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**ПРИРОДНИ РЕСУРСИ И ТЕХНОЛОГИИ**
**NATURAL RESOURCES AND TECHNOLOGY**




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## Содржина/Contents

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# 3D MODELING ON GEOPHYSICAL EXPLORATION DATA OF A POSSIBLE PORPHYRY SYSTEM IN THE AREA PETROSHNITSA, REPUBLIC NORTH MACEDONIA

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**Abstract**: The latest geophysical exploration of the Petroshnitsa area have provided progress in understanding the geology of the particular area. The results from the study of the geophysical exploration campaign done by „Geomac" Ltd, Sofia, Bulgaria, in 2015 for Sardich MC, Skopje, North Macedonia, were compiled and used in the 3D model to highlight areas of interest. Using professional Vulcan software helped to envisage a 3D model to highlight areas of interest which most probably are areas related in depth with gold and copper vein-impregnation of sulphide mineralization. This 3D model should improve our understanding and complement the geological data of Petroshnitsa in our next step in exploration to define a possible porphyry system.

**Key words**: 3D model; Petroshnitsa; porphyry system; gold; copper.

# ЗД МОДЕЛ ВО СОГЛАСНОСТ СО ГЕОФИЗИЧКИТЕ ПОДАТОЦИ НА ПОРФИРИСКИОТ СИСТЕМ, ПЕТРОШНИЦА, РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

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**Абстракт:** Последите геофизички истражувања извршени во рамките на истражениот простор Петрошница, придонесоа прогрес во познавањето на геологијата во одредениот истражен простор. Резултатите од студијата добиени во 2015 од страна на Геомак, Софија, Бугарија, а извршена за потребите на Сардич МЦ, Скопје, Северна Македонија, беа комбинирани и искорисени за ЗД моделирање на истражниот простор сè со цел да се потенцираат површините / деловите од интерес. При изработка на ЗД моделот е користен професионалниот софтверски пакет Вулкан со чија помош се потенцираат деловите од интерес кои најверојатно во длабочина се зони поврзани со Au (злато) и Cu (Бакар) жици, импрегнации од сулфидна минерализација. Изработката на овој ЗД модел овозможува подобро познавање и комплиментирање на геолошките податоци за нашиот следен чекор во истражувањето од истражениот просторот Петрошница со цел да се разграничи можниот порфирски систем.

**Клучни зборови:** ЗД модел; Петрошница; порфирски систем; злато; Бакар.

## 1. Introduction

The main result of the research is a compilation of a 3D model based on the geophysical exploration data and geological data, facilitating the next steps in its research and exploration to define a possible porphyry system [1]. This 3D model was prepared based on the anomalies obtained from the induced polarization. The electrical tomographic and geomagnetic field of the area was not used in the model. On the geological map are presented all elements of a single paleovolcanic structure which main channel is localized in the central part of the area Petroshnitsa [2]. In the area, a number of radial, potentially ore-bearing, structures have been distinguished. In the southern part of the volcanic structure, along the boundary between the intensively and weakly altered volcanics, an arc-shaped 120 m thick ore zone was formed [3]. It could be interpreted as a part of a larger concentric structure. The arc-shaped zone has enhanced contents of gold (Au) and copper (Cu).

## 2. Geological Features

The Petroshnitsa area is located in the northwestern periphery of the Kratovo-Zletovo paleovolcanic area, in the northeastern part of the Republic of North Macedonia. In accordance to the metallogenic subdivision schemes, Petroshnitsa is a part of the Lece-Chalkidiki metallogenic zone [2, 4, 5, 6]. The following lithostratigraphic units have been distinguished within the mapped area:

### 2.1 Neoproterozoic – Early Paleozoic

In the mapped area are exposed metamorphic basement rocks belonging to the Lower complex of the Serbo-Macedonian Massif (Fig. 1). The complex comprises amphibolite facies metamorphic rocks – mainly gneisses [7, 8]. Common feature is the uneven migmatization as gneisses are turned into banded migmatites. Quartz veins are abundant. The general thickness of the complex within the mapped area exceeds 600 m.

### 2.2 Paleogene

The volcanoclastic unit tuffite is restricted only in an outcrop area of 0.2 $km^2$ west-northwest of Del summit. It occupies the lowermost part of the volcanic complex as its boundary with the metamorphic basement is not exposed on the surface.

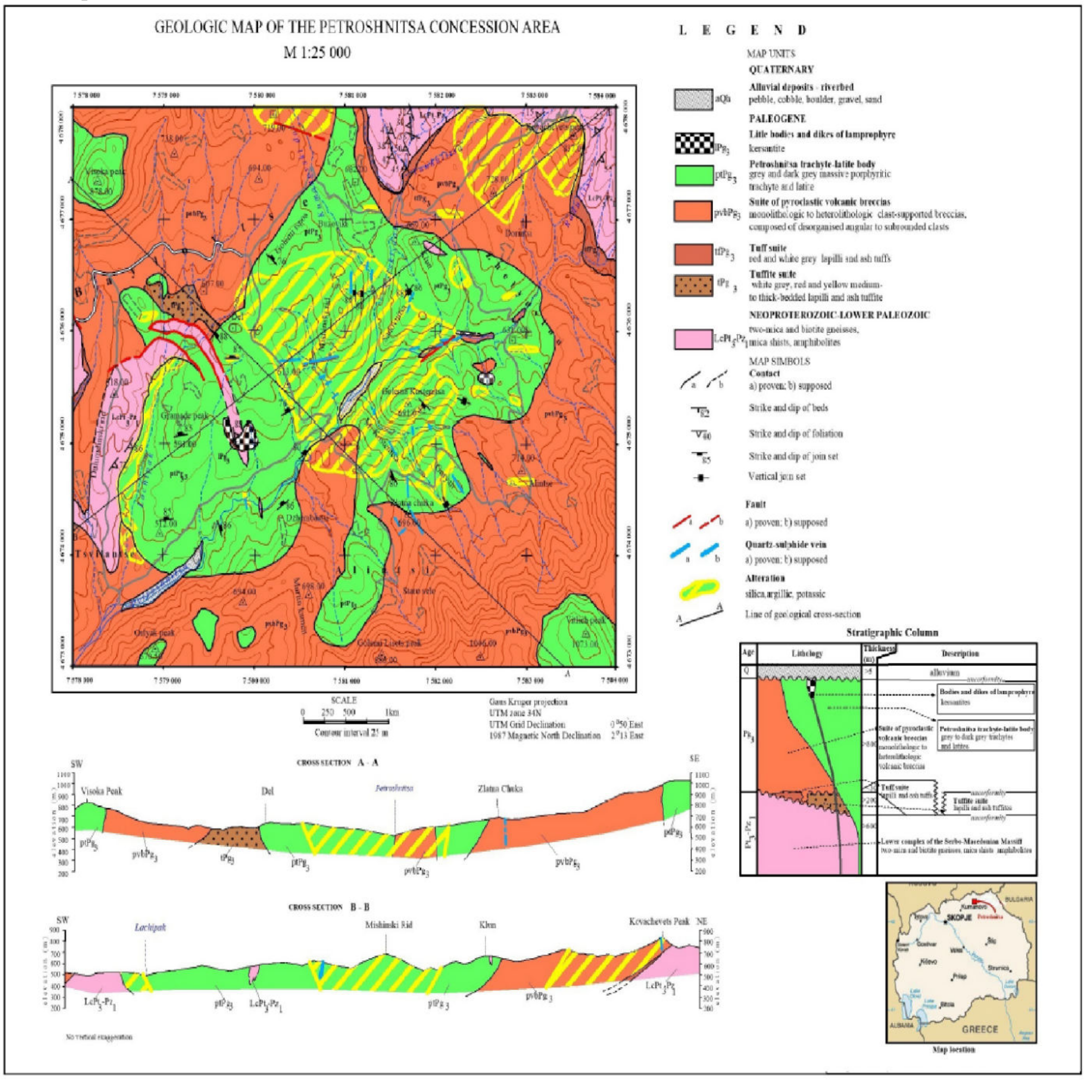


Figure 1.: Geological map of the Petroshnitsa mineralized area (Sl. Mankov, 2015 Report for the geological mapping and geophysical studies of the territory of the exploration area Pteroshnitsa)

Слика 1.: Геолошка карта на минерализираниот дел Петрошница (Сл. Манков, 2015 Извештај за геолошкото картирање и геофизички студии на територијата на истражениот простор Птерошница)

Upwards the suite is unconformably covered by pyroclastic volcanic breccias. The suite is composed of gray-white, brownish and rusty-yellow tuffites. (Fig. 2).

The tuff unit occupies the lower parts of the volcanic complex. It comprises stratified lapilli and ash tuffs as these rock varieties are distinguished for the first time during the recent mapping. The unit unconformably covers the metamorphic rocks of the Lower complex. Upwards, it grades or has a sharp contact with the suite of pyroclastic volcanic breccias. The tuff is composed of red, pink and gray lapilli tuffs alternating with thin layers of ash.

Figure 2.: View of the well stratified succession of the strongly altered tuffite suite, WNW of Del summit
Слика 2.: Поглед на добро стратифицираната секвенца на силно изменета туфитна група, западно-северозападно од врвот Дел

The suite of pyroclastic volcanic breccias occupies over one third (ca. 12 $km^2$) of the exploration area. The upper boundary coincides with the recent erosion surface. The pyroclastic breccias are intruded by the Petroshnitsa trachyte-latite body and several smaller bodies of similar composition as well as a single lamprophyre dyke. The intrusive contacts are steep to subvertical [9, 10]. The breccias are composed mainly of latite and trachyte pyroclasts.

The Petroshnitsa trachyte-latite body is composed up of Miocene trachyandesites, covered by volcanic breccias to the south-southwest and northwest. Nevertheless, during the recent mapping it was established that the metamorphic basement along with the covering volcanoclastic rocks are intruded by a relatively huge body and several smaller ones of latitic to trachytic composition [11]. The huge one is distinguished as the Petroshnitsa trachyte-latite body and occupies an area of ca. 10 $km^2$ in the central part of the map. The Petroshnitsa body is irregular-shaped and SW-NE elongated, reaching up to 5 km in length and 1.5-3 km in width. The contact of the Petroshnitsa body with the host rocks are easily observed in a number of outcrops. The sharp contact of the body with two-mica gneisses of the Lower complex traces along 2 km in the western slope of the Lachipak gully. It strikes at 25° and dips at 80-85 ° to the SE.

The unit Lamprophyric bodies and dykes in the Petroshintsa area are represented with two small lamprophyric bodies and a single dyke that crosscuts the rocks of the Petroshnitsa body as well as the xenoliths of gneisses and volcanic breccias. The larger body (with apparent length of ca. 250 m and width 50-100 m) crops out 500 m east of the Gramade summit. It is irregular in shape and crosscuts the latite-trachyte rocks as well as the fault-limited strip of two-mica gneisses. The second body and dyke are located in Zhelyuvino village. They are emplaced into trachyte-latite rocks and volcanic breccias. Lamprophyries are dark-gray to black, dense rocks. They are massive in structure and porphyritic, serial porphyritic, microlitic or trachytic in texture. The primary phases are plagioclase, biotite, clinopyroxenes, amphibole, apatite, titanite and the secondary - carbonate, chlorite, quartz, fine-grained white mica.

**2.3 Quaternary**

The formations are represented by alluvial deposits comprise the flood plain of Petroshnitsa River. They are represented by inequigranular sands and gravels with angular to rounded pebbles with diameter 5– 30 cm and boulders with diameter up to 20-30 cm. The thickness of the deposits varies from 1 to 12 m.

## 3. Methodology

The geophysical methods applied in the Petroshnitsa exploration area are related to prospecting vein-impregnation type of Au-Cu mineralization [2, 3]. Vulcan software was applied to treat the data.

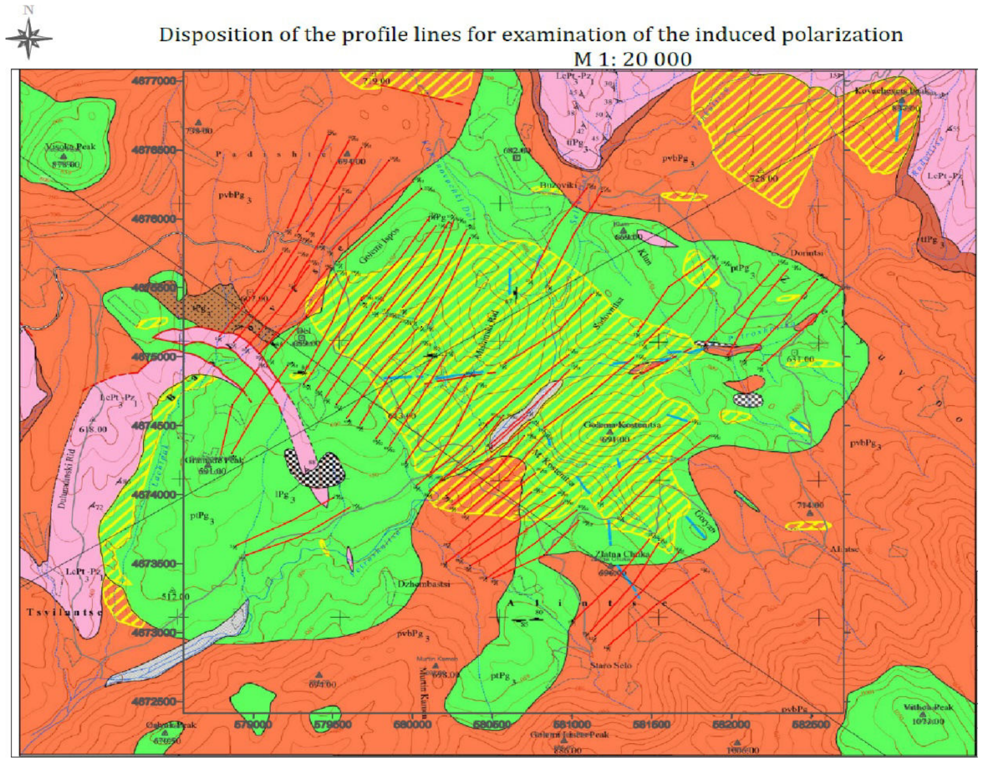


Figure 3.: Geological map of Petroshnitsa with the location of the geophysical exploration (Sl. Mankov, 2015 Report for the geological mapping and geophysical studies of the territory of the concession area Pteroshnitsa)

Слика 3.: Геолошка карта на Петрошница со локациите на геофизичките истражувања (Сл. Манков, 2015 Извештај за геолошкото картирање и геофизички студии на територијата на истражениот простор Птерошница)

**3.1 Geophysical methods and equipment**

During the geophysical tasks the following geophysical methods have been used:

- Electrical tomography (electric imaging);
- Induced polarization method.

These methods allow the study of the area on the surface as well as in depth up to 180-220 m.

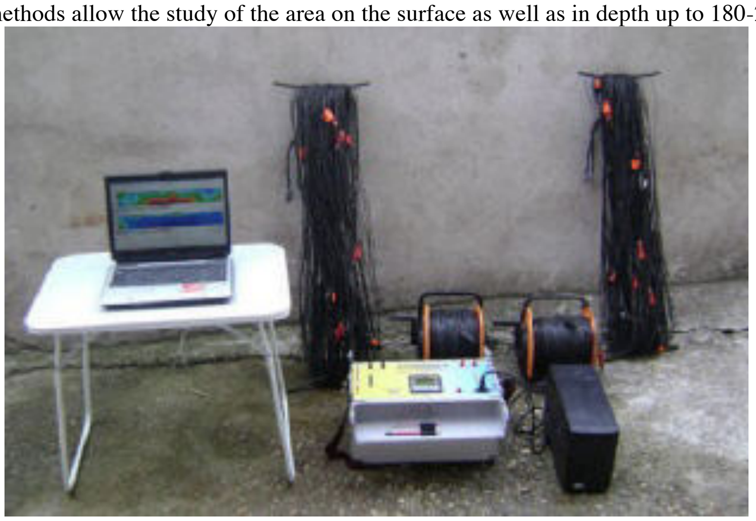

Figure 4.: Electrical tomography equipment (Electrogeotest M2)

Слика 4.: Електротомографска опрема (Electrogeotest M2)

The electrical tomography and the method of induced polarization were realized using a multifunctional geophysical apparatus Electrogeotest M2 (Fig. 4).

The primary field in the resistivity methods (particularly the electric tomography or electric imaging) is created by point or dipole sources located along a cross-section on the Earth's surface at an equal distance to each other [12]. Using two electrodes, the ground is fed with a constant current, and other two electrodes measure the tension in-between. An electrode selector groups the source and receiving electrodes in accordance to initially settled scheme. The resistivity is automatically calculated by multiplying to a coefficient (k) settled in the scheme:

$$\rho_{пр} = k\frac{\Delta U}{I};(\Omega.m),$$

where: $\Delta U$is the electric potential difference; I is the current strength.

Data is recorded as a file in a computer built into the measuring device. The file could be subjected to a further processing. Several schemes of a measuring exist depending on the configuration of the source and receiving electrodes: dipole-dipole, pole–dipole, pole–pole. If it is possible, the cross-sections have to be oriented normal to the trends of the supposed structures. In the studied area, the cross-sections are oriented almost normal of the main trends of the supposed ore-bearing and other structures –faults, quartz veins, ore zones, etc.

In case of an induced polarization, the primary field is created by point or dipole sources arranged along cross-sections at one and the same distance from each other. The method of the induced polarization is based on the measuring of secondary electrical potentials generated due to the polarization of rocks when a permanent or low-frequency alternating current flow through them. In a case of an absence of a polarizing current, an equilibrium concentration of current-carrying ions exist around the mineral grains within the rocks [12. In the electric current flow, the discharge conditions of the ions and their concentration near the surface of the grains is modified. If in an equilibrium state the potential of the grains in respect to the medium has a value Δϕ, then in case of current flow the potential of these particles, which are oriented parallel to the direction of the polarizing current, is changed as follows:

$$\Delta\phi = \frac{RT}{uF}\ln(1-\frac{j}{j_{max}})$$

where : j is the density of the polarizing current; $j_{max}$ - maximum possible current density near the grains; R, u, F, T - are the gas constant, valency of ions, Faraday constant and the absolute temperature; Δϕ - the concentration polarization.

Taking into account that the density of the polarizing current is considerably lower than the maximum density, the formula can be written as follows:

$$\Delta\phi = \frac{RT}{uF}.\frac{j}{j_{max}}$$

When the polarizing current is switched off, the potential difference arisen due to the change of a concentration is trending to zero as through the medium flows a current in a direction opposite to the polarizing current. The induced potentials largely depend on: the duration of the polarizing field, the physical-chemical environment, the polarization properties of geoelectrical cross-section, etc.

During the field studies the apparent polarizability is determined by the formula:

$$\eta_{\text{пр}} = \frac{\Delta U\text{пп}}{\Delta U\rho_{\text{пр}}}.100\ \%$$

where: $\Delta U$пп – is the potential difference between the electrodes M and N after the switching off the polarizing current; $\Delta U\rho_{\text{пр}}$ - the potential difference between the same electrodes at a *current flow along a line AB*.

The method is effective for a prospecting of impregnation-type and vein-impregnation type mineralization with relatively low contents of useful components. Generally, such mineralization are difficult for exploration by the classical electrical exploration methods.

**3.2 Vulcan software**

Use of a professional Vulcan software helped to envisage a 3D model to highlight areas of interest in our next step on exploration to define a possible porphyry system. The geophysical data was provided in a DXF format. These cross-sections (Fig 5. and Fig 6.) were then imported into Vulcan.

## 4. Geophysical Data

Geophysical measurement through the electric profiling method are accomplished along cross-section lines with a direction of 30°, distance between the particular cross-sections 100 meters and step between electrodes 25 meters [12]. The selected network allows to achieve the above required geological task. The used apparatus Electrogeotest M2 supplied with a commutator for 32 electrode allows measuring the potential between two electrodes in an electrical current. Simultaneously with the measurement of the stabilized current up to 200 mA and voltage up to 400 V, the induced polarization for two seconds in 200 ms taking the integral retention value of 0.1 seconds was defined.

The geophysical measurements using the method, electric tomography and induced polarization were carried out along 64 cross-sections [12]. The results and their interpretation were produced in DXF format (Fig. 5 and Fig. 6).

Use of the geophysical data in the 3D model, a simple example below explains the reason why the Induced polarization cross-sections were used in the 3D model.

Example, on cross-section 20 two methods are presented, Electrical tomography (Fig. 5) and Induced polarization (Fig. 6). The Induced polarization cross-section clearly shows a strong anomaly in purple (chargeability above 5 msec a most probably sulphide mineralization in depth) hence reason the Induced polarization method was used for the 3D model. Whereas the Electrical tomography shows no sign of significant anomaly in the same area.

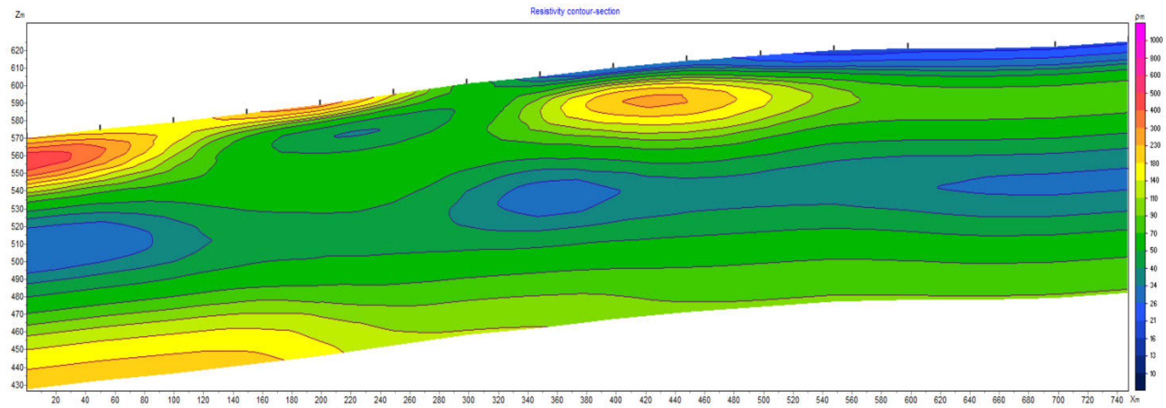


Figure 5.: Geophysical cross-section № 20 - Electrical tomography
Слика 5.: Геофизички профил № 20 - Електротомографија

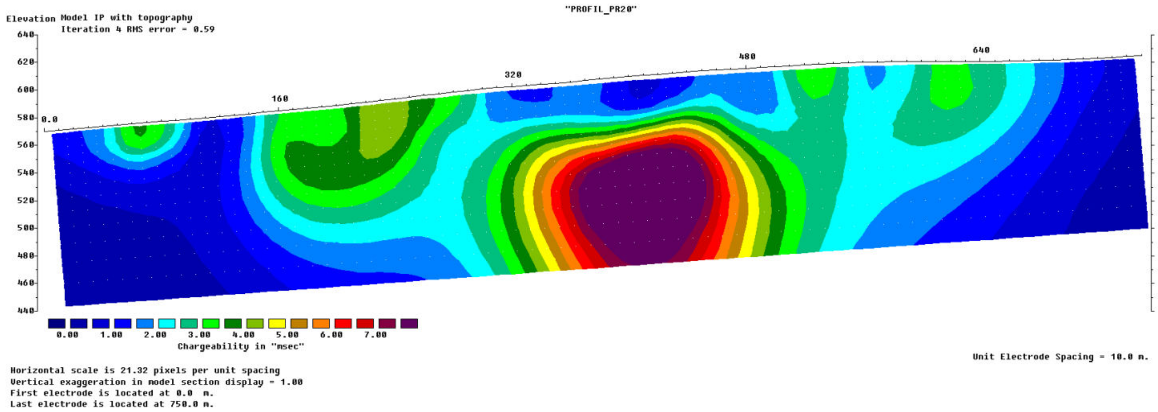


Figure 6.: Geophysical cross-section № 20 - Induced polarization
Слика 6.: Геофизички профил № 20 - индуцирана поларизација

## 5. 3D Modeling Based On Geophysical Data

Using a software Vulcan helped put together a 3D model (Fig 7) to envisage the data. The task was to position the geophysical cross-sections onto the topography in their true location, this helped to view the data in 3D. The anomalies together in conjunction with the geological data highlighted areas of interest for our next step of projecting exploration drill holes (Fig. 8).

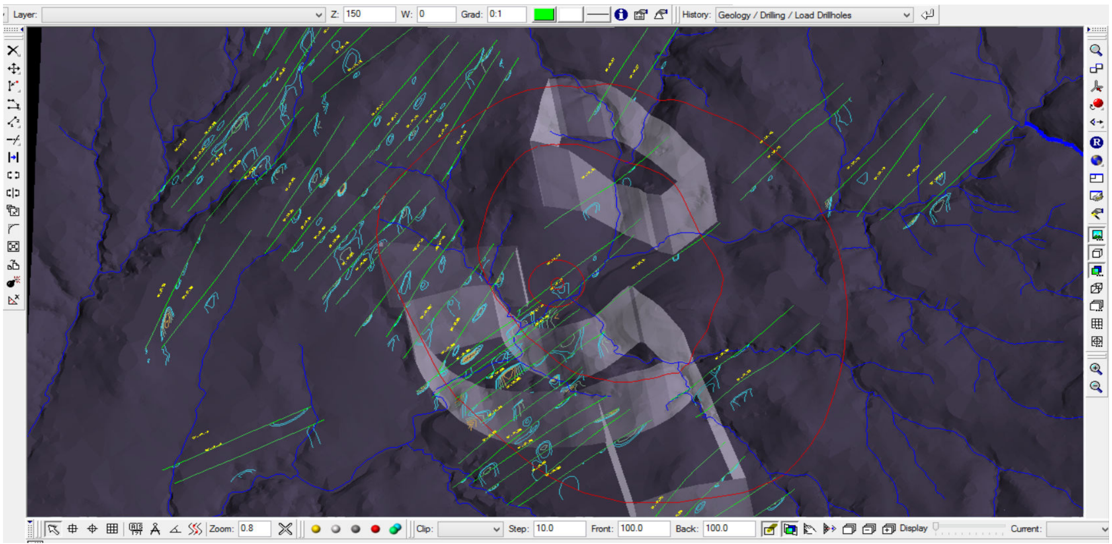

Figure 7.: 3D model of Petroshnitsa based on the geophysical exploration data and prognostic geological areas
Слика 7.: 3D модел на Петрошница базиран на податоци за геофизичко истражување и прогностички геолошки области

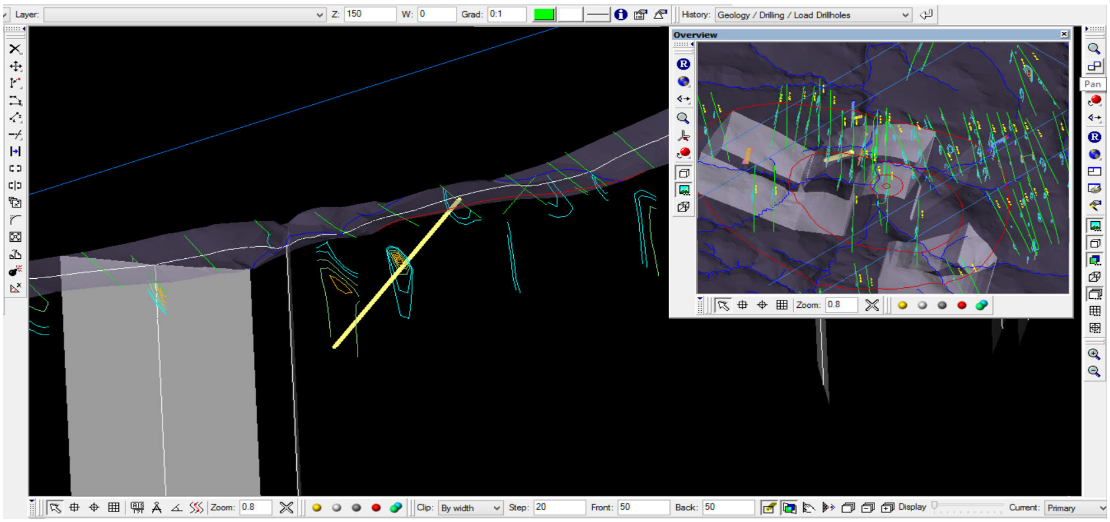

Figure 8.: Cross-section with projected drill hole based on the geophysical data and prognostic geological areas
Слика 8.: Профил со проектирана дупнатина врз основа на геофизички податоци и прогностички геолошки области

## 6. Conclusion

Latest complex, geological and geophysical explorations of Petroshnitsa area have defined interesting anomaly locations (domains). These domains which most probably are areas related in depth with gold and copper vein-impregnation of sulphide mineralization should further undergo exploration. Several drill holes have been projected based on the information presented in the 3D model. Direct implications of impregnation mineralization of Au-Cu-Mo and polymetallic mineralizations to define a possible porphyry system are yet to be confirmed by an exploration drilling campaign.

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