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МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО

ТРЕТ КОНГРЕС
на
Геолозите на Република Македонија

ЗБОРНИК НА ТРУДОВИ

-КНИГА 2-

Уредници:
Лепиткова, С. & Боев, Б.

Струга, 2016

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3D MODELING OF SOME COPPER DEPOSITS IN THE REPUBLIC OF MACEDONIA

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Abstract
This paper aims at presenting the 3D models of respective geological settings, deformation structures and geochemical distributions, in terms of better understanding of the related ore-genetic processes and exploration potential. Since the beginnings of mining industry the challenge of mineral exploration is to approach new exploration targets. In that direction, 3D and 4D modelling are the new exploration tools that can help the mineral explorers to visualise, interpolate and interpret geological data, which are critical time- and money-saving methods. In this study 3D-models had been constructed for several Macedonian Cu±Au polymetallic deposits Kadiica, Plavica, Kazan Dol and Borov Dol. Our 3D models were built by mapping geochemical variations in the Move software by Midland Valley for Kadiica Cu-porphyry deposit and Borov Dol Cu-Au porphyry deposit (gives the opportunity to the user to create slices of the 3D grid and take a closer look to the spatial variation of an assay) as well as in Target 3D for ArcGIS system for Cu-Au high-sulphidation epithermal Plavica deposit and Cu vein type deposit Kazan Dol.

Key words: copper deposits, 3D model, software, modeling, valorization

INTRODUCTION

During the last decade and half the extensive detailed geological exploration of particular ore deposits in the Republic of Macedonia took place. As it is already known, the territory of the Republic of Macedonia is a constitutional part of the geotectonic setting of the Serbo-Macedonian metallogenic province, which facilitates the formation of polymetallic mineralisations. This zone hosts many known deposits having been discovered and located in the areas of Kadiica deposit near the Pehcevo, Plavica deposit in the close vicinity of Kratovo and Probistip, Kazan Dol deposit near the Valandovo and Borov Dol deposit near the city of Radovis.
Both software represent a solid basis for modelling of certain copper and gold ore bodies within different deposits (Kadiica, Plavica, Kazan Dol and Borov Dol). Without any doubts a better understanding of the geometry and intensity in 3D will aid further detailed geological exploration at depth for all above mentioned ore deposits and may potentially lead to new discoveries. For each aforementioned deposit were used lithological and geochemical data from exploration drill holes, which allowed construction of the 3D grid that depicts the distribution of each assayed element (Ag, As, Au, Mo, Pb, Zn, Cu). Also, there were created slices of the 3D grid and we were able to take a closer look to the spatial variation of an assay. For the 3D modelling of particular deposits were applied software packages that allow definition of morphological shapes of supposed ore body (ore bodies) at depth, which practically can suggest directions for their further exploration, especially if responsible person(s) decide that the exploration should continue with angled exploration drill holes.

REGIONAL AND LOCAL GEOLOGICAL SETTING

The metallogeny of the southern Balkan Peninsula is determined by the geodynamic evolution of the Tethys-Eurasian metallogenic belt (TEMB) and ancient crystalline massifs (Jankovic 1997). The southern Balkan Peninsula, including the Republic of

Macedonia, is a sector of the central TEMB. The formation of ore deposits was related here to certain chronological stages and geodynamic settings: (I) Late Permian-Early Triassic intracontinental rifting along the northern boundary of Gondwana and/or its already detached fragments; (2) Jurassic intracontinental rifting marked by ophiolitic complex; (3) suprasubduction magmatism; and (4) postcollision (orogenic) continental setting and related formation of various base- and noble-metal deposits (Pb-Zn-Ag, Cu-Au, Au-As-Sb-TI, AuAg). The VZ extends in the NW-SE direction between the SMM and Pelagonian Massif. The SMM is located between the Carpathian Mountains and Balkanides in the east and the VZ in the west. The collision of the African and Eurasian plates was accompanied by closure ofthe ocean and subduction of the oceanic crust beneath the SMM. Deep faults that formed at the time at the active continental margins have important metallogenic implications. Collision, postcollision processes, and Tertiary magmatism were crucial for localization of base-metal ore mineralization. Other important ore-localizing structural elements are volcanic calderas, domes, and dikes. Three variously oriented fault systems are recognized. The first, NW-trending fault system coincides in the strike with major tectonic units. The second and third systems extend in the northeastern and meridional directions, respectively. The third system has important implications for the development of Tertiary magmatism and related iron skarn and porphyry copper mineralization. Volcanic activity progressed beginning from the late Oligocene, and ore mineralization fonned in the Miocene. The geotectonic setting of Serbo-Macedonian Zone (SMZ) facilitates the formation of numerous copper mineralisations (Kadiica, Plavica, Buchim, Ilovitza and Osogovo in the Republic of Macedonia). The SMZ metallogenetic belt consists of strongly deformed metamorphic rocksof Palaeozoic age superimposed by Tertiary magmatic activity. Substantial copper mineralisations and deposits occur associated with acidic stocks of Tertiary age, making shallow intrusions into SMZ Paleozoic metamorphic formations. The mineralized and host-rocks belong to Oligocene-Miocene calc-alkaline complexes of dioritic, granodioritic and syenitic composition. It is likely that the widespread calc-alkaline igneous suites resulted from an anatectic partial smelting of the lowermost continental crust, in post collision activity processes.

Local Geology of Kadiica – Bukovik/Kadiica region.- Bukovik-Kadiica deposit is located in the eastern part of the Republic of Macedonia in a hilly region close to the border with Bulgaria and 2 km northeast of the town of Pehcevo. The deposit can be described as one of a number of dacite plugs of Neogene origin that exist within the SMZ as part of the volcanic complex intruding into Palaeozoic sediments, andesites and gabbros. On a larger scale the Kadiica region is underlain by metamorphic rocks (metadiabases, schists, gabbro, diorite and younger grantoids) of Upper Proterozoic to Palaeozoic age (Tasev, 2010; Tasev et al., 2012). The Bukovik-Kadiica ore district has been located in the most eastern parts of the Besna Kobila-Osogovo-Tassos metallogenic zone (Aleksandrov, 1992; Janković et al., 1995) and has been characterized by complex polymetallic mineralisation. Within the same ore district there were determined ore body systems and intersected dykes of quartz-latites with an absolute age of 24–12 Ma (Serafimovski et al., 2001; Serafimovski T. et al., 2010). According to Singer et al. (2008) the ore of Kadiica deposit has an 1x0.6 km axis dimension and covers an area of 0,5 km^2. The ore veins are also variable, ranging from several centimeters up to 2 m, and rarely over 5 m in size. Investigations done so far have determined about 16 veins of NW-SE to NNW-SSE and ENE-WSW to E-W extension most commonly subparallel to each other. Occasionally they bend and intersect (commonly under a sharp angle) such as ore veins 2, 3, 4, 6 and 7 (Figure 1). Flank branching of main ore veins is common (ore vein 1) which results in formation of apophyses of small dimensions.

Local geology of the Plavica deposit.- As a part of well known Kratovo-Zletovo ore area in general it is characterized with a complex composition of mainly Tertiary volcanic- sedimentary complex imposed on the foundation of the Serbian-Macedonian massif, which represents constituting part of the western Tethyan belt. The district is host to vein-type Pb-Zn mineralisation, Cu-Au stockwork and disseminated mineralisation, and high-sulphidation epithermal Au depo-

stis. The Probistip Formation is comprised of andesitic tuff, sandstone, bituminous siltstone and volcaniclastic breccias. The Probistip Formation overlies the Zletovo Formation, which is composed of ignimbrite, volcanic breccia, and lava flows of dacitic and andesitic composition. The deposit is hosted by a sequence of andesitic to dacitic volcanic units of mixed sub-aerial and sub-aqueous nature, dipping approximately 30° south. Mineralisation occurs within steeply dipping, vuggy silica bodies up to 500 m long, and between 100 m and 150 m wide. At surface, the vuggy silica zones form prominent ridges trending W-WNW. The Plavica contains many of the features inherent in high sulphidation epithermal deposits such are: vuggy silica, advanced argillic alteration, in association with pyrite and sulphides and sulphosalts. High content of gold is associated with silica bodies, (Alderton and Serafimovski, 2007) and the advanced argillic alteration indicates existence of fluids with low pH.

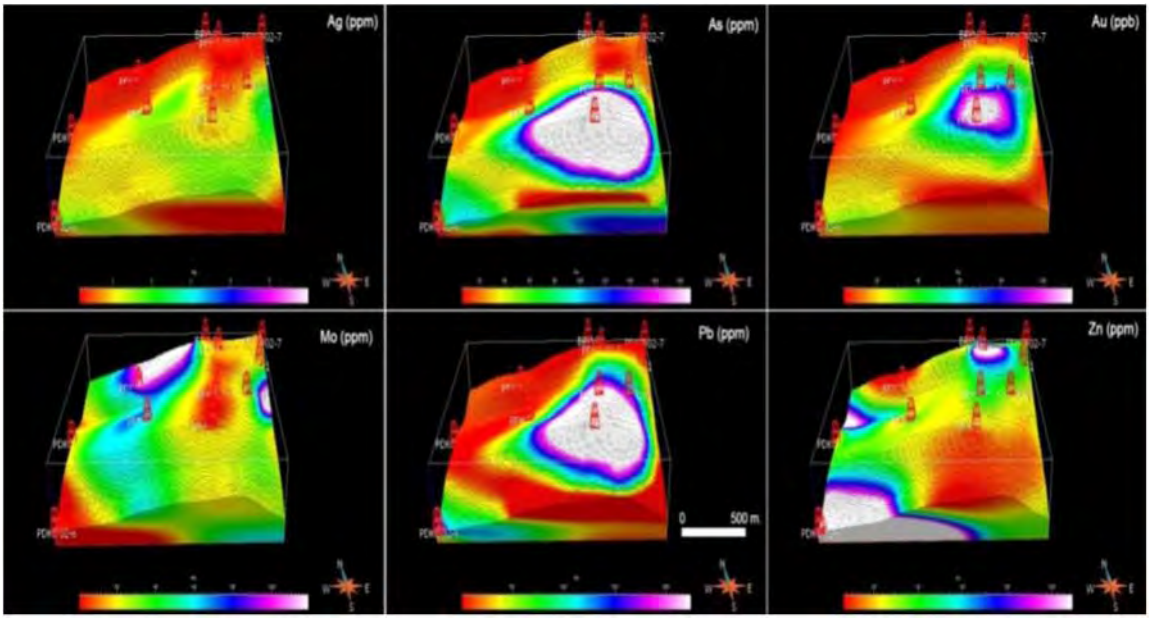
Local geology of the Borov Dol ore deposit.- The Borov Dol orefield is localized at the margin of a volcanic caldera in the southern part of the ore district within the VZ. The NW-trending faults control the Neogene latite and quartz latite dikes, necks, and extrusions. The Borov Dol deposit is related to this volcanic-plutonic complex. The ore-bearing volcanic rocks are metasomatically altered. The volcanic rocks belong to andesite, latite, trachyte, and rhyolite, including transitional varieties. At the Borov Dol deposit, porphyry copper mineralization occurs as a ring around the subvolcanic andesitic body that cuts through older volcanic rocks. The intensely altered volcanic rocks host the ore. Potassic and quartz-sericite alteration are noted at the surface. Down the dip, the orebody morphology is conformable to the andesitic stock. The ore mineralization is stringer-disseminated; ore disseminations (70%) prevail over ore veinlets (30%) (Tudzarov and Serafimovski, 1995). Chalcopyrite as the major mineral in primary ore is accompanied by pyrite, molybdenite, magnetite, gold, bornite and sporadic enargite, famatinite, galena, and tennantite (Stefanova and Serafimovski, 2006).

Local geology of the Kazan Dol ore deposit.- The geological setting in the closest vicinity of the Kazan Dol deposit has been built by Precambrian metamorphic rocks (gniess in westernmost parts of the terrain as well as two-mica cordierite gneiss). Paleozoic products are represented by grey-greenish sericite-chlorite schist in southernmost parts of the area while the Mesozoic has been represented by Furka granites (central and south-eastern parts of the area), quartz and quartzless porphyries (along tectonic lines of NNW-SSE direction), quartz keratophyre and keratophyre. These granites have determined absolute age of 155±5 m.y. by Rb/Sr method, (Šoptrajanova, 1967) and 156±6 m.y. (Borsi et al., 1966). Magmatic rocks as diabase occur southern of the Tarla Tepe hill and are represented with NW-SE extension. At the contact with marble there were determined carbonate-limonitic breccia while at the contact with gneiss, silicification and feldspatization occurred. Preliminary information indicated that at the Kazan Dol locality were determined copper mineralizations in the oxidation zones (Ivanov, 1966) related to the Jurassic granitoids intruded into the crystaline schist, as well as copper veins (Janković et al., 1997) related to chlorite-mica schist that have formed narrow zone. Also, at the Kazan Dol locality were determined typical copper tetrahedrite veins, which define Alpine metallogeny in this part of the Republic of Macedonia (Serafimovski, 1995), as well as impregnations along the crushing zones intercalated with quartz veins (Serafimovski et al., 1997). Localized areas of quartz veining are associated with copper mineralization with individual veins rarely exceeding 150 metres in strike (Čifliganec, 1993). Veins are usually narrow ranging from millimetre stock-work veins to individual veins up to a few metres thick. Primary mineralization consists of rarely observed chalcopyrite and very minor pyrite while locally pyrrhotite, sphalerite and tetrahedrite-tennantite have been reported within narrow veins. Secondary copper minerals are very widespread on the Kazan Dol area. The main oxide copper minerals are tenorite, malachite and locally cuprite, although azurite, native copper, covellite, chrysocolla, limonite and manganese minerals are widespread in the Kazan Dol mineralized area.

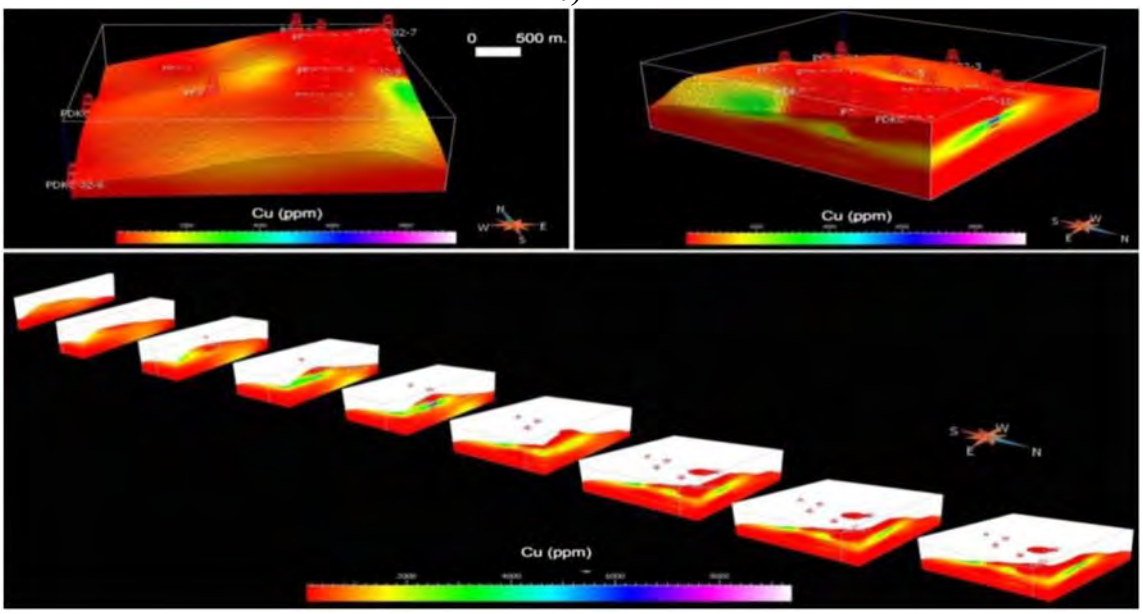
RESULTS AND DISCUSSION

The Kadiica ore deposit.- Using the lithological and the geochemical data from

11 drill holes at the Kadiica deposit, a 3D grid was created that depicts the distribution of each assay (Ag, As, Au, Mo, Pb, Zn, Cu; Fig. 1a). The software gives the opportunity to the user to create slices of the 3D grid and take a closer look to the spatial variation of an assay. From the grid showing the Cu distribution, an ore body with dimensions of 1000 x 600 m and 50 m thick, could be indicated. From the geochemical distributions it could be illustrated that high values of As are followed by high values of Au and Pb and low values of Zn. Different to Au and Pb the Cu mineralization is located at deeper levels. Also, higher-grade Cu mineralization appears in the western part of the main ore body (Fig.1b).



a)



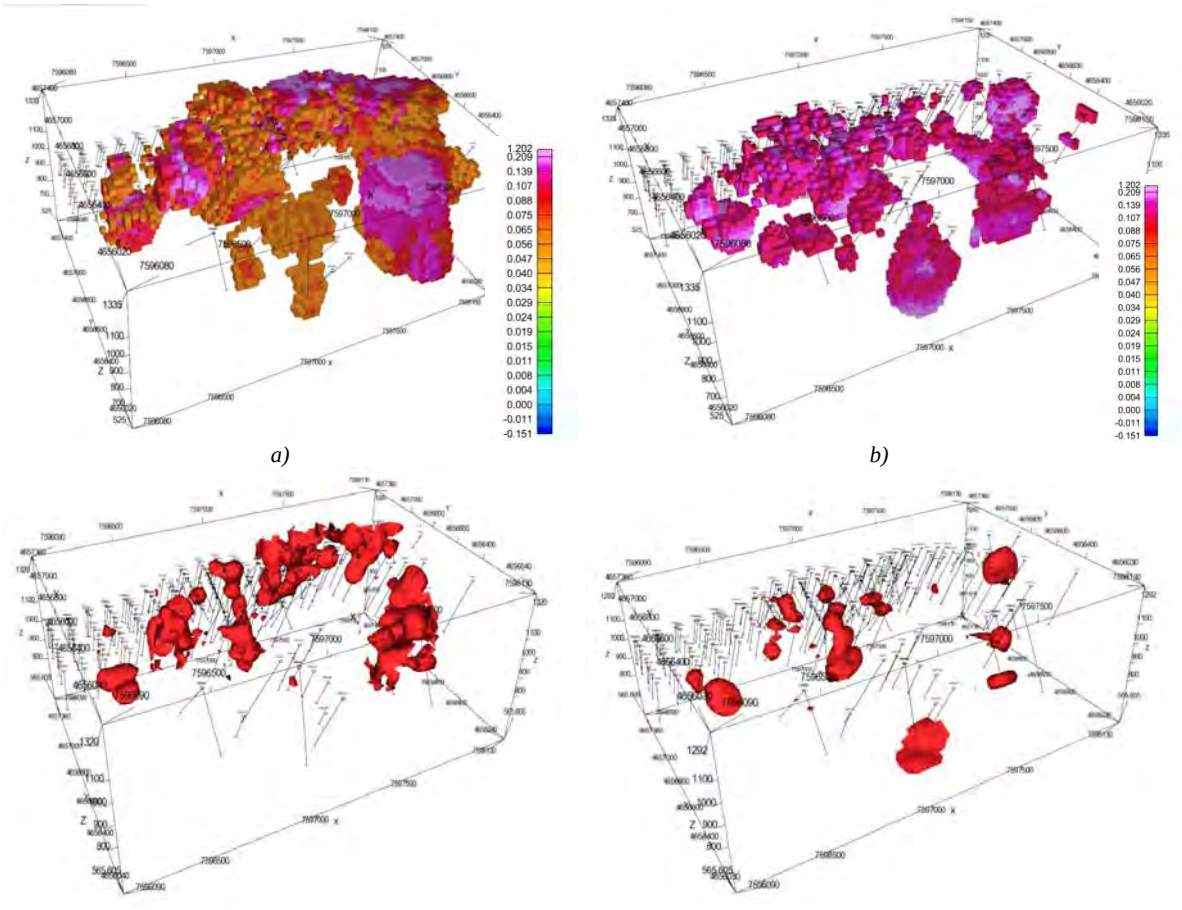
b)

Fig. 1 *a) 3D geochemical distribution in Kadiica deposit for the following assays: Ag, As, Au, Mo, Pb, Zn and b) 3D geochemical distribution of Cu along E-W geological sections across Kadiica deposit.*

The Plavica ore deposit.- A comprehensive and in many ways detailed study conducted at the Plavica, beside geochemistry and geophysics, included respectable array of 195 exploration boreholes totaling 47300 m. We used all the boreholes, including the negative one so we can get more representative situation in the 3D modelling. The study results have shown interesting gold and copper concentrations in certain mineralized

zones, which are the basis for construction of ours 3D model with use of professional computer software package Target 3D for ArcGIS in integration with data in form of MapInfo tables and 2D DXF files. Although mineralisation estimation of domains was modeled based only on metal grade, with definition of cut-off grade and top cut grade values for the Plavica deposit, the ore body was 3D modelled, with respect to intersecting fault zones, overall geological setting and the compositional distribution of metal grades (Figure 2a/b). Setting up the complete 3D geological model of the Plavica ore deposit all available data and sources of information were compared and integrated as it was case with 3D deposits elsewhere (Arvanitidis et al., 2013).

The contours of the ore bodies, both for gold and copper, have shown strong correlation to the fault systems in the area (being of N-S, NW-SE and sporadically SW-NE direction and respectively reflecting their spatial position. Following sound geological reasoning during the creation of the model, a considerable amount of knowledge regarding the mineralized area and the ore body was specifically updated (mineralization extending up to 300 m at depth); some new N-S striking and cross-cutting fault structures were interpreted. For completion of this 3D model two different methods are used. The first is projection using block with help of kriging method and displayed volume through 30 m blocks. Figure 2a represents model of Au with 0.2g/t cutoff grade. Figure 2b represents Cu model with 0.12% cutoff grade.



a) *b)*

c) *d)*

Fig. 2 *a) 3D model of Au (seen from SE); b) 3D model of Cu (Seen from SE); c) 3D model for Au using "solid" display (Seen from SE); d) 3D model for Cu using "solid" display (Seen from SE)*

This 3D model displays visible concentration of Au in the NE part of the deposit. In the western part there is also smaller ore body deeper underground. Looking at this model one can clearly see that Cu mineralization is not connected with Au mineralization. Cu is present through all the area, slightly deeper than Au. We would like to stress out that the actual 3D model of the Plavica polymetallic deposit we can see that it strongly reflects the

geochemical Au-Cu pattern already seen at the geochemical geochemical cross sections (Serafimovski et al., 2014). The second method used for 3D modelling is the method of isosurface where "solid" bodies are formed. In our case we used different cutoff grade for projecting the solid bodies with cutoff grade of 0.4g/t for Au and 0.2% for Cu (Figure 2c/d).

The Borov Dol ore deposit.- After an extensive geological exploration programme at the Borov Dol ore deposit was finished, based on geochemistry, geophysics and exploration data of around 100 exploration drill holes totaling more than 20 000 m we proceeded with construction of an appropriate 3D model. The study results have shown interesting copper concentrations between levels 630m and 300 m, which represents the basis for construction of ours 3D model. The drill holes were selected on positive vs. negative basis and were taken only those that positively contribute to the copper body contouring. When plotted in 3D, the majority of the geochemical groupings have a strong association with the lithologies of the deposit sequence (Figure 3e/f). Newly defined morphological contours of the ore bodies within the Borov Dol deposit basicaly are of stockwork-impregnated type (Figure 3c/d), which in general mimic inverted glass cup or cone that at depth deforms.

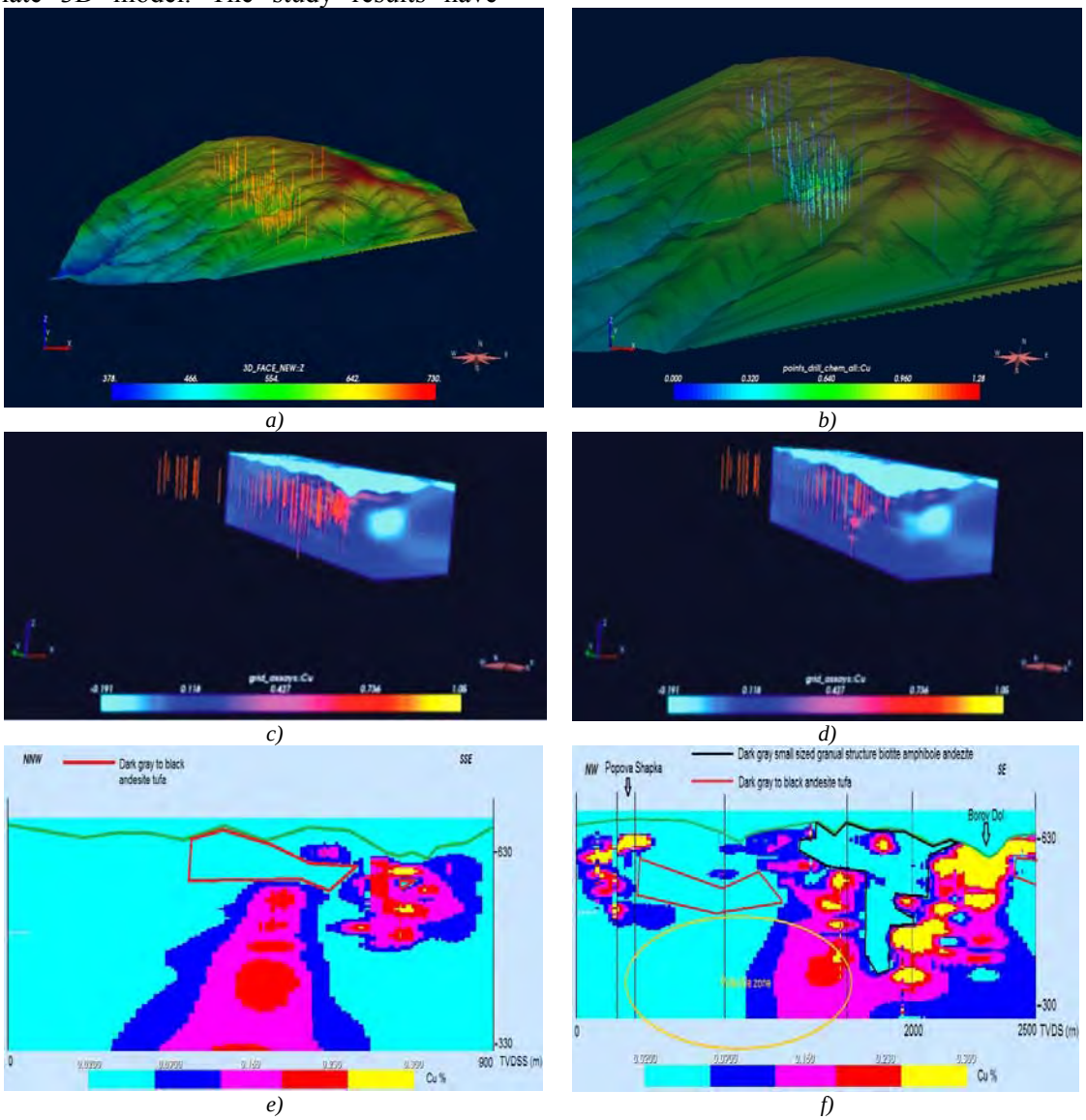
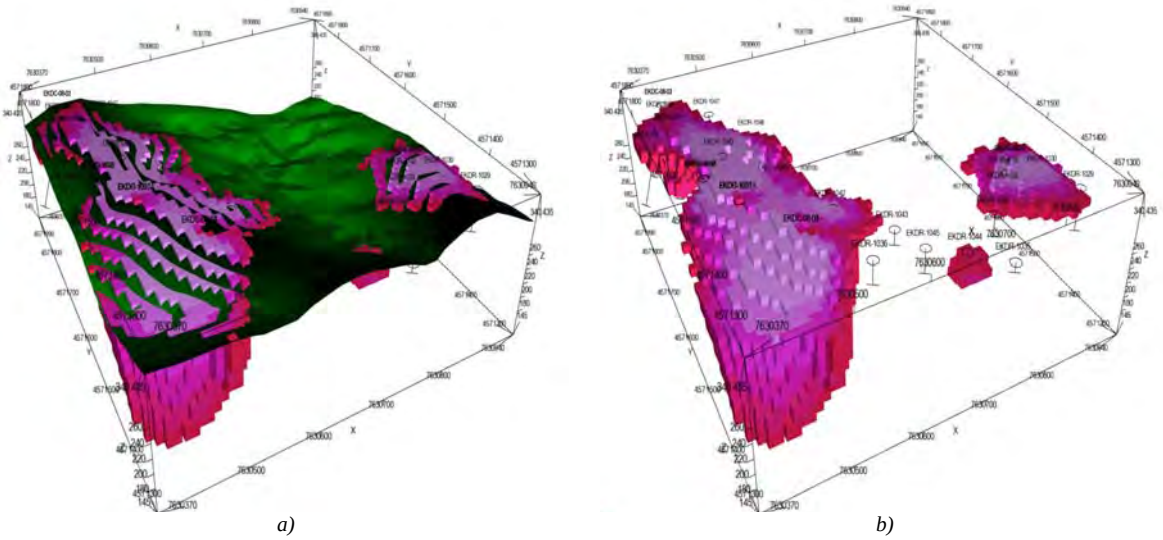


Fig. 3 *a) Surface and the drill holes; b) Variation of copper in the drill holes; c)/d) cross sections from west to south on the grid with the variation of copper; e)/f) cross sections, striking NNW-SSE and NW-SE, cutting through Borov Dol Cu mineralization*

The Kazan Dol ore deposit.- Detailed study conducted at the Kazan Dol locality beside geochemistry, geophysics and exploration trenches included respectable array of 53 exploration drill holes totaling 3442 m with an average depth of 90 m and 3052 samples. The study results have shown interesting copper concentrations in oxidation zones, which represents the basis for construction of ours 3D model. The drill holes were selected on positive vs. negative basis and were taken only those that positively contribute to the copper body contouring. When plotted in 3D, the majority of the geochemical groupings have a strong association with the lithologies of the deposit sequence (Figure 4).



a) *b)*

Fig. 4 *a) 3D model of the Kazan Dol deposit with terrain surface displayed; b) 3D model of the deposit*

The biggest advantages of constructing 3D volumes instead of 2D cross sections is the possibility to define ore grade volume gains and losses of the entire mineralized systems (Chmielowski et al., 2013). Construction of 3D model of this particular ore deposit will be used to constrain key features pertinent to ore genetic models, such as net gains or losses of elements within the entire ore system as well as the source of metals in the deposits as it was mentioned elsewhere (Fisher et al., 2013; Chmielowski et al., 2013). During the creation of the model, a considerable amount of knowledge concerning the mineralization area and the ore body was specifically updated (thickness of more than 160 m); some new N-S striking and cross-cutting fault structures were interpreted, but further investigations are required to determine their metallogenetic relationship to any of the mineralization processes.

CONCLUSION

At the end of this compilation study some conclusions stand out itself. At the Bukovik-Kadiica deposit 3D model suggests Cu distribution (within an ore body) with dimensions of 1000 x 600 m and 50 m thickness. Geochemical distributions illustrated that high values of As are followed by high values of Au and Pb and low values of Zn, while opposite to Au and Pb the Cu mineralization is located at deeper levels.

The Borov Dol 3D model confirmed interesting Cu concentrations between levels 630 m and 300 m, as well as that the deposit basically is of stockwork-impregnated type, which in general mimic inverted glass cup or cone that at depth deforms.

At the Plavica deposit construction of the 3D model have revealed its isometric to lens/lensoid morphology, which swerves and distorts at depth. It has been proved with the 3D model spatial position of gold and copper mineralization within the Plavica deposit between hypsometric levels 1305 and 600 m.

The present exploration at the Kazan Dol continues in the southern parts of the deposit where exist positive Cu and Zn anomalies as a direct reflection of oxidized Cu-veins enclosed in crushing zones. Displayed 3D model defines the spatial position of Cu mineralization in the Kazan Dol deposit between hypsometric levels 340 and 180 m.

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