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# Thermal-Energy Potential of the Liptov Depression

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## ABSTRACT

The Liptov depression represents an intramontaneous depression in the core mountain belt of the Inner Western Carpathians. Results from four geothermal boreholes 1,987 to 2,500 m deep were used for evaluation of geological structure, geothermic and pressure conditions, hydraulic parameters of aquifers, spatial distribution and chemical composition of geothermal waters and their thermal-energy potential.

Geothermal water aquifers in Liptov depression are represented by Triassic dolomites and limestones with the fissure-karst permeability. Aquifers were documented by geothermal boreholes at depths of 1,255 to 1,625 m. Their thickness varies between 300 and 1,000 m. Productive lengths varied from 65 up to 535 m during performed pumping tests. The average value of the intrinsic transmissivity coefficient $T_p$ ranges in the interval $2.41*10^{-12} – 1.05*10^{-10}$ $m^3$, the permeability coefficient $k_p$ in the interval $3.82*10^{-14} – 9.05*10^{-13}$ $m^2$.

The geothermal field activity varies considerably: geothermal gradient ranges from 18 to 32 °C/km, the heat flow density from 44 to 77 $mW/m^2$. At the depth of 500 – 5,000 m there occur waters at 20 – 150 °C. The chemical composition of waters is mainly of the Ca-Mg-$HCO_3$-$SO_4$ and Ca-Mg-$HCO_3$ types respectively, with mineralization of 0.4 – 5.1 g/l. Thermal-energy potential of the Liptov depression was estimated by distributed parameter model at 34.589 $MW_t$.

## 1. INTRODUCTION

The Liptov depression is one of the 26 prospective geothermal areas of the Slovak Republic. This 611 $km^2$ large depression is located in the north-western part of Slovakia (Figure 1). It is elongated in the E-W direction and fringed by the Nizke Tatry, Zapadne Tatry, Chocske vrchy and Velka Fatra Mts. The possibilities of obtaining and utilization of the geothermal waters in Liptov depression were manifested in the past by a number of natural springs of mineral waters.

The first hydrogeothermal evaluation of the Liptov depression, oriented on research of the geothermal resources, was done for Demanova area, followed by drilling of the first geothermal borehole FGL-1 in Pavcina Lehota (Remsik et al. 1979). Research of geothermal resources of the Liptov depression has continued by project of the partial research work of the development of science and technique (Zembjak et al., 1986). In the frame of the project, the thermal potential of the whole area of the Liptov depression was assessed based on knowledge of geological, geophysical, hydrogeological, geothermic and geochemical conditions, and drilling of three research boreholes in Besenova (ZGL-1), Liptovska Kokava (ZGL-3) and Liptovsky Trnovec (ZGL-2/A) was proposed. Boreholes were drilled in 1986 – 1991. After finishing of drilling works, complex evaluation was done and results were summarised in reports of Fendek et al. (1988), Remsik et al. (1990) and Remsik et al. (1992).

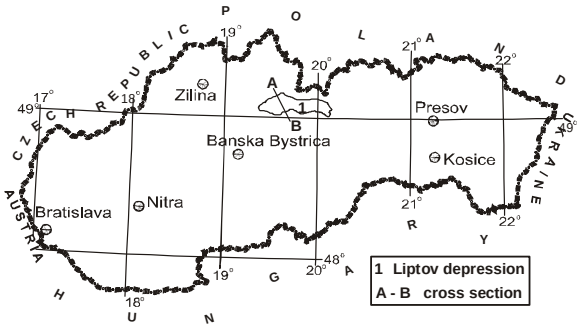



**Figure 1: Location of the Liptov depression**

Based on the results of these four geothermal boreholes, other research boreholes, and works performed in the Liptov depression (Remsik et al., 1993; Remsik et al., 1994; Fendek 1998 and Remsik et al., 1998) the complex evaluation of the hydrogeothermal conditions in Liptov depression was performed.

All the research works enabled to obtain basic data for evaluation of the pressure conditions, hydraulic parameters and amounts of geothermal waters of the Liptov depression.

## 2. GEOLOGICAL AND HYDROGEOTHERMAL STRUCTURES

The Liptov depression is an intramontaneous depression in the Inner Western Carpathians. It is filled with Paleogene sediments whose thickness ranges from 100 m (Besenova) to 1,700 m (Liptovska Mara). Paleogene flysh sediments are represented by alternation of clays and clayey shale with sandstones. Clays mostly prevail. On the base, basal conglomerates are developed.

The substratum consists of the Choc and Krizna nappes, which form elevated and sunken morphostructures. Choc nappe is higher tectonic unit then Krizna nappe. Choc nappe consists of the Triassic rocks with prevailing limestones and dolomites, less presented are Lunz beds (clayey shales and sandstones). The maximal thickness of the Choc nappe sequence is up to 1,000 m. Krizna nappe consists of rocks of the Triassic up to Lower Cretaceous ages. They are represented by quartzites, clayey shales, limestones, dolomites, detritic, marly limestones and sandstones with the maximal thickness of 1, 500 m. The lowest tectonic unit is the envelope sequence (with the same rock composition as Krizna nappe), which doesn't occur directly under the Paleogene sediments.

Spatial distribution of the Choc and Krizna nappes in the substratum of the Paleogene sediments is very variable. In

the western part of the depression, both nappes are presented equally, they can occur next to each other. In the middle and southern part of the depression Choc nappe dominates, in the northern part Krizna nappe sequences prevail. Sequences of Choc and Krizna nappes build mountain ranges which surround the depression and represent infiltration areas of the hydrogeothermal structures of the Liptov depression. Cross section A – B (Figure 2), which is delineated also in Figure 1, shows the hydrogeothermal situation in north-west – south-east direction, being drawn through wells ZGL-2/A and FGL-1.

Hydrogeological conditions in the area are conditioned by the geological-tectonic structure. Geothermal waters in the Liptov depression are discharged through natural springs and wells. Beneath the Paleogene there may be one to three hydrogeothermal structures positioned one above another in which geothermal waters are mostly associated with Triassic dolomites and limestones ("carbonates" throughout the following text) of the Choc and Krizna nappes and, possibly, also of the envelope (autochthonous) unit (Figure 2). These hydrogeological structures are largely open (having recharge area on adjacent slopes of surrounding mountains, as well as transit-accumulation and discharge areas) or semi-open (discharge area is missing). The Triassic carbonate aquifers with geothermal waters are from 300 to 1,200 m thick.

Geothermal waters occurring in the Choc nappe Triassic carbonates at depths 500 to 2,800 m have the temperature of 20 to 90 ºC while these in similar rocks of the Krizna nappe at depths of 900 to 4,000 m could be 25 to 125 ºC hot. The temperature of geothermal waters occurring in Triassic carbonates of the envelope unit at depths of 2,500 to 5,000 m might amount to 70 – 150 ºC.

## 3. GEOTHERMAL CONDITIONS

The activity of geothermal field is very variable, mainly as a result of convective heat transport in the rock environment. Temperatures (in ˚C) at different depths (in metres) are as follow in Table 1 and Figure 3.

Table 1 Temperatures at different depths

| Depth | 1,000 | 1,500 | 2,000 | 2,500 |
|---|---|---|---|---|
| Temperature | 29 – 46 | 37 – 62 | 46 – 76 | 54 – 87 |

Geothermal gradient in wells 2,000 to 2,500 m deep varies from 18 to 32 ºC/km and heat flow density ranges from 55 to 77 mW/m$^2$. The lowest values of the geothermal parameters have been noted in the eastern (Kokava depression – well ZGL-3) and southern (well FGL-1) parts of the depression while the highest occur in the west (well ZGL-1). Convective heat transfer in the Kokava depression (negative anomaly – well ZGL-3) and Besenova elevation (positive anomaly – well ZGL-1) disturbs the thermal field of the depression. Relatively non-disturbed thermal field with average values of the geothermic parameters occurs in the Liptovska Mara depression (well ZGL-2/A).

## 4. METHODS OF STUDY

Study of the hydrogeothermal conditions of the Liptov depression was done in four steps. First, general knowledge on geological structure and results of already realized structural geological borehole VL-1 Vlachy was taken into account by proposal of new geothermal wells location. In the second phase, four new geothermal wells well drilled in the depression during 70-ties and 80-ties of the last century. Consequently, results of wells drilled were analyzed. Hydraulic parameters of aquifers were estimated based on hydrodynamic tests results. In the end, method of mathematical modelling by Aqua programme was used for calculation of thermal-energy potential of the depression. Results of modeling were compared with the results of the thermal balance method

## 5. RESULTS

Geothermal wells were situated in elevations (ZGL-1) as well as in depression (e.g. ZGL-3) of the pre-Paleogene substratum. They tapped geothermal waters in Triassic carbonates of the Choc (FGL-1, ZGL-2/A) and Krizna nappes (ZGL-1, ZGL-3) at depths ranging from 1,315 to 2,486 m.

Hydraulic parameters of aquifers were calculated based on results of hydrodynamic tests performed on all geothermal wells in the depression (Table 2). The absolute transmissivity coefficient of the Triassic carbonates varies from $2.4*10^{-12}$ m$^3$ (FGL-1) to $1.1*10^{-10}$ m$^3$ (ZGL-3) and permeability from $3.8*10^{-14}$ m$^2$ (ZGL-1) to $9.1*10^{-13}$ m$^2$ (ZGL-3), both parameters decreasing from east to west. Well discharges range between 6 and 31 l/s and water temperature at the wellhead between 32 and 62 ºC (Table 3). Controlled by the discharge and temperature, the thermal power of wells attains 0.4 – 5.9 MW$_t$ at water temperature drop to 15 ºC.

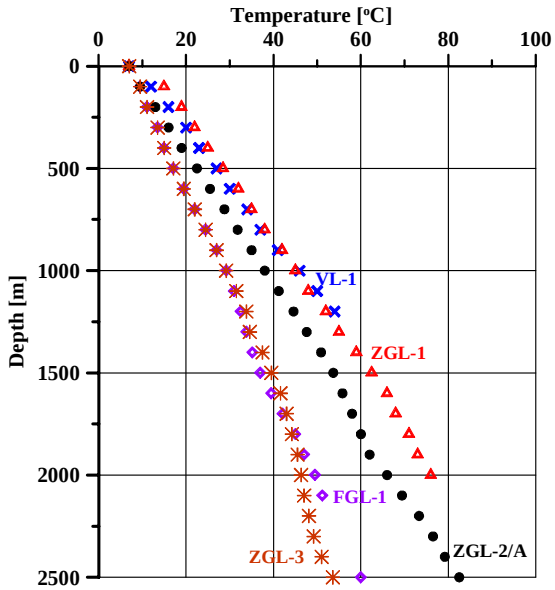



**Figure 3: Temperatures at different depths obtained from deep wells**

The depth of bubble points for geothermal wells in Liptov depression varies in the interval 162 to 225 m. The maximal depth of the bubble point was estimated for the well ZGL-2/A. According to the positioning of the bubble point it can be claimed that its utmost depths can be expected in the northern and north-eastern part of the Liptov depression. In these parts of the depression, the influence of the free gas content (gaslift) on the density of geothermal waters during their exploitation will be the greatest. Also higher contents of gases could be expected, what may cause, possibly, technological problems (scaling, corrosion) during exploitation of the geothermal water.

In accordance with the preceding claim, the highest values of the gaslift were estimated for boreholes ZGL-2/A and ZGL-3 (Table 4), in which they represent 50 to 83 % of the

measured drawdown. The ratio of the gaslift and thermolift on the measured drawdown in boreholes (expressed in percents) showed that for geothermal boreholes in the depression are the gaslift values of 5 to 71 % higher than values of the thermolift. At the same time, the influence of the free gas content and the water temperature represent 18 to 95 % of the measured drawdown. As a result of their influence on the boreholes exploited by the free outflow the bettering of the borehole discharge occurs. It means that without these influences, the value of the free outflow on geothermal boreholes ZGL-1 and ZGL-2/A would be only 27 to 70 % of the values measured during pumping tests.

Spatial distribution of piezometric levels for geothermal wells and selected boreholes tapping mineral waters of the Liptov depression showed that the dominant element forming the probable groundwater flow direction under natural conditions is placed in the north-eastern part of the depression. The course of hydroisopiezes (Figure 4) is in the southern part of the depression formed by the influence of water recharge in the area to the south-west of the Liptovsky Jan (well B-2) and Demanova valley. In the northern part it is formed by the influence of water recharge in the area to the north of villages Jalovec and Konska. Evident diminishing of the piezometric level slope can be observed in the area to the north of villages Liptovska Anna and Kvacany. The point of the lowest piezometric tension is located in the south-western part of the depression between the villages Liptovska Stiavnica (well LSH-1) and Vysny Sliac (well VSH-1). Another potential area of the cold water infiltration is to the south-east of the connecting line between boreholes LSH-1 and VSH-1.

The average value of the hydraulic conductivity coefficient in the area was estimated on $5.645*10^{-6}$ m/s, corresponding by the piezometric gradient of the $2.94*10^{-3}$ to the filtration velocity of $1.66*10^{-8}$ m/s. According to this, taking into account the value 0.1 for the coefficient of the filtration cross-section effectiveness of geothermal water aquifers, the value of the estimated average effective geothermal water flow velocity is $1.66*10^{-7}$ m/s, which represents 5.2 m per year.

The main Ca-Mg-$HCO_3$-$SO_4$ type of mineralization amounts to about 0.4 to 5.0 g/l (Table 3), while gases are represented mainly by $CO_2$. Sulphates in geothermal waters (Remsik et al., 1998) came largely from Lower Triassic formations with evaporites ($\delta^{34}S$ = 23.3 to 27.1 ‰); the isotopic composition of oxygen in geothermal waters shows that they are of meteoric origin.

The thermal-energy potential (TEP) of geothermal waters in the Liptov depression was evaluated by the thermal balance method and mathematic modelling using AQUA programme (AQUA, 1994), both techniques yield similar results. The prognostic TEP of geothermal water natural resources amounts to 34.6 $MW_t$ (248 l/s of water with temperature 27 to 70 ºC). From the total amount, 14 $MW_t$ (84 l/s of water with temperature 32 to 62 ºC) can be classified as a verified TEP (Table 3) while further 20.6 $MW_t$ (152 l/s of water with temperature 30 to 70 ºC) still remain to be verified by further investigations.

## 6.CONCLUSION

The Liptov depression is a typical intramontaneous depression in the Inner Western Carpathians where geothermal waters are associated with Triassic carbonates of the Inner Carpathian tectonic units (largely Choc and Krizna nappes) overlain by Paleogene sediments. Estimated geothermal parameters allowed dividing of the depression into two geothermally different parts, whereby the western one can be characterized by a higher geothermal activity.

Geothermal waters with the temperature of 20 to 150 ºC occur beneath the Paleogene at depths of 500 to 5,000 m. With regard to their temperature, geothermal waters can be classified as low-temperature (T < 100 ºC) and medium-temperature (T = 100 to 150 ºC). As far as their chemistry is concerned, geothermal waters here are represented by Ca-Mg-$HCO_3$-$SO_4$ type containing $CO_2$. Their T.D.S. ranges from about 0.4 to 5.0 g/l. Genetically, they are mostly meteoric waters with carbonate and sulphate mineralization. Geothermal waters occur in open and semi-open hydrogeological structures (their recharge areas lie in the adjacent mountain ranges), which implies that they and their TEP are renewable in time and space. The prognostic TEP of geothermal waters amounts to 34.6 $MW_t$, 14 $MW_t$ of which have already been confirmed by drilling. This energy source is a significant contribution to the energetic potential of the Liptov depression. It is particularly valuable because of its renewability.

## REFERENCES

AQUA – groundwater flow and contaminant transport model, AQUA *user´s manual*, Vatnaskil Consulting Engineers, Reykjavik, (1994).

Fendek, M.: Capture of geothermal waters in Besenova, *Proceedings*, Balneotechnical days 98, Faculty of Civil Engineering, STU, Bratislava, (1998), **92-102**.

Fendek, M., Bodis, D., Biely, A., Kullmanova, A., Gasparikova, V., Snopkova, P., Kral, M., and Janci, J.: Research geothermal well ZGL-1 in Besenova – approval of prognostic resources of the geothermal energy of the Liptov depression – western part, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1988).

Remsik, A., Biely, A., Bodis, D., Fendek, M., Gross, P., Kullmanova, A., Michalko, J., Rakova, J., Samuel, O., Snopkova, P., Kral, M., Janci, J., Franko, J., Drozd, V., Stepankova, K., and Skollova, Z.: Research geothermal well ZGL-3 Liptov in Liptovska Kokava, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1990).

Remsik, A., Biely, A., Bodis, D., Fendek, M., Gross, P., Havrila, M., Kullmanova, A., Rakova, J., Samuel, O., Snopkova, P., Michalko, J., Kanava, M., Kral, M., Janci, J., Pobis, J., and Drozd, V.: Research geothermal well ZGL-2/A Liptov in Liptovsky Trnovec, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1992).

Remsik, A., Fendek, M., Kral, M., Bodis, D., and Michalko, J.: Geothermal energy of the Liptov depression, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1993).

Remsik, A., Fendek, M., Kral, M., Bodis, D., and Michalko, J.: Geothermal waters of the Liptov depression and their thermal-energy potential, *Proceedings*, Possibilities of geothermal waters utilisation in Slovakia, Slovak association for technics, Bratislava, (1994), **30-35**.

Remsik, A., Fendek, M., Mello, J., Kral, M., Bodis, D., and Michalko, J.: Liptov depression – regional hydrogeothermal evaluation, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1998).

Remsik, A., Franko, O., Biely, A., Gross, P., Kullmanova, A., Lukacik, E., and Samuel, O.: Research geothermal well FGL-1 in Pavcina Lehota, *Research report*, Geological Survey of Slovak Republic, Bratislava, (1979).

Zembjak, O., Biely, A., Bodis, D., Fendek, M., Franko, O., Gabauer, G., and Balint, J.: Research of geothermal resources of the Liptov depression, *Project* of the research work for the period 1986 – 1990, Geological Survey of Slovak Republic, Bratislava, (1986).

**Table 2 Hydraulic parameters of aquifers**

| Well<br>Locality | Aquifers | Perforated interval [m] | Absolute transmissivity coefficient [$m^3$] | Transmissivity coefficient [$m^2/s$] | Permeability coefficient [$m^2$] | Hydraulic conductivity coefficient [m/s] |
|---|---|---|---|---|---|---|
| FGL-1<br>Pavcina Lehota | Triassic limestones and dolomites | 1,315-1,570 | $2.41*10^{-12}$ | $3.19*10^{-5}$ | $8.60*10^{-14}$ | $1.14*10^{-6}$ |
| ZGL-1<br>Besenova | | 1,420-1,964 | $5.15*10^{-12}$ | $1.16*10^{-4}$ | $3.82*10^{-14}$ | $8.61*10^{-7}$ |
| ZGL-2/A<br>Liptovsky Trnovec | | 1,624-2,486* | $4.33*10^{-11}$ | $1.02*10^{-3}$ | $2.07*10^{-13}$ | $4.88*10^{-6}$ |
| ZGL-3<br>Liptovska Kokava | | 1,475-2,365 | $1.05*10^{-10}$ | $1.82*10^{-3}$ | $9.05*10^{-13}$ | $1.57*10^{-5}$ |

* at the depth of 1,877 to 2,233 m Lunz beds (clayey shales and sandstones) occur

**Table 3 Data from geothermal wells**

| Well<br>Locality | Aquifers | Perforated interval [m] | Discharge [l/s] | Water temperature [ºC] | Thermal power [$MW_t$] | T.D.S. [g/l] | Chemical type of water |
|---|---|---|---|---|---|---|---|
| FGL-1<br>Pavcina Lehota | Triassic limestones and dolomites[1] | 1,315-1,570 | 6.0* | 32.0 | 0.42 | 0.4 | Ca-Mg-$HCO_3$ |
| ZGL-1<br>Besenova | Triassic dolomites[2] | 1,420-1,964 | 27.0** | 62.0 | 5.30 | 5.3 | Ca-Mg-$SO_4$-$HCO_3$ |
| ZGL-2/A<br>Liptovsky Trnovec | Triassic dolomites and limestones[1] | 1,624-2,486 | 31.0** | 60.7 | 5.89 | 5.9 | Ca-Na-Mg-$HCO_3$-$SO_4$ |
| ZGL-3<br>Liptovska Kokava | Triassic limestones and dolomites[2] | 1,475-2,365 | 20.0** | 43.5 | 2.42 | 2.4 | Ca-Mg-$HCO_3$-$SO_4$ |

[1] Choc nappe, [2] Krizna nappe, * pumping, ** free outflow

**Table 4 Comparison of gaslift and thermolift values with the measured depression $p_{me}$ for geothermal wells**

| Well<br>Locality | Depression $p_{me}$ [MPa] | Gaslift | | Thermolift | |
|---|---|---|---|---|---|
| | | MPa | % from $p_{me}$ | MPa | % from $p_{me}$ |
| FGL-1<br>Pavcina Lehota | 0.186 | - | - | 0.033 | 17.7 |
| ZGL-1<br>Besenova | 1.349 | 0.238 | 17.6 | 0.172 | 12.7 |
| ZGL-2/A<br>Liptovsky Trnovec | 0.949 | 0.476 | 50.1 | 0.218 | 22.9 |
| ZGL-3<br>Liptovska Kokava | 0.298 | 0.247 | 82.9 | 0.035 | 11.7 |

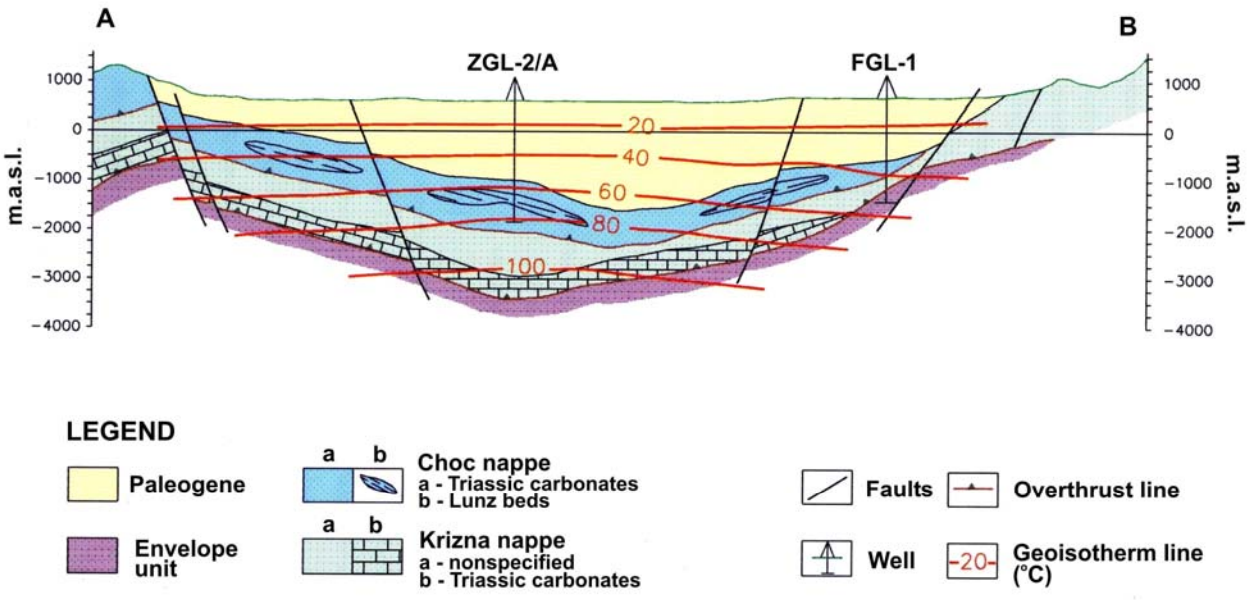
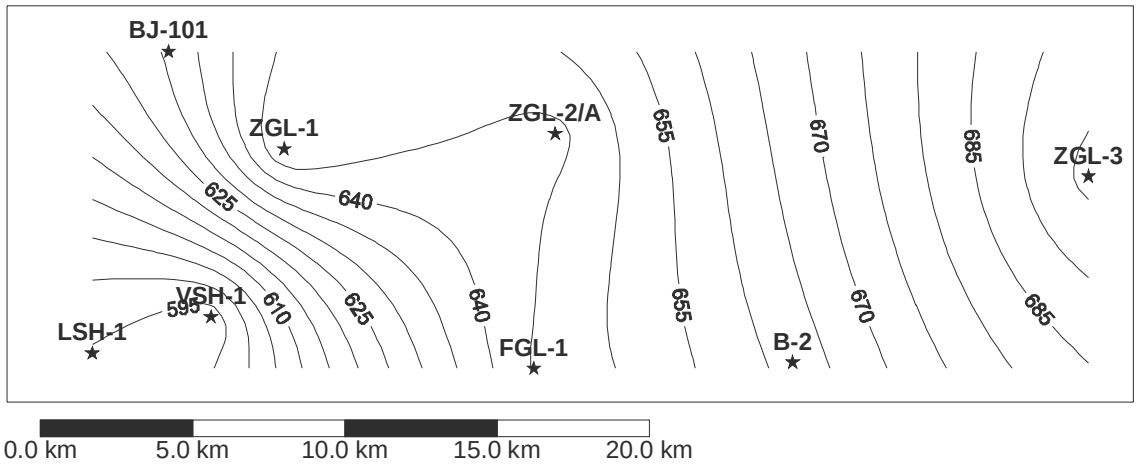



**Figure 2: Hydrogeothermal cross section A – B through the Liptov depression**



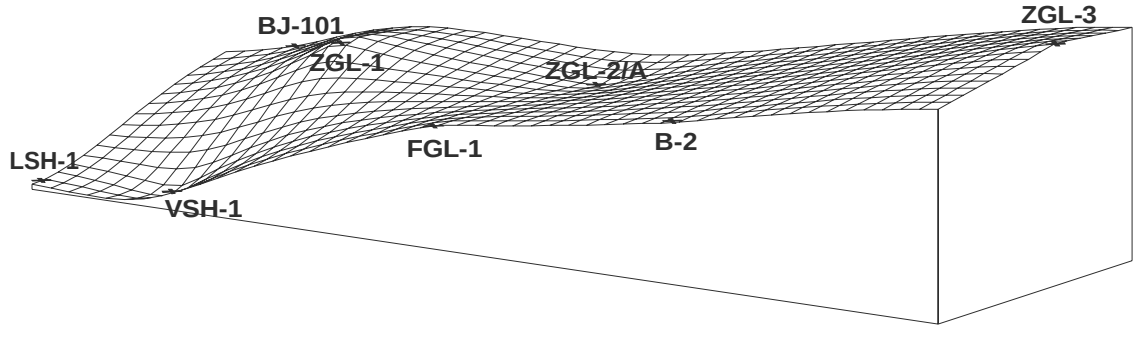




**Figure 4: Piezometric level of geothermal waters in Liptov depression**