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# Thermodynamic Analysis and Quality Mapping of a Geothermal Resource at the Ďurkov Hydrogeothermal Structure, Košice Depression, Eastern Slovakia

Branislav Fričovský [1], Ladislav Vizi [2], Miloš Gregor [1], Marián Zlocha [2], Martin Surový [2], Radovan Černák [1]

1 Dept. of Hydrogeology and Geothermal Energy, Dionýz Štúr State institute of Geology, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

2 Dept. of 3D/4D Modelling, Dionýz Štúr State institute of Geology, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

branislav.fricovsky@geology.sk

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## ABSTRACT

Geothermal energy in Slovakia is under a systematic research since 70's of the last Century. Out of 27 identified prospective geothermal fields within a territory of the West Carpathians, the Ďurkov depression hydrogeothermal structure in the Košice Depression is repeatedly accented as of the most enormous potential for a heat (and in some, rather wishful, plans for power) production. Unlike a conventional evaluation of thermal potential and temperature, this study aims at description of the reservoir under an exergetic concept; quantifying reservoir enthalpy, exergy and specific exergy index prior classifying a system according to a thermodynamic quality.

The geothermal resource is a geothermal water with only a minor equilibrated steam fraction ($X_S < 0.18$), questionable in natural occurrence. A reservoir associates Mid Triassic carbonates, occupying depths of $z_{top}$ = 1,600-2,600 m and $z_{btm}$ = 1,600-2,600 m. At given geothermic conditions, a mean reservoir enthalpy reaches h = 640 kJ.kg$^{-1}$ for the entire body, however, only 10 % exceed a h = 800 kJ.kg$^{-1}$, a limit to classify a resource of high enthalpy. Specific exergy index has been calculated within an interval of SExI = 0.04-0.25, with a mean of SExI = 0.11. Only 10 % of the reservoir at depths of z = 3,100-3,900 m can target a SExI > 0.2 with more than 90 % probability of success. A geothermal resource and the entire system can be classified thus as of a moderate-low exergy (thermodynamic quality) for SExI = 0.05-0.2 or of a moderate low exergy for SExI = 0.05-0.5. Thermodynamic data show the resource is rather suitable for a large-scale heat (district heating) production – supply.

## 1. FOREWORD

The Slovak Republic is a low-AHSs country with mean yearly emissions of 25 % below a ratified level. Although, national economy is still fossil-fuels oriented. Indeed, renewables contribute only 23 % on domestic electricity and 19 % on domestic heat primary energy consumption. By a contrast, onset of systematic research and development of geothermal energy dates back to the 70's of the last Century, progressively increasing a number of geothermal installations in a direct-use from 43 MWt in 1980 (Franko et al., 1990) to 149 MWt in 2015, not including heat pumps (Fendek and Fendeková, 2015). Recent global environmental constraints prompt, however, the country towards renewables. With 27 geothermal water bodies covering roughly 40 % of the country identified (Fendek and Fendeková, 2010), the geothermal energy appears of a significant potential, assumed app. 6500 MWt in probable reserves.

The Ďurkov hydrogeothermal structure has been recognized the most prospective system amongst the all (e.g. Vranovská et al., 2000). Even several plans on district heating individual (e.g. Halás et al., 1999) or binary geothermal power plant bound (Kukurugyová et al., 2015) exist already, a conceptual, engineering approach to analyze the geothermal resource is still missing. Preliminary studies based on a borehole data classified the structure as of moderate-low exergy (Fričovský et al., 2016a,b). This paper presents a first insight into local reservoir thermodynamics and thermodynamic quality mapping.

## 2. BACKGROUND

### 2.1 General considerations

Hydrogeological conditions triggering evolution of geothermal resources in Slovakia owe to lateral extension and vertical position of prospective Mid Triassic carbonates organized in multiple superpositioned nappes, resultant to Alpine tectonics; and Neogene Germanic-type neotectonics, forming deep sedimentary basins associating a resource with sands and sandstones in major (Franko and Melioris, 1999). Heat flux and accumulation outlines as consequent to different structure and depths of neotectonic blocks, overall crustal thickness and non-uniform mantle propagation, seating and depth of major crustal faults; and spatial distribution of Neogene – Early Pleistocene neovolcanism (Fendek et al., 1999). Still, geothermal plays in the West Carpathians (Slovakia) are conduction-dominated, orogenic belt-type (Moeck, 2014).

Two different regions of geothermic activity are distinguished within the West Carpathians. Intramountain depressions show rather low to moderate heat flux density (q = 60-90 mW.m$^{-2}$). This increases within Neogene deep sedimentary basins towards q = 90-120 mW.m$^{-2}$ (Franko and Melioris, 1999), classified moderate-high to high in local conditions. Amongst the latter is the Košice Depression (Figure 1), terminated along Neogene volcanic range of the Slanské vrchy Mts. to to east and a core-mountain massif of the Slovenské Rudohorie Mts. to the west (e.g. Vranovská et al., 2015).

### 2.2 Site definition

The Ďurkov hydrogeothermal structure (DDHS) represents a depressed morphostructure of Mesozoic carbonates beneath, in vast majority, Neogene sedimentary basin fill in the western part of the Košice Depression. To the west, the structure terminates along a N-S trended fault zone parallel with the line connecting towns of Vyšný Čaj – Olšovany – Ďurďošík – Trsťany. Eastern margin corresponds with deep extension of Neogene volcanites. A northern limit corresponds to the tectonic contact with the Bidovce pre-Tertiary depression, whilst to the south, the system is delineated arbitrary to the uplifting blocks of Mesozoic carbonates along a Ruskov – Vyšný Čaj line (Figure 1).

### 2.3 Deep geological structure

The Košice Depression as a neotectonic morphostructure is resultant to the Neogene Germanic-type tectonics. In general, Quaternary exclusively terrestrial accumulations, Neogene sedimentary to minor volcanosedimentary formations and Mesozoic carbonates form a relevant deep geological structure. A crystalline beneath has not been subjected to a study yet.

Obviously, Quaternary accumulations (fluvial, proluvial and deluvial forms) are only several meters thick; thus are usually neglected in vertical and horizontal extension. A thickness of the Neogene profile reaches up to 2000-3000 m within the structure. Atop, Sarmatian clays with rare rhyolite and andesite volcanoclastics are 200-1000 m thick (Vranovská et al., 1999a). Beneath, carbonate sandy clays alternating sparsely with tuffites form up to 1500 m thick Badenian part of the profile. Carbonate claystones with minor sandstones and basal brecciated conglomerates represent a bottom 400-600 m thick base of the Neogene succession (Vranovská et al., 2015).

Mid Triassic dolomites represent an analogue to the Krížna Nappe series of the Western Carpathians. Because of tectonic dissection of the Košice Depression, a thickness of the Mesozoic profile varies between 200-2000 m (Vranovská et al., 1999a), increasing pseudo-axially in the NW-SE and SW-NE direction. It is generally assumed that the greatest thickness corresponds to the major depression of the DDHS in the Ďurkov town area. However, the entire structure is dissected into several elevated and depressed blocks of Mesozoic carbonates beneath the Neogene sedimentary cover along multiple faults; i.e. those of N-S and SW-NE trend in major.

A geochemical modeling conducted to explain high arsenic concentrations (cAs = 19-36 mg.l$^{-1}$) in Na-Cl type geothermal water associated with the DDHS (TDS = 20,000-30,000 mg.l$^{-1}$) has proven the system as hydrogeologically closed (Bodiš and Vranovská, 2012; Vranovská et al., 2015). A lack of natural reservoir recharge is amongst the most pronounced in considering of closed-loop systems at the site.

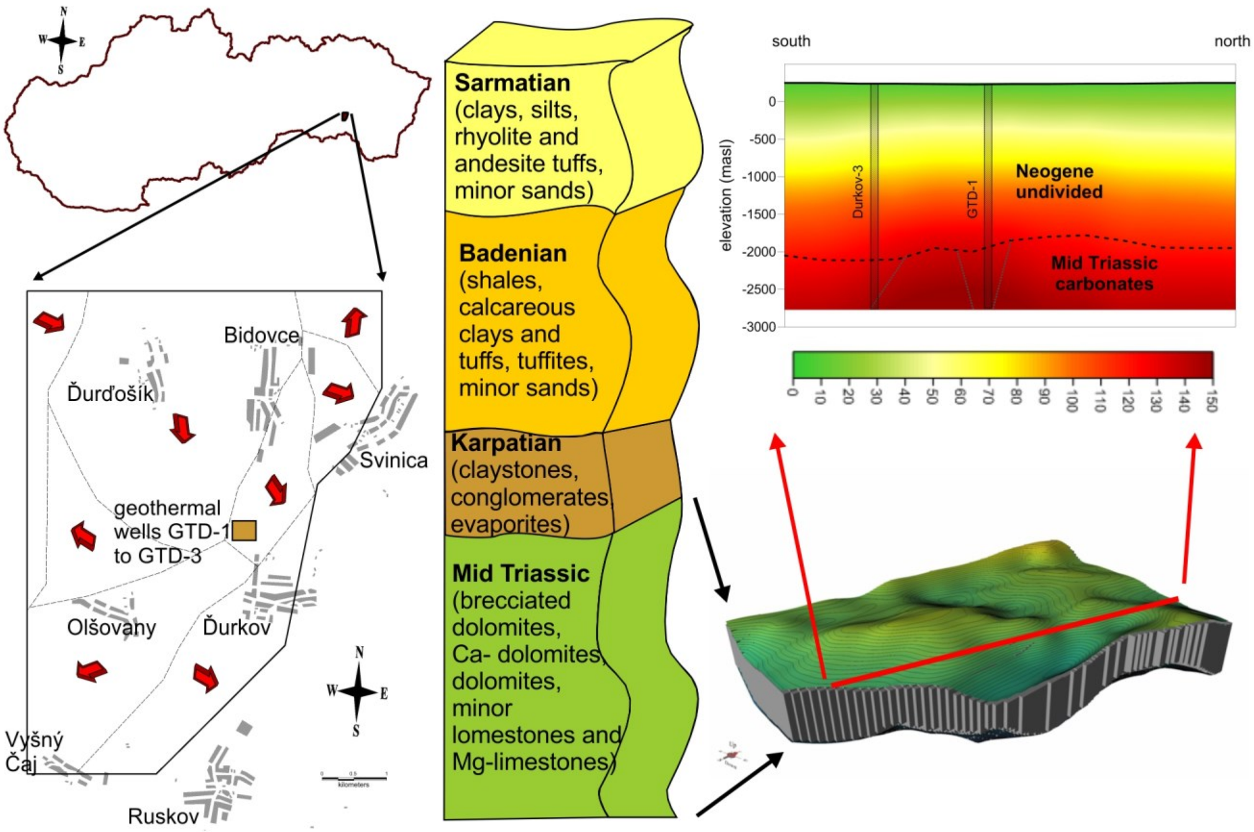

Figure 1: Site definition of the Ďurkov depression hydrogeothermal structure; tectonic segmentation with direction and slope of tectonic blocks; vertical profile and lithology, temperature profile and a reservoir body.

## 3. METHODOLOGY AND APPROACH

Under theoretical considerations, renewability of a geothermal resource at natural (initial, reservoir etc.) conditions can be attributed to the closed thermodynamic system. At such, the 1st Law of Thermodynamics is adequate enough, whilst the resource and the system can easily be described according initial-state conditions; i.e. the temperature. However, resource production is an artificial aspect of geothermal energy utilization, far beyond a thermodynamic concept of a closed system. Indeed, multiple irreversibilities apply, the 2nd Law of Thermodynamics must be considered.

### 3.1 A concept of exergy

According to the 1st Law of Thermodynamics, the energy of the closed system at initial (natural) conditions is a conservative measure (1) well described along a balanced enthalpy flow (2). The latter neglects heat and work transfers (Ozgener et al., 2007):

$$\dot{Q}_{in} - \dot{Q}_{out} + \sum \dot{m}_{in}.h_{in} = \dot{W}_{out} - \dot{W}_{in} + \sum \dot{m}_{out}.h_{out} \tag{1}$$

$$\sum \dot{m}_{in}.h_{in} = \sum \dot{m}_{out}.h_{out} \tag{2}$$

where $Q$ is heat transfer rate, $m$ is the mass flow, $W$ is the work rate, and $h$ is the enthalpy; symbols “in” and “out” refer to a system inlet/outlet conditions.

Under artificial production, the state of the system changes, and multiple irreversibilities apply as the entropy generates. Then, only a part of an energy can be sufficiently converted into a useful work – the exergy (DiPippo, 2005), also denoted as a thermodynamic quality (Lee, 1996). Unlike the energy, the specific exergy (3) is rather consumed or destroyed during a resource utilization due to entropy generation (Ozgener et al., 2005):

$$e = (h_{DP} - h_{RC}) - T_{RC}(s_{DP} - s_{RC}) \tag{3}$$

where $e$ is the specific exergy, $h$ is the enthalpy, $T$ is the temperature, and $s$ is the entropy; indexes “*DP*” and “*RC*” refer to a definition and reference point respectively.

A maximum thermodynamic quality (exergy) is achieved if the system transfers from definition to the dead-state p-T conditions. The latter corresponding to the triple-point (4):

$$e = h_{DP} - 273.s_{DP} \tag{4}$$

where $e$ is the specific exergy, $h$ is the enthalpy, and $s$ is the entropy; index “*RC*” refers to a definition and reference point respectively.

Otherwise, pseudo-dead state conditions can be specified (Ozgener et al., 2006) variously; whether at reinjection or spill, a condenser etc. A definition point is typically defined to the borehole inlet or wellhead, as this take an advantage in a fact that this is a first point where the resource can actually undergo a conversion process or can generate work (Lee, 2001).

### 3.2 A concept of specific exergy index classification

Geothermal resources (fields) tend to get subjected both for quantitative and qualitative analysis. In exergy concepts, the quantitative definition of thermodynamic quality relates to the specific exergy index – SexI (Lee, 1996, 2001) calculation. Instead of some arbitrary criteria, such as it is with the temperature, this is a normalized parameter (5) relating a maximum exergy of the system theoretically available, to the maximum exergy of a saturated steam at p = 90 Bar-abs and T = 303 °C with a triple point sink condition; i.e. e = 1192 kJ.kg$^{-1}$ (Lee, 2001):

$$SExI = \frac{h - 273.15s}{1192} \tag{5}$$

where: *SExI* is the specific exergy index, and $h$ and $s$ refer to the geothermal resource enthalpy and entropy at a definition point.

To map thermodynamic quality, Lee (1996, 2001) introduced several limits: a SExI = 0.5 represents a thermodynamic quality of saturated steam at p = 0.1 MPa and T = 100 °C, whilst a SExI = 0.05 describes a thermodynamic quality of saturated water at T = 100 °C and p = 0.1 MPa. Thus, the SExI = 0.2 represents a limit for double-phase system at p = 2 MPa and p = 1,000 kJ.kg$^{-1}$. Under given criteria set, geothermal resources can be classified as:

a) low thermodynamic quality exergy; SExI < 0.05 (typically single-phase, water dominated geothermal fields)

b) moderate-low thermodynamic quality / exergy; 0.05 ≤ SExI ≤ 0.2 (two-phase, water dominated geothermal fields)

c) moderate-high thermodynamic quality / exergy; 0.2 ≤ SExI ≤ 0.5 (typically two-phase, vapor dominated geothermal fields)

d) high thermodynamic quality / exergy; SExI > 0.5 (single phase dry steam, two-phase vapor dominated geothermal fields).

Along with numerical consideration, geothermal resources are frequently analyzed using Mollier's and Rant's diagrams, plotting enthalpy to entropy and entropy to the specific exergy of the resource respectively. Since introduction, the concept of exergetic (engineering) classification has been successfully applied in analyses of geothermal fields in Turkey (Etemoglu and Can, 2007), Poland (Barbacki, 2012), Japan (Jalilinasrabady – Itoi, 2013), Mexico (Ramajo et al., 2010) or in Slovakia (Fričovský et al., 2016a,b).

### 3.3 Review on modeling procedure

3D distribution of thermodynamic parameters for the Ďurkov depression hydrogeothermal structure Mid Triassic reservoir was modeled using geostatistical simulation software ISATIS. A grid consisted of equal cells with 50x50x10 m resolution, delineated along a stable surfaces representing a top and a base of the reservoir. A scope of the entire simulation was to estimate 3D distribution of reservoir specific enthalpy, exergy at triple-point conditions and specific exergy index prior searching for local thermodynamic anomalies set by a cut-off of 800 $kJ.kg^{-1}$ for specific enthalpy and 0.05 and 0.2 for specific exergy index. To achieve this, a numerical probabilistic simulation became mandatory.

Applying a Turning band method, 100 realizations were conducted to simulate a spatial distribution of given variables. This has been chosen as one of fastest and well established methods in parametrical and 3D simulation. A primary presumption expected unstationarity in a vertical direction according to a fact that both, enthalpy and entropy are a function of temperature, and, thus, a depth. A conduction, identified as a heat transfer endmember within a system reasons the assumption well. A simulation range has been, however, conditioned along universal co-kriging of primary input data per each realization. A mean of simulation-obtained subpopulation per each node has been used to determine a value of parametric estimation either for enthalpy or specific exergy index in a 3D resolution. We used the given cut-off limit ($h = 800\ kJ.kg^{-1}$, SExI = 0.05 and SExI = 0.2) to detach a part of subpopulation estimated as under the criteria. This allowed delineation of local anomalies meeting a given criteria. Moreover, use of cut-off also allowed probabilistic determination of distribution of selected variables and target values within the reservoir.

## 4. RESULTS

Thermodynamic calculations, necessary as input for a later simulation, and quality mapping has been performed on regularly-gridded model with a cell of 100 x 100 m in horizontal direction. A vertical resolution adjusted the reservoir thickness per each node to equally distributed 10 points. Reservoir geometry is based on a multi-parametric model with inputs from borehole lithology, logging, seismic profiles and morphostructural maps (Vranovská et al., 1999b) and other hardcopy or grid data (Pachocká et al., 2010). Stationary thermodynamic data derivation succeeded geothermic calculations (temperature, heat flux, radiogenic heat production etc).

### 4.1 Reservoir specific enthalpy

Most of studies on DDHS promote the system as of moderate to high temperature, according to local classification schemes (e.g. Fendek et al., 1999). Temperature ($T_{gw}$), total dissolved solids ($M_{gw}$) and calculated hydrostatic pressure ($p_{gw}$) were used to determine specific enthalpy in reservoir conditions (Figure 2); so that $h_{(z)} = f(T_{gw}, M_{gw}, p_{gw})$ where $T_{gw} = f(z)$, $M_{gw} = f(T_{gw})$ and $p_{gw} = f(z)$. A review on stationary temperature field is provided in Table 1.

It is a clear SE trend observed for increase in specific enthalpy within the reservoir body as a function of depth and proximity to the Slanské vrchy Mts. The top of the reservoir extends in depths of 1,660-2,600 m, so that the reservoir enthalpy at a top varies $h_{top} = 390\text{-}740\ kJ.kg^{-1}$. Approximately 50 % of the calculated enthalpy is less than $h = 540\ kJ.kg^{-1}$. Towards the base at z = 1,960-4,000 m, the enthalpy fairly increases, i.e. $h_{btm} = 440\text{-}1{,}060\ kJ.kg^{-1}$. As given by the model, a mean enthalpy at the base of the reservoir is $h = 710\ kJ.kg^{-1}$. A most significant rise in enthalpy is estimated for the SE part of the system, where the gradient in enthalpy is $\delta h_{res} = 200\text{-}260\ kJ.kg^{-1}.km^{-1}$. An overall thickness of Mid Triassic carbonates in this part is assumed for $\Delta z = 500\text{-}1{,}500$ m.

Unlike general assumptions, only 10 % of the entire reservoir exceed the arbitrary given limit of $h_{res} > 800\ kJ.kg^{-1}$ criteria to distinguish between low and moderate (high) enthalpy geothermal waters (Figure 3). Distribution within the reservoir is uneven, skewed left. A zone of $h_{res} > 800\ kJ.kg^{-1}$ locates at the SE margin of the reservoir, in depths of z = 2,870-4,000 m below the surface. The zone of elevated, moderate (high) enthalpy, is most probably located east from the Ďurkov village. It corresponds to the tectonic block hit by geothermal wells GTD-1, GTD-2 and GTD-3. A vicinity to neovolcanic Slanské vrchy Mts. and possible metamorphism plays a huge uncertainty to hydraulic properties in that zone though, increasing a risk of failure when tapping for geothermal water and deliverability. Instead of focusing to the E, we propose to delineate the prospective zone along a depressed block of carbonates running N and NE from geothermal wells.

**Table 1. Review on temperature distribution with depth for the Ďurkov hydrogeothermal structure, including Neogene profile**

| True vertical depth | Minimum | Mean | Variance | Maximum |
|---|---|---|---|---|
| [m] | [°C] | [°C] | [°C] | [°C] |
| 500 | 34 | 39 | 11 | 45 |
| 1000 | 59 | 66 | 16 | 75 |
| 1500 | 80 | 92 | 24 | 104 |
| 2000 | 96 | 111 | 32 | 129 |
| 2500 | 109 | 124 | 35 | 144 |
| 3000 | 12 | 138 | 37 | 159 |
| 3500 | 145 | 154 | 39 | 174 |

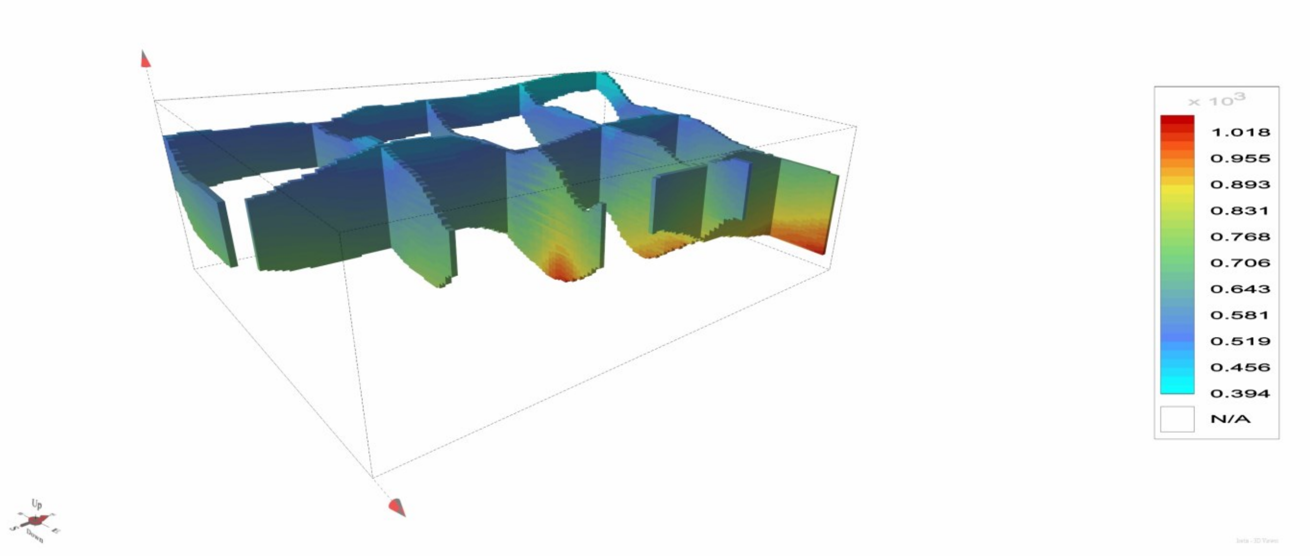

**Figure 2: The Ďurkov hydrogeothermal structure: reservoir enthalpy distribution; a SE view**

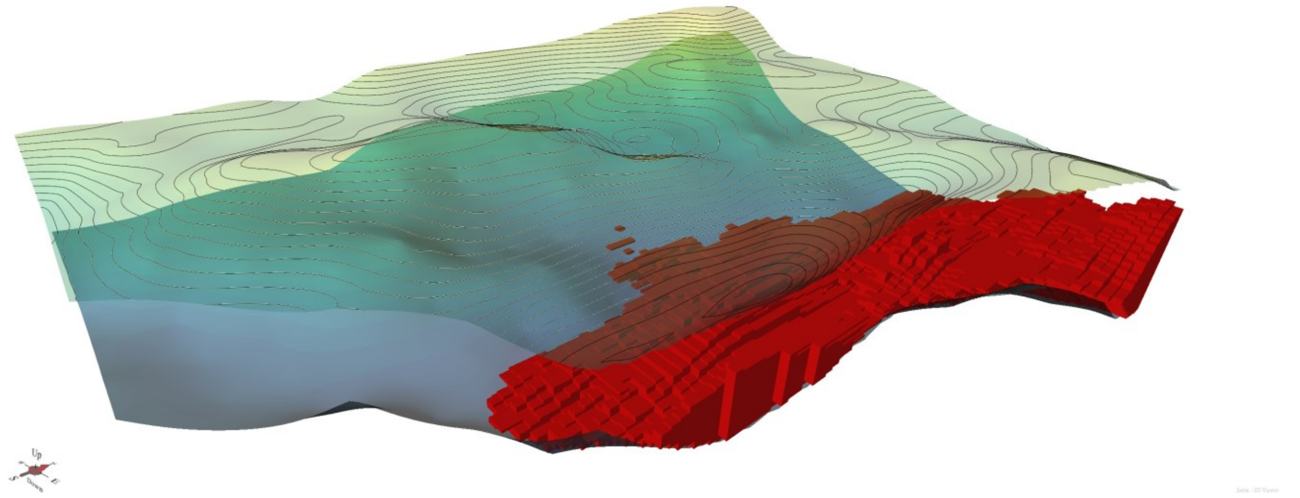

**Figure 3: The Ďurkov hydrogeothermal structure: A moderate (high) enthalpy reservoir zone ($h_{res} > 800$ kJ.kg$^{-1}$); an E view**

### 4.2 Specific exergy index

By definition, the specific exergy index relates exergy of the given fluid described at a triple point conditions over a maximum exergy available, i.e. e = 1192 kJ.kg$^{-1}$. Similar to specific enthalpy, we set the specific entropy; so that the $s = f(T_{gw}, M_{gw}, p)$. Thus, the specific entropy varies $s_{top}$ = 1.2-2.1 kJ.kg$^{-1}$.K$^{-1}$ for the top and increases to $s_{btm}$ = 1.4-2.8 kJ.kg$^{-1}$.K$^{-1}$ at a base of the reservoir. For the entire reservoir body, a mean specific entropy is estimated for s = 1.75 kJ.kg$^{-1}$.K$^{-1}$.

Quantitatively, the specific exergy index is calculated for SExI = 0.04-0.25, with a mean of SExI = 0.095 if the reservoir is taken as a solid body. This is strikingly different compared to other hydrogeothermal systems in the West Carpathians. Based on local geometry and geothermics, a specific exergy index fairly increases between a top ($SExI_{top}$ = 0.04-0.06) and bottom ($SExI_{btm}$ = 0.1-0.25); so a mean at a top and a base does (SExI = 0.08 and SExI = 0.14). A tendency of SExI to increase follows well the trend of reservoir specific enthalpy (Figure 4); i.e. a clear trend with depth and a direction, the SE margin of the structure, is well expectable. Thus, for what is called the prospective zone in this paper, the specific exergy index interval reduces to SExI = 0.11-0.25 at depths of z = 2,870-4,000 m. However, SExI > 0.2 occupies a minimum depths of 3,100 m rather to the E. This part has not been documented yet, bearing a huge risk of failure when targeting to tap the geothermal resource there.

### 4.3 Thermodynamic quality classification

Under a given range of specific exergy index calculated, 95 % of the reservoir exceeds the SExI = 0.05 criterion to consider an associated resource as of moderate-low thermodynamic quality. Exception is the NW periphery of the structure at depths of z = 1660-1780 m west from the town of Ďurďošík, where carbonates are fairly elevated ($z_{top}$ = 1,600-1,800 m; $z_{btm}$ = 1,800-4,000 m).

A second standard given by Lee (1996, 2001) recognizes moderate-high thermodynamic quality geothermal resources if SExI > 0.2. In geothermic conditions at the DDHS, approximately 10 % of the reservoir exceeds the level of specific exergy index (Figure 5) only. Obviously, the zone of elevated thermodynamic quality correlates well to the zone of highest reservoir specific enthalpy, concentrated along E margin of the structure. When considering depths, zones, where moderate-high geothermal resource can be found with 90 % probability of success locates in depths of z = 3,100-3,900 m.

Indeed, a skepticism arises when evaluating the elevated thermodynamic quality, at least as implied by SExI calculation. A zone of 90 % success covers 40 % of a reservoir thickness in maximum (Δz = 90-600 m) within the prospective zone. A vicinity of neovolcanites triggers geothermic activity there. Meanwhile, an effect of metamorphism and reduction in permeability can not be omitted. Thus, when considering an anomaly hunting / stacking approach (Cumming, 2009) for a future exploration of the entire geothermal structure, a focus on a tectonic block running NE between Ďurkov and Bidovce/Svinica towns is strictly recommended, as this has been sampled already. This should limit a risk of failure apparent where targeting for highest SExI or enthalpy.

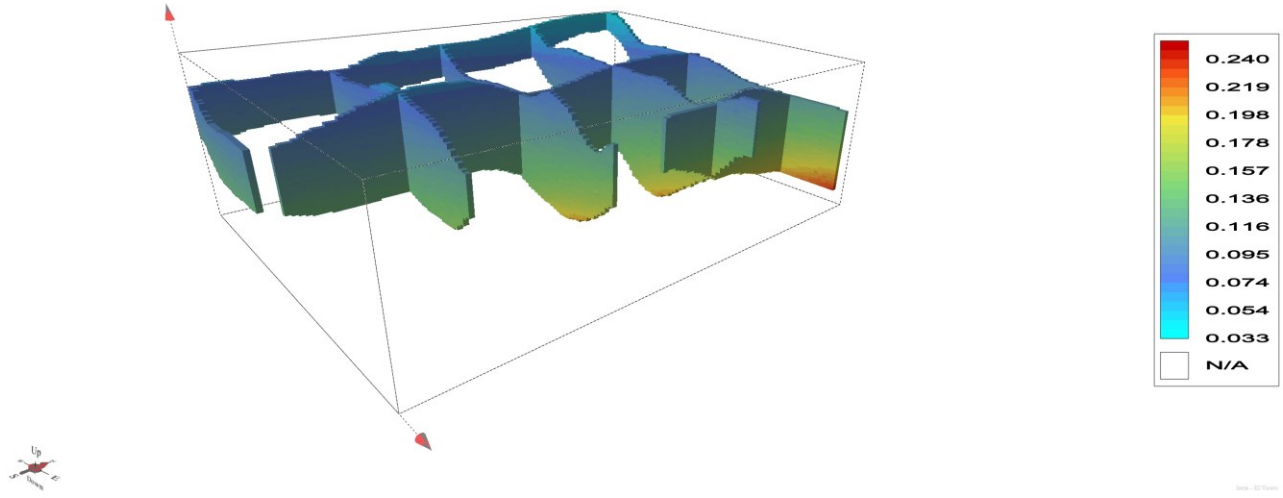

Figure 4: The Ďurkov hydrogeothermal structure: reservoir specific exergy index distribution; a SE view

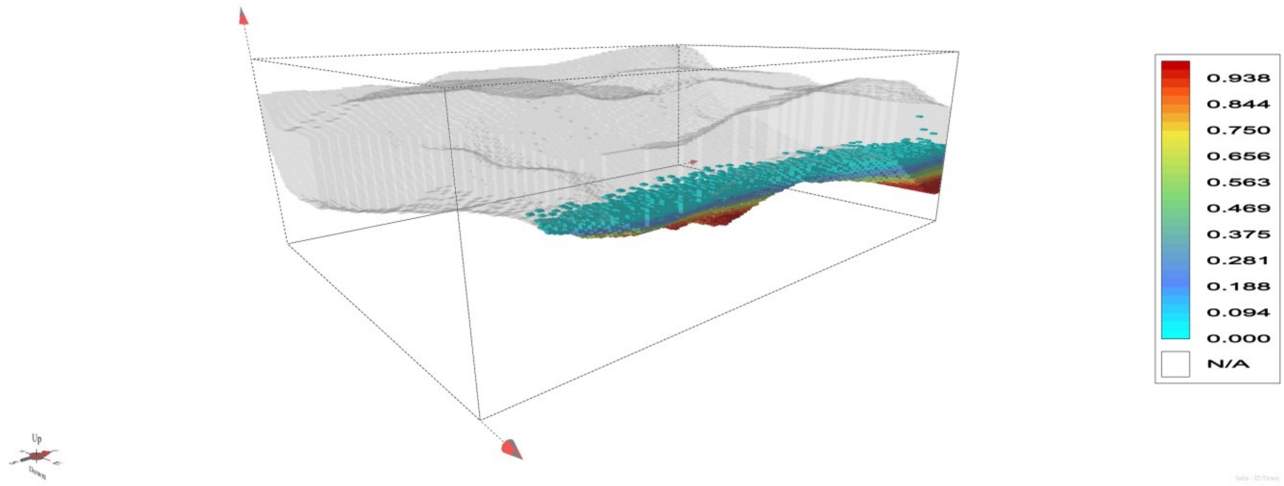

Figure 5: The Ďurkov hydrogeothermal structure: reservoir SExI > 0.2 occurrence probability; a SE view

### 4.4 Thermodynamic quality mapping

To map thermodynamic quality of the geothermal resource associated with the Mid Triassic reservoir, we used state diagrams for enthalpy versus temperature (Figure 5) and entropy versus enthalpy and exergy (Figure 6); both plotting calculation results for a prospective zone of the reservoir only. This should be delineated as a part of the reservoir following a tectonic block hit by GTD-1 to GTD-3 wells in 1999 (Vranovská et al., 1999), running N of the Ďurkov town and arching NE between a towns of Bidovce and Svinica (Figure 1, 3 and 5). Vertically, the zone is limited along a top and bottom of the reservoir. So if we consider this part as elevated in geothermic and thermodynamic parameters, a rest of the reservoir is, consequently, of lower exergetic quality.

A plot of reservoir enthalpy to reservoir temperature shows only a minor equilibrated steam fraction up to $X_S = 0.18$, increasing with depth. In fact, recently unpublished sustainable reservoir management evaluation for the structure (in preparation; Fričovský et al., 2019) questions presence of a steam cap in the reservoir and so a possibility of a double phase at depths does. However, for a prospective zone, a resource specific exergy at a triple point conditions ranges e = 90-290 kJ.kg$^{-1}$. A reservoir out of the prospective zone does not reach the saturation curve at all. A difference between the DDHS and some geothermal systems worldwide is striking (Figure 6), even if reservoir temperature is comparative. Indeed, with higher steam fraction at Wairakei ($X_S \approx 0.23$) or Ohaaki ($X_S \approx 0.6$), both record higher specific exergies; i.e. e = 400 kJ.kg$^{-1}$ and e = 650 kJ.kg$^{-1}$ respectively; and are used for geothermal power production. It would, thus, be thermodynamically inefficient (if not impossible) to consider a direct or flashing power generation systems at the DDHS, even temperatures may imply some potential.

Evident is also the difference between the DDHS and selected geothermal fields on the Mollier's and Rant's plot (Figure 7). Even within the prospective zone delineated by heat flux and temperature anomalies, when stacked, only a few percentage exceeds a SExI = 0.2 (moderate-high exergy) line, although reservoir temperatures between the DDHS and, e.g. Ohaaki, are approximately the same. Rather is the system comparable to Podhale, Fuzhou, Tianjin or Balcova geothermal fields.

Thus we recommend the system of DDHS to be classified as of moderate-low thermodynamic quality (moderate-low exergy).

## 5. DISCUSSION AND CONCLUSIONS

The DDHS is repeatedly reported as the most prospective geothermal system in the West Carpathians. Three geothermal wells (GTD-1 to GTD-3) have been installed there in 1999 (Vranovská et al., 1999a,b; Beňovský et al., 2001) targeting the prospective tectonic block N from the Ďurkov village. According to borehole (wellhead) data, at temperatures of $T_{GTD-1} = 125$ °C, $T_{GTD-2} = 129$ °C and $T_{GTD-3} = 123$ °C the sampled production enthalpy counts $h_{GTD-1} = 617$ kJ.kg$^{-1}$, $h_{GTD-2} = 645$ kJ.kg$^{-1}$ and $h_{GTD-3} = 600$ kJ.kg$^{-1}$, so that the calculated production exergy at given wellhead enthalpy varied e = 120-130 kJ.kg$^{-1}$ if defined for the triple-point sink conditions. At least for a case of stabilized production conditions. Consequently, specific exergy index was calculated for SExI = 0.09-0.11, proving moderate-low thermodynamic quality at wellhead as a definition point. Hence boreholes terminated at depths of 3,100 m, and expected base of Mid Triassic carbonates may extend down to 4,000 m, wellhead conditions make obtained (calculated) results for reservoir conditions fairly reasonable. A necessary approximation is that, although a drop in primary and secondary permeability, a complete Mid Triassic reservoir profile is saturated with a geothermal fluid. This has been neither proved, nor refuted.

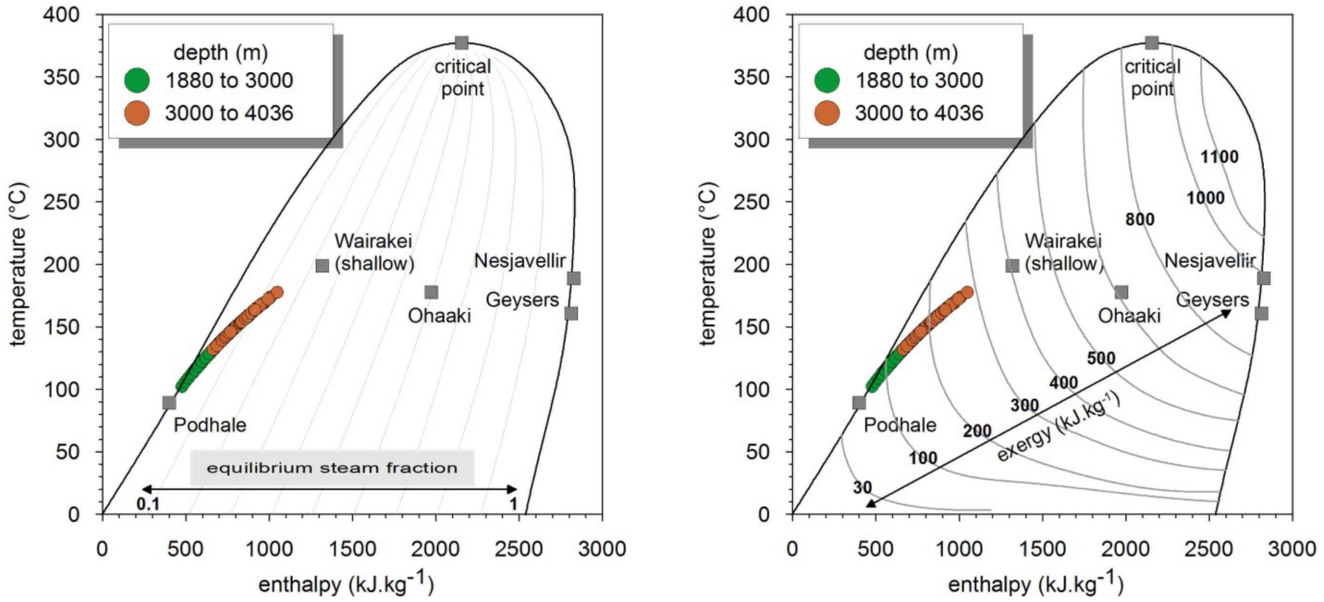

Figure 6: The Ďurkov hydrogeothermal structure – "prospective zone"; T-h diagrams

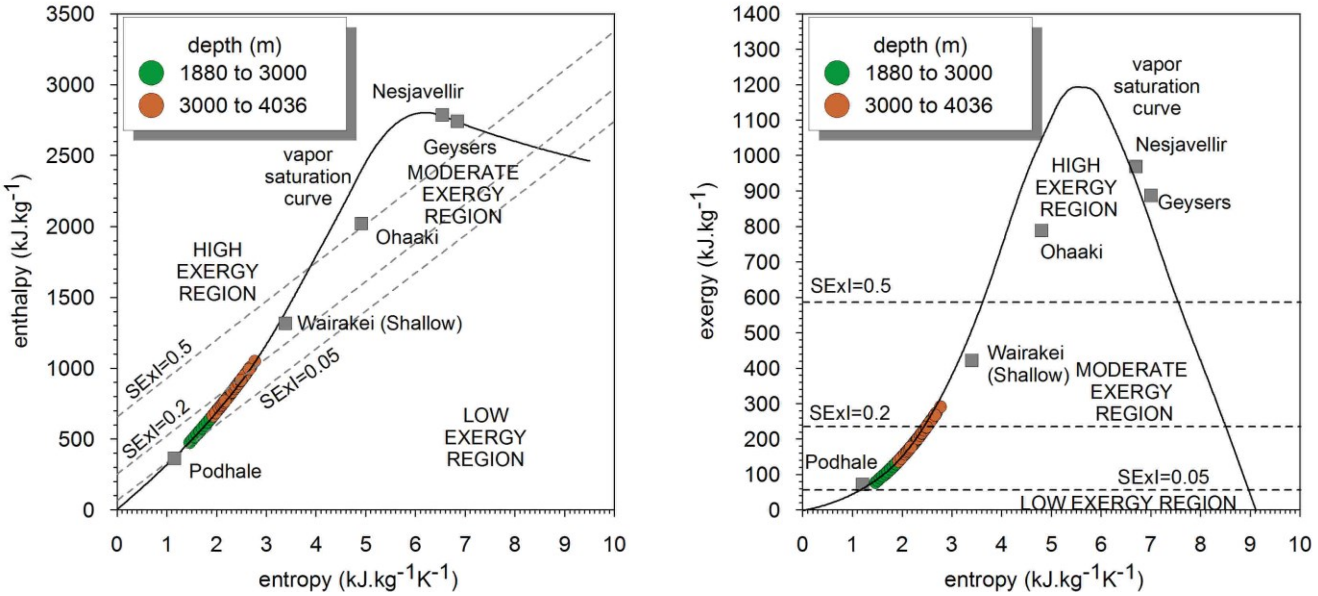

**Figure 7: The Ďurkov hydrogeothermal structure – "prospective zone"; Mollier's (left) and Rant's (right) diagrams**

Thermodynamic conditions for the Ďurkov depression hydrogeothermal structure imply its similarity to several moderate enthalpy, liquid (water) dominated geothermal fields worldwide. Indeed, the Podhále (Barbacki, 2012), Tianjin (Axelsson and Dong, 1998), Fuzhou (Pang et al., 2015) or Balcova (Ozgener et al., 2006) systems produce a geothermal resource for large-scale utilization, such is the district heating or individual space heating in combination with agriculture and recreation. All are also classified of moderate-low or simply a moderate (SExI = 0.05-0.5) exergy. In fact, no project operates the Ďurkov depression until now. Thermodynamically, the system is not adequate for power production, lacking a sufficient steam fraction. However, with a cumulative discharge of Q = 115 l.s$^{-1}$ and thermal output of 28 MW$_t$ as proven over closed-looped pumping test, with GTD-1 serving as reinjection well (Vranovská et al., 1999b; Beňovský et al., 2001), utilization of a geothermal resource for geothermal district heating appears outright energetically and exergetically. The more is the fact accented with a town of Košice a 13 km to the west only, still served with coal and natural gas in district heating systems (Fričovský et al., 2013). Thus, instead of increasing a share of geothermal resources on a primary energy mix in the country; reducing energetic dependency of a state on foreign resources; $CO_2$ mitigation; and transition towards the sustainable development at least on a municipal scale, the geothermal resource is set stand-by, somewhat ignoring its potential.

The thermodynamic study on DDHS reservoir conditions has proven the site as of moderate-low thermodynamic quality. A low equilibrium steam fraction disqualifies other than direct use of the resource, proven by moderate SExI calculated; i.e. SExI = 0.05-0.2 in 85 % of the reservoir above depths of 3,000 m. Beneath, a risk of failure when targeting that zone increases dramatically. Suitability of the resource for a large-scaled, district heating and cascaded projects is also proven along a similiarity of reservoir (and wellhead) conditions with geothermal fields worldwide. More investigation at the site is required, though.

## 6. REFERENCES

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