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Original scientific paper

GEOCHEMICAL STUDY AND 3D MODELLING OF THE KAZAN DOL COPPER DEPOSIT, REPUBLIC OF MACEDONIA

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A b s t r a c t: The latest explorations and study of the Kazan Dol locality displayed interesting lithogeochemistry and soil geochemistry results. Very indicative were copper contents of up to 9942 ppm Cu, zinc up to 1235 ppm Zn, lead up to 5501 ppm Pb, molybdenum up to 24 ppm Mo, etc. These anomalous zones were direct product of copper vein mineralizations in oxidation zones, which have been confirmed with later exploration drill holes. In some individual samples, from trenches and drill holes, copper content reached up to 4% Cu while the more common content is around 0.4% Cu. More than 27 drill holes were chosen for the construction of the 3D model of the Kazan Dol mineralized area, Republic of Macedonia. With use of the professional software ArcGIS was prepared 3D model of the deposit, which reflects the mineralization between level 340 and 180. This particular model should improve our understanding of the copper bearing mineralizations in this area.

Key words: 3D model; Kazan Dol deposit; copper vein type; soil geochemistry

INTRODUCTION

The Kazan Dol deposit has been located in the southeastern Macedonia, approximately 4 km southern of the city of Valandovo and in the close vicinity of the Kazan Dol village as well as close to the border of Greece. Spatialy belongs to the southern slopes of the Plaush Mountain while in the geotectonic view it is located in the Vardar zone. The 2008 exploration program by PDX and EurOmax resulted in the delineation of a near surface shallow dipping copper oxide zone, 25 to 100 metres thick, over a length of approximately five kilometres with widths up to and in excess of 200 metres. Initial drilling encountered 47 metres grading 0.59% copper and surface trenching encountered 210 metres at 0.4% copper, 175 metres at 0.44% copper as well as 175 metres at 0.39% copper. At Kazan Dol North trenching and drilling has identified an oxide copper zone which extends over an 800 metre by 400 metre area. This copper mineralization has defined a sub horizontal body of about 50 metres thick of oxide copper mineralization. Kazan Dol South has now been identified and it is the extension of the Kazan Dol North mineralization (Carter, 2009). It has been mapped over more than 3 kilometres with the highest copper grades seen in outcrops on the property. Mineralization occurs within and above a shallowly dipping thrust which has now been defined over a strike approaching 5 kilometres (Kazan Dol North and Kazan Dol South appear to be one zone).

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, are a critical time- and money-saving methods. The model is built by mapping geochemical variations in Target 3D for ArcGIS system, and using this as a basis for modelling of certain copper ore body. A better understanding of the geometry and intensity in 3D will aid renowned deep exploration for hypogene mineralization and may potentially lead to new discoveries.

METHODOLOGY

Soil sampling was conducted at Kazan Dol area over an area of 3–5 km^2. A total of 167 samples were taken on 100 metre spaced lines and at 100 metre intervals. At Kazan Dol during 2004 and

2009, 58 lines were surveyed and analyzed for 15 elements using a hand held NITON XRF scanner. For increased precision Niton analysis was not undertaken in-situ but takes either a –80 mesh soil sample in the field or a larger sample which is dried at Euromax's warehouse as conditions dictate. This resulted in significant increase assay precision and is strongly recommended for all such surveys involving handheld XRF devices. Maps of the geochemical anomalies were plotted for the most important elements. All of the samples were located using GPS, and these coordinates and elevations were recorded.

For the construction of the Kazan Dol deposit 3D model was used Target 3D, which was developed for the Target for ArcGIS system. This particular system enables to display drillhole, surface and other data types in an interactive three-dimensional environment. The *Target 3D Viewer* 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.

Grids created in "sectional" views (e.g. from Target or Interactiv IP applications) can be displayed directly into the 3D view, in their correct orientation, using Geosoft's "on-the-fly" technology. Other grids and images (including bitmaps and jpegs) can be opened and easily located in any specified orthogonal plane. 3D "Voxel grids" can also be displayed in a 3D drillhole map and modified using the Target 3D Tool. 3D Voxels can be created using the Voxels/Grid Voxel menu item, on the Target 3D Toolbar.

GEOLOGICAL FEATURES OF THE DEPOSIT

The wider area of the Kazan Dol is built mainly by metamorphic rocks of Precambrian (finegrained biotite gneiss, muscovite-biotite gneiss and muscovite gneiss) and Lower Paleozoic age (sandstones and marbl breccia), as well as Mesozoic products represented by so-called Furka granites, quartz and/or quartzless porphyries, serpentinites, diabase, gabbro etc. Cenozoic has been represented by Tertiary and Quaternary products.

The geological setting in the closest vicinity of the Kazan Dol deposit has been built by Precambrian metamorphic rocks, yellow and compact porphyroblast gniess in westernmost parts of the terrain as well as two-mica cordierite gneiss present along the Jurt-Deresi, Armut-Tepesi, Kazan Dol village and Bogdanci direction. Paleozoic products are represented by grey-greenish sericite-chlorite schist in southernmost parts of the area. 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 (Figure 1).

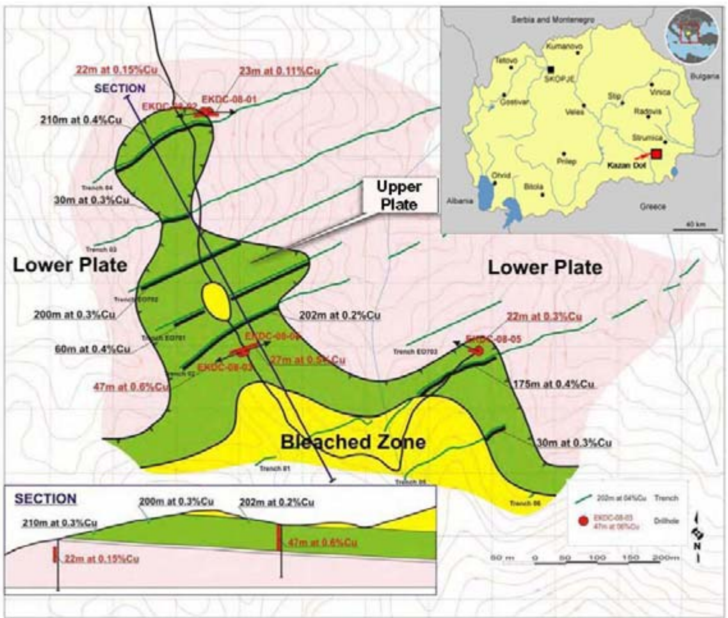


Fig. 1. Geological map and cross section (inset) of the Kazan Dol deposit (Carter, 2009)

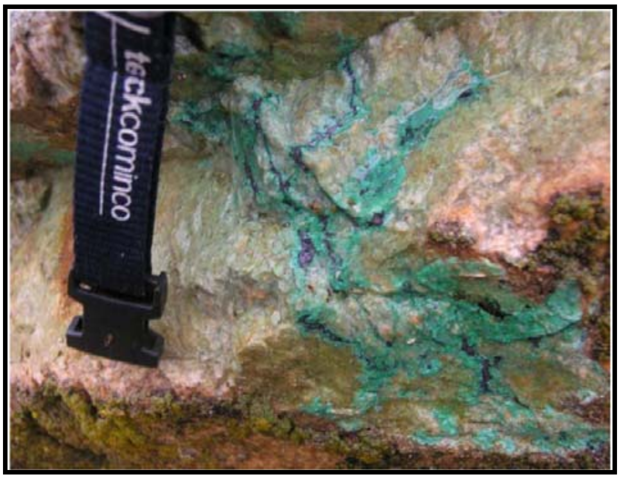
These granites have determined absolute age of 155±5 m.y. by Rb/Sr method, (Šoptrajanova, 1967) and 156±6 m.y. (Borsi et al., 1966). For this Jurassic granitoids were related interesting mineralizations of Cu, Fe, Zn of skarn type and especially Cu-vein type of the Kazan Dol type (Ivanov, 1966).

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. Keratophyre occur as vein intrusions in diabase. Their thickness reach up to 1 m. That are hard, fine-grained rocks with grey-yellowish to yellow-pinkish color and massive structure.

Former information, although very obscure, indicated that at the Kazan Dol locality were determined copper mineralizations in the oxidation zones (Ivanovski, 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 impregnated mineralizations along the crushing zones intercalated with quartz veins (Serafimovski et al., 1997).

The latest findings (Carter, 2009; Alexandrov and Bombol, 2011) point out that the copper mineralization at the Kazan Dol is hosted within and above an apparently regional extensive thrust in close proximity to keratophyre and quartz-keratophyre dykes (Figure 1). 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. At Kazan Dol North copper mineralization has been mapped at surface and in trenches over an area of 800 by 400 metres while at Kazan Dol South a narrower zone up to 150 metres wide has been mapped over more than 3,000 metres. 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 (Figure 2).



a)

b)

Fig. 2. Illustration of characteristic mineral association in the Kazan Dol deposit:
a) malachite (*green*) and cuprite (*blue*),
b) malachite (*green*) and tenorite (*purple*)

Azurite, native copper, covellite, chrysocolla and brochantite have been reported during mapping. Limonite and manganese minerals are widespread in the area of the Kazan Dol mineralized area. It is suggested that the thrust was both the focus of intrusion of the keratophyre and quartz-keratophyre dykes and copper rich hydrothermal fluids which deposited primary copper minerals both within the thrust and in the immediate hanging wall schists. The strong brittle deformation within the Vardar zone created the secondary porosity which has allowed the deep oxidation of the primary mineralization to form the extensive secondary copper deposits.

GEOCHEMICAL FEATURES

Geochemical sampling at the Kazan Dol area was conducted on primary (rock chip-lithogeochemistry) dissemination halos as well as on secondary (soil sampling) halos. The results from the lithogeochemical study displayed high anomalous values for the majority of studied 105 samples of over than a 1000 ppm Cu, while only small number of samples have shown extremely anomalous concentrations of more than 10 000 ppm Cu. That fact encouraged execution of soil sampling programme on a grid 100 × 100 m and a total of 167 soil samples were taken. This sampling represented the background of our studies within this paper. Material for soil samples was taken from depth of 20–30 cm (sub-surface part), so-called B-horizon, and weighted 2–3 kg each. Samples were dried at room temperature, sieving through sieves while samples for chemical analysis (150 g) and duplicates (150 g) were sieved through sieves of –80 mesh, however the pulverization process was performed in chemical laboratory. Results from chemical analyses have shown anomalous concentrations of several elements, the most important being Cu, Mo, As, Ag, Pb, Zn, Bi, Co, Ni, Ba etc. Special attentions deserves copper and zinc anomalies, which geochemical maps we display here (Figures 3 and 4). Here we would like to stress the major features the most important elements and their associations in 167 samples from the Kazan Dol mineralized area.

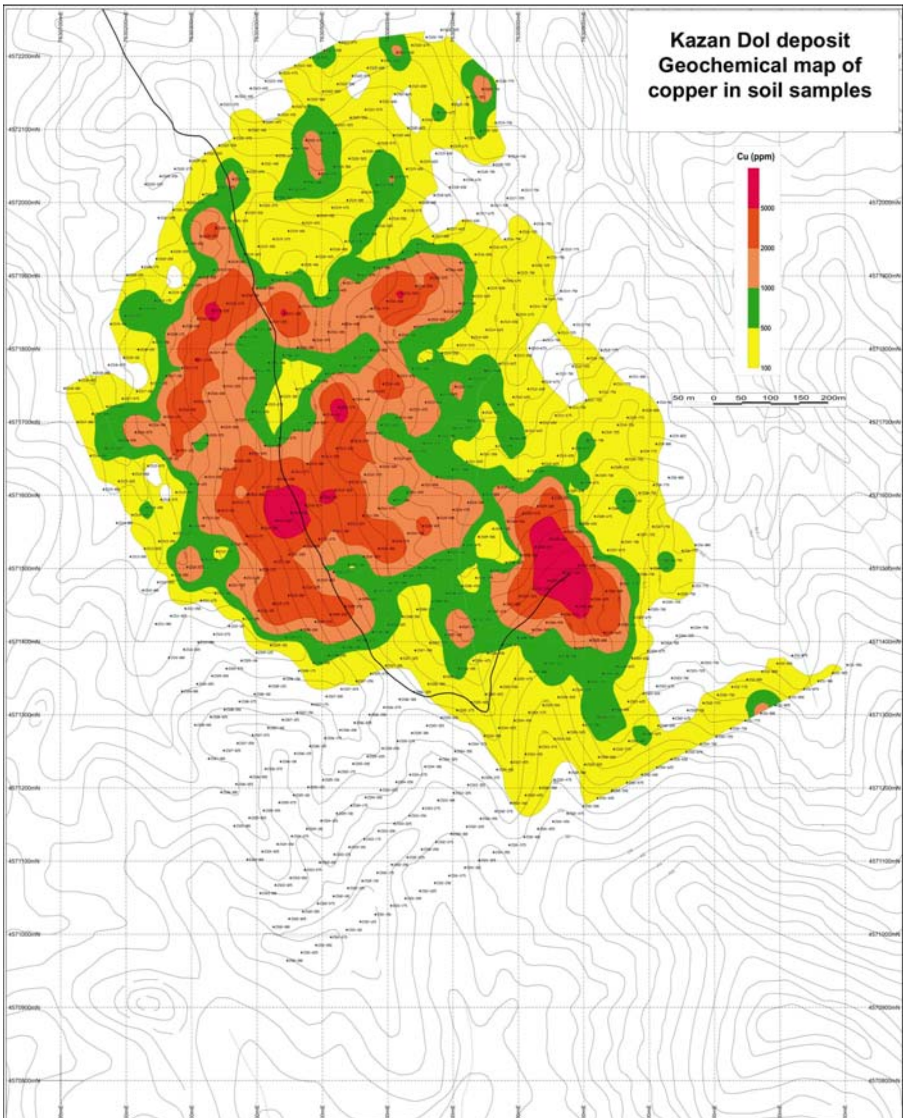


Fig. 3. Copper geochemical anomalies in soil at the Kazan Dol area

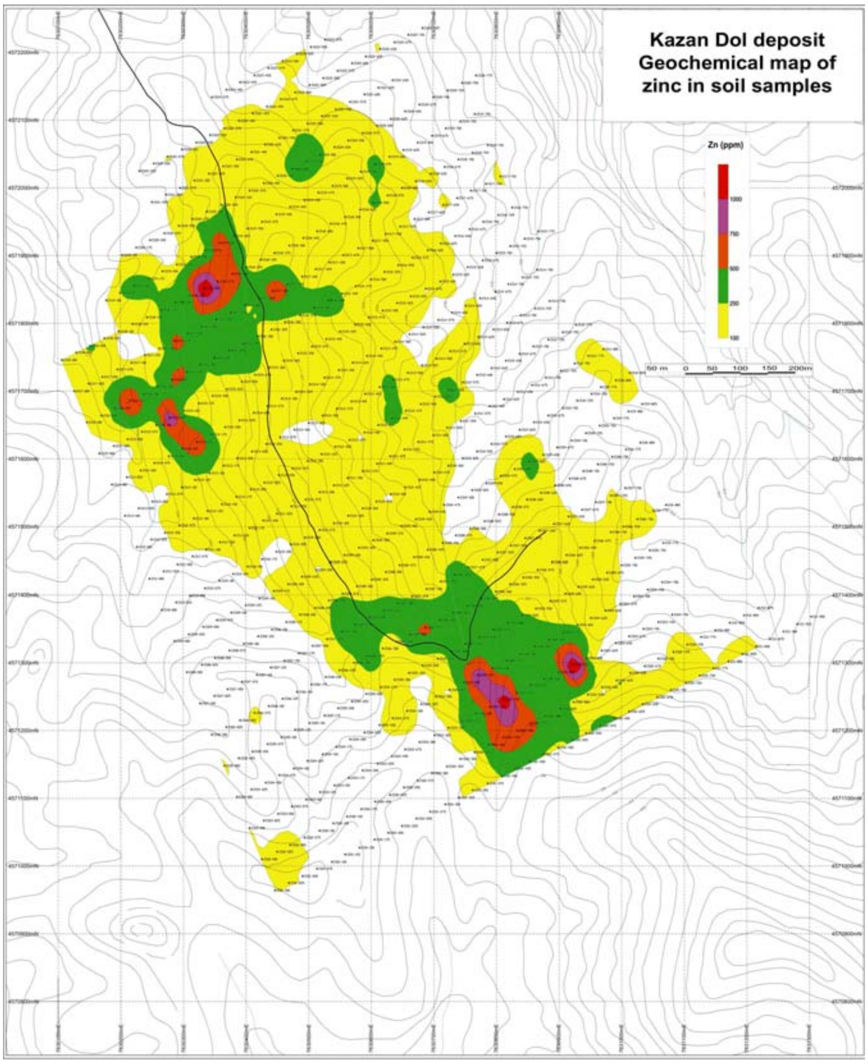


Fig. 4. Zinc geochemical anomalies in soil at the Kazan Dol area

Copper concentrations were in the range 24–9942 ppm in sample ZS-12-250 (Figure 3). In 64 samples copper concentrations ranged 24–100 ppm Cu and that are not anomalous values, in 62 samples concentrations were 101–500 ppm Cu and that are low anomalous values, in 18 samples were detected values of 501–1000 ppm Cu and that are highly anomalous values while in 23 samples concentrations higher than 1000 (reaching 9942 ppm Cu in sample ZC-12-250) which are contents representative for copper ore in deposits with well-developed oxidation zones.

Molybdenum concentrations were mainly < 3 ppm Mo (164 samples), which are not anomalous values however while only in three samples (17 ppm ZS-12-250, 18 ppm ZS-8-50 and 24 ppm ZS-17-250) they are low anomalous.

Arsenic concentrations were mainly < 3 ppm As (130 samples) while in the rest of 37 samples concentations of this particular element were in the range 3–56 ppm As. All of these are very low and does not represent any geochemical interest.

Antimony concentrations mainly were < 5 ppm Sb (126 samples) while in the rest of 41 samples they it ranged 5–13 ppm Sb (the highest one being recorded in ZS-19-700). Antimony concentrations, similar to those of As, are not of special geochemical interest because their low values.

Silver concentrations in 158 samples were < 1 ppm Ag while in 9 samples they were in the range of 1–5 ppm Ag (the highest in ZS-6-150). Although concentrations of 1–5 ppm Ag are low anomalous in geochemical aspect they are still important as an indicative ones.

Lead concentrations were in the range of 11–5501 ppm Pb (the highest one being recorded in ZS-18-250). In 145 samples lead concentrations were in the range 11–100 ppm Pb and they are not anomalous at all, in 19 samples concentrations ranged 100–1000 ppm Pb and being low anomalous while only in 3 samples concentrations were higher than a 1000 ppm Pb (1094 ZS-16-150, 3083 ppm ZS-12-550 and 5501 ppm ZS-18-250), which are highly anomalous concentrations and very important geochemical indicator.

Zinc concentrations were in the range 23–1235 ppm Zn. Zinc concentrations in 59 samples ranged 23–100 ppm Zn and that were not anomalous values at all. In 107 samples zinc concentrations were in the range 100–1000 ppm Zn, which qualifies them as low anomalous and only in one sample (ZS-18-25) was detected concentration of 1235 ppm Zn that is highly anomalous (Figure 4).

Cobalt concentrations ranged 4–35 ppm (the highest one being recorded in sample ZS-18-050). In 52 samples cobalt concentrations were 4–10 ppm Co and those are not anomalous at all, while in 115 samples cobalst concentrations were in the range 11–35 ppm Co, which classified them as low anomalous values.

Nickel concentrations were in the range 3–55 ppm Ni (the highest one recorded in sample ZS-19-200), that means that nickel concentrations were not anomalous and thus not being geochemically interesting.

Barium concentrations were in the range 26–930 ppm Ba (the highest one being recorded in sample ZS-6-250). In 123 samples barium ranged 16–100 ppm Ba and they are not geochemically anomalous, while in 44 concentrations ranged 101 –930 ppm Ba being low anomalous.

Gallium in soil samples ranged 3–59 ppm Ga (the highest value being recorded at ZS-22-55) and the majority of them are anomalous.

As it may be seen from the interpretation on the map (Figure 3) copper anomalous values occupied an area larger than 3 km^2 and practically indicated the contour of later defined copper mineralizations. Copper anomalous values were followed by interesting anomalies of zinc, cobalt, nickel and gallium, which are not directly related, but however they represent close geochemical association as a group that originates from the ultramafite-ophiolite Jurassic complexes, in these areas transformed by later hydrothermal solutions that produced vein mineralizations in the Kazan Dol deposit. During the post-magmatic migration of geochemical elements was formed group of so-called crust elements such are lead, barium, bismuth, arsenic and antimony, which basic relations should be looked no further than crystalline schist and cataclized granite where circulated hydrothermal fluids.

3D MODELLING, RESULTS AND DISCUSSION

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 with use of professional computer software package Target 3D for ArcGIS. The drill holes were selected on positive vs. negative basis and were taken only those that positively contribute to the copper body contouring.

Using the Target 3D Tools enables us to interactively control the transparency of individual items, enabling data to be displayed with a cumulative (light-table) effect. Data such as Maplnfo tables and 2D DXF files can be imported directly into the 3D environment and drawn on any surface displayed in the current 3D view.

The Target system automatically detects the type of data that is being imported, including: drillhole (collar) locations with their unique Hole ID, Easting (X), Northing (Y), Elevation (Relative Level) and Total Depth (EOH) where the X, Y and Depth must all be in the same units. The Azimuth and Dip are also included in the collar file.

Geochemical assay data are typically acquired by obtaining core or rotary drill samples over specific depth ranges (from–to ranges) and sending samples to an assay laboratory. Numerical results are typically returned from the laboratory in electronic format and can be imported quickly into the system. Before import, we must make sure that our data files contain the following information – HOLE ID, FROM, TO and a series of ASSAY results. On the DH-Data menu, click Import and then select Text File. Drill Hole meny>Ascii Import Wizard>Browse>KZM_ASSAYS (Figure 5).

To begin the work with Target 3D we need to select the area that we would like to concentrate on from the Hole Selection Tool . This will enable us to display only the area of the project that is of interest to us. Target Drillhole> Hole Selection Tool dialog appears > Select using polygon tool to define a polygon around the holes required (Figure 6).

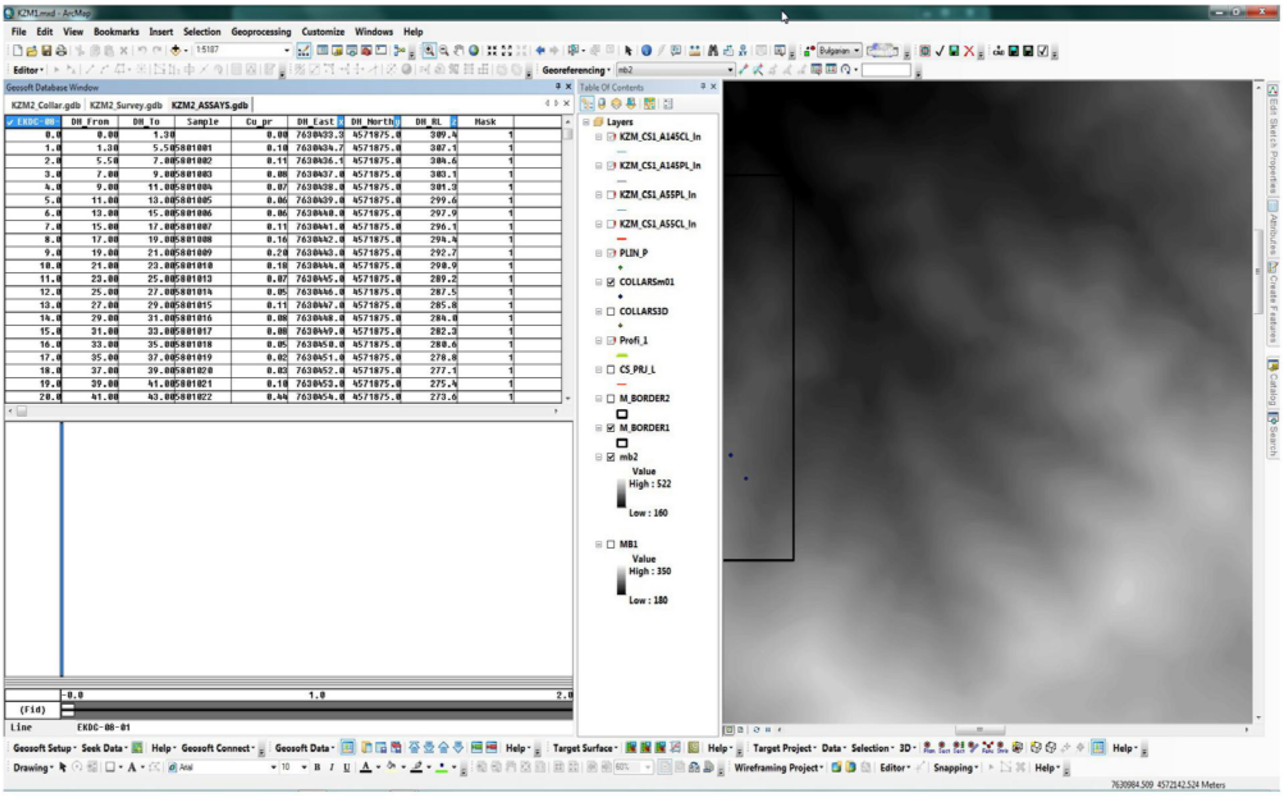


Fig. 5. Drill hole data input into the Target 3D explorer

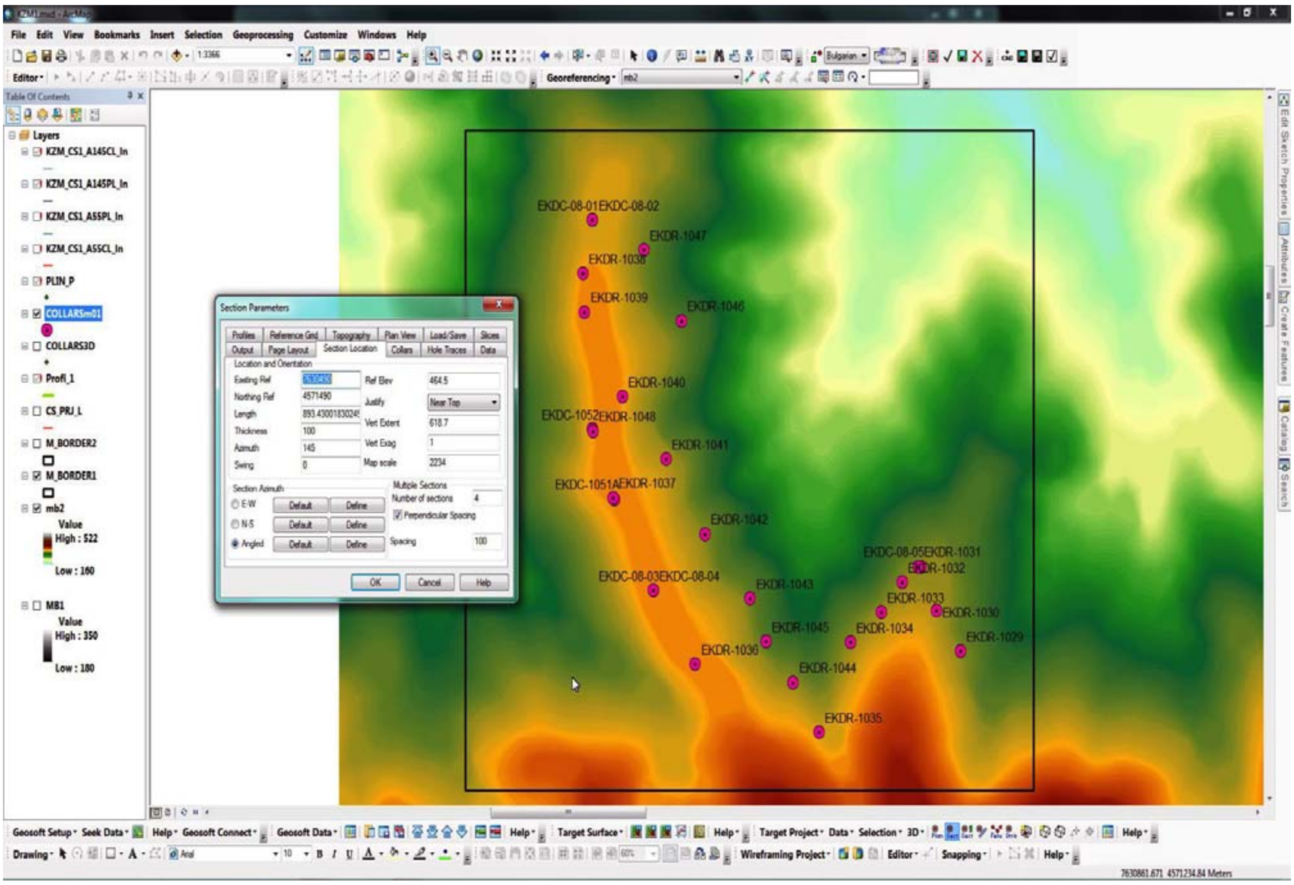


Fig. 6. Drill hole selection for the 3D model

Also, we have to create a Target 3D Voxel Grid, which selects the holes we would like included in our Target 3D Voxel grid, using one of the Hole Selection Tool options. From the Target Drillhole toolbar, select Voxels>3D Gridding from Current Geosoft Database>3D Gridding dialog is displayed. To Create a Target 3D Map on the Target Drillhole toolbar>Generate 3D Drillhole Plot b>3D Map Parameters dialog, Page Layout tab, on the 3D Map Parameters dialog, is displayed by default. The following page layout parameters can be controlled from this tab. Background Colour of the 3D view Axis Colour and Font used for annotating the 3D view. Plot Legend (right side of map), including company Logo (image file) and specifying the map Titles. Select the Hole Traces tab>. This tab dialog includes the following drillhole trace parameters: > Colour of the Hole Trace Hole Labels including location, annotations, text size, colour and font. Depth Ticks (annotations etc.) along the hole trace Select the Data tab. The Data and Plot types are selected from drop-down lists, just as you would select data for your Plans or Sections to be plotted. The three available gridding methods are Minimum curvature, Kriging and a TIN based technique. To define the Gridded data parameters> Define button. Plot topography box to enable the topography parameters using the Browse buttons, locate the Topography grid M01GGRD file and the Overlay grid on topography file (Figure 7). 3D block models were used to produce vertical and horizontal slices at required depth levels. "Chair clipping" view was created to visualize 3D distribution within the investigated area. Threshold attribute values have been used to create the isosurfaces or threshold block models. An element grade distribution block model was generated via ordinary kriging method. Ordinary kriging was developed by Matheron (1971) in the early sixties and plays a special role because it is compatible with a stationary model, only involves a variogram and it is the form of kriging used most in resource exploration (Chile's and Delfiner, 1999). Ordinary kriging estimates based on moving average of the variable of the interest satisfying different dispersion forms of data (Goovaerts, 1997). Although mineralization estimation of domains was modeled based only on metal grade, with definition of cut-off grade and top cut grade values for the Kazan Dol deposit, the ore body was 3D modelled, with respect to intersecting fault zones, the overall geological setting and the compositional distribution of metal grades (Figure 7).

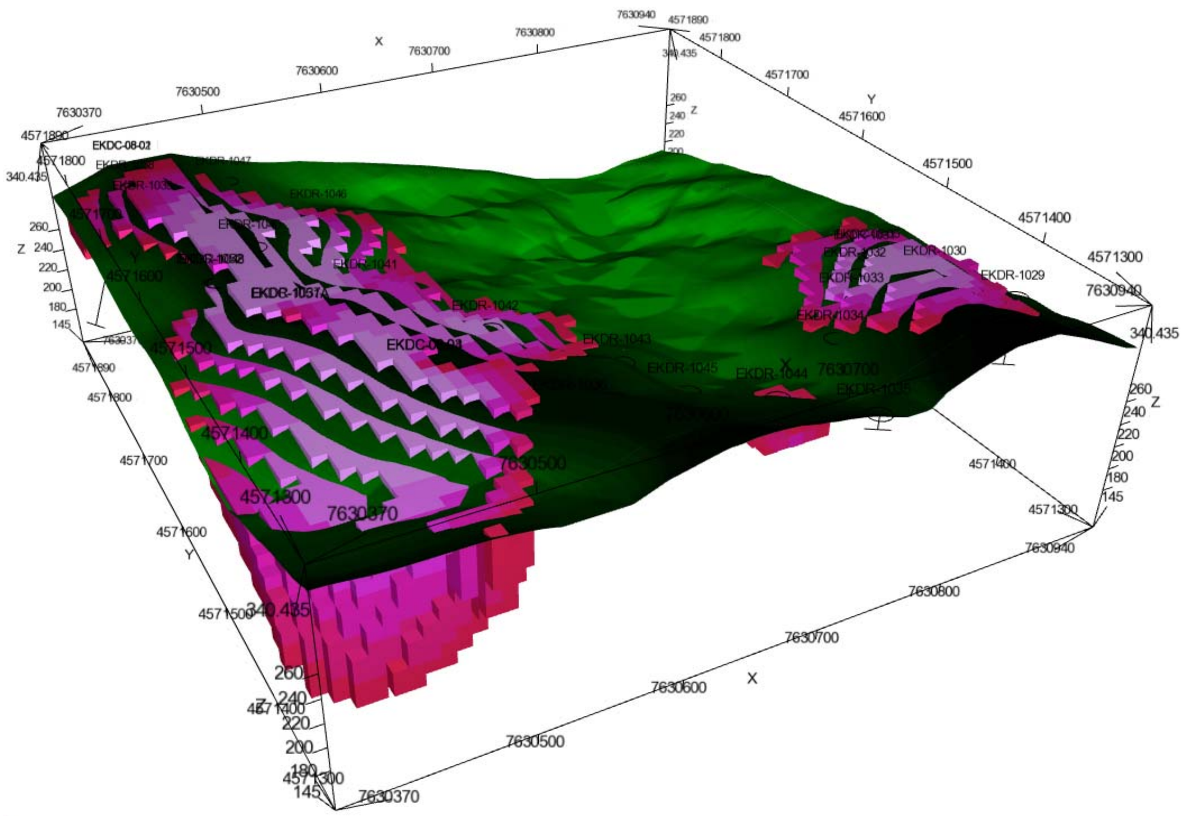


Fig. 7. 3D model of the Kazan Dol deposit with terrain surface displayed

When plotted in 3D, the majority of the geochemical groupings have a strong association with the lithologies of the deposit sequence (Figure 8). 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 (Figure 8), but further investigations are required to determine their metallogenetic relationship to any of the mineralization processes.

Must to mention is that from the actual 3D model of the Kazan Dol deposit we can see that it strongly reflects the pattern already seen at the copper geochemical map in the Figure 3. The present exploration at the Kazan Dol continues in the southern parts of the deposit where exist positive copper and zinc anomalies as a direct reflection of oxidized copper veins enclosed in crushing zones. Exploration continues with shallow exploration drill holes (in average up to 100 m).

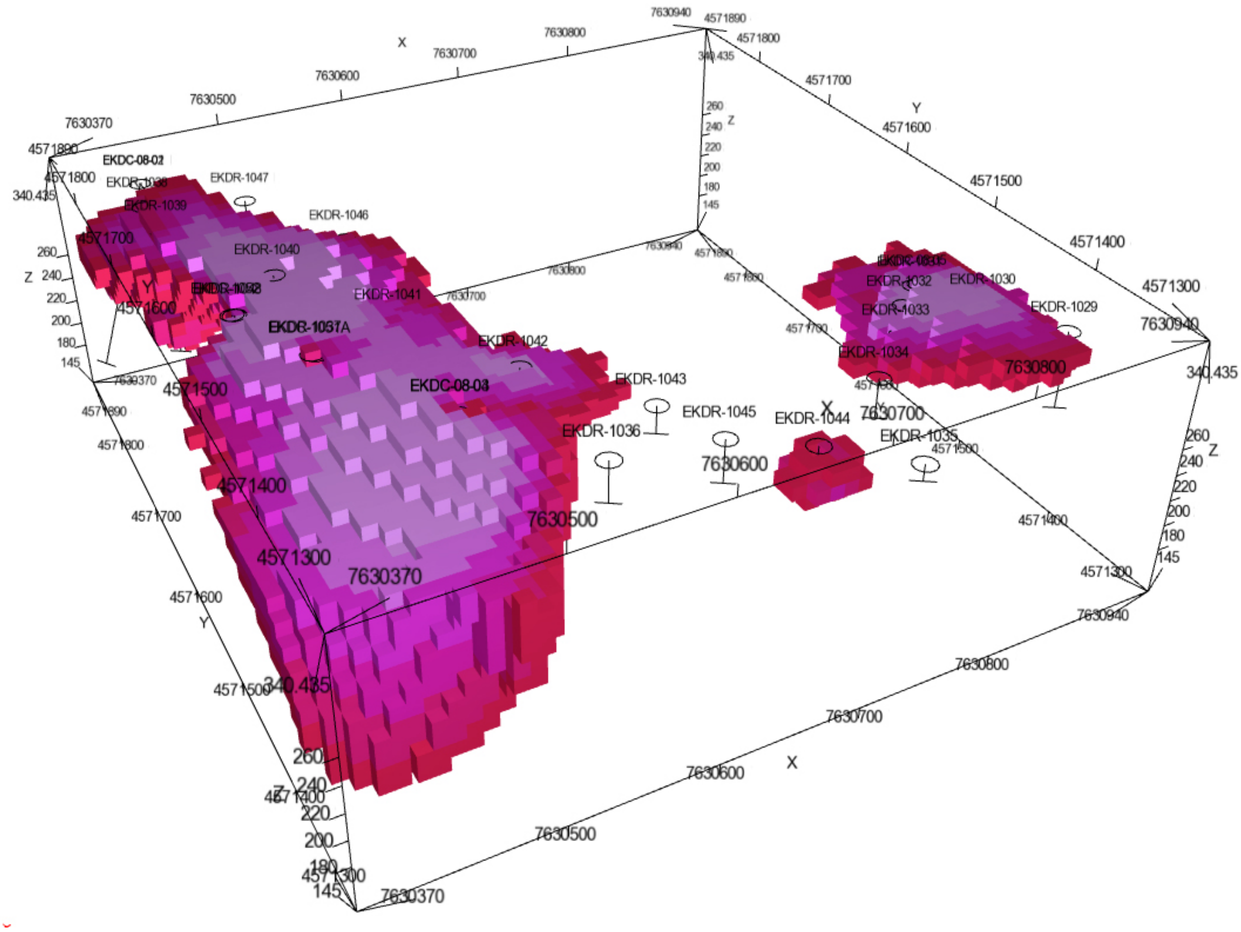


Fig. 8. 3D model of the Kazan Dol deposit

CONCLUSION

Recently conducted geochemical explorations defined interesting anomalous zones of copper in the Kazan Dol locality followed by anomalies of zinc, lead and occasionally nickel and cobalt. Direct implications of copper geochemical anomalies, confirmed by exploration drill holes, are copper mineralizations related to crushing zones and quartz vein structures, which at particular oxidized positions contain copper. Increased zinc, nickel and cadmium concentrations resulted by leaching of ophiolite complexes, while increased lead and bismuth concentrations are direct reflection of adjacent Jurassic granitoids.

Copper oxide mineralization is defined in surface/sub-surface parts, not more than 70-80 m at depth. There dominated oxide copper minerals cuprite, tenorite, as well as minerals such are covellite (products in zone of secondary enrichment) and relics of chalkopyrite, pyrite and tetrahedrite. This ore mineralization was determined within vein type structures, zones of crushing and representative quartz-tetrahedrite veins localized in the Jurassic granitoids.

Displayed 3D model clearly defines the spatial position of copper mineralization in the Kazan Dol deposit between hypsometric levels 340 and 180 m.

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Р е з и м е

ГЕОХЕМИСКО ПРОУЧУВАЊЕ И 3D МОДЕЛИРАЊЕ НА НАОЃАЛИШТЕТО НА БАКАР КАЗАН ДОЛ, РЕПУБЛИКА МАКЕДОНИЈА

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Клучни зборови: 3D модел; наоѓалиште Казан Дол; бакарен жичен тип; геохемија на почви

Најновите истражувања и проучувања на локалноста Казан Дол покажаа интересни литогеохемиски и металометриски резултати. Многу индикативна беше содржината на бакарот до 9942 ppm Cu, цинк до 1235 ppm Zn, олово до 5501 ppm Pb, молибден до 24 ppm Mo и др. Овие аномални зони се директен продукт на бакарните жични минерализации во оксидните зони, кои биле потврдени со подоцнежните истражни дупчотини. Во некои поединечни примероци, од раскопините и дупчотините, содржината на бакарот достигнала до 4% Cu, додека повообичаено е содржината да се движи околу 0.4% Cu. За конструкција на 3D модел на минерализираната област Казан Дол беа избрани повеќе од 27 дупчотини. Со употреба на професионалниот софтвер ArcGIS беше изработен 3D модел на наоѓалиштето, кој ги рефлектира минерализациите помеѓу нивоата 340 и 180. Токму овој модел би требало да го подобри нашето познавање на бакроносната минерализација во оваа област.