VOLCANIC RING MORPHOSTRUCTURES IN THE WESTERN SREDNOGORIE, BULGARIA

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ABSTRACT. The focus of this study is the interpretation of images obtained by the ASTER optical instrument on the TERRA satellite. Its data is processed and presented in stereoscopic 3D images. Anaglyphic glasses with red and cyan colour filters are used to obtain the realistic effect of the images. The structural analysis of the data shows two ring morphostructures with distinct pattern of radial and concentric lineaments forming a clear circular morphology with a diameter of up to 9 km, located around the town of Breznik and the Kliosura village in the Western Srednogorie, Bulgaria. The radial structures show clearer sharpness with respect to the drainage system and the relief, compared to the concentric structures and the radial pattern, is predominant. The ring morphostructures are formed among the volcanic rocks of the Breznik and Klisoura paleo-volcanoes, represented by lava flow, epiclastic and pyroclastic products. A characteristic feature is the distribution of the proximal faces, represented by lava flows, volcanic bomb, and lapilli tuff in the central parts of the morphological structure, which locate the Breznik paleo-volcano approximately around the centre of the ring morphostructure. It is assumed that the radial and concentric lineaments are probably relatively well preserved remains of a volcanic cone. The tectonic events, which occurred during and after the final stage of the most intense volcanic activity, led to the formation of radial and concentric faults. They probably serve as channels for the movement of the ore hydrothermal fluid and ore hosting structures for gold-silver Milin Kamak deposit and Klisoura ore occurrence.

Keywords: ring morphostructures, lineaments, volcanic cone, Western Srednogorie

ВУЛКАНСКИ КРЪГОВИ МОРФОСТРУКТУРИ В ЗАПАДНОТО СРЕДНОГОРИЕ, БЪЛГАРИЯ

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РЕЗЮМЕ. В настоящето изследване е извършен анализ на изображения, получени от оптичния инструмент ASTER на сателита TERRA. Данните от него са обработени и представени като стереоскопични 3D изображения. За получаване на реалистичен ефект от изображенията са използвани анаглифни очила, с червен и циан цветни филтри. Структурният анализ на данните показват две кръгови морфоструктури с отчетлив рисунък от радиални и концентрични линеаментни структури, оформящи ясно обособени кръгови морфоструктури с диаметър до 9 km, ситуирани около град Брезник и село Клисура в Западното Средногорие, България. Радиалните разломи показват по-ясно изразена отчетливост по отношение на дренажната система и релефа, в сравнение с концентричните структури, като радиалният рисунък е преобладаващ. Кръговите морфоструктури са оформени сред вулканските продукти на Брезнишкия и Клисурския палеовулкани, представени от лавови потоци, епикластични и пирокластични продукти. Характерна особеност е разпределението на проксималните окологърлови фациеси, представени от лавови потоци, бомбени и лапилови туфи в централните участъци на морфоструктурата, които ситуират Брезнишкия палеовулкан приблизително около центъра на морфоструктурата. Приема се, че радиалните и концентричните линеаменти вероятно представляват относително добре запазени останки от вулкански конус. Тектонските събития, възникнали по време и след заключителния стадий на най-интензивната вулканска дейност са довели до образуването на радиални и концентрични разломи, които вероятно са послужили като канали за придвижване на рудоносните хидротермални разтвори и рудовместващи структури за златно-сребърното находище "Милин камък" и рудопроявление Клисура.

Ключови думи: кръгови морфоструктури, линеаменти, вулкански конус, Западно Средногорие

Introduction

The ring morphostructures, subject of this study, are situated in Western Bulgaria near the town of Breznik. The structures have a diameter of up to 9 km and shape the positive part of Zavala and Viskyar Mountains, which are part of Sredna Gora Mountain Range. The ring morphostructures in the Srednogorie Tectonic Zone have been a subject of study in a number of publications (Baltakov, 1975; Popov, Spiridonov, 1990; Spiridonov, 1999; Jelev et al., 2003). Many of the structures are considered as a reflection of the Late Cretaceous volcano-plutonic activity in the Apuseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt (ABTS) (Popov et al., 2002). According to the definition of Spiridonov (1999), the ring morphostructures are structures, grouped in an arched or circular shape that may incorporate geological formations of the same and different ages. The typical ring magmatic structures in ABTS played a crucial role as ore-controlling structures and many of the ore deposits were associated with them (Spiridonov, 1999). According to Baltakov (1975), part of the morphostructures, situated in Panagurishte Ore Region are likely to represent concealed plutonic body or offshoots. They can be observed and traced on the surface through their structural configuration. A great part of the volcanic complexes in ABTS shows a distinct radial-concentric shape and Spiridonov (1999) considers them as composite local volcanic morphostructures, which built up the bigger morphostructures from the third order.

The main objectives of this study are: 1) interpretation of stereo image data, obtained from the ASTER optical instrument; 2) recognition of the lineament structures; 3) determining the morphological character of the ring structures; 4) interpretation of the genesis on the morphostructure.

Geological setting

In tectonic position, the area belongs to the Apuseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt. The zone is characterised by extensional geodynamical regime and development of Late Cretaceous magmatic activity with numerous submarine volcanoes (Popov et al., 2002). Volcanic activity began in Coniacian and ended during Campanian ages (Bairactarov, 1989). The formations of Breznik, Klisoura and Vidrica paleo-volcanoes are established around the ring morphostructures. They are associated with high potassium calc-alkaline, calc-alkaline and shoshonitic series (Dabovski, 2009; Velev, 2012). The Upper Cretaceous rocks around the town of Breznik contain a succession of various potassium trachybasalts, shoshonites, ash, psephitic, lapilli and bomb tuffs as pyroclastic and epiclastic products are predominance (Fig. 1) (Velev, 2012). They belong mainly to the Breznik paleo-volcano and they form up to 1400 m thick volcanic formations (Marinov, Bairactarov, 1980). Further to the North-West they are covered by the rocks of Vidrica paleo-volcano (Dabovski, 2009). In a regional tectonic situation, the rocks are part of the Srednogorie Tectonic Zone that is divided into two main units – Sofia and Lyubash (Marinova, 2010). The most characteristic feature of the Lyubash Unit is the distinct absence of volcanic products and respectively – the ore deposits, associated with Upper Cretaceous magmatic activity. The Lyubash Unit is considered as a Late Alpine monoclinal structure (Zagorchev, 1995). The magmatic presence is regarded as an important feature for distinguishing between both tectonic units and respectively the Sofia Unit is composed of various volcanic and sedimentary rocks. The boundary between them is the Pernik fault zone (Marinova, 2010).

The rocks that form the basement belong to various Paleozoic, Mesozoic and Lower Cretaceous sedimentary successions developed mainly in the southern part of the study area (Fig. 2).

The Paleozoic rocks are built mainly of Silurian argillites, Devonian flysch and Permian conglomerates, breccia and sandstones. The distribution of these rocks is immediately south of Breznik in the Lyubash Unit. The Mesozoic rocks consist of various terrigenous-carbonate sediments that build up the Lyubash Unit and part of Sofia Unit as tectonic confined blocks.

The rock that form the cover belong to Paleogene and Neogene sediments, considered as sedimentary fill in graben systems and partially cover the southern and southwestern edge of the studied area. The Pernik graben is situated to the South of the area and consists of Oligocene and Miocene continental clastic molasse association. To the south-west, the Neogene succession fills the Graovo graben partly covering the south edge of Sofia Unit.

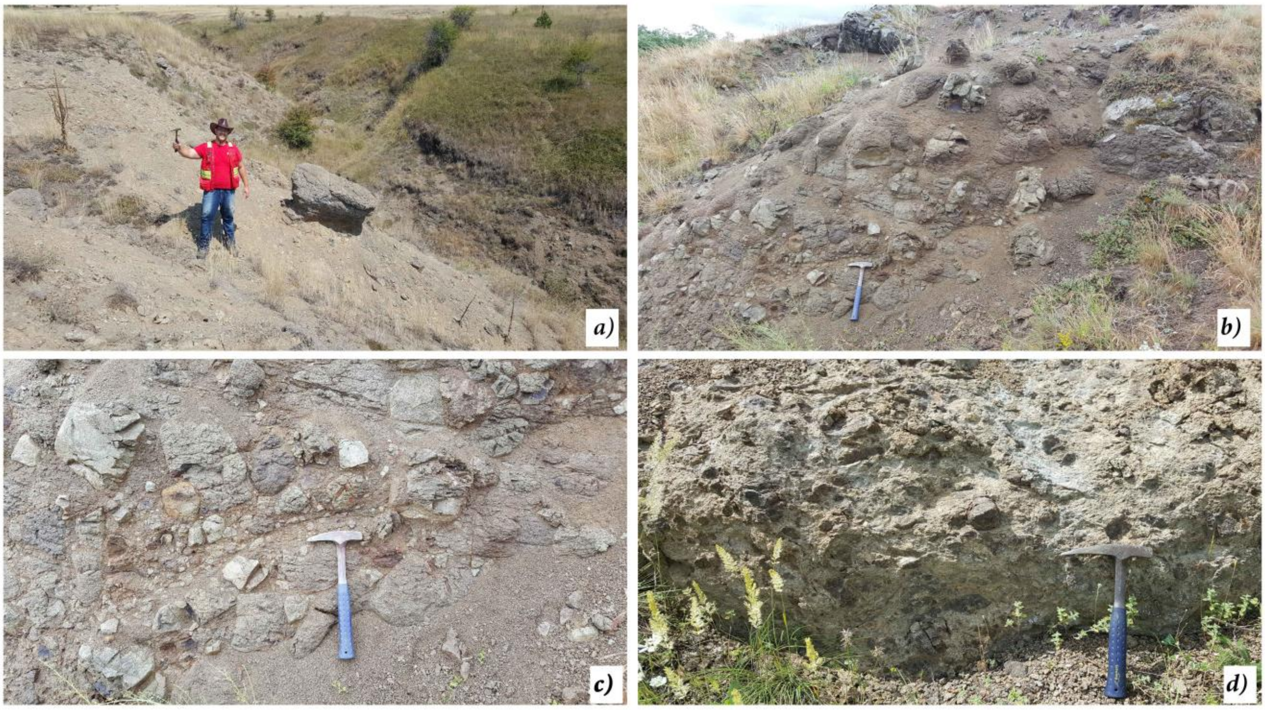

Fig. 1. Outcrops around the town of Breznik and Klisoura village
a, volcanic bombs up to 1.5 m, south of Babica village; *b*, unsorted volcanic bombs, south of Babica village; *c*, unsorted bomb tuffs, close view; *d*, poorly sorted lapilli tuff, near of the Klisoura monastery

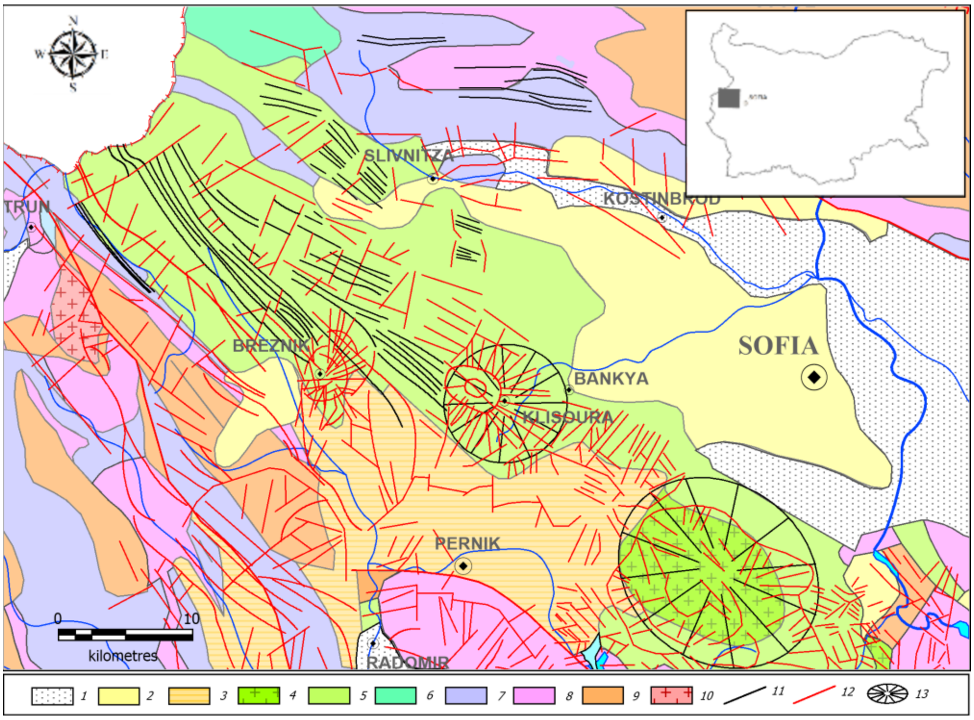

Fig. 2. Simplified geological map of the Western Srednogorie (based on Milev et al., 2007, with modifications)
1, Quaternary sediments; *2*, Neogene sediments; *3*, Paleogene sediments; *4*, intrusive complex in the Western Srednogorie; *5*, volcanogenic-sedimentary formations in the Western Srednogorie; *6*, Lower Cretaceous sediments; *7*, Jurassic sediments; *8*, Triassic sediments; *9*, Paleozoic sediments; *10*, Stara Planina granodiorite and granite (Devonian–Lower Carboniferous); *11*, lineaments interpreted as supposed sedimentary strata; *12*, lineaments interpreted as supposed faults; *13*, volcanic cones by Milev et al. (2007)

Data used

In this study, the remote sensing method has been applied for lineament mapping, visualisation and interpretation. Images obtained by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) optical instrument on the board of TERRA satellite (Abrams, Hook, 2000) has been used to help lineament extraction. For the purpose of this study, mainly optical stereo-images acquired by near infrared bands 3n and 3b of ASTER optical instrument were processed by the methodology described by Popov (2011).

When the satellite is in orbit over the Earth surface, it captures images from two separate positions to obtain a couples of stereo images. The first image is orthogonal with respect to the ground, or so called “nadir looking” and the second one is inclined – “backward looking”. The nadir and backward looking sensors have a spectral range for 3th band (0.76–0.86 μm). Therefore, to prepare epipolar image couples, both images have been paired through up to 55 control points that allow precise overlapping. A total of seven georeferenced ASTER scenes, provided by the U.S. Geological Survey, and covering the Wester Srednogorie area were interpreted in this study. In order to produce on screen a stereo effect 3n/3b/3b was used as RGB band combination (Fig. 3). The processed images were rotated 90 degrees anti-clockwise to achieve a stereo effect visible with 3D anaglyph red/cyan glasses. The cloud-free epipolar images were interpreted in GIS software for lineament extraction and drawing. In parallel with the interpretation of remote sensing data, geological mapping and detailed fieldwork were carried out by the authors around the ring morphostructure near the town of Breznik in order to identify the lineaments and rock succession and respectively, part of the lineament structures were traced on the ground.

Results and discussion

The results obtained from the remote sensing methods represent two distinctly visible ring morphostructures with roughly equal sizes (Figs. 2–4). Both structures are located inside the volcanic formations of the Sofia Unit. They match exactly with the probable volcanic centres in the Western Srednogorie Magmatic Zone.

The eastern ring morphostructure is situated at the foot of Lyulin Mountain, western from the town of Bankya, around the villages of Klisoura, Mala Rakovica and Radui. It corresponds with the Klisoura paleo-volcano that is described as part of a lower volcanogenic-sedimentary unit (Dabovski, 2009). Alongside this unit, further paleo-volcano centres of Dragotino, Radulovo, Galabovo, Zlatusha and numerous subvolcanic bodies and necks have been formed. They clearly shape a linearly elongated zone, probably caused by magmatic active NW-SE Burel fault zone (Gochev et al., 1970). These paleo-volcanoes do not show clearly visible ring morphostructures on the epipolar scenes. Further to the East, multiple intrusion rocks of the dome-shaped Vitosha pluton show structures with a visible circular shape. In the Map of Alpine magmatism in Bulgaria (Dabovski et al., 1989) and the Metallogenic map of gold deposits in Bulgaria (Milev et al., 2007), the position of the ring morphostructure around Klisoura roughly coincides with the volcanic cone that has been described west, near the town of Bankya.

The western ring morphostructure is situated around the town of Breznik and the villages of Viskyar, Babica, Goz, Arzan and Dolni Romantsi. On the epipolar 3D images, the structure has a distinct circular shape with a diameter up to 9 km. The ring morphostructure has been outlined by clearly visible concentric and radial faults, which shape the local drainage system. Unlike the Klisoura, which has highlighting concentric lineaments, the Breznik ring morphostructure have more distinct radial faulting (Fig. 4). It directly coincides with the position of Breznik paleo-volcano and, as opposed to Klisoura paleo-volcano, it belongs to the upper volcanogenic-sedimentary unit. Apparently, this ring morphostructure is a result of active volcanic activity during the Campanian stage. The lineament structures occurred during the most intensive deformations of the volcano-tectonic stage after eruptions and explosions. On the other hand, the specific configuration of lineaments obviously shows remains of a well-preserved volcanic apparatus. During the most extensive eruptions and subsequent deformation events, the newly formed structures may serve as feeder channel and/or hosting structures for hydrothermal fluid or lava products. Near Breznik, the gold-silver Milin Kamak deposit is situated, which is assigned as an intermediate sulphidation epithermal deposit (Sabeva et al., 2017). There are eight parallel ore zones with EW direction and dipping to the South. The structural analysis and ore models made in Leapfrog show three main fault systems (Marinov, 2018). They spatially coincide with the position of the concentric and radial lineaments. The products of Breznik paleo-volcano are highly altered with intensive acid leaching and are associated with argillic, advanced argillic, quartz-sericite and propylite rocks. In a plan view, the dykes and ore zones have a particular arched form which presumably associated with concentric lineaments observed on epipolar images. The volcanic fault and neck structures served as an up-flowed pathway for the dykes and later ore-bearing fluids. The local stress field created by the most intense volcanic activity can be regarded as probable explanation for the direction peculiarity of ore hosted structures with East-West direction that stands obliquely from the regional structures with direction 140–160°. Obviously, the position of the intensively altered rocks and the intermediate sulphidation epithermal deposit show an approximately close relationship with the central part of the ring morphostructure and can be regarded as an indication for the close distance of the gold-silver ore deposit Milin Kamak to the volcanic centre. On the other hand, the highly altered rocks in Klisoura ore occurrence also show a distinctly close relationship with the ring morphostructure western of Bankya. One of the specific features of the proximal volcanic facies is their position in the central part of ring morphostructure. The thick-bedded lava flow, volcanic bomb and lapilli tuff are closely related to the volcanic neck and slope and mark the position of the Breznik and Klisoura paleo-volcanoes approximately to the central part of the ring morphostructure (Fig. 1).

The area in Western Srednogorie was an arena of thrust-nappe deformation events during the Laramian phase of Alpine orogeny, which led to the formation of South-West vergent Krasava syncline (Marinova, 2010). The second tectonic event arosed during the Illyrian phase and have resulted in N-S strike-slip and normal faults, which cut the earlier nappe structures. However, our observations show that both deformation events did not rework completely the lineaments form of the ring structures and they are still clearly visible in present day topographic relief and are marked by the drainage systems. During the Neogene, sedimentary fill graben systems partially covered up and concealed the south-eastern part of the ring lineaments.

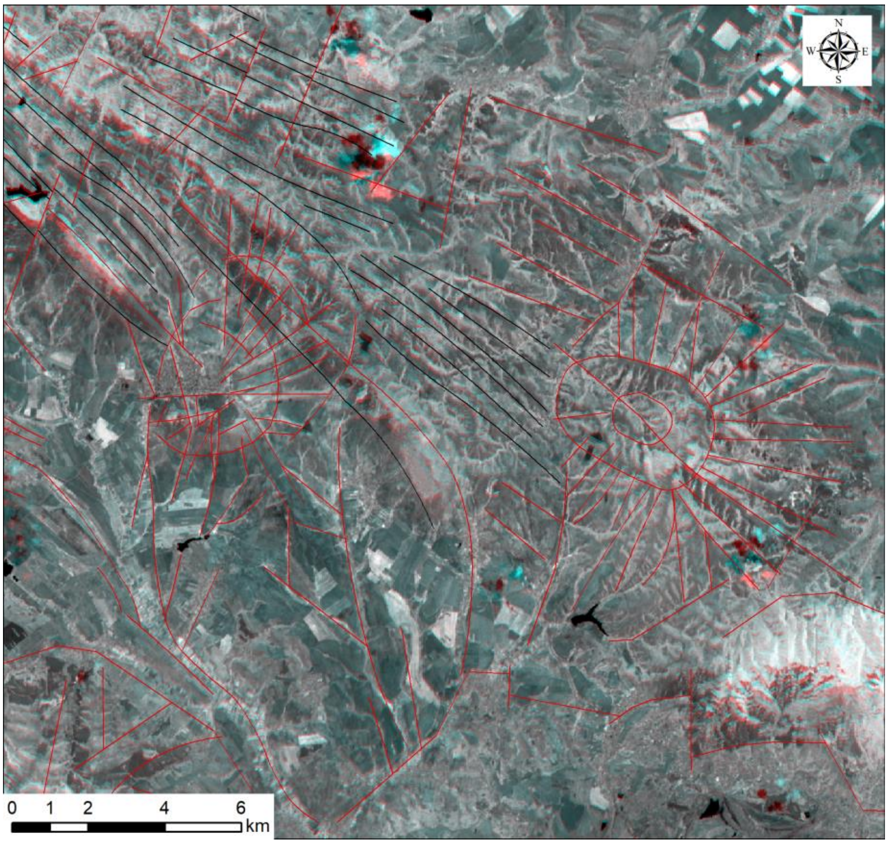

Fig. 3. ASTER stereo image over the town of Breznik area with outlined lineaments and ring morphostructures

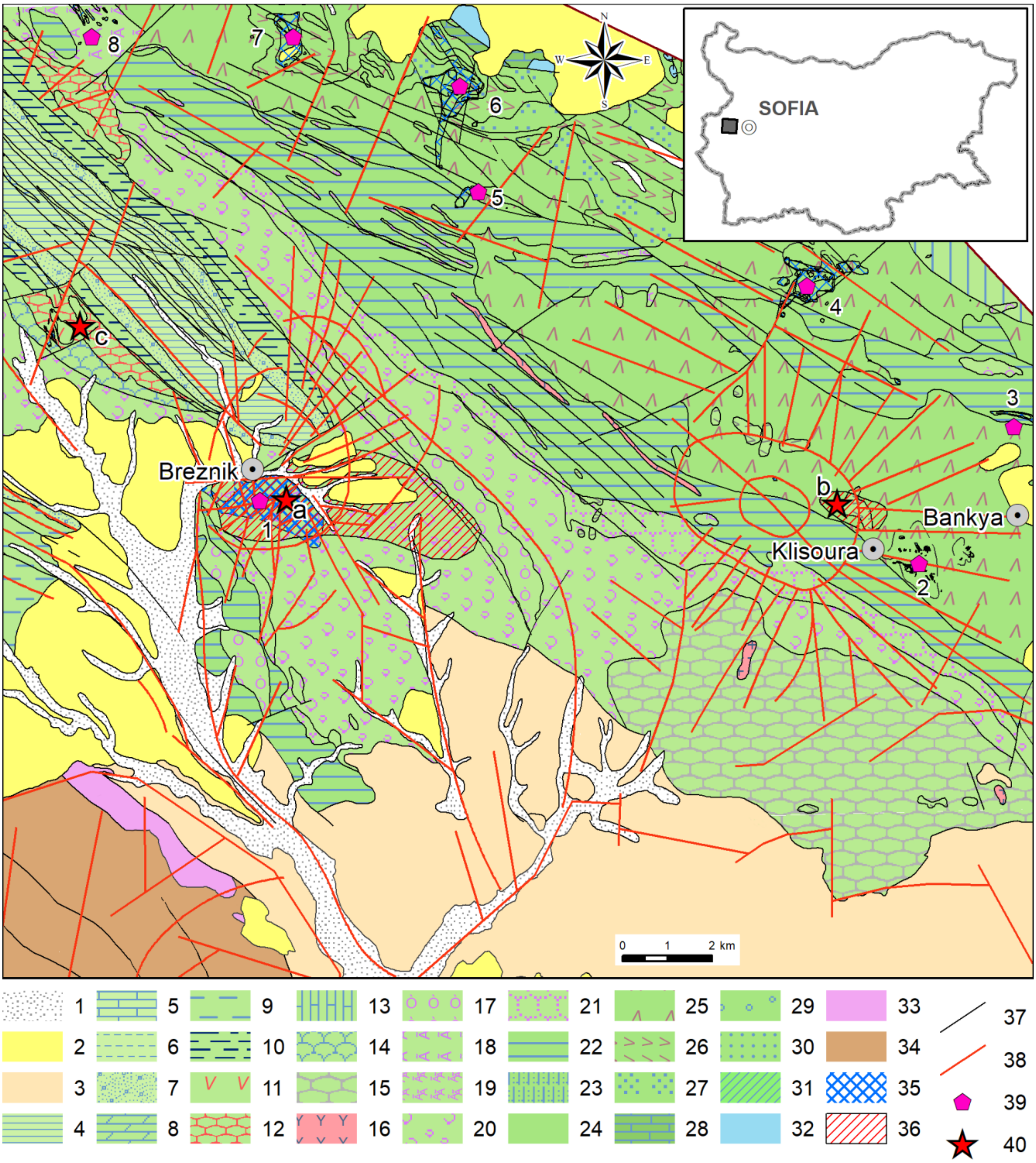

Fig. 4. Geological map of Breznik area (based on Marinova et al., 2010 with modifications)
1, Quaternary sediments; *2*, Neogene sediments; *3*, Paleogene sediments; *4*, sandstone-marly formation; *5*, reef limestone; *6*, bituminous shale; *7*, sandstone formation; *8*, conglomerate-sandstone-marly formation; *9*, sandstone-argillite formation; *10*, flysch formation; *11*, amphibole, amphibole-pyroxene andesite; *12*, pyroclastic-tuffite formation; *13*, formation of detrital-organogenic limestones; *14*, marly-tuffite formation; *15*, Lyulin volcanic complex – agglomerate tuff, ash tuff, tuffite; *16*, monzodiorite; *17*, coarse porphyritic latite and trachyte; *18*, trachybasalt and shoshonite lava and lava breccia; *19*, trachybasalt and shoshonite dyke; *20*, pyroclastic formation; *21*, package of psammo-aleuritic tuffs; *22*, tuffite-marly formation; *23*, marly-clayey-sandy formation; *24*, marly-limestone formation; *25*, Andesite and pyroclastic; *26*, biotite-amphibole andesite; *27*, limestone-sandstone formation; *28*, limestone-marly formation; *29*, conglomerate-sandstone formation; *30*, limestone formation; *31*, marly-limestone formation (Lower Cretaceous); *32*, Jurassic sediments; *33*, Triassic sediments; *34*, Paleozoic sediments; *35*, hydrothermally altered rocks; *36*, proximal volcanic facies – lava flow, bomb tuff, lapilli; *37*, lineaments interpreted as supposed sedimentary strata; *38*, lineaments interpreted as supposed faults; *39*, ore deposits and occurrences (*1*, Milin Kamak Au-Ag deposit, *2*, Klisoura ore occurrence, *3*, Pozharevo ore occurrence, *4*, Zlatusha ore occurrence, *5*, Gurgulyat ore occurrence, *6*, Bratushkovo ore occurrence, *7*, Radulovtsi ore occurrence, *8*, Pishtene ore occurrence); *40*, supposed paleo-volcanic centres (*a*, Breznik paleo-volcano, *b*, Klisoura paleo-volcano, *c*, Vidrica paleo-volcano)

Conclusions

The recognition of lineament structures by stereo images, obtained by the ASTER instrument on TERRA satellite and the fieldwork on the ground allowed to distinguish two clearly visible ring morphostructures situated around the town of Breznik and the Klisoura village. The possibility to acquire optical stereo-images nowadays is considered as an extremely useful tool for structural investigation. The ring morphostructures are regarded as a reflection of the Late Cretaceous Breznik and Klisoura paleo-volcanoes and probably represent preserved fragments of volcanic cones. They have an obvious radial and concentric pattern with a slightly elliptical shape. Lineaments show apparent direction that is different from regional structures with direction 140-160°. On the ground, the radial structures are more distinguishing and easy to trace than concentric ones and control the local drainage systems. The spatial position of lava flows, volcanic bombs and lapilli tuffs is an indicator for proximal facies and mark the paleo-volcanoes proximity to the central part of ring morphostructures. A characteristic feature regarding stress field during most intense deformation and evolution of volcano is the formation of numerous radial and concentric structures that contribute to the development of intensive hydrothermal activity and may serve as channels and hosting faults for ore-bearing fluids and dykes. Our observation shows that ore hosted faults in Milin Kamak Au-Ag deposit are probably created from this local stress field shortly after the most intensive activity. The position of lineaments close to the hinge line of the synclinal presumably explains the low erosion level, conserved Upper Cretaceous proximal facies and make the structure to stand out in present day relief. The close relationship between the altered rocks and ring morphostructures could contribute to ore and exploration geology and could be used as an indication and basis for future mineral prospecting and investigation of other ore controlling ring morphostructures in Apuseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt.

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References

Abrams, M., S. Hook. 2000. *ASTER User Hand Book. Version 2.0*. Jet Propulsion Laboratory, California Institute of Technology, 135 p.

Bairactarov, I. 1989. *Upper Cretaceous Metallogeny of Western Srednogorie and Plana Mountain*. PhD Thesis, Research Institute for Mineral Resources, Sofia, 197 p. (in Bulgarian)

Baltakov, G. 1975. Endodynamic determination of the contemporary morphogenetic processes in the Ihtimansko Srednogorie. – *Ann. Univ. Sofia*, *69*, 2, 33–39 (in Bulgarian with English abstract).

Dabovski, C., A. Harkovska, B. Kamenov, B. Mavroudchiev, G. Stanisheva-Vasileva, Y. Yanev. 1989. *Map of Alpine Magmatism in Bulgaria (Geodynamic Approach), 1:1000000*. CIPP in Map-making, Sofia.

Dabovski, H., B. Kamenov, D. Sinnyovsky, E. Vasilev, E. Dimitrova, I. Bairactarov. 2009. Upper Cretaceous geology. – In: Zagorchev, I., H. Dabovski, T. Nikolov (Eds.). *Geology of Bulgaria. Part II. Mesozoic Geology*. Marin Drinov Acad. Publ. House, Sofia, 305–638.

Gočev, P., V. Kostadinov, M. Matova, I. Velinov. 1970. The structure of a part of the southern strip of the Western Srednogorie. – *Rev. Bulg. Geol. Soc.*, *31*, 3, 289–301 (in Bulgarian).

Jelev, V., L. Nikova, J. Crummy, F. Mitreva. 2003. Characteristic of Bardo ring morphostructure (Bulgaria). – *Ann. Univ. Min. and Geol.*, *46,* Part I, 53–58.

Marinov, T., I. Bairaktarov. 1980. Alkaline basalts in the Western Srednogorie. – *C. R. Acad. Bulg. Sci.*, *33*, 4, 529–532.

Marinov, I., N. Temelakiev, P. Doychev, K. Popov. 2018. Ore controlling factors at the gold-silver deposit Milin Kamak, Western Srednogorie, Bulgaria. – *Rev. Bulg. Geol. Soc.*, *79*, 3, 125–126. (in Bulgarian with English abstract).

Marinova, P., V. Grozdev, D. Ivanova, D. Sinnyovsky, I. Petrov, P. Milovanov, A. Popov. 2010. *Explanatory Note to the Geological Map of the Republic of Bulgaria. Scale 1:50000. Map Sheet K-34-46-G (Breznik)*. Ministry of Environment and Water, Bulgarian Geological Survey, Sofia, 63 p.

Milev, V., V. Georgiev, N. Obretenov. 2007. Metallogenic map of gold deposits in Bulgaria. – In: *Milev, V. (Ed.). Gold Deposits of Bulgaria*. Zemya'93, Sofia, 208 p. (in Bulgarian)

Popov, K. 2011. Recognition of the Panagyurishte ring morphostructure by satellite stereo-images. – *Ann. Univ. Min. Geol., 54*, Part I, 81–88.

Popov, P., H. Spiridonov. 1990. On the Morphostructure of the Ore Districts in the Sredna Gora Region. – *Ann. Higher Inst. Mining and Geol.*, *36*, Part I, 31–39 (in Bulgarian).

Popov, P., T. Berza, A. Grubich, I. Dimitru. 2002. Late Cretaceous Apuseni-Banat-Timok-Srednogorie (ABTS) Magmatic and Metallogenic Belt in the Carpathian-Balkan orogen. – *Geologica Balc., 32, 2-4*, 145–163.

Sabeva, R., V. Mladenova, A. Mogessie. 2017. Ore petrology, hydrothermal alteration, fluid Inclusion, and sulphur stable isotopes of Milin Kamak intermediate sulphidation epithermal Au-Ag deposit in Western Srednogorie, Bulgaria. – *Ore Geol. Rev.*, *88*, 400–415.

Spiridonov, H. 1999. *Ring Morphostructures in the Sredna Gora*. "Prof. Marin Drinov" Acad. Publ. House, Sofia, 270 p. (in Bulgarian)

Velev, S., R. Nedialkov, I. Peycheva, A. von Quadt. 2012. Geological and petrological characteristics of the volcanic centres from the upper volcanogenic–sedimentary unit from the Western Srednogorie. – *Geologica Macedonica*, *3,* 7–12.

Zagorchev, I., V. Kostadinov, D. Chounev, R. Dimitrova. I. Sapunov, P. Chumachenko, S. Yanev. 1995. *Explanatory Note to the Geological Map of Bulgaria on Scale 1:100000, Vlasotince and Breznik Map Sheets*. Committee of Geology and Mineral Resources, Geology and Geophysics, Sofia, 60 p. (in Bulgarian with English abstract)