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Original scientific paper

3D MODELING OF THE BOROV DOL PORPHYRY COPPER DEPOSIT, REPUBLIC OF NORTH MACEDONIA

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A b s t r a c t: Recent exploration of the Borov Dol copper porphyry deposit has made a significant contribution to understanding the geological composition of the deposit and determining the ore bodies. Significant geological explorations have been carried out in the area of the Borov Dol ore deposit, and during 2019, open pit exploitation has started. Along with extensive geochemical and geophysical investigations, a drilling program has been implemented at the site and provided decent exploration results. For this 3D model, all 100 drill holes made in the period from 1966 to 2013 were used. The drill holes have a total length of 23 435 m. Four professional software packages were used in the preparation and production of 3D models at the Borov Dol site. Surfer models of surface halos of copper, gold, lead and zinc ores have been developed, which jointly define the space of the possible feeding channel for copper mineralization and associated metals. The most detailed 3D model of the Borov Dol ore deposit was completed with the professional software package MOVE, which provides the surface visualizations and variants of the 3D model to the depth. Comparison was done with the MineSight software package, which also included compatibility of the geochemical data. Confirmation of 3D modeling was obtained using the professional Vulcan software package, which gave a morphological shape of the complete ore body in 3D visualization and a view of the ore body down to a level of 300 m.

Key words: Borov Dol ore deposit; porphyry mineralization; 3D model; geochemical modeling and software packages

INTRODUCTION

The territory of the Republic of North Macedonia is part of the geotectonic setting of the Serbo-Macedonian metallogenic province where numerous polymetallic mineralizations were formed (Serafimovski, 1990). During the last twenty years Republic of North Macedonia experienced boom in detailed geological exploration of numerous ore-bearing localities. Several ore deposits such as Kadiica deposit near Pehčevo, Plavica deposit in the close vicinity of Kratovo and Probištip, Kazan Dol deposit near the Valandovo and Borov Dol deposit near the city of Radoviš, had been explored in details and even ore reserves had been calculated. The latest one, the Borov Dol ore deposit (Figure 1), reached stage of open pit mine in progress, which is great achievement for the investor as well as the local and regional communities.

In the past, 3D modeling tools have proven to be a very useful tool for exploring and studying the deposits of metallic mineral resources. This scientific paper uses a three-dimensional model of the porphyry copper mineralization in the Borov Dol deposit, eastern Macedonia, within the Bučim-Damjan-Borov Dol mining area which has an area of about 150 km^2 (Serafimovski, 1990). The main part of the porphyry copper mineralization in the Bučim-Damjan-Borov Dol mining area consists mainly of gneisses (Precambrian) and shale (Upper Paleozoic) (Lehmann et al., 2013).

Porphyry copper mineralizations in the ore region of Bučim-Damjan-Borov Dol occurs associated with acidic stocks of Tertiary age, which created shallow intrusions in the Paleozoic metamorphic formations of the Serbian-Macedonian metallogenic province. Mineralized and surrounding rocks at the Borov Dol deposit belong to the Oligocene-Miocene calc-alkaline complexes which are trachy-andesite, trachy-dacite and granodiorite. The widespread distribution of these calc-alkaline volcanic groups is probably a consequence of the partial anatectic melting of the lowest part of the continental crust caused by the processes that followed the collisions of continental plates (Christidis et al., 2014).

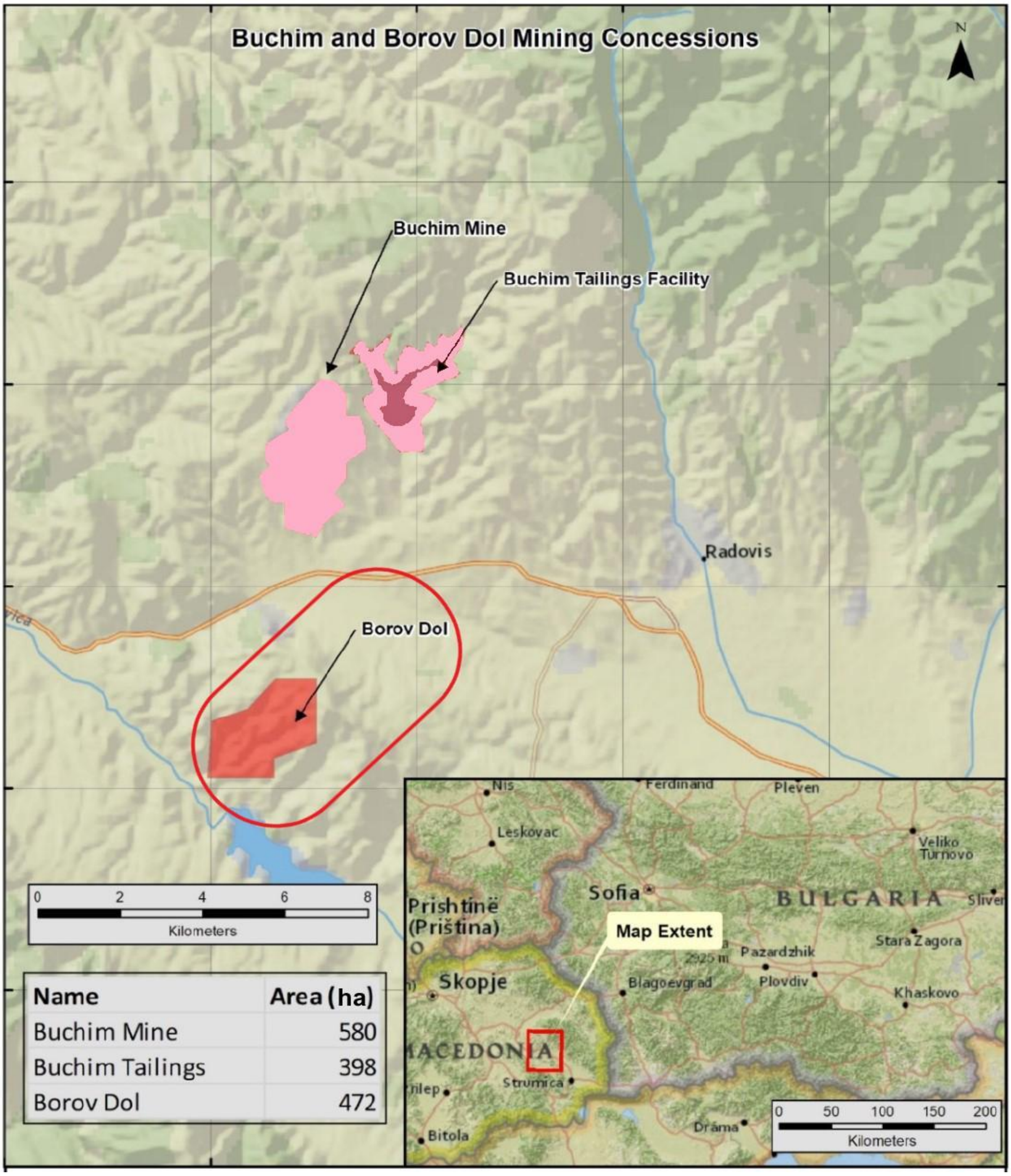


Fig. 1. Panoramic view of the Borov Dol deposit and part of the active open pit at the Bučim ore deposit (Gray et al., 2017)

Within the Bučim-Damjan-Borov Dol ore region, endogenous deposits and occurrences of Fe-skarn type, Cu, Au, Ag of porphyry type, occurrences of Pb - Zn, Ba-vein type and others are spatially and paragenetically related to the Tertiary magmatism. (Serafimovski, 1990, 1993). It should be noted that the Borov Dol ore deposit from the metallogenic point of view is most complexly studied by Tudžarov (1993), and some publications on magmatism and mineralization can be found in the works of Serafimovski et al. (1992, 2010, 2014a, 2014b), Tudžarov and Serafimovski (1994a, 1994b, 1995), Volkov et al. (2008), Lehmann et al. (2013), Stefanova et al. (2014a, 2014b) etc. We want to emphasize that Borov Dol as a very interesting por- phyry deposit in the Vardar zone is still a challenge for new research and that trend will certainly give new results in which special contribution is given to the latest work of Gjorgjiev (2020)

METHODOLOGY

The Borov Dol ore deposit's database with drill core collar, survey, assay and all the data have been provided by Borov Dol DOO Skopje. The database contains information from 100 boreholes with individual length of up to 594.1 m and count for total of 23 435 m of core and results. Drillholes have been spaced 50 to 100 m between each other and sampled at 1 m intervals, in that direction the total database consists of more than a 25 000 sampling results (multi-elemental). All of the drill holes were located using GPS, and these coordinates and elevations were recorded. The database provides informations about the locations of drillholes, their depth and orientation, lithology, mineralogy and geochemistry (Atomic Adsorption Spectrometry – [AAS] and Inductively Coupled Plasma Atomic Emission Spectrometry – [ICPAES], analyses of group of 36 chemical elements). Cut of grade for gold was calculated at 0.2 g/t Au while for copper it used to be at 0.2% Cu (0,12% Cu for the Vulcan software). The construction of the Borov Dol deposit 3D models were built by mapping geochemical variations in the Move software by Midland Valley (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). This particular software enables to display drillholes, surface and other data types in an interactive three-dimensional environment. The Move by Midland Valley 3D software enables three-dimensional viewing of our data. Drillholes are displayed in their "true" three-dimensional location and can have up to two different data types plotted along their trace. Using the Move tools we were able to interactively control the transparency of individual items, enabling data to be displayed with a cumulative effect as it was already mentioned elsewhere (Ligovski et al., 2014).

We performed several tasks to transfer majority of the Borov Dol exploration data into the Move by Midland Valley 3D software acceptable interface (Lotteri et al., 2009). Those tasks included: digital terrain model (DTM), import of geological boundaries (importing attribute table), field (dip) data import (including X, Y coordinates, dip and azimuth), data projection on aforementioned DTM, digital drawing of geological cross section(s), transfer of cross section(s) in 2D MOVE, collection of intersections, field dip data insertion, projection of the geological map on the DTM-raster, drawing of the geological maps, surface construction with 3D move.

Also, Maptek's Vulcan software package was used for 3D modeling of the Borov Dol copper-porphyry deposit. The Vulcan software package is generally used to plan and design mines that provide 3D modular visualization of geological models and mining planning and design. We use the Vulcan 7.5 version, created in 2008 to model the ore bodies of the Borv Dol ore deposit. The procedure for modeling ore bodies involves a number of operations that are grouped into several stages:

– checking the geological and geodetic data and entering them in the database (BP);

– making topography of the field;

– making the contours of the ore bodies and the separate geological units (dark gray fine-grained andesites, volcanic tuffs and faults);

– making a 3D model.

We would like to point out that for the geochemical data modeling (geochemical maps) was used Surfer software, as for lateral, also for vertical sections.

With the first type of computer program (Move/Voxler 2, etc.) we can very quickly create a 3D model based on the geochemical data of all the analyzed elements from the experiments of the exploration boreholes in the deposit and according to our observations can help a lot in predicting perspective spaces in detail for further geological exploration and understanding of ore-genetic processes. This type of software allows us to create high-quality 3D visualizations of the available data, and they are available primarily because of their relatively low cost (about $ 500). This type of software can be used in the educational process (secondary and higher education) as well as in companies engaged in the exploration of metallic mineral resources, especially massive sulfide deposits in the drilling phase.

The second type of software (such is Vulcan by Maptek) creates a 3D model of the separate geological units and mining bodies. The program is highly professional, as it enables the calculation of geological mine reserves, interpretation of geophysical data results, modeling of underground mining operations and surface mining, etc. With this type of software, a professional assessment of the geological ore reserves and the techno-economic value of the given ore deposits is performed. Such software is expensive (more than $ 30,000) and is only available for mining companies and big consulting companies that deal with mining planning and design and geology.

GEOLOGICAL FEATURES

The Borov Dol deposit is part of the ore region Bučim-Damjan-BorovDol, and it occupies its southern parts. The metallogeny of this ore region is closely related to the evolution of the Tertiary magmatism represented with subvolcanic-volcanic facies of andesite, latites, quartz latites, trachy-rhyolites etc., which are the product of intermediate to acid calc-alkaline magmatism. Numerous interesting mineralizations of Cu, Fe, Pb-Zn as well as Au are related to this magmatism. The geological structure (Figure 2) of the Borov Dol deposit, which is quite complex, contains Paleogene, Neogene and volcano-sedimentary and volcanic rocks (Serafimovski, 1990; Tudžarov, 1993; Serafimovski et al., 2010; Stefanova et al., 2015).

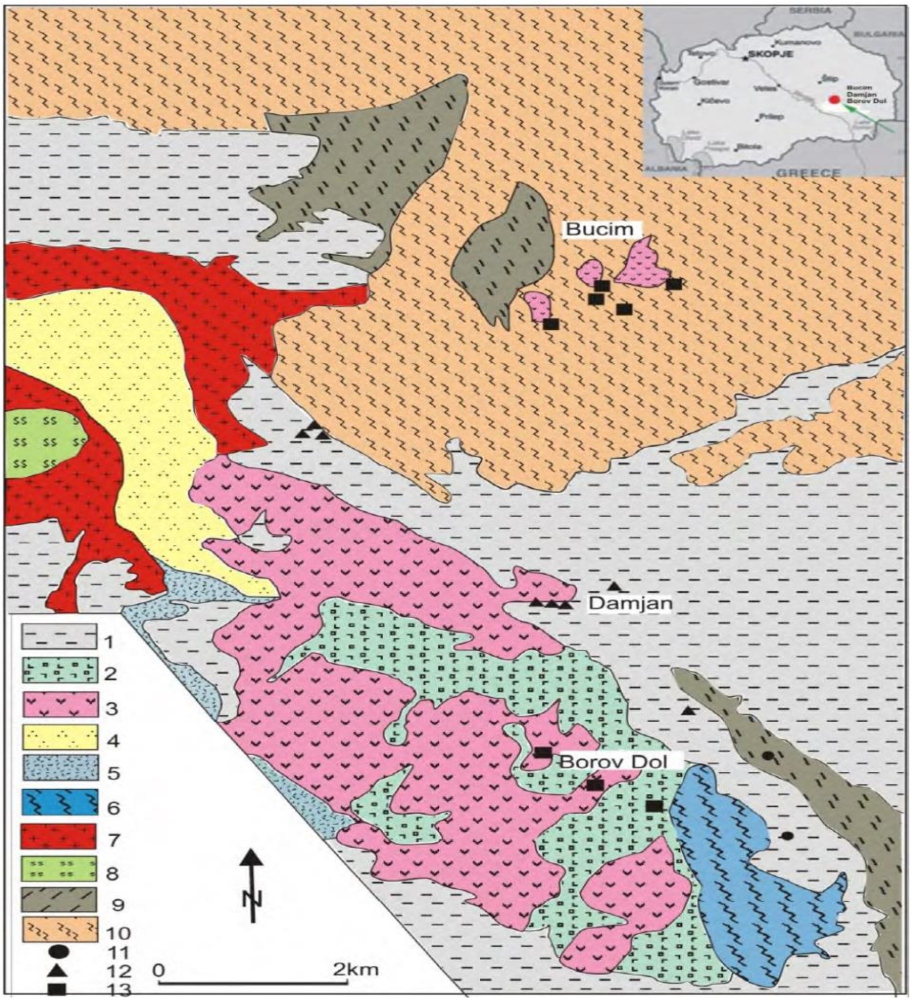


Fig. 2. Geological setting from Bučim-Damjan-BorovDol ore district (Stefanova, 2005)
1. Paleogene, neogene quarter sediments. 2. Pyroclasts. 3. Andesite and latite. 4. Cretaceus flysch. 5. Carbontites. 6. Carbonate-schist series. 7. Granite. 8. Serpentinite. 9. Micaschist. 10. Gneiss. 11. Pb-Zn vein type of mineralization. 12. Fe-skarn type of mineralization. 13. Porphyry type of mineralization

Paleogene sediments occupy a large part of the terrain and are represented with conglomerates, paleogene flysch and series of tuffites and sands. Conglomerates are heavily modified and built mostly of fragments of gneiss and quartz. Flysch facies is built of thin layers of finegrained and large-grained sandstone and conglomerates. Volcanogenic sediment series is built of sandstones, marly sandstone and limestone, and pelitic tuffs and tuffites. Tuffs are determined as andesite and their presence indicates that the volcanic activity is with sedimentation of Paleogene sediments. Neogene sediments, which are represented by conglomerates, are built of heterogeneous material dominated by pieces of quartz, crystalline shale and Paleogene sediments. Magmatic rocks are represented by volcanic and subvolcanic facies of latites, quartzlatites and andesites.

Andesites in turn, depending on the degree of change and ore amount are divided into: propilitized andesites, hydrothermally altered andesites, hydrothermally altered and mineralized andesites and andesite lava. Effusive rocks occur in the form of outcrop and lava. Large porphyritic propilitized andesites, i.e. latites and quartzlatites that occupy most of the terrain, are hydrothermally changed and mineralized. Latites and quartzlatites as products of the older phase hacked with dark grey fine-grained biotite, amphibole-andesite which in the form of neck are imprinted in the central part of the Borov Dol circular structure. The magmatism at Bučim–Damjan–Borov Dol occurred between 24.04 ± 0.77 and 24.51 ± 0.89 Ma, as indicated by chemical-annealing (CA)-LA ICP-MS zircon dating (Lehmann et al., 2013).

ORE MINERALIZATIONS

More than three decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis (Tudžarov, 1993; Serafimovski et al., 2010; Stefanova, et al. 2015). In the Borov Dol deposit with the latest geological studies was confirmed porphyry type of mineralization localized in coarse-grained hydrothermally altered andesite to latite and around fine-grained dark andesite which kind of break through characterize morphological ratio of volcanics and porphyry mineralization within the Borov Dol ore deposit. Porphyry mineralization is characterized by stockwork-impregnated types of ore mineralization, where within the Borov Dol dominate stockwork impregnations. The andesitic body cutting through the older volcanic rocks is accompanied by a porphyry copper mineralized ring in the altered volcanic rock. Surface rock includes potassic and quartz-sericite alteration. The shape of the orebody conforms down dip to the andesitic stock. The major ore mineral is chalcopyrite, accompanied, by pyrite, molybdenite, magnetite, gold, bornite and sporadic enargite, famatinite, galena and tennantite. The Borov Dol deposit includes native gold, associated with all generations of pyrite and noted as inclusions in chalcopyrite, and as Au tellurides. Above mentioned features of this ore mineralization initiated calculation of several important technoeconomical parameters, which can define the economic type of this mineralization. Namely, the degree of ore bearing along vertical extent of ore mineralization is variable, but calculation at particular levels and different drill holes gave the more realistic ratio of mineralization within this ore body. Some techno-economic parameters related to the Borov Dol ore deposit can be found in some previous works (Petrov et al., 2014).

Figure 3 shows a cross section through the Borov Dol copper porphyry deposit and it shows that the ore body with copper mineralization is in the form of a ring and occupies the east side of the volcanic structure bounded by volcanic tuffs.

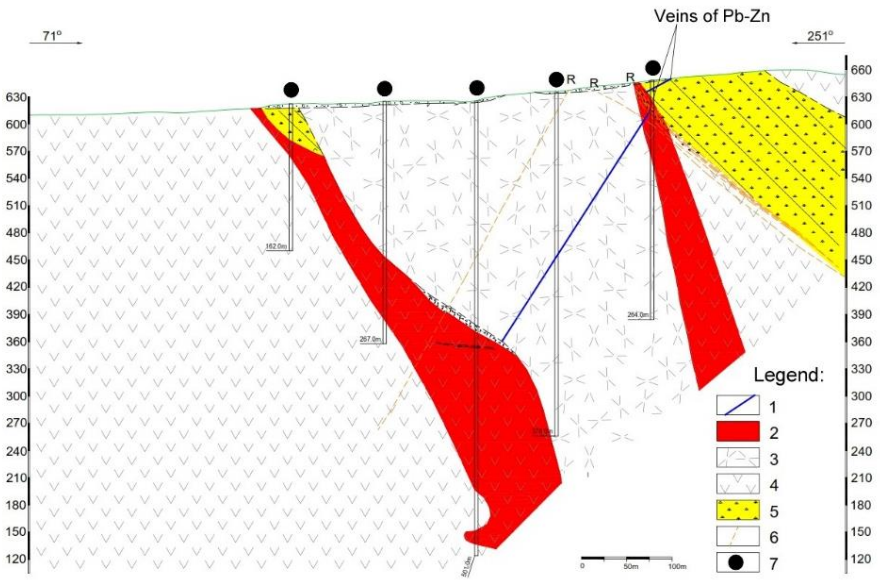


Fig. 3. Cross section of the Borov Dol ore deposit (Petrov et al., 2014)
1. Pb-Zn veins. 2. Ore body. 3. Dark gray fine-grained porphyry andesite. 4. Gray-white coarse-grained andesite. 5. Volcanic tuff; 6. Faults. 7. Explorationn drill holes

Morphologically, the ore body follows the morphology of the fine-grained andesites that as necks have been intruded in the coarse-grained altered andesites that made the mineralizing control of the porphyry mineralization in Borov Dol. This clearly shows that this is a typical magmatic hydrothermal system that used the same feeding channels for both magmatism and the ore fluids that gave the porphyry mineralization at the Borov Dol deposit (Serafimovski, 1990, 1993).

GEOCHEMICAL FEATURES AND MODELING

An analysis of the results of the primary dissemination halos at the Borov Dol ore deposit are shown on the Cu isoline map (Figure 4), made using Surfer 9.0 software, can lead to the general conclusion that Cu anomalies greatly outline ore bodies around the andesite neck. We can see that this is a centrally expressed semi-ring deformed anomaly that mainly follows the contact of the andesitic neck with the latites, quartz-latites and units of the volcanogenic-sedimentary series (Tudžarov, 1993). The concentration of copper, the shape of the haloes, their horizontal zonation and their relationship to the structures clearly confirm the existence of the southern ore body, while at the same time indicating the existence of hidden ore bodies in the middle and northeast of the locality. Also in the northwest they indicate the existence of another hidden ore body. Subsequent detailed research, which focused mainly on the results of geochemical prospecting, was discovered by the central ore body, the north ore body and the Popova Šapka ore body (Serafimovski et al., 1996), which was confirmed by our latest research and interpretation, too.

Also, beside for other elements, we have prepared two additional geochemical distribution maps, for Pb and Zn (Figures 5a and 5b). As it can be seen from the comparison of the copper, lead and zinc geochemical anomalies on the aforementioned maps, Pb and Zn are boundaries of the Cu-mineralized system.

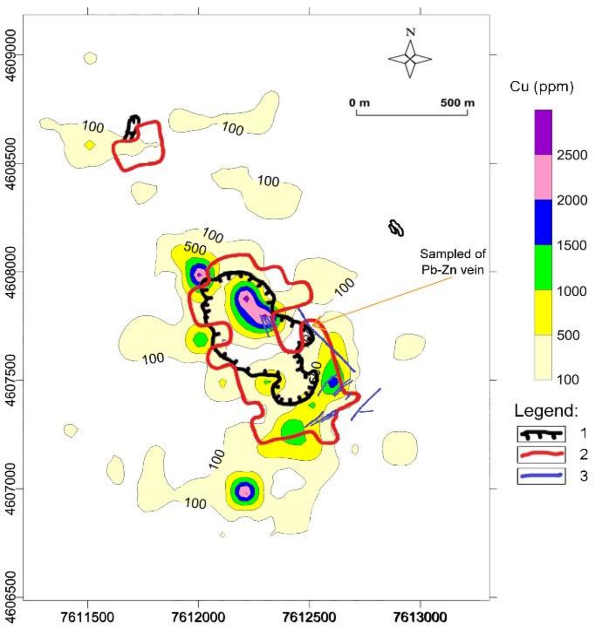
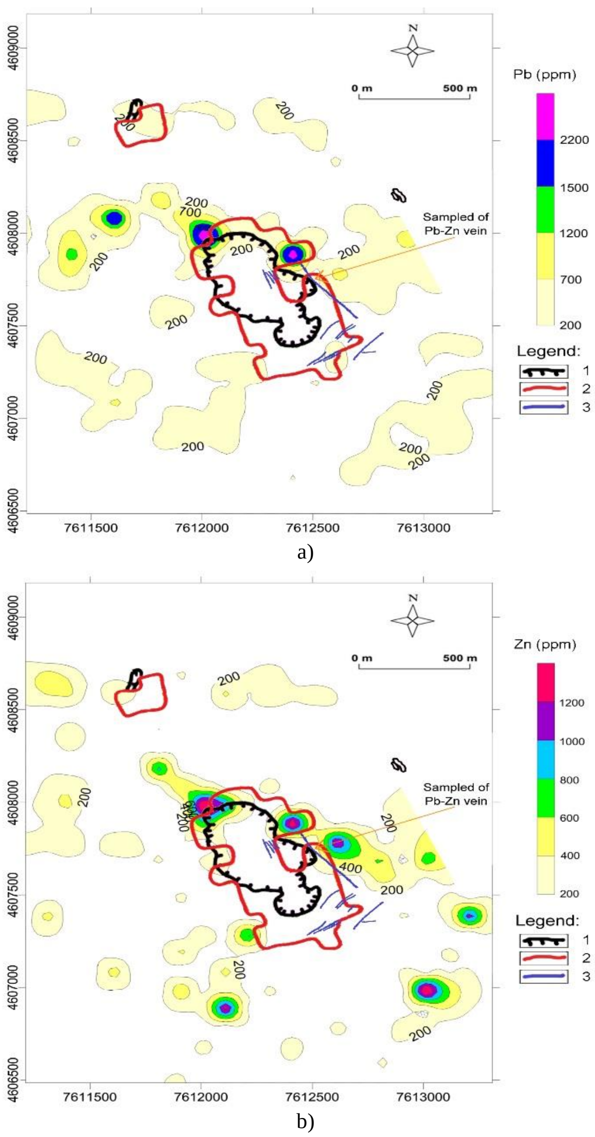


Fig. 4. Borov Dol deposit copper isolines map
1. Andesite neck. 2. Contours od the ore body.
3. Quartz-sulphide ore veins with PbS and (Zn,Fe)S



a)

b)

Fig. 5. a) Map of lead isolines at the surface of the Borov Dol ore deposit. **b)** Map of zinc isolines at the surface of the Borov Dol ore deposit
1. Andesite neck. 2. Contours of the ore body.
3 – Quartz-sulphide ore veins with PbS and (Zn,Fe)S

However, special attention should be given to the north-northwestern boundary where all of the three elements showed significant anomalies (Cu up to 2000-2500 ppm; Pb ≥ 2200 ppm; Zn ≥ 2200 ppm), which could be indicative for joint mineralizing feeding channel/mineralizing knot.

3D MODELING, RESULTS AND DISCUSSION

In many ways detailed and comprehensive study conducted on the Borov Dol deposit, beside geochemistry and geophysics, included respectable array of 100 exploration boreholes totaling of 23 435 m. We used all the boreholes, including the negative one so we can get more representative situation in the 3D modeling. The study results have shown interesting copper concentrations in certain mineralized zones, which represents the basis for construction of ours 3D model with use of professional computer software package Move by Midland Valley 3D software.

As it can be seen from the Figure 6, the exploration area of the Borov Dol deposit occupies the north-western slopes of the Smrdeš Mountain (located in the south-eastern part of the Republic of North Macedonia).

Using the geodetic data from the field and the lithological and geochemical data from 100 exploration drill holes with a total length of 23 435 m all made with diamond core, a three-dimensional net was created that reflects the distribution for each chemical analysis in the investigative space (Cu, Au, Ag and Mo; Figures 7, 8, 9 and 10).

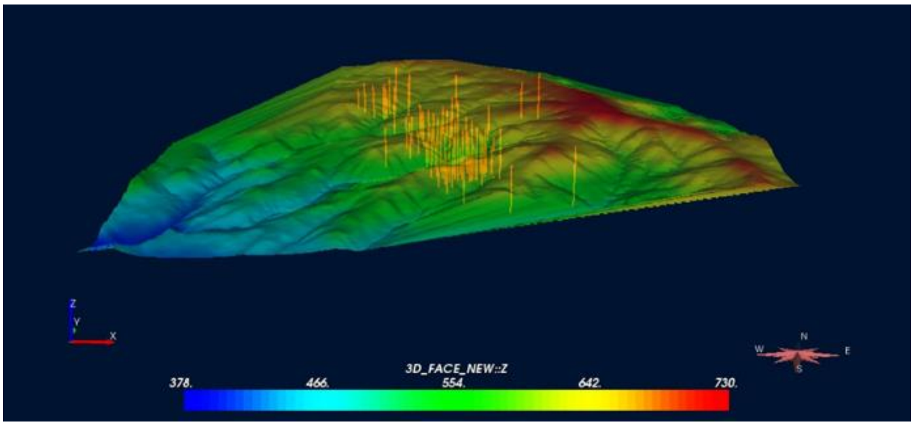


Fig. 6. Terrain of the Borov Dol deposit and position of the exploration drill holes

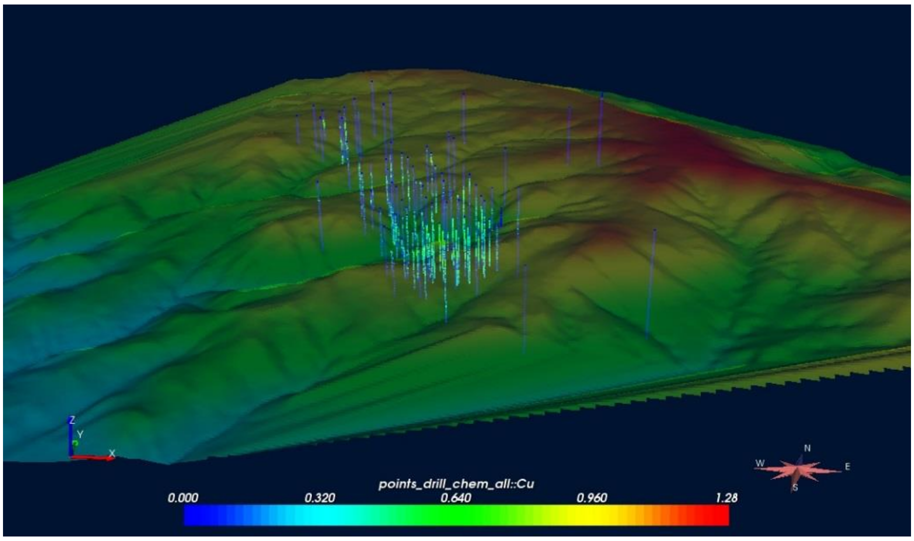


Fig. 7. Copper variability in exploration drill holes of the Borov Dol deposit

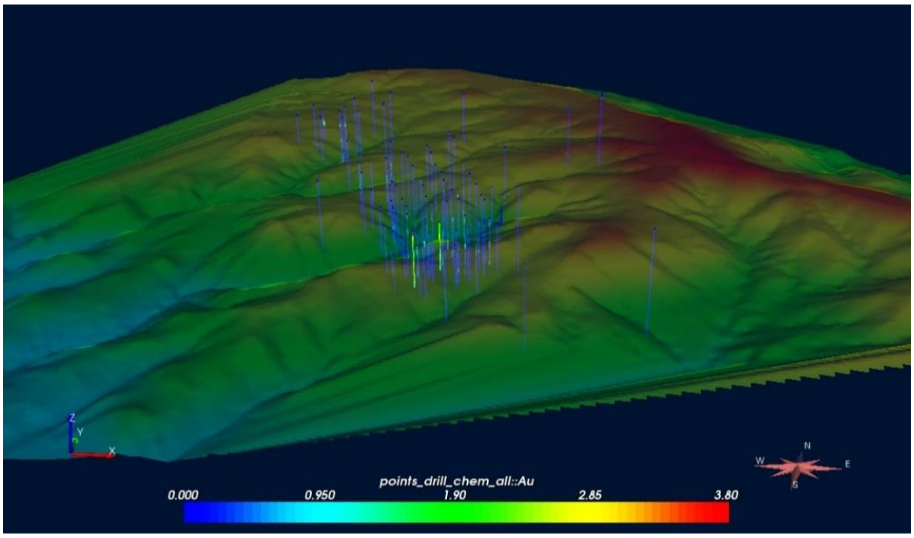


Fig. 8. Gold variability in exploration drill holes of the Borov Dol deposit

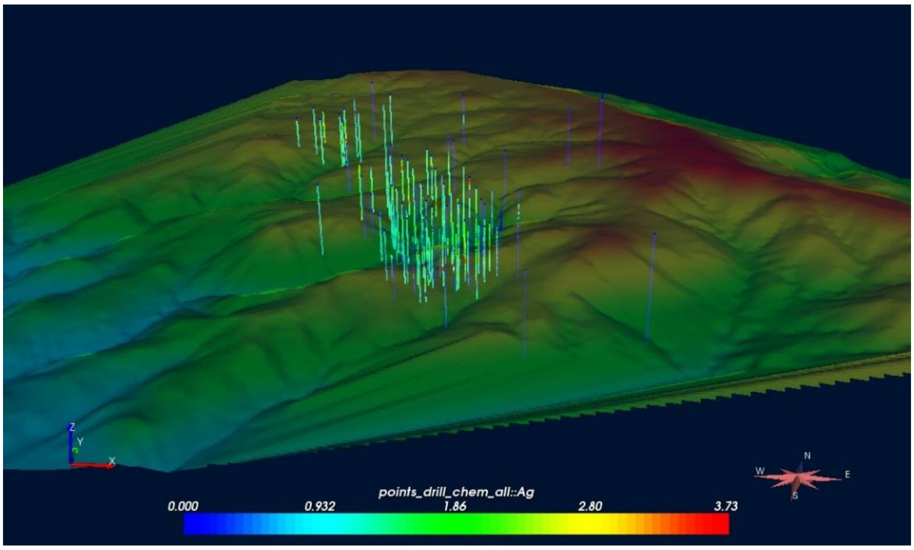


Fig. 9. Silver variability in exploration drill holes of the Borov Dol deposit

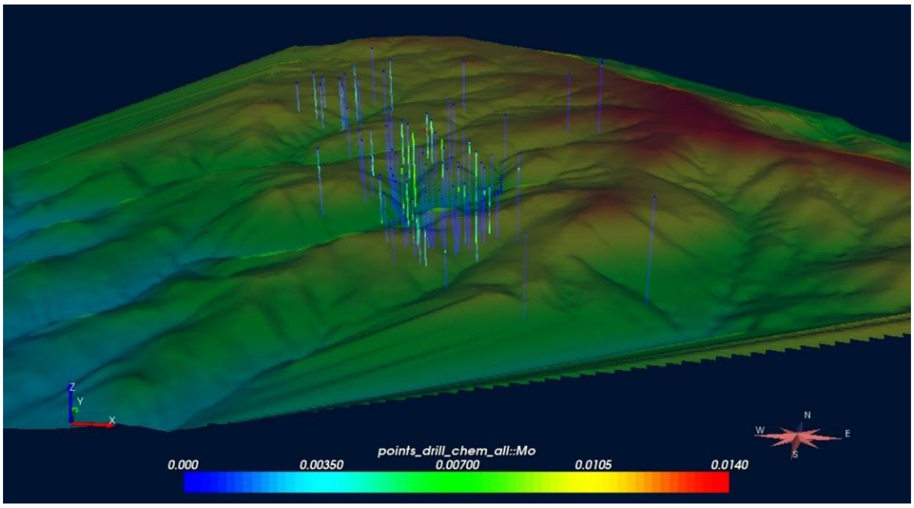


Fig. 10. Molybdenum variability in exploration drill holes of the Borov Dol deposit

Copper concentrations/mineralization pattern mainly occupies central parts of the NE-SW directed exploration drilling programme. Such a copper occupancy of the area strongly reflects the findings of the surface geochemistry (Figure 7).

Although scarce in its nature, gold mineralization was determined in S-W margins of the explored area (Figure 8).

Silver concentrations were spread across all over the explored area as it can be seen from the Figure 9.

Opposite to silver, molybdenum manifested its presence mainly in the central parts of the explored area (Figure 10). As it was expected it generally followed the copper mineralization. This finding strongly complied with findings of Serafimovski et al. (1996) and Lehman et al. (2013).

All the above elements (Cu, Au, Ag, Mo) are strongly compliant with findings of Serafimovski et al. (1996). Namely, copper showed strong association with molybdenum similarly to their findings based on the factor analysis, while silver showed strong presence compatible with both, cluster and factor, analysis haloes suggested by Serafimovski et al., 1996.

A three-dimensional surface geology has been developed and the more important fault structures in the site have been defined (Figures 11 and 12.

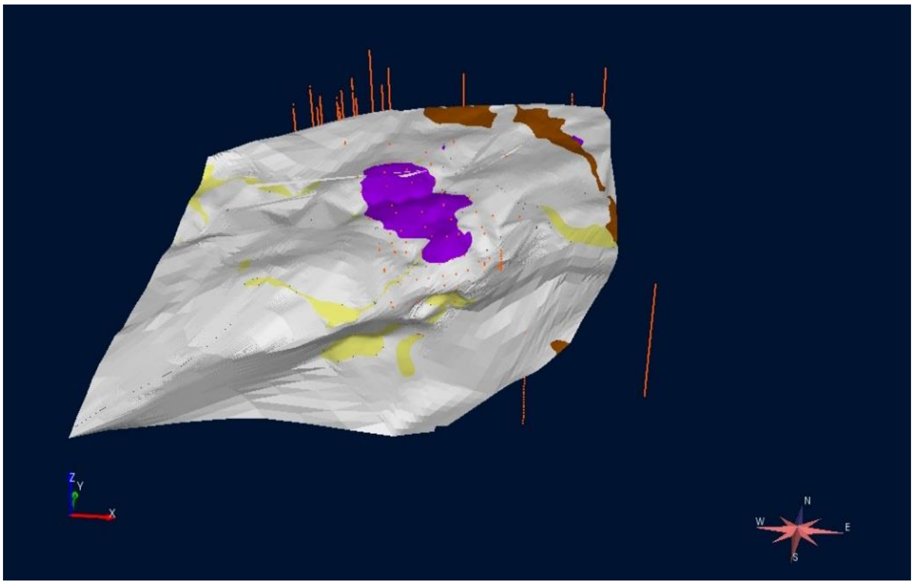


Fig. 11. 3D surface geology and exploration drill holes, the Borov Dol area.

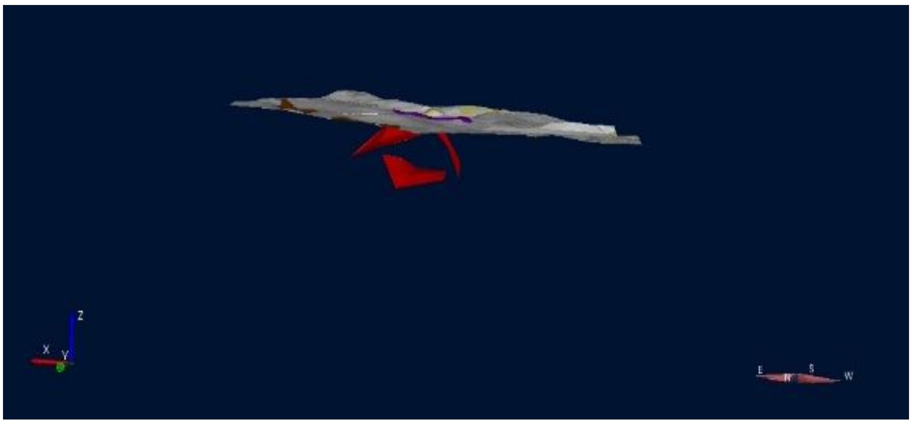


Fig. 12. 3D surface geology and some of the major faults obtained from cross sections, the Borov Dol area.

The 3D model of copper mineralization at the Borov Dol site gives us the following information (Figure 13):

i) Four ore bodies have been identified (southern ore body, central ore body, north ore body and Popova Šapka ore body).

ii) The main feeding channel for copper mineralization is below the northern ore body (Figure 14a and Figure 15A).

iii) In the northern ore body and the Popova Šapka ore body, two levels of Cu mineralization (Figure 14a) are evident, at least two phases of sulfide mineralization, where it appears that telescopic solutions of ore-bearing solutions occurred. This is confirmed by the reflected light microscopy analysis of samples from the Borov Dol deposit (Serafimovski and Tasev, 2014).

iv) Permeable settings associated with the deposition of porphyry mineralization are gray-white coarse-porphyry andesites, while dark-gray fine-grained porphyry andesites and volcanic tuffs are the screen (boundaries) of mineralization.

v) The dimensions of the Borov Dol deposit are as follows: 600 m in width, over 2,000 m in length and more than 500 m in depth.

vi) Mineralization extends to the north and into the depths where the focus of future research should be. The northern ore body should be the subject of in-depth research (Figure 13 and Figure 14).

vii) Gives opportunities for geochemical interpretations to be related to both geological and alterational models and thus to obtain an even clearer picture of the ore deposit (Ivanovski, 2016).

With the development of 3D models of Cu, Au, Ag and Fe_3O_4, a database was created to create a suitable 2D model for these examined elements in the site of any of its parts (Figure 14 and Figure 15).

The main feeding channel for magnetite mineralization at the Popova Šapka ore body is on the north side of the Damjan mine (Figure 14b).

At the Popova Šapka Au, mineralization extends north of the Damian mine, which opens up the prospect of detailed geological exploration of the Damian mine area to discover Cu, Au, Ag and other porphyry mineralization types (Figure 15B).

Ag mineralization in dark gray fine-grained andesites is associated with quartz-galena-sphalerite ore it is one of the final mineral parageneses at the Borov Dol deposit.

Construction of Cu and Fe_3O_4 cross sections, of a NW-SE direction, in the best manner confirmed the findings that abundant Fe in porphyry magmas is leached at high to moderately high temperatures by fluids and forms hydrothermal magnetite (Seedorff and Einaudi, 2004) and that such an hydrothermal magnetite is an indicator for porphyry deposits (Sillitoe, 2010).

At Borov Dol we have situation where with the latest explorations (especially the latest mineralogical analysis; Serafimovski and Tasev, 2017) in SW marginal parts of the ore body was found hematite-magnetite mineralization in form of peripheral veinlets and lenses. They are in the group of the quartz-pyrite-specularite-magnetite-kaolinite paragenesis.

Also, we would like to point out that pattern of the Cu mineralization on a cross section constructed by MOVE with our data (Figure 13) and later constructed cross section and calculations of ore reserves by the Borov Dol DOO geological team and Moose Mountain Technical Services consulting team (Gray et al., 2017) showed strong similarities (see Figure 16).

In addition to the already shown model made in the software package MOVE and the compacted model made in MineSight (Gray et al., 2017), in addition we give the latest version of the 3D model of Borov Dol made with the professional package Vulcan, which is one of the leading packages used. in the modeling and calculation of ore reserves in the porphyry deposits in the world (Figures 17, 18 and 19).

The 3D model of the copper porphyry deposit of Borov Dol prepared in Vulcan software (see Figures 17, 18 and 19) gives us the following informations:

– The volume of the dark gray fine-grained andesite in Borov Dol is about 35.1×10^6 m^3.

– The volume of volcanic tuffs in the immediate vicinity of the Borov Dol mineralization is 25.3×10^6 m^3; the volume of volcanic tuffs in the immediate vicinity of the Popova Šapka mineralization is 6.7×10^6 m^3.

– The volume of the ore body in Borov Dol is 36.7×10^6 m^3, i.e. 95.3 Mt of ore at cut-off grade of 0.12% Cu, while the volume of the ore body in Popova Šapka is 1.1×10^6 m^3.

– Volcanic tuffs greatly complicate the morphology of the ore bodies, making it difficult for the ore body to model 3D. On the other hand, it imposes the need to make more dense the exploration network at 50 × 50 m in the entire Borov Dol deposit, and in some parts even more densely 50 × 25 m.

– From a genetic point of view, volcanic tuffs are a very important geological unit for the position of the ore bodies they are a trap (i.e. screen) for ore mineralization.

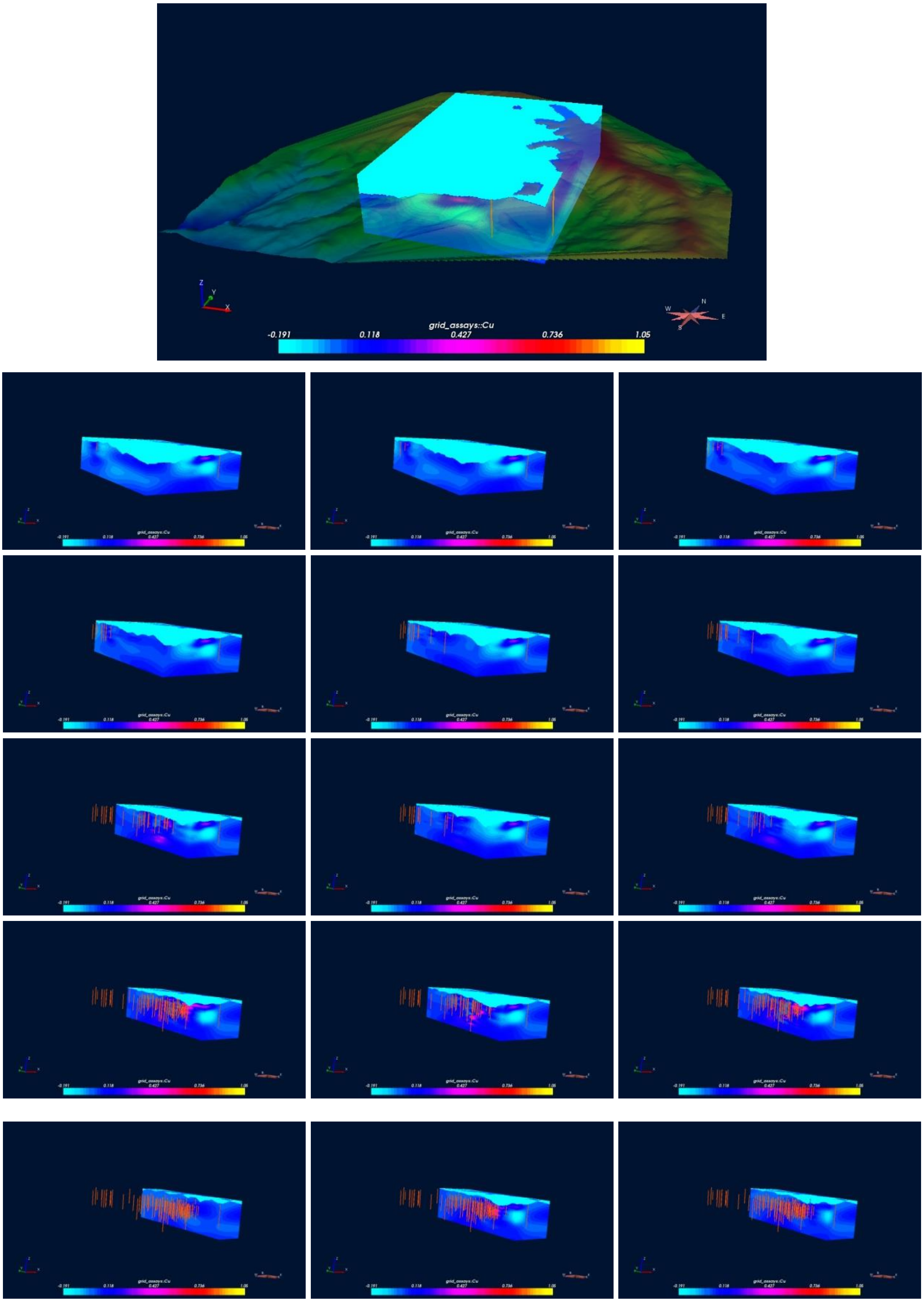


Fig. 13. Longitudinal cross-sections from NW to SE on the copper variation 3D net

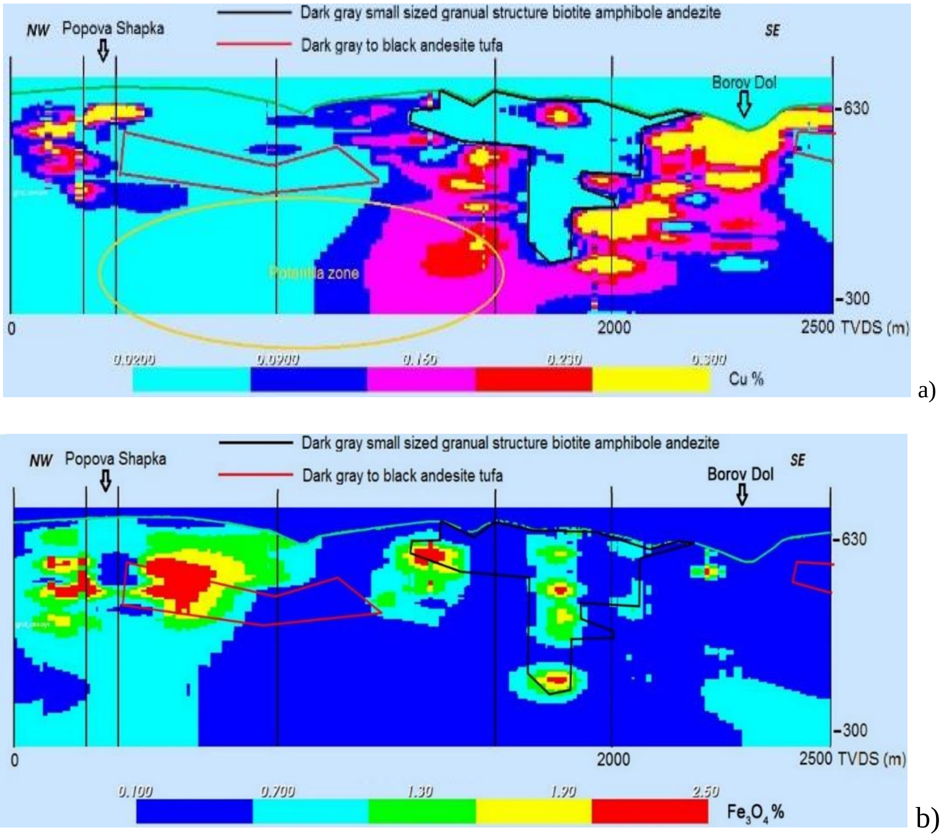


Fig. 14. Geological and geochemical cross-section, direction NW-SE, view from Borov Dol to Popova Šapka, Cu and Fe_2O_3 mineralization

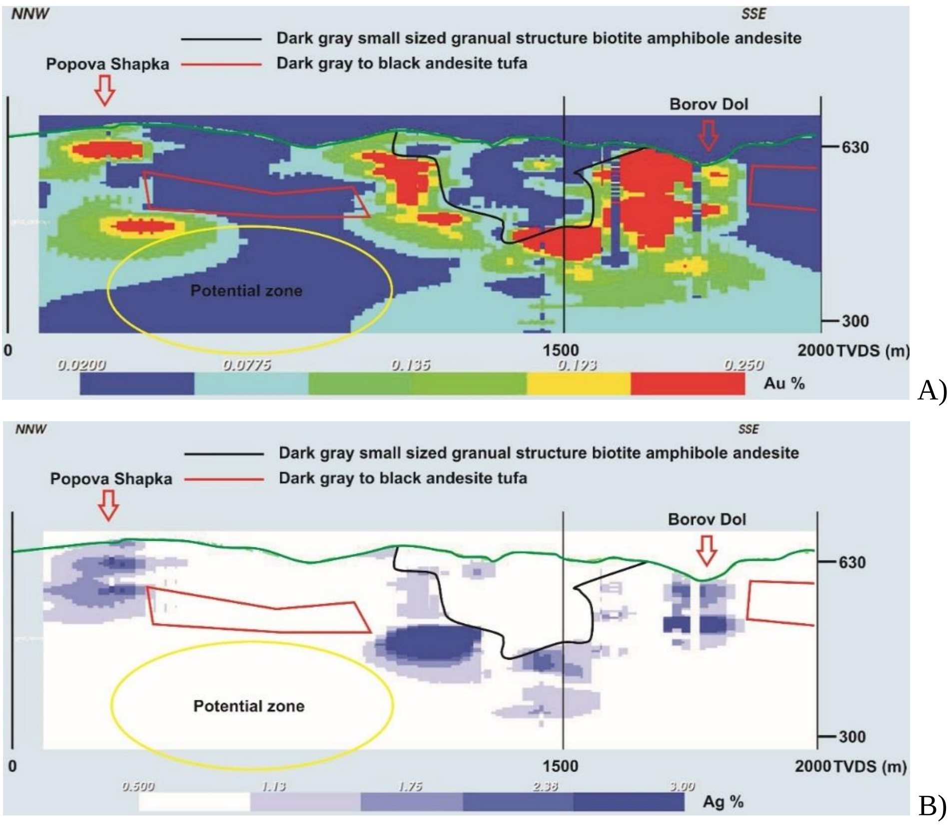


Fig. 15. Geological and geochemical cross-sections, direction NNW-SSE, view from Borov Dol to Popova Šapka, Cu, Au and Ag mineralization

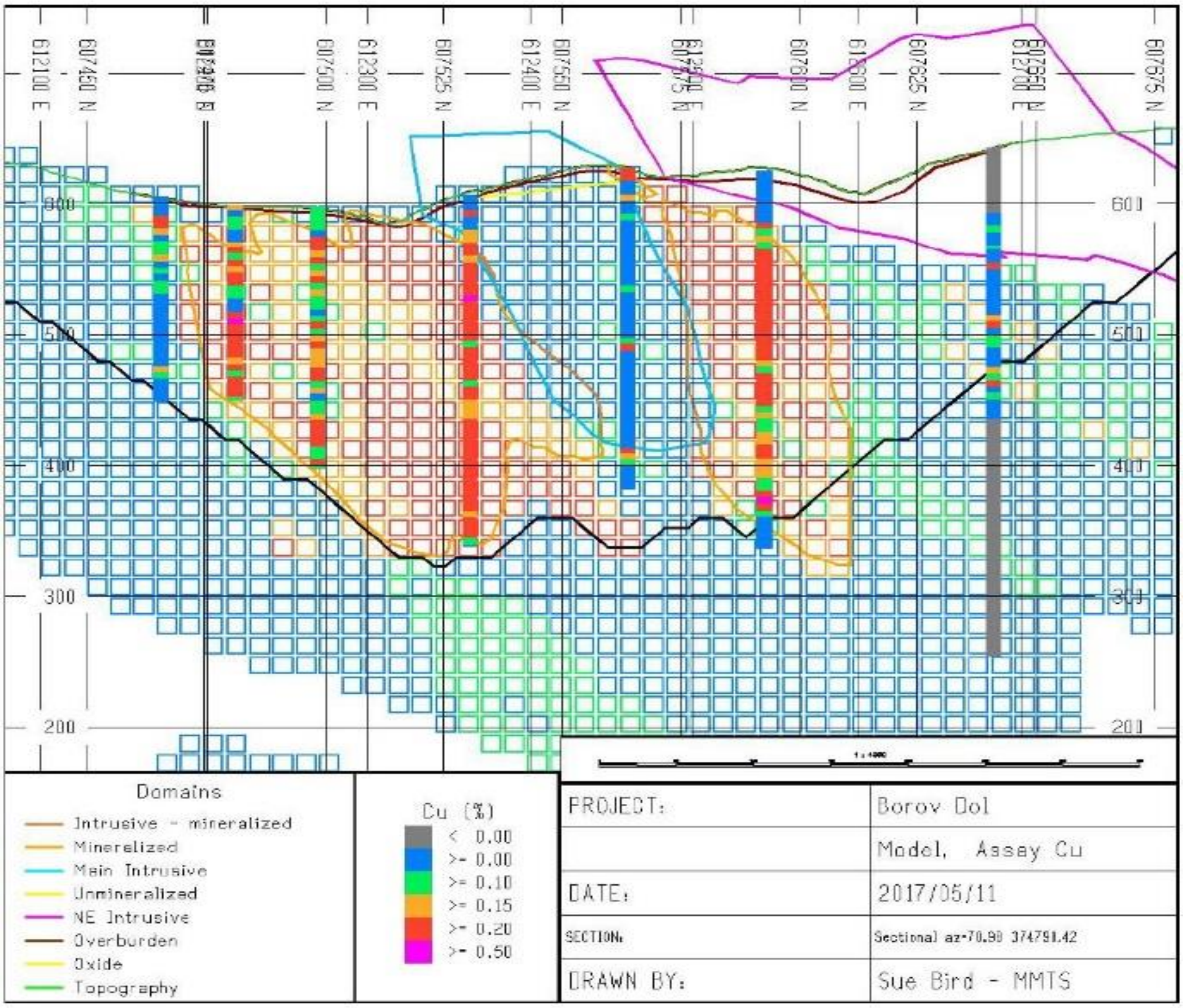


Fig. 16. Section illustrating domain boundaries, assay and domain model soding – Borov Dol (Gray et al., 2017)

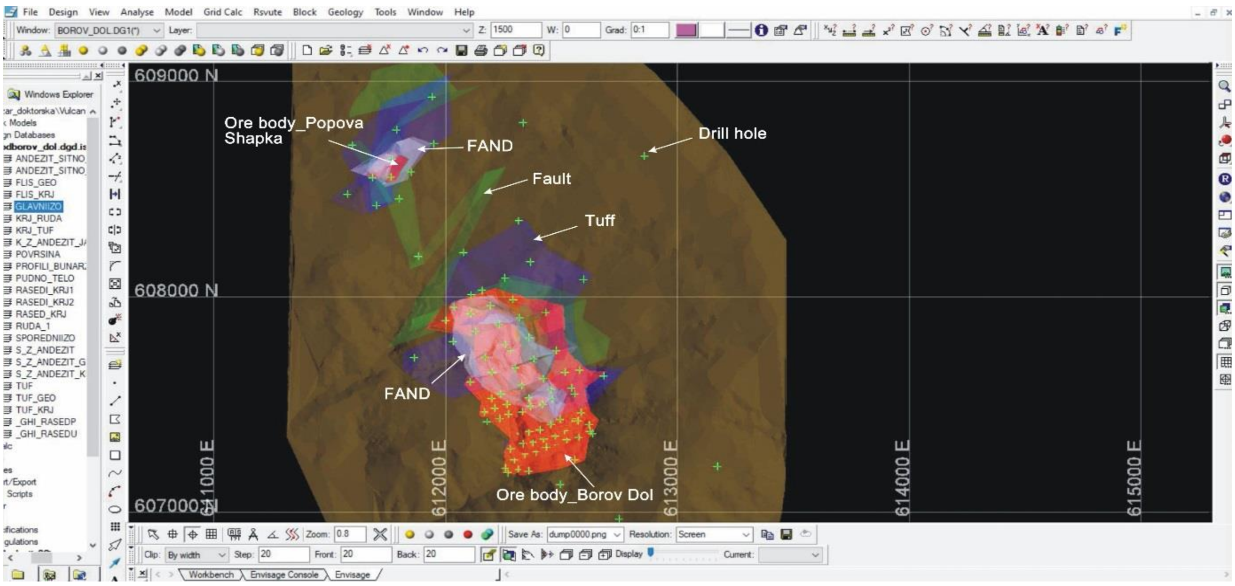


Fig. 17. 3D model of the Borov Dol and Popova Šapka deposits with shown topography, locations of exploration drill holes, contours of ore bodies and geological units (FAND – Dark-gray fine-grainned porphyry andesite)

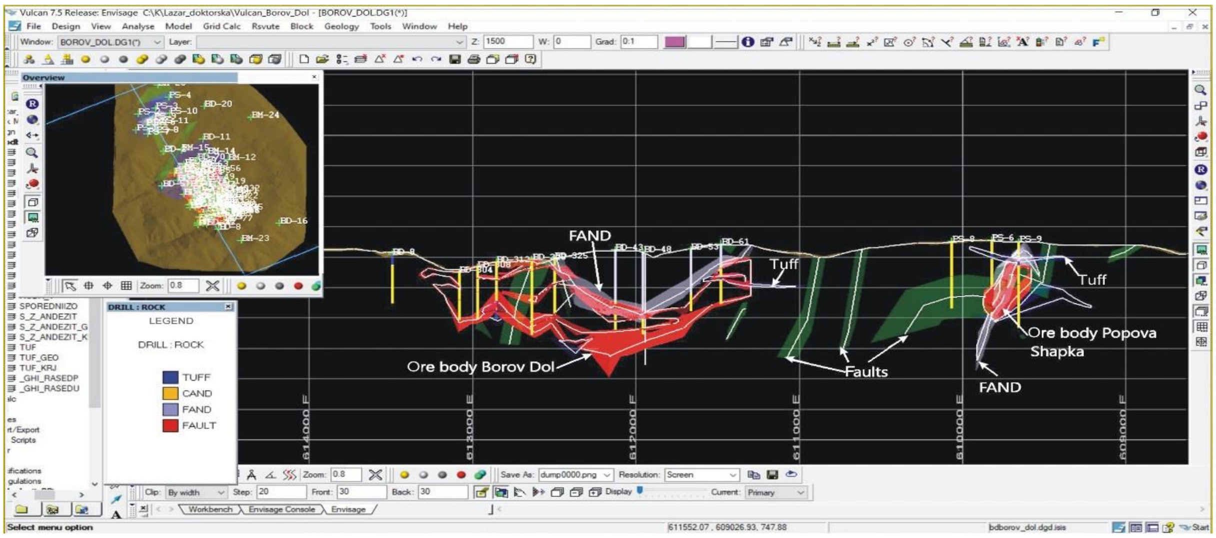
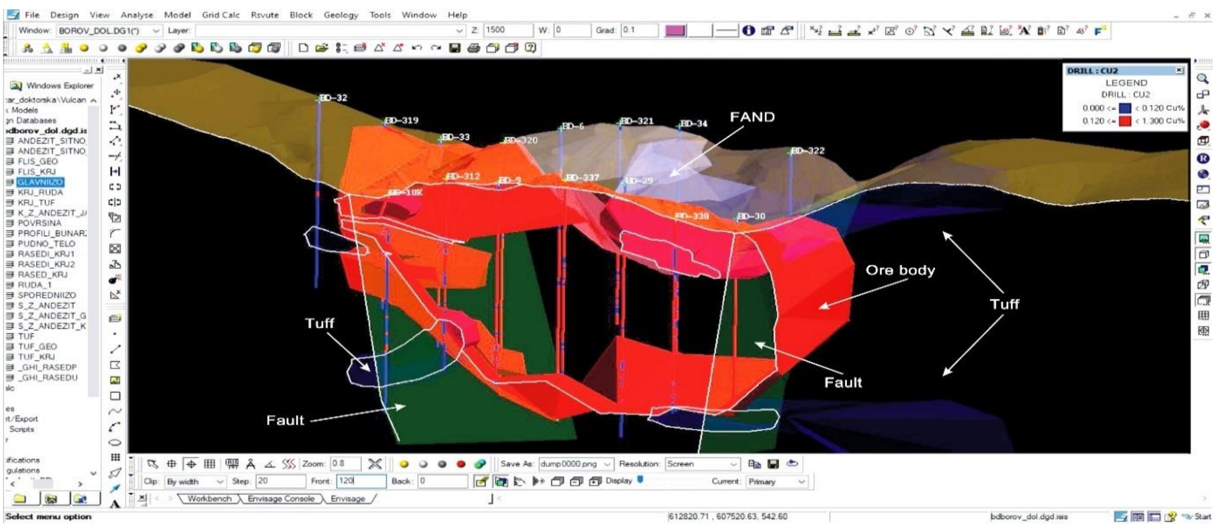
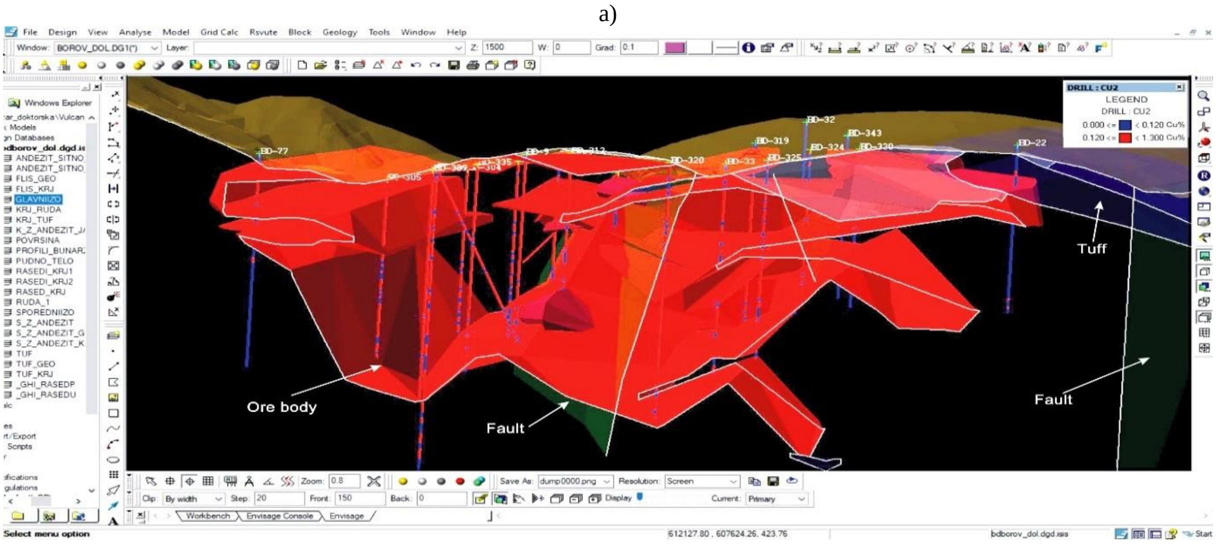


Fig. 18. 3D modeling of the longitudinal cross sections, through the eastern part of the Borov Dol deposit with view 30 m in the front and 30 m in the back from the cross-section line (CAND – gray-white coarse-grained andesite; FAND – Dark-gray fine-grainned porphyry andesite)



a)



b)

Fig. 19. Final 3D model of the Borov Dol ore deposit made in Vulcan by Maptek software. a) Southern part view; b) Northern part view

CONCLUSION

Latest complex, geological, geochemical and geophysical explorations defined interesting copper mineralization at the Borov Dol deposit followed by significant presence of silver, zinc, lead and some other occasional metals. Direct implications of copper geochemical anomalies, structural features and metallogenetic setting were confirmed by exploration drill holes, which confirmed that mainly copper mineralizations are related to faulting zones, stockworks and disseminations that directly reflect structural-tectonic setting of the area. The copper mineralization of polymetallic character with construction of the 3D model have revealed its isometric as well as spindle-shaped morphology, which swerves and distorts as depth increases. It has been proved with the 3D model spatial position of copper mineralization within the Borov Dol deposit between hypsometric levels 600 and 300 m.

Working with the data from the exploration drill holes made it possible to visualize a geochemical model that is difficult to create with the classic mapping of the core from the drill holes. Given that the mineralization in this ore deposit is closely related to the Tertiary volcanism and regional and local structures, this type of modeling has given other indicators such as the position of the feeding channels of mineralization and permeable environments associated with the deposition of porphyry mineralization. This paper, using 3D models, showed interesting concentrations of copper and gold in certain mineralized zones. In addition to the already established mineralizations, it also encourages the prospect of potential ore body in the insufficiently explored area of Popova Šapka and further north to the Damjan mine. This model is important for the Borov Dol deposit, and may be upgraded and reworked in the future. The benefits of creating a 3D model of mineralization in Borov Dol are greater than the investment. The required number of working hours is reduced, while the variety, accuracy and precision of the obtained results are increased.

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Р е з и м е

ТРОДИМЕНЗИЈАЛНО МОДЕЛИРАЊЕ НА БАКАРНОТО ПОРФИРСКО НАОЃАЛИШТЕ БОРОВ ДОЛ, РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

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Клучни зборови: наоѓалиште Боров Дол; порфирска минерализација; 3D модел: геохемиско моделирање; софтверски пакети

Најновите истражувања на бакарното порфирско наоѓалиште Боров Дол дадоа значаен придонес за разбирање на геолошкиот склоп на наоѓалиштето и утврдување на рудните тела. Во областа на наоѓалишето Боров Дол се извршени значајни геолошки истраги, а во текот на 2019 година е започнато со површинска експлотација. Заедно со обемните геохемиски и геофизички истраги, на предметното наоѓалиште е имплементирана програма за дупчење која даде пристојни истражувачки резултати. За овој 3D-модел беа искористени сите 100 дупнатини изведени во периодот од 1966 до 2013 година. Дупнатините се со вкупна должина од 23 435 m. Четири професионални софтверски пакети беа користени при подготовката и изработката на 3D моделите во наоѓалиштето Боров Дол. Преку Surfer беа изработени модели на површинските ореоли на расејување на бакар, злато, олово и цинк, кои заеднички ги дефинираат просторот на можниот доводен канал на бакарната минерализација и придружните метали. Најдетално 3D-моделот на наоѓалиштето Боров Дол беше комплетиран со професионалниот софтверски пакет MOVE со кој се добиени површински визуализации и варијанти на 3D-моделот кон длабочина. Компаративност беше направена со софтверскиот пакет MineSight, кој воедно ги вклучи и компарациите на геохемиските податоци. Потврда на 3D-моделирањето се доби при користење на професионалниот пакет Vulcan кој даде морфолошки облик на комплетното рудно тело во 3D-визуализација и поглед на рудното тело до ниво од 300 m.