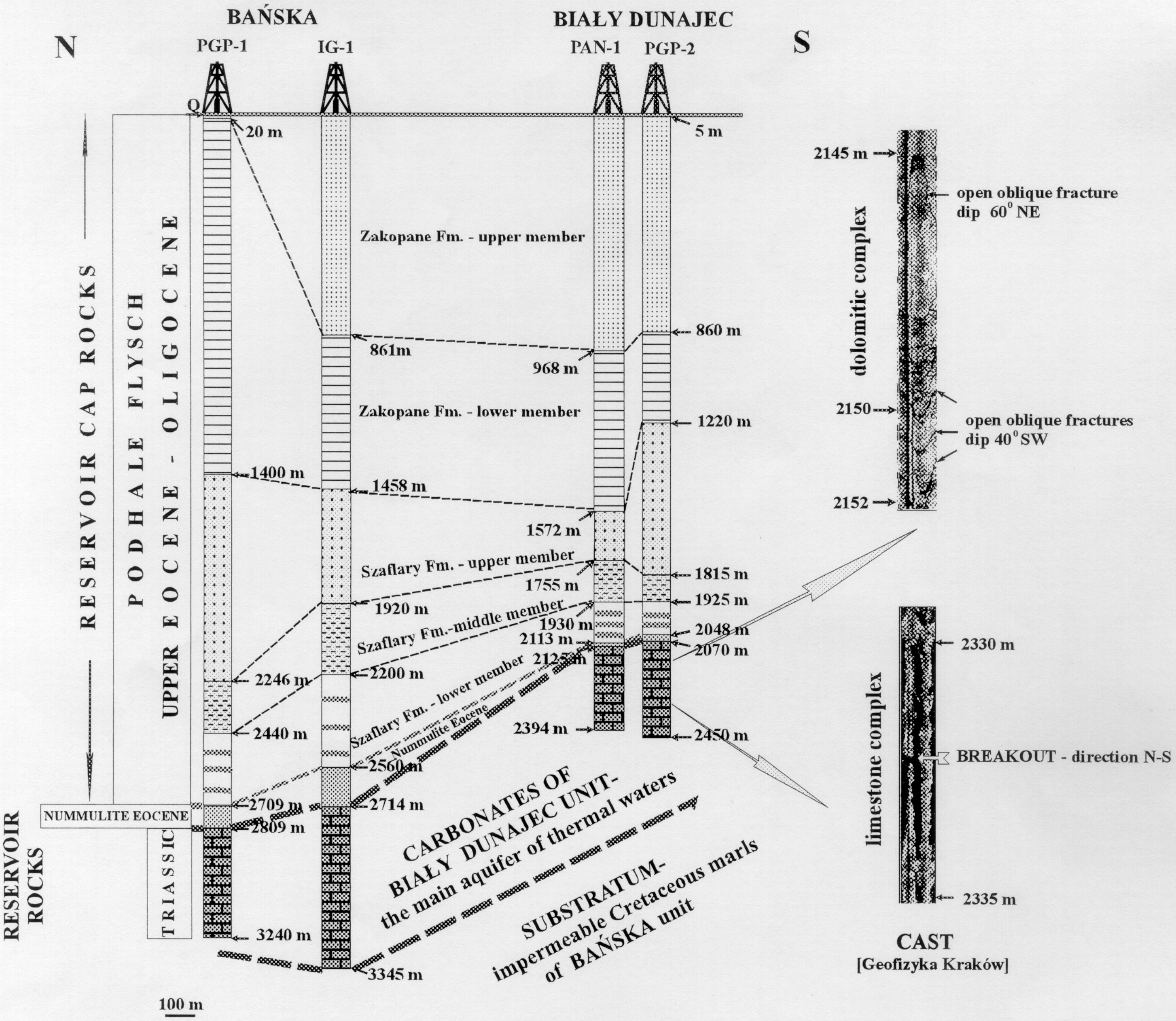
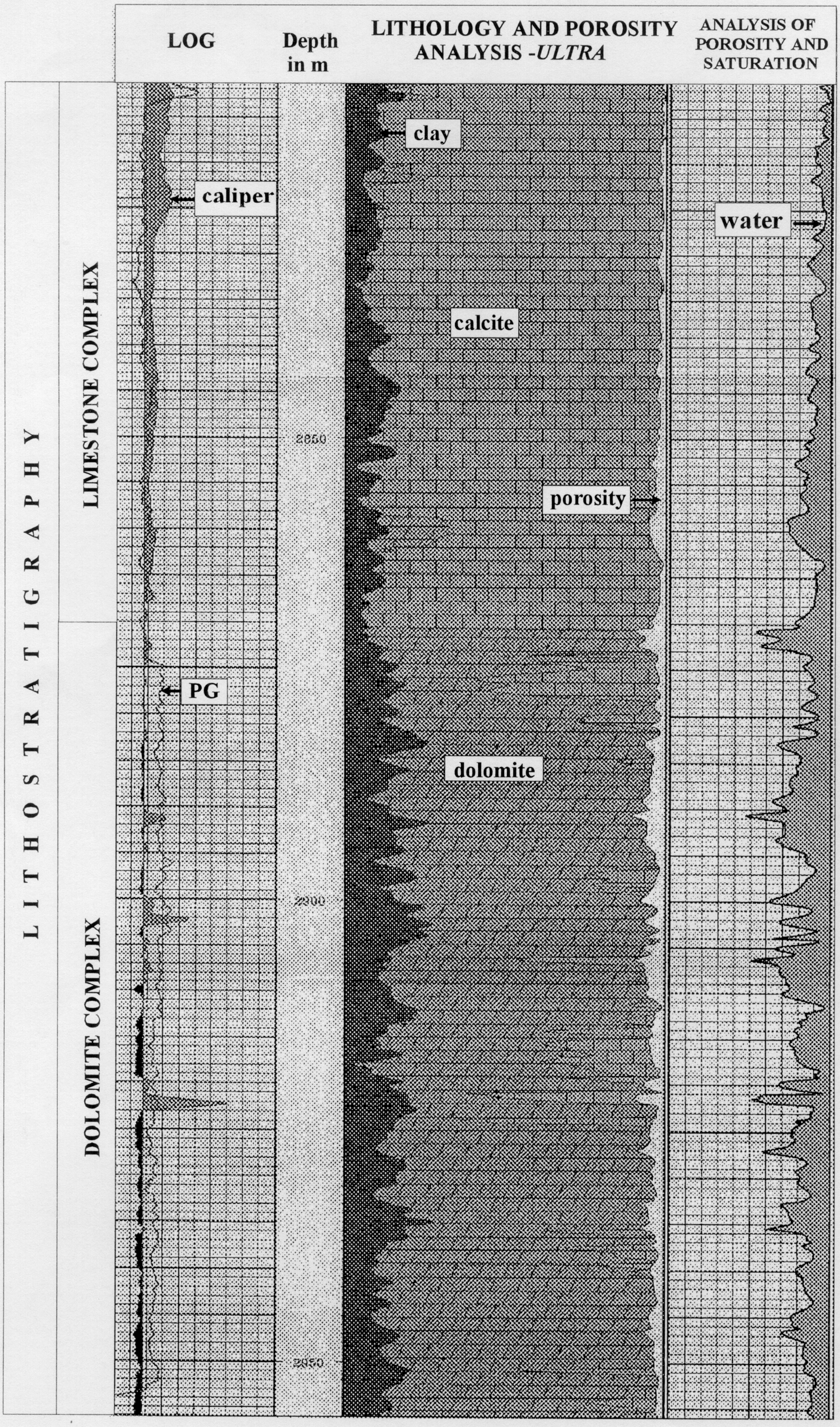


FIG.3 Correation of geological profiles of geothermal doublets: Biały Dunajec PGP-2, Biały Dunajec PAN-1, Bańska IG-1, Bańska PGP-1 and examples of CAST images from reservoir drillhole (PGP-2)



[GEOFIZYKA KRAKÓW]

FIG.4 Lithology and porosity of Triassic aquifer of Biały Dunajec unit (Bańska PGP-1 well)

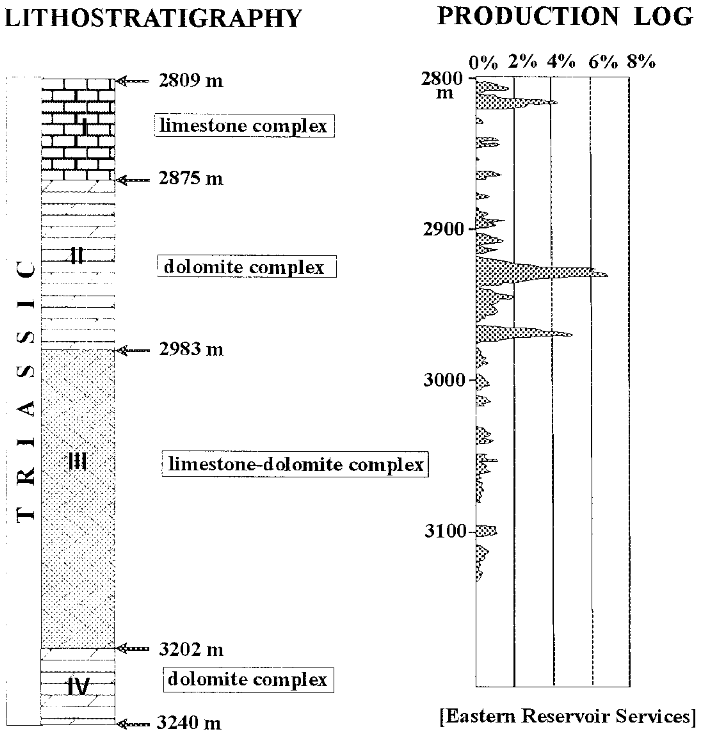


FIG. 5 Lithostratigraphy and production log of Triassic aquifer in Bańska PGP-1 well