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PROCEEDINGS OF THE SECOND BIENNAL SGA MEETING
GRANADA / 9 - 11 SEPTEMBER 1993

CURRENT RESEARCH IN GEOLOGY APPLIED TO ORE DEPOSITS

Edited by

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Current Research in Geology Applied to Ore Deposits. Fenoll Hach-Ali, Torres-Ruiz & Gervilla (eds) (1993). ISBN 84-338-1772-8

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

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Au ore genesis in late Hercynian vein type deposits from the Iberian massif is mostly controlled by structural factors, especially : i) a long-lived tectonic activity affecting the crystalline basement during the progressive uplift of the Hercynian belt, ii) strong microfracturing stages of the previous quartz lenses due to latest brittle deformational stages, iii) rheological heterogeneities.

Au-vein type deposits from Western Europe display a multistage metallogenesis, a multistage and complex deformation of the vein structures which host the ores, each deformational stage being characterized by specific metal deposition and wall rock alteration. The time-space relationships between deformational events, the percolating fluid 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 areas characterized by fairly good mining potential, comparing ores formed during similar geological events, and located within same metallogenic province. It has been supported by EC (Brite Euram programme, contract MA2M 0033).The area chosen is the north-wester Iberian province, which was one of the most actively prospected areas for gold, in Europe, in the last years.

The Au-mineralizations from the Hisperic zone

A large number of gold occurrences is known in the Iberian massif. Some were known (and mined) in Roman and pre-Roman times, others were found in more or less recent times, mostly as a result of the efforts of national mining bureaus and geological surveys, and exploration companies, sometimes with involvement of universities. These Au-concentrations occurs in many situations and rocks, often in granites (Corcoesto,Tomino along the Malpica-Tuy shear zone, Penedono, Pino), or in Paleozoic sediments (anchi- to epizonal metamorphic series displaying enrichments in organic matter presenting rather low maturation index, quartzites, metavolcanites metasediments and greenschist/lower amphibolite facies metasedimentary sequences) in the case of Franca , Tres Minas, Vila Pouca de Aguiar deposits in Portugal.

The careful characterization of geological and structural environments of Au-veins is essential for a correct understanding of the role played by surrounding rocks, and is of prime importance in exploration. Thus, the nature 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 contrasted rheological properties of rock units on the propagation of deformation, and the fluid-rock interactions controlling redox processes have to be especially investigated.

Conditions of ore formation have been estimated through a multidisciplinary characterization of wall-rocks, paleofluids (P-T-X-V conditions), paleopathways (microfracturing patterns), traps, 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 in granites: the examples of Corcoesto, Tomino, Pino and Penedono

The Corcoesto area (North Western Galicia, Spain; *Rio Tinto Minera s.a. prospection zone*), belongs to the northern part of the major deformation zone , so-called Malpica-Tui shear band in Galicia (Spain). This major shear zone is underlineated by series of syntectonic granite intrusions formed during the D3 deformational stage. Field works at Corcoesto have consisted in the complete drilling of a deep drill hole (746.5 m depth). The mineralized zone is characterized by an intense

VPA this phase is not well marked in A autochtonous unit, prevailing a S1 foliation while in the other units D2 developed a S2 foliation that transposes the S1, mainly in the most pelitic lithologies.Some quartz veins occur related to this deformation stage; 3) the D3 event is responsible for a large subvertical kilometric folds and for the uplifting of the former structures. These ones are reactivated with dextral shearing sense. At França D3 does not produce any penetrative cleavage, besides important shears, it was observed large subvertical folds near these shear bands and the quartz veins are affected by dextral shearing sense, these shears are filled up by iron oxides and quartz. In VPA, D3 deformation affects all the units with subvertical crenulation-cleavage (S3), stricking N120°E; a late D3 brittle ductile deformation is expressed mainly by a tensional fracture system N40° to N50°E. The rotation of the greatest principal stress (s1) from NE to NNE induces a sinistral shear sense in this tensional fractures and in some cases the earlier subvertical foliation N120(S0//S1//S2) is reactivated with dextral shear sense. In same places this shear deformation is accompained by intense hydrothermal alteration with silicification and chloritization (Tres Minas); 4) the D4 event affects all the former structures . D4 is a brittle phase with two conjugated fracture system stricking N10W to N20E, conditionned by a strain field that is consistent with a dextral shearing prevailing in the previous shear planes N120 Vilariça fault (N10E) in frança area and Regua - Verin fault (N15-to N20E) in VPA area are D4 events.

In VPA area Au-mineralizations occur in different structures associted either in quartz veins predominatly subvertical and stricking N30E to N50E (Vale de Campo, Vale de Egua and Velhaquinhas) corresponding to sinistral fractures related to D3 or with silicified zones in metasediments which are related to dextral shear zones N120E Tres Minas mineralization is controlled by the latter one.

Studies of textural and chronological relationships between the differents ore minerals have shown that arsenopyrite, pyrite and galena are the main sulphide minerals in mineralized structures from França and VPA areas and appears associated with late quartz infilling of D3 to D4 structures. At França 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 intragranular spaces between pyrite and arsenopyrite, or in microcracks inside arsenopyrite/ pyrite generally associated with galena and sulphosalts. The latter 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 its own set of P-T conditions, mineral assemblage, fluid composition and deformational state (closely related to fluid flow regime). The order of succession knows no exception.

Quartz matrix formation : Milky quartz veins and veinlets formed mostly after the emplacement of late peraluminous granites (probably Westphalian); they also post-date some subsolidus alteration affecting these granites (albitization-tourmalinisation at Penedono, quartz dissolution at Pino, greisenisation at Tomino). Diffuse alteration, and sulphide crystallization in some instances (pyrite, then barren arsenopyrite) in the surrounding rocks seem to preceed the deposition of massive milky quartz in open space (tension gashes at Corcoesto and Tomino, filling of earlier structures at Penedono). 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.

High P-T conditions (pressures above 1Kb and temperatures of 350° to 550°C) are recorded and are roughly the same as those which prevailed during the late metamorphic stage in the Variscan terranes during or just after the hyper-collision event.There is no clear evidence of gold deposition at that 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 reworked and were repeatedly subjected to intense fracturation; there were several alternances of micro-crack formation and healing or sealing by hyaline or clear quartz. Sulphide deposition (barren arsenopyrite) locally took place in the microcrystalline quartz, but was never massive. The alternances of increasing and decreasing permeabilities recorded by the quartz veinlets formation are reflected in strong pressure variations in one and the same vein, as demonstrated by the extreme range of calculated fluid densities from one inclusion to the other even within a small quartz grain (see later).Some gold intrduction could be related to this stage in some instances. In both cases, early carbonic fluids percolating granite are assumed equilibrated with the metamorphic host rocks, subparallel faulting and microfracturing of sandwiches of granite bands and metamorphic series, but coïncide strictly with the presence of dense networks of quartz-arsenopyrite veinlets (tension gashes) within the foliated granites. In most mineralized areas (the two granite sills), the dominant structures are thin quartz-arsenopyrite veinlets oriented from surface two to 500 meters depth : i) N30° E, nearly parallel to the foliation plane (dip : 50±10°W) , ii) N90° to N110°E (dipping 50-70°N), the E-W direction being dominant , iii) N150°, less frequent.

A great variety of fluids linked to long lived heat anomalies within the same shear zone which affected the metamorphic surrounding rocks. Quartz preceding arsenopyrite in the dominant N90-110°E veinlets are CO_2-H_2O rich fluids and are followed by H2O-(CH4-CO2) 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 assemblage chlorite-phengite-Au-Bi/Bism. They are followed by one late generation of low temperature brine.

Similar geometric and chronologic features have been found at Tomino (South Galicia, Spain, *ITGE prospection zone*) where the granite is affected by an intense microfracturing accompanied by strong water-rock interactions of relatively high temperature (greisens). 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 to 10 cm thick) are limited to granitic dyke and oriented N70°-80°W, steeply dipping Northwards. The quartz veins are often spaced about 1 m, with thickness ranging from simple fissures, with occasional filling sulfides to few dm. Structurally, quartz veins are filling extension gash fractures developped in the last stage of the third phase of deformation. The foliation in the Pedrada granite is parallel to the schistosity and corresponds to the third phase of the hercynian deformation.(N 160°-170°E dipping around 50° NE) .

Oriented samples have been taken along a profile vein/fresh granite of the Urgal zone. Microfissuring is only represented as fluid inclusion planes either in the granite or in the major quartz tension gashes, oriented N80±10° direction. In the vein itself, the geometry of the late microfracturing is dominated by fissures parallel or sub-perpendicular to the (N150°E) to the vein direction. The number of cracks decreases from the vein towards the granite, indicating a chanellized fluid (CO2-CH4 rich fluids) migration through cracks. New reactivation produces the arsenopyrite crystallization, but a late brittle event is needed to get new microfissuring and mineralization (dilute aqueous fluids associated with gold-chlorite, and chalcopyrite, sphalerite, bismuthinite, native bismuth) associated with aqueous fluids of relatively low temperature.

At each stage there is a constant orientation of the microcrack network indicating a probable permanence of the major stress direction all along the hydrothermal history of the granite.

Au concentrations in metamorphic series : the Vilariça fault zone and the Vila Pouca de Aguiar area

Important structural studies have been carried out in North-Eastern Portugal (Vilariça fault zone -França deposit and Vila Pouca de Aguiar area VPA) in order to reconstruct the evolution in the different deformational stages and their relationships with metallogeny. These two areas also are considered to be better for giving a good image of relation between metasedimentary host rocks with mineralized structures.

Vila Pouca de Aguiar (VPA) is a vast area characterized by several occurrences of auriferous mineralizations namely Tres Minas (were the Romans have exploited 16Mt on two open pits) and the northeasternmost sector (Curros) woth several occurrences of gold mineralizations.

In the França and VPA areas, the admitted regional structural models for the Central Iberian Zone appear to be valid. França is situated on autochtonous "Douro inferior Group" involving host rocks of lower Devonian and VPA on the parautochtonous "Peritransmontano Group" involving host rocks of lower Silurian (Landoverian) to lower Devonian (Ribeiro, 1974). Cartography and lithostratigraphic studies on VPA area allowed the individualization of four lithostratigraphic units (A, B, C, D), predominantly constituted by quartzites , chlorites phyllites, black shales interbedded with acid metavolcanic and dalc silicate rocks. The A unit represents an autochtonous basement and B, C, and D units the parautochtonous (Peritransmontano Group).

At least, four Hercynian deformational phases are recognized : 1) The D1 characterized by axial planar slaty cleaveage (S1) with vergence to the north (domain of the recumbent folds). There is a continous deformation process between D1 and D2 giving place to important thrust nappes, responsible for the parautochton character of the "Peritransmontano Group"; 2) the well marked subhorizontal S2 cleavage. At França, it is overturned to south , with reverse sense of the thrusts ; at and are very similar to those described in the metamorphic environments such as in 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 microfissuring and main gold deposition/enrichment stage: A renewal of tectonic 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 deposits formation. 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/Bismuthinite) and sulphosalts (Pb-Ag dominated)in frequent association with calcite (or siderite at França)- (Fe) chlorite, (± sericite) , along these cracks, especially when they crosscut earlier sulphides (arsenopyrite). The economic ores do not result from a reworking of preconcentrations. Although at the root of the concept of maturation of gold bearing shear-zones (Bonnemaison and Marcoux, 1989), 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 arsenopyrite lattice, again at variance with the maturation concept.

CONCLUSIONS

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

- as 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 a segment of the Variscan belt at the end of its hyper-collision stage, while long lived thermal anomalies (315-285 Ma) evolved at depth.

-the main factors controlling the enrichments are linked to the :

1- formation of the main channels : the complex superimposition of early deformations from D1 to D4 are responsible for specific structures which have evolved from ductile to britlle 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 (Bonnemaison 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 shears is generally minor along the mineralized faults.

2- the formation of the most efficient trap for ores at the stage of Au mobility, 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 superimposition of each brittle stage on the early quartz matrix (milky quartz cemented by microcrystalline quartz).
- strong rheological heterogeneities, such as those produced by the presence of metric quartz lenses within micaschist, or granite bands in metamorphic rocks (Corcoesto, Tomino) show that stress intensities are higher in the quartz vein, in the center and near its boundaries, this explaining a more intense fracturing of the vein than the host rock, and the lack of mineralization outside the quartz vein. Therefore, the early quartz matrix (milky quartz cemented by microcristalline quartz) acquires its permeability thanks to further stress reactivations, which yield higher fluid flows within the veins than in the surroundings. This process explains that only quartz veins are mineralized although the gold inputs are late compared to the quartz matrix formation.

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