The ore textures of the Neves-Corvo volcanogenic massive sulphides and their implications for ore beneficiation

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Abstract

The Neves-Corvo mine opened officially in December 1988 and it is already the biggest producer of copper in the Iberian Pyrite Belt (IPB). Tin production started in 1990. The ore deposits of the IPB are related to felsic submarine volcanism which developed during the lower Tournaisian to the middle Visean. At the end of the first phase of Hercynian deformation in the middle Westphalian, the ore deposits were affected by low-pressure metamorphism producing schistosity and prehenite–pumpellyite greenschist facies assemblages in the volcanogenic sediments of the IPB.

The unique nature of the mineralogy of the Neves-Corvo deposit compared with other IPB deposits is mainly a result of the introduction of later Cu-rich hydrothermal solutions to the primitive ore pile and the presence of tin mineralisation. The cupriferous ores are rich in tetrahedrite–tennantite, stannite, kesterite, stannoidite and mawsonite.

Cassiterite occurs in Neves-Corvo: (*a*) as thin layers of euhedral crystals in cupriferous ores, partially replaced by chalcopyrite; (*b*) in the schistosity of a banded black shale chalcopyrite hanging wall formation; (*c*) as metre-sized lenses of massive cassiterite overlying the cupriferous ores.

The ore textures at Neves-Corvo are complex, due to intergrowths of fine colloform pyrite with the base metal minerals. Because of the low grade of metamorphism, colloform, geopetal and soft-sediment diagenetic features are preserved in the 'complex ores'. These 'complex ores' have contents of 0.5% Cu, 1% Pb and 5.5% Zn. In copper-rich ores (7.9% Cu and 1.4% Zn), replacement of the primary ore by chalcopyrite has obliterated most of these textures and produced fine chalcopyrite–tetrahedrite–pyrite intergrowths. The textures clearly indicate the genesis of these ores but they impose a practical problem in recovery of the metals. There is no clear correlation between these textures and the ore classification used at the mine, but an understanding of the textures is vital since the 'complex ores' require fine grinding to achieve liberation and the fine grinding adversely affects the froth flotation processing of the ore.

The implications of the complex sulphide textures for ore beneficiation have been studied using reflected light microscopy, with determination of modal analyses and grain-size distributions of free particles and middlings from concentrates and tailings.

The outcome of a one-year intensive study is that the ore microscopy laboratory at the mine now produces daily information about the textures of the feed ores so that metallurgical engineers can optimise the performance of the ore dressing plant.

KEYWORDS: ore textures, sulphides, Iberian pyrite belt.

Geological setting

NEVES-CORVO lies in the Portuguese sector of the Iberian Pyrite Belt (IPB) and consists of five ore bodies—Neves, Corvo, Graça, Zambujal, and Lombador. These occur within a volcano–sedimentary complex at the top of a felsic volcanic submarine pile at depths of 300 to 700 m (Figs. 1 and 2).

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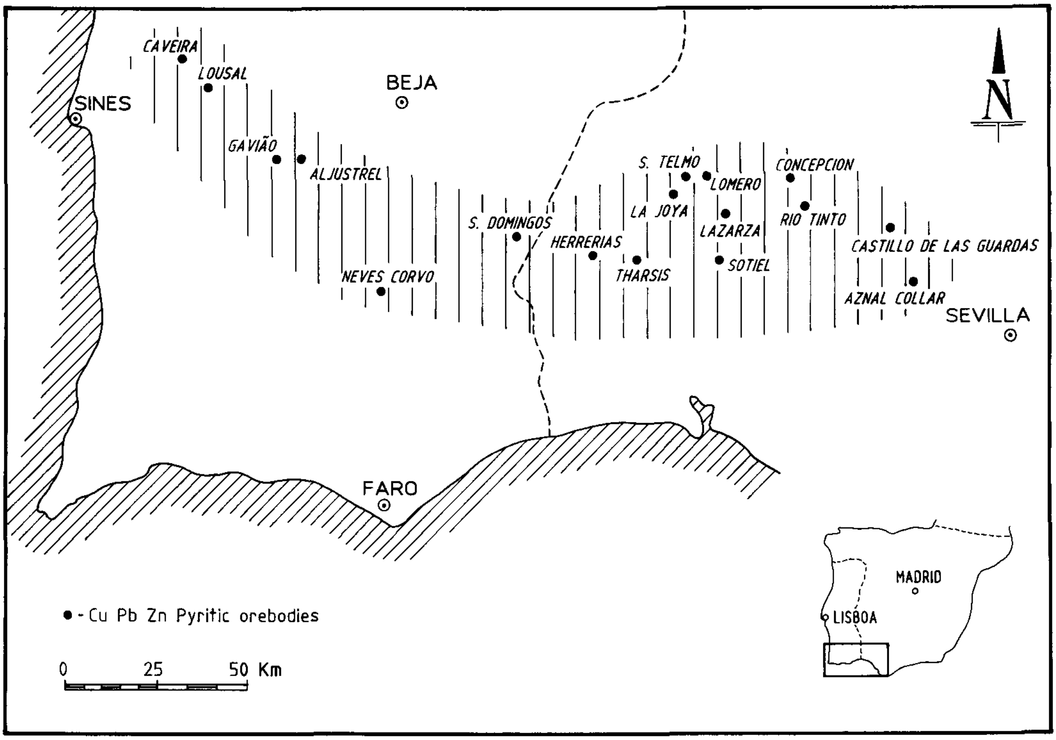

FIG. 1. Map of the Iberian Pyrite Belt showing the location of the major Cu-Pb-Zn pyritic orebodies.

The acid volcanic pile is composed of three different units of pyroclastic tuffs, which are separated by discontinuous intercalated shale units of lower Tournaisian to middle Visean age. The top level of the acid volcanic pile, where the massive sulphides are located, is marked by a thin hydrothermal–sedimentary horizon of jasper, carbonates and minor chlorite shales passing gradationally into a flysch of Culm age (Leca *et al.*, 1985; Carvalho, 1986).

The ore deposits were affected by low-pressure metamorphism producing schistosity and prehenite–pumpellyite greenschist facies assemblages during the Hercynian deformation (Munhá, 1983).

Mineralogy and ore types

The unique nature of the mineralogy of Neves-Corvo deposit compared with other IPB deposit is mainly a result of the introduction of later Cu-rich hydrothermal solutions to the primitive ore pile and the occurrence of an important tin mineralisation event.

On a geological basis, the ore types were classified by mine geologists as *massive sulphide mineralisation, fissural, rubané* and *breccia ores* (Fig. 3).

On a chemical compositional basis, taking into account the Cu, Zn, Pb, Ag and Sn grades, the *massive sulphide mineralisation* was later divided into the MC, MB, MS, MT, MZ, MP and ME ore types.

A mineralogical characterisation of these ore types has been made by Gaspar (1990):

MC—Copper-dominated ores with lesser amounts of other metals (Plate 4*a*). These cupriferous ores are mainly formed by chalcopyrite replacing earlier colloform pyrite and sphalerite. Recrystallised pyrite, stannite, kesterite, stannoidite, tennantite, tetrahedrite, freibergite and arsenopyrite are the main accessory minerals. Minor quantities of bournonite, galena, pyrrhotite, meneghinite, aikinite, kobellite, bismuthinite, enargite and magnetite occur.

MB—A bimetallic ore containing significant Cu and Zn. In these ores several generations of sphalerite with different characteristics occur: colourless, orange or reddish-brown sphalerite in transmitted light; growth-banded sphalerite sometimes showing effects of hydrothermal leaching; sphalerite 'diseased' by chalcopyrite or tetrahedrite; recrystallised sphalerite with twinning exuding chalcopyrite (Plate 4*b*).

MS—Copper-rich ore but containing economic levels of tin. The tin mineralisation in these ores is due to the sulphides, stannite, stannoidte, kesterite and mawsonite and to the cassiterite which occurs in thin layers of euhedral crystals partly replaced by chalcopyrite (Plate 4*c*).

MT—Tin-rich ores with low base-metal grades. The mineralisation is mostly euhedral cassiterite with interstitial quartz, carbonates and sulphides. The cassiterite occurs in the chloritic shales of the *rubané* and as metre-sized lenses overlying the massive sulphides (Plate 4*d*).

MZ—Zinc-domianted ore with lesser amounts of other metals. Galena is always interstitial to sphalerite and both minerals recrystallise very often, forming banded ores in partly recrystallised pyrite (Plate 4*e*).

MP—Polymetallic ore rich in Zn but containing signficiant amounts of Cu, Pb, and Ag. The carriers of Ag are freibergite, tetrahedrite, and tennantite.

ME—Pyrite ore containing low base-metal grades, typically less than 2.0% Cu + Pb + Zn. The pyrite is mainly colloform and occurs in several generations and textures due to slumping, reworking and brecciation. Chalcopyrite, sphalerite, galena, tetrahedrite, and tennantite are interstitial in colloform pyrite (Plate 4*f*).

The terms *fissural* and *rubané* were introduced in the ore classification by French geologists during the early stages of the geological exploration of the Neves-Corvo ore bodies. The *fissural* is a typical stockwork in tuffs and shales on the footwall, and the *rubané* is a banded ore of alternating sulphides and chloritic shales.

The *fissural* type and the *rubané* type contain some of the copper and tin reserves of the Corvo deposit but are not known to contain significant 'complex sulphide' mineralisation.

A *breccia ore* type, considered to be an epiclastic ore with clasts of tuffs cemented with sulphides (Carvalho, 1986), is not included in the total reserves for all five ore bodies (Table 1).

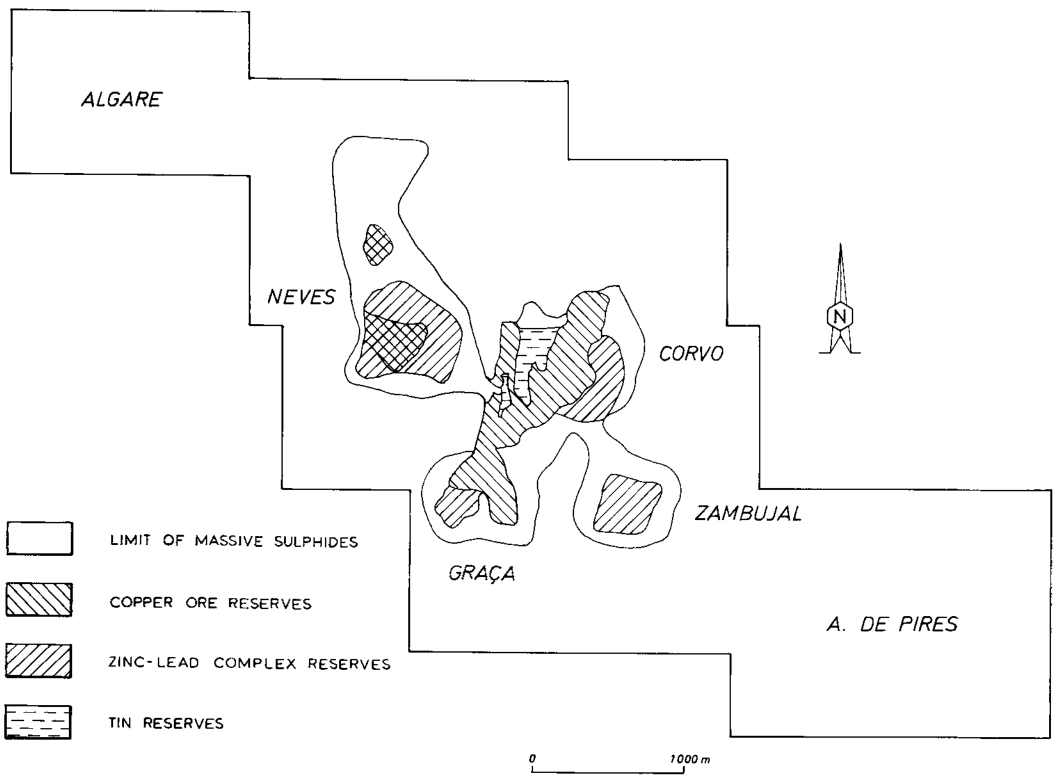

FIG. 2. Plan of the lease area of Neves-Corvo showing distribution of the different ore types (after Chadwick, 1989).

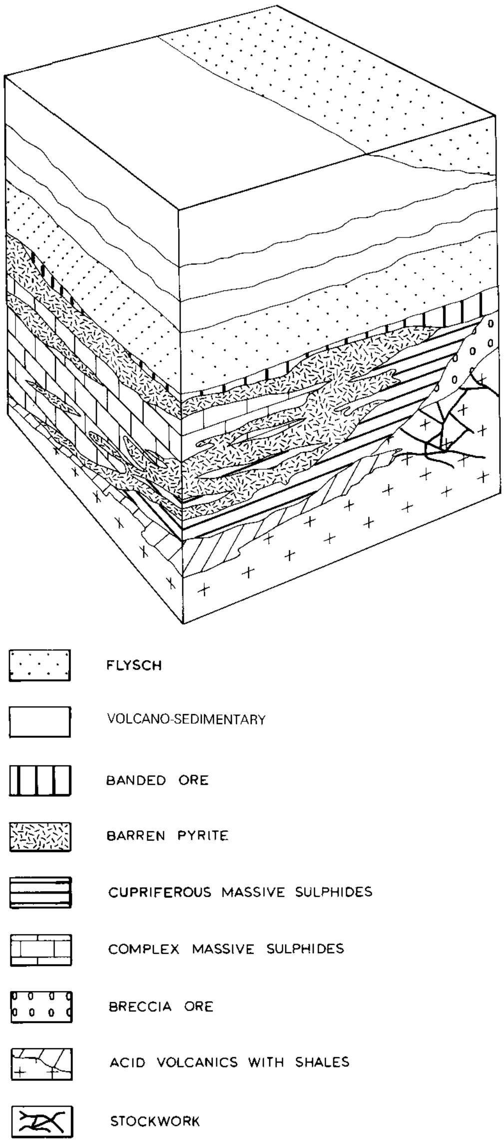

FIG. 3. Simplified block diagram of the ore types (Carvalho, 1986).

Ore textures

The ore textures of the Neves-Corvo deposit are complex due to the fine intergrowths of colloform pyrite with the base-metal sulphides. Because of the low-grade of the metamorphism, colloform, geopetal and soft-sediment textures are preserved in the 'complex ores' (Plates 4*a*, *b*, *f*).

Some of the textures are very similar to the ones found in the Kuroko deposits (Barton, 1973; Eldridge *et al.*, 1983; Watanabe, 1974). Some of the textural and paragenetic features of pyrite, sphalerite and chalcopyrite of the 'complex ores' are like those described for the sulphide chimneys from the East Pacific Rise and Plume Site, Southern Juan de Fuca Ridge (Graham *et al.*, 1988; Marchig *et al.*, 1988; Paradis *et al.*, 1988) (Plate 4*f*).

In the copper ores, the replacements and recrystallisations due to an introduction of a later and hotter Cu-rich hydrothermal solution erases most of the primary textures. Remobilisation of chalcopyrite, tetrahedrite and tennantite are common in the copper ores.

Textural types of the 'complex ores'

A textural and mineralogical classification of the 'complex ores' was carried out in order to help the definition of the necessary degree of selectivity during mining and beneficiation, when significant variations of ore types occur between or within different lenses.

Since pyrite is the main mineralogical phase of the 'complex ores', a classification was drawn up using only the pyrite textures and the shape and amount of chalcopyrite and sphalerite in the ores.

Five textural types, each one divided into sub-types, were established and a systematic macro and microscopical study of drill cores from the 'complex ores' of the Corvo, Graça and Neves ore bodies was carried out.

The five types considered correspond to the mostly abundant pyrite textures, and the establishment of the sub-types took into account the relative quantities of chalcopyrite and sphalerite occurring in each pyrite texture, in an attempt to find if any mutual relationship between textural types and the ore type classification used at the mine could be shown to exist.

As expected, a clear correlation between the textural classification and the one established on the basis of contents of subordinated metals does not exist since in the 'complex ores' the same

Table 1. Total reserves for all five ore bodies in all categories (after SOMINCOR, February 1990)

	Million tons	%Cu	%Pb	%Zn	%Sn
Copper ores[1]	30.2	7.9	—	1.4	—
Tin ores[2]	2.7	13.6	—	1.3	2.4
Complex ores[3]	44.4	0.5	1.0	5.5	—

[1] *Copper ores* include MC, MB and MS ore types.
[2] *Tin ores* include MS and MT ore types.
[3] *Complex ores* include MZ and MP ore types.

Textural ore-types		Sub-types
PR	reworked coarse pyrite alternating with bands of fine pyrite showing flow texture; base metal sulphide occur interstitially in pyrite.	PRZ–PRCu–PRPo
PMa	massive recrystallised pyrite with interstitial base metal sulphides.	PMaZ–PMaCu–PMaPo
PZ	colloform pyrite with several grain sizes, rich in sphalerite mostly banded.	PZR–PZCt
PG	pyrite showing graded bedding with interstitial base metal sulphides.	
PBr	brecciated pyrite cemented by base metal sulphides and/or carbonates.	PBr–PBrPo

Key for sub-types: Z—rich in sphalerite; Cu—rich in chalcopyrite; Po—rich in both sphaleite and chalcopyrite; PZR—reworked sphalerite in pyrite; PZCt—convolute bedding of sphalerite in pyrite.

mineralogical phases occur within different textural features.

All textural types and sub-types are present in the Neves ore body, while in Corvo and Graça a lesser variation was found, seemingly in accordance with the metallogenic history of these two ore bodies. The introduction of a later Cu-rich hydrothermal solution to the primitive ores erases some of the characteristic textures of the early 'complex ores'.

As far as the copper ores of Corvo, Graça and Neves are concerned, all the observations suggest that a metallogenic model similar to the one proposed by Eldridge *et al.* (1983) and Ohmoto *et al.* (1983) for the yellow ores of the Kuroko deposit can also be accepted for Neves-Corvo. Evidence of replacements of the primitive pyrite–sphalerite ores by later chalcopyrite has frequently been found (Plates 4*a*, *b*).

Implications of ore textures for beneficiation

Since 1977, one of us has been working on the implications of ore textures for beneficiation of the complex sulphides of the IPB (Gaspar and Conde, 1978; Gaspar, 1984).

The experience achieved in the field of the ore microscopy applied to ore dressing problems made it possible to set up at Neves-Corvo an ore microscopy laboratory that produces daily information about textures of the feed ores and grain-size distribution of the products resulting from grinding and froth flotation. This enables the metallurgical engineers to optimise the performance of the ore dressing plants.

The relicts of replaced ores in chalcopyrite and the grain-size of the recrystallised pyrite impose a grinding to 15 μm in order to achieve economic copper concentrates.

The liberation of 80% of the cassiterite is achieved with a grinding running from 25 μm to 100 μm, since the cassiterite occurring in the shales is coarser than that in the *copper ores*. These grain sizes make concentration possible not only by flotation but also by gravity methods as well.

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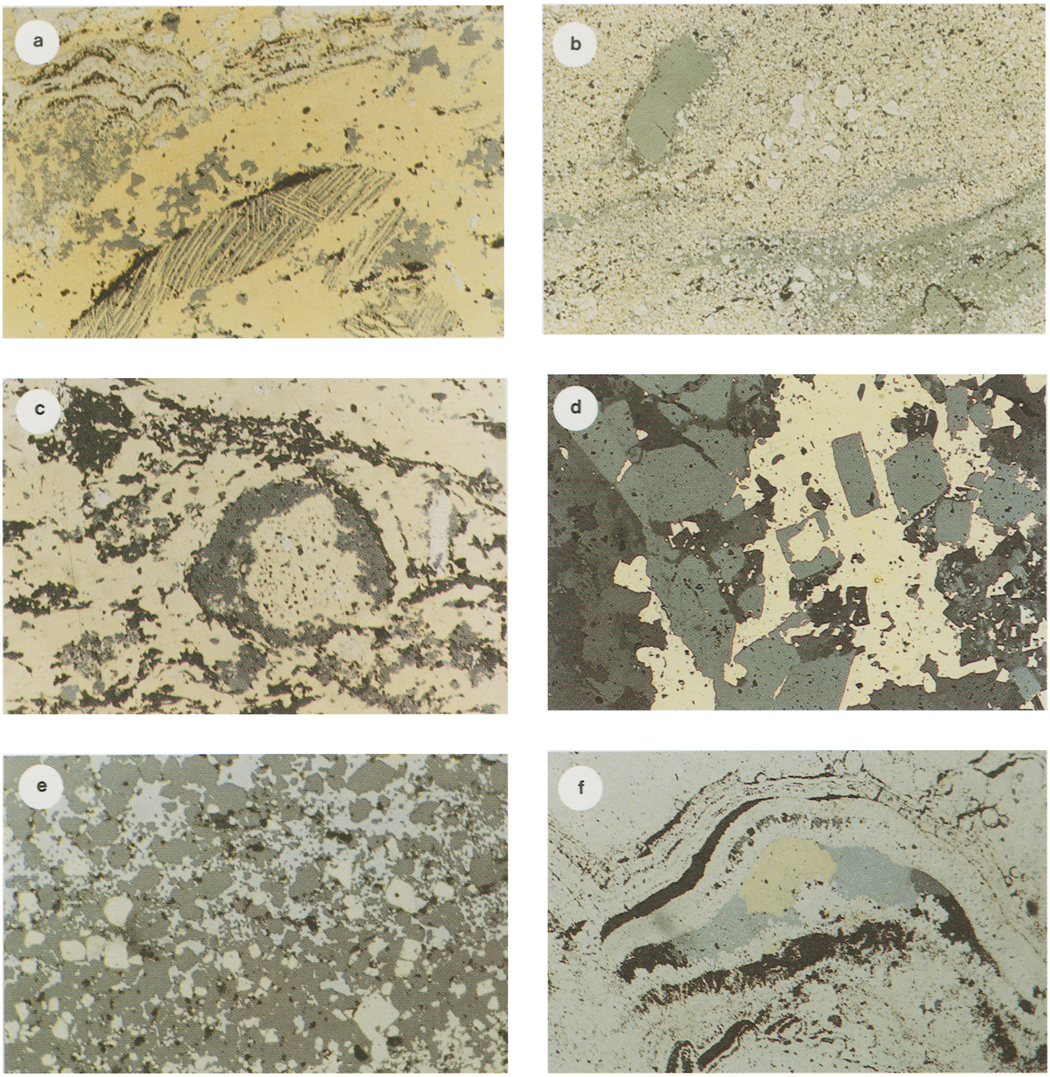

PLATE 4. (*a*) Corvo copper ore (MC type). Chalcopyrite replacing earlier colloform pyrite and sphalerite (width of plate 1 mm). (*b*) Corvo bimetallic ore (MB type). Reworked sphalerite and anhedral pyrite in a matrix of chalcopyrite (width of plate 5 mm). (*c*) Corvo copper-rich ore containing bands of euhedral cassiterite and phyllosilicates partly replaced by chalcopyrite (MS type) (width of plate 2 mm). (*d*) Corvo tin-rich ore with low base metal grades (MT type). Euhedral cassiterite being replaced by chalcopyrite after carbonates (width of plate 2 mm). (*e*) Graça zinc-dominated ore (MZ type). Galena interstitial to sphalerite without 'chalcopyrite disease'. Euhedral to anhedral pyrite mostly in sphalerite (width of plate 2 mm). (*f*) Corvo colloform barren pyrite with rims and bands of tetrahedrite, chalcopyrite and sphalerite (ME type) (width of plate 2 mm).