

GOLD IN METAMORPHIC ROCKS: FACTS AND FANCY

GHEORGHE UDUBAȘA¹, SORIN SILVIU UDUBAȘA²

ABSTRACT. The characterization of shear zone related ores (SZRO) is still a matter of debate. In an attempt to attenuate the existing controversial points of view some classifications of the SZRO are here proposed, taking into account both their mineralogy and geochemistry (protore nature, ore minerals assemblages etc.) and their size. The small scale SZRO seem to depend on the existence of a protore, as a source of metals, whereas the large scale SZRO may have an epigenetic overprint and the source of metals can be multiple, juvenile included. Finally, a fractal-like classification of ore deposits is proposed, in which the SZRO have their natural place.

Keywords: shear zone related ores, gold, copper, “mesogenesis”.

Introduction

The gold deposits are probably the best studied mineral deposits in the world, by using all the investigation methods available. Thus, high confidence models have been proposed for some deposits, e.g. Carlin type. However, sometimes less successful results occurred too, e.g. the well-known failure in Indonesia. The study of the gold deposits will surely continue in the future as the “gold period” of the mankind seems to be endless.

The present paper is mostly dedicated to the late professor Valer Lucca at the Cluj University, who published in 1937 an interesting paper on gold mineralization at Someșul Rece. It is this paper which can be considered as a first attempt to put the field observation in the front of any explanation.

The Example of Foregoers (Predecessors)

The paper of Lucca (1937) should be taken as a good example of clear separation between observation (mostly in the field) and interpretation (the well known German dualism: Bemerkung – Deutung). A paragraph from his paper (p. 159) is convincing: “The ores form quartz lenses in association with metamorphic rocks, mostly with sericite or chlorite schists. As a rule they are concordant to the schistosity, but sometimes show discordant relationships. They are also conformable to the rock folding and in some places follow dislocation alignments. The dip is either vertical or horizontal. The size is also variable, from several cm to 20-30 m in length, 20 m in depth and up to 1 m thick. The lenses outline is very irregular.

¹ Geological Institute of Romania, 1, Caransebes Str., 78344 Bucharest – 32, e-mail: udubasa@igr.ro

² University of Bucharest, Faculty of Geology and Geophysics, 1, Nicolae Balcescu Blv., 70111 Bucharest, e-mail: udubasa@geo.edu.ro

Lenses can appear fasciculated or they can disappear but their continuation on several meters is common". Not a word about rock alteration!

It is however true that his genetic interpretation is now hardly difficult to be accepted. In that time the only alternative was the dominating conception of Lindgren's magmatic-hydrothermal genesis. A very similar case is that of Valea lui Stan gold mineralization, where Petrușian (1936) first has made observations and then, separately, gave a genetic interpretation, epigenetic as well (Lindgren's school).

The Evolution of the Ideas

It was the Valea lui Stan (Capățâna Mts.) gold ore which prompted a new genetic concept to promote, i.e. of "tectogenetic ores" (Udubașa et al., 1976), maybe not very suitable, based on very detailed observations of Petrov (1974) made on gold ores from the Yenisei area. By adding some new additional parts, the concept of "tectogenetic ores" (TO) has been used by many other investigators of gold ores in metamorphic rocks, as shown thoroughly by Mârza (1999). Nevertheless, some corrections should be made: not all the authors mentioned by Mârza (pages 347-348) were concerned about the TO. "Not guilty" persons are Chivu, Teodoru, Tomescu, Serafimovici, Gurău, etc. Moreover, some expressed purely syngenetic views (e.g. Gurău), some other – epigenetic views (Serafimovici). Further confusions have been introduced also by assuming a "total metal import" into the shear zones and by considering any fault as a shear zone. Such an enlargement of the term shear zone led to (at least partly) unsuccessful results of prospecting workings in South Carpathians. A supplementary confusion introduced also Bonnemaïson (1986).

In an attempt to find out a metal source, to explain the lack of hydrothermal alterations and of lithostratigraphic control of gold ores in metamorphites, Udubașa et al. (1976) and Udubașa & Hann (1988) have refined the concept by (1) using the term "protore" and (2) emphasizing the critical role of the shearing plane versus foliation; all of this in order to reduce the number of unknown factors of the shear zone related ores (SZRO). In such a way a new class of ore deposits has been postulated to exist, in which the epigenetic overprint is a function of the size of the shear zones (Udubașa et al., 1998; Udubașa & Udubașa, 1998). In a fractal-like classification of mineral deposits the shear zone related ores (SZRO) have their natural place (Fig. 1).

A somewhat different point of view by accepting an overall import of metals expressed Popescu & Tămaș-Bădescu (1998); they classified the SZRO as follows: I. "pre-shear" (eventually with the same meaning of our protore); II. "syn-shear" (the real SZRO) and III. "mixt-shear".

Some constraints

The "parallel metallogeny" of Mârza (1999) is an interesting idea by pointing out the necessity to accept the convergence processes. The idea is good but does not help much. Both Petrușian (1936) and Lucca (1937) recognized the peculiarities of the gold ores at Valea lui Stan and Someșul Rece respectively, but the genesis could not escape the purely magmatic archetype.

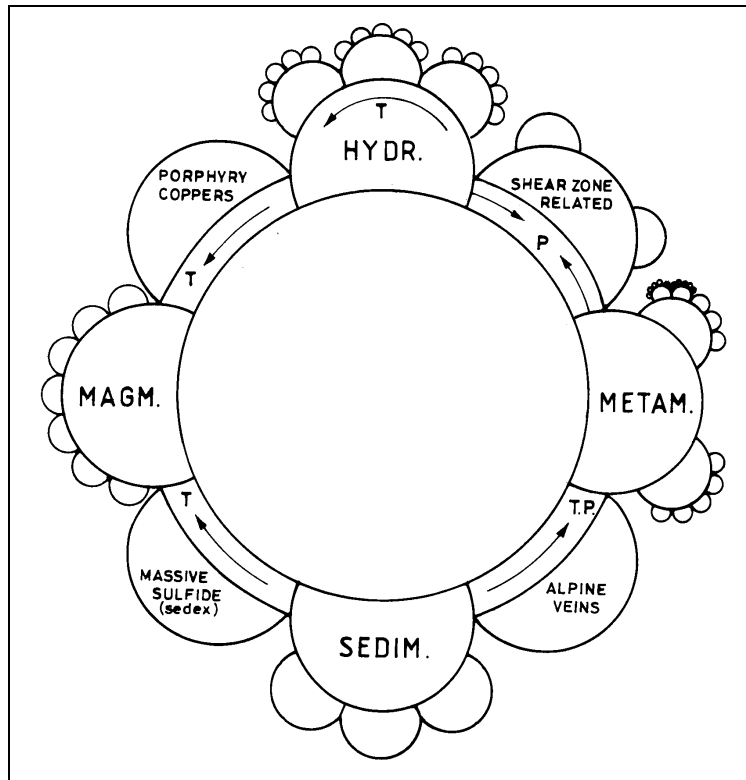


Fig. 1 – A possible, fractal-like, classification of mineral deposits, in which the shear zone related ores have a symmetrical position to the “intermediate” ore deposits, such as porphyry coppers or massive sulfide deposits (acc. to Udubaşa et al., 1998). Hemispheres – smaller and smaller – suggest the possibility to locate also less and less larger entities (ore deposit, ore body, mineral parageneses, etc.).

Fluid circulation on shear zones produces significant changes of the host rocks, irrespective of the PT conditions and of the affected rock types. Very obvious is the influence of fluids on the metamorphic rocks, e.g. the case of metasomatic ores hosted by limestones and micaschists from the Rodna ore deposit. The micaschists are transformed by “hydrothermal diaphoresis” into secondary rocks consisting mostly of clay minerals. Even the limestones become a kind of “gruss” around the ore bodies (Fig. 2) due to partial dissolution of the calcite grains. After seeing such devastating effects it is normally impossible to accept anymore that the fluids percolating along the faults, rock contacts etc. do produce nothing in the rocks. A different case of epigenetic overprint has been seen at Borşa – Gura Văii, Maramureş county; here the Neogene microdiorites cut both the stratabound Pb-Zn-Cu ores, and the host rocks. The contact effects are stronger in ores, producing homogenization of exsolved phases and slight optical changes of sulfides.

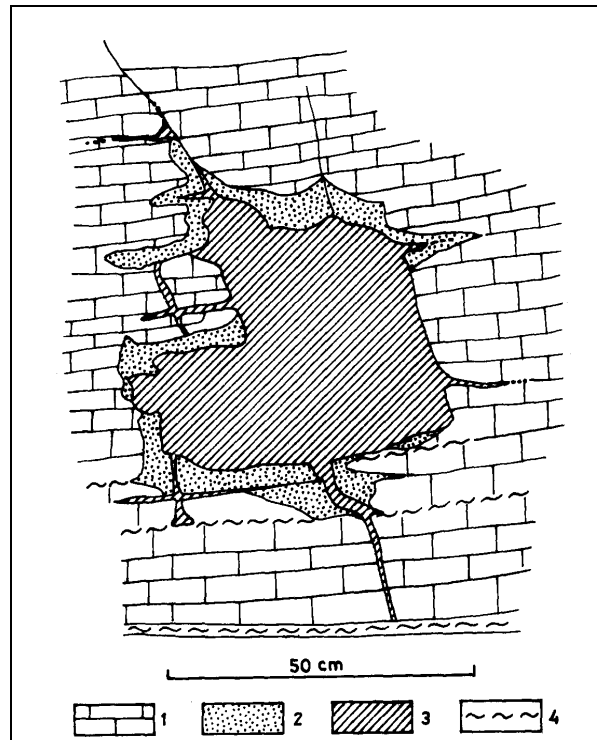


Fig. 2 – A metasomatic ore body located in metamorphic limestones of the Rebra Group (Upper Proterozoic), showing around it a partly “disintegration” of limestones (“Gruss”). The micaschists bands are completely argilised. Underground sketch (Rodna - Valea Vinului mine, Nepomuc level; G. Udubașa, 27.08.1968). 1- metamorphic limestones; 2- limestone “gruss”; 3- Pb-Zn ore; 4- argilised micaschists.

The Necessity of the Protore

It is obvious that in the case of the small-scale shear zones the circulation of juvenile fluids is less probable. This is why the existence of a protore, identified as such in several cases, is a necessity in order to identify a more reasonable source of metal(s). At Valea lui Stan and Valea Pianului (Sebeș Mts.) the amphibolites could be assigned to protores, showing highest gold contents as compared to other metamorphic rocks (Table 1). In addition, the nature of the sheared rocks correlates well with the main geochemical features of the gold ores (Table 2). The transformations within the shear zone show a retromorph overprint with excess production of either quartz or carbonates. Two distinct types of small sized SZRO can be delineated: (1) quartz dominated type with gold and additional elements as a function of the host rocks, e.g. Pb (Ghimnav Valley, Leaota Mts.), Cu (Valea lui Stan, Someșul Rece), Bi (Costești near Horezu, Căpățâna Mts.) or Sb (Jidoștița, Mehedinți Mts.), to which a constant

presence of As can be added; (2) carbonate dominated type, be calcite (Râmestî near Horezu, Căpățâna Mts.), be ankerite (Leaota Mts.), commonly associated with Fe and Cu sulfides. In the Leaota Mts. the fahlband-like ores are accompanied by variable amounts of Bi, Ni, Co, Ag, U etc.

Table 1

Gold contents of some metamorphic rocks from South Carpathians (ppm)

	Au
- Retromorphic amphibolite, Pianu Valley	0.1300
- Garnet amphibolite, Valea lui Stan	0.0446
- Retrom. Amphibolite, Vasilatu Valley	0.0305
- Biotite gneiss, Valea lui Stan	0.0075
- Micaschist, Valea lui Stan	0.0037
- Feldspar rich gneiss, Valea lui Stan	0.0025

Source: Udubasa et al. (1992)

Method used: RNAA (radiochemical neutron activation analysis).

Table 2

Relationship between protore petrography and dominant metal association in ores

- Amphibolites, Valea lui Stan	Au-As-Cu
- Biotite gneiss, ultrabasite, Jidostita	Au-As-Pb
- Biotite gneiss, amphibolite, ultrabasite, Costesti	Au-As-Bi
- Kyanite micaschists with quartz lenses containing titanian hematite, Valiug	Au-As-Sb
- Amphibolite, sericite schists, Somesul Rece	Au-As-Cu
- Amphibolite, granite, Ghimbav Valley, Leaota Mts.	Au-Pb-Bi

Sources: Lucca (1937), Udubasa (1993), Udubasa et al. (1992, 1998)

In both types of small sized SZRO there are no hydrothermal alterations. Rock transformations include desilicification of silicates (amphiboles to chlorites) or decarbonation of amphiboles and their relative Mg enrichment by Fe capture in sulfides. Such transformations are long-time lasting processes suggesting gradual re-equilibration of mineral parageneses in a metamorphic environment.

Syngensis-Epigenesis vs. "Mesogenesis"

The epigenetic overprint is more and more evident as the size of the shear zone increases. Not only an influx of deep-seated fluids is possible but also the anatectic granitoid formation, like in the Singhbhum shear zone, India. In such cases the ores may contain additional elements such as Cu, U and other metals. Talapatra (1968) advocated also the relationships between migmatite development and ore formation. The "solid solution" between the end-members syngensis and epigenesis (Udubaşa et al., 1998) occupies the whole area of the SZRO (Fig. 3). The unsolved problem is the identification of structural changes, which unequivocally can characterize the intermediate members (if any). This is why the term "mesogenesis" has been adopted in order to define the SZRO.

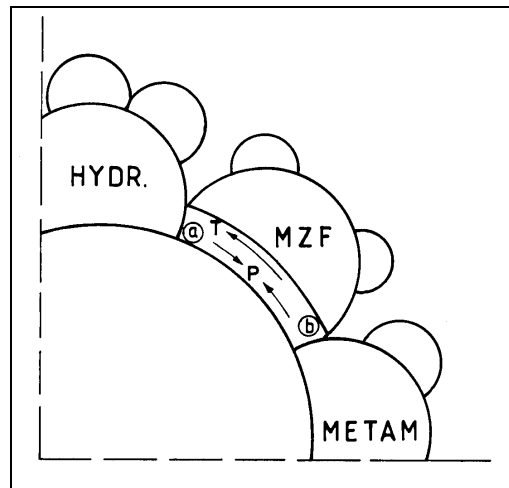


Fig. 3 – A detail of Fig. 1, showing the field of SZRO. a) mineralizations in large scale shear zones, in which epigenetic overprints are present; b) mineralizations in small scale shear zones, which should have a protere.

The PTX Conditions

The number of primary fluid inclusions in shear zone quartz is relatively small due both to natural decrepitation and to volume reducing and their closing. The fluid inclusions have a low salinity, the main components being CO_2 and NH_4 . The existing data suggest temperatures between 200°C and 500°C and pressures coincident to greenschists to granulitic facies. The stable isotopes ratios suggest both the contribution of meteoric waters and of those derived by metamorphic dehydration.

The sulfides of the shear zone ores at Valea lui Stan show a large variation of the sulfur isotope ratios, i.e. $\delta^{34}\text{S}$ between -17.83 and $+23.76$ ‰, suggesting multiple sulfur sources. The sulfides in the Leaota Mts. show the same large variations with a narrow interval of the $\delta^{34}\text{S}$ around -20 ‰ for the so-called Tâncava-Tibra ore type, which is very similar to the Scandinavian fahlbands (Fig. 4). See Udubașa (1993) for other details.

Ductile and Brittle

There are no pure ductile or pure brittle shear zones, at least if one takes into consideration the small sized ones. In addition, the ductility of metamorphic rocks is a matter related to the position of the shear plane to the foliation. The shear zones are typical of compressional settings, in which quartz, carbonates and sulfides concentrate in the dilatant zones (Boyle, 1959), the volume of which is relatively small (about 5 %) as compared to the whole shear zone. This corresponds to the volume of mineralized (quartz and carbonates included) bodies, e.g. at Valea lui Stan and elsewhere. The Alpine-type veins, generally non-mineralized, form in distensional zones (the veins are commonly open, show vugs with well developed crystals etc., features not encountered in the shear zones).

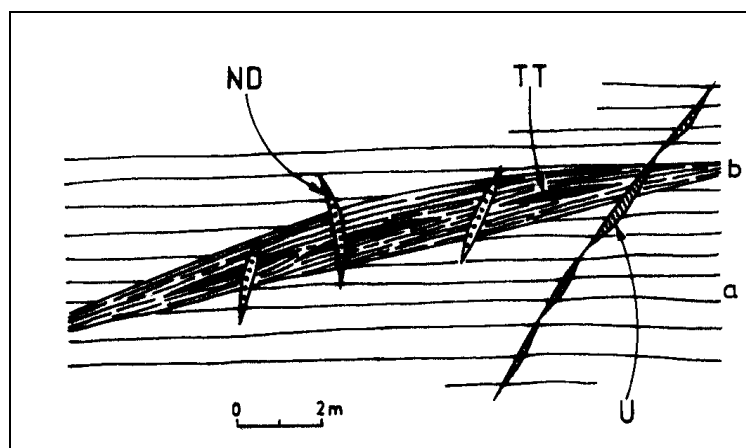


Fig. 4 – Fahlband-type mineralizations in the Leaota Mts.; pyrite-pyrrhotite ore of Tibra - Tâncava type (TT) in sheared rocks (b), Co-Ni-Ag-Bi ore of Neguleț - Dăniș type (ND) and late uranium mineralizations containing pitchblende and “tucholite” (U), located in micaschists and paragneisses (a) of the Lerești Formation (Upper Proterozoic to Lower Paleozoic) (Udubașa, 1993).

Magmatism and SZRO

Within the large scale shear zones the presence of magmatic rocks is relatively common. The anatectic soda granites are widespread in the huge Singhbhum shear zone (Fig. 5) but their relationship to the ores is not very obvious. The large gold fields of Ramagiri, Hutti, Kolar in Andra Pradesh, India, are also located in sheared rocks. The special genesis of such ores was early recognized by Ghosh et al. (1970) in the following way: “the gold-quartz mineralization in the Ramagiri gold field is envisaged to be the result of chemical reconstitution of the host andesitic lava aided by fluids given out during metamorphism of the associated sediments, and is of metamorphogenic (lithogene) origin” (p. 801). Alternative, non-magmatic models have been proposed also for other important gold ores in metamorphic rocks, e.g. Morro Velho, Homestake, Yellowknife, Muruntau, Yenisei River zone etc. (see Udubașa & Hann, 1988, for details and references). The important shear zone in the North of the Sebeș Mts. (Stelea, 1999) is accompanied by small bodies of dominant granodioritic to trondhjemitic character (Dobrescu & Liegeois, 2001). Nevertheless, the mineralizing grade of this shear zone is very reduced, suggesting that such rocks have had no major metallogenetic function. Ores occur only in the Pianului Valley, where the shear zone intersects a gold-rich amphibolitic pile (Fig. 6).

In small sized shear zones the magmatites are lacking. At Valea lui Stan there are only gneisses, at Someșul Rece and Văliug (Semenic Mts.) the Upper Cretaceous – Paleocene magmatites occur far away from ores. In other SZRO they are completely missing.

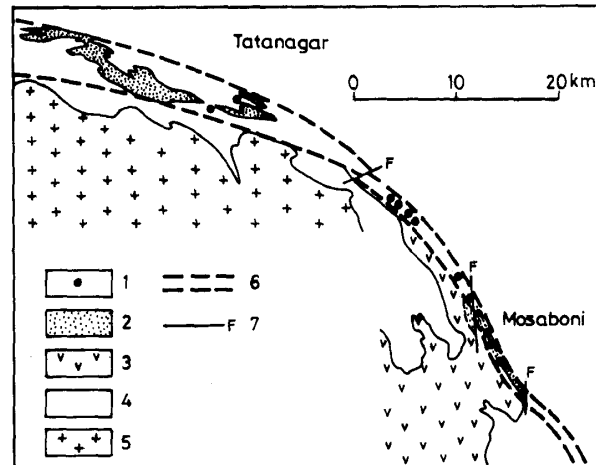


Fig. 5 – Copper mineralizations in the Singhbhum shear zone, Bihar, India (acc. to Ghosh, 1972, simplified). 1- copper deposits; 2- soda granites; 3- epidiorites; 4- metamorphics; 5- Singhbhum granite; 6- shear zone.

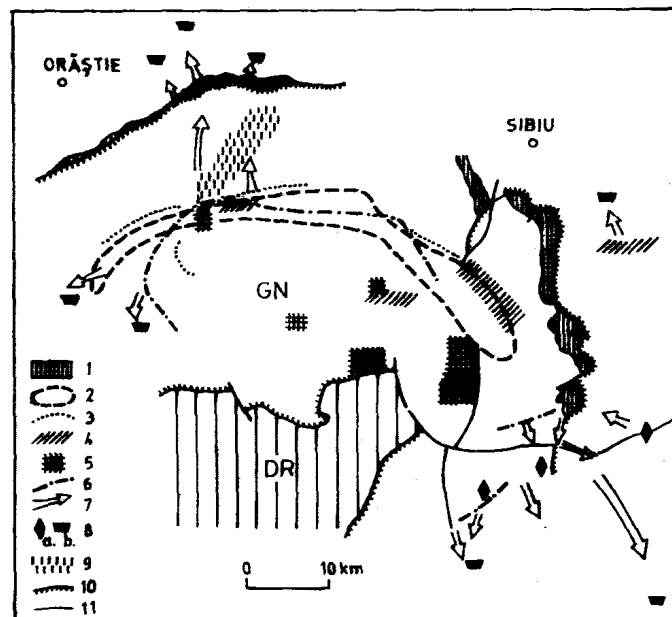


Fig. 6 – Gold occurrences in the central South Carpathians. 1- Sibișel Formation (greenschists), the main protore, showing incipient characteristics of a greenstone belt; 2- the manganese belt; 3- lenses of quartz and titanian hematite (locally rich in gold), in micaschists; 4- kyanite micaschists; 5- pegmatites; 6- blastomylonite belts; 7- migration trends of gold derived from different protores; 8- gold occurrences: a) primary, in shear zones, b) secondary, in alluvia; 9- the "gold anomaly" in the Sebeș Mts. (Udubasa et al., 1992); 10- Alpine overthrusts; 11- faults. GN = the Getic Nappe; DR = Danubian Realm.

Conclusions

Even if (too) shortly presented, the SZRO can be considered to represent a special class of mineralizations, called here "mesogenetic". They cannot be put in relation to a magmatic-hydrothermal activity, nor can they be correlated with the Schneiderhöhn's (1954) concept of ore deposits regeneration. Even if it is commonly easier to call the "classical archetypes" in explaining the genesis of ores, it is necessary also in some peculiar cases to search for alternatives, inasmuch as they can be coherently classified together with the classical ores. The understanding of the SZRO is not purely of academic interest, sometimes it is of utmost importance in successful prospecting and exploration activities.

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