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INVESTIGATION FOR GEOTHERMAL ENERGY UTILISATION IN THE TOWN KOSICE, SLOVAK REPUBLIC

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ABSTRACT

At present the project of geothermal energy utilisation is planned to be set in eastern Slovakia – Kosice basin. The total heat output is planned to be 100 - 110 MW_t, using 8 production and 8 reinjection wells. Within the first phase of work 3 geothermal wells - vertical GTD-1 and directional GTD-2,3 - were drilled in Durkov geothermal structure (Fig. 1) during 1998 – 1999, which proved predictions about the existence of geothermal reservoir. The main inflows of geothermal water come from the upper part of Mesozoic dolomites in the depth 2 100 - 2 500 m TVD, the smaller inflow zones were observed in the lower parts up to the well bottoms in 3 200 m. The transmissivity of the dolomites range from $6,3.10^{-3}$ – $8,2.10^{-5}$ m^2/s, degassing point, mainly CO_2, is in depth 750 – 1195 m. The temperature of geothermal water on the wellheads range in 123 – 129°C, dynamic wellheads pressure range in 0,9 – 2,2 MPa and free flow flowrate 56 – 65 kg/s. Chemical character of water is remarkable natrium chloride type with TDS 29-32 g/l. Origin of the geothermal water according to the chemical and isotopic analyses is supposed to be fresh water salted by trapped sea water in Neogene sediments and consequently penetrated to the lower parts in Mesozoic dolomites. Model calcium-carbonate equilibrium calculations as well as measurements in situ suggest scaling and corrosion properties of the water. The results of wells significantly exceeded expected parameters that seemed to be promising for the realisation of the geothermal energy utilisation project in near future. The feasibility study of the whole project was elaborated. The payback time was calculated for 5 years.

1. INTRODUCTION

In the near future the project of geothermal heating will be completed with heat output 100-110 MW_t in Kosice, the second biggest town in Slovakia. Project requires drilling and completion of 8 production and 8 reinjection wells. Geothermal reservoir is located about 15 km east of Kosice in the depth 2000 - 3500 m in Mesozoic dolomite aquifer. The heat flow of the area is 110 mW/m^2, heat capacity of carbonates is 807 J/kg.K. The geothermal water of 125 - 130 °C delivered from production wells after heat exchange to secondary loop fresh water will be reinjected back to the aquifer. Because of geological conditions and chemical properties of the geothermal water the reservoir can be used only by the reinjection system. High TDS content in the geothermal water restrain its discharge into adjacent brooks or rivers. The heat will be delivered to TEKO Kosice by pipeline from heat centre in Olsovany where the heat will come from well sites heat exchangers in Bidovce, Durkov, Slanec and Ruskov. The geothermal heat will supply the dwellings of the town Kosice by already existed network from TEKO Kosice. To explore reservoir properties three geothermal wells GTD-1 – 3 were drilled during 1998-1999. The results of wells exceeded expected parameters.

2. DURKOV GEOTHERMAL STRUCTURE

2.1 Geological setting

From 26 geothermal areas in Slovakia the most prospective one is the Kosice basin. That is situated in eastern Slovakia between Ore Mts. on western side and Slanske vrchy Mts. on eastern side; its shape is elongated in N-S direction. Basin is fulfilled by thin layer of fluvial Quaternary sediments (up to 10 m), Neogene sediments – Sarmatian clays (thickness 500-1000 m), Badenian calcareous sandy clays (thickness up to 1300 m), Karpatian calcareous claystones with conglomerates on base (thickness up to 400 m). Thickness of Mesozoic dolomites which form underlying layers of Neogene rocks rise eastward from 300 to 2000 m (Pereszlenyi et al. 1998). Mesozoic dolomites are deepening from west to east. From lithologic viewpoint there are dark grey breccia dolomites with calcite veins, which are incorporated to Mesozoic mantle of Cierna Hora Mts. (Kullmanova, 1970) Kosice basin is folded by 3 main fault zones - Karpatian direction (NW-SE), transversal direction (SW-NE) and Hornád direction (N-S). Faults cut basin into smaller structures, mainly Karpatian and transversal directions are important. One of them is Durkov structure located in SE part of Kosice basin, restricted by Slánske vrchy Mts. on eastern side. Slánske vrchy Mts. are formed by Neovolcanic rocks – andesites and pyroclastic rocks that were formed later than Mesozoic reservoir dolomites. Because of higher geothermic gradient they influence the eastern side of Kosice basin. Presence of geothermal reservoir is caused by temperature gradient in Neogene rocks 50,3 °C/km and in Mesozoic rocks 32,3 °C/km, heat flow of region is 109,9 mW/m^2. But the most important are the dolomitic rocks which are the reservoir rocks of geothermal water, these rocks do not occur in the whole area of Kosice basin in sufficient thickness.

3. RESULTS OF INVESTIGATION

3.1. Drilling and testing

Investigation wells GTD-1, GTD-2 and GTD-3 are located in Durkov geothermal structure and proved existence of geothermal water reservoir (Fig. 2). The Durkov geothermal structure is called the depression of Neogene basement where Mesozoic dolomites occur in depth 2000 m and more and their thickness is at least 1000 m. All three geothermal wells were drilled from one place; well orientation are recorded in Tab. 1. Technical casing 9 5/8" is cemented, production zone is cased by 7" liner with total length of perforation of 548 m in GTD-1, 596 m in GTD-2 and 30 m in GTD-3. The data of GTD-2 well completion are summarised in Tab. 2. All the wells were drilled through Neogene rocks and geothermal reservoir was found on the top of Mesozoic dolomites just below Neogene Karpatian conglomerates (Fig.3) (Kovac et al., 1998). The average production zone is about 300 m thick, low productive horizons occur deeper in tectonic dolomitic breccia. During one step tests wells discharged water freely without pump utilisation. The main inflow zone located on top of Mesozoic rocks is fractured and karstic one. After drilling, completion and cleaning of the wells all of them were tested. GTD-1 was stimulated by acid before well test, the others were not stimulated. The well test data from wellheads and surface measurements during tests are summarised in Tab.3 and Fig.4. During the drilling fresh water and later discharged geothermal water from one well was used as circulation into drills. The high TDS of the water restricted its discharging into adjacent brooks, so the insulated pit with volume of about 7000 m^3 was built for the testing purposes. The well tests were too short to obtain steady state.

3.2. Hydraulic parameters

The evaluation of the well test data resulted in reservoir characteristics calculations.

Hydraulic parameters of GTD-1 from well test – T = 2,089 . 10^{-4} m^2/s , k_f = 4,471 . 10^{-7} m/s (Fendek, 1998). Effective thickness of collector was appointed to 467 m according to flowmeter measurements. For long term discharging flowrate of 56 kg/s was suggested with expected depression 0,97 MPa (Fendek, 1998). Degassing point was appointed to 750 m depth.

In reality two well tests on GTD-2 were done, the first one just after well completion, second one after a half-year time. During the first test the wellhead temperature 124°C, dynamic wellhead pressure 0,2 MPa and free flowrate of 70 kg/s were reached. The hydraulic parameters of GTD-2 were calculated from the first test - for production T = 8,16 . 10^{-5} m^2/s , k_f = 9,44 . 10^{-8} m/s, for built up T = 1,34 . 10^{-4} m^2/s , k_f = 1,55 . 10^{-7} m/s (Giese, 1998). Degassing point was appointed to depth 1070 – 1100 m TVD (Giese, 1998). After production on GTD-2 injection into GTD-1 was done with flowrate 50 kg/s, t = 15°C and 0 MPa on well head.

After half a year (March 1999) one-week production test on GTD-2 was performed with the continual injection into GTD-1. The preliminary experiences were confirmed and 50 kg/s of 48°C geothermal water was injected with 0 MPa wellhead pressure on GTD-1. Free flow in the longer period from GTD-2 showed increasing of the wellhead temperature up to 129°C with flowrate 50 kg/s and wellhead pressure 1,4 MPa. The chemical composition of the water which is almost the same as the one in GTD-3 and increasing of wellhead temperature comparing to the first well test showed that tests after wells completion were too short for reaching the real reservoir conditions. During the test downhole pressure interference measurements with GTD-1 and 3 were performed that showed very good communication between GTD-1 and GTD-3, GTD-3 and GTD-2 and poorer interference between GTD-1 and GTD-2. It seems that the transmissivity from GTD-3 towards the other wells is almost the same. The data interpretation were very difficult because of continuos production and reinjection, the hydraulic characteristics are summarised in Tab. 4 (Jetel, 1999).

Preliminary test before 7" liner setting was performed on GTD-3. This confirmed powerful inflow zone in karstic dolomites on contact with Neogene basement thick about 55 m. Later on the well test was done in one step free discharging with flowrate 65 kg/s. Temperature on wellhead reached 123°C, dynamic wellhead pressure was 2,2 MPa. Maximum free flow could reach about 140 kg/s. Degassing point was appointed to depth 1146 – 1195 m TVD (Giese, 1999). Hydraulic characteristics for production T = 3,41 . 10^{-4} m^2/s , k_f = 8,5 . 10^{-6} m/s (Giese, 1999). During the well test downhole pressure interference (2000 m TVD) was recorded. Pressure fall-off on GTD-1 was performed in 10 minute after opening of GTD-3 and pressure difference reached 30 kPa. Degassing points of the wells are too deep, the utilisation of submersible pumps are concerned.

Heat output of each well is about 15 MW.

3.3. Geochemical properties

From geochemical point of view the hydrogeothermal structure Durkov is complicated system – water-steam-solid phase. TDS value in both wells range in 29 g/l to 32 g/l. The biggest differences are in Ca, Mg, SO_4 and HCO_3 content. The chemical composition of water is remarkable Na-Cl type with low content of Na-HCO_3.

In chemical analyse of condensate curiously high contents of non-volatile components, mainly Fe, Mn, Na occurred. On the other site the condensate is enriched by volatile components, mainly NH_4 (concentration is three times higher). Cause of content distribution is not clear, Fe and Mn are probably enriched by corrosion of inner part of testing equipment. Character of distinguished components distribution in different conditions are documented at Fig.5. Lowest total content of solids in geothermal water occurs in condensate, Fe is exception. Ca and Mg content in solid phase is highest in samples taken after gas separator where equilibrium is caused by CO_2 degassing and mainly carbonates of Ca and Mg precipitate into solid phase. The same dependence can be observed in Sr behaviour that has similar chemical properties. Content of SiO_2 is similar in sampling before and after separator, but in condensate the solid form of SiO_2 does not occur (Tab. 5). Compared with other geothermal sources in Slovakia, there is an interesting amount of arsenic (20 to 50 $mg.l^{-1}$), boron (about 1000 $mg.l^{-1}$ as HBO_2), lithium, bromides (16.9 - 20 mg/l) and iodides (10 - 14 $mg^{-/}l$).

On the base of isotopic analyses of oxygen in sulphate the reservoir temperature for GTD-1 is estimated to 159–165°C (Mizutani-Rafter, 1969). For water from GTD-2 calculated reservoir temperature is 140–148°C, for GTD-3 151–158°C (Mizutani-Rafter, 1969).

From genetic point of view of geothermal water we suppose that it is halogenic water originated probably from meteoric water infiltrating through the salt-bearing formation of Karpatian into Mesozoic collector. Following arguments support this opinion (D.Bodis *et* al., 1998, 1999):

- Remarkable sodium-chloride type of geothermal water
- Very low value or lack Na-HCO_3 component. It means that water was not degraded by infiltration what is confirmed by values of coefficient HCO_3/Cl in range 0,057 – 0,079.
- Value of coefficient Cl/Br is higher than 1000 that represent ratio in present ocean water
- Molar ratio Cl/Na in geothermal water correspond to stoichiometric solubility of this mineral
- Geothermal water has low content of biogene elements, mainly iodine
- Isotopic composition of $\delta^{18}O$ and δD of geothermal water is very similar, in case of downhole samples almost identical ($\delta^{18}O$: -0,36 to 1,31 $^0/_{00}$, δD : -49,3 to –50,1$^0/_{00}$). Isotopic composition excludes sea origin of geothermal water. For geothermal water in carbonates, in medium temperatures (150°C) there is transfer of

isotopic composition of oxygen towards higher content of heavier isotope because of water-rock interaction. Isotopic composition of hydrogen does not change mainly in chloride type water (Truesdell – Hulston, in Fritz – Fontes eds.1980). In this case as meteoric water we consider content of δD about 50 $^{0}/_{00}$.

3.4. Technological properties

The physical and chemical properties of GTD-2 and GTD-3 wells, which are intended for production, are almost identical. They are characteristic by their increased mineralisation consisting especially from higher amounts of chlorides (16.6 - 17.1 $g.l^{-1}$), sodium (10.85 - 11.78 $g.l^{-1}$), HCO_3^- (1653 - 2135 $g.l^{-1}$), sulphates and potassium. Typical is high content of dissolved gas varying from 12.7 to 17 m^3 of gas per m^3 of water, 98% of which is CO_2 (in one sample from GTD-3 even 21 $m^3.m^{-3}$). The calcium carbonate system is very sensitive to the changes of pressure (and consequent degassing) and temperature. Calcium content ranges within 320 - 413 $mg.l^{-1}$ (downhole sample). The results of chemical equilibria model computations revealed that under partial degassing, when pH rises to more than 5.57 at GTD-3 wellhead (pCO_2 2.2 MPa, 125°C), the water tends to form scaling. For instance free Ca^{2+} ions are supersaturated at GTD-3 wellhead, compared with the relevant equilibrium concentration is 61 $mg.l^{-1}$ at pH 6.4 (pCO_2 0.373 MPa, 125°C) and when degassed more severely (pH 7.0 or higher) the free Ca^{2+} ions (scale forming) supersaturation reaches 173 $mg.l^{-1}$(pCO_2 0.079 MPa, 70°C). On the other hand, when the water would be kept under pressure high enough to maintain a sufficient amount of CO_2 dissolved, serious corrosion takes place due to the increased contents of Cl^-, SO_4^{2-}, NH_4^+, CO_2-HCO_3^- etc. The required partial CO_2 pressure to maintain the calcium ions in solution reaches app. 2.1- 2.2 MPa for GTD-2 and GTD-3 wells (Drozd and Vika, 1998). The wellhead pressure at GTD-3 under free outflow condition is 2.2 MPa, which is enough, but at GTD-2 well the pressure is only 1.7 - 1.8 MPa i.e. a submersible pump will be needed to rise the pressure at the wellhead and consequently in the heat exchanger system.

As an example in Tab.6 the results of calcium-carbonate system model calculation are given, where delta Ca means supersaturation (+) or undersaturation (-) of the geothermal water by free Ca^{2+} ions with respect to the equilibrium state.

These results were confirmed by coupon check. During the hydrodynamic test the steel coupons (plates) were mounted at the wellhead, behind gas separator and at the discharge from the system. At GTD-3 the scaling occurred during the hydrodynamic test only between separators, at the wellhead and outflow from the system corrosion was observed, which can be explained by high pressure at the wellhead. The corrosion rate reached around 5 $mm.y^{-1}$, the scaling rate was 0.9 $mm.day^{-1}$ (GTD-2). The dependence of free Ca^{2+} ions oversaturation on partial CO_2 pressure and temperature is in graphic form on Fig.6.

The analyses of scale deposits proved the scaling consists in the main part from $CaCO_3$, with small amounts of SiO_2 and $FeCO_3$.Under different condition (partial degassing and correspondingly higher pH, lower temperatures) except calcite the water is supersaturated also by caolinite, quartz, dolomite and strontianite, which will co-precipitate. The heavy metals concentrate in scaling (e.g. As in sandy deposits from tanks).

With respect to these results the treatment of water by inhibitor will be necessary for its long-term utilisation, except, as a matter of course, careful handling of pressure and other auxiliary precautions. The inhibitor will protect against scaling and corrosion. The best solution is the dosage of inhibitor downhole at the aquifer to protect the whole system - both the casings and heat exchangers with pipelines (Drozd and Vika, 1998). The dosage of inhibitor will also enable to use lower pressures in the heating system.

4. CONCLUSIONS

The investigation done during 1998-1999 in Durkov geothermal structure showed the presence of geothermal reservoir with heat potential at least 100 MW_t. This structure is located about 15 km eastern from Kosice, second biggest town in Slovakia and the geothermal heat should supply about 60 000 flats in Kosice. The Durkov structure is the depression of Neogene basement over 2000 m deep with the thickness of reservoir rocks more than 1000 m. The main inflow zones of geothermal water is in the depth 2100 – 2600 m on the top of Mesozoic dolomites with fissure and karstic permeability. The wells parameters got from the well tests were better than originally expected - geothermal water temperature at wellhead 124 - 129°C , free flow 56 – 65 l/s, dynamic pressure on wellhead 0,97 – 2,2 MPa , degassing point in depth 750 - 1146 m, hydraulic parameters: T range from 8,16 . 10^{-5} m^2/s to 3,41. 10^{-4} m^2/s and k_f range from 9,44 . 10^{-8} m/s to 8,50 . 10^{-6} m/s. Geothermal water has high TDS content (25 - 32 g/l) with remarkable natrium-chloride type. From genetic point of view it is halogenic water originated probably from meteoric water infiltrating through the salt-bearing formation of Karpatian into Mesozoic collector. The geothermal structure according to chemical and isotopic indications is the confined one utilised only by reinjection. On the basis of thermodynamic modelling great possibility of scaling (plausible phases are predominantly carbonates) as well as of high corrosion, which implies the necessity of inhibitor dosage, pressure maintenance (2.1-2.2 MPa) and other precautions. To complete the whole project with at least 7 production and 7 reinjection wells with total heat output 100 MW_t the modelling of reservoir conditions is performed. The model is calculated for 30 years operation with various production and reinjection flowrates. To avoid improper technology implementation the long term semi-operational test will be performed. The ratio gas/water, production pressure drop, temperature drop in reservoir, chemical composition, reinjection pressure, scaling and corrosion equilibria will be investigated. The results of the wells provide good possibility for one heat exchange centre construction.

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Figure 1: Durkov geothermal structure location

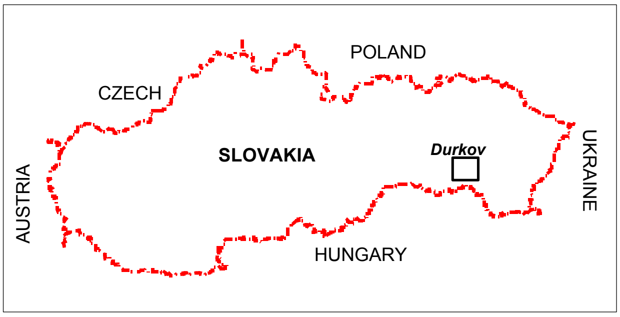


Table 1: Wells orientation

WELL	GTD-1	GTD-2	GTD-3
Azimuth	0 (vertical)	140°	264°
Angle	0	38°	39°
TVD (m)	3 210	3 151	2 252
TMD (m)	-	3 730	2 612

Table 2: GTD-2 well completion

TMD (m)	Casing
0 - 31	20“
0 - 503	13 5/8“
400 - 2661	9 5/8“
2601 - 3704	perforated 7“ liner

Table 3:Well data in dynamic conditions

WELL	GTD-1	GTD-2	GTD-3
T_{wh} (°C)	125	129	123
P_{wh} (MPa)	0,92	1,4	2,20
T_b (°C)	144	154	131
P_b (MPa)	29,3	27,4	21,9
Q (l/s)	56	50	65

Table 4: Hydraulic properties of Mesozoic dolomites from well test in March 1999 (J.Jetel, 1999)

WELL	T (m^2/s)
GTD - 1	$(2,1 \, , \, 5,7) \, . \, 10^{-4}$
GTD - 2	$1,6 \, . \, 10^{-4}$ - $8,2 \, . \, 10^{-5}$
GTD - 3	$6,3 \, . \, 10^{-3} – 3,4 \, . \, 10^{-4}$
GTD-1 – GTD-2	$(1,3 \, , \, 3,9) \, . \, 10^{-3}$
GTD-1 – GTD-3	$3 \, . \, 10^{-3}$ - $2 \, . \, 10^{-2}$
GTD-3 – GTD-1	$8,4 \, . \, 10^{-3}$
GTD-3 – GTD-2	$(4,2 \, , \, 8,4) \, . \, 10^{-3}$

Table 5: Distinguished ions concentrations (mg/l) in solid phase (0,45μm filter)

Sample	**Mg**	**Ca**	**Sr**	**Mn**	**Fe**	**SiO_2**
Wellhead	*0,800*	*95,030*	*0,064*	*0,130*	*6,543*	*41,490*
After separator	*6,900*	*183,530*	*2,467*	*1,127*	*8,970*	*43,920*
Condensate	*0,170*	*4,580*	*0,011*	*0,111*	*0,000*	*0,020*

Table 6: The chemistry of calcium in GTD-3 water (not degassed, resp. very little)

Temp. (°C)	**Press. [MPa]**	**Condition**	**cCa^{2+} equil. ($mg.l^{-1}$)**	**delta Ca^{2+} (mg/l)**	**part.pressure of CO_2 [MPa]**	**cCO_2 ($mg.l^{-1}$)**	**pH**
131.8	*19.55*	*aquifer 2400m*	*75.4*	***-0.19***	*2.541*	*9421*	*5.49*
129.9	*12*	*casing 1300m*	*72.5*	**0.3**	*2.515*	*9397*	*5.51*
125	*2.2*	*wellhead*	*76.2*	**0.2**	*2.2*	*8460*	*5.57*
110	*2*	*cooling*	*120.4*	***-8.7***	*2.073*	*8593*	*5.50*
100	*2*	*cooling*	*151.6*	***-12.6***	*1.843*	*8152*	*5.50*
90	*2*	*cooling*	*202.0*	***-38.2***	*1.602*	*7672*	*5.50*
80	*2*	*cooling*	*235.4*	***-45.0***	*1.421*	*7416*	*5.50*
70	*2*	*cooling*	*270.3*	***-47.9***	*1.232*	*7234*	*5.50*
60	*2*	*cooling*	*315.4*	***-62.2***	*1.087*	*7290*	*5.50*

Figure 2: Well's situation in the structural map of Neogene basement

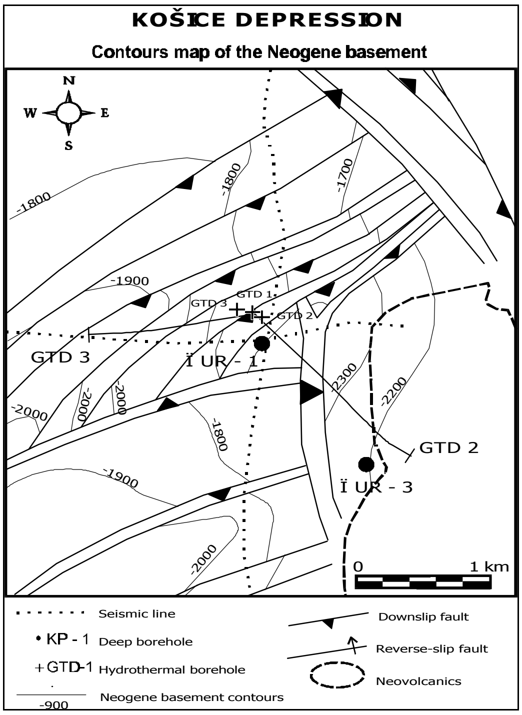


Figure 3: Geological profiles of GTD-1 and GTD-2

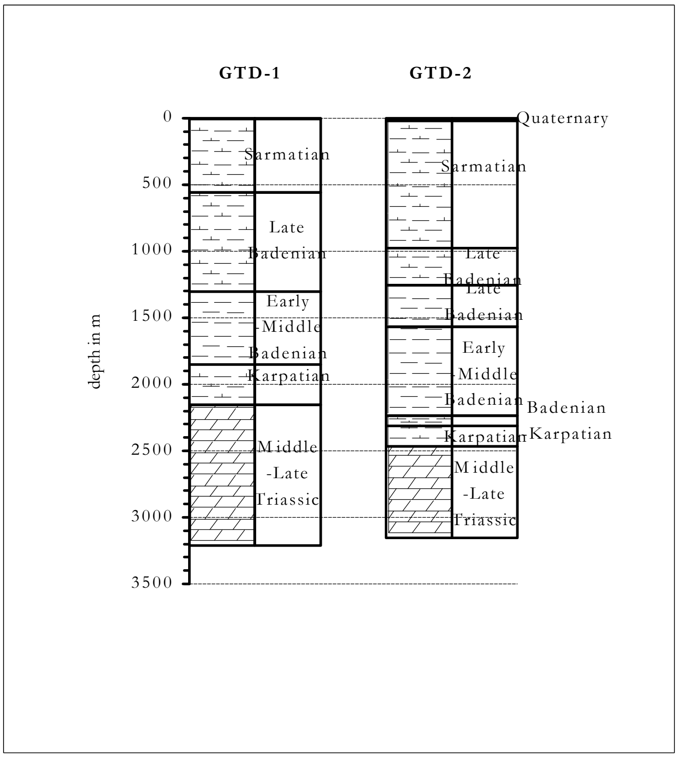
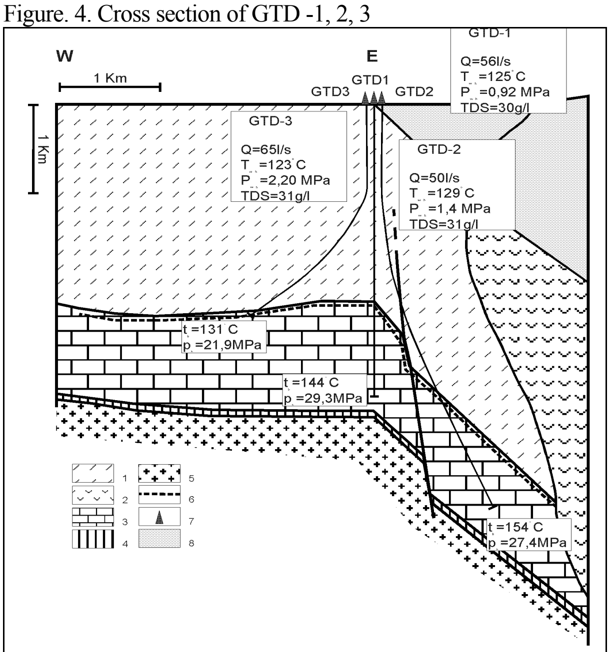
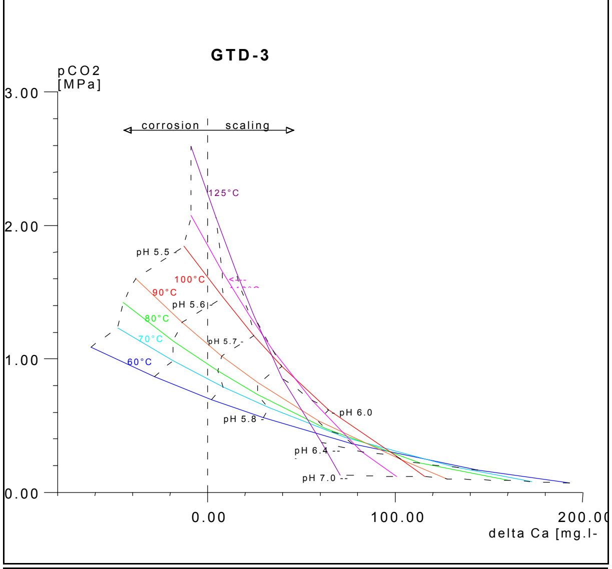


Figure. 4. Cross section of GTD -1, 2, 3



1-Neogene sediments, 2-Neovolcanics, 3-Triassic dolomites, 4-Werfenian shales, 5-Palaeozoic crystalline rocks, 6-Main inflow zone. 7-Well heads, 8-Surface

Figure. 6. Dependence of free Ca^{2+} ions supersaturation on partial pressure of CO_2 and temperature.



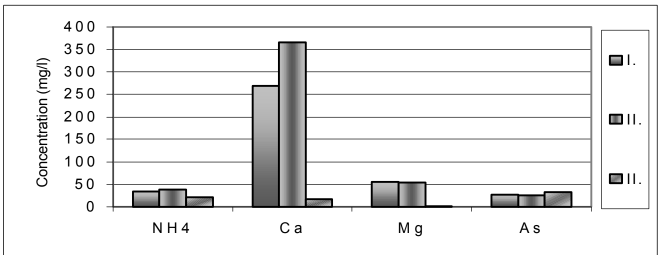


Fig. 5 Concentration of selected ions in geothermal waters
I.(wellhead), II.(after separator), III.(condensate)