Mineral. Deposita 25 [Suppl] S42–S52 (1990)

MINERALIUM
DEPOSITA

Gold ores related to shear zones, West Santa Comba-Fervenza Area (Galicia, NW Spain): A mineralogical study

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Received: May 1989/Accepted: September 6, 1990

Abstract. Recent research has discovered high-grade Au ores in NNE-SSW trending shear zones in metamorphic proterozoic and palaeozoic terranes, some 40 km NW of Santiago de Compostela (NW Spain). The orebodies are bound to late-stage Hercynian structures, mainly due to brittle deformation, which are superimposed on earlier ductile shear zones, cutting through various catazonal lithologies, including ortho- and paragneisses, amphibolites, eclogites, and granites. Ore mineralogy, alteration, and ore textures define a frame whose main features are common to all prospects in the area. Main minerals are arsenopyrite and pyrite – accompanied by quartz, adularia, sericite, ± (tourmaline, chlorite, carbonates, graphite), as main gangue minerals – with subordinate amounts of boulangerite, bismuthinite, kobellite, jamesonite, chalcopyrite, marcasite, galena, sphalerite, rutile, titanite, scheelite, beryl, fluorite, and minor native gold, electrum, native bismuth, fahlore, pyrrhotite, mackinawite, etc., defining a meso-catathermal paragenesis. Detailed microscopic study allows the author to propose a general descriptive scheme of textural classification for this type of ore. Most of the ores fill open spaces or veins, seal cracks or cement breccias; disseminated ores with replacement features related to alteration (mainly silicification, sericitization, and adularization) are also observed. Intensive and repeated cataclasis is a common feature of many ores, suggesting successive events of brittle deformation, hydrothermal flow, and ore precipitation. Gold may be transported and accumulated in any of these events, but tends to be concentrated in later ones. The origin of the gold ores is explained in terms of hydrothermal discharge, associated with mainly brittle deformation and possibly related to granitic magmas, in the global tectonic frame of crustal evolution of West Galicia. The mineralogical and textural study suggests some criteria which will be of practical value for exploration and for ore processing. Ore grades can be improved by flotation of arsenopyrite. Non-conventional methods, such as pressure or bacterial leaching, may subsequently obtain a residue enriched in gold.

Gold ores have been mined in NW Galicia (NW Spain) since pre-Roman times (Fig. 1), but mining activity ceased at the beginning of this century. Preliminary research on old (mostly Roman) mines and workings in the last decade demonstrated several interesting prospects in Hercynian metamorphic terranes (Rodriguez 1984), some of which were recently drilled and proved to contain high-grade ores. The mines and prospects which have been studied (listed in Table 2) are located (Fig. 2) in a broad belt of variable width of 1–5 km, which extends for 15 km in a NNE-SSW direction between the townlands of Mazaricos and Zas in the Province of La Coruña.

This investigation forms part of the programme of research which ENADIMSA is carrying out in the region, and which aims to define a basic frame of reference to understand the process of metal concentration and evolve more precise exploration criteria. The present paper basically addresses these problems from the point of view of mineralogy. The study has been centred on the Meanos ore, where drilling carried out has given access to fresh rock with high grades, although mineralized samples from the other occurrences (Fig. 2), as well as country rock from the whole area, have also been studied.

Geology

The ore belt, which is situated towards the eastern, mylonitized, NNE-SSW trending edge of the allochtonous Malpica-Tui Unit, MTU (IGME 1984), forms part of a regional gold-bearing metallotect, broadly defined by the eastern margin of this unit (Fig. 1).

The detailed geology of the area under study is the subject of an ongoing investigation by ENADIMSA and by BRGM (Pagés and Chambolle in press). The essential features of the deposits considered and those of their geological framework are summarized in Fig. 2 and Table 2.

The ores occur in veins or in irregular breccia bodies hosted by various lithologies, generally intensely de-

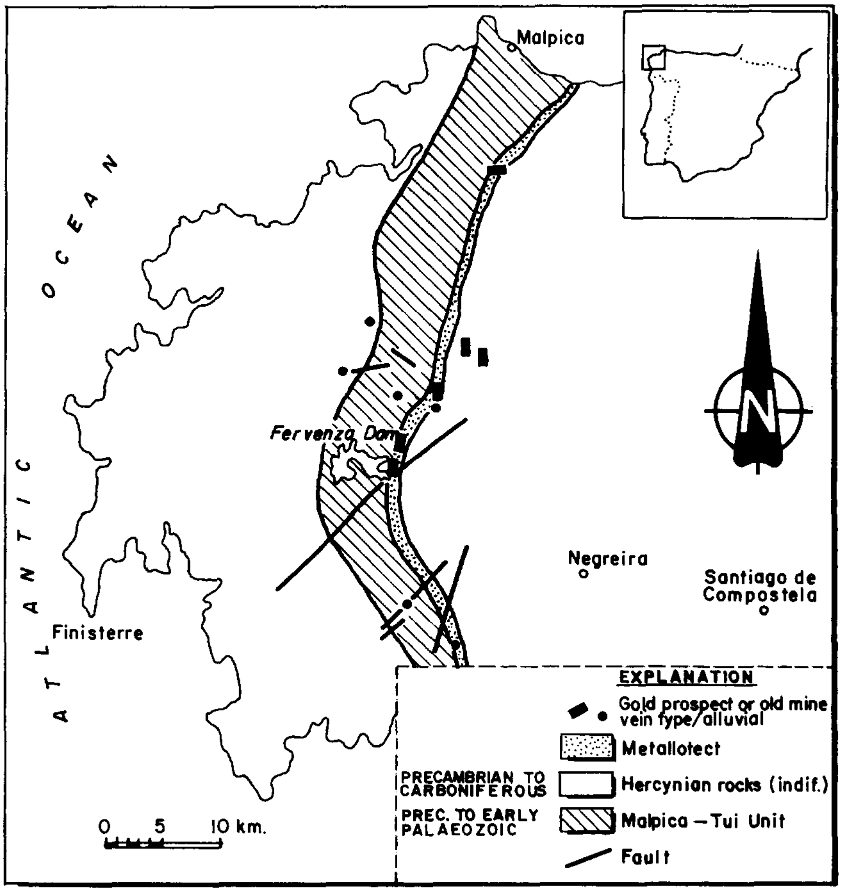


Fig. 1. Sketch map of NW Galicia, showing gold prospects and the position of the allochtonous Malpica-Tui Unit (modified from IGME 1982)

formed, of the MTU or of the basement, the Schist Belt of Central Galicia (Dominio Esquistoso de Galicia Central, IGME, 1984). The host rocks are frequently mylonitized metamorphic Precambrian to Devonian rocks (migmatites, ortho- and para-gneisses, micaschists, amphibolites and eclogites), and granitic intrusions.

There is an especially close spatial relationship between mineralization and late brecciation with hydrothermal infill affecting pre-existing lithologies, including the mylonites and the granitic rocks (Fig. 2). As such, the hydrothermal concentrations were generated after the emplacement of the MTU and the granites. The country rocks show typical *alterations* (Nodal 1986) related to the hydrothermal infill. Silicification, potassic alteration (adularization), and sericitization are the most widespread (Figs. 4a, b, c); locally, tourmalinization (Fig. 4d) and chloritization can acquire importance. In contrast to other auriferous districts, the carbonate alteration is generally poorly developed in the area, although the appearance of abundant graphite, related to the mineralization in some zones, might suggest that some fluids were rich in CO_2.

The majority of the prospects reveal a spatial relation with the intrusive granitic rocks, although in some of these (Fousas de Vila) this relation can only be inferred from geochemical and structural data (Pagés and Chambolle, in press) and from the mineralogy, and in others (Meanos, Rial) it is not evident.

Table 1. Mineralogical composition

Gangue

Quartz, adularia, sericite, tourmaline, chlorite, accessory carbonates, scheelite, apatite, beryl, fluorite

Ore

Principal components: arsenopyrite, pyrite
Minor components: boulangerite, bismuthinite, kobellite, jamesonite, chalcopyrite, marcasite, rutile-sphene, graphite, galena, sphalerite, pyrrhotite, native gold, electrum, native bismuth, fahlore
Trace components: mackinawite, cubanite, magnetite, miargyrite, petzite, cosalite
Secondary minerals: leucoxene, digenite, covellite, chalcocite, cerussite, anglesite, limonite, scorodite, mansfieldite, beudantite

Mineralogical-textural study of the gold ores

Mineralogical Composition (summarized in Table 1)

Apart from the accompanying silicates – chiefly quartz and adularia, ±(sericite, tourmaline, chlorite) – and accessory carbonates, scheelite, etc. which constitute the gangue, the ore is composed essentially of arsenopyrite with subordinate pyrite. Minor components, listed in order of decreasing abundance in Table 1, are scarce in the majority of the samples and are usually fine- to very fine-grained. In the case of surface samples, scorodite,

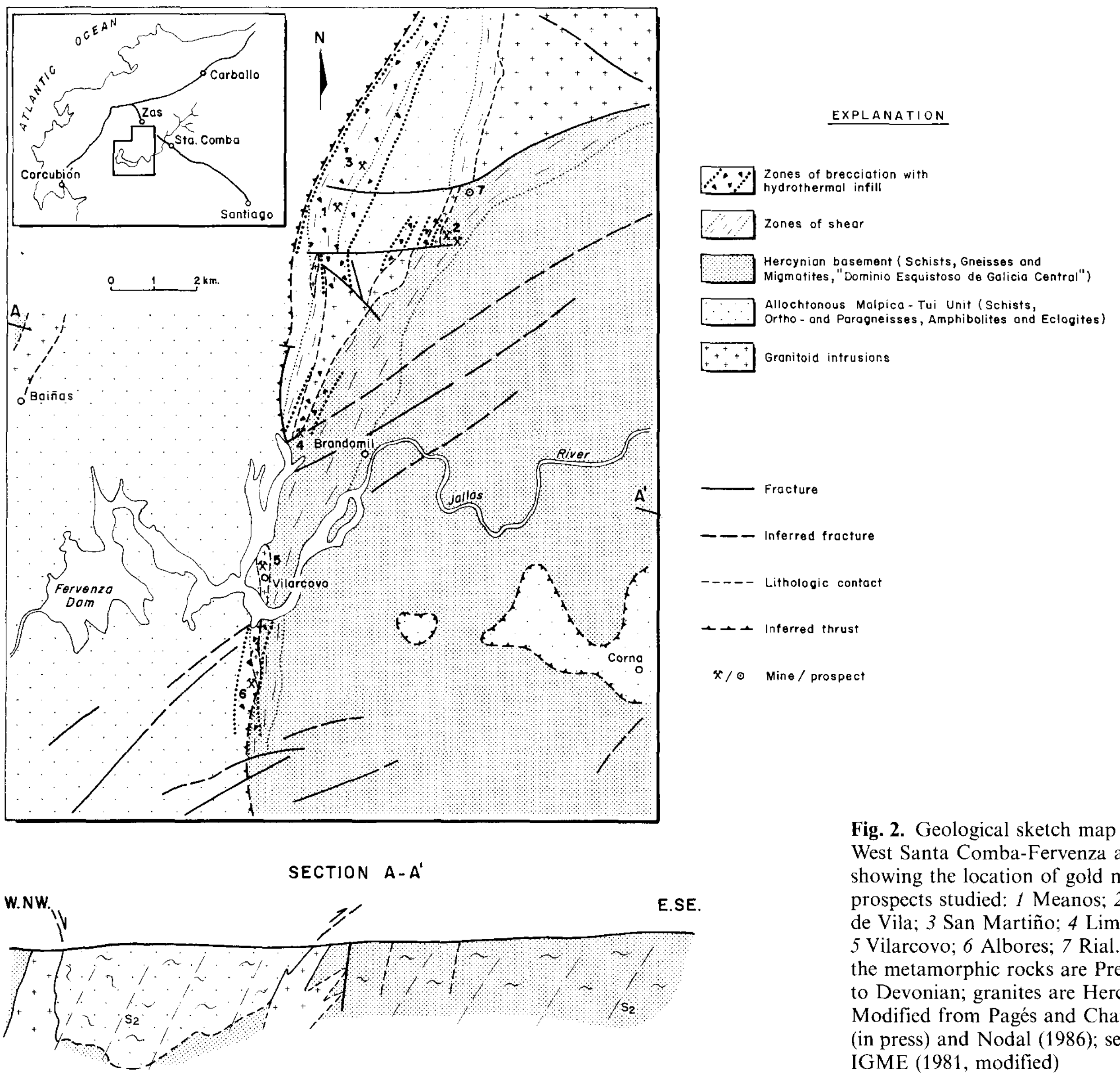


Fig. 2. Geological sketch map of the West Santa Comba-Fervenza area showing the location of gold mines and prospects studied: *1* Meanos; *2* Fousas de Vila; *3* San Martiño; *4* Limideiro; *5* Vilarcovo; *6* Albores; *7* Rial. Ages of the metamorphic rocks are Precambrian to Devonian; granites are Hercynian. Modified from Pagés and Chambolle (in press) and Nodal (1986); section after IGME (1981, modified)

Table 2. A mineralogical characterization of the ores in the West Santa Comba/Fervenza Area

Mine or prospect	L S	Host rock	Main alteration	Main ore minerals
Meanos/ S. Martiño (*)	1/3 B, V	Metasediments, orthogneisses metabasites, aplites, often mylonitic	Sericite, adularia, quartz	Arsenopyrite with minor sulphides and sulphosalts, nat. Au and Bi, electrum (see Table 1)
Fousas de Vila (**)	2 V	Mylonitic basement gneisses near granite contact	Tourmaline, quartz, sericite, adularia	Arsenopyrite, galena, sphalerite, scheelite, minor sulphosalts, native gold
Limideiro (*)	4	Deformed granite and metamorphic rocks	Sericite and clay (very intensive)	Arsenopyrite, no visible gold observed (very scarce outcrops)
Vilarcovo (*) (**)	5 V	Granitic mylonite and graphitic gouge along fault	Quartz, graphite	Sphalerite, galena, arsenopyrite, native gold/electrum, petzite (?)
Albores (*)	6 V, B	Protomylonitic granite, metasediments, and mylonites	Quartz, tourmaline, chlorite, graphite	Gold-bearing arsenopyrite, minor base-metal sulphides
Rial	7 D	Mylonites and ultramylonites from basement gneisses	Adularia, sericite, quartz, usually syn-mylonitic	Arsenopyrite, traces of pyrrhotite, sphalerite, kobellite, graphite

L, Location No. Fig. 2; *S*, structural type (*B*, *V*, breccia bodies, veins; *D*, disseminated mylonitic ore)
(*) Abandoned Roman gold mines, (**) mines active in nineteenth/twentieth century

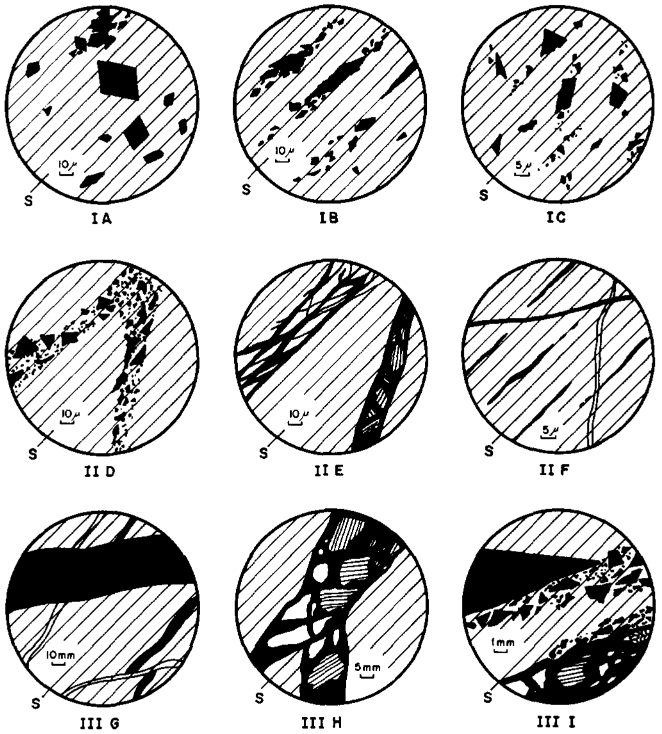


Fig. 3. Textural types of arsenopyrite in shear zone gold ores of the West Santa Comba-Fervenza area. *Black:* arsonopyrite; *white:* silicate gangue; *S*, trend of main S-surface. *Type I:* disseminated ores (subtypes: *A* – idiomorphic crystals and aggregates; *B* – lenticular aggregates // S; *C* – microclasts). *Type II:* stringer or fine-banded ores (subtypes: *D* – bands of microclasts; *E* – cement in microshears; *F* – filling microfissures and S-planes). *Type III:* massive ores (subtypes: *G* – fissure and vein fill; *H* – breccia cement; *I* – cataclastic fill or cement). Scale is only approximate (very variable grain size)

mansfieldite, beudantite, and limonite take the place of arsenopyrite, often replacing it pseudomorphically.

The paragenesis represented in Table 1 corresponds to the typical Meanos occurrence, with the exception of scheelite, beryl, fluorite and petzite (?), observed only in samples from Fousas de Vila, Rial or Vilarcovo. In other localities, differences in the proportion of the distinct components appear (Table 2); e.g. a greater abundance of galena and sphalerite in Fousas de Vila or an absence of gold minerals in Rial.

Description and textural study of the ores

A visual examination of drill-core, trench-cuts etc., permits a categorization of the sulpho-arsenical ore generally as post-mylonite and related to the late cataclasis mentioned above. Two types can be distinguished: disseminated and massive. Often, both exist in the same sample, the former as a wall-rock impregnation and the latter as a fracture-fill and breccia cement.

Arsenopyrite

As the principal component of the ore, the arsenopyrite shows the most characteristic textures. These will be briefly analyzed, in order to characterize the ores of the Santa Comba-Fervenza area, and also to contribute to a typological classification scheme of shear-zone gold ores.

Microscopic examination shows that, from a geometric point of view, the textural relationships between arsenopyrite and gangue or host correspond to the types: 1d (disseminated) and 3a ("vein-like" or "sandwich-type") established by Amstutz (1960). The latter has to be subdivided in this case into two new types: (i) finely banded (transitional with 1d), and (ii) massive. They correspond to types I, II and III (and 9 sub-types: A to I) represented in Fig. 3 and defined as follows:

Type I (1d, Amstutz 1960): finely disseminated μm to mm-sized arsenopyrite grains, generally idiomorphic, sometimes following the schistosity (Fig. 5b), but more often not (Figs. 4b, c). Often related to hydrothermal infill structures. Typically post-deformation, but occasionally deformed (Fig. 5b) or even crushed down to microclasts which follow shear-planes (Fig. 5a, transition to type II).

Type II (transitional 1d–3a), fine-banded: arsenopyrite in tabular or banded microstructures, either as infill in microfissures and veinlets (widths of μm to mm) oblique to the schistosity, or in stringers or shears, sometimes crushed (Fig. 5a). Quantitatively of little importance.

Type III (3a, Amstutz 1960): arsenopyrite in tabular masses of mm/dm thickness, with a tendency to form coarse-grained idiomorphic aggregates, intergrown with other ores and with gangue. Hydrothermal infill textures are dominant. Deformation is usually slight (Figs. 5c; 6c, d) but occasionally is intense (Figs. 5d; 6a, b).

The typical occurrence of the arsenopyrite is as post-mylonitization fill or as breccia cement which can be affected in varying degrees by later episodes of generally brittle deformation. The observed textures can be interpreted as the result of a *late-stage repetitive cataclasis* with associated hydrothermal influx, so that the deformation produced each time in the evolution of the structure can affect the minerals which developed in the previous event and which are overgrown in turn by the next hydrothermal generation. Scanning electron microscope (SEM) studies of all the types of arsenopyrite did not detect any compositional differences between them.

As regards *chronology*, a certain ambiguity is inevitable given the usual obliteration of the early textures of the ore, due to its recrystallization during subsequent deformational events. Therefore the classification pre-, syn- and post- has to be related to the last deformation: the late cataclastic stage. The position of the "B" subtype is questionable with regard to the type of schistosity "S" and the particular textural characteristics, since some late-stage mylonitization is not to be excluded (see Figs. 4d, 5b). However, in a simple fashion, the following succession can be suggested: (1) deformed or cataclastic ore (subtypes C-D-I: *pre*-late cataclasis): Figs. 5a, d; (2) ore partially affected by deformation and recrystallized or re-grown (pre-/*syn*-late cataclasis: subtype B): Fig. 5b; (3) little or not deformed ore (subtypes F-A-E-G-H: syn-/*post*- late cataclasis): Figs. 4b, 5c.

In *summary*, the observed textures indicate a succession of cycles of brittle deformation + hydrothermal infill, each cycle being represented by the appearance of

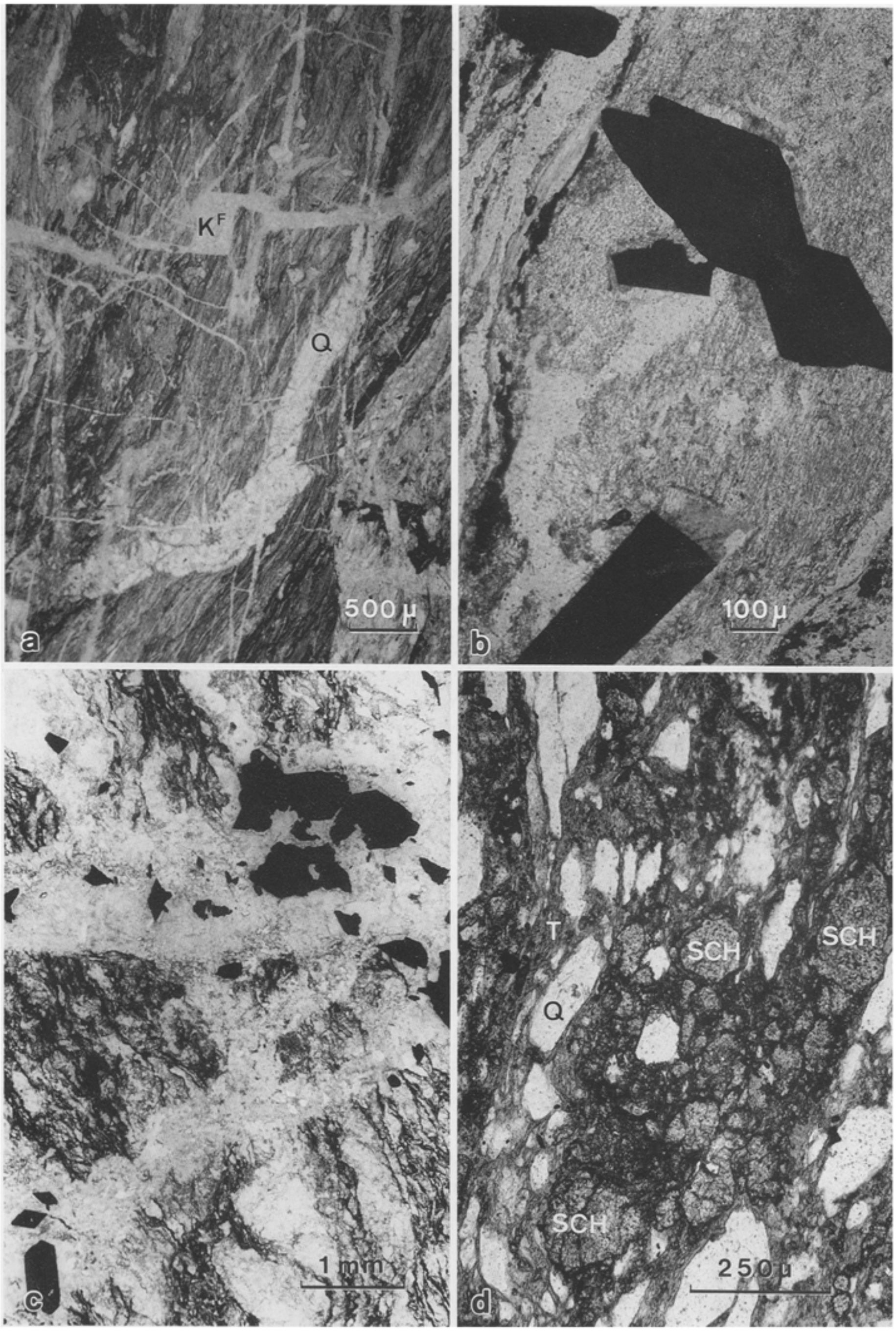


Fig. 4a–d. Host rocks of the gold ores. Photomicrographs with transmitted light, //N. **a** Hydrothermal alteration of ultramylonitic country rock, Rial. Earlier, deformed, veinlets of quartz (*Q*), and younger microfissures sealed by adularia (*KF*), which also replaces the original quartz-feldspar-mica matrix. **b** Late, undeformed arsenopyrite phenocrysts (*black*), with pressure shadows with adularia and quartz, growing on a sericitized plagioclase fragment, in brecciated plagiogneis. Type IA, disseminated, ore. Fousas de Vila. **c** Typical host rock of gold ores in Meanos: mylonitic graphite paragneis, brecciated, silicified, sericitized and potassically altered, showing abundant veinlets with hydrothermal infill, in this case quartz and adularia (*white*) and arsenopyrite (*black*). **d** Intensely deformed (proto-mylonitic) early hydrothermal vein: microclasts of quartz (*Q*), scheelite (*SCH*) and arsenopyrite (not seen) in an oriented matrix of acicular tourmaline (*T*). Rial

some or all of the textural subtypes A to I, in the approximate order I-D-C-B-H-G-E-F-A (I, D, and C, superimposed on pre-existing ores).

Pyrite. Subordinate with respect to arsenopyrite, although being in places the principal component of the ore, it may be also scarce or absent (Fig. 6a). It is often optically anisotropic, and its textures are similar to those of arsenopyrite, showing a greater amount of post-cataclastic features.

Marcasite. Relatively frequent although not abundant, it usually accompanies or even cements late pyrite. It can appear associated with arsenopyrite or pyrite, sometimes replacing them, and is also disseminated in the host rock. Occasional "bird's-eye" textures observed in marcasite suggest that it may be secondary to pyrrhotite.

Sphalerite and galena. These are generally late minerals with respect to arsenopyrite (Figs. 5c, 7c). Of irregular distribution, they are abundant in some zones (e.g. Fousas de Vila) but usually scarce or absent. SEM analyses show that sphalerite contains about 7% Fe and up to 4% Cd (i.e. Fe-Cd-rich przibramite variety), while only traces of Ag have been detected in the galena.

Boulangerite, bismuthinite, kobellite, jamesonite and chalcopyrite. These are present in small inclusions and filling microfissures in arsenopyrite (Figs. 6a, b) and pyrite which they frequently corrode; rarely in disseminations

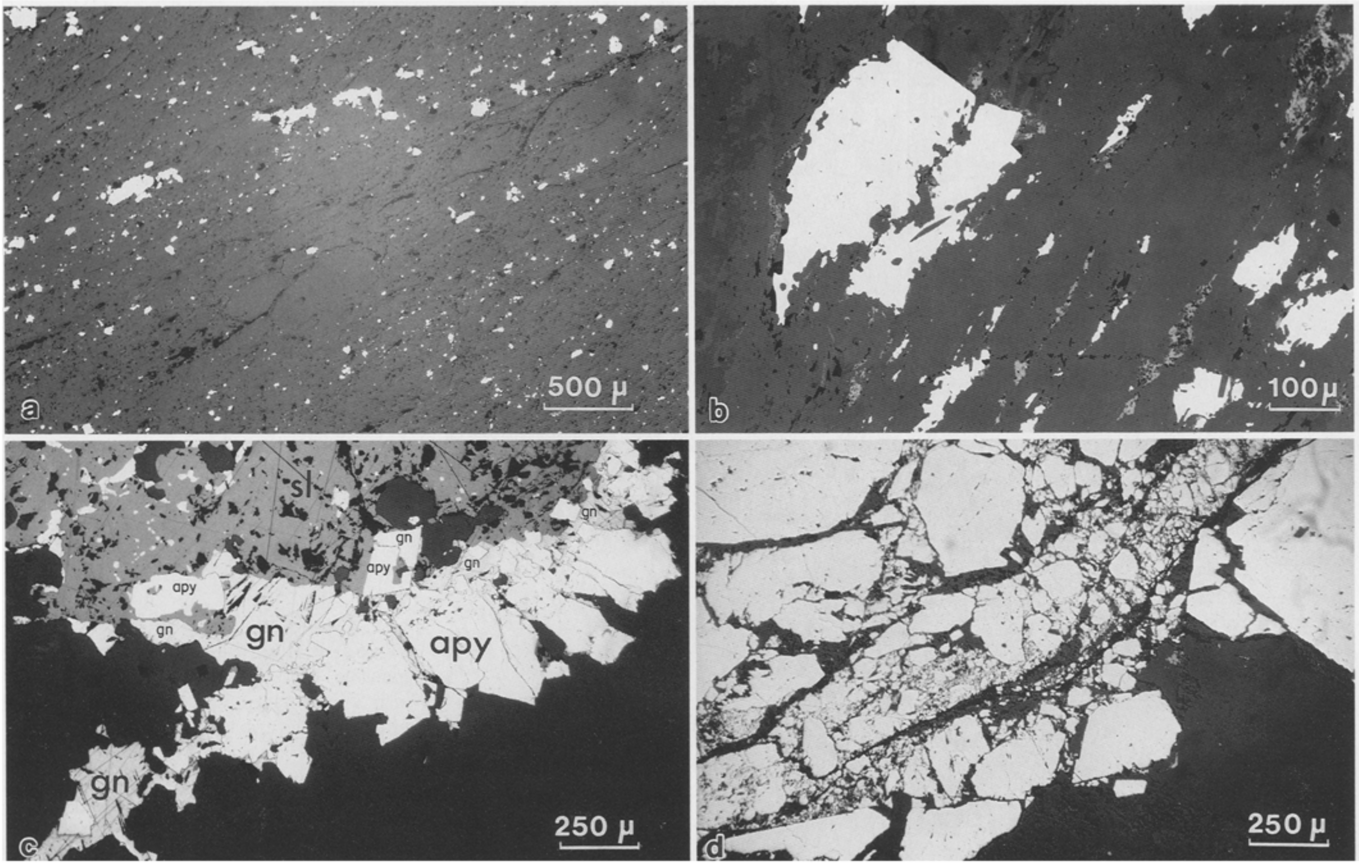


Fig. 5. Different stages of deformation affecting the ores (arsenopyrite: *white;* silicate gangue: *black*). Photomicrographs with reflected light, //N. **a** Disseminated, mylonitic ore in quartz-feldspar-mica ultramylonite, Rial. Textural types IC-II D (see text). **b** Recrystallized mylonitic ore, intergrown with quartz and tourmaline, in mylonitic quartz tourmalinite with rutile (grey), Fousas de Vila. Textural Type I B. **c** Slight brecciation of quartz-arsenopyrite (*apy*) vein. Cracks sealed by: (1) galena (*gn, corrodes apy*) and (2) sphalerite (*sl*). Textural type III (G-H). Fousas de Vila. **d** Cataclastic arsenopyrite ore, textural type III (I). Meanos

or veinlets in the rock. In the case of the first four minerals, the very fine grain-size has required SEM analyses to confirm their identity. Appreciable quantities of Cu, Pb and Sb have been detected in bismuthinite and of Ag in kobellite. These minerals may or may not occur together and may also be accompanied by *pyrrhotite, marcasite, native bismuth* and native gold/electrum in minute inclusions or in fine bimineralic (Fig. 7b) or, rarely, polymineralic aggregates. Tetrahedrite, miargyrite, cosalite (?) and petzite (?) can be present in trace amounts, also as minor inclusions in arsenopyrite or pyrite.

Gold. This is present in the native form in practically all cases. The SEM analyses carried out have always detected significant quantities of Ag (6–35%), but *electrum* (>25% Ag) has only been found in some samples (Vilarcovo and Meanos) where the noble metal tends to be associated with sulphides.

It is present in blebs of the order of 1–5 μm, less often up to 50 μm and exceptionally up to millimetric dimensions. Almost always forming inclusions or microfissure infills in arsenopyrite, it sometimes occurs in sulphide (mostly pyrite) or silicate minerals.

In detail, the textural relations observed can be characterized by the following forms:

1. Native gold, with or without bismuth carriers (e.g. Fig. 7b), silicates (e.g. Figs. 6c, d; 7a), sulphosalts or sulphides (e.g. Fig. 7c), *in generally massive, type III, arsenopyrite*: *1a* as minute inclusions, sometimes poikilitic (Figs. 7a, b); *1b* in microfissures (Fig. 7c); *1c* in blebs along cleavage planes; *1d* interstitial and as intergranular films (Fig. 6d).

2. Native gold cementing microclasts of arsenopyrite included *in late pyrite.*

3. Native gold *in silicates* (adularia, quartz or chlorite), in general close to crystals of arsenopyrite (Fig. 7d).

4. Native gold *associated with silicates,* cementing microfissures *in arsenopyrite,* with or without corrosion phenomena (Figs. 6c, d).

The close spatial relationship observed between native gold and arsenopyrite (which tends to be maintained even when the noble metal occurs within pyrite or silicates) is in general independent of the deformational characteristics of the arsenopyrite, but not, it seems, of types I-II-III (Fig. 3). The greater part of the gold (group 1 forms) is found in massive arsenopyrite of type III (in whichever of the subtypes G, H or I), and only in exceptional cases in arsenopyrite of types I and II (especially sub-type B).

Rutile. This is a common accessory of the ore, although it is more abundant in the host, where it appears disseminated in small tabular crystals. It is almost always altered to leucoxene.

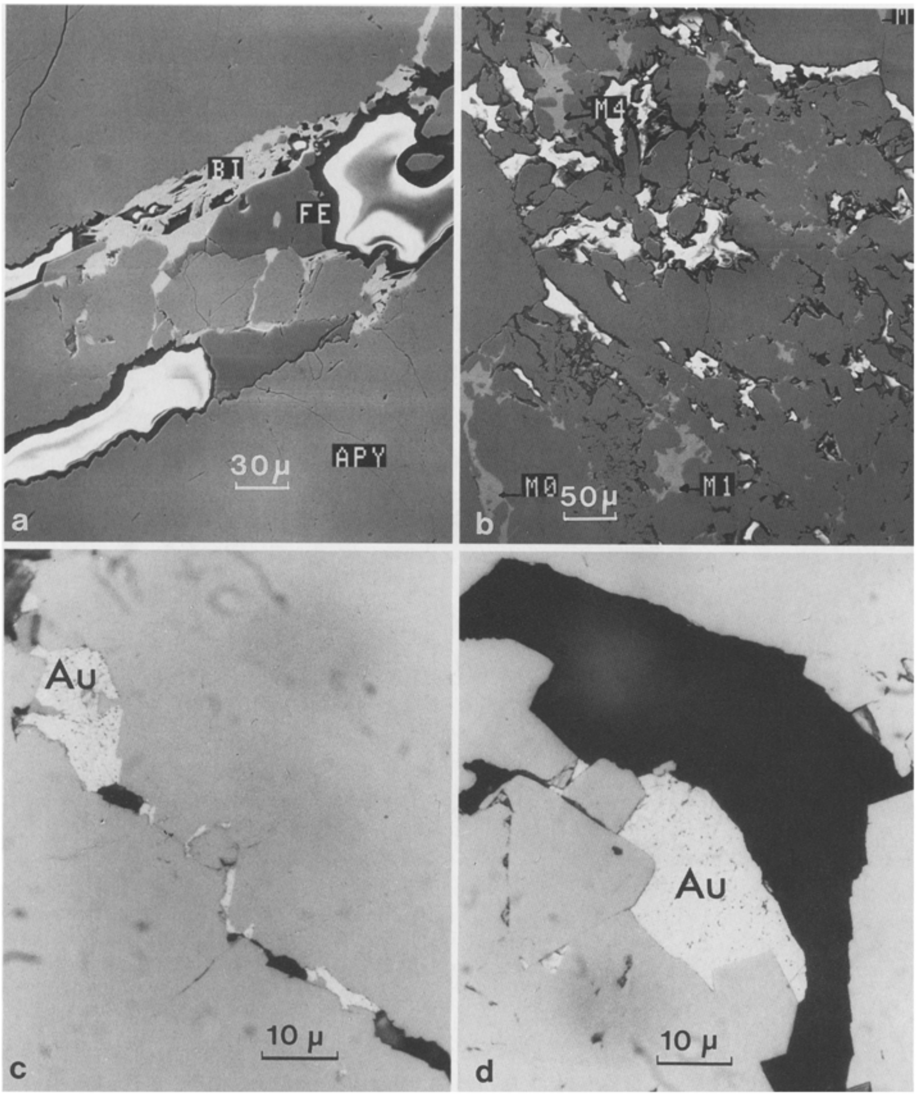


Fig. 6a–d. Late-stage processes in massive, type III, arsenopyrite (Meanos): **a, b** SEM images; **c, d** reflected light photomicrographs, immersion, //N. **a** Repeated cataclasis affecting the ores. Crack in arsenopyrite (labelled *APY*), sealed by: (1) pyrite (labelled *FE*); (2) a second generation of arsenopyrite; and (3) bismuthinite (labelled *BI*). **b** Brecciated arsenopyrite welded by jamesonite (M_1) and boulangerite (M_0, M_4, M_5). **c** Native gold (*Au*) and silicate (*black*) sealing microfissure in arsenopyrite (*white*). **d** Native gold (*Au*), containing 10% Ag, and silicates (quartz, chlorite, *black*) in crack and interstitial in arsenopyrite (*white*). Slight corrosion of arsenopyrite by gold

Graphite. This also occurs frequently – although seldom abundantly – in the mineralization with which it has to be associated, not only for the spatial relation observed in hand samples and in the field, but also for the appearance in mineralized samples of spherulitic graphite with fibrous-radial textures. Although the greater part of the graphite may be of metamorphic origin, it appears certain that there is a hydrothermal contribution related to the processes which give rise to the mineralization. These contribute also some *apatite, tourmaline*, etc., and (in some showings) some *scheelite, beryl*, and *fluorite*.

Sequence of crystallization

Table 3 gives an overview of the sequence of crystallization of the minerals already described, in the geologic-tectonic framework of their host structures.

The principal chronological frame of reference is the late-stage cataclasis which permits a distinction to be made between pre-, syn- and post-late cataclasis ores, according to the brittle deformational effects produced in them. The regional metamorphism and the subsequent dynamic metamorphism (mylonitization) related to the emplacement of the allochtonous MTU (Malpica-Tui Unit) can constitute a frame of reference for the pre-cataclastic ores. However, this frame of reference is rarely observable given the intensity of the late deformation in the mineralized zones. Moreover, the mylonitization in these makes it difficult to recognize any previous texture. For this reason all the early ores have been placed in a single group ("metamorphic minerals"), characterized by the presence of dynamic metamorphism. These early ores are actually observed in the host rock (e.g. in the ultramylonites of Rial), but scarcely in the well-mineralized zones. Most of the ore can be therefore considered of the post-metamorphic, late cataclastic type; the crystallization of gold usually follows that of arsenopyrite.

Discussion and genesis

The spatial relation between the concentrations of gold and the eastern, mylonitized margin of the allochtonous MTU is noteworthy. The mineralization occurs in late

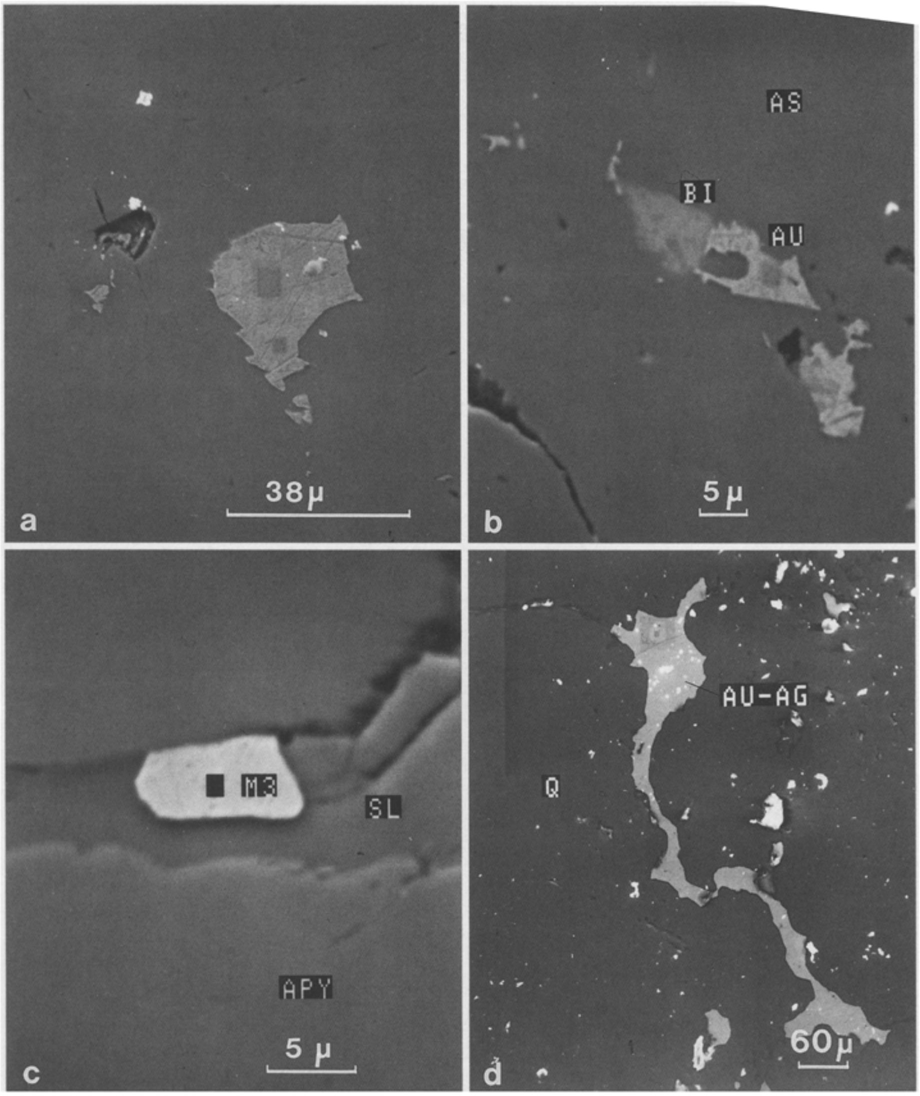


Fig. 7a–d. SEM images of earlier (**a, b**) and later (**c, d**) gold ores from Meanos (a, b, c) and Vilarcovo (d). **a** Blebs of native gold (*white*, relief, 6.1% Ag content), with minute adularia inclusions (*black*), in massive, Type III, arsenopyrite. **b** Bimineralic inclusions of native gold (9.5% Ag) and bismuthinite in massive arsenopyrite (labelled *AU, BI, AS*, respectively). **c** Microfissures in arsenopyrite, sealed by sphalerite (labelled *SL*, 7.6% Fe) and electrum (M3: 64.6% Au, 35.4% Ag). **d** Quartz vein (*Q*), with microfissures sealed by electrum (AU-AG: 69.9% Au, 30.1% Ag)

structures (cross-cutting with respect to the mylonitic schistosity), characterized by brecciation, hydrothermal infill and alteration. A more or less direct spatial relation to granitic intrusive bodies is common, though not constant.

From a *mineralogical* point of view, there are notable similarities between all the occurrences in the area, whose main features are summarized for comparison in Table 2. There is a clear affinity in mineralogical composition and the ores have a hydrothermal, hypogene-epigenetic origin, in a broadly meso-katathermal range.

From a *textural* point of view, there is also a coincidence in the typological characterization of the ores (Fig. 3). These are almost always post-mylonitization, although they can be pre-, syn- or post-late-cataclasics.

There are also some noteworthy *differences* between the ores of different zones (Table 2 and Fig. 2):

– Mineralogical composition: There is an increase in the mineralogical variety and in the content of sulphosalts and/or native gold from Rial (simple mineralogy, dominated by arsenopyrite, K-feldspar and quartz, no gold observed as mineral phase; Table 2) to Meanos (the richest and most complex ores; Table 1); moreover, there is a greater abundance of sulphides, such as galena and sphalerite (Fig. 5c), and of tourmaline (Fig. 5b) in Fousas de Vila, where scheelite, fluorite and beryl are also observed.

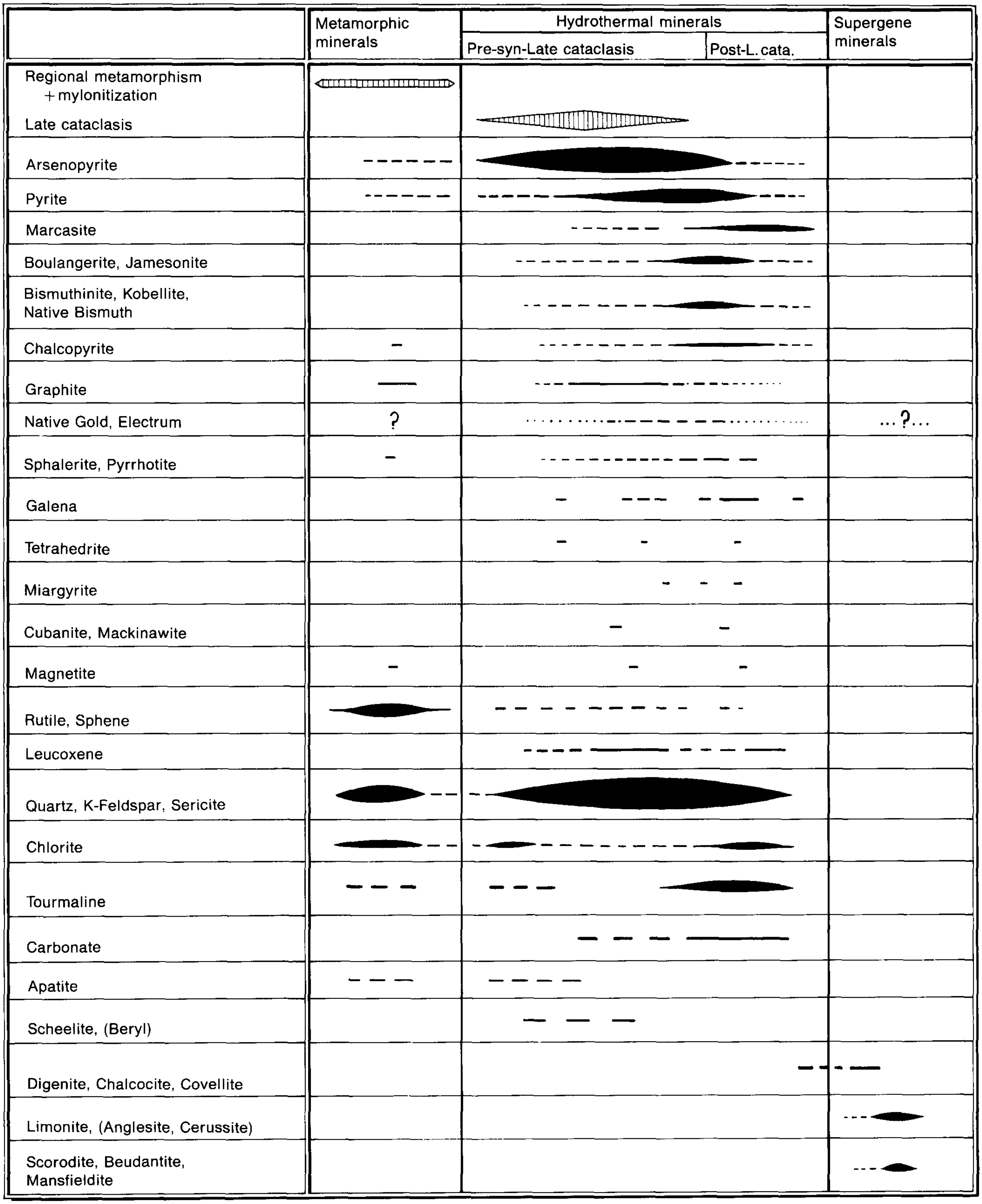
– Hydrothermal activity: This increases in a similar manner, being scarce in the first locality (Figs. 4a, d) and intense or ubiquitous in the others (Fig. 4c).

– Textures: There are predominantly syn-deformational (mylonitic), disseminated ores in the ultramylonitic host at Rial (Fig. 5a); and massive ores related to repeated episodes of late cataclasis in the remainder of the showings and mines (e.g. Figs. 5c, d; 6).

The overall grouping of similarities and differences permits a *synthesis* of the above-mentioned deposits to be made within the framework of a common model of tectonic and hydrothermal evolution. This model implies a transition from ductile to brittle conditions, with successive reactivations, accompanied by hydrothermal circulation and ore accumulation, as illustrated by ore textures.

The Rial ores would represent an early stage, with dominant mylonitization and scarce to incipient late hy-

Table 3. Sequence of crystallization



drothermal influx. The other extreme of the process would be represented by the Meanos ores, with clear dominance of late cataclasis (creation of new structures ripe for hydrothermal infill) and a more abundant, varied and developed hydrothermal influx which produces a greater accumulation of gold. From the point of view of mineralogy, the other showings could be considered as an intermediate stage between the former two, as suggested by the intensity, and variety or degree of evolution of the hydrothermal influx.

It seems easy to explain the significance of the late cataclasis as an auriferous metallotect. In a ductile regime, the restricted permeability and porosity of the medium does not facilitate hydrothermal circulation, but fracturing and creation of open space by brittle failure favour the circulation of solutions and the subsequent hydrothermal infill. The repetition of episodes of brecciation and infill accounts as much for the present texture of the ore (co-existence of cataclastic generations and intact generations which cement them) as for the evolution of its paragenesis (greater variety and mineral wealth in the later episodes). Native gold occurs related to cataclastic generations or sulphoarsenides but also to subsequent, post-deformational, generations, However, higher gold contents are to be expected where the ores are massive and the late-stage features (syn-/post-late cataclasis) well represented.

The processes described are characteristic of many auriferous vein-type deposits related to shear-zones in metamorphic terranes, a type which is known worldwide. Its most typical occurrence is in Archaean greenstone belts. It is also known, with some variations, in Palaeozoic terranes. In spite of evident differences (such as those implied by the different composition of the crust, the size of the metal concentrations, etc.) most of the main geological and mineralogical features described in this paper are also found in typical Archaean lode gold deposits, e.g. as defined by Hodgson and MacGeehan (1982) in the Superior Province of the Canadian Shield, or as summarized by Colvine et al. (1984).

Recent work on European gold deposits of Hercynian age led Bonnemaison and Marcoux (1987) and Touray et al. (in press) to propose a typology which can also be applied to the Fervenza ores. These can be described as "post-metamorphic type, Au-As subtype" in the classification of the latter authors. If Meanos ores are referred to as typical of the area, they can be included in the "mature-intermediate type" as defined by Bonnemaison and Marcoux (1987). Gold ores of this type are very pure (90% Au) and become progressively enriched in silver (25–60% Ag) with later remobilization, according to these authors.

The values obtained in Fervenza ores (6–35% Ag) also appear to correspond overall to this classification, taking into account that, according to the textural evidence, diverse episodes of successive mobilization and concentration are superimposed within a single deposit, giving rise to several generations of native gold. There is, therefore, a broad agreement with the sequence established in the area described: early and weak mineralization in Rial; mature in Meanos; also mature, but with perhaps more developed later stages in Fousas de Vila and Vilarcovo (richer in Ag, with nugget gold).

There are still some unanswered questions. Although the type is well known in its essential features (Colvine et al. 1984), many genetic aspects are still in debate, such as the precise concentration mechanisms, the origin of the hydrothermal fluids, and the ultimate source of the gold. These will not be discussed here as detailed studies are in progress and knowledge of the orebodies is still in a preliminary state.

Nevertheless, the model proposed for Archaean deposits by Hodgson (1986) provides an approach that can be very useful to the understanding of Hercynian deposits as well. The genesis of the gold orebodies, according to this model, relates to crustal evolution through a sequence of rifting, sedimentation, deformation, porphyry intrusion, alteration and mineralization. In this sequence, granitic magmas seem to play an important role in the mobilization and final concentration of gold, whose ultimate source would be in the mafic rocks of the Greenstone Belt.

Present ideas about the geology of western Galicia allow a comparison with this model, while still speculative. They imply continental rifting (Lefort and Ribeiro 1980) and development of an Ordovician "proto-ocean" to the West; the emplacement of the Malpica-Tui Unit (MTU) is explained, accordingly, by an eastwards-thrusting of the thinned crust as a result of continental collision in Devonian times (Ortega and Gil 1983). The present boundaries of the MTU are major, superimposed normal faults, and granitoid bodies (see Fig. 2) whose intrusion was largely controlled by these fractures (IGME 1984). The granitic magmas could account for the extraction and mobilization of gold from MTU and basement rocks at depth, and for its redistribution by hydrothermal solutions, related to late-stage deformation. This explains the character of the eastern MTU boundary as a significant gold metallotect (Fig. 1). The West boundary is largely sealed, along more than 100 km, by a barren granodioritic body.

Exploration ore-dressing

Some of the above-mentioned features, added to the usual multi-element geochemistry, geophysics, etc., can be useful guides for *exploration* in the area:

- Relation to important regional structures, thrusts and faults; identification of shear-zones, especially with superimposed and repeated late cataclasis and hydrothermal infill.
- Presence of sulphides, especially massive (type III) arsenopyrite with Bi sulphosalts, accompanied by quartz, adularia, tourmaline, graphite, scheelite, etc.
- Alteration phenomena in the country rocks: potassic alteration, sericitization, silicification; locally tourmaline, chlorite or carbonate alteration.
- Presence of granitic intrusives or dykes.

The mineralogical and textural characteristics observed allow also some conclusions to be drawn about the *processing* of the ores.

Firstly, the close association of native gold with arsenopyrite suggests that the overall Au grade can be improved by preconcentration (flotation) of the sulpho-arsenide. This should be easy in view of the dominant type of arsenopyrite associated with gold, i.e. massive, relatively coarse-grained arsenopyrite, described as type III (see textures, Fig. 3).

Secondly, the fine grain-size of the native gold poses serious problems of recovery by conventional methods.

Direct cyanidation will give poor results as the gold locked in arsenopyrite remains relatively inaccessible to the reagent.

For these reasons it is advisable to consider unconventional methods, such as pressure leaching – applied successfully in Porgera, Papua New Guinea – or bacterial leaching of the arsenopyrite preconcentrate, thus avoiding the environmental impact of the otherwise necessary roasting of this material; nevertheless this impact can also be limited by treatment of the fumes. These methods are described by Weir and Berezowsky (1984), Ollivier (1986) and Lesoille (1987), respectively. The last-mentioned of these authors describes the roasting and gas treatment of the gold ores from Salsigne (France), also rich in arsenopyrite, and on which bacterial leaching is at present being tested. In every case the objective is to obtain a gold-bearing residue susceptible to cyanide leaching with an acceptable yield.

Conclusions

Gold deposits of the Fervenza area are hypogene epigenetic deposits of the meso-katathermal range bound to late-stages of mainly brittle deformation. They occur in shear-zones affecting Hercynian metamorphic terranes and intrusive granitic rocks.

Mineralogy can be locally complex, but only a few minerals are abundant; mainly quartz, adularia, arsenopyrite, pyrite, sericite and locally sphalerite, galena, bismuth sulphosalts, chlorite, graphite, scheelite or tourmaline. Native gold occurs usually in fine-grained, micron-sized particles. It contains variable amounts of silver (6–35%) and tends to be associated with arsenopyrite and with bismuth ores. The geometric classification of ore textures in Fig. 3, which helps compare the different deposits and understand their complex genesis, could be useful for the textural characterization of ore bodies related to shear zones in other districts as well. Flotation is suggested as an easy way to improve Au grades; prior to direct cyanidation, the pre-concentrate should be treated with non-conventional methods, such as pressure leaching or bacterial leaching.

The ores originate as part of a system characterized by a transition from ductile to brittle deformation with associated hydrothermal circulation, typical of vein-type gold deposits in shear zones, in Archaean as well as in Hercynian terranes. If compared with the former, there exist however some noteworthy differences; e.g. deposits of the Superior Greenstone Belt (Hodgson 1986) are large and hosted by rocks of low metamorphic grade, with intensive carbonate alteration and abundance of mafic volcanics (about 65%), in contrast to smaller metal concentrations, higher grade metamorphism, subordinate carbonate alteration and less abundant mafic volcanics in the Fervenza area. There are some close similarities with other European Hercynian deposits, e.g. Le Bourneix type, as defined by Bonnemaison and Marcoux (1987).

Acknowledgements. The author wishes to thank ENADIMSA/INI for permission to publish this work; likewise, all his colleagues in that company, for the information and facilities given, especially T. Nodal, author of the petrographic works consulted, and A. Bonilla, for his critical discussion of ore-dressing. He also wishes to thank Drs. M. Bonnemaison and E. Marcoux (BRGM, Orleans, France), for their information and discussions about European Hercynian gold deposits. The assistance of Prof. C.J. Hodgson (Queen's University, Kingston Ontario) during fieldwork in the summer of 1987 is also gratefully acknowledged; the author benefitted very much from Prof. Hodgson's experience and deep knowledge of Archaean gold deposits.

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