CURRENT RESEARCH IN GEOLOGY APPLIED TO ORE DEPOSITS

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MAJOR STRUCTURAL FACTORS OF Au CONCENTRATIONS IN THE NORTH-EASTERN IBERIAN MASSIF (SPAIN-PORTUGAL): A MULTIDISCIPLINARY AND MULTISCALE STUDY

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Au ore deposits in late Hercynian vein-type deposits from the Iberian massif is mostly controlled by structural factors, especially (i) a long-lived tec tonic activity affecting the crystalline basement during the progressive uplift of the Hercynian belt, (ii) using microstructural stages of the pre-core quartz-lenses due to latest brittle deformational stages, (iii) rheological heterogeneities.

Vein-type deposits from Western Europe display a multisegmented polyphase and complex deformation of the vein structures which host the ores, each deformational stage characterized by specific metal deposition and wall-rock alteration. The one-space relationships between deformational events, the nucleating field types, and the specific resulting fluid-rock interactions and metal deposition, the exact timing of gold introduction within the veins are generally unknown. This work is an attempt to model Au-bearing vein formation, and to define the processes of Au-enrichments in area characterized by fairly good mining potential, comparing ores formed during similar geological events, and located within same metallogenic province. It has been supported by BRITE (Brite Euram programme, contract M2-020033). The area chosen is the northwestern Iberian province, which was one of the most actively prospected areas for gold, in Europe, in the last years.

The Au-mineralizations from the Hercynian zone:

A large number of gold occurrences is known in the Iberian massif. Some were known and mapped in Roman and pre-Roman times, others were mapped in time of exploration, mainly as a result of the efforts of mineral mining bureaus and geological surveys, and exploration companies, sometimes with involvement of universities. These Au-concentrations occur in many situations and rocks, often in granites (Coroeste, Tomino along the Malpica-Tuy shear zone, Peredoño, Pino), or a Palaeozoic sedimentary geological join in epigenetic metasomatism series displaying enrichment in organic matter preserving rather low mineralization rocks, quartzites, metasediments metasomatized and prehnitoid facies meta-sedimentary sequences) in the case of France, Tres Minas, Vila Pouca de Aguiar deposits in Portugal.

The careful characterization of geological and structural environments of Au veins is essential for a better understanding of the role played by surrounding rocks, and is of prime importance in exploration. Thus the range of host rocks (type of granite, chemistry and physical characteristics of metasediments and volcanics), and the degree and style of deformation, are key factors for the understanding of ore forming processes. The role of pre-concentrations, the effects of contrived rheological properties of rock mass on the propagation of deformation, and the fluid-rock interactions controlling rocks processes have to be especially investigated.

Conditions of ore formation have been estimated through a multidisciplinary characterization of wall-rocks, palaeoclimates (P-T-X-Y conditions), geotopographies (microtopographies patterns), trap, deformation and ores, and multiscale characterization of the enclosing formations (regional, field and mine studies of the host formations, soil geochemical studies, low and deep drillings, and structural studies).

Results

Au veins: granites, the examples of Coroeste, Tomino, Pino and Penedo.

The Coroeste area (North Western Galicia, Spain, Rio Tinto Mining I.p. progression zone), belongs to the northern part of the main Au deposit zone, so-called Malpica-Tuy shear band in Galicia (NW Spain). This major shear zone is underlined by series of syenite intrusive bodies intrusion formed during the D3 deformational stage. Field works at Coroeste have consisted in the coarse selecting of a deep drill hole (146.5 m depth). The mineralized zone is characterized by an intense...
VPA this phase is not well marked in A autonomic units, prevailiug a S1 Injection while in the other units D2 developed a S2 injection that transposes the S1, mainly in the meso pellic liohiliotes. Some quartz veins occur related to the deformation stage 2, the D3 stage is responsible for the large subvertical kilometric folds and for the uplifting of the outer structures. These veins are reactivated with dehedral shearing sense. At France D3 does not produce any penetrative cleavage, besides cross shears. It was observed large subvertical folds and one quartz band and a quartz vein are affected by dehedral shearing sense, these shears are filled up by iron oxides and quartz. In VPA, D3 deformation affects all the units with subvertical extension-cleavage (S3), striking N120°E, a late brittle-ductile deformation is expressed mainly by a tensal fracture system N40°E to N50°E. The rotation of the greatest principal stress (S1) from SE to NE induces a sinistral shear sense in these tensal fractures and in some cases the earlier subvertical foliation N120°S (S1/S2) is reactivated with dehedral shear sense. In some places these shear deformation is accompanied by intense hydrothermal alteration with silicification and chloritization (Tes Mines), D4 the D4 event affects all the inner structures. D4 is a brittle phase with two conjugated fracture system striking N190°W to N200°E, conditioned by a strain field that is consistent with a dehedral shearing prevailing in the previous shear planes N125°W Villanuca fault (N100°E) in France area and Régna - Verin fault (N15°-N20°E) in VPA area are D4 events.

In VPA area Au-mineralizations occur due to different structures associated either in quartz veins predominantly subvertical and striking N30°E to N50°E (Vale de Campo, Vale de Eguad and Vehânumba) corresponding to sinistral fractures related to D3 or with silicified zones in metasediments which are related to dehedral shear zones N120°E Tres Minas mineralizations is controlled by the latter one.

Studies of textual and chronological relationships between the different ore minerals have shown that arsenopyrite, pyrite and galena are the main sulphide minerals in mineralized structures from France and VPA areas and systems associated with the quartz infillings of D3 to D4 structures. At France gold occurs at a combined state within arsenopyrite II as well as electrum during a relatively late stage (quartz II - siderite - sericite - chlorite) of the vein fillings; in VPA mineralized structures electrum or gold occur predominantly, as a latter phase in intraplateau spaces between pyrite and arsenopyrite, or in microcracks inside arsenopyrite pyrite generally associated with galena and sulphides. The latest gold is associated with aqueous fluid migration.

**Main Stages of Fluid Migration in Relation with Deformation**

Three successive stages are recorded in the formation of most studied gold-bearing quartz veins. They are each characterized by set of P-T conditions, mineral assemblage, fluid composition and deformational state (closely related to fluid flow regime). The order of succession known no exception.

**Quartz-muscovite formation**: Milky quartz veins and veinsless formed mostly after the emplacement of late per aluminous granitoids (probably Westphalian), they also post-date some subsidence alteration affecting these granitoids (subaerial weathering at Pendémono, quartz dissolution at Pita, greisenization at Tomino). Diffuse alteration, and sulphide crystallization in some instances (pyrite, chalcopyrite - arsenopyrite) in the surrounding rocks seem to precipitate the deposition of massive milky quartz in open space (tension gashes at Concordia and Tomino, filling of earlier structures at Pendémono). No true mylonites were developed in the surroundings of the quartz veins. These features are at variance with those of typical Late Variscan shear-zones which are generally observed nearby at a regional scale.

**Hydrothermal conditions (pressures about 100 and temperatures of 350 to 500°C) are recorded and are roughly the same as those prevailing during the late metamorphic stage in the Variscan deposits during or just after the hyper-tensional event. There is no clear evidence of gold deposition during the stage, even at low concentrations in sulphides (pyrite, pyrrhotite, arsenopyrite) (see below).**

**Quartz vein reactivation**: Due to repeated tectonic reactivation, early milky quartz veins were strongly reactivated and were repeatedly subjected to intense fracturation; there were several alternations of micro-crack formation and healing or sealing by hyalite or clear quartz. Sulphide deposition (barren arsenopyrite) locally took place in the microcrystalline quartz, but was very massive. The alternation of increasing and decreasing permeabilities recorded by the quartz veins formation are affected in strong pressure variations in the and the same vein, as demonstrated by the extreme range of calculated fluid densities from one section to the other even within a small quartz vein (see left). Some gold introduction could be done to this stage in some instances. In both cases, early carbonate fluids percolating granite are assumed equilibrated with the metamorphic host rocks.
subparallel faulting and microcracking of sandwiches of granite bands and metamorphic series, but coincide strictly with the presence of discrete networks of quartz-anataseUMMY white clay (tension gashes) within the foliated granites. In most mineralized areas (the two granite sill), the dominant minerals are thin quartz-anatase red beds oriented from surface two to 90 meters depth; (i) NSW; E, nearly parallel to the foliation plane (dip: 32°15’ SW), (ii) N90°E to N10°E (dipping 50°-70’), decl. W direction being dominant, (iii) N15°W, less frequent.

A great variety of fluids linked to low-field heat anomalies within the same shear zone which affected the metamorphic surrounding rocks. Quartz precede anatase in the dominant (N90°-110°E) veins or are CO2-rich fluids and are followed by H2O-CO2-CaCO3 fluids having a low density volatile phase. Aqueous fluids have been recognized in most samples in fluid inclusion planes, especially in the mineralized areas, and are associated with the occluded-chlorite-phenocoele-Bi-BiFm. They are followed by fast late generation of low temperature brines.

Similar geometric and chronologic features have been found in Tomiso (South Gaulia). Spain, IGS prospectron zone, where the granite is affected by an intense microcracking accompanied by strong water-rock interactions of relatively high temperature (greyish). Field and laboratory works demonstrate a rather unusual geometric feature of the fluid migration: 'The highest density of quartz veins occurs in the central part of the granite dyke (Alto de Pozas), within a segment of 2 km length. The sets of quartz veins (1-2 cm thick) are limited to a granite dyke and oriented NNW-SSE, nearly dipping Northwards. The quartz veins are often spaced about 1 m, with thickness ranging from simple features, with occasional filling, suffices to few mm. Structurally, quartz veins are filling extension gash fractures developed in the last stage of the third phase of deformation. The foliation in the Pozas granite is parallel to the schistosity and corresponds to the third phase of the hemi-peridotitic deformant (N 160°-170°E dipping around 50° NE).

Oriented samples have been taken along a profile westwards of the Ural zone. Microcracking is only represented as fluid inclusion planes either in the granite or in the major quartz tension gashes, oriented N90°E-SW direction. In the vein itself, the geometry of the late microcracking is dominated by fissures parallel or subperpendicular to the (N150°E) to the vein direction. The number of cracks increases from the vein towards the granite, indicating a channelled fluid (CO2-CaCO3 rich fluids) migration through cracks. New microcracking produces the anatase recrystallization, but a last breccia event is needed to get new microcracking and mineralization (clot quartzous fluids associated with goethite and, chlorite, biotite, muscovite, nacline schist) associated with aqueous fluids of relatively low temperature. At each stage there is a constant oscillation of the microcrack network indicating a probable persistence of an major stress direction all along the hydrothermal history of the granite.

As complications in metamorphic series: the Vilarica fault zone and the Vila Fraca de Agua area.

In some structural studies have been carried out in North-Eastern Portugal (Vilarica Fault Zone-Pinhel de Pires and Vila Pousa de Agua area VPA) in order to reconstruc the evolution in the different deformational stages and their relationships with metallurgy. These two areas are also considered to be better for giving a good rough of relation between metamodromic host rocks with mineralized structures.

Vila Pousa de Agua (VPA) is a vast area characterized by several occurrences of precious mineralization namely Tomislava (now the Romans have exploited ISM on two open pits) and the north-south-oriented (Current) with several occurrences of gold mineralization.

In Franco and VPA area, the admitted regional structural models for the Central I6rian Zone appear to be valid. France is situated on the metamorphic "Donau inferior group" involving host rocks of lower Devonian and VPA on the parasutonic "Peritrianasan Group" involving host rocks of lower Silurian (Llandoverian - to lower Devonian (Silurian). Cartography and laboratory studies on VPA are allowed for the identification of the following lithostratigraphic units (A, B, C, D), predominantly constituted by quartzites, chlorites phyllites, black shale interbedded with acidic metavolcanic and calcitite intercalae. The A unit represents an autochthonous bimestrata and B, C, and D units the parautochthonous (Peritrianae Group).

At least, four waterantonite deformational phases are recognised: (i) The D1 characterized by axial planar shear cleavage (S1) with reference to the north (domain of the monoclinic foliads). There is a continuous deformation process between D1 and D2 giving place to important thrust nappes, responsible for the paratautochthonous character of the "Peritrianae Group"; (ii) the well marked subhorizontal S2 cleavage, at
and are very similar to those described in the metamorphic environments such as in the Vila Pouca area. However, these fluids which are important for the formation of chemical traps for gold (sulphides and early quartz deposition), seem to have less impact on the transport and deposition of the economic concentration of gold.

**Intense microfracturing and main gold deposition/enrichment stage: A trend of isotopic reactivation (frequently a compressive regime characterized by new specific directions of major stresses) under quite different P-T conditions resulted in the main stage of gold ore deposition. The reactivation of early quartz veins (stages 1-2), resulting in microcracks which were now healed but not sealed by quartz. Native gold deposition took place, together with sulphides (galena, chalcopyrite-Bi/Blismuthinite) and sulphosalts (Fe-Ag dominated) in frequent association with calcite (or siderite at Franca-Fa. ChE-zircon), along these cracks, especially when they intersect earlier sulphides (anoeosmine). The economic ores do not result from a reworking of preconcentrations. Although at the root of the concept of remobilization of gold bearing shear-zones (Bonnefous and Marcoux, 1980), the very fact of gold preconcentration in early sulphides could not be assessed in our studies. There is no evidence for a remobilization of early concentrated gold in the anoeosmine fraction, again with variance at the maximum concept.**

**CONCLUSIONS**

The interactions between regional studies, industrial research and laboratory approaches have helped to get a definition of the factors controlling ore formation (deformation, lithology, time-space relationships between ore deposition and major geological events...) and the modelling of oncolastic processes. They yield to the following conclusions:

- a whole, the successive appearance of the three stages just described reflect a series of major changes which are in turn correlated to the evolution of the Variscan belt: changes in P-T-X conditions (see Boiron et al., this abstract volume), and changes in the factors controlling the fluid migration. The nature of the fluid migration and the geometry of the thermal anomalies has changed from stage to stage. It appears that the successive events recorded in the more long lived mineralized areas reflect progressive uplift of segments of the Variscan belt at the end of its hyper-deformation stage, while long lived thermal anomalies (315-285 Ma) evolved at depth.

- the major factors controlling the enrichment are linked to the:

  1. formation of the main channels: the complex subaerial exhumation of early formations from D1 to D4 are responsible for specific structures which have evolved from ductile to brittle regime and are associated with the main shear zones affecting the Gallicia area. The earliest quartz deposition, which creates the specific potential trap for later mineralizations are formed at that stage (D3 to D4). Contrary to the "gold bearing shear zone" model (Bonnefous and Marcoux, 1987, 1989), it is shown that mineralized faulted areas are not typical ductile shear zones: major shear zones are barren, and the evidence of early ductile deformation due to shear is generally minor along the mineralized faults.  

  2. the formation of the most efficient trap for ores at the stage of Auvriolite, which is favoured by:

     - strong microfracturing stages of the previous quartz lenses due to late brittle deformational stages. Such microfracturing is extremely complex in detail, and results from the superposition of each brittle stage on the early quartz matrix (milky quartz cemented by microcrystalline quartz).

     - strong rheologic heterogeneities, such as those produced by the presence of metamorphic quartz lenses within micaschists, or granite bands in metamorphic rocks (Cornejuso, Torino) show that stress intensification is higher in the quartz lenses in the center and near its boundaries, creating strong increasing of intense fracturing of the vein than the host rock, and the lack of mineralization outside the quartz veins. Therefore, the early quartz matrix (milky quartz cemented by microcrystalline quartz) acquires its permeability thanks to further stress modifications, which yield higher fluid flows within the veins than in the surroundings. This process explains that only quartz veins are mineralized although gold input are late compared to the quartz matrix formation.

References
