IDENTIFICATION OF THE LOW-ENTHALPY PODHALE GEOTHERMAL RESERVOIR BASED UPON LONG TERM INTERFERENCE AND PULSE HYDRODYNAMIC TESTING

Stanislaw Nagy[1], Piotr Dlugosz[2]

[1] University of Mining and Metallurgy, Al. Mickiewicza 30, 30-059 Kraków, Poland
[2] PEC Geotermia Podhalanska S.A., ul. Szymony 17, 34-500 Zakopane, Poland

Key Words: geothermal, interference well testing, hydrodynamic model, Podhale reservoir

ABSTRACT

A hydrodynamic system of Podhale, S - Poland, low-enthalpy reservoir is presented. Results of long-term interference and pulse testing made on 5 geothermal wells located in Podhale region, S - Poland, are presented together with single well test results obtained during 1995-1998. Variety of storage and transmissivity of main Eocene/Triassic geothermal reservoir is detected. Verification of reservoir model has been done according to obtained data. High anisotropy has been detected and main axes of anisotropy were fixed. Hypothetical internal and outer barrier was verified. The hydrodynamic and other reservoir parameters were summarised.

INTRODUCTION

Geothermal waters have been known to exist in Poland since the 10th century. They have been used mainly for medical purposes in health resorts. Eight of Poland's 36 health resorts use geothermal waters. A complex investigation of geothermal water resources occurrence in the Tatra Mountains was initiated after WWII. Since 1963, 19 shallow and deep petroleum and geothermal wells have been drilled in the Podhale Basin both in central part as well as at the edge of Tatra Mountains. Observations indicated the existence of a deep, low temperature geothermal system (85-90°C). The construction of the first geothermal plant in Poland began in 1989 as an implementation of geological, geophysical and drilling investigation of the Podhale Basin carried out by the Mineral and Energy Research Center of Polish Academy of Sciences. The plant is situated in the Bialy Dunajec Valley, 10 km north of Zakopane, 90 km south of Krakow. Actually, the plant consists of the production wells Banska IG-1, Banska PGP-1 and the injection wells Bialy Dunajec PAN-1, Bialy Dunajec PGP-2. The geothermal heat is extracted from geothermal water by the use of heat exchangers where heat is transferred into secondary loop and supplied to the district heating system. Expansion of the system to connect more buildings is planned and reach level heat production of 1200 TJ/ year This amount of heat is enough to cover the heat demand of Zakopane, Nowy Targ and other villages and towns located in the region. Total cost of the project is around 85 Million US$, what makes it the largest geothermal district heating system in Central Europe. Project is implemented by the PEC Geotermia Podhalanska – Joint Stock Company. (Dlugosz, 1997). As natural parks surround the Podhale Basin, the environmental benefits of geothermal energy application in place of traditional energy sources (coal and natural gas) are significant.

GEOLOGY OF THE PODHALE BASIN

The Podhale Basin is located in the southern part of Poland, with the Tatra Mountains to the south and the Pieniny Klippen Belt to the north (Fig.1). It occupies 475km^2 of the central part of the geological and morphological unit, while the rest, around 520 km^2, extends into the territory of Slovakia. Geothermal reservoirs exist in the whole area that lies within Polish borders (Dlugosz et al., 1995, Dlugosz, 1996). The Podhale Basin is a part of the Central Carpathian Palaeogene Basin. Two deformational processes caused its structural setting during Tertiary period. The first one is related to the extension that affected the Central Western Carpathians in Palaeogene/ Eocene time, leading to the development of the Podhale fore-arc basin. The second deformational process is related to the compression which affected the Podhale Region in late Oligocene/Miocene time, leading to the termination of sedimentation and subsequent uplift of the basin (Wieczorek, 1998).

The basin is an asymmetric unit. In the northern part, the water bearing formations are located deeper than in the southern part. The main recharge area is postulated to occur in the south, on the outcrops in the Tatra Mountains. The Cretaceous and Jurassic formations that build the Pieniny Klippen Belt do not posses good reservoir properties, and the reservoir is hydrological sealed towards the north. The bedrock of the subbasin is built of Mesozoic rocks, which are mutually thrust upon each other, like in the Tatra Mountains. Over the bedrock, the Palaeogene rock system consists of the upper Eocene - Oligocene flysch formation underlain by Middle Eocene carbonaceous conglomerates and limestone's. The Podhale flysch formation acts as a cover for the geothermal aquifers. The main geothermal reservoir and the best producer are Eocene numulitic limestone, Triassic dolomite and limestone, and Jurassic sandstone. The different stratigraphic units do not correlate on logs below the top of the reservoir.

The Eocene conglomerate-limestone sequence can in most places be found on top of the Middle Triassic limestone and dolomite, but closer to the Tatra

Mountains the Triassic nappe beneath is missing and the foundation is either Cretaceous or Jurassic rocks. The thickness of the Eocene and middle Triassic rocks varies considerably in the basin. Estimates of the thickness of the reservoir (based upon seismic) are imprecise, even at borehole locations, since only the top of the structure can be correlated and most of the wells were not drilled to the bottom of the formation due to the drilling problems. Several faults seem to be present in the geothermal system. These faults are of NNE-SSW trending and their origin is likely to be found in the relaxation tectonics combined with differential basin subsidence. The faults can play a significant role in serving as a conduit for geothermal fluids from deeper reservoirs; however, their exact position and communication properties have not been determined. (Dlugosz et al., 1995, Dlugosz 1996).

The reservoir rocks appear to be considerably fractured, both at micro, intermediate and macro scale, likely due to overthrusting. The micro fractures are healed by calcite infilling and they do not participate in mass flow. The intermediate fracture system is filled with clays. It is not clear if shale swelling is occurring within the fractures. The major contributor to flow is the large macro fracture system.

SINGLE WELL TESTS AND RESERVOIR MODEL

The main reservoir in the area of the experimental geothermal plant is found to be in the Middle Eocene and Middle Triassic limestone, dolomite and conglomerate formations. During 1996-1998 has been performed hydrodynamic tests in following wells: Bialy Dunajec PAN-1, Banska IG-1, Poronin PAN-1, Furmanowa PIG-1, Chocholow PIG-1, Banska PGP-1, Bialy Dunajec PGP-2. Geotermia Podhalanska drilled the last two wells during 1997 and 1998. The main parameters obtained from the tests are summarized in the table 1. Generally, in the N part of reservoir in the parallel faults zone, the geothermal aquifer may be described as nearly homogenous field with transmissivity 110-260 [D×m]. The sealing fault in the N (Pieniny Klippen Belt) of Bańska IG-1 and Bańska PGP-1 is verified at range 2000-1700 m. The Bialy Dunajec PAN-1 and Bialy Dunajec PGP-2 wells are probably situated in the transverse faults crossing at angle 60°. In the S of Poronin PAN-1 well at distance about 3000-4500 m a constant pressure boundary may be noticeable, which is rechargeable boundary connected to this reservoir.

LONG-TERM INTEREFERENCE TEST

During 1997 and 1998 a long-term pulse-interference test has been carried using 5 wells. Two of them (Banska IG-1 and Bialy Dunajec PAN-1) were active and other 3 (Poronin PAN-1, Furmanowa PIG-1 and Chocholow PIG-1) were passive. The summary of impulse data is shown in the table 2. Well locations and other data are presented in the table 3. Pressure impulse during time of test is shown at figs. 3 and 4. Different interpretation technique like: 1° Theis, Sabet, simulation of pulse and interference test; 2° Agarval, Horner together with type curve matching for single well test were used (Gringarten, 1981). Analysis of test was done using Hantush and Thomas (1966) method. The average transmissivity (at reservoir conditions) is 3.13 10^{-3} m^2/s and average storage is 6.1 10^{-5}. The aquifer is non homogenous. The main anisotropy axes are presented on fig. 6. Based on Hantush and Thomas method following results were obtained:

- transmissivity along main "a' ellipse axe – T_y – 6.63 10^{-3} m^2/s (242 D m)
- transmissivity along second "b' ellipse axe – T_x – 1.48 10^{-3} m^2/s (54 D m).

Assuming constant average effective thickness this is equivalent conductivity of 6.63 10^{-5}m/s and 1.48 10^{-5} m/s (2.21 10^{-12} m^2 and 0.54 10^{-12} m^2). Assuming constant storage the different effective thickness is obtained and different directional permeability, which is presented in the table 4. A result of investigation is consistent with other data like age of water, chemistry of water. Verification of reservoir model has been done according to obtained data.

CONCLUSIONS

A hydrodynamic system of low enthalpy geothermal aquifer in Podhale Basin, (S–Poland) is highly heterogeneous. High anisotropy has been detected and main axes of anisotropy were fixed. Presented results of long-term interference and pulse testing (made on 5 geothermal wells) shown four times larger transmissivity in the main ellipse anisotropy axe in comparison to the second. Variety of storage and transmissivity of main Eocene/Triassic geothermal reservoir is detected. The range of storage is between 3.8 10^{-5} – 9.6 10^{-5}. Verification of reservoir model has been done according to obtained data. Hypothetical internal and outer barrier was verified. The hydrodynamic and other reservoir parameters were summarised.

NOMENCLATURE

c_r	heat capacity, J/kg°C
c_r	rock compressibility, bar^{-1}
d	distance, m
h	formation thickness, m
k	permeability, mD
p_r	reservoir pressure, Pa
r_i	radius of investigation, m
T_r	reservoir temperature, °C

REFERENCES

Dlugosz P., Sokolowski J. & Bujakowski W., 1994 - Experimental geothermal plant Banska-Bialy Dunajec and the geothermal supply programme in Podhale region- southern Poland. International Symposium, Geothermics 94 in Europe.From research to development, Orleans-France 8-9 February 1994. Document BRGM no.230:423-430

Dlugosz, P., and Nagy, S., 1995; "Determination of Hydrodynamic Parameters of Podhale Geothermal Reservoir" Bulletin of the Polish Academy of Sciences, Earth Sciences, Vol 43. No. 4.

Dlugosz P.,1996 – Physical model of geothermal aquifer in Podhale Basin (in Polish), PhD thesis, UMM (AGH), Kraków.

Dlugosz, P, 1997 – Geothermal Project Podhale – present state and plans for future (in Polish) –Proc. Scientific Seminar – Problems of geothermal and wind energy utilization in Poland, Polish Acad. of Sciences

Gringarten A.C. et al., 1981, Evaluating Fissured Formation Geometry from Well Test Data: a Field Example, SPE 10182

Sokolowski J., 1992 – Documentation of geothermal well Banska IG-1 (in Polish). Geosynoptyka i Geotermia, Vol. 1, PAN CPPGSMiE, Kraków.

Sokolowski, J. et al. , 1995; "*Geothermal Provinces and Basins in Poland*," PGA and Polish Acad. of Sciences.

Chowaniec J. et al, 1997: Hydrogeology documentation of Podhale Basin (in Polish) Kraków – Zakopane.

Chowaniec et al., 1998: Hydrogeology documentation of Bialy Dunjec PGP-2 i Bańska PGP-1 wells. (in Polish) PEC Geotermia Podhalańska S.A., CPPGSiE PAN, PIG OK, Kraków – Zakopane.

Hantush M.S., R.G Thomas, 1966, A Method for Analysing a Drawdown Test in Anisotropic Aquifers, Water Resour. Res., 2, p.281

Wieczorek J., 1998: Geologic characteristic of Podhale geothermal reservoir, Proc. IX Conf. UM&M (AGH) WWNIG (in Polish)

Report KBN9 T12A 038 14, (interim report) unpublished (in Polish), Krosno 1999 (W. Szott and J.Dudek)

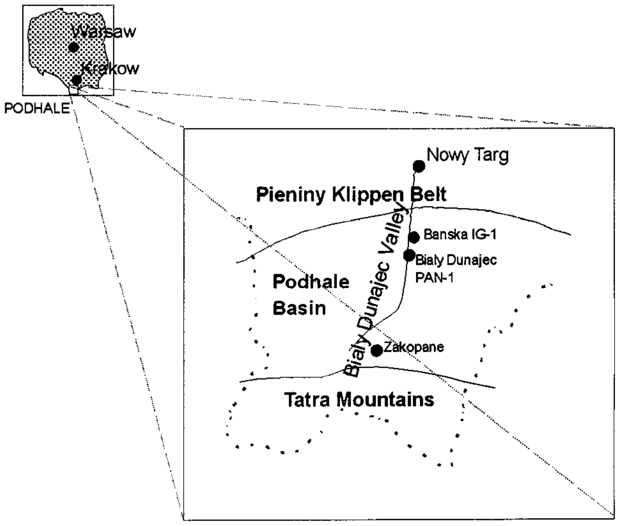

Fig. 1 The schematic map of location of Podhale Geothermal Reservoir in Poand

Table 1. Selected hydrodynamic data obtained from single well tests

Type of model	Transsm. [m²/s]	Boundary type	L_1[m]	L_2[m]
Banska IG-1 well				
Double por.	371.3 10^{-5}	parallel	1740	1740
Bańska PGP – 1 well				
Double por	732.6 10^{-5}	parallel	1480	1290
Poronin PAN – 1 well				
Double por	186.8 10^{-5}		?	?
Bialy Dunajec PGP – 2 well				
Double por	431.0 10^{-5}	∠ 60°	551	1350
Bialy Dunajec PAN – 1 well				
Double por	460.8 10^{-5}	∠60°	771	1490
Chocholów PIG – 1 well				
Double por.	484.0 10^{-5}	fault	1440?	?
Furmanowa PIG – 1 well				
Homog.	217.0 10^{-5}	?	-	-

Table 2. Summary of pulse data

Well	Production (1)	Time	Production (2)	Time
Biały Dunajec PAN-1	175 m^3/h	284 h	0 m^3/h	284 h
Bańska IG-1	50 m^3/h	284 h	50 m^3/h	284 h

Table 3. Well locations and other data

Well	Biały Dunajec PAN-1	Bańska IG-1	Poronin PAN-1	Chocholow PIG-1	Furmanowa PIG-1
Well radius	0.108 m	0.078 m	0.078 m	0.078 m	0.108 m
Distance to principal well (Banska IG-1)	1126 m	0.0 m	6649 m	14923 m	9257 m
X-coordinate	153 m	0.00 m	-1106 m	-14201 m	-4820 m
Y-coordinate	-1116 m	0.00 m	-6556 m	-4582 m	-7903 m

Table 4. Parameters obtained from pulse-interference test (* calculation based upon constant storage)

Well	S[-]	h_{eff} [m]*	Trans. [m^2/s]	Directional conductivity* [m/s]	Directional permeability* [m^2]
Poronin PAN-1	4.81 10^{-5}	50	193.3 10^{-5}	3.9 10^{-5}	1.4 10^{-12}
Furmanowa PIG-1	9.61 10^{-5}	100	469.3 10^{-5}	4.7 10^{-5}	1.7 10^{-12}
Chocholow PIG-1	3.85 10^{-5}	40	431.0 10^{-5}	10.8 10^{-5}	3.2 10^{-12}

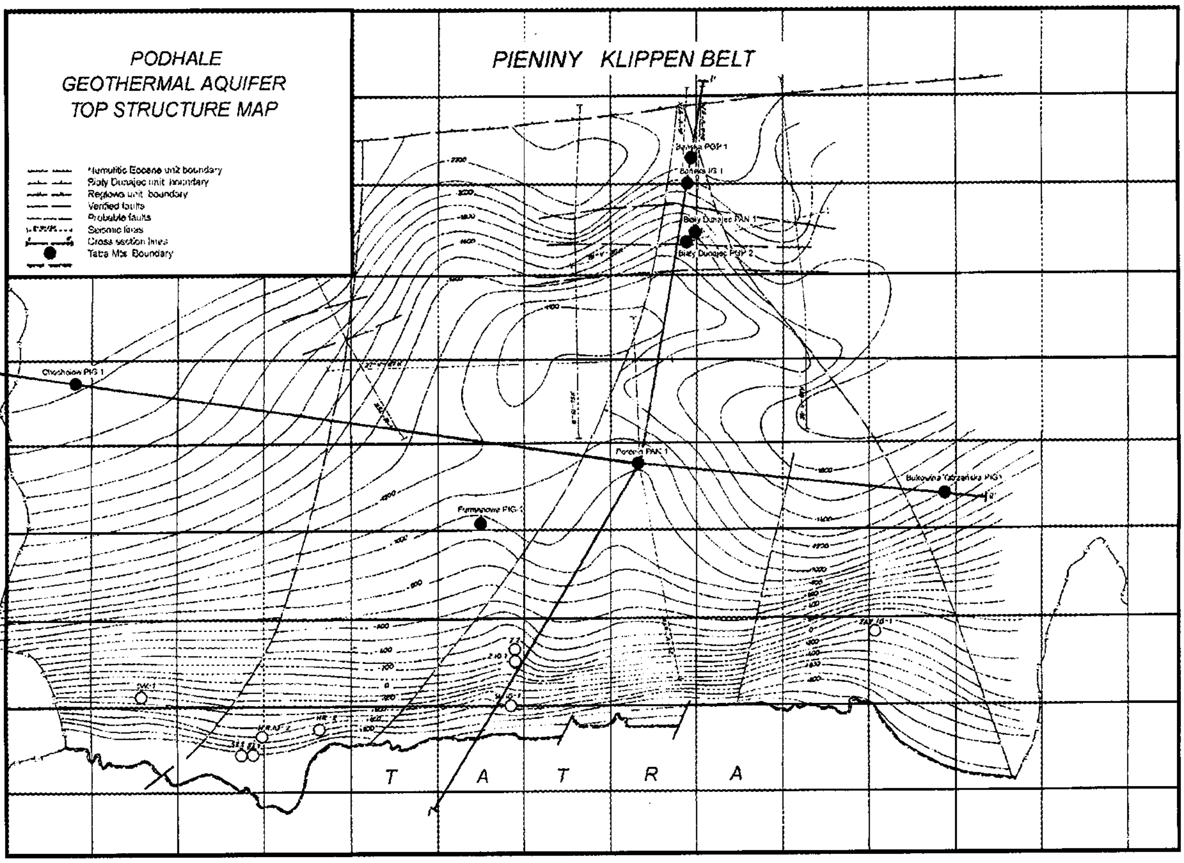

Fig. 2 Map of structure of Low-Temperature Podhale Geothermal Aquifer (after Wieczorek, 1998, and J. Dudek (Report KBN9 T12A 038 14))

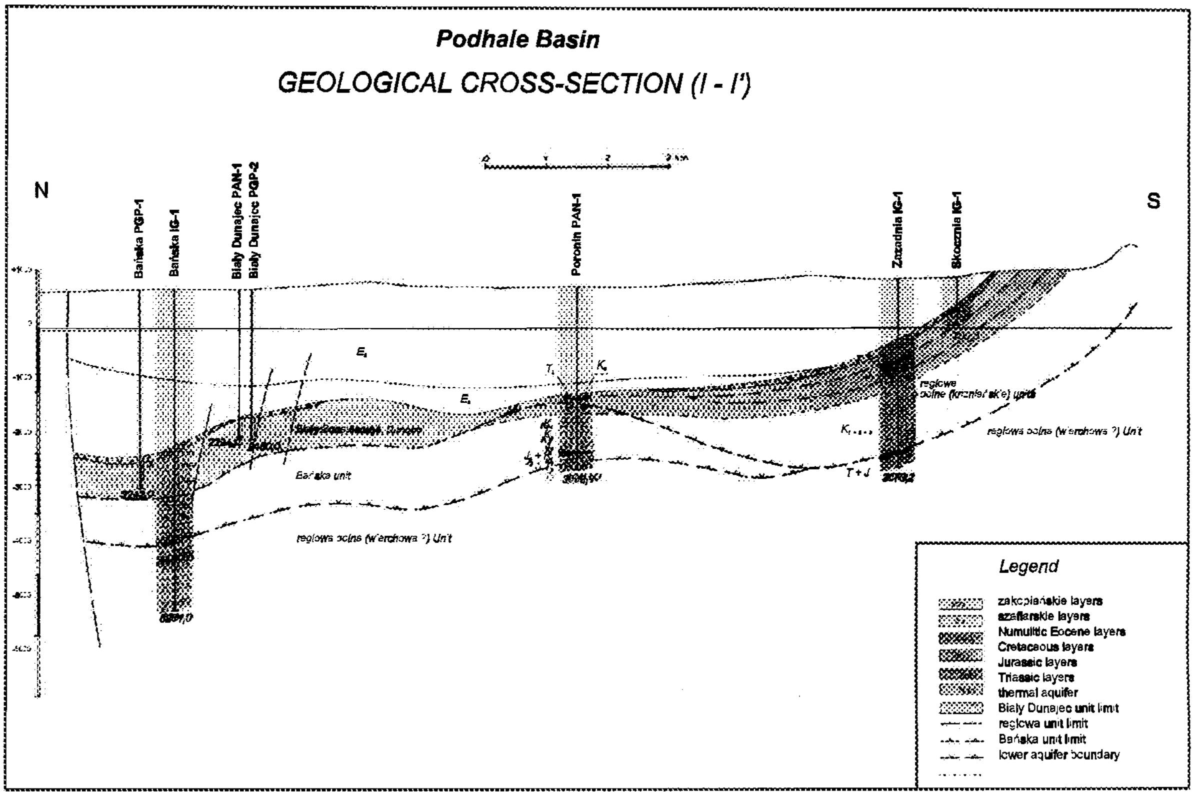

Fig. 3 Geological cross-section I-I' (J. Dudek (Report KBN9 T12A 038 14), Wieczorek, 1998)

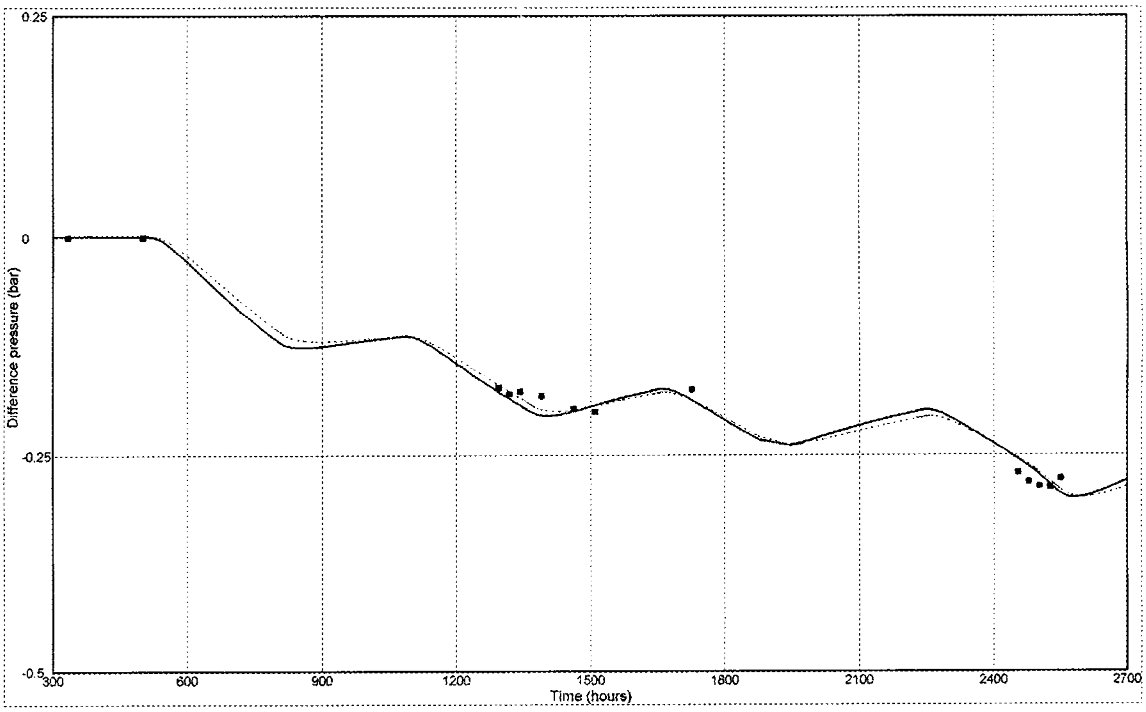

Fig. 4 Pressure response in the Furmanowa PIG-1 well during long-term pulse-interference test

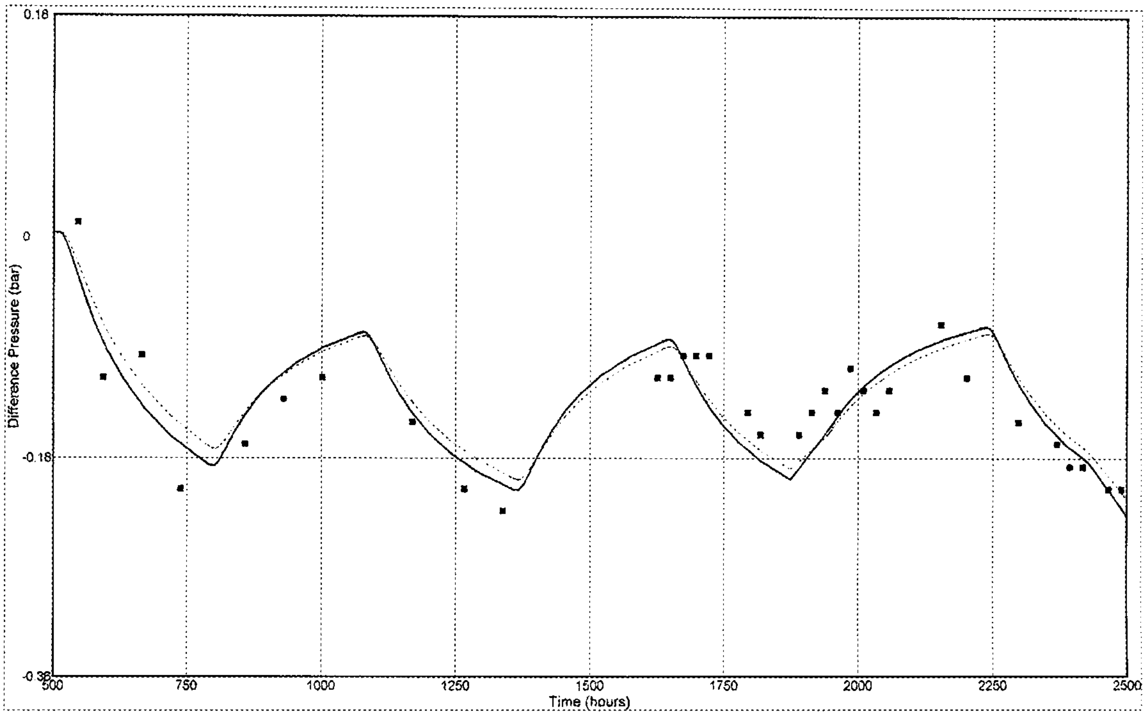

Fig. 5 Pressure response in the Poronin PAN-1 well during long-term pulse-interference test

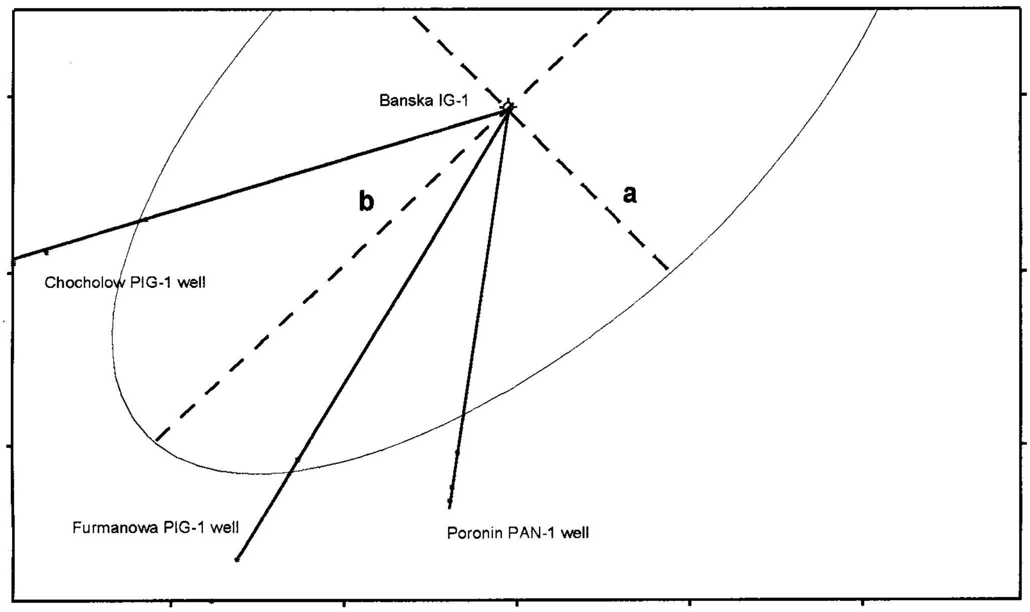

Fig. 6 Simplified sketch describing anizotrophy in transmissivity in the geothermal aquifer