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MINERAL PARAGENESIS IN THE VARISCAN METALLOGENY OF SPAIN *

A. ARRIBAS **

RESUMEN.—Se definen en este trabajo las paragénesis características de los más importantes yacimientos españoles relacionados con la metalogenia varíscica de la Península Ibérica.

En la primera parte se delimitan las áreas ocupadas por las formaciones hercínicas y se resumen los rasgos geológicos, tectónicos y metalogénicos del basamento, tanto del que forma el Macizo Hespérico como del que constituye el núcleo de las zonas arogénicas alpinas.

En la segunda parte se definen las paragénesis en función de sus asociaciones minerales y rocas encajantes, lo que permite clasificarlas en 3 grupos: Varíscicas, pre-Varíscicas y Varíscicas tardías.

Al primer grupo, que es el estrictamente varíscico y por ello el más importante, corresponden 32 asociaciones minerales —(K.U-Ce), (K.Be), (na.U-Ti), (na.Li), (K.Na-Sn), (q.Sn), (q.Sn-W), (q.W), (q.W-B), (q.As-U), (q.Mo-Au), (q.P), (sk.U-Mo), (sk.Pol-Fe), (q.Co-Ni-Bi), (Co-Ni-Cu), (q.Ba-Pb-Ag), (q.Cu), (q.Pb-Ba), (q.Pb-Zn), (f.Zn-Pb), (c.Zn), (e-Fe-Cu), (e.Fe-Pol), (e.q-Mn), (q.U-Cu), (q.U-Fe), (q.U-BG), (q.U-F), (Sb), (q-Sb), (Sb-W) y (Sb-Hg)— de carácter pegmatítico, filoniano, metamórfico y volcano-sedimentario.

En el segundo grupo hay 12 paragénesis —(a.Ti-Zr), (a.Sn-Ce), (sk.W), (Fe), (v.Fe-Pol), (v.Fe-Cu), (v.Ba-Mn), (v.Hg-Fe), (m.Ti-Cr), (m.U-Ni-Co), (m.BGPC) y (m.Hg-Ba)— de naturaleza ígnea y metamórfica. Y en el tercero se incluyen 2 asociaciones minerales —(F.Ba) y (Ba-Fe)—, una sedimentaria y otra filoniana, situadas en sedimentos triásicos cuya edad es superior a 220 m.a., ya que ésta se ha considerado como el límite superior de los fenómenos metalogénicos alpinos.

SUMMARY.—The mineral paragenesis which characterize the most important Spanish ore deposits related to the Variscam metallogeny are given in this paper.

In the first part, the limits of the Hercynian orogenic belt of the Iberian Peninsula are established, and summarized the main geological, tectonic and

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** Department of Geology and Mineralogy, University of Salamanca (Spain).

metallogenic features of the basement which makes up both the Hesperian Massif and the inner zones of the Alpine orogen.

In the second part, the paragenesis are defined. This is made according to their mineralogy and host rocks, which allows to classify the mineralogical associations in three groups: Variscan, pre-Variscan, and late-Variscan.

The first group is the most important as it is formed by the strictly Variscan mineral associations. It includes 32 paragenesis —(K.U-Ce), (k.Be), (na.U-Ti), (na-Li), (k.Na-Sn), (q.Sn), (q.Sn-W), (q.W), (q.W-B), (q.As-U), (q.Mo-Au), (q-P), (sk.W-Mo), (sk.Pol-Fe), (q.Co-Ni-Bi), (Co-Ni-Cu), (q.Ba-Pb-Ag), (q.-Cu), (q.Pb-Ba), (q.Pb-Zn), (f.Zn-Pb), (c.Zn), (e.Fe-Cu), (e.Fe-Pol), (e.q-Mn), (q.U-Cu), (q.U-Fe), (q.U-BG), (q.U-F), (Sb), (q.Sb), (Sb-W) and (Sb-Hg)— of pegmatitic, vein-like, metamorphic and exhalative-sedimentary origin.

In the second group, 12 igneous and metamorphic paragenesis —(a.Ti-Zr), (a.Sn-Ce), (sk.W), (Fe), (v.Fe-Pol), (v.Fe-Cu), (v.Ba-Mn), (v.Hg-Fe), (m.Ti-Cr), (m.U-Ni-Co), (m.BGPC) and (m.Hg-Ba)— are included. Finally, in the third group, 2 paragenesis —(F.Ba) and (Ba-Fe)—, one sedimentary and other hydrothermal, occur in Triassic sediments, the age of which is older than 220 m.y. This age has been considered as the upper limit of the Alpine metallogenic processes.

I.—LIMITS AND GEOLOGY OF THE SPANISH HERCYNIAN BASEMENT

The Iberian Peninsula is a well defined although a rather complicated geotectonic unit in the southwestern corner of Europe (Fig. 1).

From the stratigraphic point of view, the Peninsula consists of four main geological formations: (1) a few Precambrian units which were folded prior to the Hercynian orogeny; (2) the Paleozoic and most of the Precambrian, folded simultaneously during the Hercynian orogeny; (3) the Mesozoic and Cenozoic sedimentary rocks included in the Alpine orogen; and (4) the Cenozoic and some rare Mesozoic sediments which were not involved in this orogenic system. It should be pointed out that all the Precambrian was incorporated into the Hercynian orogeny. Therefore, it crops out only in the cores of some Hercynian anticlines. The Paleozoic rocks not deformed by the Hercynian orogeny are very scarce.

Structurally, the Peninsula is build up of two main tectonic assemblages (Fig. 2): the Hercynian basement and the Alpine cover. The two are always present in the major geotectonic units of the Peninsula.

The Hercynian basement, which extends mostly to the west, occupies a broad surface of Spain and Portugal. It has been called the Hesperian Massif, and represents the southernmost part of the West European Variscan orogenic Belt. On both sides, especially to the east, the basement is largely covered by the Mesozoic and Cenozoic sediments of the Alpine orogene, but it still outcrops in the innermost parts of the other five major tectonic units of the

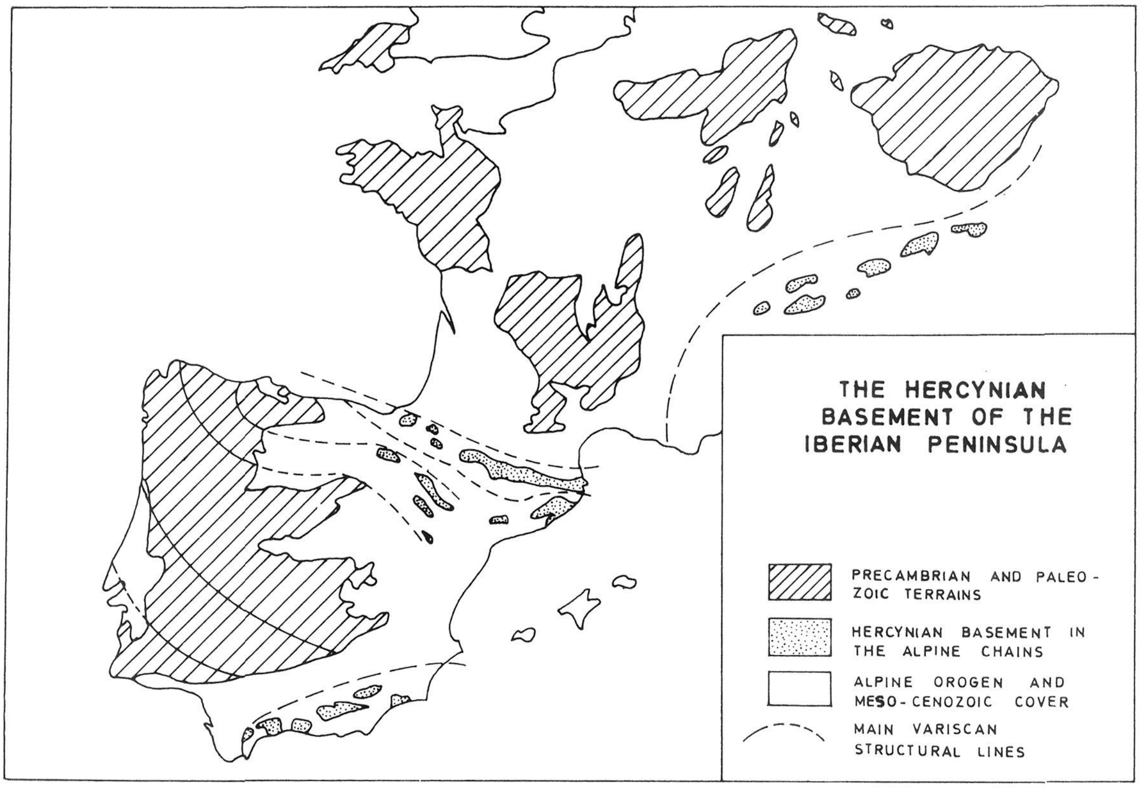

FIGURA. 1

Peninsula: the Cantabrian and Iberian Chains, the Catalonian Coastal Range, the Portuguese Mesozoic Belt, the Betics, and the Pyrenees. However, in some of these units, it is sometimes difficult to establish the relationship between the Paleozoic formations and the Hercynian basement because the original features of the rocks have been strongly modified by the Alpine movements.

During the Alpine orogeny, a faulting tectonics was superimposed on the basement and gave place to the formation of five main tectonic basins: the Ebro, Duero, Tajo, and Guadalquivir Basins in Spain, and the Sado Basin in Portugal. All belong to the same fracture system which has developed in Europe since the beginning of the Tertiary. Important uplifts such as the Axial Zone of the Pyrenees, the Sierra Nevada, and some units of the Central Cordillera, resulted from the same tectonic event.

1. Geotectonic evolution of the Hesperian Massif

The Hesperian Massif, named henceforth the Iberian Meseta when referring to the Spanish side, has been a broad platform of relative structural stability since the beginning of the Tertiary. It is limited by the Basque-Cantabrian Chain on the north; by the Iberian Range on the east; by the Guadalquivir Fault, which can be traced along more than 400 k., on the south; and by the Porto Fault, which separates the Meseta from the Portuguese Mesozoic Coastal Range, and the Sado Basin, on the west.

The Meseta consists of plutonic and metamorphic rocks ranging in age from Precambrian to Permian. In general, they strike NW from the Guadalquivir Fault up to beyond the Portuguese and Galician border, then bend to the N and even to the NNE when approaching the Atlantic coast in Northern Spain.

The oldest geological formations in the Hesperian Massif belong to the upper levels of the Precambrian. In Galicia, they consist of several lithological units: the mafic and ultramafic plutonic and polimetamorfic rocks of the Ortegal, Ordenes and Lalin Complexes, and the acid volcanics, pelitic schists and graywackes of the Narcea Anticline and the core of the Mondoñedo recumbent fold. In the central areas of the Meseta, these pelitic rocks are quite similar to those of the pre-Ordovician formations. Therefore, when no Cambrian quartzites or limestones are present, it is impossible to discern the limits of these formations, and they are represented as a unit in the geological maps of Spain and Portugal. This unit is named the «Pre-Ordovician schist and graywake complex» or the «Beiras formation», because it is in this Portuguese province where their outcrops are more important.

Most of the Iberian Meseta is made up of Paleozoic rocks, metasediments and metavolcanites, which have been metamorphosed to varying degrees, mainly in the greenschists facies. Quartzites, shales, carbonate rocks, micaschists, and differente kind of gneisses, as well as lava flows and tuffs, ranging from basalts to rhyolites in composition, with interbedded spilites and keratophyres and flysch deposits, particularly in the northwestern corner of the Meseta, are the most common rock formations. The whole sequence was intruded by large volumes of granitic rocks during the Hercynian orogeny (Fig. 3).

The geology of the Iberian Meseta has been synthesized in many papers, among others, LOTZE (17), SOLÉ (21), CAPDEVILA et alt. (7), and JULIVERT et alt. (15). On this base, the Meseta can be subdivided in five units running parallel to the Hercynian fold axes (Fig. 2). They are, from north to south, the Cantabrian (I), West Asturian-Leonese (II), Middle Galicia-Tras-os-Montes (III), Central Iberian (IV), Ossa-Morena (V), and South Portuguese (VI) Zones. All are well characterized by their lithological, paleogeographical, tectonic and metallogenic features. And it is interesting to note that, for most of these features, the Hercynian orogenic belt shows a roughly bilateral symmetry: Upper Paleozoic formations occur towards the margins, and Upper

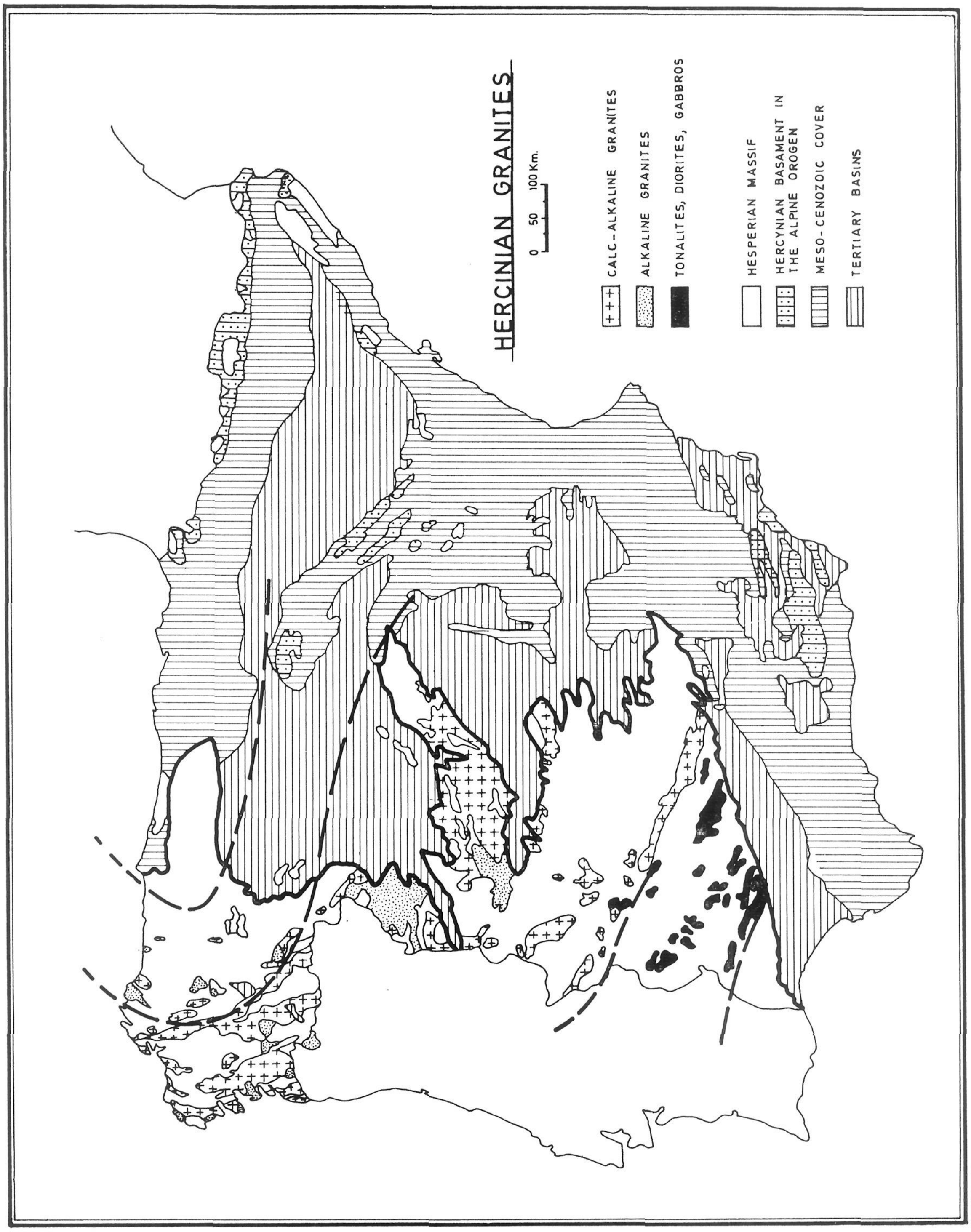
HERCINIAN GRANITES
0 50 100 Km.
CALC-ALKALINE GRANITES
ALKALINE GRANITES
TONALITES, DIORITES, GABBROS
HESPERIAN MASSIF
HERCYNIAN BASAMENT IN THE ALPINE OROGEN
MESO-CENOZOIC COVER
TERTIARY BASINS

FIG. 3

Precambrian, Lower Paleozoic and plutonic rocks prevail in the central areas. As the younger formations show opposite overturns, the Meseta seems to be a big anticlinorium in which the mineral deposits broadly follow a pattern of symmetrical distribution.

Although pre-Hercynian orogenic movements, probably related to the Caledonian Sardian phase, are known in some scattered points of the Iberian Meseta, the most important tectonic, magmatic, and metamorphic features displayed in the basement are Hercynian, and took place 340 to 280 m.y. ago between the Lower Visean and Upper Stephanian times.

Later on, a new period of deformation gave place to an important Late Hercynian fracture system in which long strike-slip faults, trending dominantly to the NE, NW and E-W, prevail. Some of these fractures were reactivated during the Alpine orogeny, at the end of the Tertiary, giving place to a block tectonics that sometimes produced vertical displacements of more than 1.500 m.

A summary of the geology of the Portuguese part of the Hesperian Massif is included in the paper presented by THADEU (22) at the IAGOD Seminar. Therefore, as the main geological features of the Meseta are very much the same in Spain and Portugal, this contribution should be consulted for a better understanding of the geotectonic and magmatic evolution of the Zones (III) and (IV) which are shared by both countries. For the whole of the Massif, the most relevant metallagenic features are summarized below.

a) *The Cantabrian Zone (I)*

The Cantabrian zone occupies the inner part of the Hercynian arc in northern Spain, the so-called Asturian knee. This zone is characterized for a small development of the Lower Paleozoic, mainly Cambrian to Ordovician. From Devonian to Lower Carboniferous, an important transgresion took place in the area. It reached its maximum extent during the Westphalian, when a sequence of sandstones, shales, and carbonate rocks, several thousands of feet thick, was deposited. These rocks were deformed by two tectonic phases —one between the Namurian and Westphalian, the other before the Stephanian— which produced overthrusts and upright folds respectively. Metamorphism, when existent, is regional and low grade. Several important coal deposits occur in this zone as well as some minor mercury, copper, barite, and antimony ores.

b) *The West Asturian-Leonese Zone (II)*

This zone is bounded by two antiforms which correspond to the Narcea and «Ollo de Sapo» anticlines. It consists mainly of monometamorphic rocks, Lower Paleozoic in age, made up of Cambrian, Ordovician, and to a lesser extent Silurian quartzites, schists, and occasional limestones. All these materials have undergone two main Tectonic deformations. The first, pre-Visean in age, produced overturned and recumbent folds, such as those of Mondoñedo and Caurel, whereas the second gave place only to upright folds in pre-Westphalian times. Both the number of granitic intrusions and the intensity of the regional metamorphism increase to the west. Several anthracite beds and two ironstones deposits are being mined here. Also, some significant lead-zinc orebodies are either being worked or explored in this zone, mainly in the Cambrian limestones and the Ordovician quartzites.

c) *The Middle Galicia (III) and Central Iberian (IV) Zones*

This zone is the largest geotectonic unit in the Meseta. It extends for more than 600 k. from Galicia, in the north, through the northern half of Portugal, to the Pedroches batholith, in the south, making up the real backbone of the Iberian Peninsula.

Two lithological formations have been recognized in this unit. The oldest, which consists mainly of pre-Ordovician rocks —Precambrian and Lower Paleozoic, some of them pertaining to the monotonous Beiras formation— extends mainly to the north, its metamorphic degree varying from the chlorite to the sillimanite zone. However, within the northern part of Galicia, three overthrusts of old Precambrian polimetamorphic rocks, the Ortegal, Ordenes and Lalin basic complexes —which could be mantle plumes according to van CALSTEREN et alt. (6)—, as well as the so-called blastomilonitic graben, show mineralogical assemblages of the amphibolite, granulite and eclogite facies which occasionally have been retrograded by a regional metamorphism of lower degree. All these rocks, which make up the Middle Galicia Zone (III) and its continuation in Portugal with the Trás-os-Montes complexes of Braganca and Morais, have been subjected to an intense mineral exploration. So far, one workable copper orebody and some minor chromite occurrences, all associated with mafic and ultramafic rocks, have been found there.

The younger formation, made up essentially of Cambrian to Silurian and, in a few places, Devonian slates, conglomerates, basic and acid volcanics, and occasionally limestones, underlies the southern half of the zone. In this area, regional metamorphism, when existing, is only of the greenschist facies. Besides this, three important geological features make this zone clearly different from the others of the Hercynian Meseta: (1) the sharp unconformity between the thick Lower Ordovician quartzites and the underlying Cambrian and Precambrian basement; (2) the regularly spaced, parallel, synform structures of the sedimentary sequences; and (3) the large amount of syntectonic and post-tectonic granitic intrusions to which several important ore deposits are genetically associated (Fig. 3).

In the Central Iberian Zone, two main tectonic phases have been recognized. They are similar in age and style to those of the western Asturian Zone, but in the southern part, the axial planes of the pre-Visean folds are subvertical.

The magmatic activity was dominantly granitic, and gave place to granitoids of different age and composition. The geochemical features of these rocks are given in several papers, among them, those by OEN (18), CAPDEVILA et alt. (7), CORRETGÉ et alt. (8) and APARICIO et alt. (1). As these granitoids could have been affected by the last main Variscan tectonic phase, there are syn to late kinematic and postkinematic plutons, the so-called younger and older granites.

The first type, consisting mainly of leucogranites rich in alcalis and alumina, with almost exclusively muscovite, frequently contains appreciable amounts of cordierite, andalucite, sillimanite and tourmaline, and show high $^{87}Sr/^{86}Sr$ ratios. The emplacement of these granites is closely dependent on the tectonic processes and metamorphism of the basement. They were apparently formed by humid anatectic fusion in the middle levels of the crust. Occasionally they show a later albitization stage which sometimes is clearly related to the formation of the uranium and tin deposits.

The second type of granitoides consists mostly of rocks of calc-alkalic composition, adamellites and granodiorites, which intruded the crust during the latest episodes of the Hercynian orogeny, mainly after the climax of the major tectonic events. Their emplacement took place in zones of structural weakness, and they were probably originated by melting of lower crust materials contaminated by basic rocks of infracrustal origin in a dry environment during regional metamorphism. The deep-seated origin of these granitoides is also confirmed by the low $^{87}Sr/^{86}Sr$ ratio.

Important uranium deposits, mostly veins in the granites and surrounding metasediments, and some interesting pegmatites, which contain beryl, niobium, tantalum, lithium, and rare earth minerals occur in this zone. The most significant ore deposits, however, are those of tin, tungsten, antimony, lead, zinc, copper, and mercury.

The Sn-W ores are associated with intrusions of syn- and late kinematic granites. They occur as veins and lodes which traverse both the granite and the adjoining schists, or as greisen bordered veins in the extremely altered apices of the granitic bodies. The possibility that some deposits can be associated with older granites is not precluded.

Several Au-Ag occurrences in the Meseta are genetically related to the

Sn-W mineralizations. The same is true of some Sb-Au ores which frequently contain scheelite as an accesory mineral.

The Pb-Zn, Pb-Zn-Cu, and Pb-Ag ores occur as sulfide vein-type deposits. They lie both within the granite and far from the igneous rocks, and they are nearly always fault controlled. Several important deposits are widely distributed along this Central Zone. Special atention should be drawn on the Linares and Peñarroya mining districts, which for a long time were the most important lead producers in Europe. They are located on the eastern and southern margins of the Pedroches batholith, which stands out for its remarkable mineral zoning. Here, closest to the plutonic body, or extending well into them, some pegmatites and uraniferous veins, and several small Sn-W occurrences are present. Next to the granite, there are some minor Ni-Co-Bi occurrences, all mined out, which are followed outward by numerous Pb-Zn-Ag ores. Although most of them are exhausted, some are still in operation. For example, the Los Guindos vein, to the NE of Linares, is more than 9 mi long; in some places, the oreshoots of silver-rich galena were more than 6 ft across. Finally, farthest from the granite, several Cu-Fe, hematite, and mercury deposits occur.

The most important and famous mineral deposit in this zone is Almaden, the world's biggest mercury mine. The deposit is located on the northern slope of Sierra Morena, on a ridge of Silurian quartzites which makes up the southern flank of the so-called Almaden syncline. Some layers of siltstones, carbonaceous shale, and minor basic lavas and tuffs are interbedded in the quartzites. Faulting is clearly post-ore, as the faults cut off the mineralized beds, and are barren. The Almaden orebody, as well as three other exhausted mines, and several minor occurrences located along the northern flank, now under exploration, are all in the same stratigraphic unit of the Silurian quartzite. Accordingly the mineralization is now regarded as typically strabound.

During the Tertiary, the faulting tectonics gave rise to a number of important structural features in the Iberian Meseta. Among other zones of the basement, Galicia, in the NW corner of the Peninsula, was intensely fractured with development of several tectonic basins in which thick beds of lignite were deposited. In the Central Iberian Zone an outstanding NE- trending horst, the Central Cordillera, with vertical displacements of more than 2.000 m., led to the development of the Tajo and Duero Basins where some evaporite deposits of glauberite and mirabilite are in operation.

d) *The Ossa-Morena Zone (V)*

It consists mainly of slightly to highly metamorphosed Cambrian and

Precambrian rocks, locally reaching the amphibolite facies, conformably overlain by some minor monometamorphic Silurian and Devonian sediments. The zone is separated from the Central Iberian by a major overthrust, which accounts for the strong paleogeographic differences between the two zones. The Precambrian, more than 5.000 m. thick, includes polimetamorphic slates, graywackes, micaschists, quartzites, amphibolites, and gneisses. The Cambrian, locally as thick as 2.500 ft., is made up of slates and carbonate rocks, with interbedded volcanites. The same kind of rocks build up the scarce Silurian and Devonian formations present in the Zone.

Two main tectonic events are recognizable here. The first, probably Visean in age, gave place to overturned and recumbent folds towards the foreland. The second, represented by upright folds, took place during Westphalien times.

The granitoids differ considerably from those of the preceding Zone, Now, the dominant calc-alkalic rocks, mostly granodiorites, are accompanied by tonalites, quartzdiorites, and even more basic types such as diorites and gabbros. In that case, some of the rocks were probably formed by magmatic differentation.

The ore deposits are also of a completely different kind, and seem to be transitional to those of the following Zone. In the western side of the area, there are some workable iron and sulfide deposits which are associated with a Cambrian to Silurian volcanic-sedimentary sequence. Along with the country rock, the ores have been repeatedly metamorphosed in differing degrees, mostly in the amphibolite and greenschists facies, during the Hercynian orogeny. They occur both in the volcanites, which are mainly highly silicified rhyolites, and in the interbedded carbonate layers. In contrast, in the eastern side, several pyrometasomatic iron deposits stretch along the contact of granodiorites and diorites with the Cambrian limestones.

e) *The South Portuguese Zone (VI)*

This Zone lies almost entirely in Portugal. It is separated from the Ossa Morena Zone by an overthrust, with the Cambrian and Precambrian formations lying on the Upper Devonian to Upper Westphalian epimetamorphic rocks which make up this southernmost part of the Iberian Meseta. A generalized stratigraphic sequence of this region shows, from bottom to top: (1) Siliceous and pelitic schists of unknown thickness, containing some fossiliferous limestones of Famenian age near the top: (2) A volcanic-sedimentary formation made up of a big pile of tuffs and lava flows, basaltic to rhyolitic in composition, and (3) A thick flysch sequence, consisting of shales and graywackes, and interbedded conglomerates, Upper Visean to Upper Vestphalian in age.

The volcano-sedimentary formation makes up the so-called Iberian Pyrite Belt, which extends from the north of Sevilla in Spain, to Lousal, near the Atlantic coast, in Portugal. The Belt, a typical eugeosynclinal rock sequence, consists of carbonaceous black shales, andesitic to rhyolitic tuffs and lavas, rocks of the spilite-quartz keratophyre association; volcanic chemical sediments; rocks and ores of the manganese-jasperoid and the pyritic iron formations, and some very large stratiform sulfide deposits of the marine-volcanic association. Along the Belt, which occupies an area 120 K long and 10 K wide, there are 60 operating or abandoned mines, and more than 300 sulfide occurrences. The Belt contains more than 500 million tons of proven ore and another 500 million tons of estimated reserves. Most of the orebodies are lenses of massive pyrite, occasionally copper-bearing, which can be, as in the case of the Río Tinto orebody, as large as 3 K long, 300 m thick, and 400 m deep. Other deposits consist of very thin, alternating layers of chalcopyrite, pyrite, sphalerite and galena, in which the remaining sedimentary structures —load casts, slumpings, gradded bedding— can be still observed. Most of the deposits occur between the extremely altered lavas and the overlying pyroclastics, within the tuffs, or between these rocks and the overlying shales.

The tectonic deformations in the South Portuguese Zone are not so intense as in the preceeding one. However, during the Middle Westphalian, isoclinal folding, overturned and recumbent folds towards the SW., and imbrications, specially conspicuous when the more competent masses of pyrite are present, are regular features in the area. The magmatic events are also less important than in the Ossa-Morena Zone, and the granodiorites are restricted to the boundary with it.

2. The hercynian basement in the alpine orogene

During the Mesozoic, the Hesperian Massif tended to be an upthrown block sourrounded by areas of marine sedimentation, the margins of which offer important differences. So, on the north, northwest and southwest, the Iberian Meseta is bounded by oceanic basins; on the southeast, by a mountain chain of the alpine type, the Betics, and its foredeep, the Guadalquivir Basin; and on the northeast, by a broad and highly deformed platform which gives support to the Cantabrian, Iberian and the Catalonian Coastal Ranges. This platform contains also an important marginal depression, the Ebro Basin, which to some extent could be considered as the foredeep of the Pyrenees. In all these units, the Hercynian basement outcrops (Fig. 2).

a) *The Basque-Cantabrian Range*

It borders the Meseta to the north, representing the western extension of the Pyrenees. The eastern half corresponds to and axial depression where Mesozoic and Cenozoic sediments are present. To the west, the fold axes rise again, and the Hercynian basement crops out on the northern border of the already mentioned Cantabrian Zone of the Meseta. Here, a block of slightly folded and strongly faulted Mesozoic and Cenozoic sediments forms the western end of the Range, and is abruptly cut off by the northern coast of Spain. However, the most recent works carried out on the continental shelf have proved that the Mesozoic and Cenozoic sediments extend offshore, under the Atlantic Ocean, at the bottom of a west-trending submarine basin which extends all along the coast from the Bay of Biscay to Galicia. This basin is bounded by an outstanding tectonic structure, the Labrador-Biscay Fault, striking WNW, which seems to coincide with one of the longest transform faults of the North Atlantic.

Some important mineral deposits occur in the Range. The biggest fluorite deposits in the Peninsula occur in the Triassic. There are some minor mercury and barite occurrences, and several important salt domes which pierce through the Tertiary. In the Upper Cretaceous, there are numerous stratiform lead-zinc orebodies of the Mississippi-Valley type, and the iron ores of Bilbao.

b) *The Iberian and the Catalonian Coastal Ranges*

They consist of an irregular network of mountains in which the Hercynian basement is overlain by an episcontinental sequence of Mesozoic, locally Eocene, sediments. The main character of these mountain chains is their irregularity. They consist of several «en échélon» faults which cut across the Paleozoic basement and the overlying sediments. Both the Iberian Range, which occupies and intermediate position between the Meseta and the Ebro Valley, and the Catalonian Coastal uplift are minor chains comparable in structure to the epidermic folding of the Jura. In the Iberian chain, the Paleozoic formations show analogous composition —schists, quartzites, and occasionally limestones— to those of the West Asturian Zone. The Mesozoic consists of a whole sequence extending from the Triassic to the Jurassic and Cretaceous. All these terrains, along with a few Eocene outcrops, show predominantly a carbonate facies. There are two important exceptions: the arkosic sandstones and the conglomerates of the Lower Cretaceous, namely the continental sediments of Weald and Albian age.

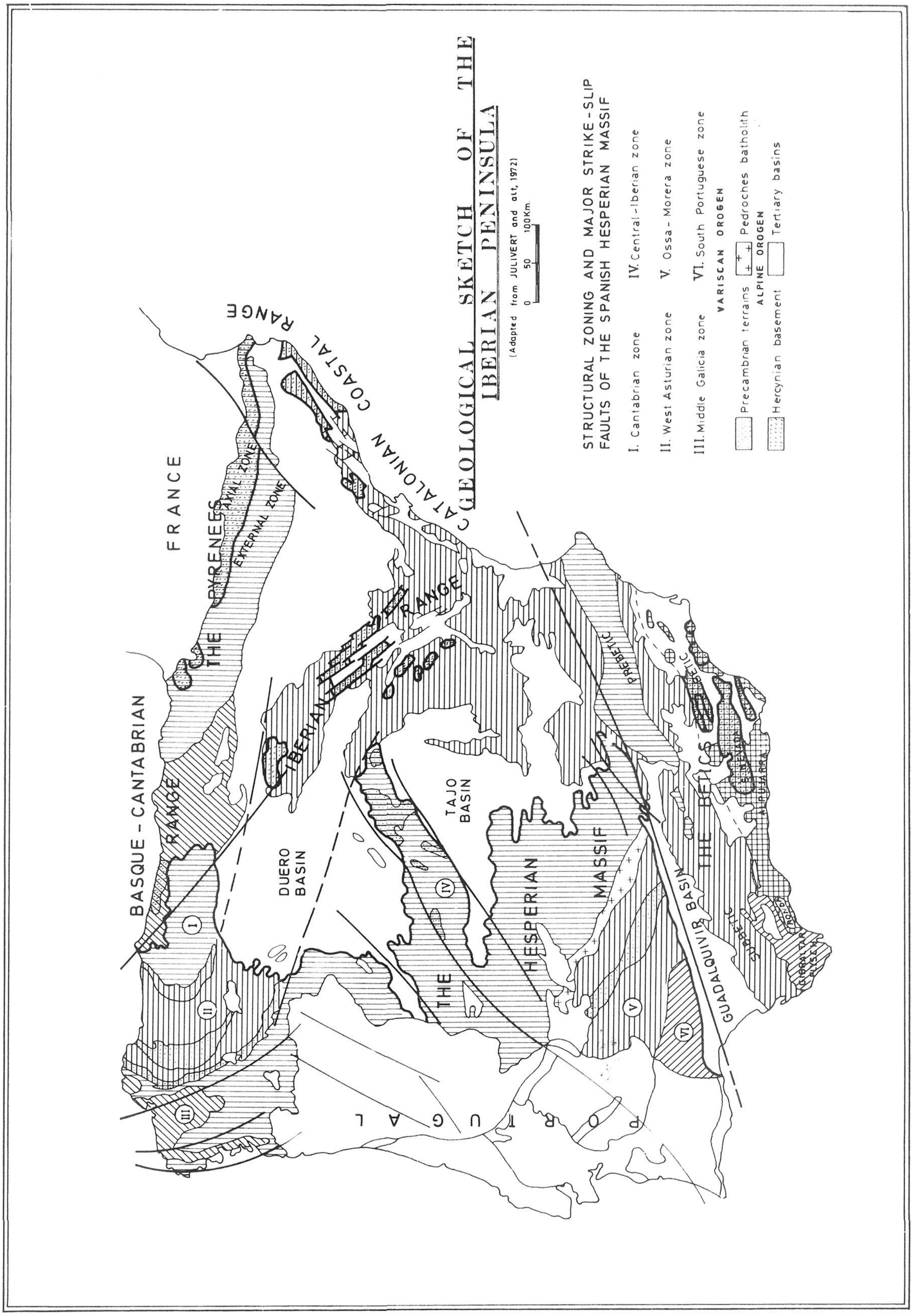
GEOLOGICAL SKETCH OF THE IBERIAN PENINSULA
(Adapted from JULIVERT and al., 1972)
0 50 100Km
STRUCTURAL ZONING AND MAJOR STRIKE-SLIP FAULTS OF THE SPANISH HESPERIAN MASSIF
I. Cantabrian zone
II. West Asturian zone
III. Middle Galicia zone
IV. Central-Iberian zone
V. Ossa-Morera zone
VI. South Portuguese zone
VARISCAN OROGEN
Precambrian terrains
Pedroches batholith
Hercynian basement
ALPINE OROGEN
Tertiary basins
FRANCE
THE PYRENEES
AXIAL ZONE
EXTERNAL ZONE
BASQUE-CANTABRIAN RANGE
CATALONIAN COASTAL RANGE
THE IBERIAN RANGE
DUERO BASIN
TAJO BASIN
THE HESPERIAN MASSIF
GUADALQUIVIR BASIN
THE BETICS
PREBETIC
SUBBETIC
P O R T U G A L

FIG. 2

Consequently with the composite character of these tectonic units, the mineral deposits are also diverse. In the Paleozoic basement there are several mineable Pb-Zn-F-Ba hydrothermal veins and some minor Ni-Co-Au occurrences, both related to the Hercynian granites. Also in the Paleozoic of the Iberian Range, some workable coal measures, nearly all mined out, and two relatively large iron deposits of Silurian age occur. The Mesozoic of the Iberian Range contains some small metasomatic and vein-type iron deposits, and several Pb-Zn occurrences of the Mississippi-Valley type which occur in the same stratigraphic member as those of the Cantabrian Range. Furthermore, there are some important and occasionally radioactive lignite deposits. Also, the largest and most significant radioactive occurrences in the peninsula are now under exploration in this zone. They are Wyoming-type arkosic sandstones.

Between the Iberian and the Catalonian Coastal Ranges, on the south, and the Pyrenees, on the north, is the Ebro Basin. It corresponds to a large downthrow block which was largely covered by thick Tertiary sediments produced by the fast erosion of the mountains built by the Alpine orogeny. Since the Upper Eocene, the Basin has been almost completely isolated from the Mediterranean by the uplift of the Catalonian Coastal Range. The environment then created favored the formation of the big halite and potash deposits of the Navarre and Catalonia areas. Here, gentle folds of Miocene age trended across the Oligocene salt basins, giving place to intensely distorted salt domes which pierced to the surface and are still growing at a rate of one inch per year.

The Basin subsided more strongely to the NW, where more than 13.000 m of Oligocene conglomerates and other clastic sediments have been drilled for oil without reaching the underlying Cretaceous limestones. However, it has been in the Cretaceous sediments underlying the Tertiary on the eastern side of the Catalonian Coastal Range where the first economic, offshore oil wells, now in production, have been found in Spain. The later uplift, which was also stronger on the NW, resulted in the slight tilting of the Basin to the South. In this part of the Basin, other deposits occur, such as the Miocene glauberite deposits of Logroño, and the Oligocene and Miocene lignite beds, sometimes uraniferous, of Aragon and Cataluña.

c) *The Pyrenees*

The Pyrenees, 400 k long and 45 to 80 k wide, separate France from Spain and stretch all the way from the Mediterranean to the Atlantic coasts in the same WNW direction. Geologically, the Pyrenees are a symmetrical fold belt with and elongated core, the Axial Zone, made up of Paleozoic rocks, and two External Zones consisting of Mesozoic and Tertiary sediments. The Pyrenees have been often considered as a good example of a land-locked orogen located between the main continental part of Europe and the Iberian subcontinent. This has resulted in a relatively thin cover of Mesozoic and Cenozoic sediments, which are not truly geosynclinal, but rather epicontinental in character. The Axial Zone consists of granodiorites and Cambrian to Carboniferous sediments which have been intensely folded and subjected to varying degrees of metamorphism during the Hercynian orogeny. The southern border of the Zone consists of many small imbricated thrusts which separtes the Axial from the External Zone.

The External Zone, which has been called the Prepyrenees, corresponds to a shallow geosyncline in which the Mesozoic and Cenozoic sediments were structurally deformed during the Alpine orogeny. The Prepyrenees are subdivided in three parts: (1) The Interior Range, made up of intensely folded and faulted Mesozoic strata, Permotriassic to Cretaceous in age; (2) The Medial Basin, an elongated east-west trending synclinorium of gently folded Paleocene sedimentary rocks which coincides with an important tectonic structure, the South Pyrenean Fault; and (3) the Exterior Range, which consists mainly of folded and faulted Mesozoic strata.

The magmatic activity related to the Alpine orogenic cycle was not important in the Pyrenees. Some acid and basic lavas are interbedded in the Triassic and Cretaceous, and some basalts were extruded in the eastern end of the chain during the Quaternary. But they are clearly post-tectonic, and must be ascribed to the rift system of Western Europe.

The most important mineral deposits in the Pyrenees are all related to the Hercynian orogeny, and occur both in the granites and in the metamorphic rocks. Although in no case is the metallogeny of the Pyrenees comparable, qualitatively or quantitatively, to that of other regions of the Peninsula, some interesting mineral occurrences can be mentioned here. Among them, some Pb-Zn-F and Ni-Co veins, tungsten pyrometasomatic and talc deposits, stratiform lead zinc deposits of Silurian age, Stephanian coal beds and several U-V-Cu occurrences. However, the most interesting orebodies, both from the metallogenic and economic standpoint, are the magnesite deposits of Devonian age in Navarra.

d) *The Betics*

They are one of the main structural units of the Peninsula, which stretches from Cadiz and Gibraltar in the west, to Cartagena and Valencia in the east, bordering the southwestern end of the Mediterranean. Like the Alps, the Betics developed, at least in part, from a true geosyncline. Although this cordillera is only 480 k long and 100 k wide, the tectonic structures extend toward the NE up to the Balearic Islands.

The Betics have been subdivided in three main tectonic assemblages. South of the Iberian Meseta lies the Guadalquivir Basin, which becomes more and more shallow to the east, and is finally replaced by a thin epicontinental cover called the *Prebetic.* It consists of very gently folded Mesozoic sedimentary rocks. To the south of the Prebetic, lies the *Subbetic,* which contains truly geosynclinal rocks of Triassic to Lower Miocene age. Although not intensely deformed, these rocks were sheared off over the evaporites of the Triassic, giving place to epidermic structures —«décollements»— of the Jura-type. The souternmost unit is the *Betic* proper. Very schematically, it consists of five main tectonic units: the allochtonous Sierra Nevada Complex, the Alpujarra and Malaga Nappes, the so-called Gibraltar Flysch, and the Ronda Ultramafic Complex.

The *Sierra Nevada Complex,* which represents the Hercynian basement, is made up of crystalline rocks —micaschists, gneisses, marbles, amphibolites, and serpentines—, several thousands of meters thick. They range in age from Paleozoic, and perhaps Precambrian, to Lower Triassic.

The *Alpujarra Nappe System* consists of three telescoped overthrusts, made up of Triassic shales and carbonate rocks, which contain some Paleozoic schists at the base of the lower unit.

The *Malaga Nappe,* consisting of Paleozoic to Miocene rocks, is the highest structural unit in the Cordillera. It is generally regarded as an allochthonous unit, originated several tenths of kilometers south of the Betic, which moved over the crystalline basement before the uplift of Sierra Nevada. At present, most of the nappe lies to the north of the Paleozoic Complex.

The *Gibraltar Flysch* occupies the westernmost part of the Cordillera. Here, the tectonic structures bend to the south, and extend along the Ultra Rif unit in Northern Morocco. The so-called «flysch» of most writers consists of a sedimentary sequence made up of Cretaceous-Eocene marls and thin-bedded limestones, as well as some Oligocene clastic rocks. This allochthonous unit is supposed to be the cover of the Betic orogene, which slid off to a more external, presently landward position, following the Sierra Nevada uplift. This gravity-driven allochthony should have preceded the counterclockwise rotation, relative to Africa, of the Iberian Peninsula.

Special mention should be made of the *Ronda Ultramafic Complex.* It consists of Alpine-type peridotites, predominantly harzburgites, with minor amounts of dunite and lherzolite, occasionally serpentinized. These rocks also crop out across the Strait of Gibraltar, in Ceuta and Beni Bouchera, on the Moroccan coast. For a long time, these peridotites were considered to be ultramatic intrusions either of Silurian or of Jurassic age. Later on, two other origins have been proposed: (1) Tertonic emplacement of upper mantle material along the border of the European and African plates during the Alpine orogeny. However, no mafic igneous rocks which could represent and oceanic crust, are present. (2) Intrusions of high-temperature mantle material into thin zones of the continental crust subjected to regional lithospheric extension during the Miocene. According to LOOMIS (16), the more recent data concerning the K/Ar age of the contact metamorphic aureole, as well as the fabric of the peridotite bodies and the existence of two zones radiating NE and SE from Gibraltar, both characterized by high positive Bouguer gravity anomalies, seem to support the validity of the last theory.

The magmatic activity was limited to two preorogenic and one postorogenic epochs in the Betics. The preorogenic rocks consist of basalts, spilites, and pillow-lavas of Jurassic and Lower Cretaceous age. The postorogenic epoch is the mos important from the metallogenic standpoint. It includes eruptions of late Miocene to Pleistocene andesites and dacites, and Mediterranean-type potassic volcanites which overlie several areas between Almeria and Cartagena.

The mineral deposits of the Betic Cordillera are numerous and diverse, and occur in both the basement and the Alpine cover. However, the occurrences of the Hercynian basement are limited to some small Pb-Zn, Cu-Fe and Pb-Ag veins in the Sierra Nevada Complex.

The most important orebodies in the Betics lie within the Meso-Cenozoic sediments, mainly in the Alpujarra Nappe System. Here, the Triassic carbonate sequence contains stratiform, finely banded, galena-barite-fluorite —more rarely sphalerite— orebodies. There are also workable iron ores of sedimentary or metasomatic origin, namely on the northern slope of Sierra Nevada, and some small talc deposits which have been originated by silicification and hydration of the carbonate rocks along the shear zones of the Alpujarra dolomites.

In any case, the most interesting mineral occurrences in the Betic Cordillera are related to the Neogene volcanic activity. Among them, the most important are the Pb-Zn-Ag deposits of the Cartagena district and the Au-Te ores of Cabo de Gata.

The famous mineral deposits of the Sierra de Cartagena have been worked, like those of Río Tinto, Almadén and many others, since Phoenician and Roman times. They are of two types: (1) Vein-like, originated in the dacitic and andesitic igneous bodies which cut across the Paleozoic and Triassic rocks of the imbricated Alpujarra Nappe System; (2) Metasomatic, originated through massive replacement of carbonate beds when these beds were invaded by hidrothermal solutions. The carbonates underwent a thorough silicification and greenalitization, and were later mineralized with magnetite, pyrrhotite, and Pb-Zn-Cu-Fe sulfides.

In the Betic Zone, apart from these occurrences, there are two small magnetite deposits and several minor W and Ni-Cr mineralizations near to or in the Ronda Ultramafic Complex, and two strontianite deposits in the Miocene sediments which fill two postorogenic tectonic basins located south of Granada and Murcia respectively.

II.—MINERAL PARAGENESIS OF THE HERCYNIAN BASEMENT

There are many different paragenetic associations in the Hercynian basement of Spain, although only a few are or have been or economic interest *. Most of the mineral associations are found in several deposits; others, in only a few scattered occurrences of the basement.

1. Variscan paragenetic associations

1. *Uranium-cerium potassic pegmatites (k.U-Ce)*

There is only one occurrence in Spain, which is famous for its large brannerite and uraninite crystals. It is located in Sierra Albarrana (Córdoba) where the pegmatite bodies occur in biotite and amphibolite gneisses. They consist of quartz, micas, feldspars, and some beryl and tourmaline, as well as monazite, brannerite (up to 20 cm long), uraninite, rutile, ilmeno-rutile, magnetite, chalcopyrite and pyrite. Among the secondary uranium minerals, autunite, becquerelite, schoepite and torbernite are always present (3).

2. *Beryl potassic pegmatites (k.Be)*

Thet are very abundant and widespread in the metamorphic rocks which surround numerous granitic bodies, especially the leucogranites, of the Central Iberian zone (5).

The mineral assemblage consists of k-feldspars, acid plagioclases, late albite, quartz, micas, and small to large crystals of tourmaline, apatite —sometimes of the wilkeite variety—, and beryl.

* References quoted henceforth refer only to publications containing significant information on the geology of the most important Spanish mineral occurrences.

3. *Uranium-titanium sodic aplites (na. U-Ti)*

Only one locality has been reported, Villanueva del Fresno (Badajoz), in the Ossa-Morena Zone. The ore minerals, pyrite and davidite, the latter up to 2 mm across, are distributed in a albite dyke consisting of fine grained quartz, biotite and albite. The host rocks are Cambrian micaschists and tourmalinized spotted hornfelses (3).

4. *Lithium sodic pegmatites (na. Li)*

They are quite rare, and always related to the cassiterite deposits of the Central Iberian Zone.

In Lalín (Pontevedra), the pegmatite dykes extend in a zone more than 5 km long made up of garnet and staurolite micaschists of Ordovician or Silurian age. They consist of quartz, microcline, albite, muscovite and beryl, with big crystals of spodumene up to 20 cm long. The dykes are crossed by veinlets of quartz with cassiterite, molybdenite, pyrite, and chalcopyrite.

In El Trasquilón (Cáceres), there is a pegmatite body, made up of quartz, albite, k-feldspar and ambligonite, in a leucogranite containing disseminated cassiterite.

In La Fregeneda (Salamanca), a large pegmatite dyke with Li-muscovite and lepidolite is associated with a stockwork of quartz-cassiterite veins crossing the Cambrian schists and amphibolites.

5. *Cassiterite-columbite microgranites (K. Na-Sn)*

Rather numerous, in big dykes or small stocks, they are related to the final evolution of the leucogranites. Many of them have been or are still worked for their tin, niobium, and tantalum content. All these aplitic granites are located in the Central Iberian zone; among them, Penouta and Laza (Galicia), Losacio (Zamora), Golpejas (Salamanca), and Cañaveral, Torrecilla, and Trasquilón (Cáceres) are the best known deposits (4, pp. 109-160).

The mineralogical assemblage consists of quartz, albite, k-feldspar, muscovite (rare biotite), cassiterite, columbite-tantalite, tapiolite (free or included in the cassiterite), ilmenite, rutile, apatite and, occasionally, gold and fluorite. Locally, albitization, muscovitization and caolinization may be very strong.

6. *Quartz-cassiterite association (q.Sn)*

Very frequent, both in quartz veins and stockworks crossing Paleozoic schists and hornfelses, in the exocontact or in the proximity of the Hercynian leucogranites. All the deposits are located in the Central Iberian zone, especially in Zamora (Calabor, Arcillera and Carbajales), Salamanca (Lumbrales, Cubito and Fregeneda), and Cáceres (Teba, Torrecilla, Valdeflores). Tourmalinization of the host rocks is usually very well developed.

Quartz, muscovite, beryl, apatite and tourmaline are the most important minerals accompanying the cassiterite, arsenopyrite and pyrite. Scheelite and wolframite are very rare or absent. However, in some occurrences, like Bustarviejo (Madrid) and Trasquilón (Cáceres), the paragenesis contains small amounts of chalcopyrite, stannite, bismuth, bismuthinite, schapbachite, pyrrhotite, marcasite, sphalerite and galena.

7. *Quartz-casiterite-wolframite association (q.Sn-W)*

This association is very frequent in the Central Iberian Zone. It differs from the preceding type because wolframite and usually some sulphides accompany the cassiterite. Scheelite, although in very small quantitites, may be present. Tourmalinization and greisenization of the host rock is well developed, especially when the veins and stockworks are located in the exocontacts of the granite. Apart quartz, muscovite, apatite, topaz and beryl, the ore minerals are: cassiterite, wolframite, scheelite, arsenopyrite, pyrite, chalcopyrite, molybdenite, bismuthinite, ilmenite and rutile.

Deposits of this type are: San Finx, Lovios, Casayo, Fontao, and Santa Comba (Galicia); Guadalix and S. Rafael (Madrid); Garrovillas (Cáceres); San Nicolás (Badajoz); and several occurrences in the Pedroches batholith (13, pp. 129-131).

8. *Quartz scheelite-wolframite association (q.W)*

This paragenesis is not so widespread as the preceding one, but its deposits are sometimes very important. In fact, the main differences are the absence or scarcity of cassiterite and the presence of scheelite together with wolframite as the tungsten minerals. Copper and bismuth ores are also common, but their amounts differ greatly from one deposit to another.

The mineral assemblage consists of quartz, wolframite, scheelite, pyrite, chalcopyrite, arsenopyrite, ilmenite and bismuthinite. According to the geological setting, two types of deposits can be distinguished here.

8a. *Quartz veins and stockworks in the Cambrian schists* surrounding two micas granites, e.g., Navasfrías and Masueco (Salamanca), La Parrilla and Oliva (Badajoz). In this locality, quartz veins, containing siderite, chalcopyrite, bornite, enargite, chalcocite, covellite, bismuthinite and gold, are present in the same area of the tungsten lodes. Greisenization and tourmalinisation are rare or conspicuosly absent.

8b. *Quartz veins and stockworks in the granite,* near the top of the batholit.

The paragenesis is rather simple, and consists of scheelite —which is the most important W mineral—, wolframite, pyrite and very abundant arsenopyrite. Chalcopyrite, bismuthinite, emplektite, fluorite cassiterite, and tourmaline appear in minor amounts. Sometimes, traces of gold.

The type deposit is Barruecopardo (Salamanca), at present the biggest producer of tungsten in Spain. The so-called stockwork, consisting of a swarm of parallel, subvertical veins, is more than 3 km long, 200 m wide, and 100 m deep. Microclinization is widespread, especially in depth, whereas albitization and greisenization prevail near the cupola of the granite. Here, wolframite, is predominant, accompanied by some cassiterite.

Santa Genoveva, in Salamanca; Santibáñez, in Cáceres; and Ponferrada, in León, are also deposits of this type.

9. *Quartz-scheelite-dravite association (q.W-B)*

This paragenesis occurs in vein-type deposits. It consists mainly of quartz, arsenopyrite and scheelite, ocassionally some tourmaline (dravite), and minor amounts of pyrite, pyrrhotite, apatite, chlorite, muscovite, ilmenita, magnetite and fluorite.

The veins are always associated with stratiform skarn-type scheelite deposits existing in the basement —pre-Variscan (sk.W) association—, to which they cut almost at right angle. The veins are blind and usually restricted to the area of the «skarnoïds», and range in lenght from several centimeters to some meters. Apparently, they are due to the reworking of pre-existing tungsten ores during the Hercynian orogenic cycle. The main differences with the quartz-scheelite association of the preceding type, which is always related to the final stages of the granite evolution, are: the absence of tin; the higher amounts of tourmaline, which is always dravite, as is explained by the high magnesium content of the enclosing carbonate rocks; the lack of connection with any kind of intrusive rocks; and the close spatial relationship with the pre-existing tungsten ores.

10. *Arsenic-gold association (q.As-Au)*

Although gold is frequently found in numerous alluvial placers of the Iberian Meseta, as well as in some stream sediments coming from the Hercynian basement of the Betics, no true gold deposits have been found connected with the Variscan metallogeny. So far, the most significant occurrences correspond to a system of parallel veins and veinlets which cross some strongly oriented muscovite leucogranites in Galicia. They occur near Carballo and Santa Comba, located to the W and NW of Santiago respectively. Besides quartz and gold-bearing arsenopyrite, these veins contain pyrite, chalcopyrite, pyrrhotite, scheelite, and some tourmaline.

11. *Molybdenite-gold association (q.Mo-Au)*

This paragenesis has been found in only one place, in the Salave granitic stock, near Tapia, on the coast of the West Asturian zone. This stock is made up of diorites and granodiorites, and even of more basic differentiates, which have been strongly silicified in some definite areas, especially in the contact with the surrounding Paleozoic schists. In these areas, a stockwork of quartz veinlets, with minor carbonates, contains the following ore minerals: pyrite, molybdenite, stibnite, and gold-bearing arsenopyrite.

It should be emphasized that quartz veins with molybdenite are just mineralogical curiosities in some Variscan plutonites of the Central Iberian Zone, namely in the Guadarrama Mts. Apart from quartz and molybdenite, pyrite, chalcopyrite, stannite and arsenopyrite are the ore minerals most frequently found in these occurrences.

12. *Quartz-apatite association (q.P)*

This is a very peculiar and widespread paragenesis in the leucogranites of the southern half of the Central Iberian zone, more precisely in Extremadura, where they are called «fosforites» (12). The veins —sometimes 1 km long, 1 to 3 m wide, and up to 100 m deep— consist almost exclusively of quartz and apatite, namely of the radial-fibrous variety dahllite.

The veins are found both in the endocontact of some leucogranites (Albalá, Ceclavín, Alburquerque), which themselves are frequently tin- or uranium-bearing, or in the surrounding Lower Paleozoic schists (Aldea Moret, Logrosán, Aliseda).

13. *Scheelite-molybdenite skarns (sk.W-Mo)*

So far, this paragenesis has been reported in the Costabona Mts, in the Hercynian basement of the Pyrenees. It is of the same type than those located on the other side of the French border. Another occurrence is to the north of Alós de Isil, on the northern border of the Beret granite.

The skarns develop at the contact of lower Paleozoic limestones and Hercynian granodiorites, and consist of a calc-silicate assemblage containing scheelite, molybdenite, pyrrhotite, bismuthinite, chalcopyrite, pyrite, arsenopyrite, magnetite and sphalerite. Some wolframite is also present (13, pp. 156-157).

In Sierra Bermeja, close to the Alpine ultrabasic complexes of Ronda, in the Málaga province, there is another skarn-type occurrence with good crystals of scheelite, garnets and magnetite. The host rocks are metamorphosed Paleozoic limestones, but no molybdenite has been reported in this deposit.

14. *Iron-polimetallic sulphides skarns (sk.Pol-Fe)*

Iron skarns are rather frequent at the contact of Cambrian dolomitic limestones and intrusive bodies of monzonites, quartzdiorites, and minor syenites, in the Ossa-Morena Zone. Massive or vein-like pyrometasomatic deposits of this kind, worked out or in operation, are El Pedroso, in Sevilla, and Cala and San Guillermo, in Badajoz. Their paragenesis is rich iron oxides and silicates, polymetallic sulphides, and occassionally radioactive minerals, namely in the orebodies of Tauler and Burguillos (Badajoz) (3).

The mineral assemblage consists mainly of diopside, hedenbergite, hornblende, tremolite-actinolite, hastingsite, andradite, forsterite, brucite, spinel, feldspars, carbonates, biotite, chlorite, allanite, sphene, axinite, clinozoisite, epidote, scapolite and quartz. The ore minerals are mainly magnetite, chalcopyrite, pyrite, marcasite, arsenopyrite, pyrrhotite, cobalthite, löllingite, vonsenite, and uraninite; goethite, malachite, azurite, melanterite and sulphur are frequently found in the oxidation zone.

15. *Co-Ni-Bi association (q.Co-Ni-Bi)*

This association is found in quartz-carbonate veins crossing the contact between the Pedroches granodiorite and the Carboniferous schists sourrounding it in the Córdoba province (5). The small deposits which have been operated there are located on both the northern (Torrecampo, Conquista) and southern (Pozoblanco, Villanueva) borders of the batholith.

The mineral assemblage consists of quartz, carbonates, bismuthinite, bismuth, Ni-Co arsenides, niccolite, gersdorffite, cobaltite, emplektite, tetrahedrite, pyrite, arsenopyrite, and traces of galena, gold and pitchblende. A similar paragenesis, not so significant and showing a poorer mineralogical assemblage, exists at the contact of a granodiorite and the Paleozoic schists and limestones of Gistain, in the Pyrenees of the Huesca province.

16. *Co-Ni-Cu association (Co-Ni-Cu)*

This paragenesis is just a mineralogical curiosity, although some mining was carried out in the Carboniferous limestones of the Villamanin area (León), where most of the occurrences are located (19). It consits of villamaninite —type locality—, linnaeite, chalcopyrite, pyrite, bravoite, niccolite and tetrahedrite, with minor amounts of pyrolusite, psilomelane, heterogenite, malachite and azurite as seccondary minerals.

17. *Pb-Ag-Barite association (q.Ba-Pb-Ag)*

Although at the present time no veins of this type are in operation, this paragenesis has been significant because it produced paying ore in both the Hesperian Massif and in the Hercynian basement of the Catalonian Coastal Range and the Betics.

Among the main deposits of this type are the Atrevida mine, near Vinbodí, and the Eugenia mine, near Bellmunt, both in the Tarragona province. They consisted of large quartz-barite veins which crossed, respectively, the Cambro-Ordovician schists of the Sierra de Prades and the Lower Carboniferous quartzites of the Bellmunt area, in both cases at a short distance of the granite. The paragenesis is: galena, sphalerite, niccolite, gersdorffite, Ni-Co arsenides, maucherite, silver, siegenite, millerite, argyrose, pearceite, hessite and marcasite. In the Bellmunt mine there are also minor amounts of tetrahedrite.

Another important deposit was Hiendelaencina, in the Guadalajara province. Here, the paragenesis is made up of sphalerite, galena, pyrite, chalcopyrite, tetrahedrite, freieslebenite, myargyrite, stephanite, ruby silver, argentite, and only traces of Ni and Co (5). The quartz-barite veins, in that case containing abundant carbonates —mostly siderite and ankerite— cross the facoidal gneisses of the so-called «ojo de sapo» Cambrian formation. The origin of these veins is to be related with the Hercynian granites which outcrop not far from the mine.

18. *Quartz-copper sulphides association (q.Cu)*

Around the Pedroches batholith, a number of quartz veins, containing a paragenesis made up almost exclusively of copper sulphides, is frequently found. These deposits have been worked both in the granite (La Virgen, Villaviciosa) or, most frequently, in the surrounding schists (Hornachuelos, Navalespino, Posadas). When in the granite, they are usually uraniferous and therefore related to the (q.U-Cu) association (4).

Apart quartz, this paragenesis consists of chalcopyrite, pyrite, bornite, tetrahedrite, freibergite, chalcocite, covellite, cuprite, tenorite, and minor amounts of sphalerite and galena. Malachite, azurite, and some barite may also be present.

19. *Pb-Zn association (BGPC)*

This paragenesis is very important in the metallogeny of the Hercynian basement all over Spain. For instance, the Pedroches batholith, especially the Linares district, was the first lead producer in Europe for many years (10). The following paragenetic types can be distinguished according to the peculiarities of the mineral assemblages.

a) *Quartz-galena-barite association (q.Pb-Ba)*

Numerous veins of this group have been or are still being worked in Sierra Morena, both in the granite and in the surrounding rocks. They consist namely of quartz, carbonates, barite, galena —always more or less silver-bearing—, and minor amounts of pyrite, marcasite and chalcopyrite. The age of some galenas coming from deposits of this group has given the following results: Los Guindos, 250 m.y; San Antón, 220 m.y; El Cobre, 220 m.y; and San Juan, 190 m.y. As in other Hercynian areas of Europe the ores belong to a Late-Variscan stage.

Other examples of these lead deposits are located near Pozoblanco, Peñarroya, Almadén and Azuaga, all in the Córdoba province. Alosno (Huelva) and Sotillo (Madrid) are also of the same type. Bono, in the Lérida province, is an example of the deposits located in the Hercynian basement of the Pyrenees.

b) *Quartz-galena-sphalerite association (q.Pb-Zn)*

The gange minerals are still the same, but the sphalerite and galena appear in almost equal amounts. Examples of this intermediate type are Béjar (Salamanca); Guadalcanal, Cazalla and Constantina (Sevilla), and Corumbel (Huelva), where pyrite was predominant. Some deposits such as Escalona (Toledo) and Lumbrales (Salamanca) are uraniferous.

Some poorly known BGPC vein-like occurrences, containing minor amounts of magnetite and pyrrhotite, located in the Cambrian and Ordovician quartzites of the West Asturian zone, such as Oscos, Fonsagrada, Mondoñedo and Caurel, probably are of pre-Variscan age. They have been strongly deformed by the Hercynian orogeny.

c) *Fluorite-sphalerite-galena association (f.Zn-Pb)*

The only difference with the preceding type is the presence and abundance of fluorite. Deposits of this association occur in the Hercynian basement of the Hesperian Massif —Castillo de las Guardas (Sevilla), Cerro Muriano (Córdoba), and Colmenar del Arroyo (Madrid)—; The Catalonian Coastal Range —Osor (Gerona)—; and the Basque-Cantabrian Zone —Arditurri (Guipúzcoa). All are intragranitic except the latter, which is close to the contact.

d) *Carbonates-sphalerite association (c.Zn)*

This type occurs mainly in the Paleozoic schists, mostly Carboniferous, of the Basque-Cantabrian Zone, not far from the granite. The Modesta mine, in Guipúzcoa, is an outstanding example of this paragenesis. It consist of predominant carbonates —mostly siderite—, barite and quartz. The ore minerals are black sphalerite and minor amounts of chalcopyrite, tetrahedrite, pyrite, and galena.

20. *Pyrite-chalcopyrite exhalative association (e.Fe-Cu)*

This paragenesis, consisting mostly of pyrite and minor amounts of chalcopyrite, sphalerite and galena, is characteristic of the sulphide orebodies of the Río Tinto district, the Spanish side of the Iberian Pyrite Belt (4).

The origin of these deposits is clearly exhalative-sedimentary. They are closely related to the submarine, explosive, acid volcanism so extensively developed in the South Portuguese Zone of the Iberian Meseta. However, due to the removilization of some stratiform orebodies during the low-grade metamorphic processes developed contemporaneously with the folding phase, this paragenesis may also be found in some hydrothermal veins, especially in the northern part of the area.

Apart the main constituents of the ore —pyrite, chalcopyrite, sericite, chlorite and quartz—, the following minerals can also be found in different quantities: pyrrhotite magnetite, hematite, marcasite, melnikovite, tetrahedrite, stannite, sphalerite, galena, bornite, linnaeite, enargite and gold. Among the secondary minerals, goethite, cuprite, tenorite, chalcocite, covellite, gratonite, melanterie, voltaite, poitevinita, smolzenikite, jarosite, chalcantite, malachite, azurite, copper and sulphur may be present.

The deposits belonging to this association can be divided in three types: massive, stockworks, and layered pyrite mineralizations, each one presenting some peculiarities in their paragenesis.

The huge size of some massive lenses and layered deposits, e.g., Tharsis, La Zarza, and Río Tinto, especially the latter which consists of two different orebodies —San Dionisio and the Southern Lode—, making up one single orebody more than 3 km long, 200 m wide, and 400 m deep, can be explained by the inflow of sulphide muds and or detrital sulphides into topographical depressions more or less distant from the volcanic centers. Then, the sulphides could concentrate on or amid acid pyroclastic rocks, giving place to massive, autochtonous or subautochtonous orebodies, or in more distant sedimentary facies, originating layered, allochtonous orebodies. In that case, the sulphides are interbedded in shales, frequently with a great amount of carbonaceous matter.

The stockwork type —well developed in Cerro Colorado, San Dionisio, San Miguel and Nuevo Planes— represents the feeder channels, i.e., the original sites of the fumarolic activity through which the arrival of the mineralizing fluids took place. They are normally found directly under or in the vicinity of the pyritic layers.

21. *Fe sulphides-polymetallic exhalative association (e.Fe-Pol)*

This paragenesis is closely related to the preceding one. The main differences are: richer mineralogical assemblages, higher sphalerite and galena content, and an almost exclusive layered structure of the orebodies which frequently show typical sedimentary textures.

Besides the primary and secondary minerals named in the pyrite-chalcopyrite association, the following species can be found, or have been reported, in this paragenesis: arsenopyrite, bournonite, cobaltite, Ni-Co arsenides, freibergite, jamesonite, ullmanite, löllingite, bismuthinite, gersdorffite, argentite, ruby silver, bismuth, stromeyerite, and silver. Usually, baritine and iron rich carbonates are present among the gangue minerals.

Typical deposits of this polymetallic sulphide association, e.g., S. Antonio, Aznalcóllar, Sotiel and San Telmo, are usually found far from the exhalative centers, and sometimes without showing any apparent relation with the volcanic rocks. Their minerals were deposited in a shaly environment, frequently interbedded with tuffs or siliceous layers. The sedimentary textures of the ore, such as graded bedding, breccias, slumpings and load casts, indicate submarine erosion of solidified sulphides and redeposition into new bassins formed by continued volcano-tectonic activity of the sea-floor.

22. *Manganese-jasper exhalative association (e.q.Mn)*

This paragenesis is restricted almost exclusively to the Río Tinto district, where it exists in more them 300 occurrences, mostly of a very small size.

Only two of them have been worked until very recently, but in the past they led to a production of more than 3 million tons, mainly Mn-oxides.

The mineral assemblage is made up of rhodochrosite, rhodonite, ocasionally spessartite, hematite, haussmanite, polianite, braunite, pirolusite, psilomelane, quartz, chalcedony, ankeritic carbonates, dialoguite, sericite, chlorite, and traces of pyrite and chalcopyrite.

The manganese ores occur mostly in lenses of gray, black and red hematitic jasper, derived from radiolarian chert and siliceous shales, interbedded with purple red shales and tuffs, mainly rhyolitic in composition. Sedimentary structures are conspicuous, and sometimes the manganese layers with oolithic texture are more than 1 m thick.

23. *Quartz-uranium association (U)*

Most of the Spanish uranium deposits belong to this group. They are located in the Hesperian Massif, both in the leucogranites or in the peribatholitic, slightly metamorphosed lower Paleozoic sediments. According to their mineral composition, this paragenesis can be divided in four categories.

a) *Quartz-uranium-copper sulphides association (q.U-Cu)*

So far, this paragenesis has been found only in the northern border of the Pedroches batholith. It is closely related to the (q.Cu) association, but when the uranium minerals accompany the copper sulphides, the veins occur only in the granite or in the exocontacts —La Virgen, Navalasno and San Valentín mines, near Andújar (Jaén)—, and no traces of other sulphides have been reported.

The mineral assemblage consists of quartz, minor carbonates, chalcopyrite, bornite, chalcocite, covellite, tetrahedrite, coffinite, pitchblende, and traces of fluorite. Among the secondary minerals, cuprite —sometimes of the chalcotrychite variety—, tenorite, seudomalachite, crysocholla, uranophane, autunnite, torbernite, uranopilite, zippeite and johannite, are the most important (3).

b) *Quartz-pitchblende-Fe sulphides association (q.U-Fe)*

It consists almost exclusively of pitchblende, coffinite, pyrite, marcasite and melnikovite distributed in a siliceous gangue —quartz and jasper, usually hematitic— with traces of calcite. Among the secondary uranium minerals, gummites, autunnite, torbernite, saleite, fosfuranilite, uranophane, iantinite, sabugalite, renardite, kasolite, and francevillite, are frequently found. The nature of the hexavalent minerals depends on the availability or certain cations in the same vein of in other pre-existing mineralizations.

Vein deposits of this group exist both in the leucogranites, e.g., Albalá, Trujillo, and Alburquerque, in Cáceres (3), or in the peribatholitic schists, like C. Rodrigo (Salamanca), Ceclavín (Cáceres) and D. Benito (Badajoz) (2). Due to the oxidation and reconcentration of the uranium near the surface, the occurrences in the schists are so far the most important uranium resources in Spain.

c) *Quartz-ptichblende-polymetallic association (q.U-BG)*

This type differs from the preceding one in which the amount of sphalerite and galena is higher, and because minor amounts of chalcopyrite and barite are also present. Among the secondary uranium minerals, uranocircite and parsonsite are frequently found in these deposits. The best examples of this association occur in Lumbrales (Salamanca) and Escalona (Toledo) (3).

d) *Quartz-coffinite-fluorite association (q.U-F)*

This paragenesis has been found only in the Peralonso deposit, in Salamanca. Here, the most important uranium mineral is coffinite, which occurs in a strongly brecciated granodiorite along a regional tectonic structure (3).

The ore-shoot consists of coffinite, pyrite, marcasite, fluorite (antozonite), gray and red jasperoid quartz, minor amounts of pitchblende, sphalerite and galena, and traces of chalcopyrite. Among the secondary uranium minerals, autunnite, renardite and uranophane are the most frequently found.

24. *Antimony association (Sb)*

Although some deposits have been worked in the past, stibnite deposits are rare in the Hercynian basement and no important producers exist today.

According to the accompanying minerals and the geological setting, three different types of stibnite associations can be distinguished here.

a) *Quartz-stibnite association (q.Sb)*

The veins consist almost exclusively of quartz and stibnite, some pyrite, and traces of sphalerite and galena. This paragenesis is characteristic of the stibnite deposits of Almuradiel (C. Real), Linares (Jaén) and Herrera (Badajoz), which are located in a wide belt running parallel to the Pedroches batholit, in the Central Iberian Zone. Other small deposits of this type have been reported in the West Asturian Zone (11, pp. 19-28).

b) *Antimony-tungsten association (Sb-W)*

Only one operating occurrence is known in the Hesperian Massif: La Codosera mine, near Alburquerque (Badajoz). It consists of stibnite, scheelite, pyrite, and calcite, as well as traces of gold. These minerals fill small fractures and breccias of the enclosing Devonian limestones which extend parallel to the southern border of the Alburquerque batholit (14).

c) *Antimony-cinnabar association (Sb-Hg)*

This paragenesis has been found only in the Cantabrian zone, in the sheared Carboniferous limestones of Mieres, Riaño, Pola, and Somiedo, in the Cantabrian zone. The ore shoot is made up of realgar, orpiment, pyrite, cinnabar, and minor arsenopyrite.

As the tectonic structures with which the ores seem to be connected are probably of Alpine age, the posibility that the mineralization is contemporaneous with this orogenic period has been suggested.

2. Pre-variscan paragenetic associations

There are many and important pre-Variscan mineralizations in the Hesperian Massif. They are related either to sedimentary processes, namely the Ordovician or Devonian iron deposits, or to the Upper Precambrian and Lower Paleozoic plutonites and metamorphites. All of them have been more or less affected by the Hercynian tectonic movements which resulted in the formation of new, and sometimes workable, deposits by remobilization and enrichment of the pre-existing ores.

A) MINERALIZATIONS ASSOCIATED WITH SEDIMENTARY PROCESSES

1. *Rutile-zircon association (a.Ti-Zr)*

This association is found in a consolidated littoral placer formed along a beach in the Lower Ordovician. The quartzite, which is an excellent marker bed, extends discontinuosly from Despeñaperros, in the Jaén Province, through

Almadén and Puertollano, to the San Pedro Mts, in Portugal, for more than 400 km. Its thickness varies from 5 to 60 cm (3).

The paragenesis consists of rutile, zircon, ilmenite titanite, tourmaline, magnetite, monazite, pyrite, graphite, quartz, sericite and chlorite. Ocassionally, it may contain zoisite and detrital feldspars. In some places, the concentration of zircon and titanium minerals may be up to 21 % and 49 % of the rock, respectively.

2. *Alluvial monazite-cassiterite association (a.Sn-Ce)*

Near Conquista (Córdoba), along the northern border of the Pedroches batholith, some workable alluvial deposits, resulting from the weathering of the granite, contain significant concentrations of cassiterite and monazite, with minor amounts of zircon, ilmenite and xenotime. Traces of scheelite, wolframite, gold, and cinnabar are also present. The alluvium urderlies a surface of 1.500 x 300 m, and extend downwards up to 35 m.

3. *Scheelite-calc-silicate association (sk.W)*

In fact, this is a pre-Variscan paragenesis which has been reworked during the Variscan metallogenic cycle, and therefore it could be related to the (q.W-B) association.

Scheelite-bearing calc-silicate assemblages of the skarn type are often found in the strongly folded Cambrian schists of the Central Iberian Zone, in the Salamanca (Morille, Santo Tomé) and Cáceres (Perales) provinces. The «skarnoïds» occur in medium to highly metamorphosed rocks of the «schist and graywacke complex», but they are never found in contact with intrusive rocks.

According to the structure, two types of deposits can be recognized here: stratiform and vein-like. The stratiform orebodies consist of plagioclase, quartz, hornblende, diopside tremolite-actinolite, clinozoisite, titanite, grossularite, idocrase, epidote, biotite, moscovite, calcite, and ocassionally piedmontite. The scheelite is disseminated among these minerals, especially around the garnets, together with apatite, rutile, albite, pyrite, arsenopyrite, chalcopyrite, pyrrhotite, ilmenite, magnetite and fluorite.

Due to their high competence to folding, boudins of these calcsilicate rocks, grading in thickness and length from several centimeters to some meters, are frequently found in all mineralized areas. A metasomatic diffusion of Ca, Mg, Al and Si at the contact of the marly and pelitic layers is responsible for the development of an amphibolite zone at the margin of the boudin plagioclase-zoisite-garnet core.

Later on, at the end of the Hercynian orogeny, a retrograde metamorphic phase gave place to a mineral assemblage of a lower metamorphic grade, and to the recrystallization of scheelite in the quartz-albite veins related to the (q.W-B) association.

4. *Iron oxides association (Fe)*

In this association, four different paragenesis can be distinguished (9):

a) Hematite, goethite, barite and chalcopyrite, in the Cambrian limestones of Peña del Hierro (Sevilla).

b) Hematite, chamosite, magnetite and siderite, in the Ordovician ironstones of Ponferrada (León).

c) Goethite, hematite and barite, in the Silurian sandstones of Sierra Menera (Teruel).

d) Goethite and hematite, in the Devonian sandstones of Furada (Asturias).

All these ores have been more or less modified during the Hercynian orogeny, especially the ironstones, which were partially contact-metamorphosed by the Hercynian granite of Ponferrada.

B) MINERALIZATIONS ASSOCIATED WITH VOLCANIC-SEDIMENTARY PROCESSES

1. *Iron sulphides-polymetallic association (v.Fe-Pol)*

This paragenesis occurs in metamorphic pyroclastic rocks and dolomitic limestones of a volcanic-sedimentary sequence which is very similar to that of the Río Tinto district. The occurrences of this type are numerous along the Aracena anticline, an important structure in the Ossa-Morena zone which runs more or less parallel to the Iberian Pyrite Belt.

The mineral assemblage found in La Nava (Huelva), at present the only operating mine in the district, consists mainly of pyrite, magnetite, hematite, sphalerite, galena, chalcopyrite, pyrrhotite, tetrahedrite, arsenopyrite, bornite, chalcocite and covellite. Among the gangue minerals, quartz, barite, carbonates, diopside, garnet, tremolite-actinolite, zoisite, epidote and micas are the most important. During the Hercynian orogeny, the orebody was strongly folded and faulted, and underwent the effects of a medium to high-grade metamorphism which was followed by a retrograde stage in the greenschists facies.

Of the same paragenetic type are the lead-zinc deposits occurrying in the Hercynian basement of the Pyrenees, namely in the moderately metamorphosed Cambro-Ordovician siliceous schists and tuffs of the Arán Valley, and in the Devonian limestones of Bonabé, both in the Lérida province. The paragenesis consists mostly of pyrite, chalcopyrite, sphalerite, galena, magnetite, and hematite. These deposits, which have been considered for a long time only as vein-like, are now regarded as metamorphosed lead-zinc orebodies of sedimentary-volcanic origin, although sometimes they have been remobilized and given place to vein-like structures.

2. *Pyrite-chalcopyrite association (v.Fe-Cu)*

This paragenetic type has been found in two pre-Variscan volcanic-sedimentary formations in Galicia, one in the Silurian and the other in the Precambrian. However, as they differ a little in their mineralogy and geological setting, two types can be distinguished here.

a) *Hematite-pyrite-chalcopyrite association*

This mineral assemblage occurs near Moeche, in the Coruña province, in an Upper Silurian greenstone sequence which contain interbedded limestones and serpentines.

The ore minerals are mainly hematite and pyrite, and minor amounts of chalcopyrite, all disseminated in a matrix made up mostly of albite, chlorite and calcite. Sphene, rutile, magnetite, apatite, epidote and quartz are the main accessories.

The host rock, a slightly metamorphosed spilite, tops a thick stratigraphic sequence of quartzites, lydites, phyllites, and acid metavolcanites.

b) *Pyrite-chalcopyrite (Ni) association*

This paragenetic type differs from the preceding one in as much as it contains traces of nickel, but no hematite. It occurs in several places (Fornás, Arinteiro) of the «Ordenes polymetamorphic complex», near Santiago (Coruña). The rock sequence, Upper Precambrian in age, is made up of gneisses, micaschists and amphibolites, very often garnetiferous, and minor amounts of peridotites. It belongs to the Portuguese Central Galicia-Trás-os-Montes zone.

The amphibolites, consisting mostly of anthophyllite, plagioclase, biotite and sphene, and the micaschists and gneisses, made up of quartz, feldspar, micas, kyanite, staurolite, and sometimes amphibole, represent a volcanic-sedimentary sequence metamorphosed in the granulite facies in pre-Variscan times.

The ore minerals, mainly pyrite, chalcopyrite and pyrrhotite, with minor marcasite and traces of pentlandite, were deformed simultaneously with the host rock by the Hercynian orogeny. During this period, the Precambrian basement was also affected by a metamorphic phase of the greenschists facies.

3. *Barium-manganese association (v.Ba-Mn)*

Stratiform deposits and occurrences of barite and manganese are quite frequent in the NW trending synclines of Vide and San Blas, in the Zamora province. The ore forms a layer, 0.5 to 15 m thick, made up of massive or nodular barite, carbonates —some with a high Mn content—, minor pyrite, and traces of sphalerite. The mineralized bed, which has been strongly folded and faulted, is located between limestones and carbonaceous shales and schists, some of them corresponding to slightly metamorphosed pyroclastic rocks. Similar mineral assemblages, but with minor amounts of chalcopyrite, are found near Llerena, in the Badajoz province.

4. *Cinnabar-Fe sulphides association (v.Hg-Fe)*

This paragenesis characterizes the remarkable Almadén orebody, the biggest mercury mine in the world. The ore is precisely located in the so-called «criadero quartzite», Llandovery in age, the only host of workable mercury mineralization. It consists of cinnabar, pyrite, pyrrhotite and marcasite, and traces of chalcopyrite, sphalerite, galena, barite and dolomite. Mercury, bilinite, hexahydrite and calcite are secondary minerals; calomel, guadalcazarite —a discredited mineral species—, natrolite and chabasite have been also reported (20).

The «criadero quartzite» is built up of two members, framed in and separated by shales. The lower member consists of a sandstone which progressively looses its argilo-carbonaceous matrix from the bottom to the top. The lower and upper limits of this quartzite are black shales and sandstones, and those of the hanging wall grade into an upper quartzite member which is, in turn, overlain by a graptolite shale and a volcano-sedimentary sequence. Metamorphism is of a very low grade, or completely absent.

The Almadén deposit, for a long time regarded as hydrothermal, is in fact a typical stratabound orebody. However, the source of the metal, for which some have postulated to a volcanic origin, still remains uncertain.

C) MINERALIZATIONS ASSOCIATED WITH MAGMATIC AND METAMORPHIC PROCESSES

1. *Chromite-ilmenite association (m.Ti-Cr)*

Ilmenite and rutile, associated with some pyrite, pyrrhothite, magnetite and chromite, and traces of chalcopyrite and pentlandite, have been reported in a few isolated points of the ultrabasic complexes of Cap Ortegal and Ordenes, in northern Galicia. None of them are of economic interest, but ilmenite is, or has been recovered, from alluvial placers in a few localities.

2. *Uranium-Ni-Co sulphides association (m.U-Ni-Co)*

It consists of quartz and quartz-carbonates veins containing the following mineral assemblage: pitchblende, niccolite, Ni-Co arsenides —mainly safflorite—, millerite, pyrite, marcasite, chalcopyrite, chalcocite, covellite, erytrine, and annabergite.

The veins occur in a granitic orthogneiss, 460 ± 65 M.Y. old, which probably corresponds to a Silurian granite highly deformed by the Hercynian tectonic movements. This granite is intruding the carbonaceous quartzites of the Precambrian «Black Series» of Monesterio (Badajoz) in the Ossa-Morena Zone (3).

3. *B.G.P.C. association (m.BGPC)*

This paragenesis, apparently restricted to the contact between the Cambrian schists and limestones, and the calcareous shales and quartz-feldespathic siltstones of the Cándana Series, in the León and Lugo provinces, has been known for a long time but only recently has got attention because of the important Pb-Zn deposists which have been discovered in this part of Spain (4).

The paragenesis is very simple: sphalerite, galena, pyrite, marcasite, carbonates, quartz, fluorite, barite, and minor amounts of chalcopyrite, tetrahedrite, chalcocite, covellite and arsenopyrite. Occasionally, albite is also present, due to the recrystallization of the sodic feldspar which is sometimes very abundant in the enclosing silstones.

The age of the galena from the two main orebodies, Rubiales and Toral, which show a vein-like and a stratiform structure respectively, gave the same value, 390 ± M.Y. As the deposits seem to be pre-Variscan, this age probably corresponds to a later recrystallization of the galena during pre-Hercynian or young Hercynian tectonic processes.

4. *Cinnabar-barite association (m.Hg-Ba)*

This paragenesis exits only in one point of the Ossa Morena Zone, near Usagre, in the Badajoz Province. The ore minerals, mainly cinnabar and pyrite, with minor galena, quartz and barite, occur as veinlets and impregnations in strongly deformed Cambrian limestones and quartzites.

3. Late variscan paragenetic associations

Only those mineralizations occurring in Triassic sedimentary rocks, and for which the age determinations in galena show values older than 220 m.y., have been taken into consideration as Late-Variscan deposits.

On the contrary, as no precise data exist as yet on the age of the veins crossing the Mesozoic formations, and as, therefore, an Alpine age could be attributed to these deposits, we would rather not comment them at this time.

1. *Fluorite-barite association (F.Ba)*

This is a very simple paragenesis consisting mainly of fluorite, barite and carbonates, minor amounts of quartz, galena, sphalerite and pyrite, and only traces of chalcopyrite. In many deposits, only fluorite and carbonates are found. This mineral assemblage is always bound to Lower Triassic sediments, both of marine and continental origin. According to the relative abundance of the sulphides, two different paragenesis can be distinguished here (4).

a) *Fluorite-galena association*

The main minerals are banded fluorite and dolomite, and disseminated galena. The deposits of this type are numerous in the Sierras of Gádor, Lújar and Baza, in the Betics, and in the Gijón area, in Asturias, where they show sometimes a vein-like structure. Here, the deposits occur just above the unconformity between the Carboniferos limestones and the Triassic sandstones and conglomerates. In the Betics, the mineralized horizons are at a higher level, in a marine sedimentary sequence, Lower Triassic in age, made up of pelitic and carbonate rocks.

b) *Fluorite-sphalerite association*

This association also occur in stratabound deposits, both in the metamorphosed carbonate rocks of the Betics —Sierra Almijara, in the Málaga province— and in the Basque-Cantabrian Mts. —Arditurri, in Guipúzcoa—, where there are several mines in operation. In this region, galena is not so abundant, chalcopyrite is present in higher amounts, and siderite is the most important mineral among the carbonates.

2. *Barite-hematite association (Ba-Fe)*

Veins made up almost exclusively of barite and hematite, sometimes with traces of chalcopyrite, are found in numerous localities crossing the Triassic rocks surrounding the Pedroches batholit and the Hercynian basement of the Iberian and Catalonian Coastal Ranges, the Betics and the Pyrenees.

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