The Iberian Pyrite Belt

Field trip guide

Joint SGA IAGOD International Meeting

Field trip B4

28 August - 3 September, 1999

Leaders: F.Tornos, J.Locutura & L.Martins

Instituto Tecnológico
GeoMinero de España

Instituto Geologico e Mineiro
de Portugal

Joint SGA IAGOD International Meeting
Field trip B4

28 August - 3 September, 1999

(modified version 8/00)

Leaders: Fernando Tornos[1], Juan Locutura[1] and Luis Martins[2]

[1] Instituto Tecnológico Geominero de España. C/Ríos Rosas 23, 28003 Madrid (Spain)
e.mail: ftaitge@iponet.es: j.locutura@itge.mma.es
[2] Instituto Geológico e Mineiro. Est. Portela, Zambujal, ap.7586. 2720 Alfragide (Portugal). e.mail: lmar@IGM.pt

With contributions from

T.Donaire, J.M.Escobar, A.Ferreira, V.Guerrero, E.González Clavijo, R.Hidalgo, F.C.Knight, J.Locutura, C.Moreno, J.M.Pons, N.Pacheco, E.Pascual, G.Ruiz de Almodovar, R.Sáez, J.C.Sousa, F.Tornos and M.Toscano

Tornos,F., Locutura, J., Martins,L. (eds.) (1999): The Iberian Pyrite Belt. **Joint SGA IAGODInternational Meeting**. *Field trip B4.* ITGE-IGM, 49 pp.

List of Participants

Bull, Stuart. CODES, Australia [S.Bull@utas.edu.au]
Cooke, David. CODES, Australia [D.Cooke@utas.edu.au]
Elliot, James. U.S. Geological Survey [jeelliot@usgs.gov]
Gamberi, Fabiano. IGM Bologna, Italy [lisaefab@tin.it]
Gemmell, Bruce. CODES, Australia [Bruce.Gemmell@utas.edu.au]
Grasso, Giuseppe L. Borneo Expl. Mining Indonesia [bemi@tarakan.wasantara.net.id]
Large, Ross. CODES, Australia [Ross.Large@utas.edu.au]
Lear, Kerry. Kennecot, Canada [LearK@kennecott.com]
Locutura, Juan. ITGE, Spain [j.locutura@itge.mma.es]
Marani, Michael. IGM Bologna, Italy [lisaefab@tin.it]
Matos, Joao. IGM, Portugal [igmbeja@ip.pt]
McPhie, Jocelyn. CODES, Australia [JMcPhie@utas.edu.au]
Oliveira, Vitor. IGM, Portugal [igmbeja@ip.pt]
Tornos, Fernando. ITGE, Spain [ftaitge@iponet.es]

Itinerary

Date	Visits	Comments
28/8	San Miguel (1)	Replacive massive sulphides and related stockwork in acid rocks (exhausted mine)
	Soloviejo (2)	Jasper-related Mn deposit and peperites (exhausted mine).
	San Platón (3)	Base-metal rich massive sulphide deposit in acid rocks (exhausted mine).
29/8	Tharsis (4)	Shale hosted massive sulphide deposit (open pit). Au-Co rich stockwork
	Virgen Peña (5)	Relationships between the basement (PQ Group) and Volcanosedimentary Complex
	El Almendro (6)	Cross section of the lowermost Volcanosedimentary Complex
	Paymogo (7)	Old quarry showing intrusive relationships between aid rocks and red shales-jaspers
30/8	Aljustrel (8)	Massive sulphide deposit in acid volcanic rocks (underground mine)
31/8	Neves Corvo (9)	Cu-Sn massive sulphides and host rocks (underground mine)
1/9	Aguas Teñidas (10)	Base metal-rich new mine in the IPB (underground mine)
	Lomero-Poyatos (11)	Highly deformed base-metal and Au-rich massive sulphides (exhausted mine)
	El Cerro (12)	Hyaloclastites in an acid dome
	La Zarza (13)	Overview of the La Zarza open pit (exhausted mine)
2/9	Riotinto (14)	Atalaya open pit, Salomon open pit and gossan (open pits). Includes relationships between cherts, porphyries, massive sulphides and stockworks.
	Jarama River (15)	Cross section of the VS Complex
3/9	Las Cruces (16)	Polymetallic massive sulphide with supergene alteration

List of authors

Donaire, Teodosio. Facultad de Ciencias Experimentales. Universidad de Huelva, Spain.
Escobar, Juan Manuel. Minas de Riotinto SAL, Huelva, Spain.
Ferreira, Nelson. SOMINCOR, Portugal
Guerrero, Victor. Navan Huelva, Calañas, Huelva, Spain.
González Clavijo, Emilio. BGS, Quito, Ecuador.
Hidalgo, Raúl. Navan Huelva, Calañas, Huelva, Spain.
Knight, Fiona C. Univ. Cardiff, UK
Locutura, Juan. ITGE, Madrid, Spain
Moreno, Carmen. Facultad de Ciencias Experimentales. Universidad de Huelva. Spain
Pacheco, Alfredo. SOMINCOR, Portugal
Pascual, Emilio. Facultad de Ciencias Experimentales. Universidad de Huelva. Spain
Pons, Juan Manuel. Navan Huelva, Calañas, Huelva, Spain.
Ruiz de Almodovar, Gabriel. Facultad de Ciencias Experimentales. Universidad de Huelva. Spain
Sáez, Reinaldo. Facultad de Ciencias Experimentales. Universidad de Huelva. Spain.
Sousa, Joao Carlos de. Eurozinc Mining Co., Aljustrel, Portugal.
Tornos, Fernando. ITGE, Salamanca, Spain.
Toscano, Manuel. Facultad de Ciencias Experimentales. Universidad de Huelva. Spain.
Videira, Juan Carlos. Riomin Exploraciones, Sevilla, Spain.

1. **Introduction** (F.Tornos)

The Iberian Pyrite Belt is one of the most outstanding massive sulphide provinces in the world, with about 1700 Mt total reserves (massive sulphides + stockworks), that make it one the largest sulphide concentrations in the earth´s crust. It includes eight giant (>100 Mt) massive sulphide deposits (Rio Tinto, Aznalcollar-Los Frailes, Sotiel-Migollas, Tharsis, La Zarza, Masa Valverde, Aljustrel and Neves Corvo) and about 44 orebodies (>1 Mt) as well hundreds of prospects (Figure 1). Traditionally, these deposits have been considered to be similar to the Kuroko type of volcanic hosted deposits (e.g., Franklin et al., 1981; Sawkins, 1990). However, their location within a transpressive basin located in a passive continental margin dominated by detritic sediments suggest that they form an independent group of volcanic-related stratabound deposits, with no known modern analogues.

The guide includes general descriptions of the sites to be visited, written by geologists from universities, geological surveys and mining companies that are currently working in the IPB (Iberian Pyrite Belt). Their descriptions present an up to date view of the geology of the massive sulphides and host rocks. No major effort has been done in order to homogenize the contributions from individual authors. As can be seen in the text and will be discussed in the trip, presently there are very different models on the geology of the IPB.

The plan is to visit many of the working mines in the Iberian Pyrite Belt as well some other abandoned mines and key outcrops of interest. Main aspects to be discussed during the trip include:

- Morphology and structure of the igneous rocks, intrusive and extrusive. Including the relationships with hyaloclastites, peperites, hydroclastic breccias and volcanosedimentary rocks.
- The hydrothermal alteration of igneous and sedimentary rocks.
- The relationship of massive sulphides with the host rocks and hydrothermal alterations.
- Exhalative vs inhalative processes in the genesis of massive sulphides.
- The effect of the ductile-brittle Variscan deformation on the igneous and sedimentary rocks as well the massive sulphides.

Acknowledgements: Thanks are given to the colleagues describing the different stops, as well Alejandro Sánchez, Americo Santos, Benito Caballero, Clive Boulter, Pedro Florido and Cecilio Quesada for their help in the location of the outcrops as well their comments and different interpretations of the geology of the IPB. The field trip in Portugal is organized by Luis Martins, Vitor Oliveira and Joao Matos. We also acknowledge Piritas Alentejanas S.A., SOMINCOR, Minas de Rio Tinto S.A.L., Minas de Tharsis S.A.L., Navan Huelva S.A. and Riomin Exploraciones S.A. for the information provided and their kindness in allowing the visit to their mines. R.Vicente made the final edition and Fiona C. Knight significantly improved the english of some of the chapters. G.Ortiz edited the geological maps. This guide has been partially founded by the INTAS-EC project 1699. It was originally written for the INTAS-EC project "Massive sulphides and near-vent communities in the Urals palaeocean" workshop and field trip during March 1999. Later, it was modified for the Field Trip 4b of the Joint SGA-IAGOD International Meeting.

*****

Cartography

Topographic maps

Spain

- 1/200000 Sheets 74 & 75
- 1/50000 Sheets 918, 936, 937, 938, 958, 959, 960 & 961

Portugal

- 1/200000 Sheets 7 & 8
- 1/50000 Sheets 35-C & D, 39-A, B, C & D, 42-A, B, C & D, 43-C, 45-A, B, C & D, 46-A, B, C & D 50-A & B

Geologic maps

Spain

- Síntesis Geológica de la Faja Pirítica.Memorias IGME, Madrid, 1982
- Mapa Metalogenetico de España. ITGE, Madrid, 1996
- 1/50000 Geologic Maps 918, 936, 937, 938, 958, 959, 960 & 961. ITGE, Madrid

Portugal

- Mineral Potential of Portugal, L. Martins, V. Borralho eds., IGM, Lisbon, 1998

2. **Geology of the Iberian Pyrite Belt with special reference to the visited localities** (F.Tornos)

The IPB formed in a basin located in the passive margin of an exotic terrane that suffered a northward oblique subduction and later collision with the autochthonous Iberian Terrane during the Variscan times. Remnants of the exotic terrane are South Portuguese Zone (SPZ) and their equivalents in the Variscan Arc, in SW Ireland and England and the Rheno-Hercynian and Moravio Silesian Zones (Ribeiro et al., 1990; Oliveira and Quesada, 1998). The transpressional deformation lead to the formation of a major volcanic belt (IPB) within a highly compartmentalised sedimentary basin on the outermost margin of the SPZ (Quesada, 1996). At present, it is limited by thrusts with a southward vergence. To the north a major structure limits the IPB with the Pulo de Lobo accretionary prism, located between the Ossa Morena Zone (OMZ) and the SPZ, while to the south the IPB is thrusted above the Baixo Alentejo Unit.

The general stratigraphy of the IPB is fairly simple. The oldest rocks form a monotonous sequence of arenites and shales (PQ Group, Upper Devonian) developed on a stable epicontinental shelf. The first evidences of the orogenesis are recorded in the uppermost PQ Group, by a major sedimentary break. The rupture of the platform lead to an increase of the clastic component and the development of very heterogeneous facies, including shallow to subaerial reef limestones, delta-related deposits and mass flows (Moreno et al., 1996) (Virgen de la Peña, stop 5).

The Volcanosedimentary Complex (VSC) is a highly heterogeneous sequence 200-700 m thick that overlies the PQ Group. The detritic rocks are fairly similar to those of the PQ Group, but with a major black and grey shale component. It also includes greywackes, quartzites and somewhat abundant and characteristic chemical sediments, mostly Mn-bearing cherts. This Complex is characterised by the presence of igneous activity including subvolcanic intrusions (domes and sills), lava flows and variegated volcanogenic sedimentary deposits (El Almendro section, stop 6). Pyroclastic rocks are traditionally quoted as very abundant (e.g., Routhier et al., 1980; Carvalho et al., 1997) but recent works (Boulter, 1993; Mitjavila et al., 1997; Tornos et al., 1998) have shown that many of the rocks earlier interpreted as pyroclastic were originally massive rocks or volcanogenic sediments; however, pyroclasts can be locally abundant (Jarama river, stop 15). Synthetic regional sections cannot be established although some authors (Strauss and Madel, 1974; Routhier et al., 1978; Sáez et al., 1996) describe three regional acid volcanic cycles and two interbedded basic ones.

Two major groups of acid rocks can be observed. The first group includes subvolcanic domes and sills affected by hydrothermal processes directly related with the formation of massive sulphides. They include those that host the stock-work at Rio Tinto (Corta Atalaya, stop 14), San Miguel (stop 1) or different outcrops in the Tharsis area (stop 4). These acid rocks may be roughly equivalent to those attributed to the first acid volcanism (V_1). There is a second group of acid porphyries that intrude the red jaspers and purple shales located in the uppermost VSC. These rocks can be observed in Paymogo quarry (stop 7), Corta Atalaya, Rio Tinto (stop 14), Jarama River (stop 15) and many other places. The existence of acid domes located just below the turbidites of the Culm Group (El Cerro, stop 12) suggest that many of the acid porphyries are very late and contemporaneous with the, previously called, V_3 in the IPB.

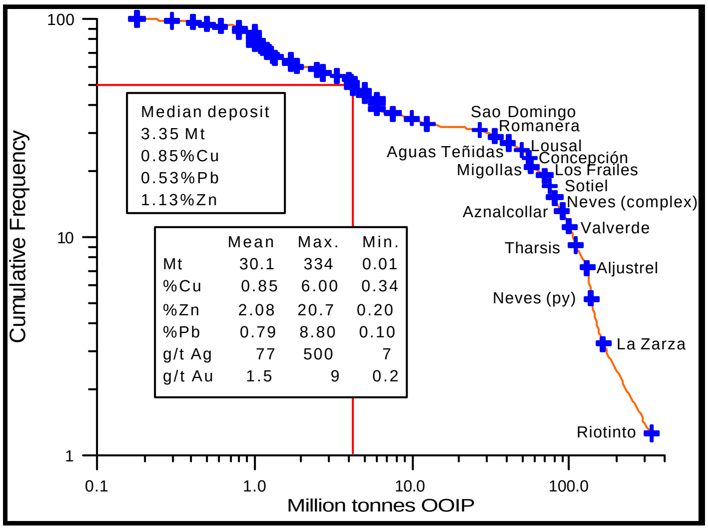


Figure 1. Tonnage-grade data for massive sulphide deposits in the IPB

The acid rocks are low-Al high-Nb calc-alkaline with no geochemical differences between them. The basic rocks belong to the alkaline to continental tholeitic suites (Munhá, 1983; Mitjavila et al., 1997; Thieblemont et al., 1998). Intermediate rocks are very scarce. In the IPB there seems to be an unique marker horizon, up to 30 m thick, made up of haematitic, radiolar-rich, purple shales sometimes interbedded with green shales and always located above the massive sulphides and the major igneous events.

The entire sequence shows a pervasive hydrothermal alteration with major geochemical modifications, including the trace element and isotopic compositions. The igneous rocks show a pervasive spilitization (Munhá, 1983) with retrogradation of the primary assemblages reflected by highly variable alteration index. The volcanism and coeval hydrothermal activity occurred in a very short time span, between the Uppermost Devonian and the Middle Upper Visean (c.350-330 Ma).

Finally, the Flysch Group (Culm) includes synorogenic turbidites that fill the foreland basin of the collisional orogen; it is highly diachronous with southwestern progradation and ranging in age from late

Visean to Westphalian (Oliveira, 1990).

The Variscan deformation (c.330-300 Ma) was related with the final collision and obduction of the SPZ on the autochthonous Iberian Terrane. It was responsible for a thin-skinned deformation dominated by thrust and fold tectonics (Silva et al., 1990). The metamorphic grade is usually very low, leading to only a minor recrystallization of the massive sulphides. However, in the northern part of the Belt where the metamorphic grade is within the greenschist facies (Munhá, 1990). In addition, near the thrusts the original relationships and textures are usually masked by an intense deformation and recrystallization (Lomero Poyatos, stop 11).

Igneous intrusive rocks related to the VSC Complex are very scarce and perhaps only the Campofrio granite, located eastwards of the IPB, can be interpreted as the remnants of a deep magmatic chamber.

In the IPB the massive sulphides are interbedded with the VSC and hosted both by igneous and sedimentary rocks. These massive sulphides are usually pyrite-rich (e.g., San Miguel, stop 1; Tharsis, stop 4; Aljustrel, stop 8; Rio Tinto, stop 14) with only few having significant base metal contents (e.g., San Platón, stop 3; Neves Corvo, stop 9; Aguas Teñidas, stop 10). There are also abundant Mn-rich chert lenses (Soloviejo, stop 2) as well some syn to post-Variscan hydrothermal veins. When the original features are pristine, the massive sulphides have a lensoidal morphology and overlie a zone of intense hydrothermal alteration. If hosted by igneous rocks there is an internal chlorite-rich (+quartz + sulphides ± pyrophyllite; Relvas et al., 1994) zone that includes the stockwork surrounded by a sericitic (+ quartz + chlorite ± sulphides) one, as in Riotinto (stop 14; García Palomero, 1980) or Aljustrel (stop 8; Barriga, 1990). Relvas et al. (1990) also quote a more external halo of very weak alteration with quartz, Na-bearing white micas and quartz-sericite-chlorite veins. When hosted by shales, the footwall showas an unique zone formed by almost massive Fe-rich chlorite (Tharsis, stop 4; Tornos et al., 1998). The Variscan deformation overprints and significantly modifies the structure and texture of the massive sulphides and host rocks, as can be seen in almost all the deposits, specially in Lomero Poyatos (stop 11).

Many of the major orebodies show a direct relationship with black shales, as occur in Neves Corvo (stop 9), Aznalcóllar, Sotiel-Migollas, Las Cruces (stop 16) or Tharsis (Stop 4). Preliminary data indicate that many of the massive sulphide deposits formed in a highly restricted time span, close to the Upper Devonian-Lower Carboniferous boundary (355 Ma).

<u>Some general references</u>

Barriga, F.J.A.S. (1990): Metallogenesis in the Iberian Pyrite Belt. In 'Pre-Mesozoic Geology of Iberia', Dallmeyer,R.D., Martinez Garcia,E. (eds.), Springer Verlag, pp.369-379

Carvalho,D., Barriga,F., Munhá,J. (1997): The Iberian Pyrite Belt of Portugal and Spain: Examples of bimodal-siliciclastic systems. In Volcanic asociated massive sulfide deposits: Processes and examples in modern and ancient settings, Barrie,C.T., Hannington,M.D. (eds.). Rev. Economic Geol. (in press).

García Palomero, F.(1980): Caracteres geológicos y relaciones morfológicas y genéticas de los yacimientos del anticlinal de Riotinto. Tesis Doctoral. Instituto de Estudios Onubenses, Huelva, 263 pp.

Gaspar,O.C. (1996): Microscopia e petrologia de minerios aplicadas a genese, exploraçao e mineralurgia dos sulfuretos maciços dos jazigos de Aljustrel e Neves Corvo. Estudos, Notas e Trabalhos, IGM, 38, 3-195

Gonzalo y Tarín,J. (1888): Descripcion física, geológica y minera de la provincia de Huelva. Memorias de la Comisión del Mapa Geológico de España, v.15, 3 tomos

IGME (1982): Síntesis Geológica de la Faja Pirítica del SO de España. IGME, Madrid, 106 pp

ITGE (1989): Mapa Metalogenético de España a escala 1/200000. Hoja núm.75 (Sevilla). ITGE, Madrid, 62 pp

Leistel,J.M., Marcoux,E., Thieblemont,D., Quesada,C., Sánchez,A., Almodovar,G.R., Pascual,E., Sáez,R (1996): The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt. Review and preface to the special issue. Mineral. Deposita, 33, 1-2, 2-30

Mitjavila,J., Martí,J., Soriano,C. (1997): Magmatic evolution and tectonic setting of the Iberian Pyrite Belt volcanism. Jour. Petrology, 38-6, 727-755

Moreno,C., Sierra,S., Sáez,R. (1996): Evidence for catastrophism at the Famennian-Dinantian boundary in the Iberian Pyrite Belt. In Strogen,P., Somervilee,I.D., Jones,G.L. (eds.) Recent advances in Lower Carboniferous Geology. Geol.Soc.London. Spec. Publication, 107, 153-162.

Munhá,J. (1983): Hercynian magmatism in the Iberian Pyrite Belt. Mem.Serv.Geol. Portugal, 29, 39-81

Munhá,J. (1990): Metamorphic evolution of the South Portuguese/Pulo do Lobo Zone. In 'Pre-Mesozoic evolution of Iberia', Dallmeyer,R.D., MartinezGarcia,E. (ed.), Springer Verlag, pp.363-368.

Oliveira,J.T. (1990): South Portuguese Zone: Intoduction. Stratigraphy and synsedimentary tectonism. In "PreMesozoic Geology of Iberia", Dallmeyer,R.D., Martinez García,E. (eds.) Springer Verlag, 333-347.

Oliveira,J.T., Quesada,C. (1998): A comparison of stratigraphy, structure and paleogeography of the South Portuguese Zone and Southwest England, European Variscides. Proceedings Usher Society, in press.

Pinedo,I. (1963): Piritas de Huelva. Su historia, minería y aprovechamiento. Summa, Madrid, 1003 pp.

Quesada,C. (1996): Estructura del sector español de la Faja Pirítica: implicaciones para la exploración de yacimientos. Bol. Geol. Min., 107, 3-4, 65-78

Relvas,J.M.R.S., Massano,C.M.R., Barriga,F.J.A.S. (1990): Ore zone hydrothermal alteration around the Gaviäo orebodies: implications for exploration in the Iberian Pyrite Belt. Abstracts, VIII Semana de Geoquimica, Lisboa.

Relvas,J.M.R.S., Barriga,F.J.A.S., Bernardino,F.B.C.P., Oliveira,V.M.S., Matos,J.X. (1994): Ore zone hydrothermal alteration in drillhole IGM-LS1 at Lago Salgada, Grándola, Portugal: a first report on pyrophillite in a central stockwork. Bol.Soc.Esp.Min.,17-1,157-158.

Routhier,P., Aye,F., Boyer,C., Lecolle,M., Moliere,P., Picot,P., Roger,G.(1980): Le ceinture sud-iberique a amas sulfures dans sa partie espagnole mediane. Mem.BRGM, 94, 265 pp.

Ruiz de Almodovar,G., Sáez,R. (1992): Yacimientos de sulfuros masivos de la faja pirítica sur ibérica. In 'Recursos Minerales de España', Textos Univ., 15, CSIC, pp.1309-1324

Sáez,R., Almodovar,G.R., Pascual,E. (1996): Geological constraints on massive sulphide genesis in the Iberian Pyrite Belt. Ore Geology Reviews, 11, 429-451

Silva,J.B., Oliveira,J.T., Ribeiro,A. (1990): Structural outline of the South Portuguese Zone. In "PreMesozoic Geology of Iberia", Dallmeyer,R.D., Martinez García,E. (eds.) Springer Verlag, 348-362

Strauss,G.K., Beck,J.S. (1990): Gold mineralisations in the SW Iberian Pyrite Belt. Miner. Deposita, 25, pp.237-245

Strauss,G.K., Madel,J. (1974): Geology of massive sulphide deposits in the Spanish Portuguese Pyrite Belt. Geol. Rundschau, 63-1, 191-211

Thieblemont,D., Pascual,E., Stein,G. (1998): Magmatism in the Iberian Pyrite Belt: petrological constraints on a metallogenic model. Mineralium Deposita, 33, 1-2, 98-110

Tornos,F., González Clavijo,E., Spiro,B.F. (1998): The Filón Norte orebody (Tharsis, Iberian Pyrite Belt): a proximal low-temperature shale-hosted massive sulphide in a thin-skinned tectonic belt. Mineralium Deposita, 33, 1-2, 150-169

1. The San Miguel Mine

Author: F.Tornos
Location: Access by dirt track (5-6 km) left (W) off the N-435 (Huelva Badajoz) in pk 67.6 (4 km N of bridge above Odiel River).
1/50000 sheet: 938
UTM coordinates: 698.35; 4181.90

The San Miguel open pit reveals one of the more pristine stockworks of the IPB as well a section depicting the relationships between the gossans and massive sulphides.

As in many other places of the IPB there are evidences of old roman mining. Contemporary workings began in 1851 and from 1859 to 1960 about 1.29 Mt of pyritic ore with 2-3%Cu and 46%S were extracted (Pinedo Vara, 1963). The copper grades were very irregular with a significant enrichment towards the supergene zone. The Au-bearing gossan has been recently removed by Rio Tinto S.A.L.

The mineralization is located between acid massive porphyritic rocks (N), fine grained volcanoclastic rocks and purple shales (S) dipping c. 70°S. The purple shales are equivalent to those of the marker horizon within the IPB. The lowermost contact is a major thrust; kinematic indicators suggest a complex history with earlier thrusting and later extension. Here, the shales show subhorizontal S_o and S_1. Near the thrust plane they are almost obliterated by a younger subvertical crenulation associated with tight folds of subvertical axial plane. They include angular fragments of acid rocks, that are interpreted as remnants of a highly deformed peperite. Probably, the thrust was channellized along the shale-acid rock + massive sulphide contact.

The mineralization occurs as several E-W to N110°E trending orebodies. The biggest (San Miguel orebody) comprises a lens 200 m length and up to 40 m thick (mean 10 m), which is probably limited by major faults.

The porphyritic acid rocks are strongly silicified and chloritized. They host an irregular stockwork in which the thickness and abundance of the veins increases upwards (S) and grade into massive sulphides. In some zones they include abundant E-W ellipsoidal, cm to m sized remnants of the altered acid rock. These features strongly suggest that the massive sulphides of the open pit represent a replacive orebody formed below the seafloor. As a major difference with other orebodies in the IPB, the massive sulphides are coarse grained and always include a chlorite + quartz matrix. The remnants of host rock and the massive sulphide - porphyry contact are defined by subhorizontal banding that crosscuts the regional stratification.

Minor shear zones and faults can also be observed in the footwall, crosscutting the stockwork and remobilizing the sulphides.

The eastern part of the open pit reveals a gossan above the massive sulphides and stockwork. It is displaced about 100 m with regards to the massive sulphides.

2. The Soloviejo Mine

Author: F.Tornos
Location: Access by dirt track opposite (E) to the entrance of the San Miguel Mine in the pk. 67.6 (4 km N of bridge above the Odiel River) of the N-435 (Huelva Badajoz).
1/50000 sheet: 938
UTM coordinates: 703.10; 4181.30

References:
Jorge, R.C.G.S., Barriga,F.J.A.S., Relvas,J.M.R.S. (1998): Soloviejo Manganese deposit: mineralogy and geochemistry, progress report. Comunicaçoes Actas V Congresso Nacional Geologia, 84-1.
Ramirez Copeiro del Villar,J., Maroto, S. (1995): Metodología de investigación aplicada a los yacimientos de manganeso en Huelva. Bol. Geol. Min., 106-2, 21-31.

Soloviejo is the largest Mn mine of several hundreds of small Mn prospects and mines in the IPB. Currently there are no manganese mines in operation but at the end of the 19th century, Spain was the biggest Mn producer in the world, with about two-thirds of global production (Ramirez & Maroto, 1995). Most of the Mn mineralization in the IPB is related with jaspers located within or near the marker horizon of purple shales.

The Soloviejo Mine worked a subvertical (dip 70-85°N) body of manganese mineralization with an E-W trend (N94°-105°E) about 3500 m in length and up to 30 m in thickness (Ramirez & Maroto, 1995). Most of the ore is in direct relationship with a jasper lens about 1100 m long. There are abundant adits, small shafts and trenches. Most of the ore was extracted by underground works but the mineralization can be seen in the major open pit. Between 1886 and 1973 about 175000 Tm of ore with 29 to 37%MnO_2 were extracted (ITGE, 1982). The deposit was reevaluated between 1992 and 1994 (Ramirez & Maroto, 1995).

The jaspers are interbedded with purple shales located below fine grained volcanoclastic rocks, siliceous shales and black shales beneath the turbidites of the Culm Group. Near the jasper lenses there are abundant breccias and veins of milky quartz; the shales display abundant SC structures as well shead folds.

The hanging wall is composed of acid rocks, that are interpreted as pyroclastic by Ramirez & Maroto (1975) and as autoclastic tuffs with interbedded lava pods and flows by Jorge et al. (1998).

Geologic mapping carried in the open pit shows that the mineralization is located in a structurally complex area, with a major discontinuity being channelized along the shale - jasper - acid rocks contact.

The acid rocks show a strong deformation with mylonitic features, pervasive cleavage and strong lineation. These rocks are brecciated and mainly formed of a microcrystalline groundmass of sericite-quartz-sulphides that include some magmatic quartz phenocrysts (1-2 mm), feldspars altered to quartz + sericite as well elongated fragments of unrecognisable rock also replaced by quartz-sericite. In the NE zone of the pit there are some brownish zones with quartz phenocrysts in a highly siliceous matrix that occur as irregular “dykes” or enclaves. These rocks are interpreted as subvolcanic porphyritic rhyolites, probably less devitrified and less altered equivalents of the main outcrop.

Near the contact with the jaspers and shales, these rocks are capped by pumice mass flows. There rocks are rather massive but include heterometric and polymictic fragments of jasper (1-40 mm), feldspathic-rich rocks (1-2 mm), brownish undevitrified-unaltered porphyrytic rhyolites (1-5 cm) and purple shales, sometimes showing evidences of tectonic rotation. Also, there are some manganese ores and folded veinlets of jasper of undetermined origin. It is suggested that the can be related with an hydrothermal brecciation, vein filling and alteration synchronous with the formation of manganese ores in the hanging wall.

Within the jasper there is a large outcrop of a massive, reddish igneous rock with feldspar and quartz phenocrysts and including cm sized fragments of jasper and purple shale. It is interpreted as a highly contaminated intrusive and massive rock that postdates the underlying massive rhyolites and the purple shales with manganese. The lack of deformation is probably due to its location inside the very rigid jaspers.

Peperitic features can be observed in some loose rocks in the entrance of the pit, probably related with the younger igneous activity. Also here are some purple shales with strong bioturbation and jaspers with elliposidal nodules that can also be interpreted as of biogenic origin.

The fault has a complex history. Both the lineation and the presence of abundant subvertical quartz veins with N0°, N20° and 100°E trends suggest that it underwent strike slip movement. However, late faulting was normal.

Jorge et al. (1998) studied the manganese mineralization and describe five types of ore. The first two are primary and consists of fine grained rodonite and rodochrosite with sericite and chlorite, replacing the jaspers. The remaining three types are oxidised and include variable proportions of pyrolusite, romanechite, lithiophorite, vernadite, cryptomelane, todorokite and hematite. They occur along late brittle faults, vugs or cavities, and are mostly related to the inner part of the fault.

In the western part of the open pit there is a thick diabasic dyke that postdates the deformation, and is probably Alpine in age.

3. The San Platón Mine

Author: F.Tornos

Location: 4 km east of Concepción Mine, accessible from a sign posted (Mina Concepción) road departing from the N-435 (Badajoz-Huelva) in the pk.69.2.

1/50000 sheet: 938

UTM coordinates: 704.75; 4182.35.

San Platón is one of the richest massive sulphide orebodies in the IPB, characterized by high Cu, Au, and locally Zn grades. The complex ore contained about 1.13 Mt with 1.2%Cu, 12.3%Zn, 0.5%Pb and 2.5 g/t Au. 1.35 Mt of pyritic ore had 1.2%Cu and 2 g/t Au. The gossan contained about 2 g/t Au (IGME, 1982). It was worked by a french company between 1906 and 1934 (Pinedo, 1962). This mineralization belongs to an E-W belt that includes several important base metal-rich orebodies such as Concepción (56 Mt), Cueva de la Mora (4.2 Mt) and Aguas Teñidas (stop 10).

The orebody is located between shales, Mn-bearing jaspers in the S and acid porphyries in the N. It has a N105°E trend with a dip of 75°N. The average thickness is about 16-18 m and has been recognized to a depth of 250 m. The massive sulphides form two lenses separated by black shales.

Unfortunately, the underground works are flooded and the mineralization can only be observed in an small open pit. The footwall rocks consist of acid volcanics with fine grained, chloritic fiammes of chloritic material with feldspar microphenocrysts in quartz-feldespathic matrix that could resemble pumice mass flows.

The orebody visible in the open pit, consists of several tectonically stacked lenses enclosed by massive chloritized dacites but without a pristine nearby stockwork. The massive sulphides are Zn-rich and are oriented following the main cleavage. The sulphides show a strong deformation with cm to dm-sized tectonic lenses of massive, fine grained pyrite in almost massive sphalerite. The rock shows a strong, subvertical, fan-shaped banding of unknown origin, which may be primary.

4. The Tharsis Mines

Authors: F.Tornos, E. Gonzalez Clavijo
Location: E and S of the Tharsis town
1/50000 sheet: 959
UTM coordinates: 667.000; 4162.900

References:
Kase,K., Yamamoto,M., Nakamura,T., Mitsuno,C. (1990): Ore mineralogy and sulfur isotope study of the massive sulfide deposit of Filon Norte, Tharsis Mine, Spain Miner. Deposita, 25, pp.289-296
Strauss,G.K., Beck,J.S. (1990): Gold mineralisations in the SW Iberian Pyrite Belt. Miner. Deposita, 25, pp.237-245
Strauss,G.K., Madel,J. (1974): Geology of massive sulphide deposits in the Spanish Portuguese Pyrite Belt Geol.Rundschau, 63-1, 191-211
Tornos,F., González Clavijo,E. (1997): Geology of the Filón Norte massive sulfide deposit, Tharsis area, Iberian Pyrite Belt Geology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series num. 27, 145-156
Tornos,F., González Clavijo,E., Lopera,E. (1997): A guide to the surface geology of the Filón Norte open pit, Tharsis district Geology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series num.27, 137-145
Tornos,F., González Clavijo,E., Spiro,B.F. (1998): The Filón Norte orebody (Tharsis, Iberian Pyrite Belt): a proximal low-temperature shale-hosted massive sulphide in a thin-skinned tectonic belt. Mineralium Deposita, 33, 1-2, 150-169
Tornos,F., Spiro,B. (1999): The genesis of shale-hosted massive sulphide deposits in the Iberian Pyrite Belt. Join SGA/IAGOD meeting, London, August 1999 (in press.)

The Tharsis mining district includes sixteen known mineralizations with estimated resources of more than 133 Mt of massive sulphides. There are three groups of deposits. The northern one is composed of the Filon Norte, San Guillermo and Sierra Bullones orebodies and the Poca Pringue prospect. The central group include Filón Centro and Los Silillos the southern one includes Filón Sur and Esperanza.

The biggest orebody is exposed in the Filon Norte open pit. Here, the mineralization is composed of three independent lensoidal orebodies, Sierra Bullones, Filón Norte and San Guillermo. In total, are about 1500 m in length, more than 400 m wide and with a mean thickness of 80 m. They contain at least 88 Mt of OOIP with 46.5%S, 2.7%Zn+Pb and 0.7%Cu, making it one of the largest deposits of the IPB. About 40 Mt of ore have been already extracted. The mineralisation extends unclosed to the north and with depth with total dimensions exceeding the known figures. The Filón Norte open pit is the only mine of the Tharsis district currently working massive sulphide; about 0.5 Mt/year of massive pyrite are extracted for producing sulphuric acid. The Au-rich gossan of nearby Filón Sur is also mined (8 Mt, 1.4 g/t Au and 27 g/t Ag).

The Filón Norte open pit is the best place for the observation of the shale hosted massive sulphides, the shale-hosted stockwork and the unusual carbonate-rich hydrothermal alteration.

The Tharsis mines were systematically worked by Romans and about 3.5 Mt of slag remains from that time. It was rediscovered in 1853 by Ernesto Deligny and in 1867 it was sold to The Tharsis Sulphur and Copper Company Limited with current mining being carried out by the Compañia Minera de Tharsis S.A.L.

Stop 1. The road section

The final km of the road from Alosno to Pueblo Nuevo has some interesting features regarding the tectonic structure and hydrothermal alteration in the northern limb of the Puebla de Guzmán structure.

Point 1a. Here the PQ group is thrusted above the VS Complex. The shear zone is marked by 2-4 m of highly altered igneous rocks. The footwall shows intense argillitization, probably related to the acid supergene alteration.

Point 1b. The PQ Unit shows structures indicative of southward thrusting. Meso to megastructures in a ramp and flat morphology can be clearly observed in the eastern bench. They are emphasised by a supergene alteration. Also, the intersection between the regional cleavage (dipping 45-60°N) and a second subhorizontal one related to thrusting is easily observed. A few hundred metres to the east, there is evidence of late subvertical extensional faulting that controls the development of the gossan exploited in the Filon Sur.

Point 1c. The Filón Sur Unit, hosting the gossanized massive sulphides, is located in a thin VSC tectonic unit sandwiched between two units composed of the PQ Group. The uppermost unit hosts an oxidised stockwork that can be observed on both sides of the road. The small adits seen here are the work of mineral collectors trying to find goethite samples (not mines!). The stockwork exhibits an irregular pattern and the thickness of the veins is very variable. Its origin is matter of debate. It has been interpreted as the rooted stockwork of the Filón Norte orebody, located some hundred of meters northwards. However, features such as the absence of hydrothermal chloritization, the presence of veins crosscutting the cleavage and the very low gold contents strongly suggest that this stockwork is late, probably late to post Variscan in age, and related to the supergene alteration of the massive sulphides.

Stop 2. Filon Norte Open pit (modified from Tornos et al., 1997)

Point 2a. General overview

This point shows a general overview of the geology and the disposition of the orebodies. The general structure can be followed due to the alternance of dark shales and phyllonites, brownish igneous rocks and the massive sulphides.

The structure is defined by four major tectonic units verging to the south and limited by thrusts. The thrusts are made up of heavily quartz veined black phyllonites. Each tectonic unit has its own lithological and hydrothermal features. The more competent lithologies define several steeply dipping tectonic horses bound by shales and phyllonites, in a hinterland dipping duplex sequence. The thrusts have higher dips in the S (left) than in the N (right), indicating a ramp and flat morphology. The tectonic reconstruction suggests that, with the exception of the PQ Group, the sequence is reversed and the Units presently located above that containing the massive sulphides, were probably their lateral equivalents.

From bottom (S) to top (N) the structure is defined by:

- Phyllites and quartzites of the PQ group, here characterized by a reddish-purple colour. They are interpreted as belonging to a (para-) autochthonous tectonic unit. The contact with the superimposed unit (Lower Unit) is an out of sequence thrust.
- The **Lower Unit** (LU) includes the massive sulphides and related shales. The orebody is lens-like. In detail, it is made up of several superimposed tectonic slices of massive sulphides and tectonically interbedded black shales. The major Filon Norte orebody is superimposed by the San Guillermo orebody, with its underlying stockwork developed in chloritized black shales. Close to the surface the massive sulphides show a well developed, but almost mined out, gossan.
- The **Lower Deformation Zone** (LDZ) above the Lower Unit. It is made up of highly deformed black phyllonites with abundant syntectonic quartz and ankerite veins.
- The **Intermediate Unit** (IU) is composed of pervasively-carbonatized basic rocks (spilites) and grey shales.
- The **Upper Deformation Zone** (UDZ) can easily be observed in the northern edge of the open pit, with about 30-40 m of black phyllonites that are very similar to those of the LDZ.
- The **Upper Unit** (UU) is made up of rhyodacites with grey shales. The hydrothermal alteration is not as pervasive as in the IU and consists of irregular silicification and sericitization of the igneous rocks. In the upper northern bench of the open pit there is a doleritic sill with characteristic columnar jointing that intrudes the detritic rocks showing peperitic features near the contacts.

Point 2b. The massive sulphides of the Filón Norte orebody

The Filón Norte orebody is a fairly monotonous massive sulphide. It is mainly composed of the Pyritic

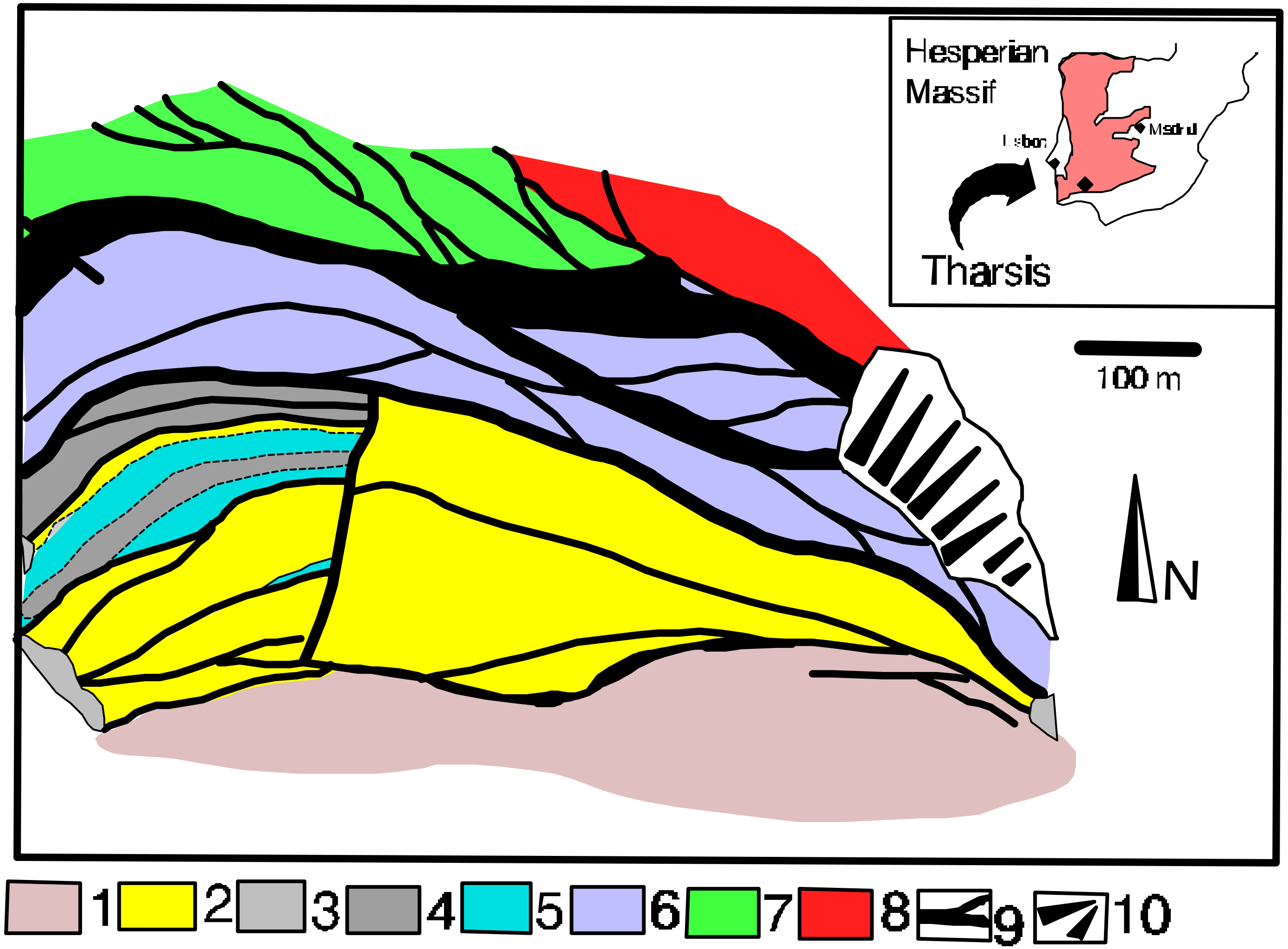


Figure 4. Geologic sketch of the Filon Norte (Tharsis) open pit. (1) PQ Group. (2) Massive sulphides (3) gossan (4) black shales (5) stockwork on black shales (6) massive basic rocks & shales (7) massive acid rocks & shales (8) Doleritic dykes (9) shear zones (10) Dumps. Modified from Tornos et al. (1997).

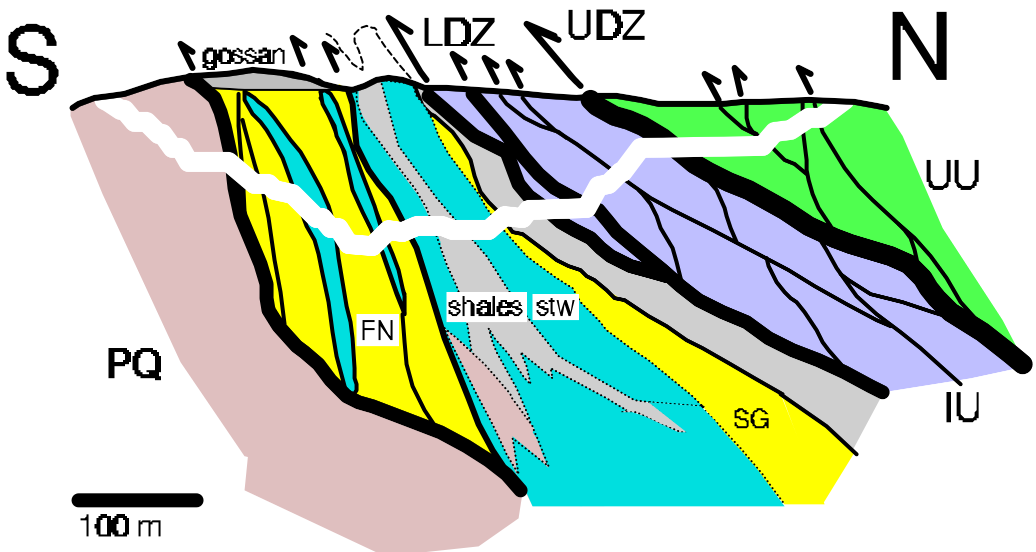


Figure 5. Schematic cross section of the Filon Norte (Tharsis) open pit (modified from Tornos et al., 1997).

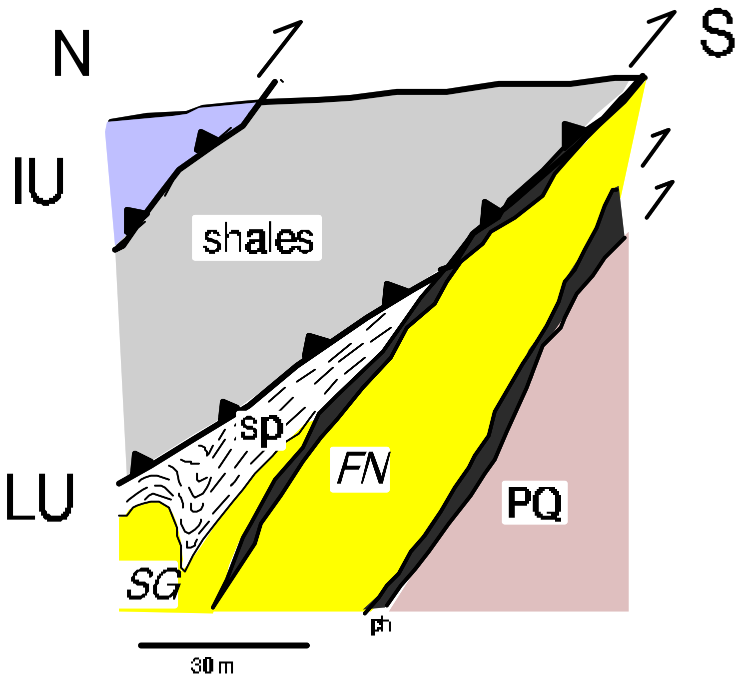


Figure 6. Cross section of the eastern Sierra Bullones open pit (modified from Tornos et al (1997)

Ore, usually very fine grained and massive, only with a poorly defined and irregular mm-cm scale banding and low base metal grades. The most significant feature is the local presence of pyrite-rich mass flows, which cut the fine grained massive sulphides and are formed by heterometric and angular pyritic fragments with some shale clasts. Here, pyrite is the dominant mineral. Other sulphides are chalcopyrite, sphalerite and galena with very minor amounts of quartz, siderite, sericite and chlorite.

The Carbonate Ore, typical of Tharsis, occurs near the base of the lens as irregular bodies made up of flattened but angular fragments of finely interbedded pyrite and siderite in a groundmass of coarser-grained pyrite and siderite. The Complex Ore shows a banded structure and is enriched in sphalerite and galena (1.03% Pb; 3.58% Zn). The Banded Ore is the most interesting one from the genetic point of view, but now is almost mined out. It consists of mm layers of sulphides and shales with abundant synsedimentary structures including sulphide turbidites with graded bedding, synsedimentary faulting or slumps.

Point 2c. The stockwork and the San Guillermo orebody

The Filón Norte massive sulphide is overthrusted by a tectonic slice that includes the San Guillermo orebody and its underlying stockwork. The stringer zone, developed on black shales, has a unique chlorite-rich zone made up of massive ripidolite with minor quartz, phengite, siderite and patchy pyrite crosscut by mm to cm scale thick pyrite-rich quartz-poor veins. This hydrothermally altered zone shows a very irregular distribution. Towards the west it quickly disappears while in the east of the open pit it is laminated between the two massive sulphide lenses. However, diamond drilling has shown that the San Guillermo orebody is always underlain by the stringer zone at depth.

The distribution of the sulphides is very irregular. In some areas the veins form a dense network and the host shales are replaced by patchy pyrite. In the uppermost 2-3 m the proportion of veins is very high and close to the contact with the massive sulphides, the shales occur as angular and replaced fragments enclosed by pyrite. The veins are deformed and the sulphides are coarser grained than in the massive sulphides. Veins which are subparallel to the regional cleavage are flattened while those with near perpendicular orientations show generalised folding. The cleavage is more intense in the less chloritized rocks. The mineral assemblage is rather complex (Marcoux et al., 1996; Tornos et al., 1998) and includes significant proportions of As-Co-S minerals, bismuth tellurides and gold. Brittle minerals, such as pyrite, arsenopyrite, cobaltite or glaucodot (with minor inclusions of fine grained gold) are cemented by the more ductile ones, such as chalcopyrite, sphalerite, galena, tellurides or coarse grained gold.

The stockwork is overlained by the San Guillermo body, which general features will be shown in the next stop.

Point 2d. The Lower Unit- Intermediate Unit section.

This short section shows the relationship between the Intermediate and Lower Units with the Lower Deformation Zone. The San Guillermo orebody is textural and mineralogically very similar to the underlying Filón Norte one, with pyrite and carbonate-rich facies. The upper contact is very sharp and bounded by some phyllonites with syntectonic quartz veins. Interbedded with the black shales, and about 1-2 m above the massive sulphides, there is a decimetre layer of brecciated black cherts that systematically caps the orebody.

The upper zone of this Unit is made up of black and grey shales. Here, the Lower Deformation Zone is composed of anastomosing and irregular metric-sized bands of phyllonites. Towards the east they form a unique and major deformation band about 10-15 m thick, but the best outcrops have been recently covered by heaps.

The Intermediate Unit is mainly composed of spilites. They are massive, highly altered and with abundant vacuoles filled with ankerite and minor quartz and pyrite; the development of cleavage is very irregular. They are crosscut by abundant individual, up to metre-sized, ankerite-rich veins. Near the track, there is one of the few non-tectonized basal contacts of the basic rocks and enclosing shales.

Point 2e. Hydrothermal processes in the Intermediate Unit.

This bench shows many of the hydrothermal features of the Intermediate Unit. The rocks are affected by a pervasive carbonatization, consisting of ankerite with minor amounts of quartz, phengite, chlorite and sulphides. The main features of these hydrothermal rocks to be observed are:

- Replacement of the shales by ankerite. This occurs near the contact with basic rocks. The shales are gradually replaced by mm-sized crystals of ankerite until the rock is completely composed of homogeneous ankerite, which occurs as lenses within the shales or phyllonites.
- Ankerite-rich veins with pervasive replacement of the walls. They are subvertical and can be as thick as 2 m.
- Ankerite-rich breccia bodies up to ten metres in size, made up of angular and heterogeneous fragments of basic rocks supported by ankerite. They can also occur in the margins of the veins.
- Polymictic mesobreccias made up of 2-3 cm to decimetric fragments of shale, green and red chert and hydrothermal ankerite in a fluidised shaly matrix; they have no fragments of igneous rocks but always display an ankerite selvage. They are metre-sized, subvertical, probably subcylindric, bodies with irregular spider-like veins. They grade into the overlying shales but the lower contact has not been observed.

The pervasive hydrothermal alteration is interpreted as pretectonic as the veins and fragments are boudined, folded and cleavaged and individual crystals of ankerite are enclosed by the cleavage. The field relationships and stable (C-O) and radiogenic (Sr) isotope geochemistry (Tornos & Spiro, 1997) suggests that this alteration is related with the hydrothermal brecciation of overpressured zones below the sill, probably due to synchronous boiling of deeper hydrothermal fluids at temperatures below 200°C with injection of the fragments with a fluidised mud into the spilites. Ankerite-rich breccias are interpreted as of proximal origin while polymictic ones have a deeper source.

On the way to the next stop, note on the left (N) of the track the black phyllonites belonging to the Upper Deformation Zone.

Point 2f. The Intermediate Unit - Upper Unit section.

This stop shows the relationships between the Intermediate and Upper Units and the Upper Deformation Zone. The Intermediate Unit has the features previously described. Here, tectonic horses of igneous rocks alternate with more ductile and deformed rocks, shales and phyllonites. The Upper Deformation Zone shows features of high strain, including syntectonic quartz veins, enrichment in organic matter and sheath folds. Within this thrust band there are several boudins of, highly silicified, mylonitized rhyodacites. Above it, the Upper Unit is composed of rhyodacites and shales. The rhyodacites occur as subvertical horses between phyllonites, defining a duplex-like structure. The cleavage related with the duplex is intersected on the base of the Unit by a later cleavage related with the Upper Deformation Zone. The hydrothermal alteration, silicification and minor sericitization, is less pervasive than in the Intermediate Unit and strongly varies from one tectonic unit (horse) to another.

Stop 3. General overview of the Sierra Bullones open pit.

The Sierra Bullones open pit has worked out a massive sulphide lens located westward the Filón Norte-San Guillermo ones. The general features of the massive sulphides can be easily observed here. The huge massive sulphide body has a lens-like morphology that in the western part of the open pit shows a ramp and flat morphology, defining a big tectonic horse interpreted as equivalent to the Filón Norte orebody. At depth, it tapers out 40-60 m below the bottom of the open pit. The contact with the unaltered PQ Group is marked by a black phyllonite. Overlaying it there is a highly strained quartz-rich phyllonite and second pyrite orebody that defines a fold, that is interpreted as an antiformal stack. It is probably equivalent to the San Guillermo orebody and is overlain by shales with interbedded pyrite layers. In the northern edge of the open pit the Lower Unit is overthrusted by the Intermediate Unit, easily recognisable due to its brownish colour.

5. Outcrops at the Virgen de la Peña hermitage area

Authors: R.Sáez, C.Moreno

Location: 6 km eastwards Puebla de Guzmán. Access through a signalised paved road leaving south of the Puebla de Guzmán-Tharsis road.

1/50000 sheet: 958

UTM coordinates: 658.73; 4163.25

References:

Moreno, C. Sáez, R. (1990): Sedimentación marina somera en el Devónico del Anticlinorio de Puebla de Guzmán, Faja Pirítica Ibérica. Geogaceta, 8, 62-64.

Moreno,C., Sierra,S., Sáez,R. (1996): Evidence for catastrophism at the Famennian-Dinantian boundary in the Iberian Pyrite Belt. In Strogen,P., Somervilee,I.D., Jones,G.L. (eds.) Recent advances in Lower Carboniferous Geology. Geol.Soc.London. Spec. Publication, 107, 153-162

Moreno,C., Sierra,S., Sáez,R. (1996): Evidence for catastrophism at the Famennian-Dinantian boundary in the Iberian Pyrite Belt. In Strogen,P., Sommerville,I.D., Jones,G.L. (eds.) Recent advances in Lower Carboniferous Geology. Geol.Soc.Spec. Publication, 107, 153-162

Sáez,R., Moreno,C. (1997): Geology of the Puebla de Guzmán anticlinoriumGeology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series num.27, 131-136

The Phyllite-Quartzite Group (PQ Group) is Devonian in age and constitutes the footwall of the regional stratigraphical record at the IPB. Its underlaying the VCS hosts the massif sulphides ores. Therefore the palaeogeography of the IPB basin at Upper Devonian times, just at the Devonian-Carboniferous boundary, constitutes the palaeoenvironment in which deposition of massive sulphide took place.

General series of the PQ Group consists of a sequence of shales with subordinated sandstones that were deposited in a shallow marine platform whose sedimentological, palaeontological and petrographical features seem to be homogeneous along the complete basin (from Lisbon in Portugal to Seville in Spain, and also, from the North to the South). This monotonous shaly series changes to a thickenning and shallowing sequence of quartzarenites, with subordinated shales and minor litharenites, characterizing the uppermost part of the PQ Group (near the Devonian-Carboniferous boundary). Locally, this upper quartzarenite sequence is abruptly replaced by other rocks with different facies, inluding: debris flow deposits, platform limestones and fan delta deposits, all them at the same stratigraphical position, although a lithological correlation is not possible. Therefore, the top of the PQ Group looks like a mosaic with patches of “exotic” sediments fitting in the quartzarenite shallowing sequence (Moreno et al., 1996).

The Virgen de la Peña area is probably the best outcrop to observe the facies of the uppermost part of the PQ Group, with the highest continental influence represented by a conglomeratic fan delta system. It is a good example for understanding relationships between some of the facies constituting the uppermost PQ stratigraphical mosaic. There the shallowing and thickening quartzarenitic sequence and their laterally associated facies are well exposed showing a wide variety of sedimentary structures and bioturbation. These lithofacies were deposited in an inner marine platform, mostly in the nearshore (Moreno and Sáez, 1990). They represent a system of sandy coastal bars running parallel to the coastline that was built-up by bedform superposition (megaripples and sandwaves). Laterally these sandy bars evolve to tabular layers made up by interbedded litharenite and shale sheets. They are interpreted as sand storm layers implying the lateral variation from nearshore to offshore environments. Sandbars are cutted by m-sized channels filled by a pebble supported conglomerate, which is made mainly by rounded heterometric quartzitic pebbles and elongated clasts of iron-manganese oxide. These clasts have low Co, Ni, Cu, Zn and Pb contents and REE profiles similar to those of the European shales suggesting that they

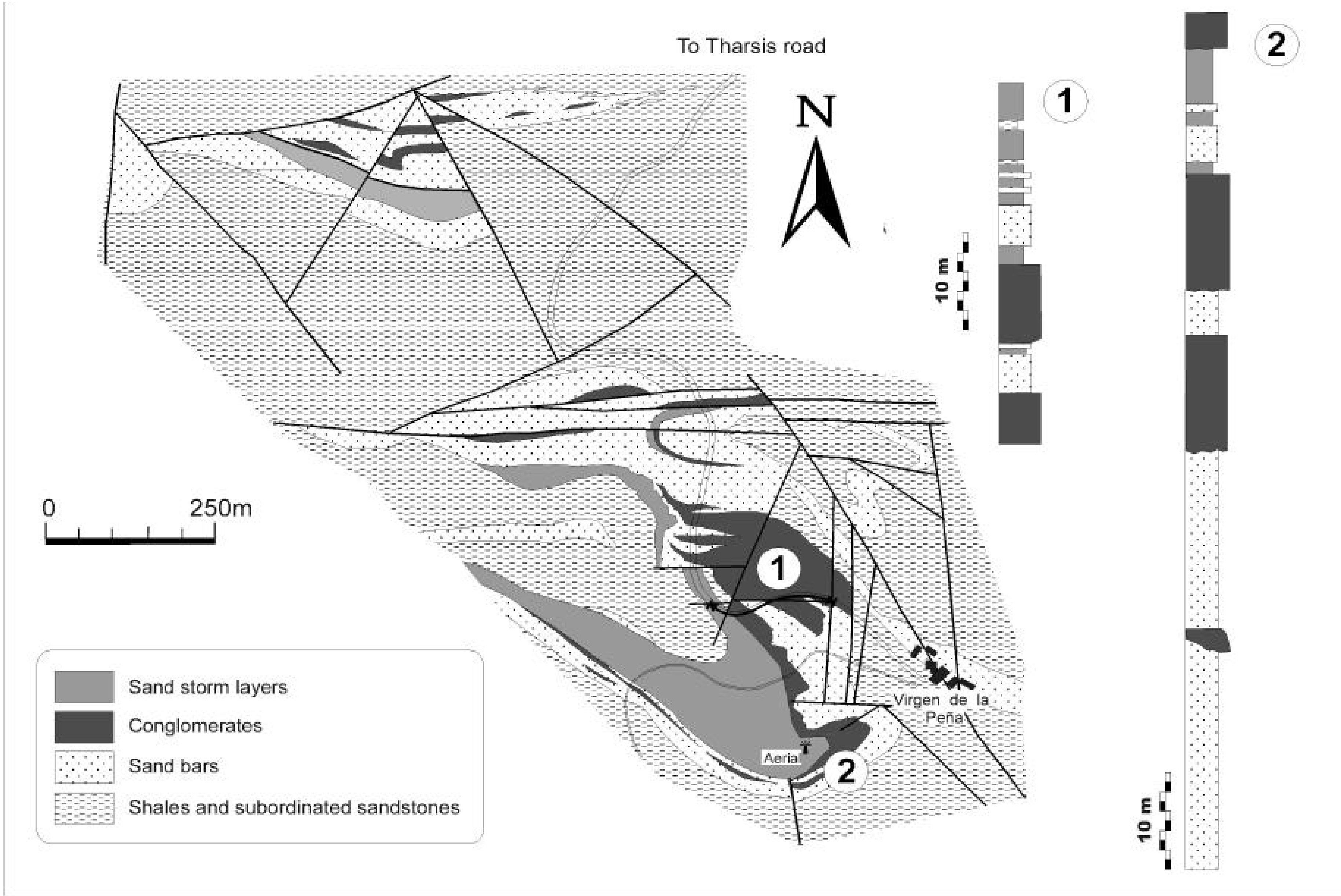


Figure 7. Geological map of the La Virgen de la Peña area (modified from Sáez & Moreno (1997)

were coming from the erosion of a continental soil, a ferricrusts (Sáez and Moreno, 1997). The channels are straight in run and cut perpendicularly the bars. Commonly channel filling was according to single flash flood event, although multi-episodic channel filling by stacking of avalanches can also be observed. Migration processes have not been observed. The main way of changes in channels position were by avulsion processes. Mud-supported conglomerates and plants debris occur randomly distributed .

In short, at the Virgen de la Peña area the uppermost part of PQ Group is exposed, corresponding to a system of littoral bars and their deepest associated facies intersected by a small fan-delta system.

Stop 1. Cross-section along the road.

Walking from the road bend to the hermitage (from W to E along the cross-section marked in the Figure 7), several of the above quoted lithofacies are exposed including: sand storm layers, sand bars, pebble supported conglomerates and mud supported conglomerates. Sand storm layers show here a typical facies made by interbedded litharenite and shale layers. Internal ordering is characterised by horizontal and undulating lamination, through lamination, wave ripples, and hummocky cross-lamination. Ripples marks on the top of the layers and bioturbation are frequent. In spite of this cross-section is not the best point to see sedimentary structures in the sand bars, this is a good place to recognise the bar progradation dispositive based on medium scale tabular cross bedding. Pebble supported conglomerates are here well exposed. Different kind of clasts and fragments of quartzarenitic bars included in the conglomerates are observed. Mud supported conglomerates outcrop also on the paved road, just downwards this point.

Stop 2. The Cabezo del Aguila hill

The Cabezo del Aguila hill, opposite to the hermitage, offers a well exposition of quartzarenitic bars, pebble supported conglomerates and mud supported conglomerates. Architecture of sandy bars by bedform superposition is well exposed here. Quartzarenite internal ordering consists of horizontal and bimodal cross-lamination, low angle cross-lamination, through lamination, and reactivation surfaces. Ripples, magaripples and sandwaves are also frequent. Some quartzite bed are plenty of small sized dish structures.

Conglomerate filled channels are also well exposed, where different kind of clasts including ferricrust pebbles can be observed. Generally, internal ordering in the conglomerates is lacking, although but some local graded bedding and pebble imbrication occur. Relationship between bars and channel are easily noticed. Here, it is also well exposed the mud supported conglomerates lithofacies and some plant debris.

6. El Almendro road section. South of the Puebla de Guzman structure

Authors: R.Sáez, C.Moreno

Location:A-499 (Santa Bárbara-Villanueva de los Castillejos), in the road to El Almendro leaving pk.34 50 m West of the crossing

1/50000 sheet: 958

UTM coordinates: 652.88; 4153.01

References:

Martí,J., Mitjavila,J., Soriano,C., Viladeval,M. (1994): La reconstrucción paleogeográfica y volcanológica de la Faja Pirítica del SW de España. Informe ITGE, 51 pp.

Sáez,R., Moreno,C. (1997): Geology of the Puebla de Guzmán anticlinoriumGeology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series, 27, 131-136

Quesada, C. (1998): A reappraisal of the structure of the Spanish segment of the Iberian Pyrite Belt. Min. Dep., 33, 45-58

This stop allow us to observe the PQ Group - VS Complex contact in the southern limb of the Puebla de Guzmán structure. Near the contact, tool marks and load cast indicate that we are at the reversed limb of a medium sized fold. Nevertheless some small structures and fault related rocks might indicate some tectonic reworking near the contact between both units. In general, this structure is classically interpreted as an anticlinorium, since the PQ Group outcrops in a core encircled by the VS Complex. An alternative interpretation of this structure, including thrusting of the PQ over the VSC, have been recently proposed (Quesada 1998).

Tectonic deformation is characterised by asymmetric folds related to the main deformation phase of the IPB. Regional foliation is parallel to the axial plane of the folds and shows southward vergence. On the scrubless area located just at the exit to El Almendro outcrops a nice curved hinge of a minor anticline. Both folds and foliation are deformed by low angle thrust faults.

Typical facies of the PQ Group are quite well exposed at the main road trench. These are characterised by a folded shally sequence with subordinated quartzarenite beds. The uppermost part of the PQ Group is made up of the shallow marine quartzarenitic sequence. The best exposure of this lithofacies is on the top of the hill, 300 m westward of the road. A level of black shales containing abundant diagenetic concretions indicate the PQ – VSC contact.

The VSC starts with some fine tuffite beds evolving to a dacitic volcanoclastic sequence, about 100 m thick. Eastward to the main road this volcanoclastic sequence changes to massive vesicular rhyolites, well exposed close to the aerial on the top of the hill. Volcanoclastic facies are constituted by quartz and feldspar fenoclasts and cm-sized vitriclasts showing glass shards (fiamme texture). These rocks have been interpreted as crystal vitric dacitic pyroclasts deposited in a very shallow marine environment by Sáez and Moreno (1997), or as autobrecciated acid rocks with differential devitrification and hydrothermal alteration by Martí et al. (1994).

7. Paymogo quarry

Autor: F.Tornos

Location: The quarry is located near a stream 350 m W of the road Paymogo-Puebla de Guzmán (A-499, pk.55.6). The dirt track to Finca El Coto, 8.8 km N of Puebla de Guzmán

1/50000 sheet: 958

UTM coordinates: 651.66; 4172.76

The quarry shows the contact between massive rhyodacites and red jaspers. Here, the rhyodacite represents the hanging wall of a thick intrusive unit (dome?) intruding the marker level of the IPB, purple shales and related Mn-rich jaspers as well underlying polymictic debris flows with pumice fragments. The rhyodacite is massive (sometimes almost aphanitic) and strongly devitrified and hydrothermally altered. Locally some flow banding can be observed in the less devitrified zones. The intrusive contact with the purple shales has very variegated shapes. There are abundant dykes, pipes, irregular veins and stratabound bodies of jasper and shales into the acid rock, sometimes up to 1 m long. They include irregularly altered unimodal fragments of rhyodacite cemented by altered rhyodacite or jasper. The upper contact of the intrusion show peperites s.s. and polimodal hydroclastic breccias cemented by red mud. Abundant jig saw contacts can be observed.

8. Aljustrel Mine Complex

Author: Joao Carlos de Sousa
Location: In the Aljustrel town, S Portugal
1/50000 sheet: 42-D
UTM coordinates: 57.500; 419.250

References:
Barriga, F.J.A.S., 1983. Hydrothermal Metamorphism and Ore Genesis at Aljustrel. Portugal. The University of Western Ontario (Ph. D. Thesis), 368 p.
Leitao, J.C.R., 1982. The Aljustrel overthrust problem in view of the new evidence from the Stº Antao area. Comunicaçoes Servicos Geológicos Portugal. 78 (2): 97-102.
Oliveira, J.T. and Silva, J.B., 1990. Carta Geológica de Portugal a escala 1:50000. Folha 46-D-Mértola. Serviços Geológicos Portugal.

Introduction and History

The Aljustrel mining complex is located in the Iberian Pyrite Belt, which represents one of Europe's most prominent metallogenetic provinces, as well as one of the oldest mining districts, with a record of over 3.000 years of mining.

The Romans mined the extensive massive gossans caps, in particular the soft, jarositic layer at the base of the gossans, for gold and silver, and the oxide and supergene sulphide ores, for copper. The most striking evidence of the above mentioned mining activity is the presence of several million tons of slags around Aljustrel and Rio Tinto, amongst other places. Mining follows the decline of the Roman Empire, until resurgence in the middle of 19th century when some copper ores were mined. Later, the large pyrite reserves became the source of raw materials for the sulphuric acid production, while some base metal contents of the pyrite cinders were then recovered by wet chemical methods.

In 1991, "Pirites Alentejanas", the mine operator, commissioned a mill and concentrator complex designed to treat ore at a rate of 1.2 million tons per year, producing zinc, lead and copper concentrates. This operation closed in 1993, due to low metal prices and several operational difficulties. Since then all the facilities have been closed, but well maintained. In mid 1998, AGC-Minas de Portugal, Lda., a wholly owned Auspex and International Vestor company, finalised an agreement with "Pirites Alentejanas", and EDM, it's major shareholder, in order to carry a feasibility study on the Aljustrel Mining Complex.

Regional Geology

There are six known volcanogenic massive sulphides deposits within the Aljustrel camp: S.João and Algares – two outcropping deposits, mined since pre-roman times, and Moinho, Gavião, Estação and Feitais. In general terms, the Aljustrel geology, especially at Feitais, could be summarised as follows (from top to bottom):

The overlying "Culm" - Conformably overlies the VS and is composed of a monotonous sequence of alternating slates and greywackes with rare quartzites and conglomerates, and represents the "flysch" stage of the South Portuguese Zone. This formation has an Upper Visean - Westphalian age.

The Volcanic-Sedimentary Complex (VS) - This heterogeneous rock sequence is composed of submarine acid volcanics and intercalated sediments with rapidly varying thicknesses and changing volcano-sedimentary facies. It contains all the massive sulphide and associated manganese accumulations. An Upper Tournasian to Lower Visean (Lower Carboniferous) age is ascribed for the VS complex, although only a few age determinations have been made.

The top of this complex, called Paraíso Siliceous Formation, comprises shales, phyllites and tuffites with

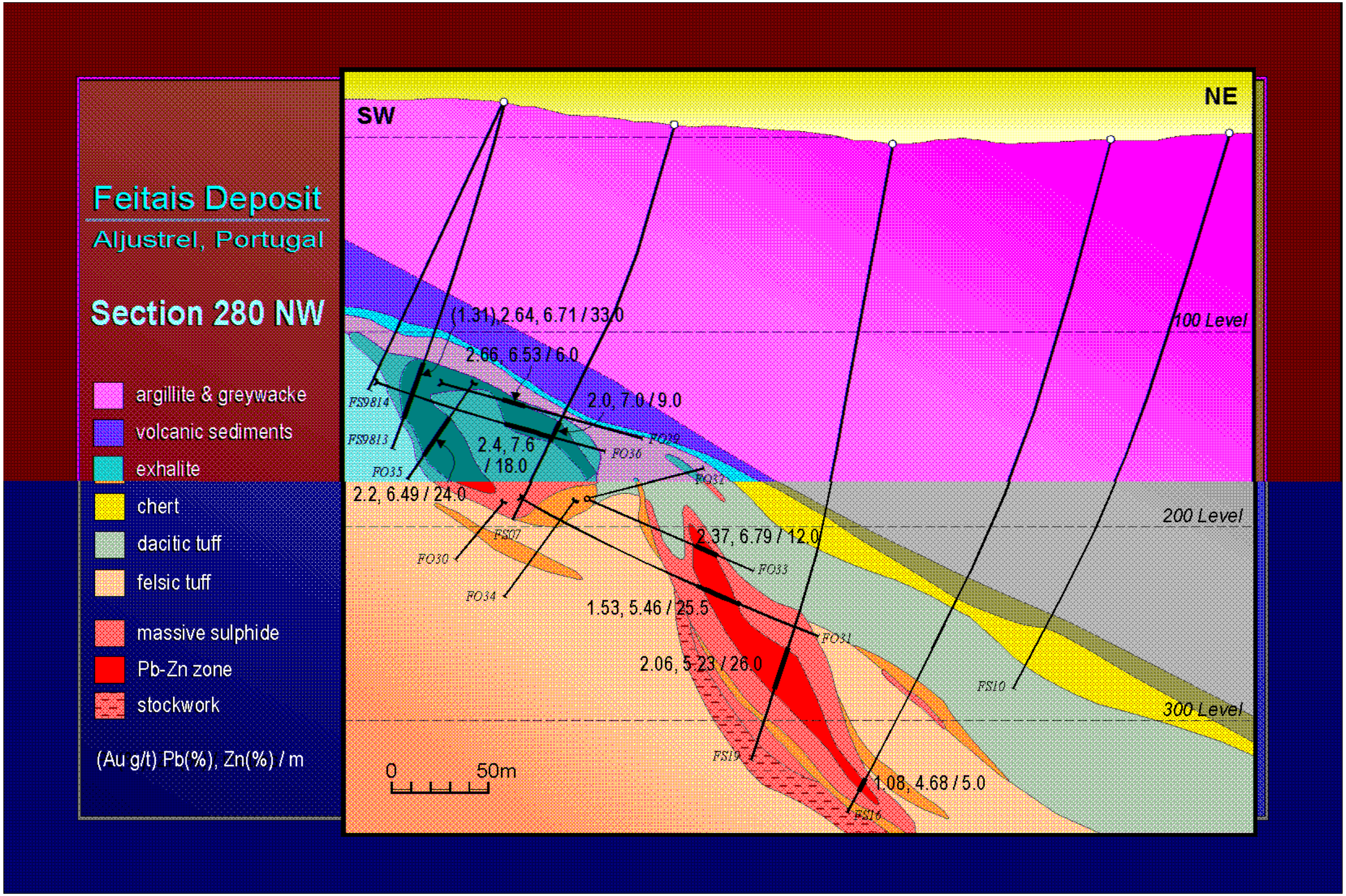


Figure 9. Section 280 NW of the Feitais orebody, Aljustrel

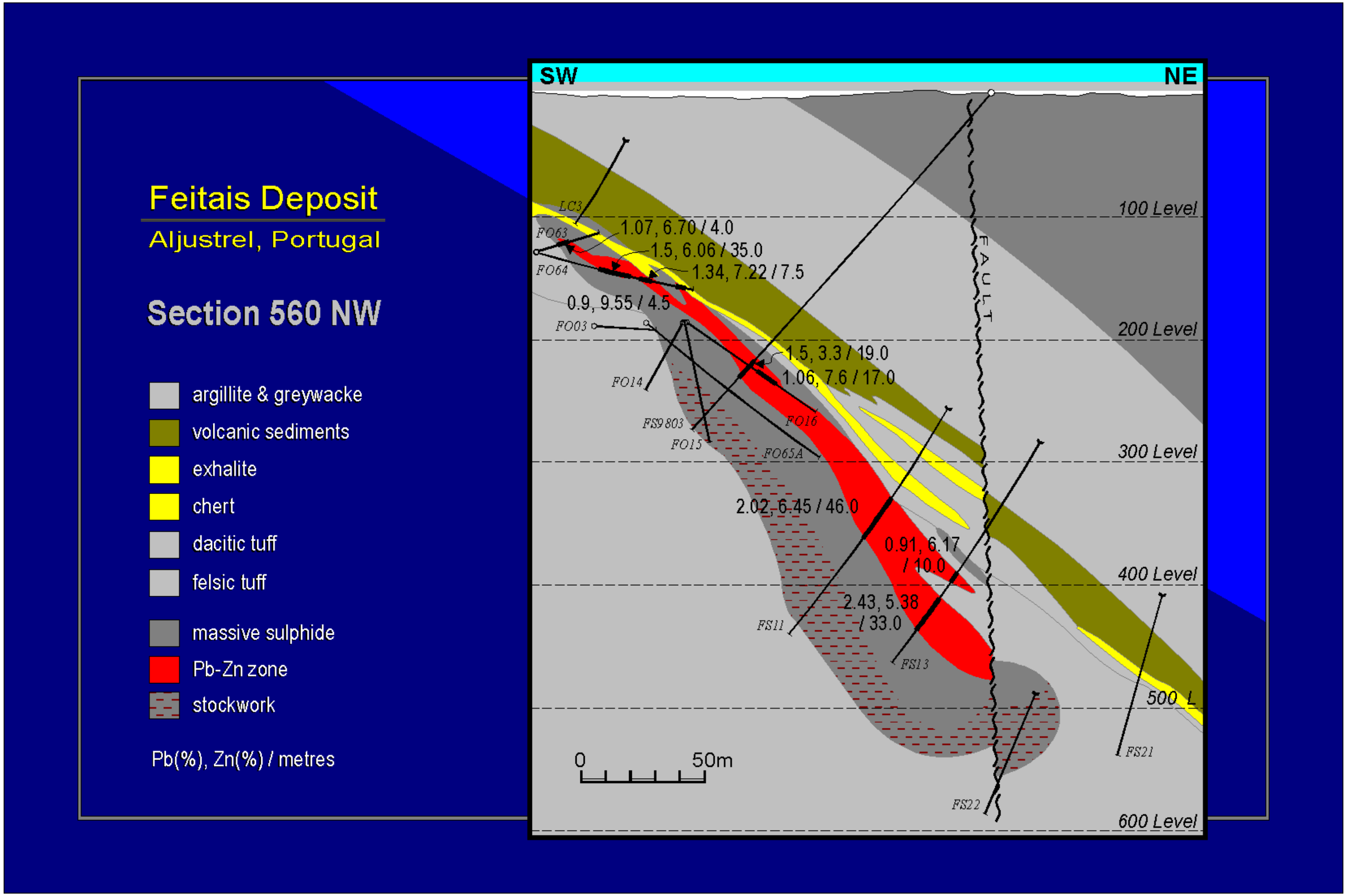


Figure 8. Section 560 NW of the Feitais orebody, Aljustrel

a jasper / chert layer close to the bottom. Locally, it also includes the manganese formation, consisting of purple-red tuffaceous slates or hematitic ashes (called "Borra de Vinho" slates) interbedded, with primary manganese silicates and/or carbonate mineralization which by weathering, turned into manganese oxides which were mined in all manganese mines. The purple slates may grade laterally into greenish-grey, tuffaceous shales.

Below the "Paraíso formation", a chloritized acid feldspar porphyritic tuff occurs. This rock type shows an important thickness variance, and comformably overlies the massive sulphide.

Within the massive sulphides, whose thickness can be as big as 120 meters, occurs some sphalerite and galena rich layers, while towards the bottom and within the stockwork, chalcopyrite rich zones are usually found. The underneath lithologic unit consists mainly of felsic volcanic (rhyolites) pyroclastic material (tuffs, lapilli tuffs,) with some autobrecciated lavas. This unit shows intense alteration, especially chloritization, sericitization and silicification, sometimes turning the original rock into almost massive chlorite.

Table 1. Selected drillhole intersections in the Feitais deposit (Aljustrel).

Hole	From (m)	To (m)	Width	True Width	Au g/t	Ag g/t	Cu %	Pb %	Zn %
FS9927	272.75	312.80	40.05	27.0	1.07	68.32	0.21	1.89	6.49
FS9928	234.30	280.10	45.80	36.0	1.09	130.75	0.18	3.53	9.29
FS9929	223.60	261.80	38.20	32.0	1.61	139.39	0.17	3.28	7.84
FS9931	302.00	327.10	25.10	22.0	1.02	57.53	0.20	1.94	7.44
FS9932	228.80	259.90	31.10	25.0	1.28	77.39	0.17	2.21	6.33
	309.00	335.30	26.30	21.1	0.16	24.82	4.46	0.15	1.17
FS9934	263.85	330.60	66.75	48.14	0.57	55.66	0.15	1.58	5.18
FS9937	263.50	291.00	27.50		0.67	76.18	0.11	2.08	6.36
	302.80	308.00	5.20		0.81	14.28	3.03	0.04	0.18
FS9942	281.90	309.00	27.1	21.4	0.42	78.38	0.11	1.87	5.84
	349.00	410.00	61.00	48.20	0.26	21.56	1.24	0.26	1.21
FS9943	256.00	283.20	27.20	20.10	0.81	117.23	0.18	2.86	7.67
FS9944	294.30	368.00	73.70	70.00	0.31	19.54	1.46	0.45	1.61
FS9947	291.10	332.40	41.30	36.20	1.01	102.75	0.24	2.67	8.69
	358.20	415.10	56.90	50.0	0.26	17.61	1.80	0.24	0.99
FS9951	328.20	407.50	79.30	67.60	0.51	63.85	0.21	1.61	5.00
	428.50	505.80	77.30	65.80	0.23	15.20	2.30	0.22	0.79

Present Activities

Euro-Zinc Mining Corporation is a company formed through a merger between Auspex Minerals, Ltd. and International Vestor Resources, Ltd. in order to consolidate their interests in the Aljustrel Mine Complex. This mine was a past producer of sulphur, copper, zinc, lead and silver, and Euro-Zinc, which has the right to earn up to 75% of this complex, is in the process of re-commissioning this mine.

A different approach analysis of the old data concerning geology, assay results and metallurgy, provided the understanding why the Aljustrel Mining Complex was not successful during its last brief operation history. EuroZinc's predecessor companies, found out two main problems in the past operational times; the mill feed grades were too low since there was little concern with the cut-off grades, and on the other hand, the mill and concentrator circuits were not efficient enough, producing concentrates at high costs.

During the review of the drill hole reserves and assay data, it was found the existence of significant intersections of high zinc grades in several drill holes scattered throughout the Aljustrel deposit. It was realised the importance to know the size, orientation and especially the continuity of these high-grade zones.

The work carried out by the company was aimed to test the continuity and grades of the previously intersected high-grade zinc zones. To achieve this goal, two heavy diamond drill programmes were undertaken, with a total of 59 diamond drill holes and 17,203 meters drilled on the Feitais deposit. Also all the previous core have been logged and resampled, in order to check the existing assays, and also to have them analysed for gold and silver. Two exemplifying cross sections of this deposit are attached.

A metallurgical test work, mineralogical and petrologic studies and obviously, an environmental monitoring program was also carried out.

A pre-feasibility study done by Rescan Engineering in 1998 showed the good economic potential of this mining complex. However, the subsequent results obtained for the feasibility study enhanced, even further, the economics of this project; the zinc, lead and silver reserves are expanding, in terms of grade and tonnage, interesting gold grades have been found, and a new copper rich zone, underneath the zinc zone, has been discovered.

As a very brief summary we present in the Table 1 some of the best drillhole intersections. A more detailed information about drill hole assays, locations and geology, will be provided during the core inspection, which will be held during the Aljustrel field trip.

9. Neves Corvo Mine

Authors: Nelson Pacheco, Alberto Ferreira
Location: South of Castro Verde, S Portugal
1/50000 sheet: 46-C
UTM coordinates: 59.120; 415.860

References:
Carvalho P., 1986. An Introdution to the Neves-Corvo Copper Mine, Portugal. Lab. Geol. Inst. Sup. Tecn. (Lisboa) 83-89. In Iberian Field Conference of the Society for Geology Applied to Mineral Deposits, SGA.

Carvalho D., 1991: A Case History of the Neves-Corvo Massive Sulphide Deposit, Portugal, and Implications for Future Discoveries. In Historical Perspectives of Genetic Concepts and Case Histories of Famous Discoveries. Economic Geology Monograph 8:314-334.

Gaspar O., 1991. Paragénesis of the Neves-Corvo Volcanogenic Massive Sulphides. Com. Serv. Geol. de Portugal. 77:27-52.

Leca X., 1990. Discovery of concealed massive-sulphide bodies at Neves-Corvo, southern Portugal - a case history. Trans. Instn. Min. Metall. (Sect. B Appl. Earth Sci.)

Oliveira J.T., Carvalho P., Pereira Z., Pacheco N., Fernandes J.P., Korn D., 1997. The Stratigraphy of the Neves-Corvo Mine Region SEG - Neves Corvo Field Conference 1997. Abstract.

Richards D., Carvalho P., Sides E., 1991. Geology and reserves of complex sulphides at Neves-Corvo. Symposium "Los Sulfuros Complejos del Suroeste de España, Sevilla.

Silva J.B., Ribeiro A., Fonseca P., Oliveira J.T., Pereira Z., Fernandes J.P., Barriga F.J.A.S., Relvas, J.M.R.S., Carvalho P., Ferreira A., Beliz A., Caetano P., Pachecho N., Albernaz J., 1997. Tectonostratigraphic Overview of Neves-Corvo Mine in the Context of the Variscan Orogeny. SEG-Neves-Corvo Field Conference 1997. Abstract.

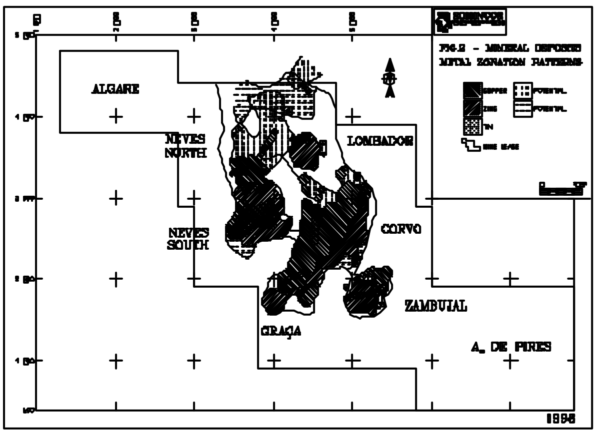


Figure 10. Situation of the orebodies and metal zonation patters in Neves Corvo

Introduction

The Neves-Corvo Mine is the most important European copper-tin mine and a world class massive sulphide deposit composed of five main mineral bodies and is exploted by SOMINCOR (Sociedade Mineira de Neves-Corvo S.A.). Copper and tin production started in late 1988 and 1990, respectivelly. Between December 1988 and June 1998 the Neves-Corvo Mine produced 12.6M tonnes of copper ore containing 996 000 tonnes of copper metal and 3.2 M tonnes of tin ore containing 59 829 tonnes of tin metal. Presently the mine exploits 2.3 M tonnes of copper and tin ores annually. The zinc resource is currently being investigated.

Stratigraphic Sequence

In 1997 the stratigraphic sequence, established several years ago (Leca *et al*,1983), was confirmed and divided into two main tectono-stratigraphic sequences: autocthonous and allocthonous, dating the

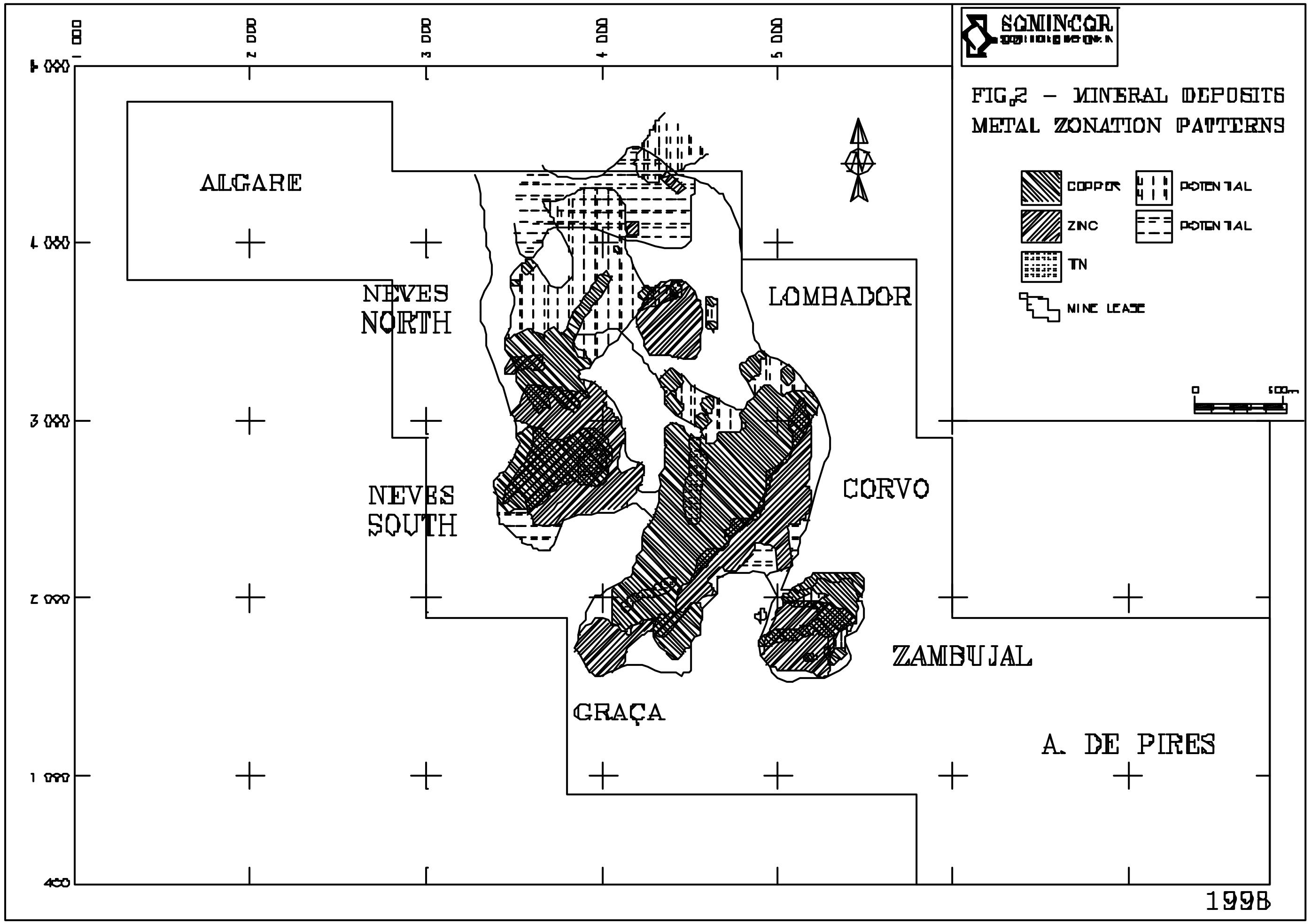


Figure 10. Situation of the orebodies and metal zonation patters in Neves Corvo

stratigraphic units by means of goniatites and miospores (Oliveira *et al*, 1997).

Autocthonous Sequence

This sequence (Figure 11) comprises, from base to top, the following units:

- **Phyllite-Quartzite Formation (PQ):** this unit is the known basement of the Iberian Pyrite Belt (IPB), is composed of dark shales (**P**), with interbedded thin siltstones and quartzites(**Q**) and limestones lenses (**c**) towards the upper part. The thickness is over 100m (base not known).
- **Volcano-Sedimentary Complex (CVS):** this complex consists of alternations of volcanics and terrigeneous sediments forming a 300m thick pile, conformably overlying the PQ Formation. The volcanics appear in four main episodes (**T0, T1, T2** and **T3**) embracing mostly rhyolites highly affected by quenching.
- **Mértola Formation (Mt2):** is the uppermost unit of the region, consist of alternations of greywackes and shales forming a typical turbiditic succession. The unit thickness ranges from a few up to 150 m and its lateral continuity has proved difficult to establish. This is due to the major thrust plane that cuts the unit at several levels.
- **Brancanes Formation (r):** this is composed of black pyritic and graphitic shales, which are very rich in organic matter. The total thickness is of the order of 50 m.
- **Mértola Formation (Mt1):** this unit corresponds to the regional Mértola Formation of the Baixo

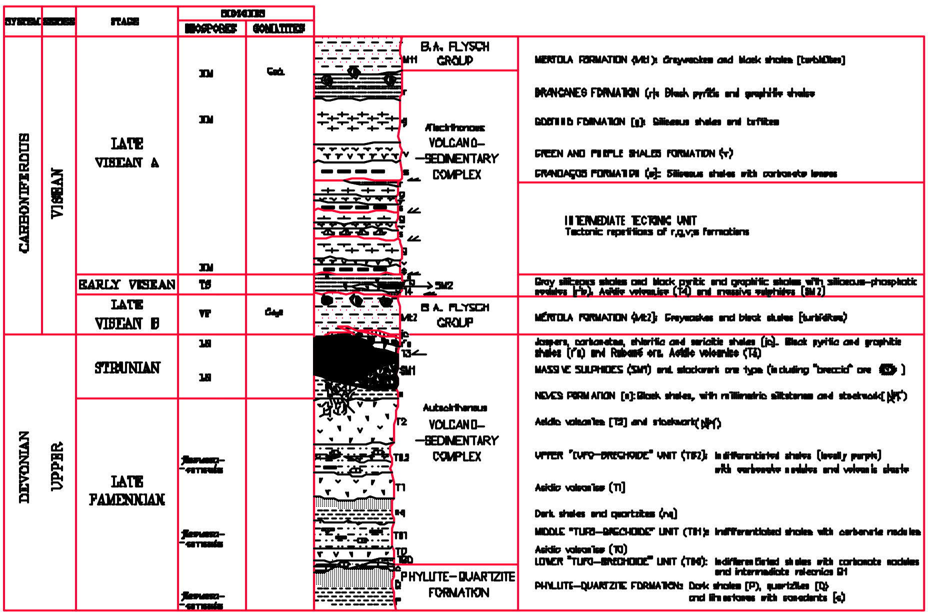


FIG.1 – STRATIGRAPHIC SEQUENCE OF NEVES-CORVO MINE

(Modified from Carvalho, P. *et al*, 1998)

Alentejo Flysch Group. It forms the uppermost local turbidite succession, composed of shales and greywackes. The thickness, in the mine area, is in excess of 700 m

Mineralization and Ore Types

The Neves-Corvo volcanogenic polymetallic massive sulphides occur in five main lenticular deposits, *i.e.*, Neves, Corvo, Graça, Zambujal and Lombador (Figure 10). All the deposits show evidence of stockwork mineralization in the footwall hosting rock formations and are almost always placed above a main acidic volcanic episode. A main characteristic is the clear lateral and vertical metal zonation patterns exhibited (Figure 10).

As a general rule the copper rich sulphides occur at the base of the deposits, and are overlain, when present, by the zinc sulphides. The "barren" massive sulphides usually appear towards the upper part of the deposits. Tin occurs in close association with the richest parts of the copper mineralization. A peculiar characteristic is the occurrence of banded "rubané" ore at the hangingwall of the Corvo deposit. Chalcopyrite rich ores are the main source of copper reserves and are defined by a 2% Cu cut-off grade for geological reserve estimation; cassiterite occurs within copper rich ores and the cut-off grade is 1% Sn.

Several mineralization types based on Cu, Sn and Zn content are identified and their characteristics are as follows:

- **"RUBANÉ";** occur at the top of the massive sulphides, mainly at the Corvo orebody . The mineralization is characterised by thin banded alternations of chloritic shales, chert-carbonate breccias and massive sulphide lenses. The "rubané" mineralization is divided, into four ore types, as follows:
  - RC: "rubané" ore with bands of chloritic shale interbeded with bands of chalcopyrite, with more than 2% copper.
  - RT: "rubané" with veins/veinlets and dissemination of cassiterite in bands, with more than 1% tin.
  - RZ: "rubané" with bands of sphalerite, with more than 3.3 % zinc.

- **MASSIVE SULPHIDES**: This is the most frequent mineralization type composed of about 95% of fine grained sulphides. Four ore types are defined :
  - MC: massive cupriferous ore characterized by disseminations and thin to thick bands of chalcopyrite within massive pyrite; the copper content is over 2%.
  - MS: is a massive rich cupriferous ore type, composed of banded or massive chalcopyrite and associated cassiterite. To define the ore as MS type 1% tin is required.
  - MT: when a large amount of cassiterite exists, with more than 8% of tin, the ore is designated as MT. The MS and MT ores are more abundant near important faults, suggesting close relationships between faults and ore genesis.
  - MZ: a massive sulphide rich in sphalerite, with more than 3.3% of zinc, that occurs as centimetric bands within massive pyrite. The bands may have disseminations of galena .

- **FISSURAL**: this is a stockwork mineralization type. The mineralization appears in the footwall shale (n) and in acidic volcanics (mainly T2 and T3), usually as cross-cutting veins and veinlets of sulphide minerals. It is represented in all the orebodies, but with stronger expression in Neves deposit. The main stockwork forming minerals are pyrite and chalcopyrite, with less frequent cassiterite and sphalerite. Fissural is divided into three ore types:
  - FC: a stockwork copper rich ore type, containing more than 2% copper present in chalcopyrite rich veins and veinlets.
  - FT: a stockwork tin rich ore type, with cassiterite disseminated in small veins filled with pyrite, chalcopyrite and quartz; the tin content is in excess of 1%.
  - F Z: a stockwork zinc rich ore type, with more than 3.3% zinc present in sphalerite rich veins and veinlets.

Description of the Neves-Corvo Mineral Deposits

Graça

This orebody is situated on the southern limb of the Rosário Anticline and dips 10º to 70º to the south. It is linked to Corvo orebody by a “bridge” of thin continuous sulphide mineralization . Plan dimensions are 700 m along strike and 500 m in dip direction, and depths below surface are from 230 m to 450 m. The maximum thickness is 80 m. The Graça orebody is crosscut and displaced by several major faults striking North-South.

Corvo

The Corvo orebody dips 25º to 30º to the northeast. The maximum thickness is 92 m and the massive sulphide lens is emplaced at depths from 230 m to 800 m. Most of the orebody is overlain by “Rubané” ore. This comprises an assemblage of chloritic shales, siltstones, and chert-carbonate breccias, which are all mineralized with cross-cutting and bedding-parallel bands and veinlets of sulphides, and occasional thin lenses of massive sulphides. Recent studies suggest that the “Rubané” ore is tectonically emplaced (Carvalho et al, 1996). Cupriferous sulphide stockwork zones (FC), consisting of veinlet sulphides crosscutting footwall shales and acid volcanics, underlie the massive sulphide lens in some places. Tin ores, mainly cassiterite rich, are closely associated with copper ores and in the “Rubané”.

Neves

Neves consists of two orebodies, called Neves-south and Neves-north, which are linked by a thin “bridge” of massive sulphides. The orebody dips 5º to 25º to the northeast, the maximum thickness is 55 m, and the dimensions are over 1200 m along strike and 700 m on dip. The Neves-south orebody is composed of several alternating lenses of zinc, copper and barren pyrite. In the Neves-north orebody copper predominates.

Zambujal

The Zambujal massive sulphide deposit straddless the crest of the Neves-Corvo Anticline; it has a thickness of 53 m and plan dimensions of 550 m along strike and 600 m on dip, with a succession of zinc-rich lenses (MZ) containing some copper mineralization.

Lombador

The Lombador deposit was discovered in 1988 following a deep drilling exploration programme at the northern termination of the Corvo and Neves orebodies. This deposit dips 20 to 40º to the north and consists of two main bodies, called Lombador-north and Lombador-south. Both display high grade zinc resources (MZ), over 8% Zn, with 2% Pb and 0.5% Cu. Maximum thickness is 100 m and its plan dimensions are over 1350 m on dip and 600 m along strike.

10. The Aguas Teñidas Este Mine

Authors: Victor Guerrero, Raúl Hidalgo, Juan Manuel Pons

Location: In the road A-488 pk. 20, 12.6 km west of the crossing with the N-435, about 2 km East of Valdelamusa.

1/50000 sheet: 938

UTM coordinates: 690.61; 4184.18

References:

Hidalgo,R., Anderson,I.K., Bobrowicz,G., Ixer,R.A.F., Gaskarth,J.W., Kettle,R.(1998): The Aguas Teñidas Este deposit. IV Simposio Internacional de Sulfuretos Polimetalicos da Faixa Piritosa Iberica, A.15,1-6

NAVAN,S.A. (1996): Aguas Teñidas deposit. Faja Pirítica en Simposio Sulfuros metálicos de la Faja Pirítica Ibérica. Huelva, 21-23/2/96

Rodriguez,P., Anderson,K., Hidalgo,R. (1996): Yacimiento de sulfuros polimetálicos de Aguas Teñidas. Boletin Geologico Minero, 107, 5-6, 673-680

The Aguas Teñidas East polymetallic sulphide deposit (ATE) is located in the northern part of the Iberian Pyrite Belt, more specifically at San Telmo anticline, which is an E-W structure near the major thrust that limit the South Portuguese Zone and the Pulo de Lobo Unit.

In the San Telmo anticline there are several orebodies. In addition to the ATE deposit, the most important polymetallic sulphide orebodies are, from West to East, El Carpio, Santa Bárbara, Cruzadillo, Lomero Poyatos, Confesionarios, Aguas Teñidas Mine, Castillejito, Cueva de la Mora and Monte Romero (Figure 12). They define a distinct mineral district, as they share some common features not described in other zones of the IPB. The massive sulphides have small tonnages -no giant deposits have been already discovered- but the base and precious metal grades are around the highest of the IPB.

The Aguas Teñidas East deposit was discovered in the second half of the 80s by the joint venture Promotora de Recursos Naturales S.A. and Billiton Española S.A. (PRN-BESA). They defined a a deep electromagnetic anomaly that was confirmed by two drillholes and further EM37 and Down-hole techniques. Finally, in the A-3 drillhole they intersected about 17 m of polymetallic massive sulphides. By the end of 1990, PRN-BESA had defined some identified geologic resources of 29 Mt of polymetallic massive sulphides, plus 6 MT of disseminated sulphides in the stockwork foreseeing the possibility of mining in an underground operation with a total of 9 Mt economically reasonable Cu-Zn grades.

Table 2. Current reserves of Aguas Teñidas Este

	Mt	%Cu	%Pb	%Zn	Ag (g/t)	Au (g/t)
Total	35.41	1.41	1.91	3.39	40	0.51
Polymetallic (3%Zn c.o.)	16.0	1.08	1.66	6.41	60	0.69
Polymetallic (6%Zn c.o.)	7.60	1.05	2.37	8.67	81	0.81
Cupriferous (1%Cu c.o.)	12.33	2.29	0.27	0.74	24	0.36
Cupriferous (3%Cu c.o.)	2.83	3.61	0.23	0.32	24	0.42

Navan Resources (1998)

Between 1991 and 1994, Placer Dome continued - in association with PRN -, the evaluation of the deposit. They made several diamond drillhole campaigns and were able to define the volume of the orebody and increase the total resources with the extension of the deposit to the west.

Since 1995, NAVAN RESOURCES Huelva S.A. has continued with the exploration of the deposit. Recently, the mining operation has started through the construction of an access ramp about 1300 meters long, and investigation drifts that allow the realization of drillings to turn mining resources into minable reserves. The current reserves are shown in the Table 2. The deposit is still open towards the West.

General Geology

The geology of Aguas Teñidas deposit is rather complex and there are still many problems that need to be solved. These problems are due to:

a.- The geological information is difficult to correlate. This is because surface geology is totally different from the underground one. The existence of intrusive units make difficult to establish an stratigraphic column.

b.- Deformation features in this area are very intense compared to other zones in the IPB. The tectonic structure is complex but very important in order to establish the geological model for this area.

c.-The lack of information about the original relationships between massive sulphides and the host rocks.

However, a very schematic description of the Aguas Teñidas lithological sequence can be established (Figure 13). The footwall of the Aguas Teñidas Este deposit seems to be a massive rhyodacite with a strong and pervasive hydrothermal alteration. The rock consists of an alternation of chlorite- and quartz-sericite-rich bands, all affected by a strong pyritisation. The pyrite occurs in stringers or disseminated, sometimes accompanied by massive chalcopyrite.

The hanging wall sequence is called the Volcano-Sedimentary Unit (UVS). From bottom to top it is formed of a unit of highly deformed green tuffites followed by an alternating grey shales, basic tuffs and spilitic lavas with an strong hematitisation. The UVS sequence is capped by 10 to 20 m of black shales with disseminated pyrite and abundant quartz. This band show features of intense deformation and is interpreted as an ultramylonite. This rock defines an abrupt lithological change. In the northern area, there is an Acid Unit made up of massive rhyolites with irregular strong chloritic and silica-rich alterations, dacites with pervasive chloritic alteration, polymictic and monomictic breccias and sediments. Near the contact with the rocks of the southern area there are abundant cherts. In the southern area, and overlapping the Acid Unit there is a sedimentary sequence of green-grey shales followed by a dacitic to andesitic sequence; along the contact with the shales there are slightly more acid breccias. This shale-dacite interface is where the orebodies of old Aguas Teñidas mine and Herreritos are hosted.

Aguas Teñidas Orebody

Two types of mineralization have been defined within Aguas Teñidas orebody, one of polymetalic massive sulphides and the other of disseminated sulphides.

The deposit has a known strike length of some 1500 m in a roughly E-W direction, plunges roughly 20°W and is open in that direction. At its eastern limit the deposit is located about 280m below the surface. The current western extent lies some 650m below surface. The massive sulphide orebody is between 150 and 300m wide and wedge-shaped, with a maximum thickness of some 80-90m in the northern margin. In the northern limit, the massive sulphides finish abruptly, suggesting the existence of a reverse fault with a strong strike-slip component. The deposit appears to be displaced by 50-60 m across a normal, westerly dipping fault at the western portion of the currently defined mineralization.

The hanging wall contact of the massive sulphide is usually sharp, and is always sheared. Footwall contacts can be sharp or gradational to replaced. However, locally they can be sheared.

In general, the mineral distribution shows a banded fine grained massive sulphide with an enrichment of Zn, Pb and Ag close to the hanging wall and an underlying coarse grained barren pyrite zone. This pyrite has sometimes a Cu enrichment that also affects the footwall host rock.

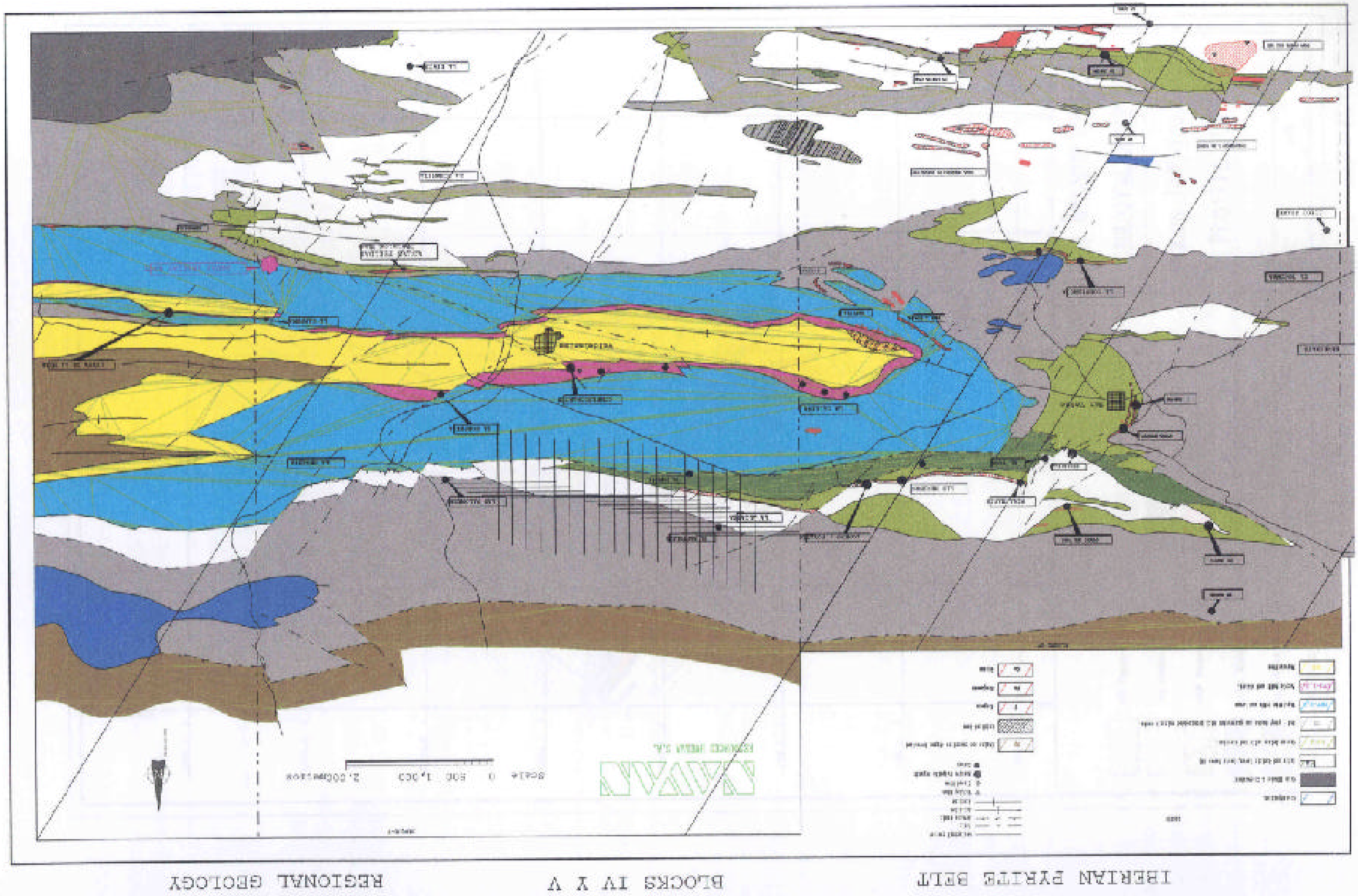


Figure 12. Geological map of the Aguas Teñidas - Lomero Poyatos area

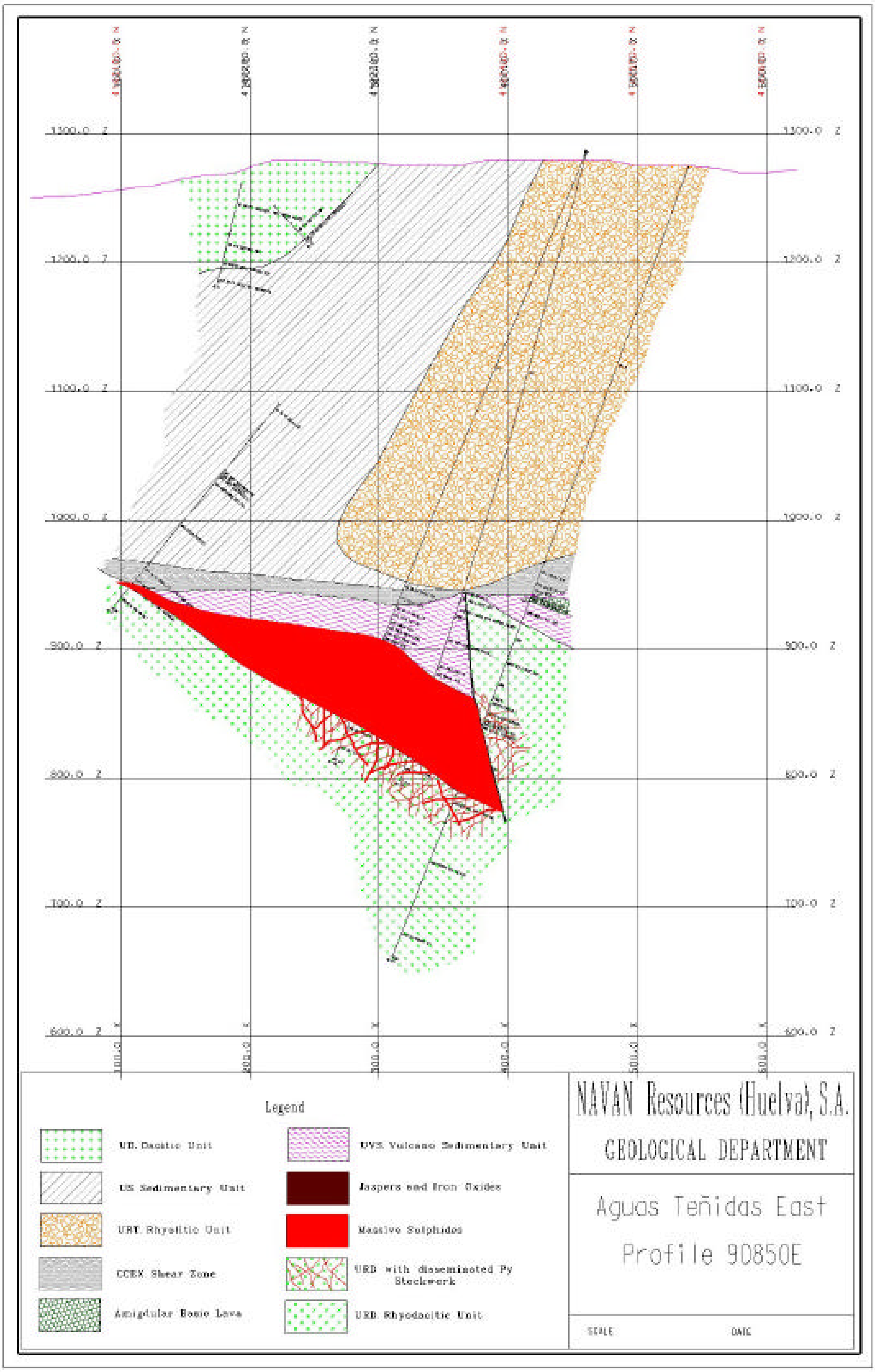


Figure 13. Cross section of the Aguas Teñidas East deposit

Mineralogy

The mineralogy of the ore is relatively simple with, in decreasing order of abundance, pyrite, sphalerite, chalcopyrite and galena accompanied by lesser amounts of magnetite, arsenopyrite, tetrahedrite group minerals and trace amounts of pyrrhotite, bournonite, stannite group minerals and various Cu-Pb-Bi sulphosalts. Quartz, calcite, dolomite, barite and sericite are the main gangue phases.

The earliest assemblage of pyrite (enclosing iron-rich sphalerite and mixed pyrrhotite-chalcopyrite, ± sphalerite inclusions) and magnetite is followed by multiple generations of pyrite, sphalerite, galena and chalcopyrite, each with their own distinctive textural and compositional features. This is exemplified by sphalerite, where the earliest generation is iron-rich (up to 12.3 mol % FeS), the main generations have up to 5.5 mol % FeS and display chalcopyrite disease, whilst the last-formed sphalerite is iron-poor with a maximum of 1.07 mol % FeS. Galena is bismuth-bearing and appears to be associated with the minor gold values found in the ores.

Significant amounts of silver are carried in the tetrahedrite which ranges in composition from $(Cu_{9.5}Ag_{0.01})\ (Fe_{1.74}Zn_{0.36})\ (Sb_{2.33}As_{1.74})\ S_{13}$ to $(Cu_{7.25}Ag_{2.05})\ (Fe_{1.24}Zn_{1.15})\ (Sb_{3.92}As_{0.42})\ S_{13}$.

11. The El Cerro outcrop

Author: F.Tornos

Location: In the road El Cerro de Andevalo-Calañas, 3 km SE of El Cerro

1/50000 sheet: 937

UTM coordinates: 685.30; 4176.70

References:

Routhier et al. (1980): Le ceinture sudiberique a amas sulfures dans sa partie espagnole meridionale. Mem. BRGM, 94, 265 pp.

IGME (1984): Mapa Geológico de España escala 1/50.000. Hoja núm.937. El Cerro de Andévalo. IGEM, Madrid.

Fernández Ruiz, J. (1985): Cartografía del aglomerado de El Cerro. Internal report. ITGE.

Southern of El Cerro town there is a big E-W trending unit of rhyolitic rocks called “Aglomerado del Cerro”. It outcrops along more than a dozen km, with an average thickness of about 250-400 m. It has been usually related to the V_2 acid volcanism (IGME, 1984) and interpreted as a subaerial and highly heterogeneous acid unit with pyroclastic agglomerates, tuffs and ignimbrites as well related epiclastic rocks (Routhier et al., 1980; IGME, 1984). It has no related massive sulphide mineralization.

Most of the rocks of this unit can be reinterpreted as acid hyaloclastites capped by monomictic mass flows probably derived from equivalent rocks suggesting that all the unit belongs to a major, partially dismantled cryptodome. The existence of peperitic contacts with the purple shales and related jaspers (see draws of Routhier et al., 1980) suggest that it was partially intrusive in this marker level and postdated it, so it can be roughly equivalent to the so called V_3 acid volcanism. Goniatite bearing rocks of the Culm Group are observed southwards. Also, the widespread presence of hyaloclastites -probably discordant below shales - suggest that it was also extrusive.

The trenches of the railway and the road as well banks of the Arroyo del Tamujoso reveal the best outcrops of the monomictic mass flows and underlying hyaloclastites. Some of the rocks show an strong cleavage and flattening that have not modified the original relationships. The rocks are apparently very homogeneous but in detail they are very chaotic, showing strikingly different structures and colours. The spatial relationships in the railway trench suggest a complex evolution, with metre-sized massive domes intruding the mass flows. They range from massive rhyodacites with flow banding and prismatic jointing to *in situ* and transported hyaloclastites (mass flows). The *in situ* breccias are monomictic, angular, highly heterometric, fragment supported and sometimes show jigsaw contacts. The allocthonous breccias have more rounded and heterometric fragments and are sometimes matrix supported. Fragments with rotated flow banding or exotic compositions (shales and basic rocks) can be observed locally. The morphology is massive but sometimes (railway trench) is possible to observe a crude metre sized banding, likely of sedimentary origin.

12. The La Zarza Mine

Author: J.Locutura
Location: In Los Silos town, that can be accessed from road leaving NE of the Cerro de Andevalo-Calañas road.
1/50000 sheet: 937
UTM coordinates: 689.20-4175.95

References:

Strauss,G.K., Roger,G., Lecolle,M., Lopera,E. (1981): Geochemical and geological study of the volcanosedimentary sulphide orebody of La Zarza, Huelva, Spain. Econ.Geol., 76, pp.1975-2000

The La Zarza Mine is situated in the center of the Spanish side of the Pyritic Belt, 6 km N of Calañas and 30 km NE of the Tharsis Mine. The orebody attains a length of 2900 m, in E-W strike, exceeds100 m in thickness and spreads down more than 500 m. It has been considered as occupying an overturned sinclinal structure whose axial plane strikes E-W and dips 70°N (Strauss, 1990). It represents a sulphide accumulation greater than 100 Mt (ab.164 Mt with 1.24%Cu, 1.09%Pb, 2.49%Zn, 47 g/t Ag and 1.79 g/t Au) of which 35 have been mined up today in an open pit and by underground workings. The underground works are now flooded and only the open pit is nowasdays accesible.

It has been mined since about 1500 BC. In 1853 it was rediscovered and worked irregularly until some years ago by Minas de Tharsis. In 1996 it finally stopped but some research continues. In the later years the production was about 600000 t/year.

In the classical classification of massive sulphide deposits in terms of relationships with volcanic/hydrothermal centres, La Zarza has been considered proximal because its evident stockwork or feeder stringer system (Strauss et al., 1981). As a whole, the deposit, although made by different ore types, has a low grade content in base metals and cannot be classified as a "complex ore". Estimations of a Chevron report a mean grade for the La Zarza ore deposit of 0.7% Cu, 0.5% Pb, 1,5% Zn, 1 g Au/t and 24 g Ag/t. Nevertheless, it has attracted the interest of mining companies these late years because locally it has quite high gold grades (10 Mt with 6 g/t) which are over those of the majority of Pyritic Belt deposits.

Geologic environment

At a regional scale, and in the subdivision of the IPB established from structural and estratigraphic criteria, the La Zarza orebody is included in the so called Central Block, close to its western boundary which coincides with a decrochement zone striking NE-SW, representing a lateral ramp with respect to the thrusts. The orebody is located within a klippe from the Northern Domain (La Zarza klippe) inside the Central Domain. This situation amplies a lithologic prevalence of acid to basic rocks (mainly intermediate) with massive character and a strong superimposed deformation.

At a more local scale, La Zarza is situated inside a E-W trending narrow band of volcanosedimentary materials within Culm. The deposit occurs in an overturned synclinal structure vergent to the South (Strauss et al., 1981).

The orebody an its wall rocks.

The strong deformation which has affected the mineralization and its host rocks, together with the intensive hydrothermal alteration shown by the late ones and the structural complexity of the deposit set up difficulties in order to identify the lithologies with some precision and to determine the statigraphy. However, three principal units can be separated from North to South.

Footwall unit.

lt is composed by different volcanic facies with a rhyodacitic to dacitic character, related to V_2 volcanic cycle (e.g., Routhier et al., 1980). It includes some intercalations of black shales. These dacitic rocks are probably connected with ignimbrites of Sierra Blanca and *nuees ardentes* deposits of El Villar, East of La Zarza. The progressive diminution of grain of the volcanic materials from Peñas Blancas towards the West, together with the increasingly reworked character of the volcanic materials in the same direction suggests the presence of a volcanic center East of La Zarza. Within the mine, these rocks show some hydrothermal which becomes pervasive in the central zone. It consists of a diffuse and weak sericitization drastically overprinted by stronger silicification and an overall chloritization processes. Its geochemical signature display anornalous high contents of Mg and Fe, in agreement with altered zones, and also As-Sb anomalies partially coinciding with the later ones. There is not a clear correspondence between hydrothermal alteration and As-Sb hights.

The orebody.

Several types of ore can bedistinguished, with different characteristics and genetic significance, Their actual arrangement and relationships, indeed different of the primary one, is of tectonic origin. The following ore facies can be found from North to South:

• Stockwork: Generally, it occurs between the volcanoclastic hydrothermally altered rocks of the footwall and most of remaining ore facies (on siliceous ore or directly on massive sulphide body). It appears even included as lenses inside the massive pyrite. lt is made up by a network of anastomosed veinlets filled by sulphides with lesser amounts of sericite, quartz and carbonates. The strong deformation acting in some zones has produced a transposition of veins following a cleavage and has lead to the parallelism of veins. The observed paragenes is, as a whole, similar to that on the massive mineralization although the relative abundance of some minerals is different (less sphalerite or galena, more pyrrhotite and cobaltite, absence of cassiterite) . Its geochemical signature is characterized by quite high contents of Co (up to 500 ppm) and high Co/Ni ratios (10-25). This feature is common to many stockworks in the IPB and elsewhere. However, it is not so significant as in the Tharsis orebody, where the stockwork reaches grades of up 4000-5000 ppm. Bi and Ag contents in La Zarza stockwork are also lesser than Tharsis ones (30-50 ppm Bi) and not significantly different of those present in other ore facies as siliceous or massive ore. Inversely to the Tharsis stockwork, La Zarza stockwork has a low Au grade (near 0.4g/t), which is under the Au grades of other ore facies. We can conclude that its geochemical signature is not so well drawn as the Tharsis one.

  A quite different stockwork, with a lees intense veining, occurs in the Southern side (level 14, Southern stockwork) at the footwall of massive ore.

• Siliceous ore ("silicatado"): It represents a quartz-sulphide association with a very wide composition range. There are variations between very siliceous types with a weak sulphide disssemination and almost massive sulphide with scarce clouds or veinlets of quartz (15 to 90% of sulphides). It can get the look of a massive sulphide with some disseminated spots of quartz or that one of an intense network or quartz veinlets in a sulphide matrix. The siliceous ore occurs mainly in the 18^{th} and 14^{th} levels, as lenticular bodies between the massive ore and stockwork ore or the footwall unit. The contacts between these facies are usually sharp (except some scarce gradual massive ore-siliceous ores

  The undeformed siliceous ore is made up by clean granular quartz of medium grain which includes microcrystalline zones, probably ghosts of silicified fragments, cutted by quartz veins with comb structure. Sulphides, mainly pyrite and minor chalcopyrite, occupy intersticial places between quartz grains and replace them. A greater abundance of sulphides seems to be related with a greater presence of later chlorite and carbonates (ankerite). In some zones, the siliceous ore has been strongly deformed and has acquired a banded structure with irregular and lenticular alternating bands of quartz and sulphides. Usually these deformed siliceous rocks are more chloritic and carbonatic and display higher contents in base metals (Pb,Zn).

The siliceous ore is characterized by high Cu grades, quite irregular, but almost always equal or over Pb+Zn contents. Co contents are lower than in the stockwork as well as Co/Ni ratios, although they are still significant (Co/Ni in the 5-10 rarge, Co in the 100-300 ppm range).

The siliceous ore can be interpreted as the siliceous core present in the higher zones of most footwall stringers and under massive sulphides.

• Massive ore and banded complex ores: Massive ore contributes to the 90% of the mineral weight of La Zarza deposit. lt exhibits usually a massive, homogeneous an finely grain-sized aspect. In some deformed zones it acquires a weak internal orientation which can grade up to a tectonic compositional banding. Another significant features are the presence of local recrystallisations and grain size growths, generally related with the presence of gangue inclusions. Pyrite grain size depends on primary factors as depositional structures (colloform textures, spheroids ..) and on postdepositional ones, as brittle deformation, dynamic recrystallisation, pressure solution and annealing, as well as other factors like the nature of the nature of the matrix of pyrite. Primary colloform and spheroid textures are relatively frequent although they display rims of pyrite overgrowths. These primary pyrite textures are not easy to identify without acid attacks in polished sections because of deformation and grain growth effects.

Having undergone a strong def ormation in greenschist conditions, those primary textural features appear beside predominant overprinted deformational effects. These are mainly cataclasis and brittle failure of pyrite and, overall, a spaced pressure solution style cleavage with seams of insoluble material or of weaker sulphides (galena, sphalerite, chalcopyrite), which can be associated to shear plans producing S-C structures. A complex deformation thermal annealing history can be drawn, involving several grain reducing an grain growing stages. These could be relatad with hydrothermal remobilizations (mainly of carbonates and sulphides).

The banded complex ore represents the product of the extreme deformation conditions which are reached in some narrow (decimetric to metric) bands. lt occurs at the N and sometimes S boundaries of massive ore facies, as well as ocasionally within it. This ore type correspond to the basal complex polymetallic ore of precedent researchers (Strauss et al., 1981). These banded ore bodies run along boundaries of massive sulphide unit or within ít, and are made by millimetric sphalerite-galena-chalcopyrite-carbonate-(chlorite) bandsalternating with more pyritic bands. Pyrite, in undeformed euhedra or moreless cataclized grains acts as strain riser with the development of quartz-carbonate-chlorite-soft sulphides pressure shadows as the host lithologies deform around pyrite grains.

The paragenetic association shown by massive ore includes pyrite, chalcopyrite, sphalerite, galena and tetrahedrite as more abundant components together with scarce chlorite, quartz, carbonates and occasionally some barite. Arsenopyrite, pyrrhotite, bournonite, stannite, cassiterite, bismuth, cobaltite, magnetite and gold (electrum) are accessory minerals. This association does not change in the banded type, where only the amounts of base metals are significantly increased. Fron the geochemical point of view, massive ore is characterized by still significant Co/Ni ratios (1 to 5) and valuable Au contents, in good correlation with As. There is a continuum towards higher grades of Pb, Zn and even cu (Au in a lesser degree) in the polymetallic bands, together with carbonates and chlorite in a late hydrothermalism stage. The strongly deformed corridors where occur are, indeed, very effective channel ways for the circulation of metamorphic hydrothermal solutions which can mobilize and redistribute the more mobile elements.

•Gangue-sulphides alternances ore: This ore type corresponds to the "resedimented" one of Strauss (1990). lt consists in centimetric to decimetric discontinuous and irregular intercalations of sulphides in mylonites or intensely deformed acid volcanic rocks of the hanging wall unit, and occurs close to the contact with the massive ore. Sometimes it appears inside the massive ore unit near of its top, in lenticular bolies of pyroclastic rocks, tectonically emplaced. The sulphide intercalations usually delineate thrusting surfaces and show tightly isoclinal folds produced in a ductile regime. These pyrite intercalations contain some amount of quartz and carbonates. They are slightly enriched in base metals and show the highest contents in Au (over 5 g/t) and Ba.

A somewhat related minor ore type is the tectonic breccia ore which appears at almost every internal contact between massive ores and pyroclastic bodies included in it. It occur in levels 10 and 14 where it constitutes irregular bands of up 20 m width, close to the contact with massive ore. They are polygenic breccias with very heterometric elements (cm to m). These breccia are plastically elongated and orientated. The mineralogic and geochemical signatures are quite similar to that ones of the precedent ore types associated to deformation bands, the differences being probably induced by their lithologic environment.

Hanging wall unit.

The rocks which are included in this unit are mainly pyroclastic acid rocks comprising some crystal tuff horizons and some lensoid intercalations of purple cherts, which usually at the top of the V_1 acid volcanic episode. They show locally a very penetrative schistosity of mylonitic character. Geochemically this unit displays a Mn-Ba signature.

Structure of the La Zarza deposit

The structural study carried out in the underground (18^{th}, 14^{th}, and 10^{th} levels) and old workings of the mine has allowed to recognize there at a lesser scale, the same structural style than yet defined at regional scale. Most of the contacts between lithologic bodies or units. are of tectonic nature, mainly those that bound the mineralization unit. They represent thrusts with irregular shapes (ramps and flats geometry which because a progressive folding all along a continuous deformation process. These surfaces dip to the N, except that ones that bound the orebody at S, which in the 10 and 14 levels are S dipping. The tectonic polarity criteria indicate normal disposition and flow sense toward the South. Thrusts have a ductile or ductile-brittle nature and are associated to mylonitic rocks, showing disconnected structures, plastic flow features and C-S structures. As a whole the deposit is made up by an antiformal sheets stack, bounded by a folded thrust to the N and an “out of sequence” thrust to the S. This structure has been produced by the propagation of flow downward and forward (S).

So, most of the rocks in the ore deposit and in its surroundings show an important deformation degree. The deformation is not spatially homogeneous but concentrated in metric or decametric corridors with ductile style. Some specific ore types are associated to these bands and are, consequently, of tectonic origin. These ore facies present important enrichments in base metals (banded polymetallic ores) and gold (hanging wall gangue-ore alternances). In addition to this remobilizing role, tectonic evolution is also responsible for increasing width of the ore, by stacking of several ore sheets (up to five in the central part of the deposit).

13. The Lomero Poyatos Mine

Authors: Emilio González Clavijo, Juan Manuel Pons, Fernando Tornos

Location: In the road H-120 (Cabezas Rubias- N-435) pk.85, 4.4 km east of San Telmo.

1/50000 sheet: 937

UTMcoordinates: Lomero (E) 682.52; 4186.25. Near the house NE of the shaft. Poyatos (W) west of the shaft 682.08; 4186.26

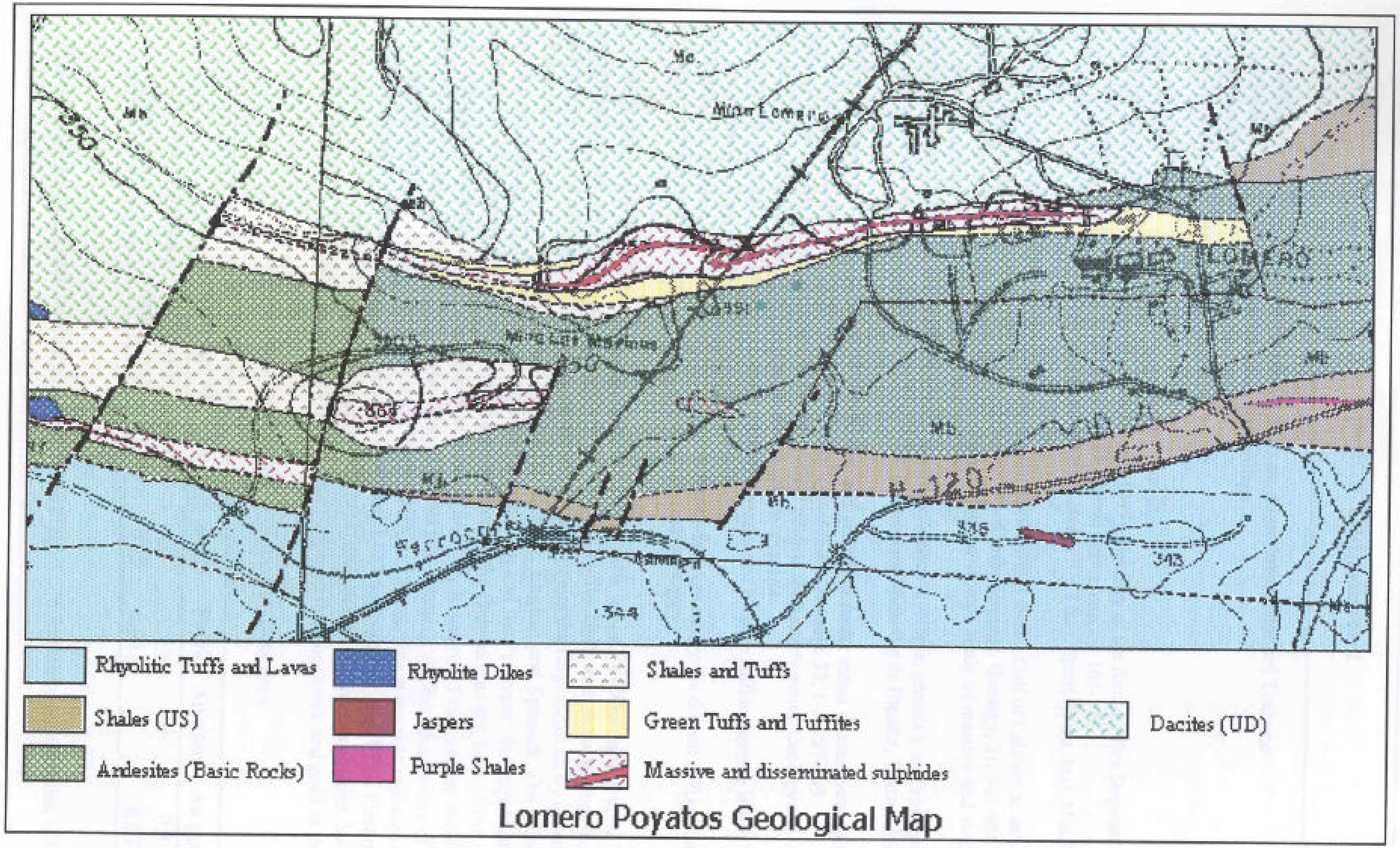


Fig.14. Geological sketch of the Lomero Poyatos area

The Lomero-Poyatos mine worked an orebody of 1.71 Mt of massive sulphides with 0.50% Cu, 7.5% Zn, 4.5%Pb, 120 g/t Ag (complex ore) and 1 Mt with 1.5%Cu (pyritic ore). The gold grades in the complex ore are between the highest in the IPB, averaging 4 g/t with some zones with up to 10-12 g/t. The gossan, originally very thin (2-4 m), also had high gold grades (4 g/t). The mine was discovered in 1853 by Deligny and was intermittently worked by small companies till 1985.

Lomero-Poyatos is one of the best places of the IPB for observing the deformation in the massive sulphides. In contrast with the southern belt, in the northern one the massive sulphides are affected by a higher metamorphic grade and show abundant evidences of strong deformation.

Close to the surface there are two independent orebodies (Lomero, E, and Poyatos, W) that form a single orebody at depth. It has an average strike of N75°E and dips 10-35°N near the surface. At depth, the orebody seems to be formed by several thin (3-10 m) stacked ore lenses, 900 m in strike located along the tectonic contact between shales (N) and igneous rocks (S). The footwall is composed of massive dacites; that show an increase of the cleavage and deformation towards the orebody. They are composed of a microcrystalline groundmass of quartz and sericite with quartz and plagioclase phenocrysts and affected by a highly irregular silicification, sericitization and chloritization. The hanging wall is also composed of massive dacites overlain by purple and green shales. The massive sulphides are limited by mylonitic bands, formed by highly silicified rocks.

The mineral assemblage of the massive sulphides is composed by pyrite, tenantite, sphalerite, galena, chalcopyrite, minor arsenopyrite, baryte, pyrrhotite and gold. There are some hematite-magnetite-rich bands (ITGE, 1989).

Stop 1. Western open pit (Poyatos).

The pit shows some irregular and highly strained subhorizontal massive sulphide orebodies mainly formed by coarse grained pyrite. Below the massive sulphides there is a highly chloritized massive dacite with increase of the grade of chloritization and tightening of the cleavage towards the hanging wall. It's contact with the massive sulphides is probably a major thrust, with a highly cleavaged and strongly silicified rock probably being a tectonic *melange* with spectacular tectonic lenses of pyrite (they can be observed in the entrance of the main adit below the shaft). Above the massive sulphides there is massive autobrecciated rhyodacite with a highly mylonitized footwall. C-S structures can be observed above the inclined adit in the open pit. The massive sulphides form highly strained boudin-like bodies a few metres in thickness that grade into mylonites-ultramylonites formed by altered acid rocks with pyritic tectonic lenses combined in a ramp and flat geometry. Above the orebody is possible to see a cleavage fan from subvertical to almost near horizontal.

Stop 2. Entrance to the main adit

The mine entrance is located just above the end of one of the massive sulphide bodies. Here, the rock is mylonitized and the massive sulphides occur as centimetre-sized lenses between highly altered (quartz + sericite) and strained dacites. Southwards there are massive plagioclase-rich basalts and pyroxene-bearing mafic rocks. The intensity of the deformation and the cleavage increase towards the mineralization suggesting that it is located near a major thrust.

Stop 3. Eastern open pit (Lomero).

The geological situation is equivalent to that of Poyatos. The hanging wall of the massive sulphides are highly chloritized dacites with feldspar phenocrysts while the footwall is made of a tectonic melange overlying the dacites observed in the Stop 1. The bottom of the open pit (when not flooded or full of garbage) show the hanging wall of the massive sulphides with abundant tectonic and highly strained pyritic lenses into mylonitized rhyodacites.

14. The Rio Tinto district

Authors: Juan Manuel Escobar, Gabriel Ruiz de Almodovar, Manuel Toscano

Location: West and northwards of the Rio Tinto village
1/50000 sheet: 938
UTM coordinates: 712.000; 4176.000

References:

Almodóvar,G.R., Castro,J.A., Sobol,F., Toscano,M. (1997): Geology of the Riotinto Ore Deposits. Geology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series num.27, 165-172

Badham,J.P.N. (1982): Further data on the formation of ores at Rio Tinto, Spain. Trans. Inst. Min. Met, 91, B26-B32

Boulter,C.A. (1993): Comparison of Rio Tinto, Spain and Guaymas Basin, Gulf of California: an explanation of a supergiant massive sulfide deposit in an ancient sill-sediment complex. Geology, 21, 801-804

Eastoe,C.J., Solomon,M., García Palomero,F. (1986): Sulphur isotope study of massive and stockwork pyrite deposits at Rio Tinto, Spain. Trans. IMM, 95, B201-207

García Palomero,F. (1992): Mineralizaciones de Riotinto (Huelva): geología, génesis y modelos geológicos para su explotación y evaluación de reservas minerales. In 'Recursos Minerales de España', Textos Univ., 15, CSIC, pp.1325-1352

Nehlig,P., Cassard,D., Marcoux,E. (1998): Geometry and genesis of feeder zones of massive sulphide deposits: constraints from the Rio Tinto ore deposit (Spain). Mineralium Deposita, 33, 1-2, 137-149

Sobol,F., Toscano,M., Castro,J.A., Sáez,R. (1997): A field guide to the Riotinto mines. Geology and VMS deposits of the Iberian Pyrite Belt. SEG Fieldbook Series num.27, 158-164

Solomon,M., Walshe,J.L., García Palomero,F. (1980): Formation of massive sulfide deposits at Rio Tinto, Spain. Trans.Inst.Min.Met., 89, Feb.1980, pp.b16-b24

Williams,S,D., Stanton,R.L., Rambaud,F. (1975) The Planes-San Antonio pyritic deposit of Rio Tinto, Spain: its nature, enviornment and genesis. Trans. Inst. Min. Met, 84, B73-B82

The purpose of these stops is to show a geological overview of the Riotinto mining area. This area is recognised as the most charismatic within the Iberian Pyrite Belt, and even at the world, by its dimensions as well as by his historical record. Here, remains patent the fingerprint let by several cultures, Thartessus, Phoenicia, Roman, Arabic and, more recently, English and Spanish. The mine has been worked since about VII-VI BC centuries, first by tartessian and then romans; the exploitation ceased about the V AD century. These miners mainly exploited in the Dehesa area the base of the gossan and the supergene cementation zone, enriched in Cu, Au and Ag. Remains of the ancient mining include about 16 Mt of slag, ancient adits and the ruins of towns and smelters. As the other mines of the IPB, it was only sporadically worked between the XVI and XIX centuries. The mine was rediscovered in the XIX century and in 1873 sold to the "Rio Tinto Company Ltd." that mined it until 1953. First mining was orientated to copper and later to pyrite. In the more recent times the successive companies, including the currently "Minas de Riotinto S.A.L." have worked the copper in the stockwork and gold in the gossans.

Table 3: Tonnage and grades of the Rio Tinto area

	Tonnage Mt	Cu %	Zn %	Pb %	Ag ppm	Au ppm
Massive sulphides	500-600	0.9	2.1	0.8	26	0.3
Stockwork	1900-2000	0.15	0.15	0.06	7	0.07

The Riotinto mining group probably represents the biggest concentration of sulphides in the earth's crust, with about 500 Mt of massive sulphides with 45%S, 40%Fe, 0.9%Cu, 2.1%Zn, 0.8%Pb, 0.5 ppm Au and 26 ppm Ag as well as about 2000 Mt of low grade stockwork (García Palomero, 1992). The mineralization is manifested as: a) stockworks in the volcanic rocks; b) lensoidal masses of massive sulphides located above the stockwork, and interbedded with rocks of the Transition Series; and c) gossan, formed by the supergene alteration of the massive sulphides and stockworks, and that it is restricted to the uppermost 70 meters below the surface.

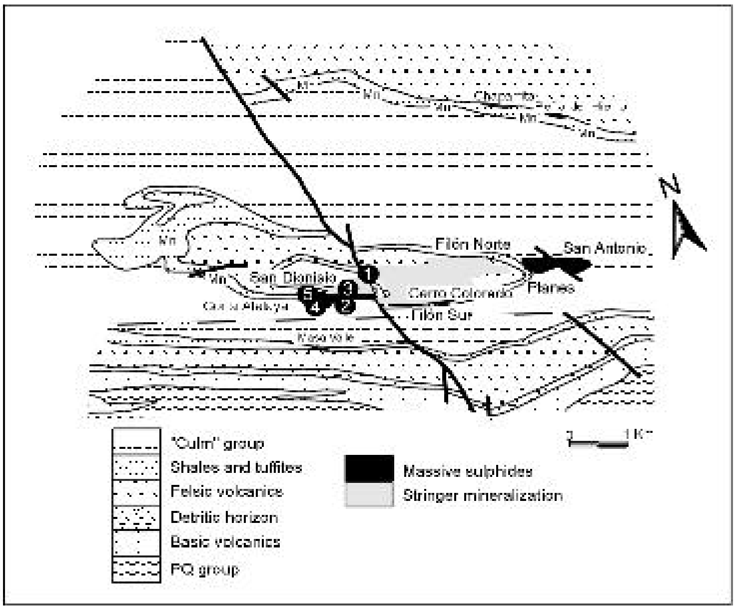


Figure 15. Geologic sketch of the Rio Tinto area showing the locations of the stops and the main massive sulphide orebodies. Modified from Garcia Palomero et al. (1980)

The massive sulphides and related stockworks appears in four separate locations of the Riotinto anticline. These four mineralised areas are (1) San Dionisio, (2) Planes-San Antonio, (3) Cerro Colorado-Filón Norte-Filón Sur and (4) Masa Valle

The big accumulation of sulphides in the Riotinto area suggests that it was the focus of one of the most intense hydrothermal processes documented until the moment, since the mineralised area occupies an area of about 4 Km^2 with a vertical extension of 400-500 meters.

The local geology of the Riotinto area is described by García Palomero (1992) and synthesised by Almodóvar et al. (1997).

Stop 1. Look out on the road of Cerro Colorado.

This stop gives a general view of the Riotinto anticline. Toward the east, it can be observed the localisation of the Filón Sur, Filón Norte and Planes massive sulphides corresponding to the mineralised level that outcrops in the Riotinto anticline. The tonnage of extracted massive sulphide (Gil Varón, comm. pers.), since 1874 to 1973, is shown in the enclosed table 4.

Table 4. Extracted massive sulphide ore in Cerro Colorado

Orebody	Mt mined	Open pit mining	Underground mining	Reserves
Filón Sur	42.4	24.2	18.2	Exhausted
Filón Norte	25.6	22.9	2.7	Exhausted
Planes	2.1	-	2.1	Exhausted
TOTAL	70.2	47.1	23.1	

The footwall of the massive sulphides hosts a chlorite-rich stockwork denominated Cerro Colorado. This stockwork is superimposed on felsic igneous rocks that have been traditionally attributed to the regional second acid volcanic episode. The rocks are pervasively chloritized and silicified synchronously with the formation of a marked network of mineralised quartz veins. Originally the tonnage of the stockwork was about 88 Mt with 0.57% Cu, and continues up to 400 m depth. At the present days, is the object of mining operations of MRT S.A.L. company for copper extraction, and the company carries out exploration operations on the east of the anticline with the purpose of extend ore resources.

Originally, here there was a big gossan between 10 and 70 m in thickness, with an average of 30 m. Only some remains are left. The gossan is enriched in Au, Ag, Pb, Sb and Bi and depleted in Cu and Zn. The grades are about 79% Fe oxides, 1.2%Pb, minor Cu and Zn, 1.8-2.5 ppm Au and 35-45 ppm Ag. This gossan was mined by MRT S.A. company in the last thirty years, until beginning of the nineties. These massive gossans are enriched in gold regarding the transported barren one, located N of the Riotinto village. This transported gossan (Alto de la Mesa) is up to 10 m thick and interpreted as surficial chemical precipitates formed along a fluvial basin (Sobol et al., 1997).

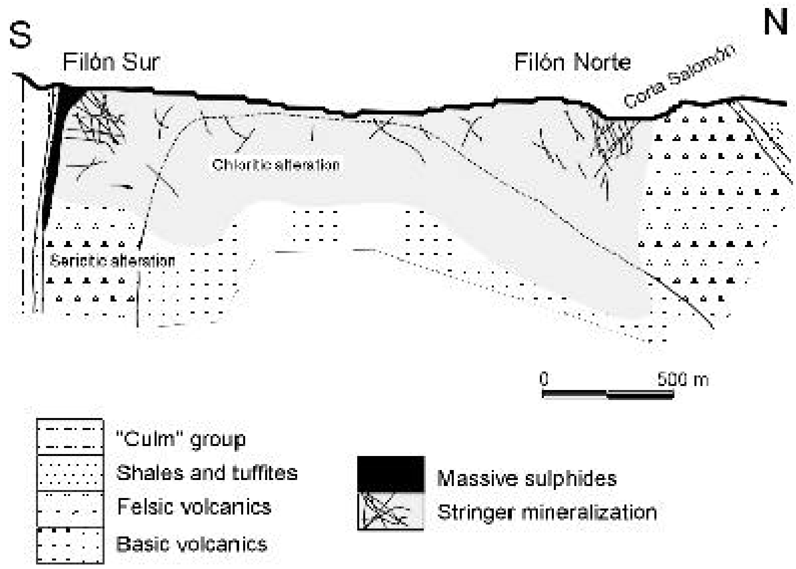


Figure 16. Generalised N-S cross section of the Rio Tinto district. Modified from Garcia Palomero, 1980).

The general structure of the Cerro Colorado area is currently interpreted as an anticline with the porphyries and associated stockworks outcropping in the core and the massive sulphides on both sides; the gossan being the product of the supergene alteration of the massive sulphides and stockworks. All these massive sulphides orebodies were probably connected and forming a great massive sulphide orebody with a thickness between 10 and 70 meters and a tonnage about 500 Mt giant orebody underlayed by a extensive stockwork zone of about 2000 Mt. This original massive sulphide related stockwork later was gossanizaded and eroded during Tertiary and Quaternary times.

However, the general structure must be much more complex, since several tectonic units and thrusts can be mapped in the area.

Stop 2. Look out on the Atalaya open pit.

This stop gives a general overview of the Atalaya open pit, where most of the rocks outcropping in the Riotinto area are well exposed. In this open pit, sulphur and copper-rich ores from the San Dionisio orebody have been mined for about one hundred years.

The mining of the Atalaya open pit started due to big collapses in underground works while mining the San Dionisio orebody. Original reserves were about 100 Mt, from which 45 Mt of crude pyrite (1%Cu) remain unmined. The tunnel, eastward and near the bottom of the pit, connects the Atalaya open pit with the underground mine (Pozo Alfredo).

The San Dionisio body shows a lensoidal shape. It is located in the southern limb of the Riotinto anticline. The local structure is more complex, since there is a tight subvertical E-W syncline whose axis pitches 30-35° to the east and that probably folds previous thrusts.

The massive sulphides are constituited by fine-grained pyrite and subordinate sphalerite, chalcopyrite and galena. Common textures include massive, banded, breccia, framboidal and colloform ones. As in Cerro Colorado, the acid porphyries in hanging wall of the massive sulphides are strongly altered, with pervasive chloritization, sericitization and silicification and development of an intense veining. These highly altered rocks are interpreted as the feeder zones of the mineralising fluids.

Looking to the North at the upper part of the open pit, it is possible to distinguish the strongly chloritized acid porphyries in the footwall; they are intensely weathered and show whitish to reddish colours. These benches correspond to the stockwork mineralization as well as the less altered hanging wall rocks affected by acid waters flowing from massive sulphide and stockwork mineralization. Down in the pit, brownish colours indi cate hydrothermal altered felsic igneous rocks also crossed by stockwork veins. Massive sulphide mineralization can be observed at the bottom of the pit, occupying the core of the syncline. Bright colours, overlaying the massive sulphide mineralization, correspond to unaltered felsic porphyries and epiclastites. Dark grey indicates shales and sandstones belonging to the "Culm" Group. Some purple colours between white porphyry and "Culm" shales correspond to the purple slates regional guide horizon.

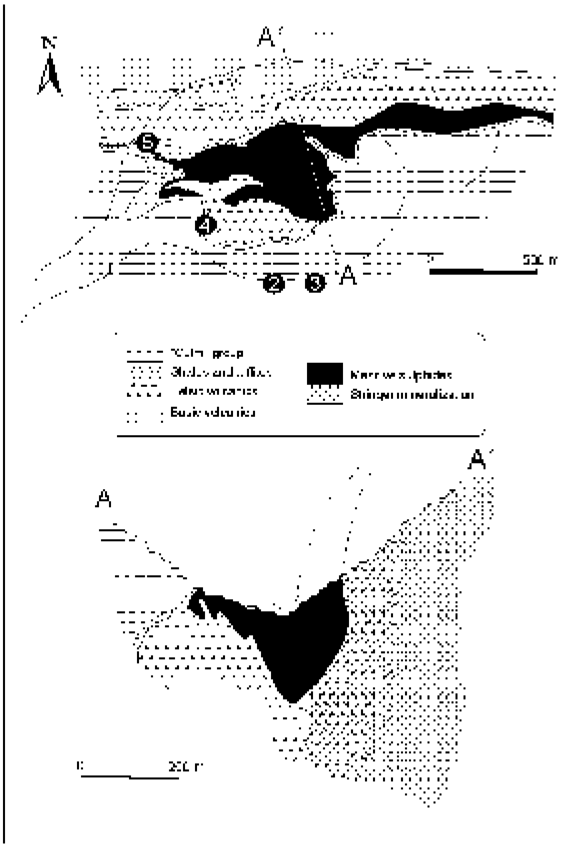


Figure 17. Geological map and cross section of the Atalaya open pit. Modified from Garcia Palomero (1980).

Stop 3. Short walk by the track from the viewpoint to the east of the pit.

Along this cross-section is possible to observe the folding style of soft rocks on the Riotinto anticline, usually detrital facies of the “Culm” group, which represents the hanging wall of the VSC and occupyi the core of the syncline. The axis plunge of the tight folds varies from 30º to 45º, either eastward or westward, locally showing sheared hinges. Tectonic cleavage is mainly parallel to the axial plane of the folds.

The same deformational style is found on massive sulphides, but folds are here less tight due to the different geological behaviour. In Atalaya open pit, this produce synformal folds with eastwards plunging axes (see Figure 17).

Stop 4. Mineralized sequence.

The upper benches show a section of the syncline (Figure 18). From south to north they include (a) Shales of Culm group; (b) porphyries; (c) black shales, including a grey to white chert; (c) massive sulphides; (d) purple and green shales being the marker level of the IPB; and (f) shales and tuffites.

Dacitic porphyries

In this cross-section, the most representative rocks are the clear dacitic porphyries with fenocrysts of quartz and feldspar with a strong and folded cleavage.The intensity of the cleavage increases towards the hanging wall. Here there are multiple evidences of tectonic rotation, suggesting that the contact with the overlying massive sulphides is a shear zone. The porphyries host some purple shale peperites, suggesting an intrusive origin but also indicate that the orginal contact has been strongly modified since the hanging wall of the porphyries are massive sulphides and not purple shales.

The petrogenetic interpretation of these dacitic porphyries is controversial. Traditionally, they have been interpreted as acid lava flows and pyroclastic ricks (Garcia Palomero, 1980). Boulter (1993) interpreted all these rocks as intrusive into wet sediments + massive sulphides, leading to the formation of widespread peperites. Nevertheless, the situation seems to be much more complicated due to the strong deformation and alteration in the area. In the open pit, many of these textures are pseudopeperitic, being in fact oxidised veins of sulphides, sediments incorporates to the igneous rock through tectonic mechanisms or processes of differential supergene alteration.

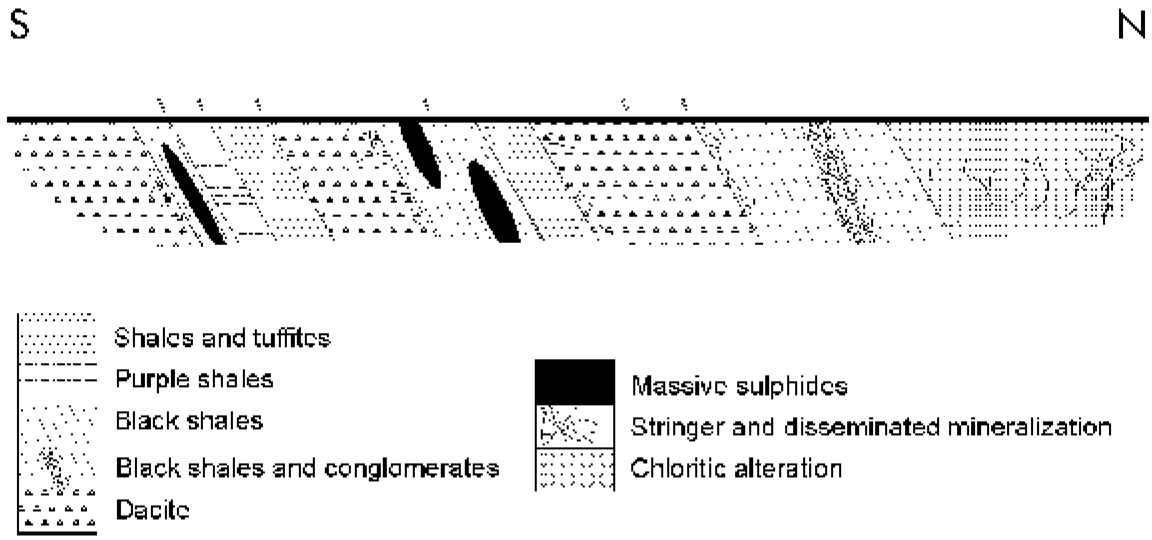


Figure 18. Schematic cross-section through bench of the 14 level.

The intensity of the hydrothermal alteration is very variable. In the south to north section, the porphyries show an increase in the alteration suggesting that they predated the formation of the massive sulphides. So, in the southern outcrops of the bench, the dacitic porphyry has not alteration at all. Towards the hanging wall it shows an increase in the proportion of sulphides, with sulphide dissemination and near the mechanic contact it has sulphide veins. In the more northern area, the intensity of the alteration increases, giving rise to a penetrative chloritization, silicification and sulfidization. However, the typical sericitic halo surrounding the chloritic stockwork as it was described in the Riotinto area (García Palomero, 1980) and other massive sulphide mineralization doesn't appear well defined in this cross-section, probably due to the tectonic complexity.

Black shales and massive sulphide mineralization

Organic matter-rich, siliciclastic black shales occur in the hanging wall of the porphyries. These rocks are always in the IPB a favourable level of tectonisation, as can be seen along the cross section..

These black shales are the regional ore horizon; they are affected by pervasive chloritization and silicification, being more patent this last one. These rocks show a penetrative replacement by sulphides, which preserve the original slaty foliation, as well as the development of stockwork veins. The massive sulphides show a marked banded texture, although locally they may be massive. The banded texture is noted by compositional and textural variations, becoming cataclastic near shear zones. Capping the massive sulphides there is a white chert level.

Purple and green shales

This unit is lithologically heterogeneous. It includes sedimentary and epiclastic rocks, that constitute a lithologic transition between the felsic complex and the Culm group. The thickness of this unit is very variable (5-50 meters), being typically a heterogeneous volcanic-sedimentary level with abundant lateral and vertical changes in the grain size and composition. Geologically, this unit represents the end of the volcanic process and the transition to the sedimentation flysch of the Culm.

The most remarkable characteristic in this series is the presence of purple shale, whose colour is due to hematite particles and represents a separation level between the acid V_2 volcanism and the Transition Series. Likewise, these slates belong together with the stratigraphic level of the manganese mineralizations outcropping in this area.

Black shales and conglomerates

In this cross-section, the last outcrop of black shales corresponds to a level interpreted until recently as debris flows made up of fragments of black and purple shale, graywackes and some fragments of sulphides in a shaly matrix (García Palomero, 1980, 1993). However, this sequence of 40-50 m is constituted by shales and conglomerates with nodules and pyrite dissemination, being the black shales a lateral equivalent to those previously described. This sequence has tectonic contact with felsic igneous rocks and is intensely deformed.

Stop 5. Feeder zone.

This stop shows an exceptional outcrop of a feeder zone of the palaeohydrothermal system. This outcrop consists of a stockwork of pyrite veins in a chloritized dacitic porphyry. The hydrothermal alteration include chloritization, silicification and sulfiditization, that increase in intensity from W to E. The highest alteration occur in what is interpreted as the feeder zone, just in front the look-out of Atalaya pit. Here, the stockwork has the biggest population of veins. The veins are constituited by quartz, pyrite, and minor chalcopyrite.

The host rocks have similar petrographic features than dacitic porphyries of the beginning of this cross-section (Stop 4). The only different features are a consequence of hydrothermal alteration conditioned by the spatial relationship with regard to the feeder zone.

This feeder zone is representative of other ones distributed through the Riotinto anticline, which represents the hydrothermal system focus that originated the massive sulphides near the sediment-seawater interface.

Others possibilities of the Riotinto area.

Besides the eminently geologic trip that can be carried out in this area, another interest points devoted to the historical record related to mining activities, which are recommended those that want to have a better vision of the environment and to understand the social and industrial significance of this mine. These points of interest include the archaeological remains of Cerro Salomón and the mining museum.

Archaeological remains.

They were prospected for the first time in 1962, when were collected prerroman vestiges between which was found ceramics, dross and crucibles and tewel fragments. The studies revealed the attendance of a principled town of the Iron Age, belonging to Phoenicians or to indigenous well supplied of Phoenician merchandise and devoted to the exercise of the mining and metallurgy.

The town extended during the centuries VIII -VI BC. through the high part of the "Cerro Salomón".

The quarry realised in the side NW of the hill put without funds the walls and the floors of a group of Phoenician or indigenous houses. It is considered a series of small rooms built of masonry and probably roofed with wood and foliage girders. Blackboard flagstones pave some of the rooms. Some of the floors are terraced because were built being adjusted to the slope of the natural soil.

The utensils found in these rooms indicate that they had been employed in metallurgical labours: granite mortars of several forms, stone anvils, balls of mashing, all they typical instruments of ancient smeltings, even though the smelting operations should be developed in other site. In the rooms also were found dross chunks, coal and drops of Pb. The chemical analysis of the dross indicates that Ag was the metal produced by those metallurgical.

Riotinto mining museum.

In this museum are exposed numerous tools and instrumental technical used for the mining of the mineral as well as for its later treatment. These archaeological pieces show an overview of the technical evolution of the mining action in the area from the Copper age (III millennium BC.) until the present century. In addition, this museum has a geological exposition, in the one, which are shown the principal geological characteristics of the Riotinto mine.

15. The Rio Jarama section

Authors: Emilio Pascual, Reinaldo Sáez, Teodosio Donaire

Location: Some of the observations will be done near the contact between the Devonian PQ Group and the Vocano-Sedimentary Complex (VSC) about 1.5 Km southward the bridge above the Jarama river in the road A-476 (Nerva-Castillo de las Guardas), pk 18.9. This area can be approached through a dirt path leaving the main road in the pk 21 to the south. Complementary observations will be done near the contact between the VSC and the Culm group close the above quoted bridge.

1/50000 sheet: 939

References:

IGME (1978): Mapa Geológico Nacional de España 1:50.000, Castillo de las Guardas (939). Serv. Publ. Ministerio de Industria, Madrid.

Lake, P.A. (1991): The biostratigraphy and structure of the Pulo do Lobo Domain and Iberian Pyrite Belt Domain within Huelva province, Southwest Spain. Umpubl. Ph. Doc. Thesis, Univ Southampton, 324 pp.

Boulter,C.A. (1993): Comparison of Rio Tinto, Spain, and Guaymas Basin, Gulf of California: an explanation of a supergiant massive sulfide deposit in an ancient sill-sediment complex. Geology, 21, 801-804

Many of the felsic and mafic igneous rocks that characterise the Iberian Pyrite Belt (IPB) can be observed along the Jarama River, including massive and brecciated facies, interbedded with volcaniclastic rocks and shales. This is one reason why the section is one of the most visited and debated outcrops in the IPB. On the other hand, peperitic contacts occur at several points in the sequence, indicating magma-wet sediment interaction processes. Accordingly, Boulter (1993) considers the whole sequence as a sill-sediment complex with several magmatic units intruding a thin and water-saturated sedimentary sequence. Alternatively, other interpretations contend that lava flows and pyroclastic rocks are dominant (Lake, 1991; IGME, 1978). In our opinion, there are compelling evidences for the deposition of a thick volcaniclastic package, probably related to a first felsic volcanic episode, which predates the sill-sediment complex development. The upper part of the sequence is also pyroclastic and is not cut by subvolcanic sills.

Stop 1 (UTM Grid: 720.8; 4173.8)

Lowermost rocks of the VSC and their contact with the underlying PQ Group. Basic subvolcanic piles.

The PQ-VSC transition is marked here by an about 10 m horizon, made of black shales with abundant diagenetic nodules, overlain by 2 m of fine-grained felsic volcaniclastic rocks interbedded with radiolaria-bearing siliceous black shales. At its top, this sequence contacts with massive, mildly alkaline basic rocks. Wet sediment injection within the basic rocks is seen in places at the lower contact of the basic sill, which also show *in situ* fracturation at its upper contact, indicating both a subvolcanic emplacement and an interaction between basic magma and unconsolidated wet sediment. In a general way, the overlying sequence consists of a number of basic sills that exhibit lobate or peperitic contacts with their host sediments, mostly black shales. Some of the sills show columnar jointing. Emplacement conditions may be different in detail, as suggested by variation of grain size and vesiculation, as well as by some textures in host rocks, in places suggesting contact metamorphism. A thin volcaniclastic sequence outcrops close to the top of the basic pile. Among the sedimentary structures in these volcaniclastic rocks, locally interbedded with black shales, fluid escape structures and syn-sedimentary faults indicate the unstability of the sedimentary basin. The section ends close to the first outcrops of felsic subvolcanic sills, which emplaced in younger volcaniclastic rocks. The felsic sequence occurs at about 200 m over the top of the PQ. It consists of dacitic coherent and autoclastic sills, intruded in a volcaniclastic sequence with some black shale beds. The first dacitic sill shows a lower peperitic contact with host siliceous shales.

Stop 2 (UTM Grid: 721.3; 4175)
Felsic subvolcanic piles and their surroundings. The upper part of the VSC: the purple slates.

The section begins at about 200 m South of the bridge over the road Nerva-Castillo de Las Guardas, at a point of the sedimentary column approximately equivalent to the end of the Stop 1, *i.e.*, a contact between dacitic sills and red shales containing radiolaria. Here we observe peperitic contacts between dacitic sills and sedimentary (shaly) horizons. Most of these contacts are characterised by *in situ* fracturation of felsic rocks, followed by wet sediment infilling. Sediment injection at the base of some sills can be also observed.

From here to the old bridge, the section shows several dacitic porphyry bodies, locally showing poor columnar jointing. Fine-grained, host detritic horizons are scarce. The upper contact of the higher felsic sill in the pile cuts different points of a volcaniclastic series, containing coarse-grained horizons with jasper and dacitic block fragments interbedded with fine-grained volcaniclastic beds and purple siliceous shales containing radiolaria.

The above described sequence is overlain by a coarser volcaniclastic sequence, probably pyroclastic, containing several types of felsic fragments, as well as quartz and plagioclase fragments, embedded in a dark, sericitic to chloritic matrix. Overall, the morphology and structure of these fragments suggests that these rocks may be pyroclastic. Siliceous, hematite-rich purple slates, making an important correlation horizon at a regional scale, outcrop at the top of this package.

16. The Las Cruces Project

Authors: Fiona C. Knight; Juan Carlos Videira

Location: 15 km N of Seville

UTM coordinates: 755.00-759.00; 4153.00-4156.00

1/50000 sheet: 984

References:

Doyle, M. (1996): Las Cruces copper proyect, Pyrite Belt, Spain. Boletin Geologico Minero, 107, 5-6, 681-683

Knight,F.C., Boyce,A.J., Rickard, D. (1999): Multigenetic origin for the secondary enrichment in the Las Cruces VMS deposit, Iberian Pyrite Belt. Joint SGA-IAGOD meeting, London (in press).

The Las Cruces volcanogenic massive sulphide body was discovered beyond the conventional south-east limit of the Iberian Pyrite Belt in 1994 by a subsidiary company of Rio Tinto (Riomin Exploraciones SA). It is the most easterly deposit discovered in the Iberian Pyrite Belt as yet, located 15km NNW of Seville & 12.5km E of Aznalcollar. This blind deposit was discovered using gravimetry surveying, the first hole was drilled in May 1994 and an extensive drilling programme in the ensuing 5 years revealed an unusually well preserved, secondary enriched massive sulphide deposit concealed beneath a thick Tertiary cover. This not only prevented its earlier discovery but has also led to a high degree of preservation of oxide and secondary sulphide zones and an intensity of secondary re-sulphidisation that cannot be explained easily by normal weathering processes.

The main economic target is the secondary copper mineralisation with less important, but still economic, primary Cu and Zn and Au in oxidised gossans with grade and tonnages summarised in Table 5.

Table 5. Current Resources of Las Cruces

Ore	Mt	Cu%	Pb%	Zn%	Au g/t	Ag g/t
Gold-rich gossan	1,334	0.18	5.86	0.03	6.68	140
Cementation zone	15.33	6.18	0.85	0.54	--	27.4
Base-metal rich primary ore	23.5	0.8	1.9	4.3	0.4	44
Cu-rich primary ore	4,7	3.7	0.3	1.0	0.2	18

Generalised Geology

Las Cruces comprises a supergene enriched volcanogenic massive sulphide, 1200 x 800m in extent, hosted by and interbedded with a sequence of volcanic tuffs and black shales which is typical for the Iberian Pyrite Belt (Figure 19). The footwall is dominated by acid volcaniclastics, which, in the vicinity of the massive sulphide, show a well developed, pyritic stockwork with associated chloritic and sericitic alteration and a central zone of kaolinitc alteration. The pyritic stockwork contains varying proportions of base metals, a common feature in the Iberian Pyrite Belt. The massive sulphide itself is hosted by a sequence of black shales approximately 80 metres, which mirrors the thickening of the massive sulphide lens. Some volcanic material is present although this is subordinate in comparison to foot- and hangingwall sequences. The hanging wall unit is similar to that in the footwall although there are less shales present. Mineralised package is overlain by 0-15 metres of Tertiary sands and 100-150 metres of Tertiary marls which has led to the high degree of preservation of the secondary enrichment observed in the deposit today.

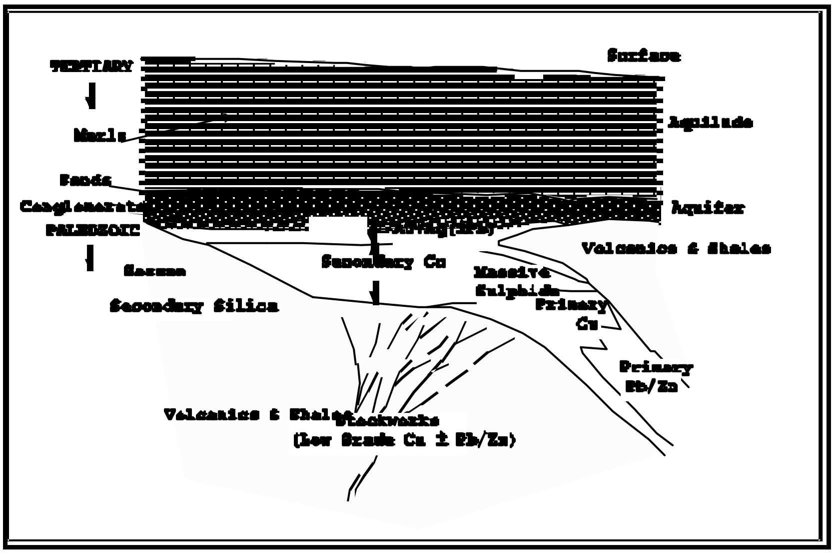


Figure 19. S-N Cross section of the Las Cruces deposit.

Known mineralisation is concentrated in the massive sulphide lens striking roughly east west over a proven distance of 1km and and is up to 100 metres thick. The primary massive sulphide unit dips to the north, at roughly 35°, to which it is still open. The angle of dip varies in the eastern, central and northern parts of the deposit. The secondary massive sulphide unit is horizontal reflecting the supergene mineralisation and the position of the palaeowater table. Whilst, mineralisation is cut out by a pre-Tertiary erosion surface to the south and limited by north-south trending fault to the west, it is still open to the north and east. To the north east, mineralisation is at approximately 400 metres depth and continues to dip to the north. Perhaps, dominant NS faulting caused strike slip displacement whereas the syn-sedimentary EW faulting affected the thickness of the deposit.

The deposit shows strong primary zoning of base and precious metals and to some extent deleterious elements such as arsenic and antimony, a feature common within deposits in the Iberian Pyrite Belt. Zoning is both lateral and vertical in relation to the disposition of the massive sulphide and its stockwork prior to tilting and folding. Where ore metals are concerned, zoning gives crude separation of mineralisation dominated by copper from that dominated by lead and zinc. Some of the main sulphides notably chalcopyrite and galena occur both in primary and secondary forms and these forms may be hard to distinguish from one another. Some of the zoning is probably related to faults.

Mineralogy

Primary Mineralisation

The primary mineralisation comprises massive, semi-massive and stockwork sulphides. This closely resembles those in numerous other deposits of the Iberian Pyrite Belt including Rio Tinto and Neves Corvo. Pyrite is almost invariably the dominant sulphide phase. Subordinate amounts of chalcopyrite, sphalerite, galena, tennantite-tetrahedrite and enargite are present. The main oxide phase is cassiterite. Gangue mineralogy is predominantly quartz, calcite, dolomite, baryte and clays with fine grained pyrite. The ore is typically fine grained with an extreme range of textural relationships. The relative proportions of minerals are controlled by primary depositional processes. Grain size morphologies of individual phases are controlled by subsequent recrystallisation processes. A Transition Zone may be present locally and is marked by the appearance of secondary copper minerals such as covellite and chalcocite.

Secondary Mineralisation

The most unusual feature in the deposit however, is the high degree of preservation of oxide and secondary sulphide zones. The mineralogy of these suggests that Las Cruces has undergone something more ferocious than normal weathering. This probably involved fluids that were distinctly hotter than normal groundwater.

Mineralogical and chemical changes occurred and the resultant mineralisation is extremely complicated. This is made up of several zones including: *in-situ* and mechanically reworked gossan, silica rich, secondary resulphidised and secondary enriched zones. These zones concentrate various combinations of base metals. Gossanisation in the upper parts of the secondary zones has concentrated precious metals in the resulting oxides. Also related to the gossanisation is intense silicification of the adjacent bedrock. This secondary silica zone appears to have been erratically enriched in gold and silver. Of far greater economic importance is the underlying secondary copper mineralisation. This is characterised by fairly flat lying, copper-rich and locally lead-rich sulphides. The enrichment of these is characterised by a range of secondary copper minerals, primarily of the chalcocite group minerals, bornites in addition to complex minerals such as sulphosalts. These sulphosalts (tennantite and tetrahedrite, as well as intermediate compositions) are a major source of Sb and As. All contain high levels of Cu, Zn and Ag but only minor Fe. In addition to the normal replacement sequences observed in copper sulphide deposits the is the presence of retrograde replacement sequences. These show chalcocite being progressively replaced by bornite, which in turn may be replaced by chalcopyrite, suggesting a late stage sulphidation event.

Mineralogical peculiarities of the deposit are particularly marked in the oxide zone. In addition to normal secondaries like goethite and anglesite, the zone contains late-stage reduction products that siderite, pyrrhotite and secondary Pb minerals. At Las Cruces, the strongest enrichment relates to chalcocite and tends to be near the top of the enriched zone, just below the former water-table. This show lesser enrichment downwards as chalcocite gives way to secondary sulphides such as covellite and bornite. however no clear cut zoning has been identified among secondary sulphides. In zonal terms, the oxide/sulphide distinction is hazy as is that between the primary and secondary sulphide zones.

Palaeoweathering and supergene effects have a crucial bearing on the quality of the Las Cruces deposit so the following points must be stressed:

•Supergene effects are very complicated and involve several stages.

•Secondary copper enrichment is uneven laterally and vertically and does not appear to cut out at any particular depth or elevation.

Paragenesis

The Las Cruces massive sulphide deposit is believed to have formed during the early Carboniferous in a volcanically active area where mineralisation took place on or close to the contemporary sea floor. The primary ores represents typical polymetallic volcanic sulphide ores that were subject to post-depositional recrystallisation and secondary grain growth. An increase in the temperature of hydrothermal fluids with time caused a change in the nature of fluids and recrystallisation.

After burial by sediments and/or volcanics, which resulted in recrystallisation leading to characteristic polycrystalline aggregates, the mineralised sequence at Las Cruces was folded and faulted. Subsequent uplift partially exposed the deposit and sub-aerial weathering at the palaeo-surface resulted in the development of a well defined mature weathering profile.

Transgression by a shallow sea occurred in the Tertiary, resulting in the burial of the deposit by a thin sand horizon overlain by marls. This resulted in significant changes in Eh-pH conditions and the secondary minerals would no longer be stable and significant changes would have occurred. Late Tertiary uplift produced the present situation of mineralisation extending down from the old erosion surface unconformably overlain by the Tertiary sediments. It appears that these sediments were crucial to the preservation of the complicated supergene mineralisation identified at Las Cruces. This is by no means a complete model as many other processes may have occurred during the history of the deposit.

Other selected outcrops in the Iberian Pyrite Belt.

Torerera Mine

Location: East of Sotiel Coronada town, in the road betwen Valverde and Calañas. A paved road, 9 km long, goes to the mine.
1/50000 sheet: 959
UTM coordinates: 686.00; 4163.45

In the road going to the mine there are some trenches that cut volcanosedimentary rocks, probably pumice-rich polymictic debris flows. They include some chloritic lenses that could be interpreted as glass shards.

Alosno Road

Location: In the road A-495 (San Bartolomé-Tharsis), p.k. 20, 5.9 N of San Bartolomé
1/50000 sheet: 959
UTM coordinates: 665.08; 4151.47

In the trenches located on both sides of the road there are some outcrops of a brechoidal (tuffaceous?) acid rock that includes highly heterometric fragments of devitrified rhyolites, sometimes with flow banding. These rocks are interpreted as irregularly devitrified and hydrothermally altered massive acid rocks. They are thrusted above shales.

Campofrio Granite

Location: 1 km N of Campofrio, in the pk 17 pf the road A-479 (Campofrio-Aracena).
1/50000 sheet: 938
UTM coordinates: 714.29; 4182.96

The Campofrio granite is the major plutonic rock in the IPB and the exact relationships with the volcanism are unknown. Here outcrops an unoriented, middle to fine grained plutonic rock with a mafic component (diorite) intruded by more acid rocks (tonalite-granodiorite).

Zalamea la Real

Location: 0.5 km SW of Zalamea in the Zalamea-Calañas road.
1/50000 sheet: 938
UTM coordinates: 706.35; 4172.60

Mafic extrusive rocks with pillow lavas can be observed in some small outcrops in the left (S) side of the road

Los Gatos Quarry

Location: N of the Filon Norte open pit in the Tharsis mine. It can be entered through a dirty road starting in the open pit.
1/50000 sheet: 959
UTM coordinates: 668.30; 4163.20

This quarry exploted massive dacites located above the key level of purple shales. Different autoclastic features can be observed.

Geologic model: Massive sulphides Iberian Pyrite Belt

F.Tornos, March, 1999

Target

1690 Mt total OOIP with 15.1 Mt Cu, 13 Mt Pb, 34.5 Mt Zn, 46000 t Ag , 47 t Au

Major grades and tonnages: >100 Mt; 6%Cu; 20.7%Zn; 8.8%Pb; 500 g/t Ag; 9 g/t Au

Median deposit: 3.4 Mt; 0.85%Cu; 1.13%Zn; 0.53%Pb; 38.5 g/t Ag; 0.8 g/t Au

Average deposit: 30.1 Mt; 0.85%Cu; 2.1%Zn; 0.79%Pb; 77 g/t Ag; 1.7 g/t Au

44 orebodies >1 Mt OOIP

Eight giant deposits: Aznalcollar-Los Frailes, Rio Tinto, La Zarza, Masa Valverde, Sotiel-Migollas, Tharsis, Aljustrel and Neves Corvo

Mining facts

High pyrite content

Cu,Co,Au,Bi enriched in stringer zones

Cu,Zn,Pb,pyrite in massive sulphides

Au,Ag in gossans

Regional geology

Transpresional basins in the subducted plate of oblique collisional orogens.

Highly compartimented sedimentary basin

Three major units:

PQ Group (Upper Devonian): shales & quartzites epicontinental platform

VS Complex(Upper Devonian- Upper Visean): Bimodal submarine igneous activity: calc-alkaline andesites to rhyolites. Alkaline to tholeitic basalts. Scarce intermediate igneous rocks. Lava flows and subvolcanic mafic dykes. Acid rocks as domes and sills. Minor (?) Pyroclastic rocks. Abundant siliciclastic sediments (shales, arenites, greywackes). Minor carbonates. Locally abundant mass flows. Minor synvolcanic granites. Abundant cherts, jaspers and Mn-mineralizations. Unique mark level of purple shales (above major volcanism)

Flysch Group (Late Visean-Westphalian): Synorogenic turbidites

Thin skinned orogen. Regional structure (Variscan) dominated by southward verging thrusts and folds

Very low to low metamorphic grade (increases to N)

Local geology

Two types massive sulphides

a) spatially related with felsic igneous rocks

b) in black shales near the PQ-VSC boundary

Not a clearly defined ore-bearing horizon

Most have black shales in the immediate hanging wall

Local grey chert cap

Ms in the northern band more deformed that in the southern band

Many ms are adjacent to major thrusts (inversion of synsedimentary extensional faults?)

Very restricted time span (. 355 Ma).

Hydrothermal alteration

Pervasive spilitization of igneous rocks (very variable AI)

Most of the massive sulphides have underlying alteration zone

Igneous hosted systems : Cone shaped alteration. Inner chlorite-rich (+Q +ser +sulphides ±pyrophyllite) alteration with a sericitic halo (Ba-rich ser+chl+Q+sulphides) and external weak alteration (quartz , Na-bearing white micas and quartz-sericite-chlorite veins)

Shale-hosted systems : Unique chlorite-rich zone in irregular to stratabound morphology.

Very subtle hanging wall alteration, if any

Morphology and structure of the mineralisation

Massive sulphides as lenses, blankets and irregular orebodies that can be tectonically stacked. Stockworks irregular to pipe-like.

Pyrite-rich massive sulphides with irregular Zn-Pb-Cu enrichments

Local base metal upgrade on deformation bands

No significative primary zoning.

Types of ore: massive pyrite, complex ore (base metal-rich), carbonate ore (siderite-rich), silica-ore (quartz-rich) and 'azufrón' (semimassive sulphides in quartz or shale gangue)

Mineralogy and textures

Pyrite-rich orebodies. Fine grained in the southern belt and middle to coarse grained in N belt.

Dominant pyrite with accessory sphalerite, chalcopyrite and galena. Many other trace minerals including tetrahedrite, cassiterite, stannite.

Some deposits are magnetite or pyrrhotite-rich

Stockworks enriched in As-Co minerals and sometimes Au and Bi-Pb sulphosalts

Quartz,siderite,phengite,chlorite major gangue minerals

Sulphates (barite) only present in some deposits (accessory)

Supergene alteration

Well developed gossan with sharp contacts.

Increase in gold and silver contents, more pronounced near the footwall

Cementation zone enriched in Cu (mined out except in deep deposits)

Transported gossans are barren

Geophysical exploration

Gravimetry: generalised methodology (basic rocks?)

Resistivity: good response (black shales?)

IP good for disseminated ores (stockworks and disseminations) (black shales?)

Electromagnetic: Good for Cu-rich orebodies. Not useful in Zn-rich ones (black shales?)

Magnetic methods usable only in minor mt or po-rich orebodies. Useful searching VSC below detritic rocks.

Combination of resistivity + gravimetry

Geochemical exploration

High (pre-)historical contamination invalidates stream and soil geochemistry

Gas geochemistry (?) (Hg, CO_2, He)

Lithogeochemistry in the equivalent horizons

Lead isotopes in gossan

C-S and o.m. in shales

Ore geochemistry

ä^{34}S between -4 and 10‰ in the stockworks and -34 to 15‰ in the massive sulphides. Two sources of sulphur: leached from the underlying rocks (or magmatic?) and acquired in situ due to bacteriogenic reduction of seawater sulphate. Barite signatures close to seawater (15-24‰)

ä^{18}O and äD (0-6‰ and -15 to +10‰, respectively) data suggest major involvement of seawater in hydrothermal systems.

ä^{13}C (-14 to -8‰) suggest carbon derived from oxidation of organic matter, seawater with a minor(?) igneous contribution.

Pb (μ=9.8), Os (^{187}Os/^{186}Os=0.69) and Sr (^{87}Sr/^{86}Sr=0.7073- 0.7202) isotopes suggest a radiogenic crustal source for the metals.

Temperatures calculated from the stockworks near 200-350°C. In the massive sulphides from 70 to 350°C.

Deep fluids were acid (+ser) to near neutral (+chl+carb), reducing fluids, probably H_2S-poor and metal-rich.

Fluid inclusions (primary?) suggest deep saline (H_2O-NaCl; 0-12 wt%) aqueous fluids (basinal brines or interchanged seawater) with lateral and local recharge of unmodified seawater. Local boiling.

Genetic models

Hydrothermal systems heated by synchronous deep intrusions or equivalent igneous rocks

Metals interpreted as leached from the basement (PQ Group) and/or cogenetic volcanic rocks.

Metal precipitation by fluid/rock interaction (stockwork and replacive ores), cooling and *in situ* increase in the m S (exhalative ores).

Not equivalent present day systems

Shallow? hydrothermal systems

Two main genetic mechanisms:

a) Synvolcanic replacement (mostly on igneous rocks)

b) Exhalation in the seafloor (anoxic brine pools; above igneous rocks and in black shales).

General references

Barriga, F.J.A.S. (1990): Metallogenesis in the Iberian Pyrite Belt. In 'Pre-Mesozoic Geology of Iberia', Dallmeyer,R.D., Martinez Garcia,E. (eds.), Springer Verlag, pp.369-379

Boulter,C.A. (1993): Comparison of Rio Tinto, Spain, and Guaymas Basin, Gulf of California: an explanation of a supergiant massive sulfide deposit in an ancient sill-sediment complex. Geology, 21, 801-804

Carvalho,D., Barriga,F., Munhá,J. (1997): The Iberian Pyrite Belt of Portugal and Spain: Examples of bimodal-siliciclastic systems. In Volcanic associated massive sulfide deposits: Processes and examples in modern and ancient settings, Barrie,C.T., Hannington,M.D. (eds.). Rev. Economic Geol., 8, 375-408

IGME (1982): Síntesis Geológica de la Faja Pirítica del SO de España IGME, Madrid, 106 pp

Leistel,J.M., Marcoux,E., Thieblemont,D., Quesada,C., Sánchez, A., Almodovar,G.R., Pascual,E., Sáez,R (1996): The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt. Review and preface to the special issue. Mineral. Deposita, 33, 1-2, 2-30

Pinedo,I. (1963): Piritas de Huelva. Su historia, minería y aprovechamiento. Summa, Madrid, 1003 pp.

Quesada, C. (1998): A reappraisal of the structure of the spanish segment of the Spanish segment of the Iberian Pyrite Belt. Mineralium Deposita, 33, 1-2, 31-44

Relvas, J.M.R.S., Massano,C.M.R., Barriga, F.J.A.S. (1990): Ore zone hydrothermal alteration around the Gaviäo orebodies: implications for exploration in the Iberian Pyrite Belt. Abstracts, VIII Semana de Geoquimica, Lisboa

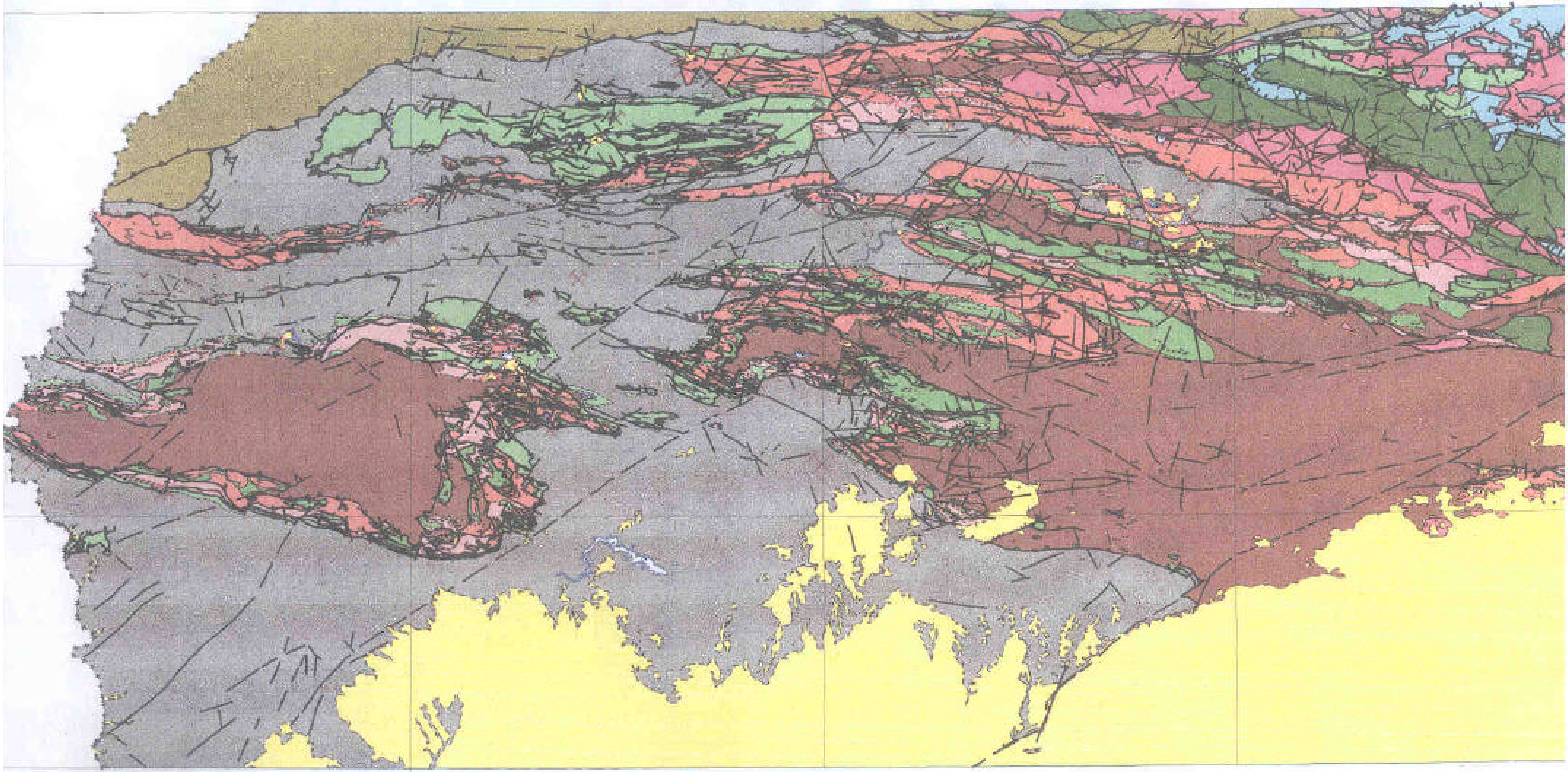
Routhier,P., Aye,F., Boyer,C., Lecolle,M., Moliere,P., Picot,P., Roger,G.(1980): Le ceinture sud-iberique a amas sulfures dans sa partie espagnole mediane. Mem. BRGM, 94, 265 pp.

Sáez,R., Almodovar,G.R., Pascual,E. (1996): Geological constraints on massive sulphide genesis in the Iberian Pyrite Belt. Ore Geology Reviews, 11, 429-451.

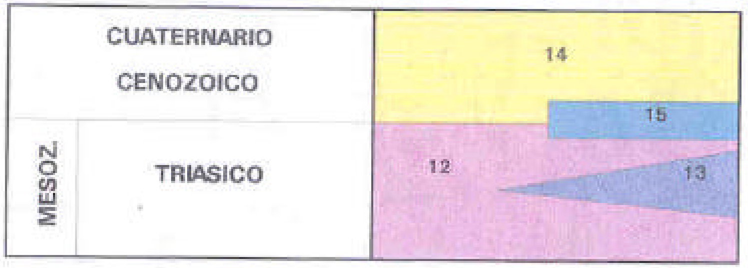
Strauss,G.K., Beck,J.S. (1990): Gold mineralisations in the SW Iberian Pyrite Belt. Miner. Deposita, 25, pp.237-245

Tornos,F., Spiro,B. (1999): The genesis of shale-hosted massive sulphide deposits in the Iberian Pyrite Belt. In Mineral deposits: Processes to Processing, Stanley et al., eds., Balkema, 605-608

SINTESIS GEOLÓGICA DE LA FAJA PIRITICA



COBERTERA POST-PALEOZOICA



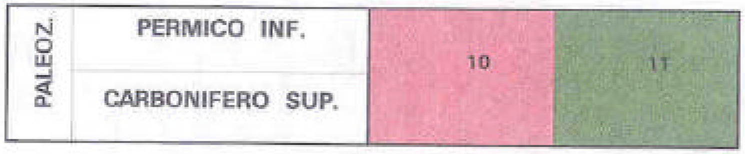
15.- Gossan

14.- Gravas, arenas y arcillas.

13.- Basaltos y doleritas

12.- Margas y arenas

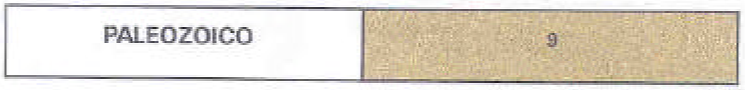
ROCAS PLUTÓNICAS Y TARDIHERCÍNICAS



11.- Gabros y dioritas

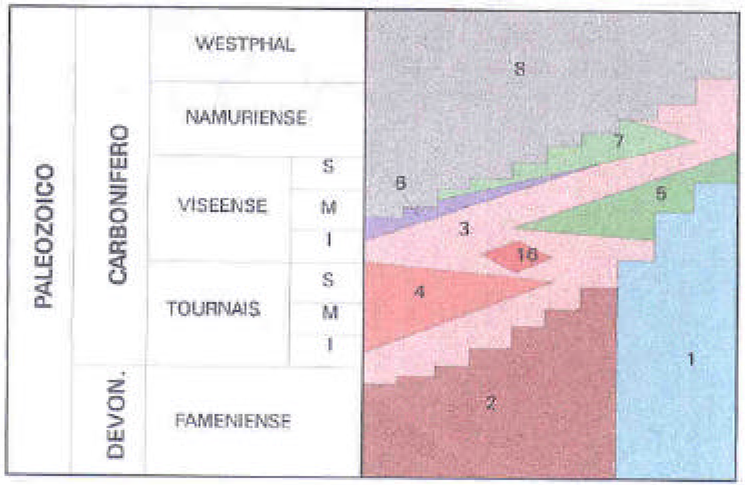
10.- Granitos y granodioritas

ZONAS PULO DO LOBO Y OSSA MORENA (Indiferenciadas)



9.- Rocas metamórficas indiferenciadas

ZONA SURPORTUGUESA (FAJA PIRÍTICA)



8.- Metagrauvacas y pizarras (Grupo Culm)

5.- Metavulcanitas básicas

7.- Metavulcanitas intermedias y ácidas

6.- Pizarras moradas y jaspes (Formación Manganesifera)

16.- Sulfuros masivos

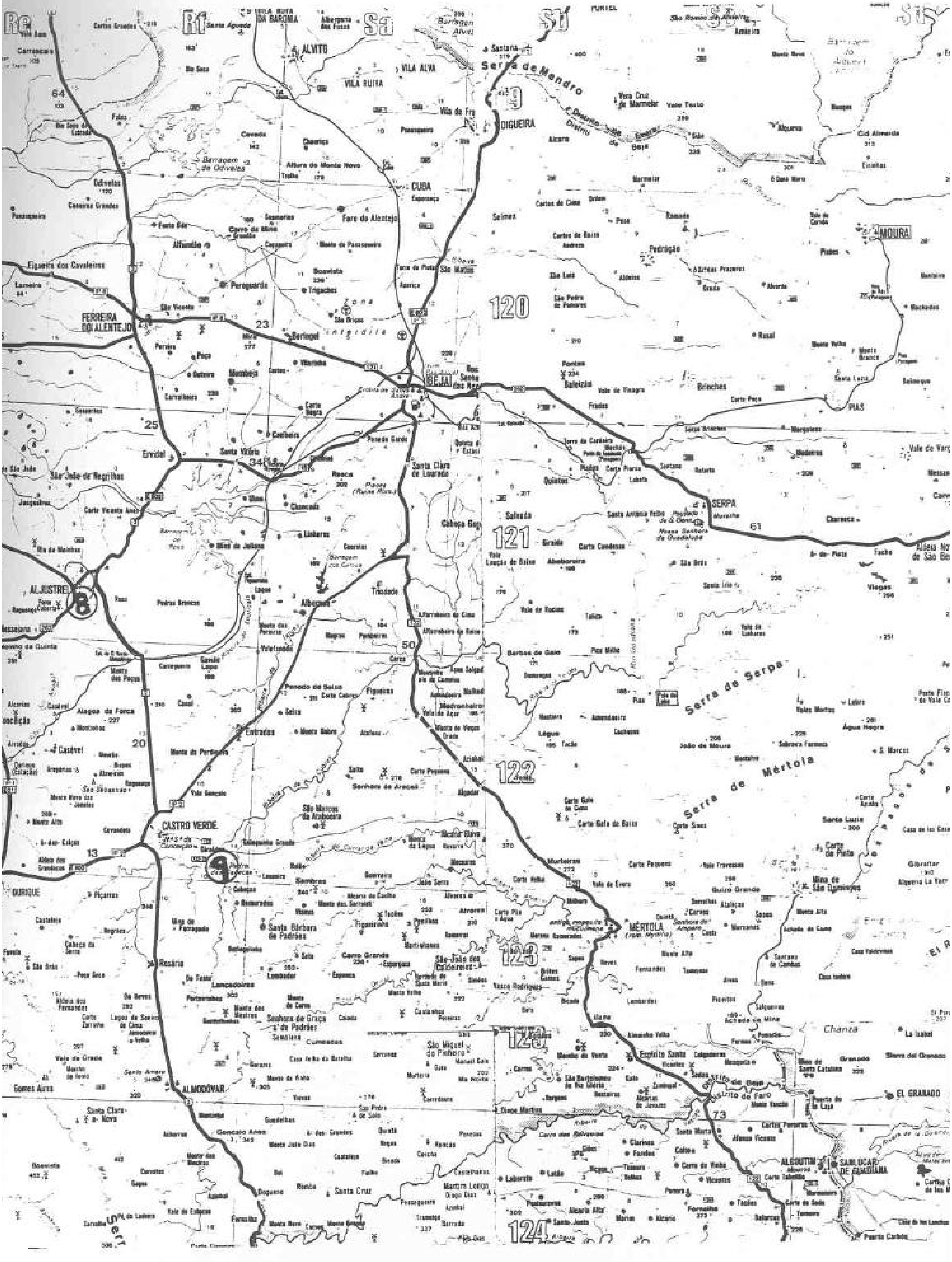
4.- Metavulcanitas ácidas

3.- Metasedimentos y epiclastitas

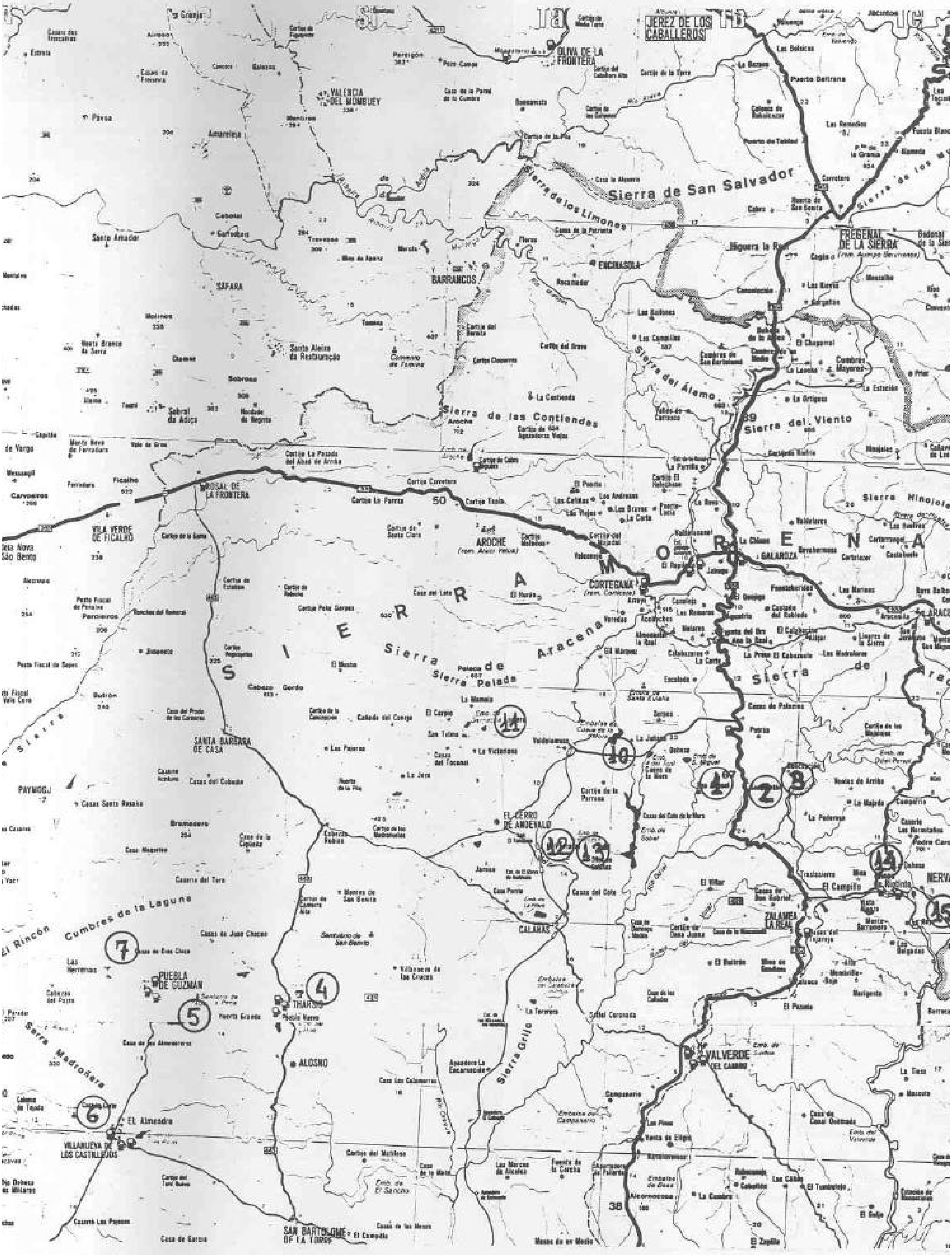
CVS (7, 6, 16, 4, 3)

2.- Pizarras, areniscas y cuarcitas (Grupo PQ)

1.- Metagrauvacas y pizarras (Bloque Oriental)



ALVITO
VILA ALVA
VILA RUIVA
Serra de Mendro
VIDIGUEIRA
Vera Cruz de Marmelar
CUBA
Faro do Alentejo
MOURA
FERREIRA DO ALENTEJO
120
BEJA
Baleizão
Brinches
PIAS
SERPA
Santa Clara de Louredo
Salvada
121
Albernoa
ALJUSTREL
Trindade
Serra de Serpa
Entradas
122
Serra de Mértola
CASTRO VERDE
MÉRTOLA
Mina de São Domingos
123
Almodôvar
Espírito Santo
EL GRANADO
ALCOUTIM
SANLÚCAR DE GUADIANA
124
Chanza


JEREZ DE LOS CABALLEROS
OLIVA DE LA FRONTERA
VALENCIA DEL MOMBUEY
Sierra de San Salvador
Sierra de los Limones
FREGENAL DE LA SIERRA
Higuera la Real
ENCINASOLA
BARRANCOS
SAFARA
Santo Aleixo da Restauração
Sobral da Adiça
Sierra del Álamo
Sierra de las Contiendas
Sierra del Viento
ROSAL DE LA FRONTERA
VILA VERDE DE FICALHO
AROCHE
CORTEGANA
GALAROZA
SIERRA MORENA
Sierra de Aracena
Sierra Pelada
SANTA BARBARA DE CASA
PAYMOGO
EL CERRO DE ANDEVALO
CALAÑAS
ZALAMEA LA REAL
NERVA
Cumbres de la Laguna
El Rincón
PUEBLA DE GUZMAN
THARSIS
ALOSNO
Sierra Madroñera
El Almendro
VILLANUEVA DE LOS CASTILLEJOS
SAN BARTOLOME DE LA TORRE
Sierra Grilla
VALVERDE DEL CAMINO
Cumbres Mayores
Cumbres de San Bartolomé
Sierra Hinojales
ARACENA
Alájar
Castaño del Robledo
Almonaster la Real
Aguafría
Jabugo
Valdelarco
Fuenteheridos
Los Marines
El Campillo
Minas de Riotinto
Montes de San Benito
Santuario de San Benito
Villanueva de las Cruces
Embalse del Sancho
Embalse del Campanario
La Zarza
Puerto Gordo
Cabezo Gordo
Cañada del Corcho
Valdelamusa
Mina Concepción
Campofrío
La Granada
La Palma
El Villar
Casas de Juan Chacón
Las Herrerías
Vila Nova de São Bento
Ficalho
Carvoeiros
Montaivo
Moreanes
El Granado
Sierra
1 2 3 4 5 6 7 10 11 12 13 14 15