Ore shoots formation in a sinistral strike-slip setting: an interpreted from the map of the Au-Ag Milin Kamak deposit in the Breznic area, Southwest Bulgaria

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Abstract. This work presents a structural interpretation of a well-known gold deposit from SW Bulgaria. The interpretation is based on the geological map and structural data, collected during the prospecting. The data indicates that a regional sinistral shearing was responsible for a low rank sinistral shear system, which created ore depositional space by the combined action of shear extension and compression. The two mechanisms opened tension gashes, dilated previously formed Riedel faults and buckled the veins and the faults. The buckling happened, when the structures were rotated anticlockwise in the compressional quadrant of the space between the regional shears thus creating buckling structures. Ore shoots have been formed in the extended domains of the main shear and along the dilated previously formed Riedel shears.

Keywords: sinistral shear, ore shoot, gold deposit, Riedel model.

Introduction

The Milin Kamak mineralized strike-slip fault and vein system is a brittle-ductile shear zone striking 280W and dipping steeply to the south. It hosts gold-silver mineralization of commercial grade, which is a part of the Cretaceous Apuseni-Banat-Timok-Srednogorie (ABTS) magmatic and metallogenic belt (Popov et al., 2002). It exposes an echelon sinistral array of hydrothermally altered zones, mostly resembling to modified Riedel shears. They show refolding and are locally opened for hydrothermal fluids.

The fault zone is hosted by altered trachybasalt to andesitic trachybasalt, volcanic and volcanioclastic rocks of Late Cretaceous age, considered as products of the Breznik paleovolcano. The presently known ore zones are indicated as altered zones in Fig. 1a. The styles of alteration are propylitic, sericite, argillic, and advanced argillic.

The petrology, ore geochemistry and mineralogy of the deposit are well studied (Velinov, 1967; Stoykov et al., 2007; Hikov et al., 2017; Sabeva et al., 2017). However, its structural features have only recently addressed, when the prospecting geologists observed that the ore tends to accumulate in ore columns located at fault intersections (Marinov et al., 2018, 2019b). The aim of the present study is to explain these features because they concern the prospecting strategy and the overall calculation of reserves.

Tectonic setting

The tectonostratigraphic trend in this region is to the NNW, as both the fold axes and the major faults strike in that direction. The evolution of the NNW-striking faults is undoubtedly related to the main folding event of the Upper Cretaceous volcano-sedimentary succession and probably reflects a struc-
cultural predisposition and inheritance of structures in the basement. The regional faults usually follow the limbs and hinges of the large folds. Since the folds are usually tight, subsidiary faults have been formed by a shear and extension of the strata across fold hinges.

Vangelov et al. (2016) described the main fault systems in the region. They suggested that the age of the NW-SE trending fault zones and the N-S to NNW-SSE trending fault zones is constrained by the sedimentary sequences, which gives a very narrow age span of activity between the early and late Miocene. Only the NE-SW and WNW-ESE oriented faults seem to be active during the Quaternary.

The lineament analysis performed by Rizova et al. (2018) demonstrated a strong NNW trend of major lineaments and NE trend of smaller lineaments. The authors confirmed the anticyclonic rotation of the main tensile axis proposed by Kounov et al. (2011) and reaffirmed the idea for a regional sinistral strike-slip shear. The sinistral shear is consistent with the geometry of the Riedel and domino fault models (Fig. 1c) and is also applicable for the regions between the main shears.

In the sense of the above-mentioned studies, it can be concluded that the WNW trending Milin Kamak fault zone (MKFZ) is a subsidiary to the regional NNW shears of the Kraishte Zone, which border it from the east and west. It appears that the MKFZ has limited strike-slip and extensional kinematics, which would not only facilitate the formation of the echelons of altered faults abating to it but would also facilitate the fluid transport.

To unravel the earliest deformation history Marinov et al. (2019a) made a remote sensing morphostructural analysis of the area and concluded that there are indications for the existence of a circular paleovolcanic structure, suggested from concentric and radial structural elements and to some extend by the distribution of the volcanic rocks. This structure must have been partially reworked by the later tectonics.

Analysis of the map pattern

The map geometry indicates that the main shear along the MKFZ is sinistral (Fig. 1b, c), and the hydrothermal alteration affected subsidiary NE-striking zones. The first practical question is: are these zones originally Riedel shears or they are veins. Ore can be hosted by the fractured peripheral zones of faults as well as by veins. It is important to know, because the veins’ axes are usually parallel to the principal stress, while the synthetic Riedel shears are oblique to the principal stress, as both can rotate and fold, passing through the contractional field, during the progressive sinistral shear.

In a sinistral shear geometry, the NE-striking ore zones can be R faults or veins and both would rotate counterclockwise towards a more northerly striking direction. This implies that the ore zones would be buckled, as the compression would open the previously formed faults creating an open space and cooling the hydrothermal fluids by expansion, which is the dominant tectonically controlled ore deposition process. The buckling of the ore zones is indeed visible on a map scale (Fig. 1a).

It appears that all the features in the MKFZ can be explained by sinistral shearing but it is still possible to have dextral shear reversals, which will also produce buckling and open NW trending faults for fluids.

Analysis of the structural data

Veins. The veins are NE and NNW-striking. These are usually smaller structures, measured in exposures and trenches. It can be argued that the – E-SW trend indicates a sinistral shear direction, because it corresponds with the NE-SW direction of the principal stress. NNW trend is not easy to be explained. It may indicate significant counterclockwise rotation of the primary NE-striking features, dextral reversals of the main shear or mineralized P shears or X-shears in the sense of the Riedel model.

Faults. Most of the faults strike in the NE quadrant which is consistent with SW-NE trend of the principal stress. Precaution should be sheared that some of the measured faults are small structures that could be of neotectonic origin thus postdating the ore formation.

Analysis of fault kinematics. The following components are incorporated in the model presented here (Fig. 1c): 1. Regional sinistral fault geometry derived from basin shape, paleostress analysis and lineament statistics (Kounov et al., 2011); 2. Overstepping segments of the MKFZ. The steps are formed at the intersection of the NE striking Riedels and the NW striking segments on the main MKFZ; 3. NE strike of the secondary altered zones, corresponding to the synthetic Riedel shears; 4. Dense population of measured faults striking to NE; 5. Principal stress direction calculated from fault striations located in the southwestern quadrant (Fig. 1d). Because the study area is intensely altered by hydrothermal fluids none of the structural relationship is clear and informative enough but all of them, taken together, allow model compilation.

Regarding the kinematic analysis (Fig. 1d), done by the method of Marrett and Allmendinger (1990), we emphasize that the studied faults are not separated on “old” and “young”. It would be a very special case to have a situation in which the present stress field corresponds to the ancient stress field, when the ore
was deposited. We assume that the measured fault motions would correspond to the latest regional stress field that created new fault sets or reactivated previously formed structures. Two fault sets are distinguished on the fault kinematics diagram (Fig. 1d): an E-NE striking set and a N-S striking set. In fact, they are similar to the active fault sets distinguished to the east in the Maritsa fault zone (Strahilov, Dimitrov, 2021). The N-S striking fault set can represent modern fault motions demonstrated by the GPS measured displacements (Dimitrov, Nakov, 2020). On Fig. 1d, the ENE striking faults can be old shears, that have been reactivated. The calculated kinematic axis strike approximately W-E. It is in spite of the strong N-S fault population. It could be seen from the diagram that the W-E striking faults have more pronounced strike – slip component, while the N-S set is represented by normal or reverse faults.

**Buckling of the ore zones.** Buckling of the NE-striking ore zones can be observed on a map scale...
and inferred from the stereographic statistics where, bedding is striking from NW to NE. We interpret the buckles in the sense of a sinistral shear geometry. They can be produced by rotation, in the progressive sinistral shear, when the structural elements pass in the shortening quadrant (Fig. 1c), around the instantaneous shortening axes. Similar geometry can also be produced by dextral reversals of the shear. If significant dextral shear took place, then we would expect to see more northwesterly striking faults and veins however the dominant strike is to NE. Indeed, there are NW-striking small veins but not many faults striking to the NW. Up to this moment, the question about limited dextral shear along the MKFZ remains unanswered and requires more studies. It is because the buckling due to the anticlockwise rotation obscured the possible dextral shear events, which can result in similar geometry. In reality, the shortening derived from the fault model of the MKFZ, coincides with the shortening of the limbs of the major regional folds that has axial surfaces striking to WNW.

Discussion – origin of the ore shoots

The ore shoots first suggested by Marinov et al. (2018) can be formed in the hinges of the buckle folds, in the dilated subsidiary Riedel shears striking to NE and in overextended regions where the Riedel shears intersect the main MKFZ. The last ones can be named tension gashes (Fig. 1b, c). The tension gashes can be right stepping or left stepping. Those on the map of Figure 1 appear to be right stepping, which is related to the sinistral shear movement (Lin, Chiba, 2017). The structural geometry along the MKFZ strongly facilitates ore shoots, so special studies have to be devoted on their geometry and mechanical control in order to ensure the effective mining.

References


