5.9. Paragem 9 (extra): Minas de ouro, Penedono

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Stop key-points

- The mineralization is mainly arsenopyrite in quartz veins, associated to second order shear zones related to the tip of the ZCDML, developed in the granites;
- The mineralization is controlled by ductile to brittle structures.

Geographical setting

Introduction

The gold mineralization at Penedono is spread by several mines and occurrences; we have selected three of them for our study, by their importance, and appropriate exposures of the outcrops.

Some of these mines have been object of mining concessions such as Dacotim and Stº António-Vieiros. The other area studied named Ferronha is a claim where some mining works for evaluation have been done in the past.

The area is located in the Central Iberian Zone *(CIZ)*, Central Portugal, on the south margin of the Douro River in the Viseu District. The three groups of mines are disposed along an axis oriented NW-SE, spaced one each other about 5 Km (Fig. 5.27).

The area have been mapped on the 1/25.000 scale in order to establish the geological settings and the structural controls of the mineralized veins as well. The main geological features common to this group of mines can be listed as follows:

- The mineralization is intragranitic and occurs in two mica granites with an emplacement controlled by sin to late D_3 variscan phase;
- The mineralization is mainly arsenopyrite in quartz veins, associated to second order shear zones, developed in the granites;
- The quartz veins are deformed and exhibit "*en echelon*" pattern. It is possible to identify several generations of arsenopyrite associated to this deformation;
- A strong hydrothermal alteration is developed both in the contact of the veins, and in the neighbourhood of the mineralized areas;
- The mines and mineral occurrences are lined up on an axis striking N60W. This trend is parallel to the main elongation of the granitic massifs, and also to the major Malpica - Lamego shear zone.

Country metassediments belong to the Douro Group of Lower Cambrian age (Sousa, 1982). The variscan deformation phases identifiable regionally are D_1 and D_3. D_1 is responsible by the regional structure of the metassediments, developing meso to macroscopic folds of sub-horizontal axis and an axial plane cleavage S_1 striking N60ºW. The D_3 phase folds are homoaxial with D_1 folds. A crenulation cleavage S_3 is well developed, also with recrystallization and orientation of biotite (Sousa, 1982).

The granitic massif that hosts the mineralization installs itself in the core of the D_3 antiform defined in the Cambrian metassediments, of the Douro Group. The internal structures defined in these granites such as orientation of the different facies mapped, and the internal granitic foliation are parallel to the D_3 structures.

Some K-Ar radiometric ages have been obtained for the different facies of this massif, giving ages ranging from 320 to 300 MA (Ferreira et al.,1987a), clearly in the limits of the age we expect for the sin to late D_3 variscan phase (Noronha et al., 1979; Dias & Ribeiro, 1995).

Geological setting

The gold mineralization at Penedono area is located in a wide band of variscan two mica granites installed in the major D_3 anticline Armamar-Meda-Escalhão. They present characteristics of peraluminous "S type" (Chappel & White, 1974), and occur as alochthonous and parauthoctonous massifs, generated by crustal melting along big shear zones related with variscan D_3 (Ferreira et al., 1987b). It is possible to identify two different granitic massifs; Tabuaço and Penedono. They have typical internal structures and they are physically separated by stripes of Douro Group metassediments (Fig. 5.27a). The Tabuaço Massif has an elliptic shape with its major axis trending N60ºW. The deformation expressed by the orientation of the micas, is almost imperceptible, being only identifiable in some facies, and it is parallel to the elongation of the massif. All the facies are affected by ductile to brittle shear. The granites of Penedono Massif are strongly deformed with a very regular foliation, also N60ºW, parallel to the contacts between the different facies. Restites and schlieren are aligned in the same direction. These facts make us consider the Massif of Penedono relatively more *in situ* than the Tabuaço massif. This massif represents a greater displacement from their roots, beeing emplaced in an higher crustal level. This difference between the two massifs can also correspond to a slight difference in the age of intrusion. In fact, some K-Ar datation confirms an age for the Penedono Massif

of 320-315 m.y., clearly sin tectonics to D_3 and an age of 315-300 m.y. to the Tabuaço Massif, corresponding to a late-D_3 installation (Ferreira et al., 1987c).

The main granite facies in the area is the Sendim granite, a two mica medium grained (f= 2-3 mm) with foliation N60ºW. In the area of the mine of Stº Antonio-Vieiros occurs the muscovitic coarse-grained Laboreira granite (size 4-5 mm). Monte Airoso granite with muscovite and tourmaline is strongly affected by shear.

The Paredes da Beira granite is muscovitic with rare biotite, locally silicified, and with phosphates (groups of triphilite-scorzalite), tourmaline and dispersed sulphides. In the Penedono area the contact of Paredes da Beira granite with the regional two mica granites is sharp and the granite is associated to several stocks and veins of aplites and pegmatites, frequently mineralized with Sn-W. Intruding the centre of the massif occurs a porphyritic granite with fine grain, biotite dominant, the Dacotim granite.

Ductil to brittle shear oriented around E-W, senestral, affect all the facies of these massifs. We consider these shear conjugated of the major shear Malpica - Lamego - Vilar Dam (Moimenta da Beira).

Geochemical and mineralogical approach

Detailed geochemical studies by Silva & Neiva (1990), indicates peraluminous affinities of these granites with a molecular ratio $Al_2O_3/(CaO+Na_2O+K_2O)$ ranging from 1.19 to 1.58, and normative corundum lesser than 3.14. In the same study, two trends were defined in the de La Roche (1964) diagrams, evidentiating fractionation and metasomatism. Trace elements indicate their collision and crust-dominated tendency. In the study (op. cit.) the authors concluded of the granite magmas were originated at about 700 ºC and 4kbar, completely crystallized at 450 ºC.

The mineralogy that represents the main evolution conducting to, and related, Au-mineralization, is summarized in Table 5.3. Earlier studies (Silva & Neiva, 1990, Sousa & Ramos, 1991) also present, more detailed, mineralogic studies.

After the magmatic stage, deuteric processes produced an initial sodium alteration, evidentiated with the albitization of plagioclase accompanied by the growth of white mica over the same plagioclase. Latter, potassic alteration is represented by the growth of microcline, both intergranular and as replacing albitized plagioclase. Deuteric alterations don't recover completely earlier mineralogy.

The hydrothermal stage is identified associated to and in mineralized veins. Greisenisation occurs in the contact vein/granite, and is responsible by lost of feldspars and an increasing in white mica.

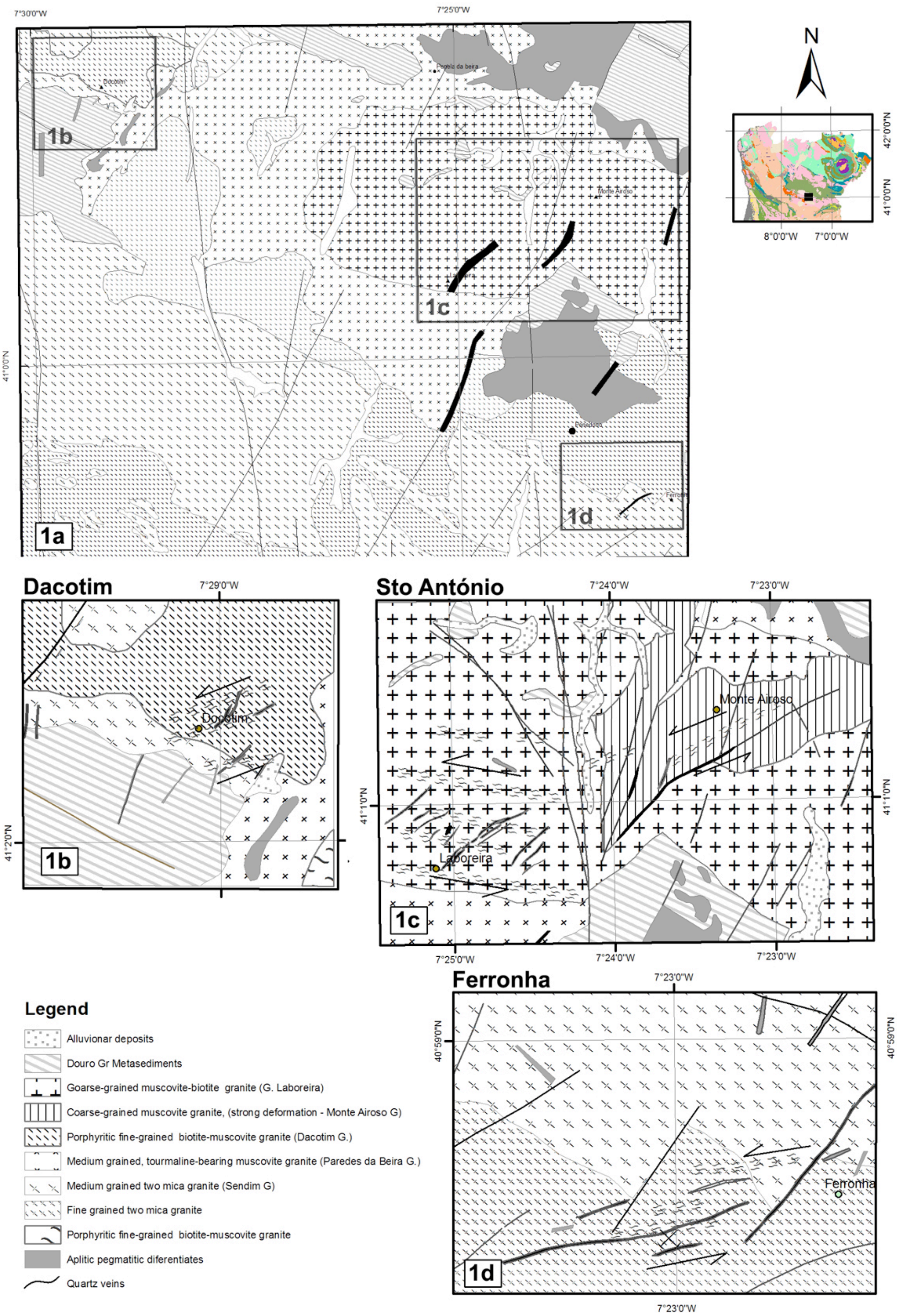
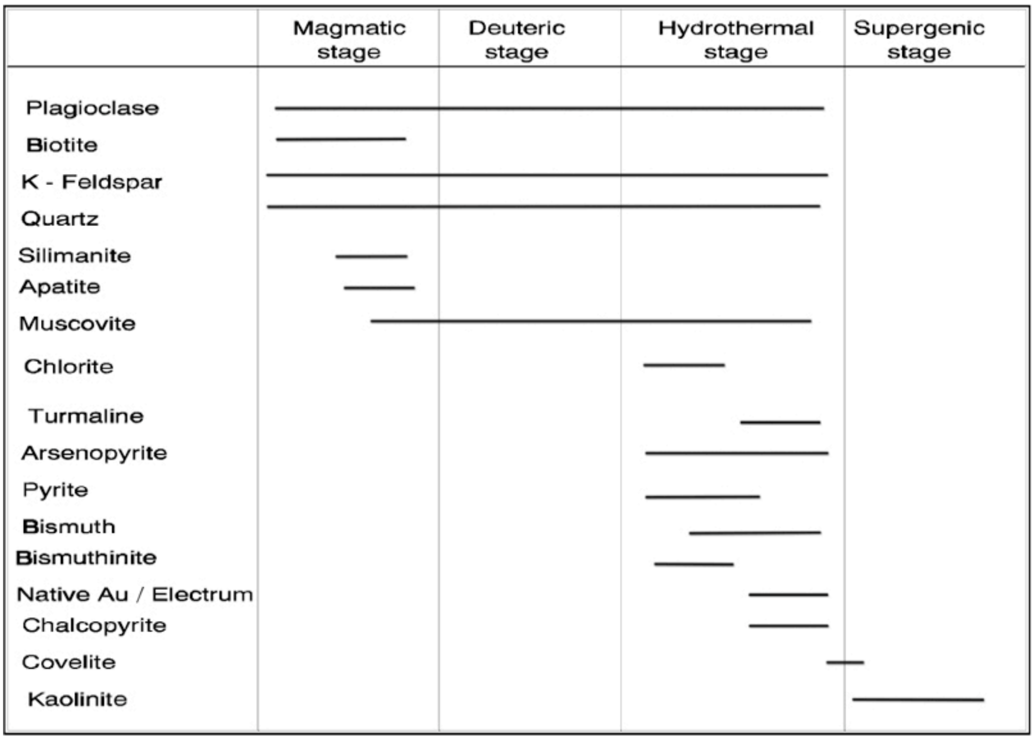


Figure 5.27 – **a**. Geological sketch map of Penedono mining area. Geological sketch maps of: **b**. Dacotim Mine, **c**. Sto António Mine and **d**. Ferronha Mine. Adapted from: Ferreira et al. (1987c). "Carta Geológica de Portugal, Folha 14-B (Moimenta da Beira) à escala 1:50000".

Table 5.3 - Mineralogy conducting or related with Au-mineralization



The hydrothermal stage is identified associated to and in mineralized veins. Greisenisation occurs in the contact vein/granite, and is responsible by lost of feldspars and an increasing in white mica.

Due to the strong deformation that affects the granites, quartz shows systematic ondulating extinction, sometimes with mortar texture. Sillimanite occur as needle-like crystals, associated to the deformation. Plagioclase, originally with a composition about An$_{15\text{-}10}$. grades to albite, An$_5$. Biotite alters to white mica in the igneous stage, concomitant to the beginning of crystallization of muscovite, and to chlorite in the hydrothermal stage. Includes zircons and monazite that develops pleocroic halos. Microcline, when igneous, is perthitic; when associated to deuteric potassic alteration, replaces albite. This replacement don't affect plagioclase that was not completely affected by albitisation White micas occurs during the different stages, exhibiting different textures. Originally as subhedral slabs or replacing biotite, the muscovite crystallizes then, needle-like, along shear planes during the late magmatic stage, associated to local subgranulation. In the deuteric stages replaces albitised plagioclase along structural planes of it, along fractures of feldspars and as disseminated minute crystals bordering plagioclase. In the hydrothermal stage, white micas crystalize as minute crystals enclosing earlier muscovite in *greisen type* aggregates, associated or not to sulphides.

The presence of sulphides and other minor metallic minerals that accompanies Au-ore, characterize the mineralisation. Arsenopyrite (Apy) is the most common sulphide, with pyrite (Py) subordinated. Bismuth and bismuthinite, this one with a small Ag amount, occurs included in arsenopyrite. Chalcopyrite occurs lately to the Apy / Py ensemble. A first breccification of Apy is concomitant to a release of native bismuth. Native gold and/or electrum are introduced with an increment of Apy breccifiation. These breccifiation is accompanied by a generalized corrosion of the arsenopyrite. Nevertheless, in the mine of Stº António - Vieiros it is visible electrum in contact with automorphic, non corroded Apy, which contains bismuth included in the border of the grain. Arsenopyrite is unzoned or slight zoned under the scanning microscope, a fact that is confirmed by electron microprobe analyses.

Supergenic alteration induced the occurrence of argilaceous minerals of the kaolinite group. These kaolinites are intergranular, coating matrix minerals. Covelite which occurs bordering quartz in interstitial sulphides in not clearly related to chalcopyrite, a fact that lead us to consider the possibility of it's occurrence in the mineralization stage (even not associated to gold/electrum, these two minerals have the same textural position) and not only in the supergenic alteration stage.

Structural controls of mineralization

A major shear zone between Tomiño - Braga - Amarante and Moimenta da Beira controls the regional structures: 1) during the D_1 deformation event, its sinistral wrench component affects the variscan basement and are coeval with the formation of the Ibero-Armorican Arc (e.g. Dias, 1994), which trend is defined by regional folds of sub-horizontal axis and penetrative S_1 foliation that varies from slaty cleavage to schistosity with low or medium grade of metamorphism; 2) in the D_3 event, a dextral wrench deformation regime is coeval with the partial melting of crustal portions and produces non-coaxial deformation in the metassedimentary cover formations. "En echelon" folds with horizontal axis and sub vertical planes are generated, and forms variable angles relatively to the major shear, with an S_3 crenulation cleavage distributed in bands; 3) during D_4 event, the regional metamorphism decay imply a brittle dextral NW-SE displacement, conjugated of the NNE-SSW late variscan faults.

The three gold mines of the region: i) Vale de Peneda-Dacotim, ii) Laboreira-Stº António and iii) Ferronha, are structurally controlled by minor sinistral shear zones oriented E-W to ENE-WSW. These structures are interpreted as conjugated systems of the regional major subvertical shear lineament Tomiño - Braga - Amarante - Moimenta

da Beira, dextral during D_3, oriented N65ºW, and located 10 km west of Penedono. The non-coaxial character of the induced shear deformation was put in evidence in other regions of the Iberian Massif (Berthé et al., 1979; Iglésias & Choucrounne, 1980). In this region, this fact is evidenced by the continuous change of the angle between the strike of the folds and the major shear plane, which decreases as they approach each other.

Each shear set controlling the referred mines has a ductile-brittle behavior and they are responsible by a fracture system, following the classic experimental models of Tchalenko (1970), or models based in field observations (Gamond and Giraud, 1982). The deformation within these bands is polyphasic. We have established a coherent model consisting of three main phases of deformation (D_3, D'_3, D_4), which is consistent with the paragenetic analysis presented by Sousa & Ramos (1991). The amount of movement along the shear zones and their ductility as well increase towards NW. Each of the three mines represents a particular model of the same major process:

i) - Vale de Penela - Dacotim (Fig. 5.27b)

The intragranitic vein field is developed by a ductile shear zone with very close C and S subvertical planes (Fig. 5.27b), respectively oriented N80ºE and N(70-80º)W. The wrench ductile displacement (D_3) generated a tension gash system with an "en echelon" array (Fig. 5.28). Five of these gashes are the main veins, with metric width and hectometric extension and As-Au mineralization. The successive movements and correlative incremental deformation (D'_3) along the shear zone deflects the "T" gashes with a decreasing in the angle with the "C" planes. A system of secondary gashes R, R' and P, develops a slight opening and in spite of this large distribution in the area the mining potential is very limited (Fig. 5.28).

ii) - Laboreira - Stº António (Fig. 5.27c)

Stº António mine is located at Laboreira granite (Fig. 5.27c), within a sinistral E-W subvertical shear, with kilometric width and 4-5 km length. The shear is responsible by the opening of 13 traction gashes oriented N45ºW, and 0.5-1 m width where a first phase of quartz, arsenopyrite pyrrotite and gold was emplaced.

The shear is, as we have already seen, a sinistral conjugate of the major dextral shear Tomiño - Moimenta da Beira. The movement along this last shear is more intense in D_3. In consequence, the minor shear of Laboreira-Arcas is successively

reactivated with sinistral movement after the opening gashes and formation of minor fractures *Riedel* and also X-P fractures.

The progressive sinistral shear along the primary gashes in D'_3, produces the fracturation of all the system, creating new secondary tension gashes as well as new *Riedel* systems, that can also be open (Fig. 5.28).

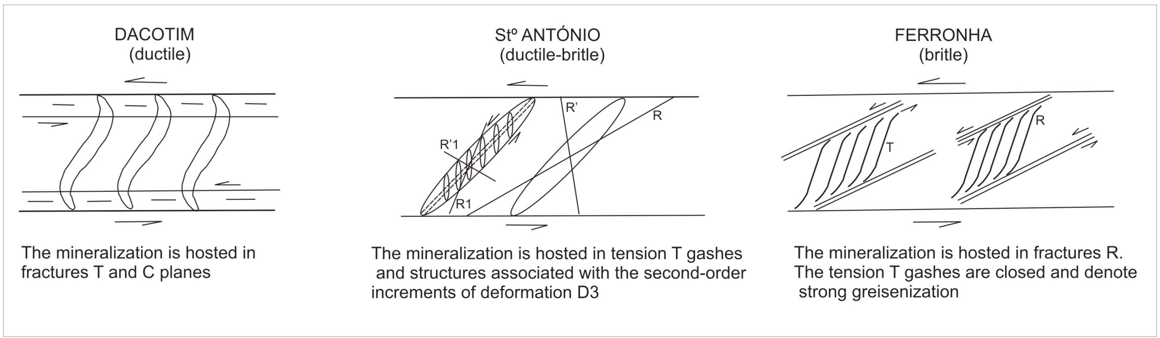


Figure 5.28 - Structural control of mineralization.

This kind of transitional ductile-brittle movement is well seen at Monte Airoso. Here the sinistral shears are oriented N55ºE and occurs also the dextral conjugated N45ºW (Fig. 5.27c). In a way, this corresponds to a late eastern extension of the Laboreira shear zone.

The ductile-brittle process induces a second phase of mineralization with the fracturation of the preliminary one and deposition of a second generation of quartz, gold, pyrite, wolframite and intense greisenisation.

A late variscan brittle phase (D_4) affects all the system. This last deformation phase is due to the rotation of the maximum stress σ_1 to approximately N-S, that creates sinistral transcurrent faults oriented N20ºE, subvertical. The rotation of the σ_1 to N-S direction (Fig. 5.29) produces either reactivation of all preexisting fractures with sinistral movement when they are in the E quadrant, or dextral movement when situated in the W quadrant. Coevally the associated transcurrent faults produce the rotation of fault bounded blocks within the granitoids. This fact is emphasized in Monte Airoso by the general rotation of the granitoid foliation to W. This brittle movement fractures the former mineral phases followed by the deposition of bismutinite, bismouth, galena, electrum, sulfossalts and tellurides identified by Sousa & Ramos (1991) and confirmed by the present work.

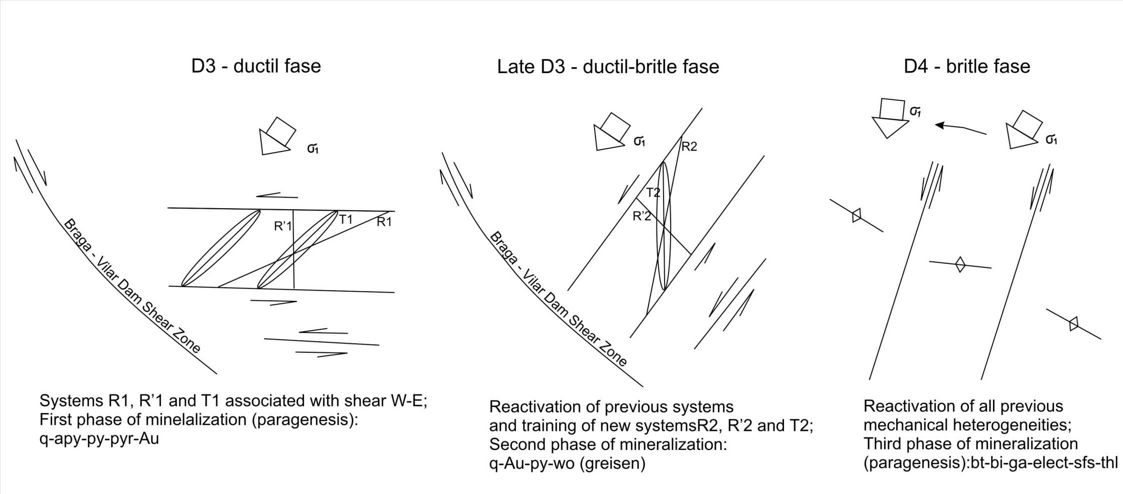


Figure 5.29 - Distribution of major mineral paragenesis in the different phases of variscan deformation.

iii) - Ferronha (Fig. 5.27d)

The vein field is located along the contact between two different granitic facies, one medium grained and the other fine grained both exhibiting strong moscovitization and turmalinization. The system of mineralized veins with W, As and Au, corresponds to four major *Riedel gashes* (R), with metric opening and kilometric length (Fig. 5.27d). The shear responsible for the gashes is dominantly brittle, with C and S planes having angles with more than 30º (Fig. 5.28), producing a system of T fractures, almost closed, sometimes with a milimetric filling of quartz, with wolframite and arsenopyrite.

The granite that contacts these gashes is strongly greisenized, occurring, by differential erosion, as small crests of greisen. They have an "en echelon" distribution, and they are located at the end of the R fractures, or in extensional zones between the gashes (Fig. 5.28). The successive movements react along the R gashes sub parallel to C planes producing the brecciation of the filling material and cementation by later hydrothermal phases.

Mining Information

The area has been exploited for gold since the Roman times. Roman mining works are still observable and consists in the exploitation of outcropping mineralized quartz veins and normally are not deeper than 30 meters.

In the forties a mining company named "*Companhia das minas de ouro de Penedono*" started the exploitation with underground mining works, till 1957, when the mine was closed. The main exploitation was done in the mine of Stº Antonio-Vieiros,

where a set of thirteen major veins oriented N40-50ºW are located on a band of 800m wide (Fig. 5.27c, Fig. 5.28).

In the mines of Dacotim and Ferronha the mining works had smaller importance. Available data from that time, taken from official departments, indicate that the main production was obtained from 1954 to 1957 in the concession of Stº António-Vieiros, with 100 800 tons, with a medium content for Au of 7,0 g/ton (see Table 5.2).

Table 5.3 - Main extractive activity in Sto António mine.

Production, in tons and Au content					
	1953	1954	1955	1956	1957
Sto António - Vieiros	16	16.000; 7,0 g/ton	49.766; 7,0 g/ton	1.838; 6,0 g/ton 15.886; 7,0 g/ton	17.156; 6,0 g/ton

In the early eighties "*Caulinorte*" retook the mining works with sampling in the veins of the three mines. In 1986 a consulting company (Partex, *Companhia Portuguesa de Serviços*) produced a preliminary feasibility study of the gold mines of Penedono.

Conclusion

The mineralized region of Penedono split into three main mining areas, Dacotim, St. António and Ferronha. In these mines, the (Au-Ag) mineralization occurs intra peraluminous granites that occupy cores of D_3 variscan antiform. From the granites that host the mineralization have been mapped several facies with mineralogical composition, texture and grain size variable. All show hydrothermal alteration, characterized by albitization, muscovitization and tourmalinization phenomena, more or less intense.

Furthermore, the deformation affecting these granites is highlighted by a N 65_W subvertical foliation and by ductile and ductile-brittle shear zones structurally related to variscan D_3 and D_4 phases

In spite of all this evidence, research on the genesis of Au mineralization in large sectors of the Iberian Peninsula (Cathelineau et al., 1993), challenge the doctrine advocated by a number of writers, including: i) as the no direct subordination of the Au metallogeny to the model of shear zones (Bonnemaison and Marcoux, 1990); ii) the reallocation of the generalized concept of granitoids as mineralizing agents; iii) absence of lithologies specialized or preferential hubs, such as black shales; iv) and independence of the behavior of gold relative to other elements such as As, Ag and W.

Indeed, for these authors, the Au metallogeny in the NW Iberian land is based, essentially: in the reconstitution of the migration stages of the embedding metamorphic fluids; on chemical controls, pH / Eh and fluid composition derived from a pre-specialized crust in Au; or based on the mechanical heterogeneity of the rheological behavior of preliminar secondary shear zones, fractures and faults.

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