3D IMPLICIT MODELLING OF ALTERATION ROCKS AND LITHOLOGICAL UNITS IN THE MILIN KAMAK AU-AG DEPOSIT: RESULTS AND APPLICATIONS

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ABSTRACT. The present study is focused on the interpretation of outcomes received from implicit 3D geological modelling. The analysis and technical possibilities allow the extraction and interpretation of the main geological characteristics and spatial distributions of the alteration rocks and lithological units. Advanced radial basic function (RBF) interpolation technique have been used in order to define the geological boundaries and provide more accurate representation of 3D isosurfaces. The implicit model is generated by non-numerical lithological data. According to the results, the distribution of dykes and later sericitic and argillic alterations emphasize strictly their common alignment in the space. This show also that dykes and alteration rocks share common hosting structures and are formed by the prior magmatic activity and subsequent ore hydrothermal fluids. The structural analysis based on lineament extraction and 3D building of fault surfaces shows three systems with NW-SE, NE-SW and E-W directions. The faults with NE-SW and E-W direction can be marked out as main hosting structures for magmatic products and hydrothermal fluids. The integration of structural data and body geometry analysis allows better understanding and more accurate definition of the local structural trend and spatial distribution of the alteration rocks and dykes.

Key words: 3D implicit modelling, faults, body geometry, Western Srednogorie

3D ИМПЛИЦИТНО МОДЕЛИРАНЕ НА ХИДРОТЕРМАЛНИ ПРОМЕНИ И ЛИТОЛОЖКИ ТЕЛА В ЗЛАТНО-СРЕБЪРНО НАХОДИЩЕ „МИЛИН КАМЪК": ИЗВОДИ И ПРИЛОЖЕНИЯ

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РЕЗЮМЕ. Предмет на настоящето изследване са резултатите получени от 3D имплицитно моделиране. Анализът и техническите възможности в триизмерното моделиране позволяват извличане и интерпретация на пространствената ориентация и геоложките особености на главните литоложки единици и хидротермални промени, разкриващи се около златно-сребърно находище „Милин камък", Брезник. С цел по-точно дефиниране на геоложките граници и предоставяне на по-акуратен облик на генерираните 3D изоповърхнини е използвана RBF (Radial Basic Function) интерполационна техника. За имплицитното моделиране са използвани символни (номинални) литоложки данни. Според резултатите, пространственото разпределение на дайките и по-късните хидротермални промени, като серицитизация и аргилизация, са с подчертано съвместно разпределение в пространството. Това показва, че дайките и хидротермалните промени споделят общи рудовместващи структури и са формирани при придвижването на по-ранни магматични продукти и по-късни хидротермални флуиди. Структурният анализ, базиран на линеаментното картиране и построяване на 3D повърхнини на разломните нарушения, показва три разломни системи с посоки СЗ-ЮЕ, СЕ-ЮЗ и И-З. Разломните нарушения със СЕ-ЮЗ и И-З посоки се маркират като главни вместващи структури за магматичните продукти и рудоносните хидротермални разтвори. Интеграцията на структурните данни и анализът на пространствената ориентация на геоложките тела позволяват по-добро разбиране и по-акуратно дефиниране на локалния структурен тренд и пространственото разпределение на дайките и хидротермалните промени.

Ключови думи: 3D имплицитно моделиране, разломи, Западно Средногорие

Introduction

This work is address on the results received from 3D geological implicit modelling applied on the main lithological units and rock alterations exposed around the Milin Kamak Au-Ag deposit. The study area is situated in the Western Bulgaria, southern from the town of Breznik. The 3D modelling is considered as precise and valuable instrument, basis for geological exploration projects and mining works. The received results serve as a suitable footing for taking geological decisions and groundwork for future prospecting and investigation works. The purpose and requirements of three-dimensional modelling can broadly differ depending mainly on the geological settings, structures framework, spatial resolution and available geological information and knowledge. To be accepted geological modelling as accurate, every volume models that consist of lithological units or alteration rocks should be combined with 3D surface data involving faults, brittle or ductile zones and topography as boundary surface. At present, the geological modelling can integrate two-dimensional (2D) GIS data, various statistical methods, database and 3D software technologies with powerful three-dimensional visualization modules (Wang and Huang, 2012). 3D modelling can be applied to build three-dimensional structural objects involving various structures, stratum, rock body, ore body, geochemical anomaly and geophysical anomaly (Kaufmann and Martin, 2008; Xiao, 2009; Wang and Huang, 2012; Pears and Chalke, 2016). Therefore, three-dimensional modelling can be used as a powerful instrument to explain the genesis of constructed geological objects through spatial analysis (Pouliot et al., 2008; Wang and Huang, 2012).

The main goals in this study are: 1) Construction of 3D implicit model based on the spatial relationship of regional lithological units; 2) Building of 3D implicit model based on the spatial distribution of the local alteration rocks and dykes in the Milin Kamak deposit; 3) Incorporating three-dimensional model with a distribution of 3D fault surfaces, extracted from lineament structures; 4) Integration of structural data and body geometry analysis for accurate definition of a local structural trend.

Geological settings

In regional tectonic position aspect, the study area belongs to the Apuseni-Banat-Timok-Srednogorie magmatic and metallogenic belt, which is considered as formed in an extensional geodynamic regime and widespread development of Late Cretaceous magmatic activities with numerous submarine volcanoes (Popov et al., 2002). During the Laramian phase of Alpine orogeny, the area in Western Srednogorie was an arena for widespread thrust-nappe deformations. This regional tectonic event has a significant effect, which leads to the formation of the slight South-West vergent Krasava syncline (Marinova et al., 2010) (Fig.1).

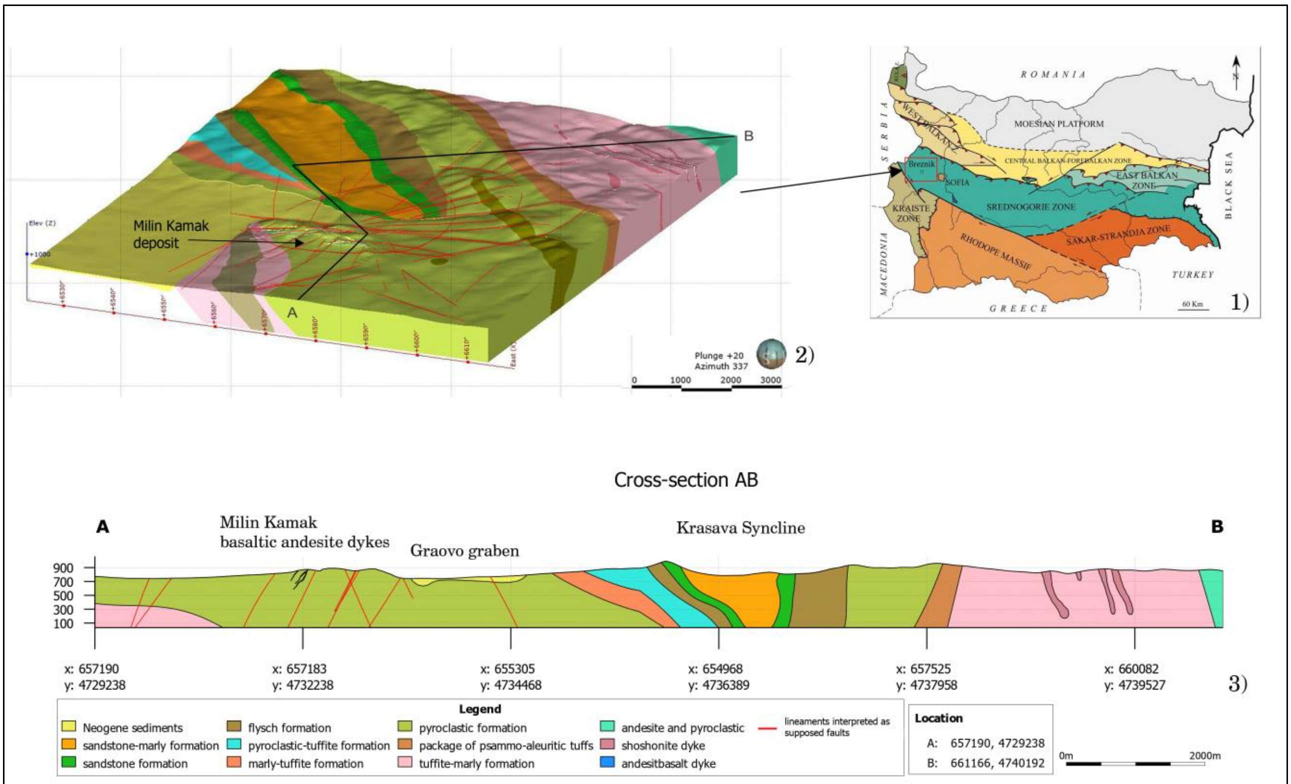

Fig. 1. Three-dimensional lithological model of regional rock units around Milin Kamak deposit
1) simplified tectonic map of Bulgaria (Ivanov J, 1998); 2) three-dimensional model of regional rock units around Milin Kamak deposit with attached lineament structures (based on Marinova et al., 2010); 3) cross-section on A-B line based on the 3D lithological model

The Laramian orogenic processes lead to the formation of regional structures with directions of 140-160°. During the Illyrian phase of Alpine orogeny, the second tectonic event arose and leads to the formation of strike-slip and normal faults with N-S directions. Prior to the main phases of Alpine orogeny, the region around Breznik was the arena of intensive volcanic activities

These events lead to the formation of numerous radial and concentric structures that contribute to the development of a ring morphostructure. This structure is considered as a reflection of Late Cretaceous Breznik paleo-volcano (Marinov et al., 2019). The volcanic activities begin through the Coniacian and ends during the Campanian (Bairactarov, 1989). The volcanics are represent by high potassium calc-alkaline, calc-alkaline and shoshonitic series rocks (Dabovski, 2009; Velev, 2012). The rock formations around Milin Kamak deposit and the town of Breznik contain an up to 1400 m thick succession of shoshonites, potassium trachybasalts, various ash, psephitic, lapilli and bomb tuffs. This succession belongs mainly to Breznik paleo-volcano (Marinov and Bairactarov, 1980). Further, away to the North-West direction the later volcanic succession of Vidrica paleo-volcano overlay the volcanic deposit of Breznik paleo-volcano (Dabovski, 2009). In a local tectonic setting, the rocks belong to the Srednogorie Tectonic Zone that is divided into two main units in the study area – Sofia and Lubash units (Marinova et al., 2010). The Lubash Unit is considered as a Late Alpine monoclinal structure (Zagorchev, 1995). The main feature of the unit is the distinct absence of volcanic products and the corresponding ore deposits associated with Upper Cretaceous magmatic activities. The Sofia Unit involves itself numerous and various volcanic products. This magmatic presence is regarded as the main important feature to distinguishing both zones.

The basement rocks in the work area consist of various Paleozoic, Mesozoic and Lower Cretaceous sedimentary successions outcropped mainly in the southern parts. The Paleozoic and Mesozoic rocks are developed mainly in the Lubash unit. In the Sofia unit, the Mesozoic sedimentary rocks are outcropped only as tectonically confined blocks in northeastern parts. This succession includes mainly different terrigenous-carbonate rocks. Various Upper Cretaceous sedimentary formations overlies the volcanic products of Breznik and Vidrica paleo-volcanoes and consequently builds up the core of Krasava syncline.

The rocks that form the cover belong to Neogene sediments. They are considered as sedimentary fill in graben systems and partially covers the southwestern part of the studied area. To the south-west, the Neogene succession fills the Graovo graben that is considered as the latest tectonic event aroused in the study area.

Data used

There are two main approaches in geological modelling – explicit (controlled by hand drawing) and implicit (automated). Three-dimensional implicit modelling has been applied for the extraction and interpretation of outcomes received by the spatial distribution of the lithological units and alteration rocks. The necessary technical background is provided by using Leapfrog GEO 5.0 (Seequent Limited), specialized software with powerful instruments for 3D implicit modelling. To ensure a more accurate representation of the 3D surfaces and geological boundaries an advanced radial basic function (RBF) interpolation techniques have been used. The concept of compiling the 3D models are different depending on different geology, spatial resolution, different data and access sources of data. The 2D surface data represent faults and geological boundaries. The volume data describe in 3D the lithological units and alteration rocks. Two 3D models of the studied area where prepared in this paper – one regional (in lower resolution and one local (around the Milin Kamak deposit, in higher resolution). The sources data for compiling the main regional lithological units were obtained from the geological map in scale 1:50000. The first stage of compiling the 3D models is drawing the polylines that follow strictly the geological boundaries of lithological units drawn on the geological map. The next step is to generate a 3D surface boundaries. The three-dimensional distribution and the slopes of these surfaces are based on structural elements taken from the geological map. Afterwards, with respect on previously created the 3D surface, the volume data are generated as wireframes. The modeling of these geological units was done in lower spatial resolution due to the limited data, large volume and the widespread distribution of the units.

The concept of compiling the local detail 3D model around Milin Kamak deposit is based on modelling of the lithological units and alteration rocks. The local model differs in methodology in comparison to the modeling of regional lithological units. The implicit modelling can use both types of data – numerical and non-numerical categorical data. In this work, the implicit modelling is generated by non-numerical data such as rock codes. Significant amount of data from various exploration works were used for the creation of the models. The geological information is obtained from surface mapping, trenches, drill holes and underground works. The data integration of more than 450 drills and 160 trenches have been used for three-dimensional modelling.

In order to generate a three-dimensional structural model, remote sensing method and surface mapping have been used to help the lineaments extraction (Marinov et al., 2019). In respect to this, it was possible to created 3D fault surfaces and to be integrated into the model of lithological units and alteration rocks.

Interpretation and Results

The results obtained from three-dimensional implicit modelling represent the spatial distributions of alteration rocks and lithological units exposed around Milin Kamak deposit located near the town of Breznik. This data allows a body geometry analysis of the main ore veins and therefore better understanding of the local structural trend. The traditional 3D modelling techniques use explicit modelling approach for wireframe models. This technique is available in many of the mining software. One of the gains of the explicit modelling are possibilities for hand (explicitly) drawn geological interpretations by polylines and can be useful instruments for simplified representation of geological units and wireframe building.

For the modelling of lithological units, ore body or other geological structures, the explicit modelling uses vertical cross-sections, elevation or inclined planes within a predefined corridor in the viewed space. Inside this space, 3D wireframes are generated manually by hand drawing in 2D sections that are manually linked through triangles (Vollgger et al., 2012). These manually linked sections lead to a design of wireframes with more straight-line nature that is unlikely to define accurate nature boundaries of the lithological units or structures (Fig. 2 e, f). The triangle intersections and open triangles are common problems in explicit 3D modelling and must be cleaned before further operation such as volume evaluation.

The implicit modelling is regarded as an alternative option for wireframes building. This modelling technique use data directly received from various exploration works like drillhs, trenches or point data derived from underground works without any manually linked polylines in the 2D section. From these measured numerical or non-numerical categorical data, computer algorithms calculate spatial interpolation between the samples and build mesh structures as 3D isosurfaces (Vollgger et al., 2012). As an automated operation the implicit modelling allows faster building of the wireframes and provides an accurate representation of the geological boundaries. This modelling is accurate, flexible and efficient compared to the explicit methodology (Knight et al., 2007; Silveira Braga et al., 2019). The 3D model is automatically updated every time when a new data is received. The results of three-dimensional implicit modelling application can be used surefire to comprehend the distribution of the alteration rocks and lithological units in the space according to regional and local structural patterns.

During the modelling process, stereo images obtained by ASTER optical instrument on TERRA satellite has been integrated into the 3D models to compute the structural trend surfaces. This information was subsequently combined with the data received from fieldworks. The lineament structures extracted in this way allowed to distinguish a distinct ring morphostructure located around the town of Breznik (Marinov et al., 2019; Popov, 2011). One distinctive feature relating to the movement of magmatic products and hydrothermal fluids are the presence of permeable settings. The early magmatic products are most often represent by layered intrusions concordant to the beds. They are formed before the most intensive activity of the Breznik paleo-volcano. Such layered sill bodies were localized SW and NE parts of the ring morphostructure. Numerous radial and concentric faults were formed in the latest stages of volcanio-tectonic evolution. The dykes in Milin Kamak deposit are associated with these later stress phases. These faults most likely served as channels and hosting structures for later ore-body fluids and dykes (Marinov et al., 2019). During the modelling process, the distribution of the argillic and sericitic alterationя and dykes show that there is strict common alignment in the space with EW and NE-SW direction (Fig. 2). This emphasizes that they share common hosting fault structures. The structural data obtained by the geological exploration in Milin Kamak deposit show three main fault systems with NW-SE, NE-SW and E-W direction, which defined local structural trend (Fig. 3).

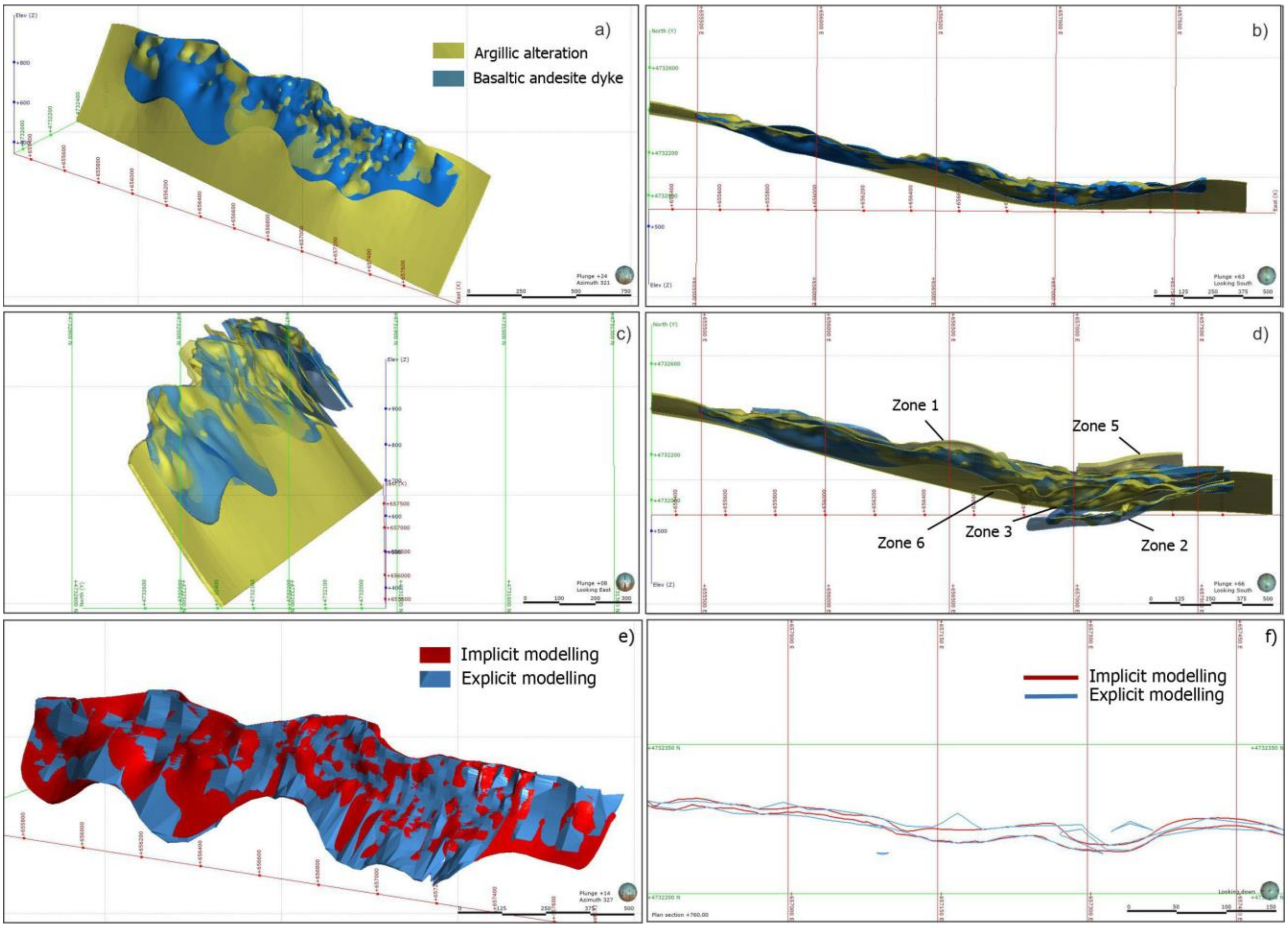

Fig. 2 Comparison of three-dimensional model of the spatial distribution of argillic alteration and basaltic andesite dykes and comparison between results of implicit and explicit modelling of the dyke

a) spatial distribution of argillic alteration around zone 1 and basaltic andesite dyke; b) in plan view; c) spatial distribution of argillic alteration around all zones and all basaltic andesite dykes; d) in plan view; e) comparison between implicit and explicit modelling of the basaltic andesite dyke; f) comparison in plan view with straight-line nature

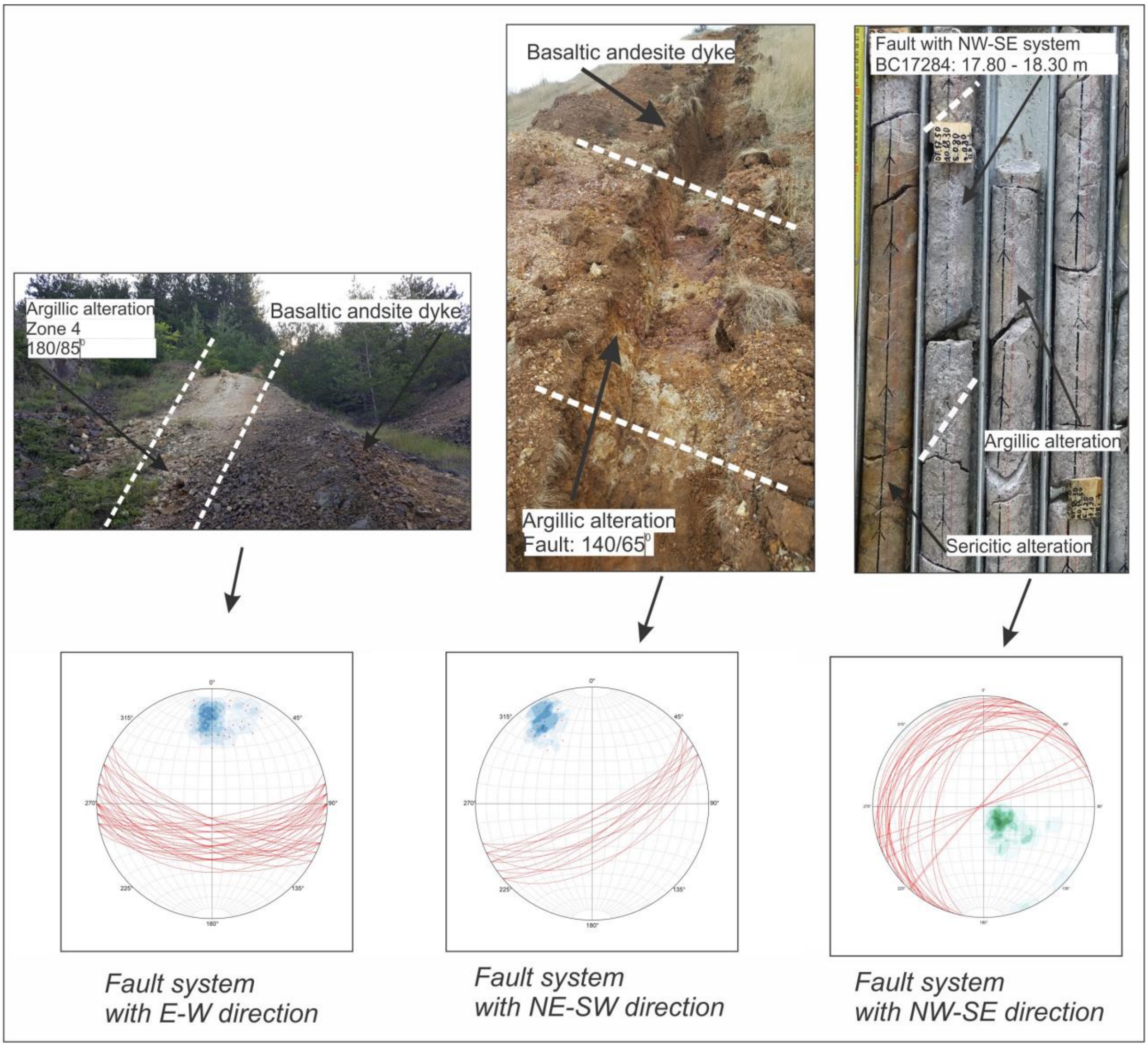

Fig. 3. Outcrops around the Milin Kamak deposit with argillic alteration and basaltic andesite dykes showing main structure systems

This trend fully coincides with the spatial distribution of lineaments defined by stereo-images. Geological structures observed in the well logs and point data obtained from underground works in Milin Kamak deposit allows to define more accurate the spatial position and dip of direction for the observed lineament structures observed on ASTER stereo images. The spatial position of the lineaments could be considered with higher confidence in the southern parts of the ring morphostructure. Whereas, due to the lack of outcrops and exploration works in the north part the 3D space orientation of the lineaments are indistinct and under discussion.

Conclusion

3D implicit modelling is used as automatic tool for building three-dimensional models for alteration rocks and main lithological unit exposes around Milin Kamak Au-Ag deposit. This automatic modelling is considered as a precise and useful instrument that allows the processing of huge amount of information in a short time. Respectively, the ability to build the model quickly allows more time to be engaged to further geological interpretation. Based on the methodology and results described in this study the following conclusion has been done:

1.) The completed 3D implicit model provides an accurate representation of 3D isosurfaces and precise construction of the geological boundary and spatial distribution of the alteration rocks and lithological units in the studied area.
2.) The results from the remote sensing methods allow to build the 3D fault surfaces based on lineament drawing. The three-dimensional fault surfaces show distinctive radial and concentric pattern that marks the volcanic cone.
3.) The local structural trend with fault systems with NW-SE, NE-SW and E-W direction defined by underground works in Milin Kamak deposit coincides with spatial position of the lineament structures in the southern part of the ring morphostructures.

4.) The spatial distribution of the dykes and later sericitic and argillic alterations emphasize strictly their common alignment in space.
5.) In the 3D geological model, the direction and dip of the dykes and alteration rocks show the same structural trend as the defined fault systems with NE-SW and E-W direction. This emphasizes that the faults with this trend serve as permeable and hosting structures for the ore-bearing fluids and dykes. The creation of these structures probably arises during the development of local stress during the final stages of the volcanic activity.

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