1. Preface

Following are the Terms of Reference (TOR) for realization of the Žiar geothermal project in Slovakia. The project aim is to produce electricity power from geothermal wells. The TOR contains basic geological and technical information concerning to the 1st stage of the project. A pilot geothermal well, GTŽ-1, will be drilled in the southern part of Žiar basin (Lovča concession). Two alternative localities for well positioning are shown on Figs. 1; 2; 3 (Lovča village or vicinity of the Žiar nad Hronom Aluminum production plant). The 1st stage of the project involves drilling of GTŽ-1 to a projected vertical depth 4 000 m. GTŽ-1 is to be the first or pilot well of the Phase 1 of the Žiar nad Hronom geothermal project. After a successful completion of well GTŽ-1 and a subsequent short-term test, a reinjection well, GTŽ-1R, will be drilled. The reinjection well is expected to be located within 6 to 10 meters of GTŽ-1 and will be deviated. The specific design of the reinjection well GTŽ-1R will be prepared after the completion of the GTŽ-1 well.

2. Geological Data

2.1. Objective of the geothermal well GTŽ-1

The main purpose of the well GTŽ-1 is the verification of the geological structure, and thermal and hydrogeological conditions of the Triassic carbonate rocks in the southern part of Žiar basin. After a satisfactory well test, the well will be a supplier of energy to a future geothermal power plant.

2.2. Location of the geothermal well GTŽ-1

GTŽ-1 will be situated either to the south of the village of Lovča or south-east of the Aluminum production plant in Žiar nad Hronom. Both locations are shown at a scale of 1 : 200 000 Fig. 1 and a scale of 1 : 25 000 on the Figs. 2 and 3. The surrounding areas are essentially flat, offering good ground conditions for the drilling floor. Supposed coordinates (systems S-JTSK; ETRS89) and altitudes of both positions of the geothermal well GTŽ-1 :

location Lovča	altitude	241 m a. s. l.
S-JTSK	X = 1 245 283	Y = 443 872
ETRS89	φ = 48°34'02.1"	λ = 18°48'36.0"
location Žiar nad Hronom	altitude	242 m a. s. l.
S-JTSK	X = 1 245 128	Y = 441 188
ETRS89	φ = 48°34'13.9"	λ = 18°50'46.0"

The precise coordinates of GTŽ-1 will be determined by geodetic survey after drilling is completed.

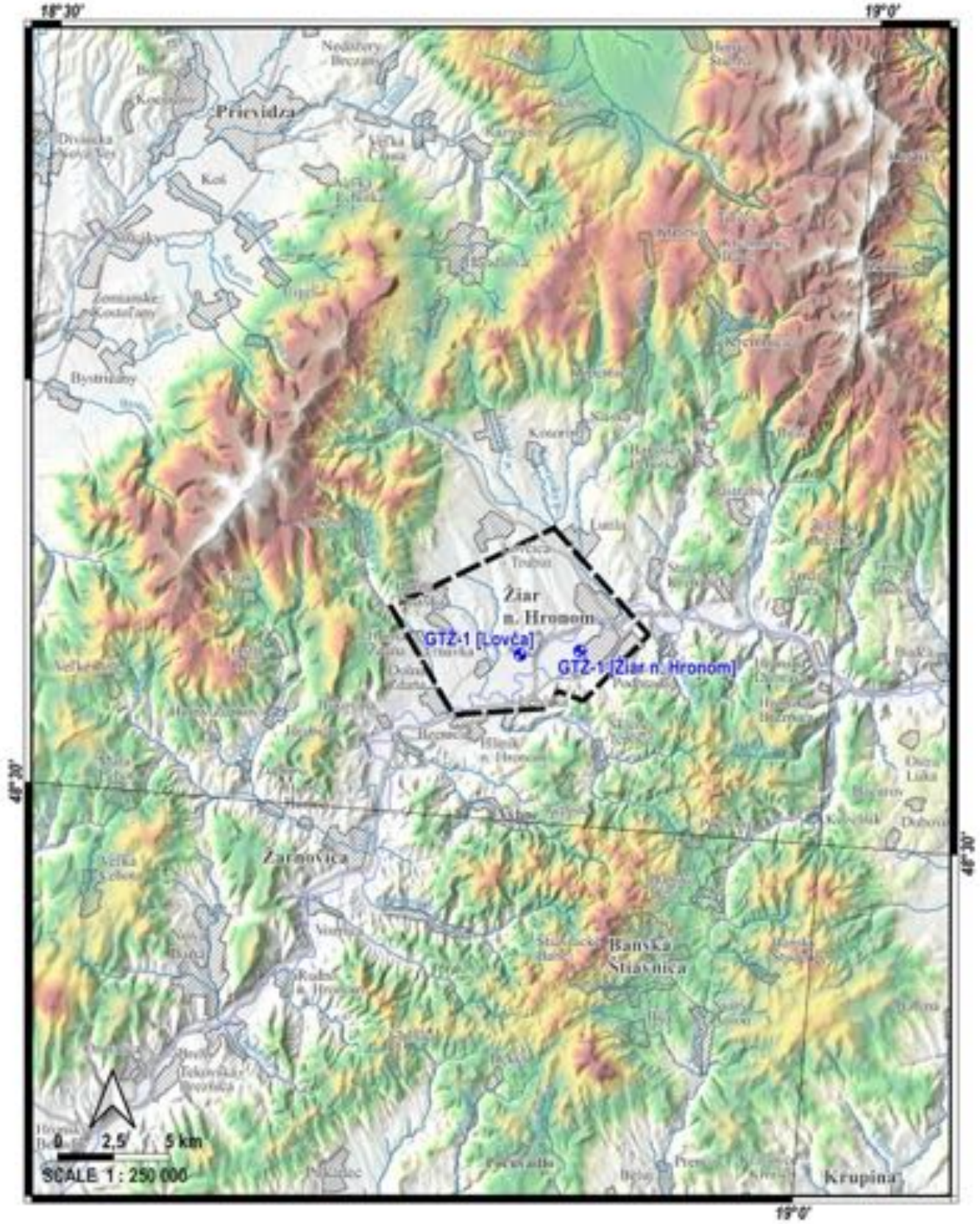

Fig. 1 : Location of the Lovča concession and Lovča / Žiar nad Hronom alternative localities in a general map 1 : 250 000.

Fig. 2 : Prospective position of the geothermal well GTŽ-1 – alternative Lovča.

Fig. 3 : Prospective position of the geothermal well GTŽ-1 – alternative Žiar nad Hronom.

2.3. Projected depth of the geothermal well GTŽ-1

The well is to be drilled vertically with a projected depth of 4 000 m. No deviation from vertical is planned.

2.4. Anticipated stratigraphic and lithologic profile

The anticipated stratigraphic and lithologic profile of GTŽ-1 is shown in the following table and in Fig. 4 :

depth interval [m]	geologic age	lithology (tectonic affiliation)
0 ~ 10	Quaternary	gravel, sand, loam (Hron river alluvium)
10 ~ 1,100	Pliocene Pannonian	clay, claystone, sand, sandstone, tuff, tuffites (Tertiary sedimentary infill of the Žiar basin)
1,100 ~ 1,500	Sarmatian Badenian	andesite, rhyolite and/or volcanoclastics
1,500 ~ 2,150		volcanoclastics, basal clastics (Tertiary volcanic and volcanoclastic infill of the basin)
2,150 ~ 3,200 m	Permian	melaphyre, sandstone, shale (volcano-sedimentary complex of the Hronicum tectonic overthrust block)
3,200 ~ 4,000	Mesozoic	dolomite, limestone, evaporite, shale (Fatricum, Hronicum and/or northern Veporicum unit)

2.5. Supposed inclination (dip) of bedding in GTŽ-1

Based on data from the regional geologic and seismic survey, following are the presumed dip-directions of bedding in well GTŽ-1 :

- Neogene (tertiary) sedimentary infill : < 20°
- volcanic and volcano-sedimentary complex : < 40°
- pre-Tertiary units : > 40°

2.6. Important horizons

Oil horizons : not expected.

Gas horizons : combustible (hydrocarbon) gas horizons are not expected.

Expected dissolved natural gases in geothermal waters are noted in the next section.

2.7. Water-saturated horizons

Unconfined aquifers are expected to be present in Quaternary gravel. Water-bearing beds may be present in the Neogene sand, sandstone, and volcanoclastic rocks or in tectonically disturbed volcanic rocks. These presumed artesian (confined) aquifers have temperatures up to 90°C. The geothermal waters of the Neogene sedimentary and volcano-sedimentary basin fill

are Na-HCO_3, Na-HCO_3-Cl to Na-Cl in chemical composition, with TDS up to 10 gl^{-1} and yield up to 5 ls^{-1}. The geothermal waters are likely to contain carbon dioxide (CO_2), nitrogen (N_2) gas, and possibly small amounts of methane (CH_4) and/or hydrogen sulfide (H_2S). Basal clastics of Neogene sedimentary infill form a separate geothermal aquifer. Artesian (confined) geothermal aquifers with temperatures up to 95°C, at hydrostatic pressure, are presumed to be present.

The Permian volcano-sedimentary unit consists mainly of aquicludes, but there may be weak inflows from fissures and tectonically disturbed zones.

The targeted geothermal aquifers are Triassic (Mesozoic) carbonate rocks underlying the Permian thrust sheet at depths beginning about 3,200 meters. Permeability may include fractures and/or karst solution cavities. Chemically, these thermal waters are expected to be of mixed Ca-Mg-Na-HCO_3-Cl-SO_4 composition, with TDS of 5 to 10 gl^{-1}. Temperatures of 130° to 150°C, and a yield up to 60 ls^{-1} are expected in the carbonate sequence. The thermal waters will be significantly saturated by dissolved carbon dioxide (CO_2), The presence of hydrogen sulphide (H_2S) is possible. A dissolved gas content (GWR) of 5 to 10 Nm^3m^{-3} is expected.

2.8. Expected production parameters of well GTŽ-1

- flow rate of geothermal water with gas content approx. 60 ls^{-1};
- temperature at well head approx. 140°C;
- overflow driven by gaslift and thermolift is expected;
- geothermal water will flow through the full profile of the well casing.

2.9. Intervals with possible complications

2.9.1. Compression and heaving

Compression and heaving in the geothermal well GTŽ-1 cannot be excluded during drilling within the silty-clay sedimentary formations in Neogene infill of basin.

2.9.2. Well caving

Well caving cannot be excluded in the shattered zone between the Neogene sedimentary infill and Permian and/or Mesozoic formations (depths around 2,000 ~ 2,100 and 3,000 ~ 3,200 m). There can also be localized caving in Neogene unconsolidated sediments (sand, volcanoclastic rocks) and/or during drilling tectonically fractured and crushed zones. These zones can occur at any depth of the well.

2.9.3. Mud and circulation losses

Small mud losses can occur in sandy formations of the Neogene basin infill. Larger mud losses can occur at contacts of volcano-sedimentary beds and compact volcanic rocks, in crushed zones in volcanic rocks and in the basal clastic beds. Total loss of circulation can occur in the fractured, brecciated and/or dissolved zones in the Mesozoic carbonate section at any depth greater than 3,200 m.

2.9.4. Tectonic faults

Tectonic faults can be present at any depth in well GTŽ-1. Tectonically crushed zones with mud and circulation losses can be expected mainly in Mesozoic carbonates.

2.10. Well sampling intervals

Cuttings will be taken while drilling the well GTŽ-1. It is proposed also that three (3) cores be cut. Petrographic and micropaleontologic analyses will be carried out at selected intervals and for selected core samples.

2.10.1. Drill cuttings

Drill cuttings will be taken every 10 m during drilling in Neogene infill of basin and Permian volcano-sedimentary complex, and at 5 m intervals in the Triassic carbonates (expected geothermal aquifer). This can be modified when needed by the on-site supervisor.

2.10.2. Coring

It is proposed to take 3 rock cores, from intervals of 5 m thickness, in the Triassic carbonates (expected geothermal aquifer). The depth intervals of coring will be specified by geological supervisor based on an analysis of drill cuttings. Oriented coring and side wall coring are not required.

2.11. Measurements during drilling

Continuous measurements and evaluation of technological parameters are needed while drilling the geothermal well GTŽ-1 including gas detection (CH_4, CO_2, H_2S).

2.12. Well logging and testing

Well logging proposed for the well GTŽ-1 is shown in the following table. It can be changed by the geological supervisor according to geological conditions in the well.

well logging		drill stem/casing (depth interval)			
method	scale	surface	1st intermediate	2nd intermediate	production
		50 ~ 300 m	300 ~ 1,700 m	1 700 ~ 3 200 m	3 200 ~ 4 000 m
caliper	1 : 500	250 m	1,400 m	1,500 m	800 m
inclination		250 m	1,400 m	1,500 m	800 m
SP	1 : 500	250 m	1,400 m	1,500 m	800 m
R	1 : 500	250 m	1,400 m	1,500 m	800 m
GR	1 : 500	250 m	1,400 m	1,500 m	800 m
TM	1 : 500	250 m	1,400 m	1,500 m	800 m
TMD	1 : 500	250 m	1,400 m	1,500 m	800 m
CN	1 : 500	×	×	×	800 m
density log	1 : 500	×	×	×	800 m
sonic log	1 : 500	×	×	×	800 m
UBI		×	×	×	800 m
CBL	1 : 500	250 m	1,700 m	1,550 m	850 m

Explanations : SP – spontaneous potential, R – resistivity log, GR – gamma ray, TM – thermometry, TMD – differential thermometry, CN – neutron porosity, UBI – Ultrasonic Borehole Imager, CBL – cement bond logging.

Note : CBL in the surface casing will be measured during well logging in the 1st Intermediate casing, CBL in the 1st intermediate casing will be measured during well logging in the 2nd Intermediate casing and CBL in the 2nd intermediate casing will be measured during well logging in the production casing.

2.13. Acidizing

After completing the drilling and intermediate casing of GTŽ-1, the drilling mud shall be aquifer consisting or replaced with water or with a combination of water, air and/or detergent foam.

Following the completion of drilling and before releasing the drilling rig, the aquifer in the Mesozoic carbonate rocks will be acidized, with approximately a 120 m^3 mixture of 15% hydrochloric acid (HCl). The exact composition of the acidizing mixture will be adjusted according to the petrographic analyses of the drill cuttings and/or cores of the aquifer rocks.

An injectivity test will be performed, to determine the Injectivity Index, as an indication of well performance. Depending upon well conditions this may be performed prior to or following the acidization.

2.14. Short-term hydrodynamic test

After drilling and acidizing, a short-term hydrodynamic flow test will be performed. The objective of the short-term hydrodynamic flow test is the measurement of temperature and pressure, and the sampling of the geothermal water for detailed chemical analysis. Geothermal waters obtained during the short-term hydrodynamic test will be cooled and reinjected back into the well.

The drilling rig will be released, and the well will be allowed to start recovery of temperature and pressure. According to the results of the acidization, injection test and short-term hydrodynamic flow test, the long-term test procedures will be developed.

2.15. Microseismicity monitoring

Microseismicity monitoring of the territory around the geothermal well GTŽ-1 will be an option. Microseismicity monitoring will begin two (2) months before the start of drilling and will continue during drilling and testing of the geothermal well. Details of the microseismicity monitoring will be proposed by the drilling company in coordination with the Project Owner. The results of microseismicity monitoring will be useful in the three-dimensional identification of tectonic faults, and to assist in the location of future production and injection wells.

3. Technical Details of Drilling

3.1. Drilling rig

The drilling rig for geothermal well GTŽ-1 must meet all the technical parameters for safe and reliable drilling, casing, logging and testing to the depth of 4,000 m, and must have a fully trained and experienced crew and supervisors.

3.2. Drilling mode

The geothermal well GTŽ-1 will be drilled as a vertical well. Drilling mode is not prescribed. Preferred is the standard rotary drilling mode.

3.3. Mud programme

Design and implementation of an optimal mud programme for the geothermal well GTŽ-1, is the responsibility of the drilling company. At depths greater than 3,000 m, temperatures 120 ~ 150°C are anticipated and must be accounted for in the mud composition and quality.

3.4. Casing and cementation of geothermal well GTŽ-1

The planned casing and cementation programme for well GTŽ-1 is shown in the following table and on Fig. 4. Casing must be produced according to the API specification 5CT. Homogenous cement slurry will be used for cementation, with provision made for elevated temperatures. Cement composition will be laboratory tested. The presence of cement throughout the cased intervals and its quality will be checked by CBL logging.

drill stem	casing diameter	casing interval	cementation
conductor pipe	Ø 30"	0 ~ 50 m	up to the surface
surface casing	Ø 20"	0 ~ 300 m	up to the surface
1st intermediate	Ø 13⅜"	0 ~ 1,700 m	up to the surface
2nd intermediate	Ø 9⅝"	1,650 ~ 3,200 m	up to the liner hanger
production casing	Ø 7"	3,150 ~ 4,000 m	no cement

Conductor pipe : Conductor pipe will have a diameter of Ø 30" to 50 m depth. The precise depth will be determined by geological supervisor on the basis of drill cuttings. The Quaternary gravel formation must be cased by conductor pipe in order to protect shallow groundwaters during the continued drilling. The top of the well will be stabilized, with steel pipe welded and cemented to the surface.

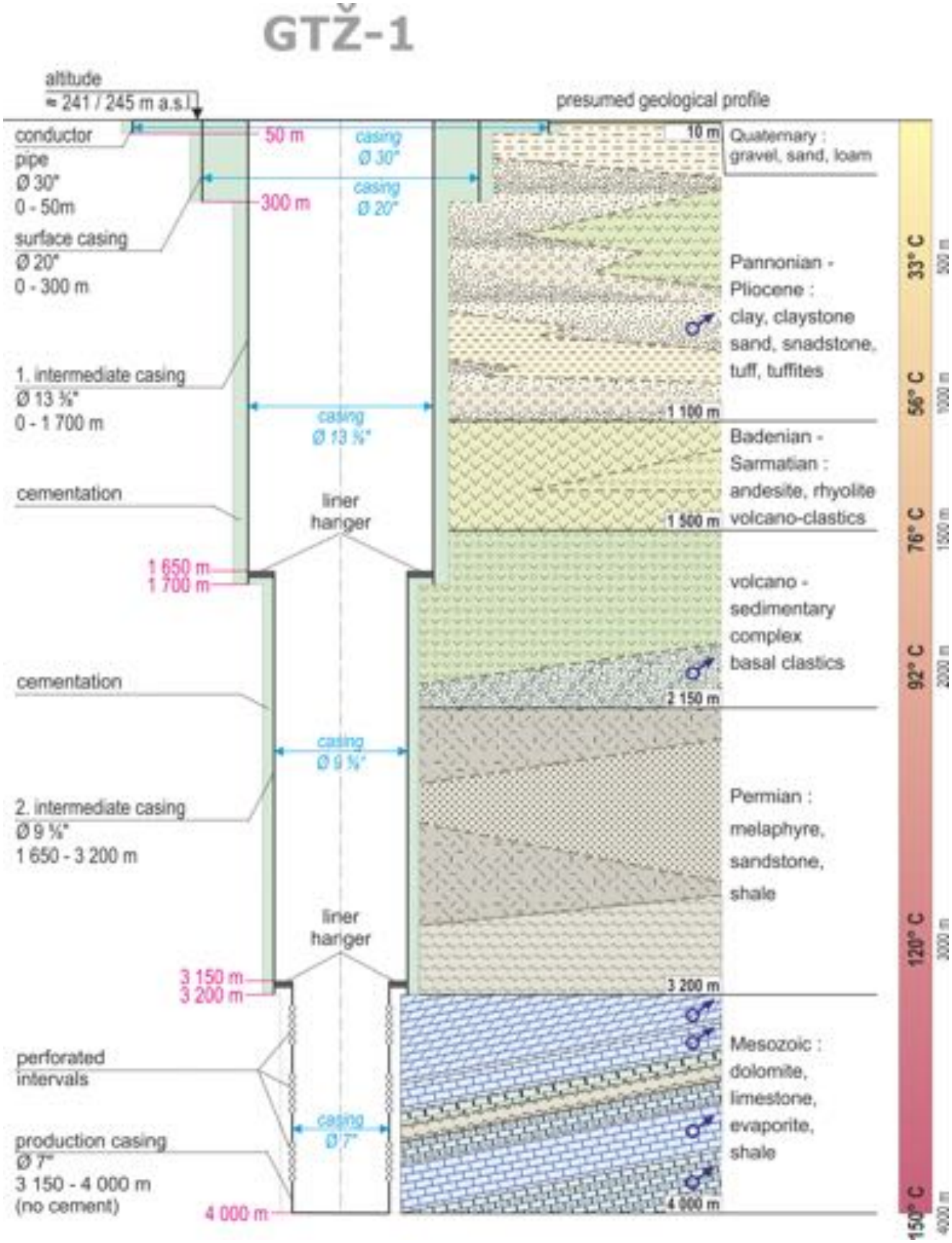

Fig. 4 : Geothermal well GTŽ-1
well construction diagram and presumed geological and temperature profile.

Surface casing : Surface casing will be of Ø 20" diameter, of seamless steel N-80, to the planned 300 m depth. The surface casing will extend to the bottom of the Quaternary clay bed. The precise bottom depth will be determined according to the results of resistivity logs. Centralizers will be used approximately for every 20 to 30 m before casing. The precise number will be determined on the basis of caliper surveys and well inclination from vertical. Surface casing will be cemented to the surface. Blow out preventer (BOP) will be installed at the surface casing.

1st Intermediate casing : The first intermediate casing will be Ø 13⅜" diameter, of seamless steel N-80. The bottom of the 1st intermediate casing is planned to be at the depth of 1,700 m. The precise depth will be determined according to the geological conditions. The space of the 1st intermediate casing will be used for a submersible pump, if one is if needed. Centralizers will be used approximately every 20 to 30 m before casing. This will be determined on the basis of caliper and inclination evaluation surveys. The first intermediate casing will be cemented to the surface. The leak check of the 1st intermediate casing will be performed according to the valid regulations (proposed pressure 10 MPa; 15 min.). BOP will be installed at the 1st intermediate casing.

2nd Intermediate casing : The second intermediate casing will be Ø 9⅝" diameter, of seamless steel P-110. It is projected as a liner with the hanger at 1,650 m depth. The bottom of the 2nd intermediate casing is planned at a depth of 3,200 m. The precise depth will be determined according to the geological conditions. Centralizers will be used approximately every 20 to 30 m before casing (this will be determined on the basis of caliper and inclination surveys). The 2nd intermediate casing will be cemented to the liner hanger. The leak check of the 2nd intermediate casing will be performed according to the valid regulations (minimum proposed pressure 12 MPa; 15 min.).

Production casing : Production casing will be a liner of Ø 7" diameter, of seamless steel P-110, with proposed length of about 850 m without cementation. The liner is planned to be end-bearing on the seat of the well with a pocket. The bottom of the production casing is planned at a depth of 4,000 m. Selected liner intervals having geothermal water production within the depths 3,200 to 4,000 m will be perforated with holes Ø 12 to 15 mm diameter. Holes, or if slots are chosen, minimally are to cover 15% of liner wall surface. Total length of perforated liner is assumed to be about 300 to 400 m. Depth intervals will be determined more precisely according to an evaluation of the well-logging data. Data will be used for the siting and drilling of future wells and the long-term exploitation of geothermal waters.

3.5. Well head equipment

An API-rated blow out preventer (BOP) must be used from the beginning of drilling 1st intermediate casing up to the final depth of the well. BOP must be rated for the pressure of at least 21 MPa. After completing the well, the standard geothermal production wellhead will be installed.

3.6. Site preparation

The geothermal well GTŽ-1 will be located on land contracted and provided by the project owner. All civil works will be supplied by PW Energy based on the requirements of the drilling company, except as noted below.

3.6.1. Access road, drill floor and terrain arrangement

Access to the both locations of well GTŽ-1 is possible using existing dirt roads (cartways) that connect to main road. Bearing capacity of roadbed must be surveyed before moving the drilling rig. The drill floor and cellar will be prepared by the drilling company. Grounds at the well locations must be landscaped in accordance with environmental and permit requirements. Required civil works will be conducted by PW Energy.

3.6.2. Energy source

It is planned that diesel power be used for drilling GTŽ-1, with an option to connect directly to the close by distribution grid, in which case establishing connection will be conducted by PW Energy.

3.6.3. Process water source

Water for use in the drilling of well GTŽ-1 and related activities could be obtained from the Hron river. Access is possible from both drilling locations. Obtaining groundwater from a well of about 15 m depth drilled in Quaternary alluvial gravel is an option, in which case a water well will be conducted by PW Energy.

3.6.4. Rig moving, rigging up and installation of technological equipment

Rig moving, rigging up and installation of technological equipment for the well GTŽ-1 will be the responsibility of the drilling company.

3.6.5. Waste disposal

Disposal of all wastes is the responsibility of the drilling company. The Žiar nad Hronom waste dump can be used for drill cuttings and for most other wastes. This dump is at a distance of 10 km from the Lovča location, and about 4 km from Žiar nad Hronom location (see Figs. 2/3).