THE TEMPORAL AND SPATIAL EVOLUTION OF MINERALIZATION CARRYING FRACTURE SYSTEM IN THE VALEA MORII DIORITE INTRUSION (APUSENI MOUNTAINS)

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1. Introduction
The Valea Morii prospect, which has been in the focus of our research, is located in the southern part of the Apuseni Mountains, where Miocene calc-alkaline intrusive and volcanic units host numerous porphyry Cu–Au and epithermal Pb-Zn (Ag-Au) mineralization (Neubauer et al. 2005). The Valea Morii mineralization can be interpreted as a part of the 12.5-10 Ma old Barza Magmatic Complex along the Brad-Musariu-Valea Morii belt, with high gold endowment (Roșu et al. 2004; Kouzmanov et al. 2007). Mineralogical and structural data for the fracture systems of the Valea Morii diorite intrusion was collected and analyzed, in order to define mineral paragenetic sequences resulted by the different porphyry and epithermal mineralization stages, as well as the temporal and spatial evolution of the fracture system and hydrothermal alteration processes.

2. Methods
The hydrothermal veins in a homogenous environment always appear to be perpendicular to the minimal main stress direction (Tosdal and Richards, 2001). In deformed rocks, which are rich in cracks, the fluid flows are influenced not only by the present stress field, but also by the older generation of cracks and fractures. The presence or missing of hydrothermal vein system has an influence on the type of the mineralization. For this reason, geometrical analyses of veins may result in important information about the mineralization style. High grade-low volume hydrothermal ore deposits are usually characterized by a few veins, whereas ore deposits with low metal grades but large volumes usually contain many well connected veins (Cox et al. 2001). Following these arguments, both mineralogical and geometrical analysis of the fracture systems of the Valea Morii porphyry mineralization was carried out. Data have been collected from the pit walls of the existing open pit at Valea Morii and from the VMSDD001 and VMSDD002 drill cores recently obtained by the SC European Goldfields SRL exploration company.

In order to convert the vein data into numbers and to correlate them between their different types, fractal analysis was performed on the collected data. The measured data was integrated in two plots: staircase plot and cumulative frequency of vein thickness plot. The staircase plot shows the cumulative vein thickness versus the distance along the base line. The gradient of a staircase plot is a measure of the extensional strain accommodated by a vein array and the irregularity...
of the curve is a measure of the heterogeneity of the strain (Gillespie et al. 1999). The cumulative frequency of vein thickness plot illustrates the vein thickness versus their cumulative frequencies on log-log axes. Straight lines on this plot, as provided by the fractal/power-law models, indicate a power-law relationship, according to the form \( N(t) \propto t^{-D} \) where \( N(t) \) is the cumulative number and \( D \) is the slope of the line. The physical meaning of higher \( D \) values is the higher abundance of the relatively thin veins. Log-normal or negative exponential distributions give curved lines on this plot. The absolute values of these plots in the power-law models are, at 0.75, slightly higher than the ideal value of 0.7. Although the frequency distributions of these models are perfectly power-law, the equivalent cumulative frequency distributions are slightly curved and over-steepened at high thicknesses, providing a higher slope (Gillespie et al. 1999).

### 3. Intrusive phases and hydrothermal processes at Valea Morii prospect

The Valea Morii prospect is situated about 12 km southeast from Brad, in the eastern part of the Barza Magmatic Complex. The Barza Magmatic Complex is a part of the Zarand-Brad Basin and it is built up by Sarmatian-Pannonian volcanic and subvolcanic rocks. In the region of Barza, the Neogene volcanism has started with the eruption of the Barza type andesite (containing amphibole and pyroxene) lavas and pyroclastics (Borçoş et al. 1977), after this has appeared the first extrusive to intrusive quartz content andesitic stocks continued by several dioritic and microdioritic intrusive bodies. In the area of Valea Morii, the underlying Jurassic basalts and Upper Cretaceous sediments are covered by middle-Miocene volcano-sedimentary rocks, intersected by several magmatic intrusions. The Valea Morii porphyry mineralization is hosted by a quartz-dioritic intrusion (QDI). This QDI is cut by a later quartz-microdiorite (LQMI) and late coarse grained porphyry dykes (CGP). The QDI shows equigranular to coarse-grained texture, and contains plagioclase, amphibole and quartz as major rock forming minerals. The LQMI is characterized by equigranular fine grained texture with pyroxene, amphibole and quartz as major minerals. The CGP is characterized by coarse grained porphyry texture, with significant amphibole content. Along the contact of QDI and LQMI, an intrusive breccia can be observed in the Valea Morii open pit, where the matrix is formed by LQMI and the rounded clasts are representing the potassic altered QDI. Both diorite types are cut by various quartz-sulphide veins and characterized with various types of hydrothermal alteration. The porphyry Cu-Au type mineralization occurs in veins with magnetite-quartz-chalcopyrite, quartz-chalcopyrite and pyrite-chalcopyrite compositions (Fig. 3). The intrusions are also cut by a later vein system which is filled up by banded and drusy quartz and carbonate and Pb-Zn sulphides. The hydrothermal fluid/rock interaction produced potassic, propylitic, argillic and sericitic alteration zones during the formation of the Valea Morii mineralization. The potassic and propylitic alteration is characteristic in the whole QDI, however intense argillic and sericitic hydrothermal alteration is restricted to the zones of epithermal veins that cut through the porphyry mineralization assemblage. Thin (~1cm) sericitic alteration halo characterizes the late porphyry veinlets filled by sulphides.

### 4. Hydrothermal alterations related to the ore forming processes

The original rock texture is well preserved within the potassic and propylitic alteration zones of the QDI. The rocks in the potassic alteration zones are silicified as well, and are characterized with grayish-greenish color and dense sets of veins. These veins are filled with biotite, magnetite, chalcopyrite, pyrite and whitish-grayish quartz. The propylitic alteration is present in the internal and also in the marginal parts of the dioritic bodies and is overwriting the potassic alteration. In the propylitic intrusive rocks three different mineral associations were identified: (1) chlorite-calcite ± clay minerals, (2) albite-epidote-chlorite ± calcite and (3) chlorite-epidote-calcite. The first mineral association appears to be present in the outer part of the ore-body, while the second and third mineral associations occur near the central part of the ore-body. The latter overprints the potassic alteration. High pyrite, chalcopyrite and magnetite content is also typical to these zones. In the zones of argillic alteration, along the epithermal veins, the primary texture of the rock has been destroyed and the rock texture is now defined by the newly formed mineral association. The clay minerals occur in knots and irregular shaped bodies and replace the products of the previous potassic and/or propililitic hydrothermal alteration and also the rock forming minerals. The rock also lost its original texture along the zones of sericitic alteration. This alteration type can be clearly distinguished from the argillic alteration, because of its higher quartz content and thus the characteristic more competent appearance. This alteration is expressly significant along the epithermal veins. At the end of the hypogenic (potassic-propylitic) alteration processes, the Cu-Au ore zone is ripped up by hydrothermal and tectonic brecciation, which was followed by the appearance of Zn-Pb sulphides and significant concentration of Au and Ag in the epithermal veins.

### 5. Mineralized fracture systems of the Valea Morii prospect

Based on the mineral paragenesis and the cross cutting relationships of the veins, nine types of veins were defined within the Valea Morii mineralization, using the nomenclature of Gustafson and Hunt (1975; A, B and D types) and Arancibia and Clark (1996; M type). The different vein types and their cross-cutting relationships are represented by drill core photos presented on Fig.3.
The strip log of the VMSDD001 hole (fig. 4) shows the relationship between the host intrusives, the relative distribution of the metal (Au, Cu, Zn) concentrations and the abundance of the different vein types. Based on these plots, the following conclusions can be drawn concerning the vein distribution and the different mineralization stages:

- The abundance of the early porphyry M, A1, A2 and A3 veins correlate well with the Au and Cu grades of the porphyry mineralization;
- The QDI porphyry host all vein types, however the M-type veins are lacking from the LQMI body, while M, A1, A2 and A3 veins are lacking from the CGP body. This suggest a well-defined temporal relationship for the different porphyric bodies, i.e. the early intra-mineral nature of LQMI porphyry (intruding after the formation of M-type veins) and the late intra-mineral nature of CGP porphyry (intruding after the formation of most A-type veins);
- The Au(ppm)/Cu(%) ratio is ~1 for the early M- and A-type veins, however significant Au enrichment can be observed for the late porphyry veins (A3, D1, D2);
- Epithermal veins introduce significant Au and base metal (Zn) mineralization into the system.

Fig. 3. Graphical representation of selected veins and their cross-cutting relationships in the drill core of the VMSD001 hole: A = 2.45m – cross-cutting relationships between early magnetite (M) and quartz (A2, A3 and A4) veins; B = 43.60m – quartz-sulphide (D1) veins with sericitic alteration halo; C = 11.35m – cross-cutting relationships of A2, A3 and A4 veins; D = 70.70m – late coarse grained quartz of vein (D2).
Fig. 4. Strip log of the VMSD001 drill core. The relative distribution of the Au, Zn and Cu assay data is based on the systematic (1 m based) sampling carried out by the European Goldfields SRL and the analytical results reported by the Gura Roșiei ALS – Minerals Division laboratory. Vein abundances (in percentage per meter basis) are based on the drill core logging of the recent study.

An analysis was carried out on the structural measurements of the observed veins of the pit walls, too. The results suggest, that the main stress field changed slightly during the different stages of the mineralization (Fig. 5):

- A1 and A2 veins show commonly NNW-SSE strike;
- A3 and A4 veins are generally distributed along NNW-SSE and NNE-SSW striking fracture systems;
- D1 and D2 veins were formed along NE-SW striking fracture systems;
- Late epithermal veins show E-W strike-orientation.

Structural measurements (angle between the plan represented by individual vein and the core axis) on drill cores also suggest variation of the stress field, however absolute directions cannot be related to this data as the measurements were not obtained on oriented cores.
Fig. 5. Stereoplots representing the veins measured on the pit wall (dip direction, dip) and the semicircles are representing the veins measured on the VMSD001 drill core (only angle between the plan represented by the vein and the core axis).

Two groups of the collected data were selected for fractal analyses according to the host rocks of veins. (fig. 6). The staircase plots (fig 6A and 6B) show the correlation between the measurements on the pit wall and on the drill cores. The plots suggest the heterogeneity of the deformation: it can be observed, that the veins in the QDI are denser then in LQMI, however in the LQMI the veins are more clustered than in the QDI. The cumulative frequencies of vein thicknesses plots (Fig 6C. and 6D) suggest, that the veins from the same groups have fractal potential and they fractal dimensions are unique.

Fig. 6. Staircase plots (A, B) and cumulative frequency plots (C, D) of the measured data.

6. Conclusions
Several intrusive and hydrothermal stages of the Valea Morii mineralization were defined. The early QDI porphyry hosts all veins types formed during the porphyry and epithermal mineralization stages. The LQMI porphyry intruded after the formation of M-type porphyry veins, while the intrusion of CGP porphyry followed the main porphyry mineralization stage. Early A-type porphyry veins are associated with potassic, sericitic and propylitic alteration and they carry Au and Cu mineralization with a metal budget close to Au(ppm)/Cu(%) ~1. All intrusive bodies were cut by late epithermal veins associated with argillic and sericitic alteration and high Au and Zn grades. The distribution of vein orientations show that the main stress field evolved during porphyry mineralization, initially forming NW-SE striking veins and later NE-SW striking veins. The epithermal veins formed along E-W striking structures. The different vein types are also distinguished by their unique fractal dimensions.

7. Acknowledgement
The authors express their thanks to the S.C. European Goldfields S.R.L. for permitting to work in the Valea Morii open pit and for the access to the drill cores. This study is part of Kun T.H. M.Sc. thesis, which is supported by the TÁMOP 4.2.1/B-09/1/KMR-2010-003 project at the Eötvös Loránd University, Budapest.

8. References


