Caderno Lab. Xeolóxico de Laxe
Coruña. 1995. Vol. 20, pp. 253-279

A typological classification of Spanish precious metals deposits

Clasificación tipológica de los yacimientos españoles de metales nobles

CASTROVIEJO, R.

Last decade's intensive exploration for precious metals in Spain led to a new understanding of various types of deposits and prospects. A summary review of recent progress is presented, allowing the systematic *(typological)* classification of the Spanish precious metals deposits shown in *Table 1:* 19 types are defined in the framework of the Iberian Geology, their exploration significance being also considered. Hypogene deposits in the Hercynian Hesperian Massif, and epithermal gold deposits in the Neogene calc-alcaline Volcanic Province of SE Spain have been very much explored and are therefore emphasized, although their mining production is by far not to compare with the precious metals output the SWIPB (SW Iberian Pyrite Belt).

In the *Hesperian Massif,* different *metallotects* have been demonstrated to be related to attractive concentrations of gold, bound to Hercynian shear-zones, in Galicia, in Extremadura, etc.; other concentrations (e. g., in Galicia and Asturias) are related to granite or porphyry intrusions (Salave) and skarn formations (Carlés). PGE or Platinum elements (± chromite) have been found in ophiolitic thrust complexes occurring in N Galicia, e. g. the Herbeira Massif of the Cabo Ortegal Complex, as had been in the 1940's in Northern Portugal (Bragança and Morais complexes). Exploration for silver has demonstrated a small orebody in Fuenteheridos (Aracena, SW Spain), not minable under severe environmental constraints, but none of the classic Spanish silver producing districs (vein-Type deposits, e. g. Guadalcanal or Hiendelaencina) has recovered activity.

Most of the EU (European Union) gold and silver production is won from only two types of deposits in the Spanish Hesperian Massif: the masive sulphides of the SWIPB, in which precious metals are won as by-products, and the related gossan deposits.

In the *Alpine domains,* the SE Spanish volcanic region (Almería-Murcia), has for centuries been worked for Pb-Ag-Zn-(Cu) and for Sn (Fe) and is presently well know for its epithermal gold and silver mineralizations (e. g. Rodalquilar and Transacción mines, Almería), but its full potential has yet to be realized. Recent work has shown epithermal precious metal-bearing bodies to occur in an area spreading over one hundred Km. northwards from those mines, and demonstrated the feasibility of their detection by remote sensing. Sediment-hosted epithermal deposits have not yet been found in the region, but are not to be excluded. An attractive, possibly economic, base metal and silver prospect is under investigation near Mazarrón (Murcia). In another context, the ultramafic massifs of the Serranía de Ronda (Málaga) are know as PGE metallotects, in which a new type of PGE mineralization has been recently defined. On the other hand, exploration for gold in the Hercynian Basement of Alpine domains has also shown interesting prospects to occur, as in the pyreneean Vall de Ribes district.
Finally, the formerly very important *detrital* (paleo-placer and placer) gold concentrations of *Neogene to Quaternary age,* occurring mainly in NW Spain although explored by various companies, did not lead to any mining activity yet. The overall picture of these years of research is an increased knowledge of the Spanish precious metals ore geology, the full reconnaissance and higher mining production of the gossan bodies of the SWIPB and the development of several prospects (Carlés-Salas, Salave, Fuenteheridos, Mazarrón, etc.) and of a gold mine (Transacción, Almería, of ephemeral activity). On the other hand, some questions have arisen which define interesting goals for future research, as the precise models of the different types of shear-zone orebodies, the evolution at depth of the Au-Ag orebodies in the known epithermal districts (e. g. Cabo de Gata, Almería), and the regional extent and exploration of these orebodies (partly, under metamorphic and sedimentary Hercynian formations) in the SE Spain Neogene volcanic province, as well as the possible existence of disseminated, sediment-hosted Carlin-Type ore bodies.

Key words: Gold, Silver, Platinum Group Metals, Typology, Metallogeny, Hercynian, Alpine, Spain, Exploration Geology.

CASTROVIEJO, R. (Dpto. Ingeniería Geológica. E. T. S. Ing. de Minas, Universidad Politécnica de Madrid. c/ Ríos Rosas, 21, 28003-Madrid)

Cuadro 1

CLASIFICACION TIPOLOGICA DE YACIMIENTOS ESPAÑOLES DE METALES NOBLES (*)			
Tipo	**Metal**	**Caracterización**	**Ejemplo**
CONCENTRACIONES MGP EN COMPLEJOS MAFICOS / ULTRAMAFICOS			
1	MGP	En el Macizo Hespérico: t. Ofiolítico	C. Ortegal
2	MGP	En dominios Alpinos: asoc. Cr-Ni (PGE-Au)	S. Ronda
CONCENTRACIONES MGP EN SEDIMENTOS Y SUELOS			
3	MGP	Detríticas / residuales, de tipos 1/2	íd. 1, 2
CONCENTRACIONES DE Ag o Pb-Zn-Ag(**) EN TERRENOS HERCINICOS			
4	Ag	Filones argentíferos en rocas metamórficas Hercínicas	Guadalcanal
5	Ag	Menas Ag en formaciones volcano-sedimentarias y carbonatadas	Aracena, Huelva
6	Ag	Filones hidrotermales Pb-Zn-(Ag)	Linares
CONCENT^{RS}. Pb,Zn/Ag EN PROV. VOLCANICA NEOGENA DEL SE ESPAÑOL			
7	Ag	En relación con intrusiones someras Neógenas en rocas pre-Terc.	La Unión
8	Ag	Concentr. epitermales relac. volcanitas Neógenas calco-alcalinas	Cabo de Gata
CONCENT^{RS}. VOLCANO-SEDIMENTARIAS EN EL MACIZO HESPERICO (***)			
9	Au	Diseminaciones Au en sulfuros masivos	Huelva
CONCENT^{RS}. HIPOGENICAS Au EN TERRENOS METAMORFICOS HERCINICOS			
10	Au	Filonianas, en zona de cizalla	Fervenza
11	Au	Hidrotermales, relac. con granitoides	Salave
12	Au	Mixtas (z.cizalla en granitoides)	Corcoesto
13	Au	En formaciones de skarn con sulfuros	Carlés
14	Au	Filones Sb(As)-Au y otros	Extremadura, León
CONCENT^{RS}. Au EN PROVINCIA VOLCANICA NEOGENA DEL SE ESPAÑOL			
15	Au	Encajante volcánico, tipo ácido-sulfatado (*high-sulfidation*)	Rodalquilar
16	Au	Encajante volcánico, tipo adularia-sericita (*low-sulfidation*)	Cabo de Gata
17	Au	Encajante no volcánico	Lomo de Bas
CONCENT^{RS}. Au EN SEDIMENTOS DETRITICOS NEOGENOS Y RECIENTES			
18	Au	Paleoplaceres, en especial Neógenos, y placeres auríferos	NO Peninsular
DEPOSITOS DE METALES PRECIOSOS EN FORMACIONES DE GOSSAN			
19	Au	Concentr. superg. Au-Ag en gossan de sulfuros masivos (*tipo 9*)	Huelva

(*) Au, Ag y MGP o *platínidos* (metales del grupo del platino).
(**) En los tipos 6 y 7 la plata sólo se ha beneficiado como sub-producto.
(***) En el tipo 9, oro y plata se benefician como sub-productos.

INTRODUCTION

This contribution aims at summarizing recent progress in the Spanish precious metals geology, after a decade of active exploration. Emphasis is laid on the interpretation and systematic classification of deposits, exploration achievements being discussed by CASTROVIEJO (1994) in another paper. This work is based on the own experience of the author and on published data or personal communications. The irregularity or scarcity of published data —exploration companies not always wanting their information to be published— is a major limitation, since confidential data are not going to be discussed.

Gold has been the most explored (and is still the most important) precious metal in Spain, a country that is the first gold producer of the European Union (EU): its annual metal output in the last years is around 7 t, which accounts for about 60 % of the total EU mining production, while the 270 t of silver produced in 1990 account for over 63 % of the total EU mining output of 426.5 t (ITGE, 1990; the most recent evolution of the SWIPB mining activity points to a declining production at present). Most of the Spanish gold and silver production is won from the oxidized outcrops of massive sulphide orebodies in the SW Iberian Pyrite Belt (Huelva and Sevilla provinces), and as byproducts from these sulphides. Platinum Group Metals (PGE) have never reached the level of mining production in the Iberian Peninsula.

PROPOSAL OF A TYPOLOGICAL CLASSIFICATION

Previous schemes and discussion of classification criteria

The present classification considers each precious metal by itself, being gold the central subject, not only because of its mining significance, but also because many of the criteria used for gold are also valid for silver —whose Spanish mining production is mostly associated with gold— and because the relatively scarce PGE prospects in Spain can be easily classified into just a few types.

Earlier typologies, both of them for gold, are included in the compilations by J. Burkhalter (IGME, 1984) and by CRESPO (1988). The one used by the first author, following that of BACHE (1980), has the evident limitations recognized by the author himself[1], which are mainly due to the scarcity of previous work on Spanish precious metals deposits, rendering systematic comparisons difficult. Nevertheless he has grouped and compared similar Spanish deposits —in the sequence shown in Table 1—, and his work has not lost its unquestionable value as the most qualified inventory providing general information on Spanish gold deposits and prospects. The more recent proposal by CRESPO (1988) establishes seven types (Table 2) but does not include much geological information known or published later, making a more updated classification advisable[2].

The present work does not aim at such a comprehensive compilation as that of J. Burkhalter; instead, only those deposits or prospects have been included that are considered to be significant or typical because of their geologic/mining features. Insignificant or geologically unknown occur-

TABLE 1

MAIN TYPES/DISTRICTS OF SPANISH GOLD DEPOSITS

AFTER J. BURHKHALTER (IGME, 1984)

1.- Primary deposits of the Asturian Arc (ASTURIAS-LEON)
2.- CABO DE GATA-RODALQUILAR (ALMERIA)
3.- Precambrian Alcudian Domain (VALLE DE ALCUDIA)
4.- Pyrite Belt (HUELVA-SEVILLA)
5.- LA NAVA DE RICOMALILLO (TOLEDO) Y SAN PABLO-MOLINILLO (CIUDAD REAL)
6.- LA NAVA DE JADRAQUE (GUADALAJARA)
7.- Galician deposits (LA CORUÑA - ORENSE)
8.- Detrital formations (in NW SPAIN and in SIERRA NEVADA)
9.- Area of LAS HURDES (CACERES - BADAJOZ)
10- Gold-antimony Belt (CACERES - BADAJOZ)
11- Eastern Pyrenees (GERONA)

....

TABLE 2

TYPOLOGY OF SPANISH GOLD DEPOSITS

AFTER V. CRESPO (1988)

1. DISSEMINATION IN HIGH-GRADE METAMORPHIC ROCKS: Nava de Jadraque.
2. DISSEMINATION OR QUARTZ-VEINLETS IN LOW TO MEDIUM-GRADE METAMORPHIC ROCKS: Valle de Alcudia, etc.
3. ASSOCIATED TO COMPLEX SULPHIDES: Pyrite Belt.
4. HERCYNIAN DEPOSITS (several subtypes: disseminated in granites; in quartz veins, etc.).
5. ASSOCIATED TO TRIASSIC Cu RED-BED TYPE DETRITAL ROCKS: Santonera.
6. VOLCANISM WITH FREE GOLD AND TELLURIDES: Rodalquilar.
7. PLACERS: Las Médulas, etc.

TABLE 3

A TYPOLOGICAL CLASSIFICATION OF SPANISH PRECIOUS METALS DEPOSITS (*)

Type	Metal	Characterizacion	Example
PGE CONCENTRATIONS IN MAFIC / ULTRAMAFIC COMPLEXES			
1	PGE	In Hesperian Massif: Ophiolitic t.	C. Ortegal
2	PGE	In Alpine domains: Cr-Ni ores, with PGE/Au	S. Ronda
PGE CONCENTRATIONS IN SEDIMENTOS AND SOILS			
3	PGE	Detrital / residual, from types 1 & 2	íd. 1, 2
Ag/bmAg (=BASE METAL-Ag)(**) DEPOSITS IN HERCYNIAN TERRAINS			
4	Ag	Vein-type Ag deposits in Hercynian metamorphic terrains	Guadalcanal
5	Ag	Ag ores in volcanic-sedimentary and carbonate formations	Aracena, Huelva
6	Ag	Vein-type Pb-Zn-(Ag) deposits	Linares
Ag/bmAg DEPOSITS IN THE NEOGENE VOLCANIC PROV. OF SE. SPAIN			
7	Ag	Volcanic-related bmAg mineralizations in pre-Tertiary rocks	La Unión
8	Ag	Volcanic-hosted Ag mineralizations of epithermal type	Cabo de Gata
Au-BEARING VOLCANIC-SED. DEPOSITS IN THE HESPERIAN MASSIF(***)			
9	Au	Gold disseminations in massive sulfide deposits	Huelva
GOLD MINERALIZATIONS IN HERCYNIAN METAMORPHIC TERRAINS			
10	Au	Vein-type, shear-zone hosted	Fervenza
11	Au	Hydrothermal, granitoid related	Salave
12	Au	Mixed shear-zone granitoid hosted	Corcoesto
13	Au	Skarn gold ores, with sulfides	Carlés
14	Au	Sb(As)-Au veins and other types	Extremadura, León
Au MINERALIZATIONS IN THE NEOGENE VOLCANIC PROV. OF SE SPAIN			
15	Au	Volc.-hosted, high-sulfidation (or *acid-sulfate*) epithermal type	Rodalquilar
16	Au	Volc-hosted, low-sulfidation (*adularia-sericite*) epithermal type	Cabo de Gata
17	Au	Not volcanic-hosted mineralizations	Lomo de Bas
GOLD CONCENTRARIONS IN NEOGENE & RECENT DETRITAL SEDIMENTS			
18	Au	Gold-bearing palaeoplacers, mainly Neogene, and placers	NW Spain
PRECIOUS METALS CONCENTRATIONS IN GOSSAN FORMATIONS			
19	Au	Supergene Au-Ag ores in gossan from massive sulfides (type 9)	Rio Tinto, Huelva

(*) Au, Ag & PGE or Platinum Group Elements.
(**) In base metal-Ag (bmAg) deposits of *types 6 & 7*, Ag has been only won as a by-product.
(***) In *type 9* gold is won as a by-product, the same as silver.

rences are rather excluded than classified in a wrong place. This choice, intended to avoid mistakes or inconsistencies, should by no means neglect or deny the possible value of those poorly known occurrences that might well be worth some research: a special group (Type 14 in the classification) includes some of them. So this classification can be considered as an open one, in which further groups could be established if necessary—this might happen with some deposits of the type just mentioned, should further research prove them to be different—, but an effort has been made in order to keep it as simple and logic as possible; the preliminary proposal by CASTROVIEJO (1993) has been revised to approach this principle, resulting in the typological classification of Table 3, which is now presented[3].

Since criteria used for the classification of mineral deposits are often controversial, a typological scheme based on broad and well established geological data, has been chosen as the most useful for exploration, and, given its descriptive character, also as the best to keep controversies in a sound frame. Deposits have been first grouped after their geological enviroment, and then characterized into types, each defined by a set of general features.

These features should be observational, unbiased by personal interpretations. In some cases, however, their use can be contested. For instance, it could be argued that the gossan Au-Ag deposits of type 19, which are surficial bodies produced by supergene enrichment of massive sulfide deposits with weaker precious metals dissemination (tipe 9), need not be classified separately from these. Nevertheless, several reasons speak in favour of such a distinction: even if they occur tightly related, their genesis occurs unquestionably at a quite different environment and time, their geometry has different constraints, exploration strategies and techniques differ accordingly, as also do their mining, ore-processing and metallurgy; last but not least, the gossan bodies are true *precious metals deposits,* which the massive sulfide orebodies are not (up to now, Au and Ag are won from them only as by-products), and the former will be exhausted in some years, while nobody has yet predicted the exhaustion of the SW Iberian Pyrite bodies. Some broad genetic criteria can therefore be useful for the classification. They are accepted, only if they are easily observable, clearly defined and unquestionably based on facts. However, arguable unnecessary distinctions are to be avoided: so in the Fuenteheridos silver deposit, consisting of small sulfide and gossan bodies, both these are grouped together in type 5, since their distinction would have hardly any practical value.

In order to avoid repetitions, deposits or prospects with more than one precious metal are classified after the main one (the other being considered as by-product), and consequently described only in the paragraph corresponding to that metal: so gossan «silver deposits» are to be found under gold (type 19), the same as «silver-bearing» massive sulfide deposits (type 9).

Finally, base metal deposits having precious metals only as by-products are out of the scope of this paper, but have nevertheless been included in the classification (Table 3), unless their contribution is insignificant. Should this not be the case, such important deposits as the massive sulphide bodies of the SW Iberian Pyrite Belt (see reserves, Table 4), would have deserved no mention.

A SUMMARY DESCRIPTION OF DEPOSIT TYPES AND THEIR EXPLORATION / MINING SIGNIFICANCE

The typological classification of *Table 3* and the following comments attempt to summarize present knowledge of the Spanish precious metals geology. The occurrences mentioned can be located and referred to their geological background in figs. 1 (general), 2 (Neogene calc-alkaline volcanic province of SE Spain), and 3 (NW Sector of the Hesperian Massif), while some basic data on assumed ore reserves and grades, earlier compiled by CASTROVIEJO (1994), can be found in Table 4 and may be useful to compare the mining importance of deposits. There are many occurrences whose individual description is not neccessary for the definition of types and would exceed the purpose of this paper. Instead, a typical occurrence has been chosen and will be described as representative for each type.

PGE DEPOSITS

Platinum Group Elements (PGE) are known to occur as concentrations in mafic / ultramafic rock bodies, which in Spain occur mainly in the NW sector of the Hesperian Massif (Galicia) and in the Alpine Domain of Southern Spain (Málaga). Some findings of PGE are known in both areas, which belong to different specific types:

1) In the Hesperian Massif: the ophiolitic, polymetamorphic type, exemplified by the Cabo Ortegal, Coruña (fig. 1 and 3), occurrences, e. g. the Herbeira Massif, showing contents of up to 6 ppm Pt+Pd (Monterrubio, 1991); similar occurrences are known in Portugal (Bragança and Morais complexes, COTELO NEIVA, 1949), or in Galicia (MONTERRUBIO *et al.,* 1992).

2) In alpine domains: the Cr-Ni-ores of the Málaga ultramafic complexes (Ronda, Ojén, and Carratraca, *fig. 1,* possible subcontinental mantle slabs). This was the first type to draw attention to Spain's Pt potential —e. g. ORUETA, 1919, Serranía de Ronda—, and the only one in which Ni ores have been mined and, more recently, explored. After the pioneer works of D. Orueta, exploration for PGE has been rather scarce (ITGE-JA, 1986-87), but several contributions have been recently published which help greatly understand the genesis and distribution of PGE.

There types of ores (Cr or chromite, Cr-Ni or chromite-Ni arsenide, and S-G or Ni-Fe-Cu sulphide-graphite ores) have been recognized. The second of them (Cr-Ni ores) shows the most attractive PGE potential (and also Au values up to 35 ppm), corresponding to a new type of mineralization occurring in the Rifo-Betic alpine belt, apparently unique in the world (LEBLANC and JOHAN, 1986; GERVILLA and LEBLANC, 1990). Nevertheless, traces of PGM have also been found as rare inclusions in chromite from the Cr-ores (TORRES-RUÍZ *et al.*, 1993).

PGE occurrences of type 3 are found as scarce detrital concentrations in stream sediments and soils related with the above formations (ORUETA, 1919, in S. Ronda; SHASHKIN, 1992, in Cabo Ortegal: results from the E. N. Adaro exploration campaign).

Some other PGE occurrences are known in other areas (e. g. Cantabrian Zone: PANIAGUA, 1994; Catalonian Costal Chains: MELGAREJO, 1992) whose main interest seems to be mineralogical and are therefore not characterized as prospects,

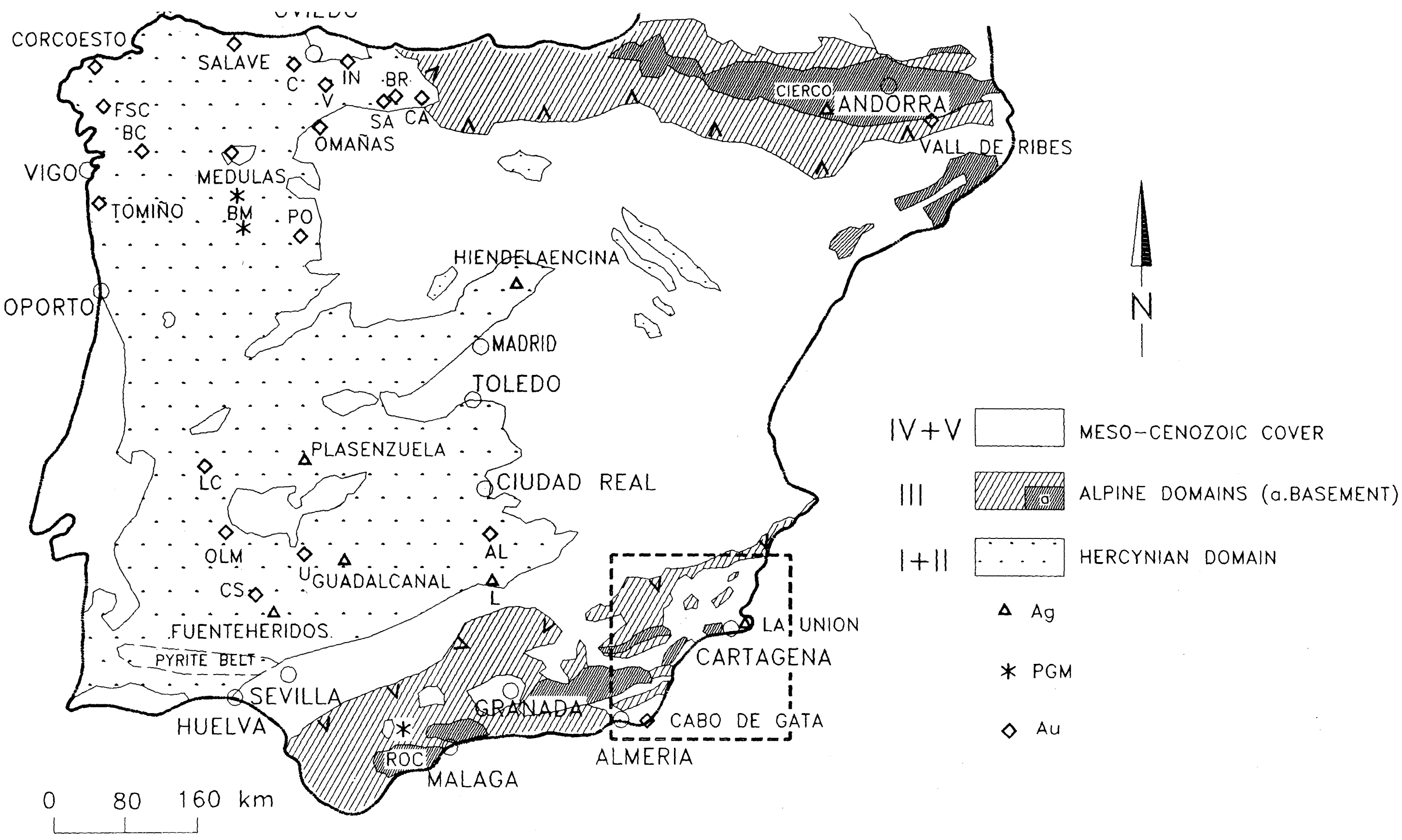

Fig. 1. Geological sketch map of the Iberian Peninsula (Castroviejo, 1994). The Hercynian Domain comprises Precambrian and Paleozoic terrains (Hesperian Massif). The Alpine Domains are composed of Meso-cenozoic terrains, and a Hercynian Basement. The Cover comprises pre- & syn-Alpine Meso-Cenozoic Terrains and post-Alpine Tertiary basins. (Inset: Area enlarged in fig. 2). Abbreviations for localities and prospects / deposits cited: AL: Almuradiel *(type 14)*; BC: Brués-Carballiño districts *(t. 11)*; BM: Bragança and Morais complexes *(t. 1)*; BR: Burón-Riaño *(t. 14)*; C: Carlés *(t. 11)*; CA: Carracedo *(t. 13)*; CS: Cala *(t. 13)* and Sultana *(t. 11)* Mines; FSC: Fervenza - Santa Comba *(t. 10,12)*; IN: Infiesto *(t. 13)*; *L: Linares - La Carolina, Sierra Morena (t. 6)*; LC: La Codosera *(t. 10)*; OLM: Olivenza Monesterio Anticlinorium *(t. 10)*; PO: Pino del Oro *(t. 10)*: ROC: Ronda, Ojén, Carratraca *(t. 2)*; SA: Salamón *(t. 14)*; U: Usagre *(t. 14)*; V. Villamanín *(t. 14)*.

TABLE 4

ESTIMATION OF RESERVES AND GRADES OF DEPOSIT TYPES(*)			
Type	*Occurence*	*Reserves*(1)	*Grade*(2)
5	Fuenteheridos	2	4 %(Pb+Zn)
		3	77 Ag
19	Río Tinto (Huelva)	37	47 Ag
			0.9 Au
	Tharsis (F.Sur,Lapilla)	5	2 Au
10/12	Mean orebody(3)	0.03	3 Au
11	Salave (Asturias)	16.5	2.5 Au
13	Carlés (Asturias)	5	5/6 Au
	Cala (Badajoz) (4)	10	0.07 Au
9	Lomero Poyatos (Huelva)	0.5	6 Au
	Masa Migoyas (Sotiel, Huelva)	6	2 Au
	Filón Norte, Tharsis	86	0.8 Au
	Masa Los Frailes (Aznalcóllar, Sevilla)	50	0.7 Au
			70 Ag
15	Rodalquilar, mean orebody(3)	0,5-1	1-3 Au
18	Type orebody	5-25 mill.m^3	0.1/0.15g/m^3Au

(*) Type indicated by number in Tab.1.

(1)in million tons, unless otherwise stated; these numbers are estimations of existing (not yet mined) reserves (june 1993; more data: Castroviejo, 1994).

(2)in ppm Au or Ag, unless otherwise stated.

(3)Data given apply only to individual, discrete bodies. The reserves of a district, or even a mine, would usually be a multiple ot the tonnage given, depending on how many bodies have been defined (mean grades are estimated to be the same). E. g. in the Rodalquilar district several of these separate bodies are known, which belong to different owners (mainly Transacción and INI or State owned mines); a reasonable assumption of 5 orebodies -total reserve evaluation is not yet finished, so these may be rather conservative estimations- would allow to expect a total Au metal content of some 2.5-3 t. Some deposits belonging to types 10 to 13 in NW Spain could be expected to contain several orebodies, with a total metal content of some 5-15 t Au (i.e. 2-10 million t reserves, grading 1.5-5 ppm Au).

(4)Concentrates of this iron mine grade 6-8 ppm Au.

unless further work demonstrates their mining potential.

SILVER DEPOSITS

Silver belongs to traditional Spanish mining and occurs in a variety of deposits types and epochs. Given its typical association with base-metals or gold, silver is very frequently won as a by-product of those metals, and the corresponding deposits should therefore not be classified under the heading of silver, but under Pb-Zn or Au. Consequently, Au-Ag deposits are discussed under gold; as for Pb-Zn-(Ag) deposits, they are *sensu stricto* out of the scope of this work and shall not be dealt with in detail, but since much of the traditional Spanish silver production is due to these deposits, they will at least be classified (type 6) and briefly characterized. The following types have been defined:

*** Silver and/or base-metal-(silver) deposits, occurring in Hercynian terrains (mostly in the Hesperian Massif):**

—Meso— to epithermal silver veins in Hercynian metamorphic terrains (type 4).

This is a very broad group, which accounts for most of the traditional Spanish silver production and which can actually embrace several classes of deposits as far as environment and genesis are concerned: e. g. Hiendelaencina (Guadalajara), Plasenzuela (Cáceres), Guadalcanal (Sevilla). The most productive and famous Spanish silver mines, Hiendelaencina and Guadalcanal, belong to this group.

The deposits of Hiendelaencina (MARTINEZ FRIAS, 1992) and others of the same Sistema Central district have been interpreted as epithermal late-Paleozoic Ag-base metal concentrations[4], related to extensional tectonics and to calc-alkaline Carboniferous/Permian volcanism (CONCHA *et al.,* 1992) their genesis is yet controversial (TORNOS *et al.,* 1993; CONCHA *et al.,* 1993). The Plasenzuela mines won silver from meso-(epi)thermal metasediments of the Complejo Esquisto-Grauváquico (Schist-Greywacks Complex) and spatially related to a granitic intrusion (LAGO *et al.,* 1989); this deposits show some close similarities with those of the Coeur d'Alène district, Idaho (USA). The Guadalcanal deposit, which shows some close similarities with the Kongsberg (Norway) and Cobalt (Ontario) deposit types, has a complex arsenide, antimonide and Ag-sulphosalt mineralogy (CASTROVIEJO, 1990 b), whose precipitation seems to be controlled by the reaction of Ag-bearing hydrothermal fluids with *Fahlband* metabasite rocks.

—Silver and base metal deposits related to volcanic-sedimentary and / or carbonate formations (type 5).

This apparently large group, is in this classification restricted to volcanic-sedimentary or carbonate-hosted silver and base metal occurrences in which Ag is not a subordinate by-product with respect to gold[5], and is typically represented by the volcanogenic Fuenteheridos (Sierra de Aracena, Huelva) deposit, recently discovered by Charte Expl. It consists of stratiform, possibly volcanogenic, sulphide bodies (pyrite, sphalerite, galena, and Ag-sulphosalts, with barite), hosted by limestones and volcanic sedimentary sequences of Upper

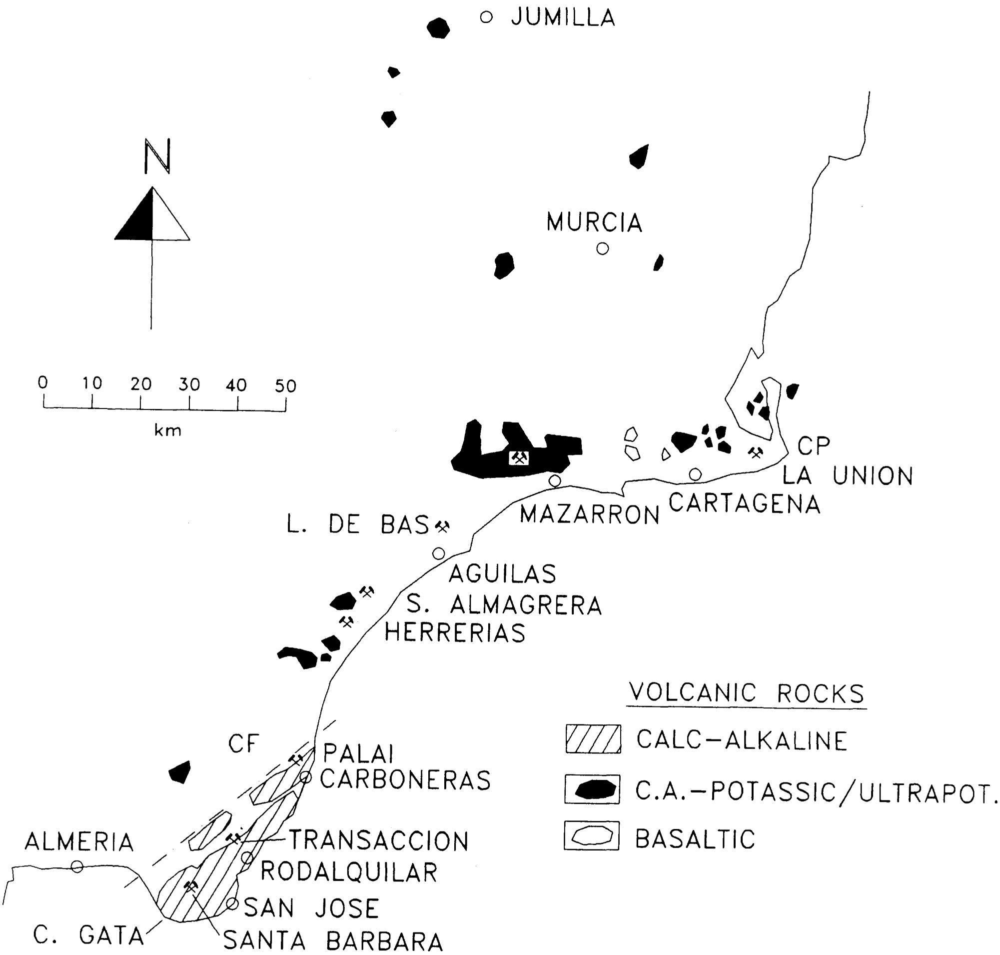

Fig. 2. Distribution of Neogene Volcanic Rocks in SE Spain (area corresponding to inset in *fig. 1*) and location of deposits prospects discussed (modified from López Ruiz and Rodríguez Badiola, 1980). The calc-alcaline potassic and shoshonitic rocks and the ultrapotasic rocks of these authors are represented together, for reasons of scale, as «C. A. potassic / ultrapotassic rocks». Mine's symbols correspond to Pb-Zn-Ag (Fe, Mn, Sn, Sb) or Au mining districts. Abbreviations used: CF Carboneras Fault; CP Cabo de Palos.

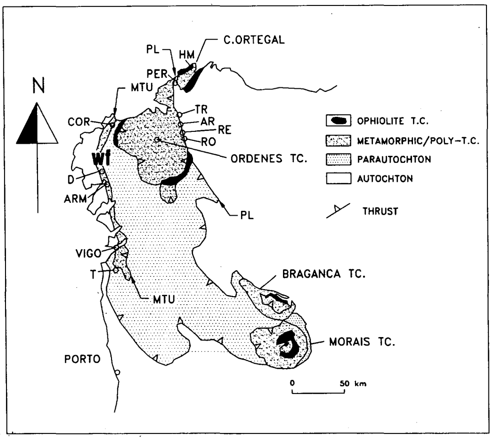

Fig. 3. Distribution of allochthonous units in the Galicia-Tras os Montes Zone (Western Galician and North Portuguese sectors of the Hesperian Massif, modified from: Ribeiro *et al.*, 1990, and Quesada, 1992), showing the position of thrust complexes *(TC)*, and of some major shear zones related to Au concentrations, corresponding to the margins of the Malpica-Tuy Unit, *MTU*, and to the Pontedeume Lineament, *Pl. Gold districs and prospects:* AR Aranga; ARM Armada; COR Corcoesto; D Donas; PER Pereiro; RE Remourán; RO Roñón; T Tomiño; TR Traviesas; Wf West Santa Comba-Fervenza area (mines & occurrences of Meanos, Fousas de Vila, San Martiño, Limideiro, Vilarcovo, Albores, and Rial, along the sheared Eastern margin of the Malpica-Tui allochtonous Unit, described in Castroviejo, 1990a, and in fig. 4, below). The Cabo Ortegal, Ordenes, Bragança and Morais *TC* comprise ophiolite complexes hosting *PGE, type 1, metallotects, including the Herbeira Massif* (HM).

Proterozoic to Lower Cambrian age, and enriched in silver by secondary supergene processes, which led to the formation of a gossan body aimed at as main mining target (ESPI, 1990). This peculiar silver upgrading needs not be neccessarily a feature of the type.

—Veint-type Pb-Zn-(Ag) deposits, occurring in the Hesperian Massif (most of them) or in the Hercynian Basement of Alpine Chains (Pyrenees), usually granitoid— or metamorphic-hosted[6]: type 6.

This group, in which silver appears only as a by-product, has been very important (e. g. the Sierra Morena districts) for Spanish and European mining, but in spite of various exploration efforts (e. g. RÍOS, 1980, in Linares, Jaén; CASTROVIEJO & MORENO, 1983, in Cierco, Lérida) all the mines still working deposits of this type in the last years, as those of the Linares - La Carolina area (Jaén) or Cierco (Pont de Suert, Lérida), have been closed down, due to the fall in metals' prices and to the near exhaustion of reserves, after decades of continuous mining.

*** Silver and/or base-metal-(silver) deposits (volcanic-related and of Tertiary age) occurring in the Neogene Volcanic Province of Southeast Spain, in a variety of environments:**

—Fe-Base metal-(Sn, Ag) vein-type, replacement and disseminated deposits related to shallow Tertiary intrusives in various Hercynian and Mesozoic lithologies from the Betic Chains (type 7).

They had since pre-Roman times an unquestionable mining significance... until recently: e. g. La Unión, Cartagena (Fig. 2). The deposits of this district, which used to be described, when active, as the world's lowest grade Pb+Zn mines, have a controversial genesis (PAVILLON, 1969; OEN *et al.*, 1975; OVEJERO *et al.*, 1976), to which several factors may have contributed (pre-Tertiary concentrations, epigenetic subvolcanic hydrothermal circulation, etc.); nevertheless, as a type, they can be conveniently characterized as concentrations spatially related to shallow intrusives of the Neogene Volcanic Region of SE Spain, even if they are hosted by metamorphic Hercynian or by Mesozoic formations.

—Epithermal Pb(Zn)-Ag(Au) and Ag ores related to Neogene calc-alcaline volcanites (type 8), which can be volcanic-hosted, sediment-hosted (not yet proved) or even hosted by Hercynian lithologies (transitional to type 7).

There are not many examples which can be properly considered as silver deposits, i. e. in which silver may be the main precious metal; two of them should perhaps be cited as the most typical: the occurrence of Herrerías, Almería, for silver (MARTINEZ FRIAS, *et al.,* 1989 & 1992); and the likely economic Zn-Pb-Ag body of Mazarrón, Murcia —under exploration by Navan—, for base metals & silver (MORALES and FENOLL, 1990). Other examples, in the Cabo de Gata (e. g. Santa Bárbara mine) and Rodalquilar (e. g. Niñas and Consulta mines) districts, Almería, will be treated under gold, which is now looked as the most important metal of these districts (see types 15 to 17).

GOLD DEPOSITS

Gold has a long tradition of mining in Spain and, the same as silver, occurs in a variety of epochs and deposit types, which can be classified as:

— Volcanic-sedimentary deposits in Hercynian metamorphic terrains:

They are the first source of present-day Spanish gold production, both as: by-product gold, disseminated in massive sulfide orebodies (type 9), very well represented in the SW Iberian Pyrite Belt, Huelva and Sevilla Provinces, fig. 1), and as

*** Supergene gold concentrations in gossan orebodies derived from the above (type 19, e. g.**

Río Tinto and Tharsis / Filón Sur and Lapilla mines, Huelva); their exploration has been very successful, leading to a considerable increase in gold production (GARCIA PALOMERO et al., 1986); they have been divided in several (sub)types and characterized by these authors.

*** Hypogene gold concentrations in Hercynian metamorphic terrains:**

These ores, already won in pre-Roman times, were among the most searched in the last years, especially in the Hesperian Massif (NW Iberia, Extremadura). The wealth of information thus produced, although not always published, allows the systematic classification of these prospects and deposits in types 10 to 14 (Table 1), some of which (types 10, 11 and 12) may appear frequently interrelated or mixed. Even if the distinction of these might seem artificial, since shear zone related deposits are also very frequently granitoid or porphyry related and viceversa, it is useful to distinguish a type of Granitoid related deposits (type 11), not necessarily implying the existence of ductile deformation or shear zone development, while the mixed type 12 implies a relationship with both granitoids and ductile deformation.

The description of some examples (fig. 1 and 3) may help define the geology of the different types: those of the West Santa Comba-Fervenza area, Coruña (CASTROVIEJO, 1990a) for type 10 (Vein-type, shear-zone hosted); Corcoesto, Coruña (GOUANVIC, 1983) for type 12 (mixed granitoid & shear-zone type); Salave, Asturias (HARRIS, 1980 a, b) for *type 11* (Hydrothermal, granitoid related); and Carlés, Asturias (GARCIA IGLESIAS and LOREDO, 1990; MARTIN-IZARD *et al.*, 1993) for type 13 (Skarn gold ores).

The West Santa Comba-Fervenza shear-zone occurrences (fig. 3), show these typical features; shear zones appear as major controls; there is evidence of fluid overpressure in a ductile to brittle transitional regime, with cyclic or repetitive rupture of the structures, as demonstrated by textural microanalysis (fig. 4); the rupture is followed each time by hydrothermal circulation and alteration, vein infill and breccia cementation; granites or porphyries are frequently observed. They are similar to other Hercyninan shear zone gold deposits in Europe (e. g. in the French Massif Central, BONNEMAISON and MARCOUX, 1987) and, as compared to the typical vein-type, shear-zone hosted, pre-Cambrian gold deposits found in greenstone belts (as in the Abitibi Belt, Canada), they are smaller in size and tonnage and tend to occur in higher grade (up to catazonal and anatectic) metamorphic rocks, in sequences where mafic volcanics are not so abundant. Favourable areas for these deposits are known along the tectonic contacts of various allochtonous units in the Hesperian Massif (see prospects in fig. 1), as in Galicia (fig. 3; Xunta de Galicia, 1991; ITGE, 1993 or in the Central Iberian Zone, and also in the Hercynian basement of the Pyrenees (Vall de Ribes district: ROBERT, 1980; AYORA *et al.*, 1992).

— Granitoid related (type 11)

This deposits show abundant hydrothermal alteration related to ore (sulphides and native gold) deposition, and gold may be associated with some specific facies. The «Salave-type» of gold deposit is defined by HARRIS (1980b) as «one formed in almost any king of feldspar-quartz-ferromagnesian-bearing rock, probably in an area of major tectonism with a zoned alteration facies of decreasing carbonatization, albitization, desilicification, sericitization, and texture destruction away from a disseminated gold mineralization associated with pyrite, arsenopyrite, stibnite and minor amounts of other sulphides». This «Salave-type» is here considered as a particular case of granitoid related gold deposit, a larger group also including other bodies in which some of the features mentioned are lacking or are different, as happens in the Brués, Carballiño and Tomiño granite-hosted vein deposits in which gold deposition is associated to argillic, sericitic or greisen-type alteration.

— Mixed shear-zone / granitoid hosted (type 12)

This type is represented by the Corcoesto (Coruña) body and various prospects in the Fervenza, W of Santa Comba (Coruña) area, Pino del Oro, Zamora, etc. Hydrothermal (sericitic, argillic...) alteration is usually intensive (less so in Corcoesto) and gold ores associated to arsenopyrite, sulphides or

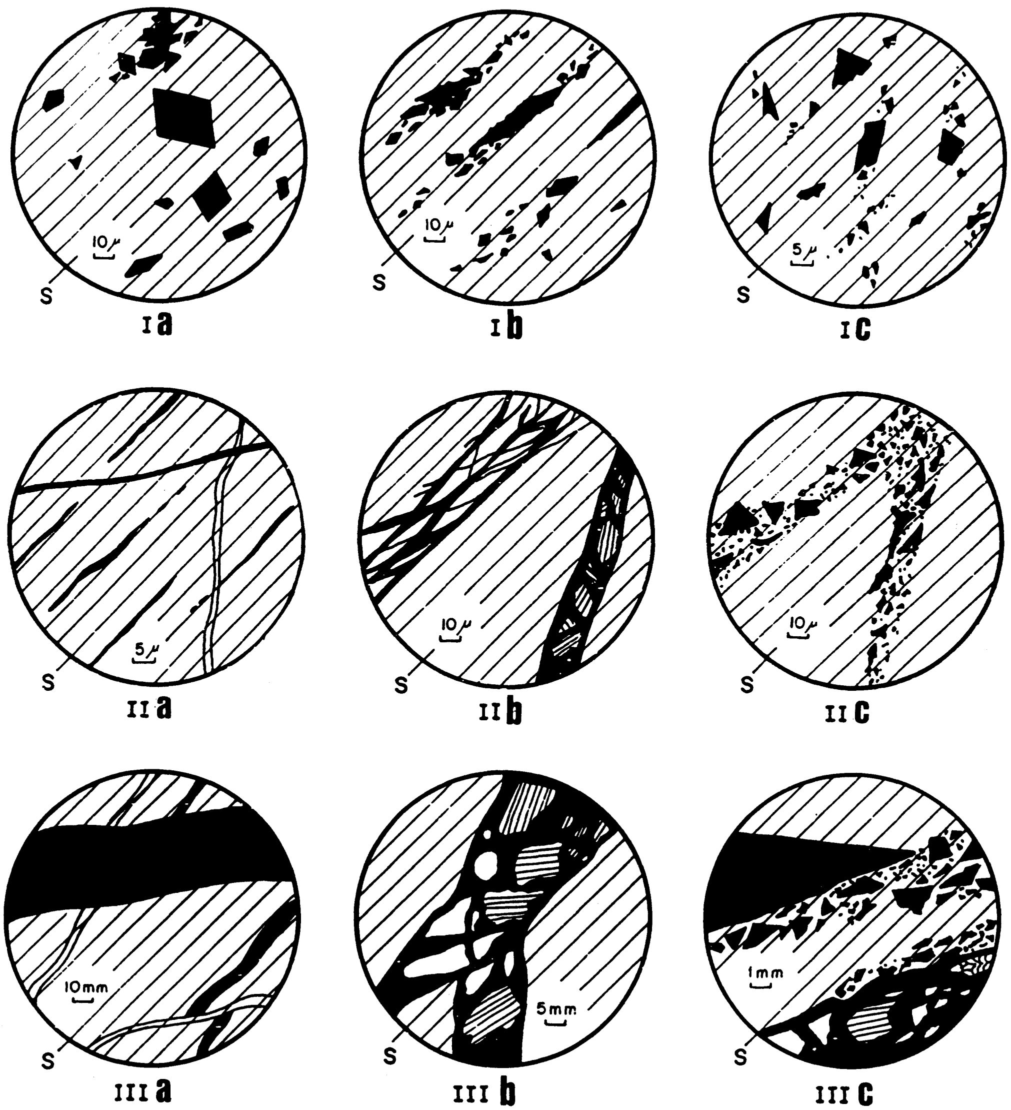

Fig. 4. A typological characterization of sulphide ore textures from shear zone Au deposits, based on observations in the West Santa Comba-Fervenzas area (modified from Castroviejo, 1990a), showing evidence of repeated brecciation, hydrothermal infill and sulphide precipitation. Black: arsenopyrite; white: silicate gangue; S: trend of main S-surface. *Type I:* disseminated ores (a: idiomorphic; b: lenticular; c: microclasts): *Type II:* stringer or fine-banded ores (a: microfissures and S-planes; b: microshears; c: microclasts); *Type III:* massive ores (a: vein fill; b: breccia cement; c: cataclastic) as a general rule, deformation and age increase from a to c.

sulphosalts, tend to occur in quartz veinlets. Chloritization and potassic alteration may be precursor hydrothermal processes, possibly related, as retrograde phenomena, to the deformational history of the structures. Recent research on deposits of this type (BOIRON *et al.* and CATHELINEAU *et al.*, 1993) resulted in a model relating gold concentration to the final events of a complex sequence, ending with the circulation of low-temperature, low-salinity aqueous fluids at nearly hydrostatic pressures, in conditions similar to those of a geothermal system. These late fluids, assumed to be responsible for the gold mineralization, may have a likely meteoric origin, and need not be related to the magmatism. Instead, the strong rheologic contrasts involved, e. g. between granite and schists, contribute to enhance the brittle behaviour, i. e. the permeability, of certain lithologies (granite lenses or quartz veints), thus exerting a major control on fluid circulation and on gold precipitation, what might explain the spatial relationship of the ores with granites or with (preexisting) quartz veins.

— The Carlés skarn body is related to a granodiorite intrusion in Devonian limestones; gold and electrum occur in copper-rich skarn lenses and subordinate quartz-arsenopyrite-chalcopyrite veinlets, with occasional leollingite, pyrrhotite, etc.; the refractory character of the ore seems to be the hardest problem for its exploitation. Other examples are know in the same (Salas, controversial genesis) or other areas (fig. 1) in NW Spain, as Carracedo, Palencia, and Infiesto, Asturias, or in the Pyrenees (Maladeta, s.) LOCUTURA and BELLAN, 1987; near Andorra s. SOLER et al., 1990). Nevertheless, the only gold production from Spanish skarn deposits at apresent comes as by-product from the Cala iron ore mine, Badajoz province (see 2), which is only a few km away from the now exhausted granitoid-related Sultana gold mine, in SW Spain.

— Some other prospects or deposits, generally of scarce mining importance for gold as far as known, have been grouped in *type 14,* most typically represented by Sb-Au or As-Sb-Au veins in Hercynian terrains, described by different authors in the Hesperian Massif. The many showings included in this group —e. g. Herrera del Duque: GUMIEL and ARRIBAS, 1987; Almuradiel: LEAL and CASTRVIEJO, 1990; Usagre: (TORNOS and LOCUTURA, 1988; BURÓN and VILLAMANÍN: PANIAGUA *et al.,* 1988 a & b— are not necessarily resulting from the same genesis or characterized by an identical geological environnment. Having not attracted much companies attention as gold prospects, they are often poorly known yet; a more precise geological characterization resulting from further research might lead to a subdivision of the group, broadly described as meso— to epithermal vein-type or epigenetic Sb-Au or As-Sb-Au concentrations, in different types[7].

**** Gold, gold-silver or gold-silver & base metals mineralizations occurring in the Neogene Volcanic Province of Southeast Spain:***

They correspond to various epithermal types of Tertiary age and are related to the calc-alkaline volcanic rocks outcropping mainly in the Almería province (Figs. 2). They are by now essentially represented by volcanic hosted deposits (types 15 and 16: high-sulphidation or acid-sulfate, and low-sulphidation or adularia-sericite types, as

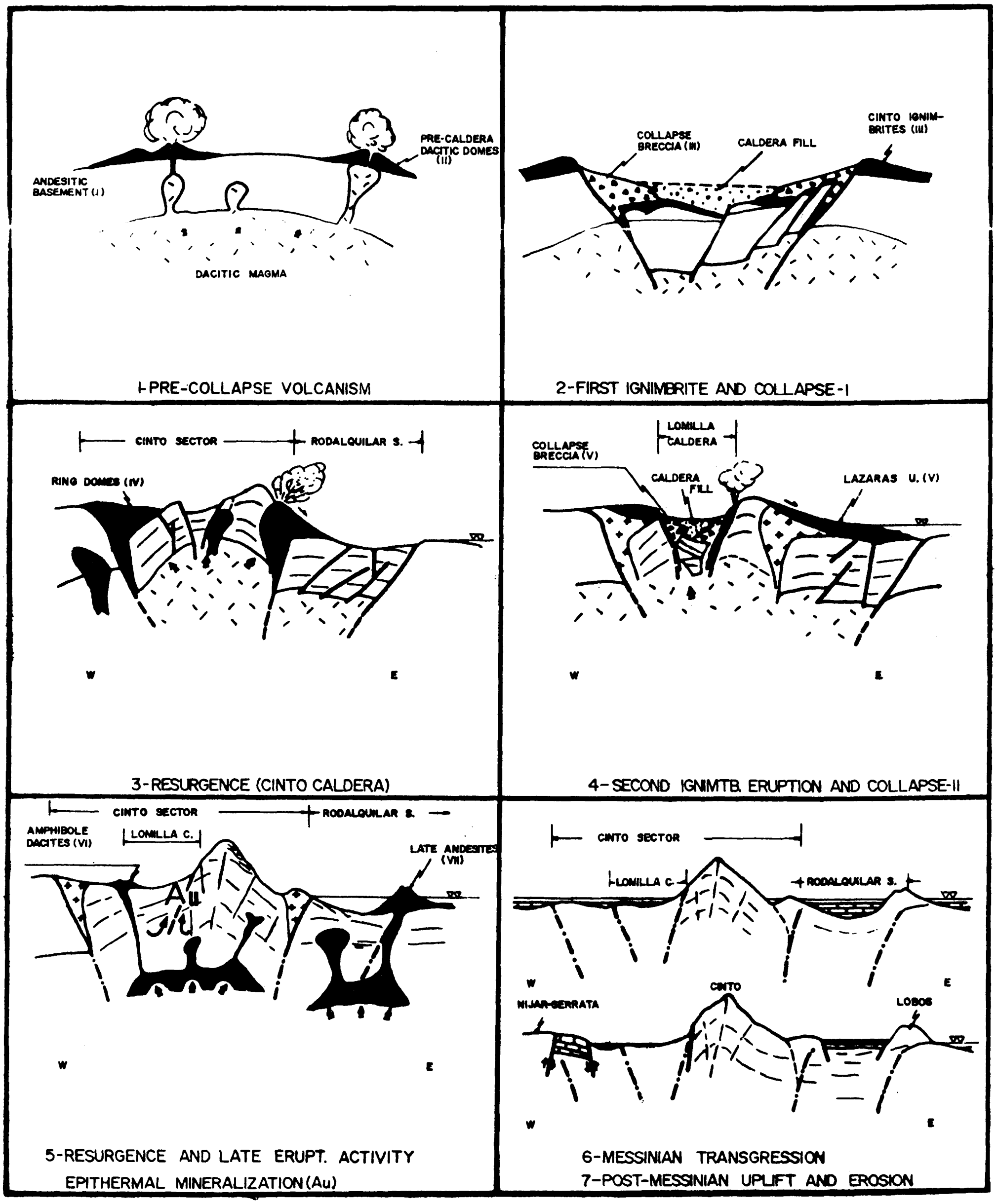

Fig. 5. Serial ENE-WSW simplified sketch sections of the Rodalquilar volcanic field, showing the successive stages in the genesis and evolution of the caldera structures related to the gold mineralization (modified from Castroviejo, 1988). The domes being intruded and the volcanic materials being erupted in each stage are represented in black.

defined by HEDENQUIST, 1987 or by HEALD *et al.,* 1987); non-volcanic hosted bodies (type 17) have been worked for Pb (Zn) and Ag, while for gold they have only been recognized as prospects (e. g. at the Sierra de Lomo de Bas, Aguilas-Mazarrón, Murcia), but the potential of the region for this type, including sediment-hosted, Carlin-type deposits, should not be neglected.

— The-high-sulfidation (type 15)

Is well characterized by the Transacción and other deposits of the Rodalquilar district, Almería *(fig. 2),* deposits (ARRIBAS *et al.,* 1988); CUNNINGHAM *et al.,* 1989, RYTUBA *et al.,* 1990), related to the Cinto and Lomillas calderas (fig. 5) and to their 11 to 10 m. y. old post-collapse magmatic and hydrothermal activity, producing intensive alteration and gold deposition in veins and disseminations in the hostrock. Native and telluride gold ores are associated to hypogene silicic and advanced argillic alterations. Alteration associations are arranged in successive zones, away from the gold orebodies: silicification, with formation of vuggy-silica, alunite-pyrophyllite or advanced argillic zone, sericitic / argillic and outer potassic / propyllitic zones. The Transacción deposit was developped into an (ephemeral) mine in the last decade. The Palaí prospect may be another example.

— The low-sulphidation (type 16)

Is represented by the *Cabo de Gata,* Almería *(fig. 2),* deposits (Santa Bárbara mine, etc.), which can be broadly described (CASTROVIEJO, 1990c) as: vein type base metal-silver orebodies, with subordinate[8] gold and with quartz or chalcedony (+barite, adularia, carbonate, sericite and clay) gangue, showing typical vein-fill and banded textures, hosted by the strongly altered rocks of an about 12-11 my. old andesitic dome field, in which no Tertiary or older sediments outcrop (fig. 6). The associated alteration sequence (away from the veins) consists of: silicification, quartz-sericite (phyllic) alteration and argillic alteration, transitional to the adularia and propyllitic assemblages typical of the country rock. A local hypogene advance argillic alteration can occasionally be observed. Frequent breccia bodies witness of repeated explosive activity related to hydrothermal discharge, and the level of formation seems clearly deeper than in the mostly very shallow orebodies of Rodalquilar (Cerro Cinto).

— Not-volcanic hosted epithermal bodies (type 17)

Are at present more scarce. Nevertheless, the Lomo de Bas occurrence (CASTROVIEJO *et al.,* 1990 a & b) is an interesting exploration example, suggesting a larger mining potential of the SE Spanish Neogene volcanic province, from Cabo de Gata, through Sierra Almagrera, Mazarrón, etc. to Cartagena/La Unión. It is related to hitherto unknown Tertiary porphyritic outcrops (found through remote sensing techniques, following a metallogenetic model), intruding the metamorphic Paleozoic terrains of the Betic chains, northwards of Aguilas *(fig. 2).*

*** Sedimentary gold concentrations in Neogene and recent detrital formations: gold-bearing paleoplacers and placers (type 20)**

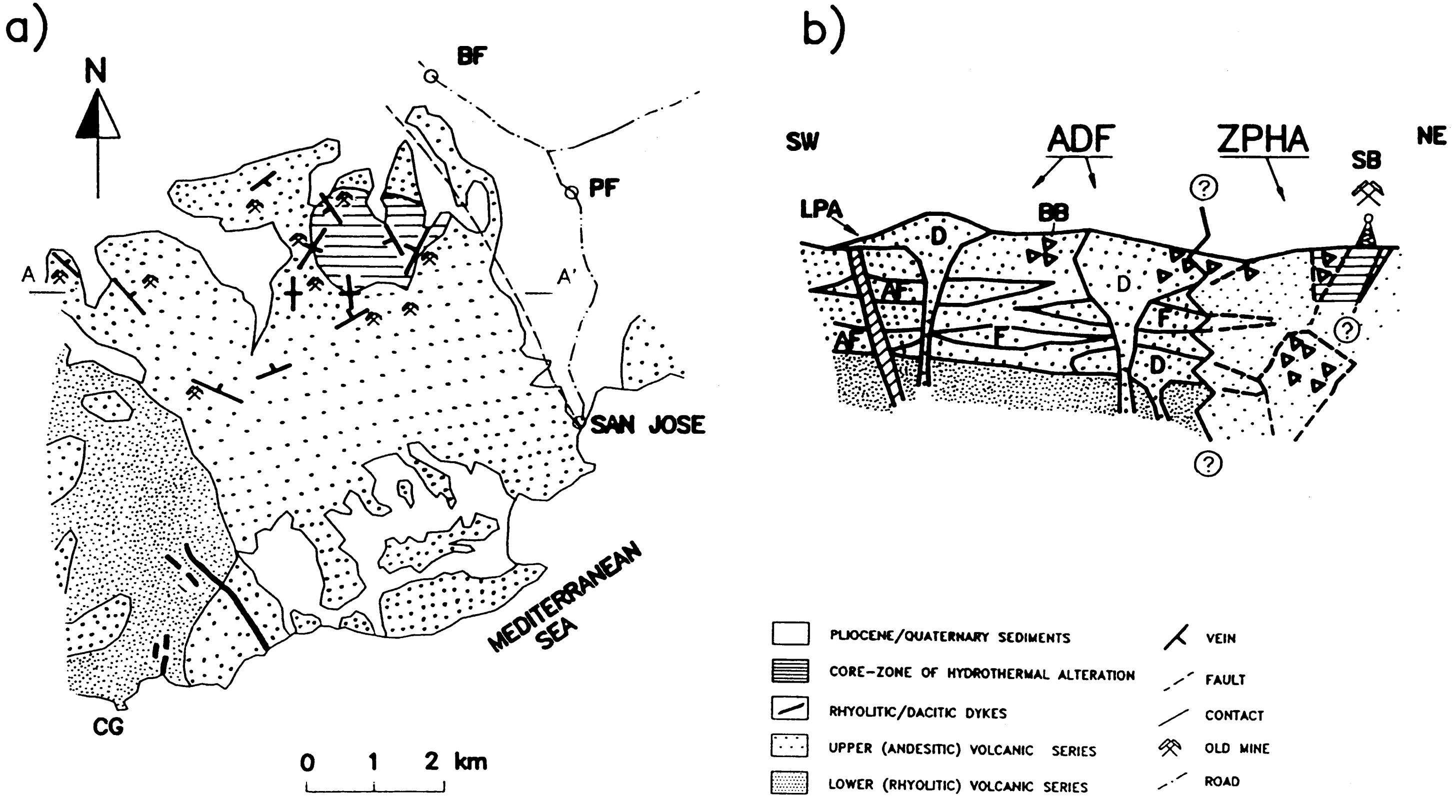

Fig. 6. Preliminary geological sketch map (a) and scheme showing field relations (b, idealized NE-SW section) in the Cabo de Gata volcanic and vein field, Almería (modified from Castroviejo, 1990 c, and Fernández Soler, 1992). The volcanic rocks of the Lower Series are mainly rhyolitic and dacitic ash flows domes and breccias, while in the Upper Series andesitic domes, flows and breccias are dominant. The core-zone of hydrothermal alteration shows intensive argillic/phyllic, occasionally advanced argillic, alterations, superimposed on an earlier pervasive potassic alteration. Compare with fig. 5: no caldera collapse structures are observed in this case.
Abbreviations: ADF Andesitic Dome Field; AF Ash-flow tuffs; BB Breccia and autoclastic breccia bodies; D Domes; F Lava flows; LPA Late (unaltered) pyroxene andesites; ZPHA Zone of Pervasive Hydrothermal Alteration.
Localities/mines: CG Cabo de Gata; PF Pozo de los Frailes; BF Boca de los Frailes; SB Santa Bárbara Mine.

Occur mainly in NW Spain and have been extensively mined by the Romans, contributing very much to Spanish prehistoric and ancient historic production, but in spite of the impressive works that can still be observed (e. g. Las Médulas and Las Omañas, León) and of archaeological and exploration works undertaken by several institutions and companies no modern mining has been developped. A detailed characterization of the deposits of this large group exceeds the purpose of this paper and can be found in the works of DOMERGUE (1970), DOMERGUE & HERAIL (1978), SANCHEZ PALENCIA-RAMOS (1983), HERAIL (1984), PORTER *et al.* (1989), PEREZ GARCIA & SANCHEZ PALENCIA-RAMOS (1992), a. o. This type occurs in other areas as well: e. g. the gold-bearing plio-quaternary alluvial fans of Caniles de Baza (Granada) and Ugíjar (Almería), related to the erosion of the Nevado-Filábride and subordinately, Alpujárride Complexes in the Alpine Domains of the Betic Chains[9].

SOME PROBLEMS FOR FURTHER RESEARCH

The foregoing discussion should have shown the noteworthy progress made in the last decade in many aspects of the geology of Spanish precious metals deposits, but there are still many unsolved problems whose solution would be important for further development. Among these, those dealing with exploration —as the ore processing research of the refractory gold ores so frequent in NW Spain, the detailed definition of ore controls and reserves of the usually irregular shear-zone deposits, the appraisal of the precious metals potential of the SE Spanish Volcanic Province, etc.— have already been stressed by CASTROVIEJO (1994) and will not be discussed any further.

The research and precise definition of the many showings or prospects grouped in *type* 14 is also to be done, and might lead, as already stated, to some revision of this group. New models, if proved to be significant, could lead to new sub-types or even types. Among them, the epithermal and Carlin types of Au deposits (se below) proposed by several authors, or the gold-bearing hydromagmatic breccias defined by JAHODA (1987) in NW Spain, occurring in the early Paleozoic Vegadeo limestones and Los Cabos Series metasediments, related to major strike-slip faults and to gabbroic intrusions.

Another question dealing essentially with typology is the more precise definition of the concept of *epithermal* deposit and its characterization, a question dealing with the assumed existence of Paleozoic epithermal *(s. s.)* deposits in Spain. This term can be —and has been— correctly applied to deposits of the calc-alkaline Volcanic Province of SE Spain. It has also been used —and sometimes contested— for several deposits in the Hesperian Massif (e. g., Hiendelaencina, various occurrences in NW Spain, etc., types 4 and 14 in Table 3). Much argument could perhaps be spared if every author made an effort to define exactly what he understands under that concept while applying it to a deposit. In fact the term seems to have become very equivocal in the literature. For some it may mean a model or a type (in fact several types, e. g. low— or high-sulphidation) of volcanic deposits in the present american use, but for others rather a set of physicochemical conditions including even plutonic deposits, in a classical european use (NIGGLI, in SCHNEIDERHÖHN, 1962). The precise geochemical research of the fluids involved and their comparison with typical epithermal fluids should help solve the problem. Some rigorous characterizations already existing in the literature, as those by HEDENQUIST (1987), by HEALD *et al.,* (1987), and by WHITE and HEDENQUIST (1990) among others, should be used as reference.

CONCLUSIONS

Spain, first precious metals mining country of the EU (European Union), has been exploration target for many companies, and consequently the knowledge of the Spanish precious metals geology has been increased, in the last decade, under the influence of favourable market conditions especially for gold. This has produced some new mining developments and a wealth of information, which the author has tried to summarize through the typological classification of Table 3. A comparison with former typologies (tables 1 and 2) allows to appraise the recent developments due to various contributions.

Precious metals concentrations occur in Spain in Hercynian and Alpine domains, and in the Meso-Cenozoic Cover. They have been classified following a descriptive typology, relying on geological facts rather than on interpretations, after the scheme in Table 3, which stablishes 19 types, thus simplifying a preliminary scheme by the author (1993) with 20 types.

* The main types of mineralizations in Hercynian terrains are: the ophiolitic (type 1) PGE occurrences in the NW Hesperian Massif (Cabo Ortegal, Herbeira); vein-type (Guadalcanal, Hiendelaencina, type 4) and strata-bound (Fuenteheridos / S.ª Aracena, type 5) silver deposits in the Hesperian Massif; hypogene gold mineralizations (types 10-13), skarn and vein types (shear-zone or granite-related) or other (tipe 14); gold disseminations in volcanic sedimentary massive sulphides (SW Iberian Pyrite Belt, type 9). The supergene gossan gold & silver deposits (type 19) derived from the latter are actively mined at present.

* In Alpine domains, the main types are: the PGE occurrences (t. 2) in gold bearing Ni-arsenide ores of ultramafic formations, Serranía de Ronda (Málaga), and the various types of gold / silver / base metal deposits in the Neogene volcanic province of SE Spain, mostly epithermal and with an attractive potential for exploration (types 7-8 and 15 to 17). Finally, in the Meso-Cenozoic Cover, well known (type 18) detrital gold concentrations (e. g. León province) occur.

Some problems demanding further research have been underlined, which are relevant for the correct understanding and classification of the Spanish precious metals deposits, as the more precise definition of many type 14 occurrences and of some controversial epithermal (?) deposits (see the preceding section, for further questions).

As far as exploration is concerned, no mining development has been achieved for PGE's. Results for silver have been more rewarding in those types in which the precious metal is associated, as by-product, with gold (see type 19) or with base metals (as the promising Zn-Pb-Ag prospect of Mazarrón, Murcia), less so, for main metal Ag (e. g., the small silver and base metal body of Fuenteheridos, in S.ª Aracena, Huelva, type 5). For gold, the volcanic sedimentary ores of the SW Iberian Pyrite Belt are still by far the country's main source, both as a by-product in the sulfide mines (type 9) and, principally, as the main metal in the gossan bodies (type 19) related to the former. The mining results of exploration on these gossan bodies have been really rewarding (Rio Tinto and Tharsis, Filón Sur & La Lapilla), but are restricted to a very limited area. In the Hesperian Massif of NW Spain, the refractory character of the ores or the small size and irregularity of the orebodies have been a serious handicap, preventing mining development for otherwise attractive type 10-13 prospects (as Carlés, Salave, etc.). The (mostly Neogene) sedimentary paleo-placer and placer gold deposits in NW Spain show also an interesting potential, but have not reached the production stage. The Tertiary epithermal gold ores from the Neogene cal-alkaline Volcanic Province of SE Spain have become a significant potential source of gold, although the last mining operation (the low-grade, open-pit Transacción Mine, Rodalquilar, Almería type 15) has been recently closed. Research done allows the distinction of types 15 to 17, i. e. volcanic-hosted (high-and low-sulphidation) and not volcanic-hosted types, and the extension of target areas in the region.

ACKNOWLEDGEMENTS

The author wishes to thank an anonimous reviewer for his constructive criticism and his colleagues J. A. Espí, C. Quesada and J. Locutura (ITGE), for their help and critical comments, as well as F. Latorre, J. Faura, and E. N. Adaro/DGM, for their support and permission to publish the parts of this work dealing with research done for E. N. Adaro/DGM. He also wishes to acknowledge Mr. Ph. Lagny and *Chronique de la Recherche Minière* who allowed him the publication of some figures and Table 4 from a paper by the author.

NOTES

[1] The following remark by this author, as recently as 1984 *(op. cit.)*, is noteworthy: «*'El encaje de los yacimientos auríferos españoles en el marco de cualquier clasificación tipológica de las existentes a nivel mundial ofrece dificultades prácticamente insoslayables en el momento actual, si se pretende efectuar con un mínimo de rigor metalogenético. Esta imposibilidad se basa en el escaso conocimiento que se posee sobre la mayor parte de las mineralizaciones dado que, en general, las explotaciones mineras y los estudios correspondientes se remontan a épocas bastante lejanas*».

[2] Besides, some of the criteria employed would need some further explanation / discussion to avoid some apparent inconsistencies: e. g., why are types 1, 2 & 3 not included in the Hercynian type, n.° 4?

[3] After this work was sent to the editor (april 1994), another classification of Au deposits was presented by R. Urbano (1994), based on the already discussed criteria of Burckhalter, and commenting some recent work by ITGE.

[4] Accordingly, and in spite of evident differences in environment and age, these deposits have been compared with those of Herrerías-Sierra Almagrera (s. below), which are related to Neogene volcanism and classified under *Type 8*, as defined here (*'Table 3)*. The controversial character of the underlying genetic interpretation cannot but support the scheme proposed in Table 3, relying rather on facts than on interpretations.

[5] The typical massive sulphide orebodies of the SW Iberian Pyrite Belt, in which silver is only a by-product, are discussed under gold, which is currently their main *precious metal.*

[6] Recent genetic interpretations of some of these deposits (e. g. Johnson *et al.*, 1993 for Cierco) may be controversial, but are still compatible with this typology, based on general features and on the geological environment.

[7] An example of this might be the study —published after the presente typology was defined— of the Villamarín (León) ores by A. Paniagua (1994), after wich they represent a Cu-Co-Ni-Au-U & PGE-bearing epithermal type, explained by a model typical for the

Cantabrian Zone —also shared by other prospects—, implying a polyphase enrichment of the various metals at different stages.

[8] Although they are now searched primarily for gold.

[9] Explored by E. N.. Adaro, pers. comm. P. Hernán.

REFERENCES

ARRIBAS, A., Jr., RYTUBA, J. J., CUNNINGHAM, C. G., KELLY, W, C., RYE, R. O., CASTROVIEJO, R. (1988) Rodalquilar deposits, Spain, First example of caldera-related epithermal gold mineralization in Europe: Part 2, Ore Genesis (abs.); *Geol. Soc. America Meet., Abs. with Program,* v. 20, n.° 7, p. A351.

AYORA, C., RIBERA, F., CARDELLACH, E. (1992). The Genesis of the arsenopyrite gold veins from the Vall de Ribes district, eastern Pyrenees, Spain. *Econ. Geology,* 87, 1877-1896.

BACHE, J. J. (1982). Les gisements d'or dans le monde. (Essai de typologie quantitative). *Mém. BRGM,* n.° 118, Orleans, 101 p.

BONNEMAISON, M., MARCOUX, E. (1987). Les zones de cisaillement auriféres du socle hercynien français. *Cron. Rech. Min.* 488, p. 29-42.

BOIRON, M. C., ESSARRAJ, S., BARAKAT, A., CASTROVIEJO, R., CATHELINEAU, M., NORONHA, F, NOGUEIRA, P., YARDLEY, B., BANKS, D., MARIGNAC, C., PEREIRA, E., URBANO, R., FLORIDO, P., GARCIA PALOMERO, F. (1993). P-V-T-X changes throughout the formation of intragranitic Au concentrations in the northwestern Iberian Massif (Spain-Portugal): an integrated Fluid Inclusion study. In: Fenoll Hach-Alí, Torres Ruiz & Gervilla (eds.) *Current Research in Geology Applied to Ore Deposits, SGA Meeting,* Granada, p. 605-608.

CASTROVIEJO, R. (1988). Edificios volcánicos y estructuras de colapso en relación con las mineralizaciones auríferas de Rodalquilar: una nueva interpretación. Unpub. Report, 27 p., In: Llanderas J. I., Castroviejo R., Díez del Corral J. Proyecto Níjar: trabajos realizados en el distrito de Rodalquilar, *Int. Report. E. N. Adaro.*

CASTROVIEJO, R. (1990a) Gold ores related to shear zones, West Santa Comba-Fervenza Area (Galicia, NW Spain): A mineralogical study. *Mineral. Deposita* 25 [Suppl], S42-52.

CASTROVIEJO (1990b). Paragénesis argentíferas de Guadalcanal (Sevilla). X Reunión S. E. M., Oviedo, 4-6 Jul. 1990; abs: *Bol. Soc. Esp. Mineralogía,* v. 13-1, p. 98-99.

CASTROVIEJO (1990c). Síntesis de estudios realizados en el área mineralizada del Cabo de Gata (1989/90). Unpub. Rep., E. N. Adaro, Madrid.

CASTROVIEJO (1992). Ore geology of the Santa Bárbara Pb-Ag and Au district (SE Spain). *Mining. Dep. Study Group, Ann. Meeting,* Univ. Aberdeen (U. K.), 6-7 Jan. 1992 (abs. vol.).

CASTROVIEJO, R. (1993). Clasificación tipológica de yacimientos e indicios de metales nobles españoles y exploración. *XV Reunión de Xeoloxía e Minería do N. O. Peninsular.* O Castro, 26/27 Nov. 1993. Abs. vol. p. 85-7.

CASTROVIEJO, R. (1994). Precious metals geology and exploration in Spain: progress and questions. *Chron. Rech. Minière, 516,* p. 3-24.

CASTROVIEJO, R., MORENO, F. (1983). Estructura y metalogenia del campo filoniano de Cierco (Pb-Zn-Ag), en el Pirineo de Lérida. *Bol. Geol. y Minero,* t. XCIV-IV, p. 291-320.

CASTROVIEJO, R., NODAL, T., PODWYSOCKI, M. H., INSUA, M. (1990a). Mineralizaciones subvolcánicas (Au-Ag-Sn-Sulfuros polimetálicos) y hallazgo de pórfidos tonalíticos neógenos en la Sierra de Lomo de Bas (Murcia). X Reunión Soc. Esp. Mineralogía, Oviedo, 4-6 Jul. 1990. Publ. *Bol. Soc. Esp. Mineralogía, 14* (1991), p. 183-200.

CASTROVIEJO, R., NODAL, T. (1990b). The exploration significance of Neogene epithermal Au-Ag-Sn-Base Metal Veins and related Porphyry System in Paleozoic Metamorphic Terranes (Murcia, SE Spain). *Min. Dep. Study Group, Ann. Meeting,* Trinity Coll. Dublin, 10-13 dec. 1990 (abs. vol.).

CATHELINEAU, M., BOIRON, M. C., ESSARRAJ, S., BARAKAT, A., GARCIA PALOMERO, F., URBANO, R., TOYOS, J. M., FLORIDO, P., PEREIRA, E. S., MEIRELES, C., FERREIRA, N., CASTRO, P., NORONHA F., DORIA, A.,

RIBEIRO, M. A., BARRIGA, F., MATEUS, A., YARDLEY, B., BANKS, D. (1993). Major structural factors of Au concentrations in the northwestern Iberian Massif (Spain-Portugal): a multidisciplinary and ultiscale study. In: Fenoll Hach-Alí, Torres Ruíz & Gervilla (eds.) *Current Research in Geology Applied to Ore deposits, SGA Meeting,* Granada Univ., p. 613-616.

CONCHA, A., OYARZUN, R., LUNAR, R., SIERRA, J., FOBLAS, M., LILLO, J. (1992). The Hiendelaencina epithermal silver-base metal district, Central Spain: Tectonic and mineralizing processes. *Mineral. Deposita* 27, 83-89.

CONCHA, A., OYARZUN, R., LUNAR, R., SIERRA, J., DOBLAS, M., LILLO, J. (1993). Reply to the comment by F. Tornos *et al.,* (1993) *Mineral. Deposita* 28, 219-221.

COTELO NEIVA, J. M. (1949). Geology and genesis of Portuguese ores of chromium and platinum, Bragança district. Coimbra Univ. Mus. e Lab. Min. e Geol., *Mem. e Noticias,* N.° 24, 289 p.

CRESPO, V. (1988). Panorama actual de la investigación minera del oro (jun. 1987). *Bol. Soc. Esp. Min.,* 11-1, 3-16.

CUNNINGHAM C. G., ARRIBAS, A., JR., RYTUBA, J. J., RYE, R. O., KELLY W. C., PODWYSOCKI M. H., MCKEE W. C., ARRIBAS, A. SR., CASTROVIEJO R. (1989). The Origin of United States-Spain Gol/Alunite Deposits: Caldera-Related, Epithermal Gold/ Alunite Deposits at Rodalquilar, Spain. *28 th. Int. Geol. Congrs.,* Washington, July 9-19 1989 (abs. vol.), 4 p.

DOMERGUE, C. (1970). Les exploitations aurifères du Nord-Ouest de la Péninsule Ibérique sous l'occupation romaine. *VI Congr. Int. Minería,* León, Cátedra de San Isidoro, *1,* p. 155-181.

DOMERGUE, C., HERAIL, G. (1978). *Mines d'or romaines d'Espagne. Le district de la Valduerna (León).* Publ. Univ. Toulousse, série B, t. IV, 303 p.

ESPI, J. A. (1990). *El Gossan y sus Yacimientos Asociados.* Lecture, School of Mines, Madrid. ETSI Minas, Univ. Politécnica de Madrid.

FERNANDEZ SOLER, J. M. (1992). *El volcanismo calco-alcalino de Cabo de Gata (Almería): Estudio Volcanológico y Petrológico.* Unpub. PhD., Dept°. Mineralogía y Petrología, Univ. Granada, 243 p. + figs., and tables.

GARCIA IGLESIAS, J., LOREDO, J. (1990). Geological, mineralogical and geochemical characteristics of the Carlés gold mineralization, Asturias, Spain. *Mineral. Deposita,* 25, p. 43-58.

GARCIA PALOMERO, F., BEDIA, J. L., GARCIA MAGARIÑO, M., SIDES, E. J. (1986). Nuevas Investigaciones y trabajos de evaluación de reservas de gossan en Minas de Riotinto. *Bol. Geol. Minero,* t. XCVII-V, p. 622-642.

GERVILLA, F., LEBLANC, M. (1990). Magmatic ores in high-temperature alpine-type lherzolite massifs (Ronda, Spain and Beni-Bousera, Morocco). *Econ. Geol., 85,* p. 112-132.

GOUANVIC Y. (1983). *Métallogenèse à Tungstène-Etain et Or dans le linéament granitique de Monteneme — Nord-Ouest Galice, Espagne—: un example d'évolution dans une zone de cisaillement ductile hercynienne.* Thèse Univ. Nancy I, 249 p.

GUMIEL, P., ARRIBAS, A. (1987). Antimony deposits in the Iberian Peninsula. *Econ. Geology, 82,* 1453-1463.

HARRIS, M. (1980a). Gold mineralization at the Salave gold prospect, northwest Spain. *Trans. Inst. Mining Metall.* Feb. 1980, Sect. B., p. 1-4.

HARRIS, M. (1980b) Hydrothermal Alteration at Salave gol prospect, northwest Spain. *Trans. Inst Mining Metall.* Feb. 1980, Sect. B, p. 5-15.

HEALD, P., FOLEY N., HAYBA, D. (1987). Comparative anatomy of volcanic-hosted epithermal deposits: acid-sulfate and adularia-sericite types. *Econ. Geol.,* 82, p. 1-26.

HEDENQUIST, J. W. (1987). Mineralization associated with volcanic-related hydrothermal systems in the Circum-Pacific basin. In M. K. Horn (Ed.) *Trans. 4th. Circum-Pacific Conference on Energy and Resources.*

HERAIL, G. (1984). *Géomorphologie et gîtologie de l'or détritique. Piémonts et bassins intramontagneux du Nord-Ouest de L'Espagne.* Editions du CNRS, Toulouse.

I. G. M. E. (1984). *Inventario de los Recursos Nacionales de Oro. Primera Fase.* Servicio Documentación, ITGE, Madrid, n.° 10946.

I. T. G. E. (1990). *Panorama Minero* 1990. Secretaría Gral. Energía y Recursos Minerales, Ministerio de Industria, Comercio y Turismo, Madrid, 719 p.

I. T. G. E. (1993). *Las Mineralizaciones de Au-As en el Lineamiento de Puentedeume, La Coruña.* In: Research Project MIDAS, Brite Euram, CEE-DG XII (MA2T, CT90-009).

I. T. G. E. - J. A. *(Junta de Andalucía)* (1986-87). *Revisión del Mapa Metalogenético de España. Area de* *los Macizos Ultrabásicos de Málaga.* Servicio de Documentación, Madrid, 2 vols.

JAHODA, R. (1987). *Geology and genesis of auriferous hydromagmatic breccias and related deposits in Northwestern Spain.* Ph. D. Thesis, Univ. Southampton.

JOHNSON, C. A., CARDELLACH, E., TRITLLA, J., HANAN, B. B. (1993) Origin of the Cierco Pb-Zn vein system (Central Pyrenees, Spain): evidence from stable isotopes, Sr isotopes and fluid inclusions. In: Fenoll Hach-Alí, Torres-Ruiz & Gervilla (eds.) *Curent Research in Geology applied to Ore Deposits,* Univ. Granada, p 135-138.

LAGO, A., CASTROVIEJO, R., NODAL, T. (1989). Las mineralizaciones argentíferas de Plasenzuela, Cáceres. España. *Bol. Geol. y Minero,* v. 100-6, p. 1059-1074.

LEAL, G., CASTROVIEJO, R. (1990). Las Mineralizaciones Auroantimoníferas de Almuradiel (Ciudad Real). X Reunión S. E. M., Oviedo, 4-6 Jul. 1990; abs: *Bol. Soc. Esp. Mineralogía,* v. 13-1, p. 102-103.

LEBLANC, M., JOHAN, Z. (1986). Un nouveau type de mineralisation platinifere: Exemple des filons à arseniures de nickel et chromite du massif lherzolitique des Beni-Bousera (Maroc). *Compt. R. Acad. Sci. Paris, 303,* p. 163-166.

LOCUTURA, J., BELLAN, A. (1987). Prospección Geoquímica multielemental en el área de Benasque (Pirineo Central), España. *II Congr. Geoquímica,* Soria.

LOPEZ RUIZ, J., RODRIGUEZ BADIOLA, E. (1980). La Region Volcánica Neógena del SE de España. *Estudios Geológicos,* 36, p. 5-63.

MARTIN IZARD, A., BOIXET, L., MALDONADO, C. (1993). Geology and Mineralogy of the Carlés Gold-Bearing Skarn, Cantabrian Cordillera, Spain. In: Fenoll Hach-Alí, Torres-Ruiz & Gervilla (eds.) *Current Research in Geology applied to Ore Deposits,* Univ. Granada, p. 499-502.

MARTINEZ FRIAS, J. (1992). The Hiendelaencina mining district (Guadalajara, Spain). *Min. Deposita,* v. 27, N.° 3, p. 206-212.

MARTINEZ FRIAS, J., GARCIA GUINEA, J., LOPEZ RUIZ, J., LOPE GARCIA, J. A., BENITO, R. (1989). Las mineralizaciones epitermales de Sierra Almagrera y de la cuenca de Herrerías, Cordilleras Béticas. *Bol. Soc. Esp. Mineralogía,* 12, p. 261-271.

MELGAREJO, J. C. (1992). *Estudio Geológico y Metalogenético del Paleozoico Sur de las Cordilleras Costeras Catalanas.* Mem. n.° 103, ITGE, Madrid.

MONTERRUBIO, S. (1991). *Mineralizaciones Asociadas a Rocas Ultrabásicas en el Hercínico Español.* Ph. D. Univ. Complutense Madrid, 332 p.

MONTERRUBIO, S., LUNAR, R., OYARZUN, R. (1992). Mineralizaciones de cromo-platinoides y oro en los complejos polimetamórficos de Galicia. *Serie Nova Terra,* Coruña, n.° 9, 114 p.

MORALES S., FENOLL HACH-ALI, P. (1990). Mineralizaciones de Pb-Zn-(Ag) asociadas a rocas volcánicas del distrito de Mazarrón (Murcia). Geoquímica y Metalogenia. *Bol. Soc. Esp. Mineralogía,* 13-1 (abs.), p. 58.

OEN, I. S., FERNANDEZ, J. C., MANTECA, J. I. (1975). The Lead-Zinc and Associated Ores of La Unión, Sierra de Cartagena, Spain. *Econ. Geol.,* v. 70, p. 1259-1278.

OVEJERO, G., JACQUIN, J. P., SERVAJEAN, G. (1976). Les minéralisations et leur contexte géologique dans la Sierra de Cartagena (Sud-Est de l'Espagne). *Bull. Soc. géol. France* (7), t. XVIII, n.° 3, p. 619-633.

ORUETA, D. (1919). Informe sobre el Reconocimiento de la Serranía de Ronda. *Bol. IGME.* t. XL (XX, 2.ª ser.), p. 1-133.

PANIAGUA, A. (1994). *Mineralizaciones asociadas a fracturas tardihercínicas de la Rama Sur de la Zona Cantábrica.* Ph. D. Univ. Oviedo, 1993; abs. in: Bol. SEM, *17* (1994), p. 285-286.

PANIAGUA, A., RODRIGUEZ PEVIDA, L. S., GUTIERREZ VILLARIAS (1988a). Mineralizaciones As-Sb-Au asociadas a rocas ígneas filonianas del NE de León: las minas de Burón. *Bol. Soc. Esp. Mineralogía, 11* (1), p. 35-46.

PANIAGUA, A., RODRIGUEZ PEVIDA, L. S. (1988b). Génesis y evolución de las mineralizaciones de Cu-Co-Ni-U-Pb-Zn-Au-Ag ligadas a las estructuras tardihercínicas en el área de Pajares-Villamanín-Bonar (Norte de León). *Bol. Soc. Esp. Mineralogía, 11* (2), p. 118-119.

PAVILLON, M. J. (1969). Les minéralisations plombo-zincifères de Carthagène (Cordillères Bétiques, Espagne). *Mineral. Deposita,* 4, p. 368-385.

PEREZ GARCIA, L. C., SANCHEZ PALENCIA-RAMOS, F. J. (1992). Los yacimientos de oro de Las Médulas de Carucedo (León). In: *García Guinea, J., Martínez Frías j. (eds., 1988). Recursos Minerales de España.* CSIC, Madrid, p. 861-873.

PORTER, D. H., PANIAGUA, A., SAEZ, J. (1989). Gold Mineralizations of NW Spain. *Excursion 3B*

Guide-Book, Gold 89 in Europe Symp., Univ. Toulouse, May 1989, 43 p.

QUESADA, C. (1992). Evolución Tectónica del Macizo Ibérico (Una historia de crecimiento por acrecencia sucesiva de terrenos durante el Proterozoico superior y el Paleozoico). In: *Gutiérrez Marco, J. G., Saavedra, J., Rábano, I. (eds.) Paleozoico Inferior de Ibero-América.* Univ. Extremadura, p. 173-190.

RIBEIRO, A., PEREIRA, E., DIAS, R. (1990). Structure in the Northwest of the Iberian Peninsula, Central Iberian Zone. In: *Dallmeyer R. D. and Martínez García E. (eds.) Pre-Mesozoic Geology of Iberia.* Springer-Verlag, Berlin, p. 220-236.

RIOS, S. (1980). Nuevas Mineralizaciones de Plomo al Oeste de la Falla de Guarromán (Linares, Jaén). *Jornadas Minerometalúrgicas (VI Nac., IV Internac.),* Huelva, 22 to 27 sept. 1980, p. 205-210.

ROBERT, J. F. (1980). *Etude géologique et métallogénique du val de Ribas sur le versant espagnole des Pyrénées Catalanes.* Thèse Univ. Franche-Comté, Bésançon (France), 294 p.

RYTUBA, J. J., ARRIBAS, A. JR., CUNNINGHAM, G. C., MCKEE, E. H., PODWYSOCKI, M. H., SMITH, J. G., KELLY, W. C., ARRIBAS, A. (1990). Mineralized and unmineralized calderas in Spain; part II, evolution of the Rodalquilar caldera complex and associated goldalunite deposits. *Mineral. Deposita,* 25, p. S 29-S 35.

SANCHEZ PALENCIA-RAMOS, F. J. (1983). *La explotación del oro de Asturias y Gallaecia en la Antigüedad.* Tesis Doct., Univ. Madrid.

SCHNEIDERHÖHN H. (1962). *Erzlagerstätten.* G. Fischer Verlag, Stuttgart, 371 p.

SHASHKIN, V. (1992). *Platínidos en las formaciones de rocas ultramáficas de Galicia.* Conf. XIV Reunión de Geología y Minería del N.O. Peninsular. O Castro, 17-21 nov. 1992. Area Xeol. Minería. Sem. Estudos Galegos, Coruña.

SOLER, A., AYORA, C., CARDELLACH, E., DELGADO, J. (1990). Gold bearing hedenbergite skarns from the SW contact of the Andorra granite (Central Pyrenees, Spain). *Mineral. Deposita* 25, p. 59-68.

TORNOS, F., CASQUET, C., GONZALEZ, J. M. (1993). Comment on the paper by A. Concha *et al.* (1992, reference in this list).

TORNOS, F., LOCUTURA, J. (1988). Mineralizaciones epitermales de Hg-(Pb, Au) en Ossa Morena (Usagre, Badajoz). *Bol. Soc. Esp. Mineralogía,* v. 11 (2), p. 124-127.

TORREZ-RUIZ, J., GARUTI, G., FENOLL HACHALI, P., GERVILLA, F. (1993). Platinum-Group-Mineral and other solid inclusions in chromite from the «Chromite Ores» of the Serranía de Ronda Lherzolite Massifs (Betic Cordillera), Southern Spain. In: Fenoll Hach-Alí, Torres-Ruiz & Gervilla (eds.) Current Research in Geology applied to Ore Deposits, Univ. Granada, p. 583-586.

URBANO, R. (1994). Exploración minera de yacimientos de oro por el Instituto Tecnológico Geominero de España (ITGE). *Bol. Geol. y Minero, 105-6,* p. 537-549.

WHITE, N. C., HEDENQUIST, J. W. (1990). Epithermal Environments and styles of mineralization: variations and their causes, and guidelines for exploration. *Jour. Geochem. Exploration, 36,* p. 445-474.

XUNTA DE GALICIA (1991). *La minería de Galicia.* Consello Ind. Comercio, Dirección Xer. Indust., Santiago de Compostela, 407 p.

Recibido: 7-IV-94

Aceptado: 9-VIII-95