RENDICONTI Società Italiana di Mineralogia e Petrologia, 39 (1): pp. 193-228

THE PALEOZOIC METALLOGENIC EPOCHS OF THE SARDINIAN MICROPLATE (WESTERN MEDITERRANEAN): AN ATTEMPT OF SYNTHESIS ON GEODINAMIC EVOLUTION AND MINERALIZING PROCESSES

CARLO GARBARINO, SILVANA MARIA GRILLO, CARLO MARINI, ANTONELLO MAZZELLA, FELICITA MELIS, GIORGIO PADALINO, SANDRO TOCCO, MAURIZIO VIOLO

Ist. di Giacimenti Minerari, Geofisica e Scienze Geologiche, Facoltà di Ingegneria dell'Università, piazza d'Armi, 09100 Cagliari

LUCIANO MACCIONI

Dipartimento Scienze della Terra dell'Università, via Trentino 52, 09100 Cagliari

MADDALENA FIORI

via Zagabria 49, 09100 Cagliari

RIASSUNTO. — Il presente lavoro, sviluppato attraverso i cinque anni del progetto finalizzato « Geodinamica » (sottoprogetto 4), finanziato, sostenuto e coordinato dal CNR, rappresenta un tentativo di sintesi sulle conoscenze riguardanti le correlazioni tra evoluzione geodinamica e deposizioni metallifere.

Il quadro di riferimento fondamentale è riferito alla microplacca sarda, sede del più importante distretto minerario d'Italia.

I più antichi processi metallogenici, almeno quelli direttamente investigabili, sono caratterizzati da deposizione di solfuri di Pb-Zn-Fe e di barite nelle dolomie e calcari della piattaforma del Cambriano inferiore e medio. Questi depositi, del tipo MBS, mostrano una zonalità verticale — e quindi cronologica — e orizzontale, cioè paleoambientale. Gli ambienti sedimentari evolvono da quelli marini-deltaici verso quelli di laguna o di « tidal-flats ».

Le mineralizzazioni di solfuri ricorrono in bacini con ristretta circolazione d'acqua, mentre la deposizione di barite è prevalente nei bacini con condizioni di mare aperto, o con maggiore circolazione d'acqua.

L'« annegamento » della piattaforma carbonatica cambriana arresta la deposizione primaria dei metalli, ma successive fenomenologie diagenetiche, tettoniche ed erosive hanno contribuito grandemente alla rimobilizzazione dei solfuri e solfati e alla formazione di corpi mineralizzati, economicamente coltivabili.

La seconda epoca metallogenica, quella ordoviciano-siluriana, è caratterizzata da deposizioni vulcano-sedimentarie di solfuri misti con paragenesi più complesse di quelle cambriane. L'orizzonte mineralizzato, ubicato al passaggio tra l'Ordoviciano e il Siluriano è costituito da uno skarn quarzoso clorítico-epidotico con rari granati e pirosseni. Tale skarn è il prodotto metamorfico di un orizzonte tufitico formato dall'apporto vulcanico di silice (e metalli) nel bacino sedimentario e dalla sedimentazione detritico-carbonatica del Siluriano.

Una potente coltre vulcanica con trends calco-alcalini (vanno infatti dalle rioliti fino alle andesiti con relativi tufi) si è insediata essenzialmente nell'Ordovciano e limitatamente nel Siluriano inferiore e può essere collegata alle ultime fasi dell'Orogenesi Caledoniana e, almeno in parte, ai prodromi di quella Ercinica. L'area in cui ricorrono il vulcanismo e i giacimenti metalliferi può essere considerata come un paleomargine attivo tra la fine dell'Orogenesi Caledoniana e l'individuazione dei primi segmenti strutturali di quella Ercinica.

L'ultima epoca metallogenica paleozoica rappresenta il prodotto della grande e importante orogenesi Ercinica. In questo lavoro non sono state studiate le ben note mineralizzazioni idrotermali filoniane di Pb-Zn-Ba-F; sono state analizzate invece alcune mineralizzazioni meno conosciute — scientificamente parlando — e ubicate nei « granitoidi » dell'Ogliastra. Si tratta di piccoli corpi con struttura a stock-work, allungati secondo le direttrici tettoniche regionali, con una paragenesi di tipo Zn-Cu-Mo. Le associazioni, gli ambienti geodinamici, i « trends » geochimici sembrano suggerire una ipotesi genetica di tipo « porphyry ». Il meccanismo dell'intrusione magmatica ercinica e l'età degli stocks granitoidi tuttavia rappresentano un limite « strutturale » per quanto riguarda le dimensioni economiche di tali mineralizzazioni.

In conclusione l'evoluzione geodinamica di questo frammento della catena ercinica, che è la microplacca sarda, ha condizionato fortemente le tipologie giacimentologiche che vi ricorrono e costituiscono un concreto esempio di correlazione tra paleoambienti e deposizioni metallifere.

ABSTRACT. — Several papers and researches over these last few years have greatly improved the knowledge on the tectonic, stratigraphic and magmatic pattern of the Sardinian microplate, a fragment of the Hercynian chain.

The synthesis of the correlation between the geodynamic environments and ore-deposits has not yet been attempted despite the economic importance of this mining district.

The present paper, which is the result of five years of research in the ambit of the « Geodinamica » project (sponsored by CNR), attempts this synthesis.

The oldest metallogenic processes are characterized by deposition of Pb-Zn-Fe sulphides and Ba sulphate in the Cambrian carbonate platform. These deposits, which may be classified as MBS type, show vertical and lateral zonings closely connected to the different paleoenvironments and carbonatic facies; these environments evolve from marine-deltaic to lagoons and tidal-flats.

The sulphide mineralizations occur in basins of reduced water movements, while the barite deposits occur mainly in the area of open sea conditions.

The drowning of the middle Cambrian carbonate platform ends the primary metal depositions, but further diagenetic, tectonic and weathering processes contributed greatly to the reworking of ores and the formation of exploitable ore bodies.

The second metallogenic epoch, the Ordovician-Silurian one, is characterized by volcano-sedimentary deposition of mixed sulphides; the ore-bearing horizon, located along the Ordovician-Silurian boundary is made up of a tuffitic rock, later metamorphosed and transformed into skarn during the Hercynian orogenesis.

A thick volcanic cycle (metarhyolites, metandesites and tuffs) mainly developed during the Ordovician, shows a calc-alkaline trend and it may be linked to the latter phases of the Caledonian orogenesis. Metal zoning is present in Central Sardinia which represented, structurally and geodynamically, an active paleomargin. This metal zoning seems to be associated to the volcanic zoning marked by more acid suites in the southern area (Sarrabus) and more basic ones toward North (Barbagia-Ogliastra).

The last Paleozoic metallogenic epoch was caused by the Hercynian orogenesis. The Authors of the present paper have not studied the well known hydrothermal veins of Pb-Zn-Ba-F; the object of their research has been the lesser known Cu-Mo-Zn mineralizations of the Ogliastra plutonites. Small bodies of Cu-Zn and minor amounts of Mo are scattered throughout the granodiorite and leucogranite of Hercynian plutonic stocks. The ore paragenesis, the general structures of the mineralizations, the geodynamic environments and the geochemical trends of host-rocks seem to suggest a genetic hypothesis of « porphyry » system for these metal occurrences. The mechanism of the Hercynian « granitoid » emplacement and the age of these magmatic stocks represent nevertheless a strong limitation for the economic occurrence of these mineralizations.

In conclusion, the geodynamic evolution of the Sardinia microplate strongly conditioned the type and the amount of base metal occurrences giving rise to a valuable example of correlation between paleoenvironments and ore-deposits.

1. Foreword

The primary purposes of this paper are the understanding of the ore-forming processes in the Paleozoic rocks of the Sardinian microplate (fig. 1) as well as the definition of the relationship between the metal depositions and the geodynamic environments.

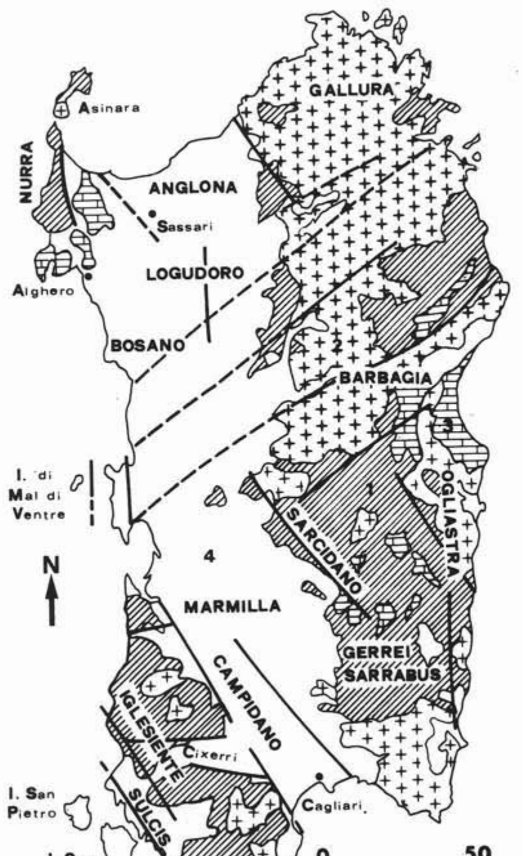


Fig. 1. — Sketch map of the island of Sardinia. The different areas referred to in the present paper, are shown. - 1 = Prehercynian basement; 2 = Hercynian granitoids; 3 = Mesozoic carbonatic platform; 4 = Cenozoic volcanites and sediments.

With this in view the Authors have attempted over the last five years to identify the main metallogenic epochs of the Sardinian microplate and their relationship with the evolution of the paleogeodynamic environments.

The general improvement of geological knowledge was of great assistance to the Authors; however in spite of this, several areas and topics had to be studied in great detail due to the lack of sedimentological, stratigraphical, structural and volcanic data.

For instance the Authors expended considerable efforts on the volcanic framework in the central Sardinia, as well as on sedimentological research on the Cambrian platform in the Southern part of the island.

Throughout the research several colleagues lent their assistance in order that the Authors might avail of their specific competences and they would mention in particular: Prof. N. MINZONI (Istituto di Mineralogia dell'Università di Ferrara) for his most valuable contribution towards a correct understanding of the stratigraphical sequence in central Sardinia; Prof. A. GANDIN (Istituto di Geologia dell'Università di Siena) who furnished the basic outlines of the sedimentological parameters in the Cambrian carbonatic platform; Prof. S. BARCA (Dipartimento di Scienze della Terra dell'Università di Cagliari) for his precious suggestions concerning the stratigraphic sequence of the Sarrabus-Gerrei area.

2. Introduction

A better understanding of Sardinian geology has been acquired in recent years; several papers have been published outlining the different characters of the stratigraphy, structural geology, etc..

The Authors referred to these papers for detailed information concerning the general structural pattern of the Sardinia (see references).

On the other hand the Authors preferred to stress how the mineralizations of the Sardinia offer, it is believed, one of the finest examples of correlation between geodynamic environments and ore deposits in the Mediterranean area.

This fact is to be attributed not so much to the extent and the importance of the mineralizations as to the variety of them in a relatively limited area. Thus the Authors, in this paper, attempt to summarize the knowledge previously gained and the results of research carried out in the ambit of the « Geodinamica » project of CNR regarding the mineralizing phases and the influences that the geodynamic environments have had on them.

With this in view the Sardinia microplate, just as far as the Paleozoic sequences are concerned, will be divided into three main structural areas (COCOZZA et al., 1974; CARMIGNANI et al., 1982).

I) South-western Sardinia; characterized by the sedimentation of carbonate platform. This area, in which the Cambrian sequence outcrops, may represent the foreland of the Hercynian orogene (CARMIGNANI et al., 1979).

Important ore deposits of Pb, Zn, Ba occur in the Cambrian dolomites and limestones showing interesting phenomena of diagenetic concentration and tectonic and supergene remobilization of metals.

In this sedimentary basin the Post-cambrian sequence is relatively thin and the Ordovician-Silurian volcanites also seems to be limited.

In spite of the Ordovician-Silurian stratigraphic reduction, strata-bound mineralizations, hosted in a « skarnoid » horizon, are to be found in the Ordovician-Silurian sequence bordering the Cambrian carbonatic platform.

II) Central Sardinia (« internal trough » COCOZZA et al., 1974). This area, from Sarrabus to Barbagia and Nurra, includes the thickest Paleozoic sequence of the Sardinia microplate. Apart from some basal laminated porphyries (« Porfiroidi ») whose role is still obscure (Precambrian?), sediments and volcanites from the Upper-cambrian up to the Lower-carboniferous are present which can attain a thickness 10,000 m. The volcanites and tuffites are rather more widespread than in the south-western region and mixed-sulphide mineralizations are present. Research on the volcanic trends and the model of the volcano-sedimentary mineralizations (Funta-

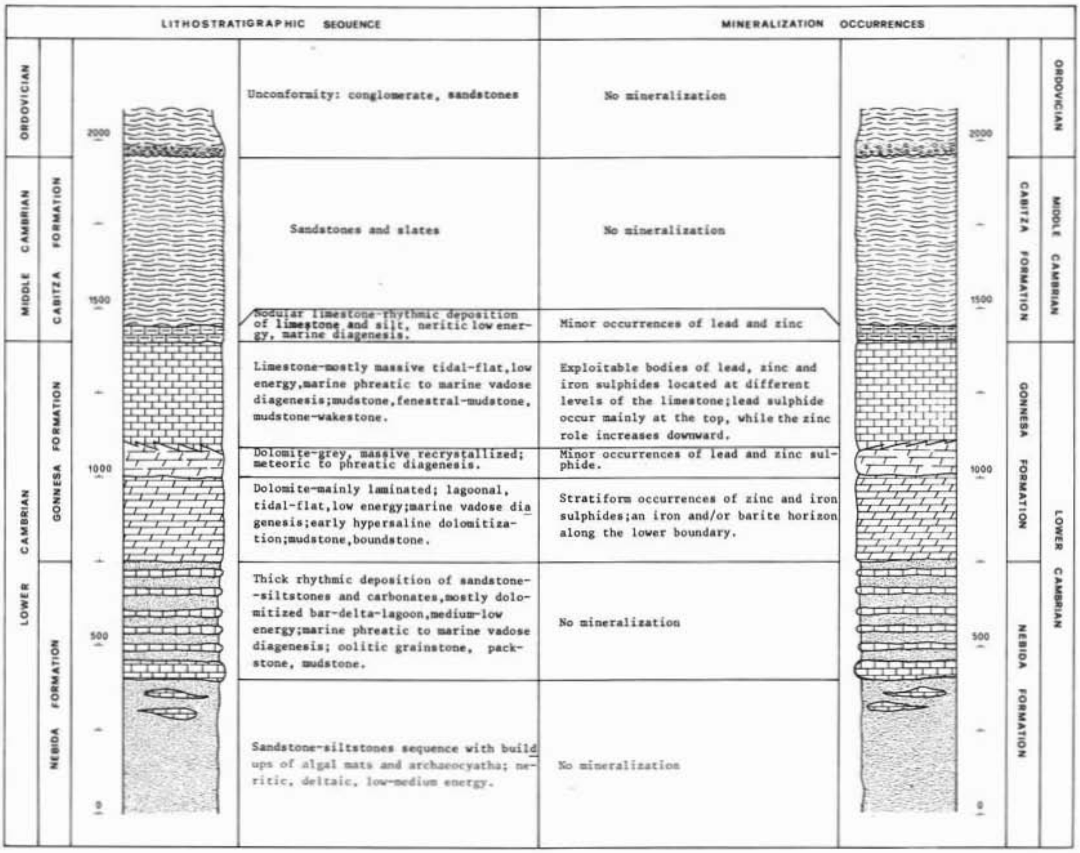


Fig. 2. — Lithostratigraphic sequence and mineralization occurrences of the Cambrian platform (Iglesiente - Northern Sulcis district).

na Raminosa type) represented the largest engagement by Authors.

III) Northern Sardinia and Corsica. This area is believed by some Authors (CARMIGNANI et al., 1979) to be the root of the Hercynian belt. Large occurrences of « granitoids » outcrop in this area as well as Cu-Mo mineralizations (in the Ogliastra region).

This Paleozoic basement is overlain by a Mesozoic and Cenozoic cover, affected by different types of paleoenvironments and mineralizations.

3. The metallogenic epochs

Five main metallogenic epochs are recognizable in the Sardinia island (PADALINO et al., 1979); the first three, the most important, occur in the Paleozoic basement while the last two in the Mesozoic and in the Cenozoic cover (tab. 1).

TABLE 1

Schematic distribution of the stages of mineralization according to ages, paleoenvironments, magmatic trends and orogenetic phases

	Age	Geodynamic environments	Main paragenesis	Magmatic trend	Tectonic phases
1	Cambrian	Platform	Pb,Zn,Ba	—	Early Caledonian
2	Ord.-Silurian	Paleomargin	Cu,Fe,F,W, Sb(?),Ag,Pb	Calc-alkal.and alkaline volcanites	From Caledonian to early Hercynian
3	Carboniferous-Permian	Converging (Hercynian type)	Mo,Sn,Pb,Zn, Ba,F,Ag,Cu,U	Calc-alkaline Plutonites	Hercynian
4	Mesozoic	Platform	Ba,Pb,Ag in karsts, Raw materials, Bauxite	—	—
5	Cenozoic	Basin and converging	Coal,Raw materials, Mn,Pb,Cu	Calc-alkaline volcanites	Alpine

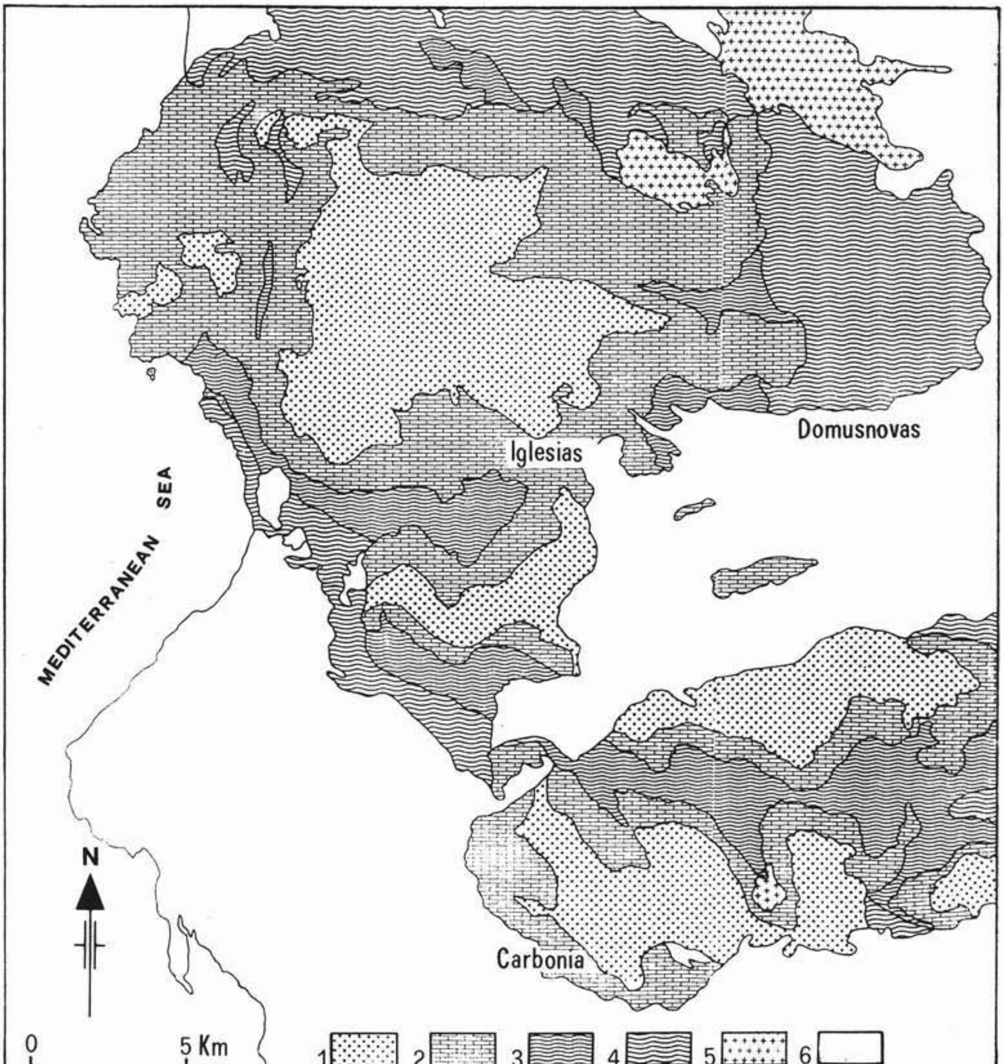
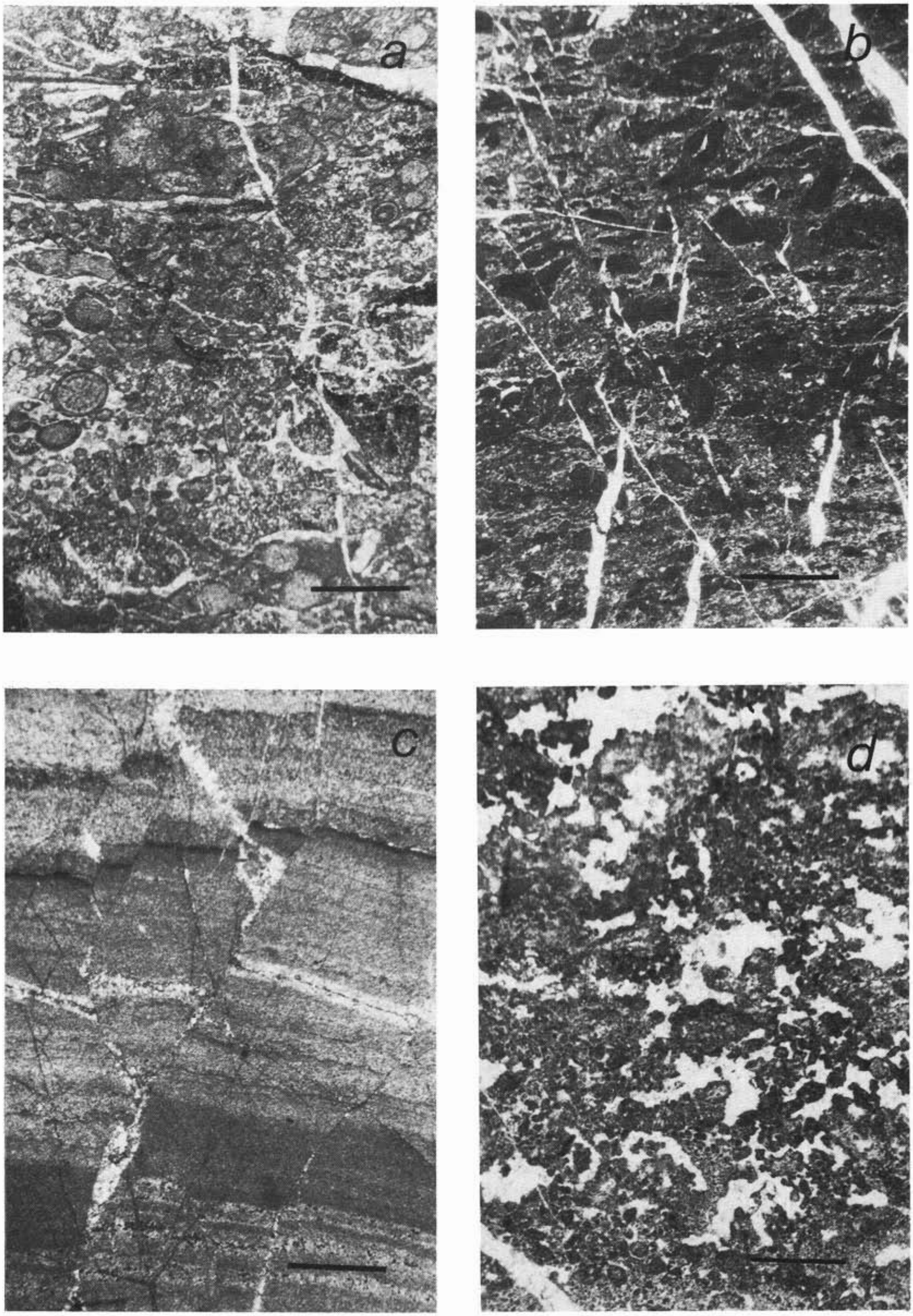
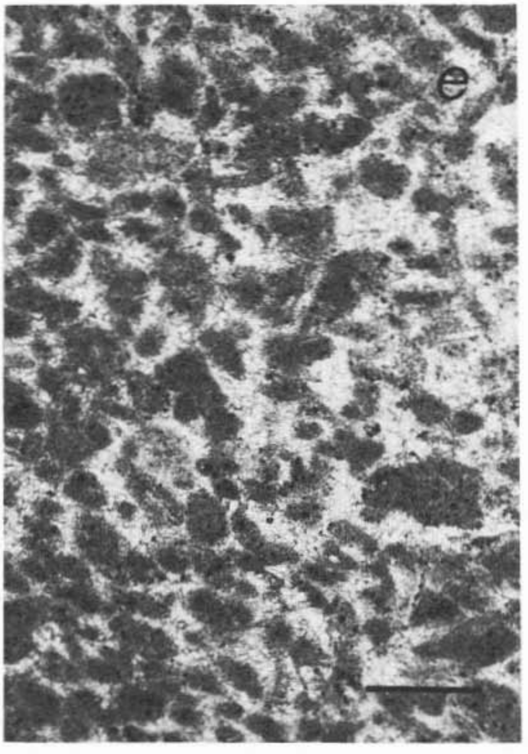


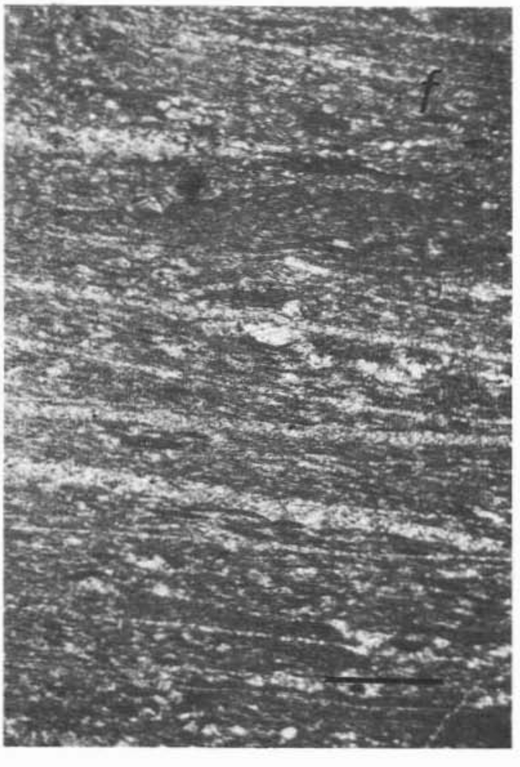
Fig. 3. — Geological sketch map of the Cambrian terrains (Iglesiente and Northern Sulcis districts). - 1 = Lower-cambrian sandstones and phyllites; 2 = Lower-cambrian carbonates; 3 = Middle-cambrian slates; 4 = Middle-ordovician conglomerate, sandstones and siltstones; 5 = Hercynian granitoids; 6 = Post-paleozoic terrains.

Thus lead, zinc, silver, barite and fluorite and to a lesser extent copper, represent the most valuable mining activities in Sardinia, while bauxite and coal offer interesting perspectives.

Tab. 1 gives the general outline of the mineralizing phases and the main paragenesis according to age and geodynamic environment. Despite this scheme, it is useful to point out that the mineralizing processes represent systems in equilibrium with the environmental evolutions and they cannot be believed as restricted in time and space. Thus f.i. the Pb-Zn-Ba mineralizations in the Cambrian carbonates have been subjected to several reworking phases, by stresses during the Hercynian orogenesis, by supergene factors during the Triassic peneplanation and Alpine tectonic rejuvenation; the Ordovician-Silurian mixed sulphides have been subjected to Hercynian metamorphism that gave rise to new ore associations and textures, etc..


a
b
c
d





Another element emerges from tab. 1; the increase of the number of metals in the ore associations from the Cambrian metallogenic epoch to the Hercynian one; in fact the Hercynian ore-paragenesis reveals a wide variety of paragenetic associations, in contrast to the relatively simple and monotonous Cambrian paragenesis.

Some Authors (ZUFFARDI, 1968; PADALINO et al., 1978) suggested that the persistence of lead-zinc and barium in the Paleozoic metallogenic epochs could be assigned to extensive heredity phenomena from the oldest ore-associations to the younger ones.

In conclusion, the Authors deemed it expedient to furnish, for the Paleozoic metallogenic epochs, the general data closely associated with ore forming processes and environmental characteristics, while they refer to the literature and to other subprojects of the « Geodinamica » project for detailed analyses of the geological history of the island of Sardinia.

3.1. THE CAMBRIAN METALLOGENIC EPOCH

The Paleozoic occurrences of the south-western Sardinia are characterized, as is well known, by a thick Cambrian sequence and a lesser Ordovician-Silurian-Devonian cover.

This area represents the most important lead-zinc-barium region of Italy and for this reason the existing literature is plentiful both from a metallogenic and geological point of view.

Fig. 4. — *a*) Polimodal grainstone, made up of coated oölites, bioclasts, intraclasts (M.te S. Giorgio - Nebida formation, P.ta Manna member); thin section, polarized light. *b*) Mudstone with irregular pisoids and vadose peloids (M.te S. Miai -Nebida formation, P.ta Manna Member); thin section, polarized light. *c*) Planar laminated mudstone, with micropeloidal levels (M.te S. Miai - Gonnesa formation, « Dolomia rigata » member); thin section, polarized light. *d*) Cryptalgal boundstone with geodic open space filling and recrystallized trapped ooids (M.te S. Miai - Gonnesa formation - « Dolomia rigata » member); thin section, polarized light. *e*) Fenestral mudstone: fine dissemination of sphalerite in peloids (S. Giovanni mine - Gonnesa formation, « calcare ceroide » member); thin section, polarized light. *f*) Laminated mudstone; tectonic lamination evidenced by a general orientation normal to the original bedding with calcite recrystallization (M.te S. Miai - Gonnesa formation, « calcare ceroide » member); thin section, polarized light. The bar is 3 mm long.

The general features of the mineralizations represent the finding of research carried out by the Autohrs (and their colleagues) over these last few years; the results now allow an interpretation of the depositional and diagenetic environments of the carbonatic platform, their evolution and their relationships with the mineralizing processes.

3.1.1. *Stratigraphic, sedimentological and petrographic scheme*

The well known Cambrian sequence may be schematized from bottom to top as follows (figg. 2-3):

I) the sequence, whose base is unknown, starts as a clastic sedimentation (sandstones, siltstones), that is followed by an alternance of sandstones and carbonatic intercalation of variable thickness (« Nebida Formation », more than 750 m thick).

The carbonatic intercalations, sometime oolitic and fossiliferous, are precursory to the setting of the carbonatic platform;

II) a thick carbonatic sequence perfectly conformable, characterized by laminated dolomite at the bottom and limestone towards the top. The entire mineralized bodies are comprised in this sequence (« metallifero » Auct., « Gonnesa Formation », from 500-800 m thick);

III) a thin horizon (max 40 m thick) of nodular limestone, preluding a new clastic sedimentation, followed by a thick sequence of phyllites and sandstones (« Cabitza Formation ») more than 600 m thick, that delineates the end of Cambrian sedimentation (COCOZZA, 1979).

The sedimentological studies of the different carbonatic facies allowed to draw up a general paleogeographic scheme of the epicontinental platform, whose evolution may be summarized as follows:

— On a littoral-deltaic platform (detrital sedimentation of the basal sandstones (ANGELUCCI, 1970) a neritic environment established. This neritic environment is confirmed by the presence of carbonatic lenticular bodies with Archeocyatus and Epiphyton interpreted by the some Authors as biohermal bodies (DEBRENNE, 1964).

— The carbonatic sedimentation increases upwards and an alternation of limestone and sandstone-silstones developed (COCOZZA and GANDIN, 1977).

This increase of carbonatic sedimentation is marked, at its base, by a continuous oolitic horizon (fig. 4*a*). The limestone intercalations decrease upwards and they are replaced by dolomites characterized by evidence of early diagenetic dolomitization (fig. 4*b*).

— This change of sedimentation indicates an early sign of environmental modification; the reduced energy, the depositional character of the dolomite denote an evolution toward a « lagoon type » basin. Probably the oolitic bar limits the exchanges with the open sea; the supplies of marine water are ensured only through tidal channels and hurricane floods.

A muddy carbonatic sediment, subjected to a vadose diagenesis in an intertidal-supratidal environment, may settle in the areas where the terrigenous supplies are negligible.

— Equilibrium and stability of the sedimentation basin are, at this point, reached and a tidal flat environment established.

On a gently undulating floor and probably in an arid, hot climate a thick carbonatic complex is deposited. Dolomites still prevail at the bottom but upwards the role of limestones becomes more prominent (fig. 4 *c, d*).

Dolomites, believed by several Authors (FANNI et al., 1981; CARMIGNANI et al., 1982) primary deposition or very early diagenesis, exhibit different facies, homogeneously distributed on a regional scale.

Mudstones, sometime finely bedded with pseudomorph nodules of evaporites, boundstone, composed of algal mats, fenestral mudstones and boundstones up to vadose pysolites represent the facies most commonly encountered.

— The most frequent limestones facies are represented by mudstone and more rarely by boundstone (figg. 4 *e, f*); these facies give rise to the typical vadose pisolites facies during the more developed stages of dissolution and redeposition. Sometime facies of laminated mudstone and mudstone-wackestone are also present; these facies seem to be have no connection with dry and vadose diagenesis.

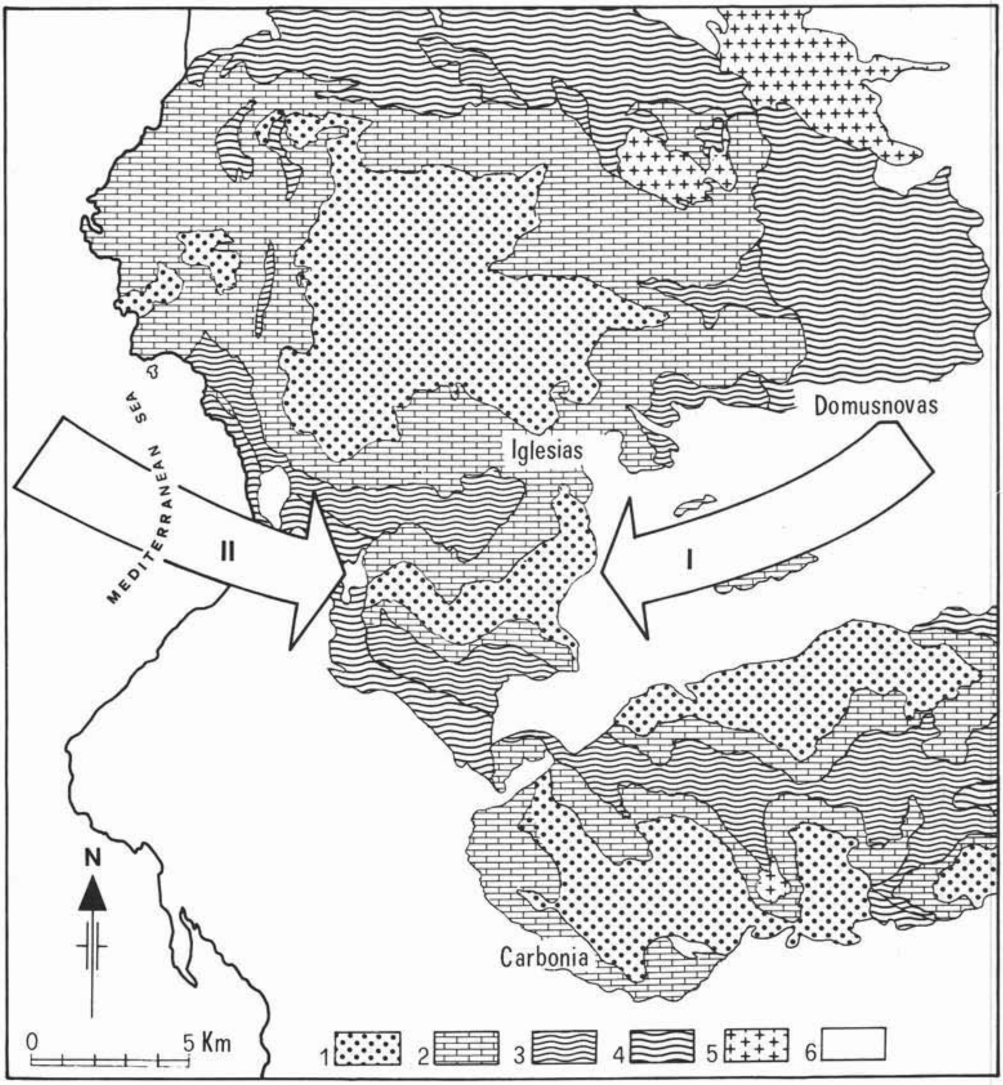


Fig. 5. — Geological sketch map of the Cambrian terrains, showing the directions of the probable supplies from the Pre-Cambrian continent to the Cambrian basin. - I = Probable supply during the « Alternanze » deposition. II = Probable supply during dolomite and limestone deposition. The geological index of the terrains as fig. 3.

The presence of the above mentioned facies is evidence of a platform evolution, with the formation of differentiated sub-environments that lead to suppose the presence of paleoreliefs and basins.

Subaereal diagenesis is prevalent on the paleoreliefs while the under-water one predominates in the basins, sometimes with restricted water circulation.

— The general trend to emersion, evidenced by some carbonatic facies is abruptly inverted during the limestone sedimentation. The nodular limestone deposition substantiates this inversion of trend; the basin deepens and detrital matter from the continent supplies the sedimentation.

The carbonatic platform is drowned and the phyllites terminate the Middle-Cambrian sequence.

3.1.2. *Geochemistry*

About 500 carbonate samples have been collected in the Iglesiente-Sulcis area along twelve complete Cambrian sequence from top to bottom. The samples have been analyzed by A.A. and XRF for Ca, Mg, Fe, Al, Mn, K, Na, Sr, Pb, Zn, Cu and Ba; the geochemical data seem to confirm the above mentioned paleogeographic features.

The Authors investigated the distribution of some metals such as Sr, Na, Mn, characteristic elements from an environmental point of view (FRITZ & KATZ, 1972; LAND & HOOPS, 1973; COOK, 1973; BENCINI & TURI, 1974; RAO & NAQVI, 1977; RAO, 1981). As far as the geochemical data (tab. 2) are concerned the following considerations should be taken into account:

I) Mn content decreases constantly from bottom (« Alternanze ») of the Cambrian carbonatic sequence towards the top (« limestone »). The limestone marks a sharp decrease in Mn content.

II) Geographically the Mn content decreases — in the « Alternanze » — from East to West; contrarily in the case of dolomites and limestone: the Mn content decreases from West to East.

III) The vertical and horizontal distribution of Mn should denote a less oxidizing environment from top to bottom of the carbonatic sequence, an early influence of continental supply from E-NE and subsequently from W-NW (fig. 5).

IV) The Sr-Na contents and its ratio show highest salinity of diagenetic environments during the « bedded dolomites » deposition.

V) The high content of Sr in the « Alternanze » may confirm a late dolomitization of these facies.

Hence, the geochemical findings confirm the sedimentological data and are thus in good agreement with the above mentioned paleoenvironmental scheme. Their influence on the mineralizing processes will be analyzed later on.

3.1.3. *Tectonic scheme*

The schematic structural frame of the Cambrian outcrops may be represented by a system of folds and faults due to at least two main, different orogenetic events; the Caledonian and the Hercynian. The Alpine orogenesis shows mainly wrench fault characters.

I) The oldest tectonic structures are represented by an early « Caledonian phase » which, acting in a N-S stress direction, caused E-W folds and a series of faults striking N 30° W and N 30° E. The N 30° W folds may be considered a typically Caledonian direction (VALERA, 1967) owing to its great number and development.

II) The subsequent tectonic events, the Caledonian s.s. and Hercynian, at the beginning still shows a N-S stress direction (POLL and ZWART, 1969). During this phase the early Caledonian folds shrunk and the N 30° W faults rejuvenated.

III) The persistence of a N-S trend enabled the development of a second stress phase acting in NW-SE and NE-SW directions. These should be responsible for the wide dispersion of the fold axes (CARMIGNANI et al., 1978).

In the Cambrian terrains the folds with the axis striking N-S may be imputed to these phases. In the Post-cambrian terrains N 70° E represents the typical Hercynian direction.

The final structure of the Cambrian sequence, caused by the above tectonic events, is characterized by folds with axes from E-W to N-S and a set of fractures striking N30°W, N-S, N 30° E and N 70° E.

Several papers are now available on the tectonic structures of the Sardinian microplate to which the reader is referred for more detailed information.

3.1.4. *The model of the mineralizing processes*

The sedimentological, structural and geochemical data enabled the evolution of carbonatic platform and the processes leading to sulphide and sulphate depositions to be delineated.

The following considerations may be outlined before to deal the model of ore deposition:

I) The mineralizations and important traces are almost always in carbonatic lithofacies; limestone, as host-rock, prevails over dolomite. Few and only limited ore occurrences are hosted in basal « alternanze » and in the « calcari nodulari ».

II) On a regional scale ore bodies exhibit a strata-bound features; on a ore-deposit scale epigenetic features are predominant.

III) Ore-associations are rather simple and monotonous; sphalerite, galena, pyrite and barite.

IV) No genetic relationships have been observed between ore bodies and igneous rocks (both plutonites and/or volcanites).

V) On a regional scale a vertical zoning is present; pyrite-sphalerite or barite occur at the bottom of the carbonate sequence and namely in the dolomitic facies, while galena and sphalerite (and minor pyrite) occur in the limestone.

VI) When barite occurs as beds in the basal laminated dolomite sulphides are absent and viceversa.

VII) The carbonatic platform is characterized by an increase in barite mineralizations southwards, and, of course, a decrease in sulphide bodies.

VIII) A close relationship can be observed between stress directions and ore bodies (Ammi, 1961; McMoore, 1968); this relation to be explained by remobilization phenomena and not to genetic factors.

IX) The geochemical analises of Pb, Zn, Ba of the carbonatic lithofacies (tab. 2) revealed how the regional metal averages are higher than world average (Turekian and Wedephol, 1981) in the epicontinental carbonates.

In view of the foregoing the Authors can now examine the mineralizing processes and answer four main questions:

1) the origin of the metals,
2) the origin of the sulphur,
3) the environment of ore deposition,
4) the environment of ore reconcentration.

As regards the origin of the metals it is possible to hypothesize a supply by leaching of an unknown paleocontinent; the thickness of basal Cambrian sandstones, the continental and/or shallow water environments during dolomite deposition may account for the large volume of materials, carried out to the sedimentary basin. As previously remarked non volcanic rocks occur in the Cambrian sequence apart from same diabase dykes that seem to be connected to Hercynian magmatic cycles (Beccaluva et al., 1981) and to have not any relationship with ore bodies.

As for the origin of sulphur, isotopic research (Brusca et al., 1965) revealed its biogenic origin, by bacteria reduction of sulphates. This assumption is in good agreement with the sedimentological data and evolution of the Cambrian platform.

The environments of ore deposition in fact are strictly conditioned by the evolution.

The deposition of « Alternanze » (P.ta Manna member) is characterized by a lagoon environment, middle to high salinity, strongly oxidizing; the mineralizing parameters were favourable only to sporadic sulphates deposition (barite nodules) while low geochemical contents of Pb-Zn and the pH-Eh parameters were not conducive to sulphide depositions.

The deposition of « dolomia rigata » is characterized by a tidal environment, low energy, very high salinity, strongly oxidizing but with some microenvironments locally reducing or at least less oxidizing (Gandin et al., 1974).

A general trend to emersion is present as well as long periods of continental phases. The high geochemical contents of Zn and Ba (and by contrast the low content of Pb)

Table 2
Geochemical data of the Cambrian carbonatic lithofacies

	Pb	Zn	Ba	Mn	Sr	Na	Sr/Na	
$\bar{x}$	82	43	51	512	152	44	3.3	Limestone
σ	58	26	19	169	43	24		
n	53	54	50	43	54	51		
$\bar{x}$	18	83	46	1176	82	172	0.5	Bedded dolomites
σ	12	68	32	509	39	69		
n	45	38	56	63	63	61		
$\bar{x}$	16	38	53	1866	136	131	0.9	"Alternanze"
σ	7	13	26	687	49	48		
n	77	58	80	86	95	88		

$\bar{x}$ = average content in ppm; σ = standard deviation; n = number of samples. The number of samples « n » is carried out from χ^2 test, which showed different distribution for each element; only samples inside mean $\pm$ 3 σ have been utilized.

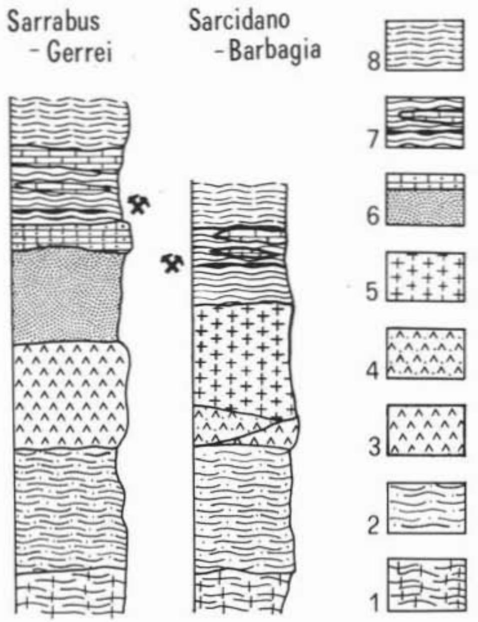


Fig. 6. — Stratigraphic sequences of central Sardinia, namely Sarrabus and Sarcidano - Barbagia. - 1 = Porphyroids of unknown age. 2 = Upper-cambrian to Lower-ordovician; sandstones phyllites (S. Vito-Solanas formations); 3 = Lower to Middle-ordovician; rhyolites and tuffs (« Porfidi grigi e bianchi » Auct.); 4 = Tuffs and volcanoclastic metasediments; 5 = Middle to Upper-ordovician; metandesites and tuffites; 6 = Caradocian-Ashgillian: sandstones phyllites and limestone, sometime strongly silicified; 7 = Silurian-Devonian; black shales, phyllites, volcanites and tuffites, limestones. Stratiform sulphides occur into the ore-bearing horizon; 8 = Lower-carboniferous (?); phyllites and sandstones.

lead to sulphide and/or sulphate depositions according to different sub-environments.

The deposition of the limestone (« Calcare ceroide ») is characterized by a tidal environment, low energy, low salinity, less oxidizing than the preceding environments. The high geochemical contents of Pb, Zn, Ba allowed sulphide depositions and an early concentration by dissolution and redeposition.

The neritic environments of nodular limestone («Calcescisti» Auct.) and «Cabitza» phyllites denote the drowning of the platform and terminate the important mineralizing processes of the Middle-cambrian.

The subsequent up-lifting, folding and faulting of early Caledonian, Caledonian and Hercynian orogenesis caused stress reworking of Cambrian sulphides, achieving in some case exploitable volumes of ores.

Furthermore, the important erosive cycle of Trias and the landscape rejuvenation of Alpine orogenesis favoured a large supergene reconcentration of sulphides and sulphates.

The Authors refer to the literature concerning this important aspect of the Cambrian metallogenic province (Brusca et al., 1967; Padalino et al., 1973, 1973; Boni, 1978).

3.2. The Ordovician-Silurian metallogenic epoch [1]

The mineralizations of the second geodynamic environment (the so called «internal basin») exhibit a sharp modification according to host-rocks, general geological features and ore associations (fig. 6, 7); the Middle-ordovician and the Lower-silurian exhibit several occurrences of mixed sulphides. The strata-bound features, the more complex ore associations compared to those of the Cambrian, the metamorphic phenomena and essentially the relationship between mineralizations and volcanites allow to outline the evolution and modification of geodynamic parameters acting in the area, included between Cambrian outcroups (Iglesiente) and the large Hercynian plutonites (Gallura).

3.2.1. *Stratigraphic and tectonic scheme*

The different geodynamic environments, the tectonic transport toward SW and the metamorphic zoning of Hercynian orogenesis allow to divide the Sardinian microplate into three NW-SE belts, namely: North-eastern belt, Central belt and South-western belt (Carmignani et al., 1978, 1982).

As previously noted the south-western belt is characterized by sligthly deformed carbonate platform (Sulcis Iglesiente) with Pb-Zn sulphides.

On the contrary the North-eastern belt exhibit high grade metamorphism, « granitization » phenomena, and tectonic shortenings.

The Central belt (Sarcidano-Barbagia-

---

(1) The researches on the Ordovician-Silurian metallogenesis have been carried out also in the ambit of the IGCP project n. 60 (Project leader: Prof. F.M. Vokes; chairman of italian working group: Prof. M. Violo).

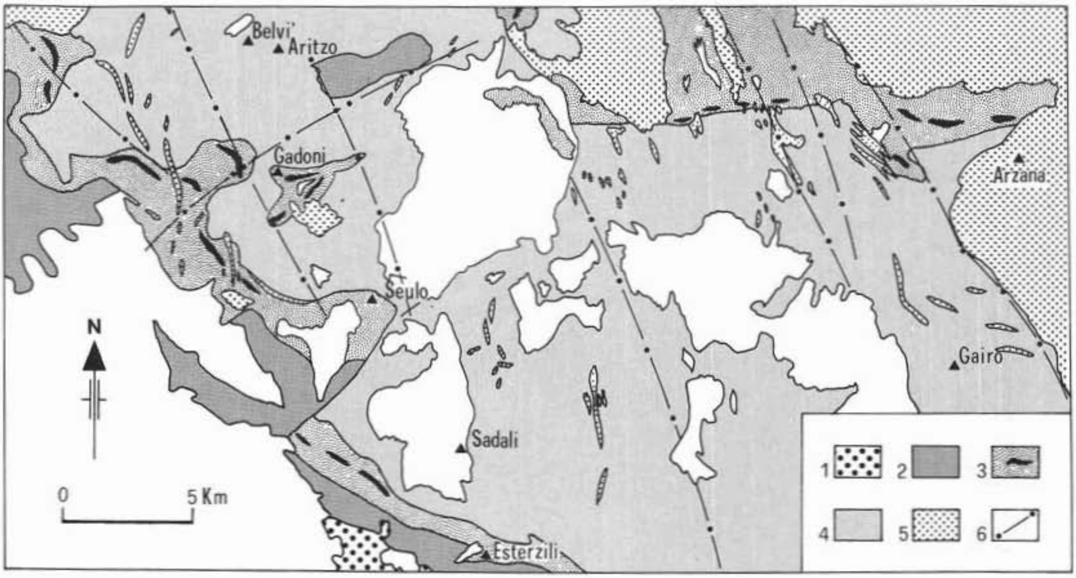


Fig. 7. — Geological sketch map of central Sardinia. - 1 = Upper-cambrian to Lower-ordovician sandstones (« Solanas » formation). 2 = Ordovician volcanic cycle (metarhyolites, metandesites, volcanoclastic sediments). 3 = Silurian-Devonian; black shales, phyllites, volcanites, limestones and the ore bearing horizon. 4 = Lower-carboniferous (?) phyllites and sandstones. 5 = Hercynian « granitoids ». 6 = Major faults.

Nurra) shows structural characteristics intermediate between the South-western and the North-eastern ones; this area is in fact affected by low grade metamorphism (chlorite zone) and by superimposition of several tectonic units (Carmignani et al., 1982).

The acid volcanism is prevalent (« porfiroidi » and « porfidi grigi e bianchi » Auct.) and the main volcanic events seem to be concluded before the Caradocian-Asghillian sedimentation; apart from thin intercalations of so-called basic volcanites comprised in the Silurian sediments, whose analytical data are not available at present (Barca and Maxia, 1982).

In the Northern area of the central belt (Barbagia) the chemism trend of the volcanism may reach intermediate composition that is Rhyodacite and Andesite. This intermediate volcanic sequence is covered, in the Meana Sardo unit (fig. 6), by black shale, phyllites, tuffites with sulphides and limestone of the Silurian-Devonian. The Authors of this paper believe that the volcanic cycle is covered, in a limited area (f.i. Funtana Cungiada, near Aritzo), directly by the Lower Carboniferous phyllites («Post-Gotlandiano» Auct.); the contact between volcanites and phyllites should be stratigraphic and in this case the volcanic paleoreliefs (old volcanic centers?) prevented the deposition of Silurian-Devonian sediments.

The most complete unit, from a stratigraphical point of wiew (Meana Sardo unit), shows the following sequences (from bottom to top) (fig. 6):

I) the basement of the sequence consists of « porfiroidi »: laminated porphyries, with large k-feldspar crystals. These « porfiroidi » should represent the products of a late Caledonian orogenic cycle;

II) a thick clastic formation (« Formazione di Solanas ») (Minzoni, 1975); probably from the upper Cambrian to lower Ordovician.

These sandstones derive from erosion phenomena of preceding magmatic and volcanic cycles;

III) a great acid to intermediate volcanic cycle.

Thin metavolcanic intercalations are present in the Ordovician-Silurian sequence bordering the Cambrian platform in the

Fig. 8. — Sheared breccia from the volcanic complex of M.te S. Vittoria. The breccia consist of sandstone and volcanite fragments, sometimes silicified, in a clayey, dark matrix.

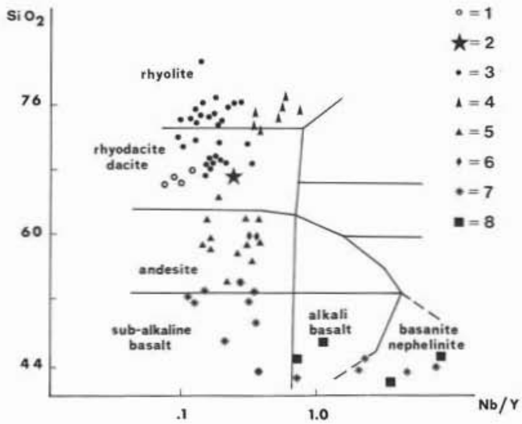


Fig. 10. — SiO_2 vs. Nb/Y plot of metavolcanites of Iglesiente, central Sardinia and northern Spain (WINCHESTER and FLOYD, 1977). - 1 = « Ollo de Sapo » formation (North-Western Spain); 2 = « Porfido grigio » from Sarrabus; 3 = « Porphyroids »; 4 = Metarhyolites; 5 = Metandesites from central Sardinia; 6 = Metandesites from Iglesiente (BECCALUVA et al., 1981); 7 = Metabasites from central Sardinia; 8 = Metabasites from Iglesiente (BECCALUVA et al., 1981).

South-western belt; but the volcanism attains its most important development in the central belt (Sarrabus-Gerrei and Barbagia regions).

The chemism and the stratigraphic location of the volcanism reveal an evolution from South (Sarrabus-Gerrei) to North (Barbagia).

In the Southern part of the central belt the acid volcanism (metarhyolites) prevails and it seems exhausted before the Caradocian sedimentation. In the northern part (Barbagia-Ogliastra) of the central belt, instead,

Fig. 9. — Devonian limestone folded and dipping southward. Funtana Raminosa mine (S. Gabriele stope).

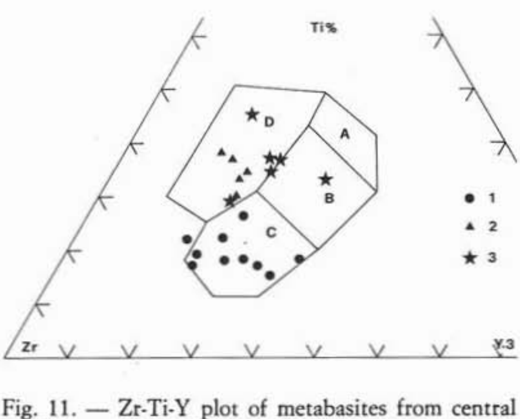


Fig. 11. — Zr-Ti-Y plot of metabasites from central Sardinia and from Iglesiente. - *Fields* $A+B$ = Low-potassium tholeiites; *Field* B = Ocean floor - Basalts; *Field* $C+B$ = Calc-alkali basalts (PEARCE & CAN, 1973). 1 = subalkaline basalts; 2 = alkaline basalts; 3 = metabasites from Iglesiente (BECCALUVA et al., 1981).

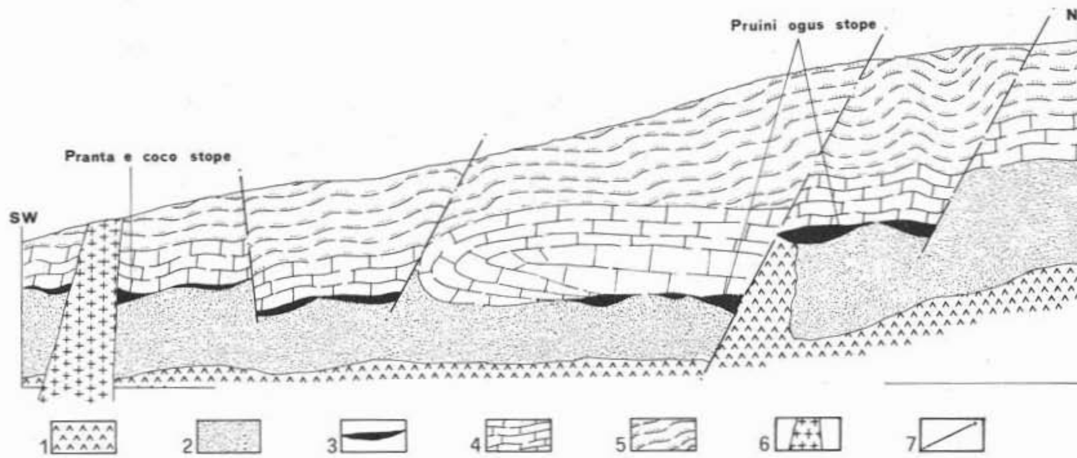


Fig. 12. — Scheme of the Devonian limestone folding during Hercynian orogenesis and of the ore remobilization (see also fig. 9). Funtana Raminosa mine (S. Gabriele). - 1 = Metandesite; 2 = Phyllites and sandstones; 3 = Ore-bearing horizon; 4 = Limestone; 5 = Phyllites and black-shales; 6 = Ercinian porphyry dyke; 7 = Faults and fractures.

the volcanism is characterized by metarhyolites and metandesite, sometime directly covered by Silurian or Low-carboniferous metasediments. This different stratigraphic location of the volcanism may be due to the overthrusts and also to paleogeographic characteristics of the basin.

Infact the volcanism caused in the central Sardinia a rather rough basin floor resulting in the numerous heteropic facies in the Ordovician-Silurian basin. Frequent transitions between volcanites, tuffs, tuffites, volcanic breccia (fig. 8) clastic sediments and limestones are observable in this area. This important aspect of the paleoenvironments will be discussed later;

IV) phyllites and sandstones lying directly on the metandesites and passing to the Silurian-Devonian formation, consisting of black-shales, limestones and phyllites.

In these formations the ore-bearing horizon occur, mainly located at the bottom of the Devonian limestone or near the boundary with the « Post-gotlandiano » cover (fig. 7).

This horizon exibhit sometime tuffitic structure and its mineralogical composition is rather variable according to the Hercynian metamorphism.

When the metamorphism is higher garnets and pyroxenes are prevalent; where the metamorphism seems to be weaker only clorite, quartz and epidotes are present.

Minor amounts of amphyboles, fluorite, magnetite and sulphides occur in this horizon. The intense silicification, the complex paragenesis may be due, as will be discussed later, to the metamorphism of tuffitic submarine deposit transformed into a «skarnoid» (Burt, 1977) during Hercynian orogenesis.

A phyllite thick cover («Post-gotlandiano» formations Auct.) whose age is still uncertain (Lower carboniferous?) seems to conclude the volcanic and sedimentary cycles before the Hercynian orogenesis.

As far as the tectonic is concerned central Sardinia terrains have been mainly tectonized by the Hercynian orogenesis; according to Carmignani et al. (1978) three main stages are recognizable during this orogenesis, namely:

I) the first stage, the most important, caused isoclinal folds and overthrusts toward West and Southwest (fig. 9) thus, shortenings of the Paleozoic sequence have been produced. A well developed flow-cleavage is associated with this stage;

II) the second stage deformed the preceding tectonic setting, causing open folds with NW-SE or E-W axis trends. A less important flow-cleavage is associated with this stage;

III) the third folding stage caused still more open folds with N-S or NE-SW axis trends.

TABLE 3

Analyses of « porphyroids » and porphyries from central Sardinia and Spain

	S1A	S1B	S1C	S2A	S2B	S2C	S3A	S3B	S3C	S4A	S4B
SIO2	73.89	76.27	74.73	73.76	74.59	71.57	71.02	69.83	72.52	71.22	71.75
TIO2	.27	.24	.31	.35	.31	.35	.35	.52	.42	.38	.36
AL2O3	14.80	12.63	14.77	13.98	13.97	15.23	14.84	15.23	14.16	15.79	15.71
FE2O3	.45	1.55	1.25	.89	.67	.44	1.53	2.56	2.49	2.34	2.00
FEO	.33	.09	.06	.07	.05	.51	.60	.07	.04	.15	.63
MNO	.01	.01	.01	.01	.01	.01	.01	.01	.02	.05	.05
MGO	.37	.59	.45	.38	.38	.48	.57	.95	.81	1.05	.65
CAO	.07	.19	.17	.28	.25	.28	.27	.36	.28	.95	.29
NA2O	.39	.34	.35	1.95	1.37	1.83	2.31	2.39	2.36	.49	.61
K2O	7.89	6.68	5.99	6.70	7.36	7.50	6.78	6.67	5.45	6.01	5.69
P2O5	.06	.15	.15	.17	.19	.19	.19	.17	.19	.23	.21
H2O	1.47	1.26	1.77	1.47	.86	1.62	1.51	1.25	1.27	1.34	2.07
NI	5	3	4	6	5	3	6	7	10	7	11
CO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CR	11	7	10	12	12	14	13	19	19	14	23
CU	17	16	16	15	61	15	20	14	16	20	16
ZN	33	24	29	18	24	25	32	52	51	340	71
V	23	15	23	21	16	18	24	38	32	31	30
SR	57	41	42	79	85	89	117	80	69	45	50
RB	263	295	269	245	238	278	209	244	205	196	178
BA	678	417	544	640	731	820	1750	1091	941	790	781
NB	5	9	9	10	7	5	6	12	10	8	ND
ZR	103	100	135	141	135	140	133	203	161	170	142
Y	47	53	64	57	55	58	50	61	53	55	46
LA	17	6	17	17	12	16	21	22	20	29	28
CE	29	ND	37	35	28	36	29	66	65	47	53
PB	62	49	39	16	17	17	39	21	30	27	32

	S4C	S5A	S5B	S5C	S6A	S6B	S6C	S7A	S7B	S7C	S8A
SIO2	68.68	75.97	77.81	75.70	75.39	77.26	81.21	72.02	68.43	68.43	68.71
TIO2	.38	.40	.31	.49	.06	.05	.05	.41	.47	.46	.44
AL2O3	18.40	16.01	14.23	16.07	16.36	12.97	12.45	14.70	16.33	15.65	16.77
FE2O3	.93	.83	1.39	.62	.74	.39	.64	1.08	4.12	2.01	2.86
FEO	1.05	.06	.08	.08	.07	.05	.10	.94	.78	1.15	.48
MNO	.03	.01	.01	.01	.01	.01	.01	.03	.03	.04	.01
MGO	.85	.59	.37	.33	.35	.20	.32	.80	1.25	1.75	1.20
CAO	.27	.22	.23	.15	.03	.06	.03	.51	.33	.59	.29
NA2O	.30	1.09	1.29	1.18	.27	.39	.30	3.12	1.02	2.79	1.69
K2O	6.66	3.26	2.81	3.58	4.55	7.72	3.10	4.22	6.51	5.08'	5.21
P2O5	.23	.07	.09	.13	.03	.03	.03	.23	.24	.23	.22
H2O	2.21	1.49	1.40	1.68	2.14	.88	1.76	1.86	.50	1.02	2.12
NI	8	3	27	10	ND	ND	ND	10	9	10	10
CO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CR	14	15	17	19	ND	ND	3	24	17	19	15
CU	18	18	16	18	16	15	18	15	21	13	ND
ZN	50	29	91	19	12	25	99	50	71	56	54
V	33	29	24	92	ND	4	5	33	37	35	35
SR	39	60	51	55	8	21	11	53	41	76	38
RB	233	89	67	103	144	181	85	138	257	162	194
BA	815	1224	1008	1437	825	1503	450	697	896	752	671
NB	9	5	ND	10	12	8	6	5	11	12	12
ZR	178	80	61	159	106	77	76	130	174	102	179
Y	54	20	19	31	54	43	39	42	61	53	59
LA	31	18	15	29	23	24	21	26	33	29	22
CE	50	36	29	54	55	43	46	45	62	55	34
PB	29	25	23	18	17	37	662	24	49	27	34

	S8B	S8C	V1	V2	GU455	GU454	GU457	E139	E140	E142	E143
SIO2	68.60	69.11	68.69	68.61	67.49	66.79	70.30	66.29	66.95	67.31	68.18
TIO2	.39	.36	.36	.35	.69	.70	.30	.57	.43	.53	.60
AL2O3	17.35	17.11	16.85	16.70	16.31	15.92	17.87	16.64	16.85	17.00	15.94
FE2O3	2.68	1.51	2.34	1.26	2.39	5.07	1.64	2.36	2.00	1.92	1.34
FEO	.08	.88	.79	1.58	.00	.00	.00	1.98	1.92	1.90	2.15
MNO	.01	.01	.05	.05	.04	.07	.01	.05	.07	.03	.04
MGO	1.05	1.02	1.08	1.25	.95	.97	1.14	1.67	1.67	.92	1.60
CAO	.28	.28	.32	.58	1.25	1.47	.12	.62	.63	.24	.92
NA2O	2.13	2.45	1.69	2.07	2.40	3.31	.17	2.51	2.25	3.12	2.53
K2O	5.03	4.86	5.59	4.96	5.63	4.22	5.59	4.99	4.84	4.37	4.15
P2O5	.21	.20	.25	.31	.22	.27	.30	.22	.17	.09	.21
H2O	2.19	2.22	1.98	2.29	2.63	1.21	2.53	2.09	1.94	2.49	2.35
NI	8	8	16	10	29	40	22	13	14	16	19
CO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CR	16	13	19	12	29	51	26	39	24	33	37
CU	19	14	12	10	17	16	16	17	22	17	24
ZN	41	45	49	48	30	59	62	84	139	97	112
V	32	28	43	31	38	75	35	64	45	55	60
SR	43	50	77	54	86	286	60	138	57	112	130
RB	189	169	188	179	205	146	135	180	171	146	151
BA	725	652	983	817	1096	1011	418	905	1114	930	741
NB	10	8	8	15	10	13	21	4	3	4	6
ZR	176	154	198	175	170	264	240	174	57	173	168
Y	54	48	46	46	59	53	65	47	21	42	54
LA	25	18	33	28	47	71	39	24	36	40	57
CE	48	57	62	50	104	149	81	85	47	79	94
PB	34	21	11	27	22	24.	33	38	8	50	38

Major elements are given as %; the other elements as ppm; *ND* = not detected.

The tectonic pattern of the central Sardinia and Nurra appears very different from that of the Southern Sardinia; in this area in fact the Cambrian and Ordovician terrains exhibit cleavage of the strainslip and not of the flow type, moreover shortening and overthrusts, even if present, do not seems as wide as in central Sardinia.

TABLE 4
Analyses of metarhyolites from central Sardinia

	V5	V8	V7	VI5	V4	VI4	VI8	GU459
SIO2	74.84	75.03	72.23	72.84	73.91	76.72	74.53	74.46
TIO2	.03	.17	.14	.04	.06	.03	.15	.15
AL2O3	14.99	14.71	16.04	15.81	15.45	14.03	14.68	14.48
FE2O3	.57	1.20	2.32	.85	1.01	.93	1.64	1.86
FEO	.36	.86	.21	.28	.93	.79	.86	.00
MNO	.03	.04	.05	.03	.04	.03	.05	.03
MGO	.30	.67	.82	.34	.87	.79	.71	1.49
CAO	.02	.04	.29	.11	.02	.04	.05	.75
NA2O	1.52	1.50	.82	.51	.57	.52	1.23	.59
K2O	5.94	3.75	4.76	7.72	4.99	4.51	3.98	3.31
P2O5	.12	.02	.21	.13	.01	.02	.02	.06
H2O	1.28	2.00	2.11	1.35	2.14	1.79	2.10	2.82
NI	7	6	9	5	7	7	7	23
CO	ND	ND	ND	ND	ND	ND	ND	ND
CR	ND	ND	ND	ND	ND	ND	ND	14
CU	5	ND	6	5	5	3	7	14
ZN	31	59	49	34	62	57	91	21
V	ND	10	13	4	ND	ND	6	14
SR	58	68	38	56	14	11	73	14
RB	175	148	183	196	177	156	159	257
BA	1604	663	908	2299	837	769	708	634
NB	14	17	18	8	14	11	13	8
ZR	60	230	95	63	78	61	211	164
Y	18	29	45	23	25	18	35	45
LA	12	104	25	20	18	9	99	67
CE	30	187	41	31	34	16	188	135
PB	9	14	10	12	ND	10	12	8

Major elements are given as %; the other elements as ppm; *ND* = not detected.

TABLE 5
Analyses of metandesites from central Sardinia

	GU366	GU361	GU350	GU352	GU360	GU372	GU364	GU461	BE1*	BE1	BE2
SIO2	61.25	55.53	58.50	58.69	57.40	64.60	55.74	61.06	59.04	58.81	58.45
TIO2	.78	1.03	.84	.88	1.10	.53	.99	.31	.87	.86	.83
AL2O3	14.43	16.77	15.61	15.07	16.82	17.08	16.67	17.83	17.52	16.88	16.49
FE2O3	2.12	1.78	2.51	1.92	1.92	1.64	2.53	6.65	.00	2.40	2.45
FEO	4.24	5.96	4.17	4.88	5.03	4.45	5.96	.00	6.83	4.45	4.24
MNO	.09	.12	.09	.11	.09	.13	.12	.05	.10	.12	.11
MGO	5.51	6.52	6.12	7.74	5.11	1.54	6.20	2.46	2.68	4.00	4.68
CAO	2.24	2.10	3.49	1.83	2.28	1.10	1.84	2.53	4.47	6.64	5.81
NA2O	5.13	2.98	2.53	4.36	3.33	1.12	5.64	1.95	3.67	2.62	2.54
K2O	1.11	1.50	2.59	.65	1.82	3.44	.85	2.96	3.13	2.24	2.44
P2O5	.25	.19	.22	.23	.17	.07	.17	.25	.29	.17	.18
H2O	2.84	5.51	3.33	3.64	4.92	4.29	3.28	3.95	2.95	.81	1.77
NI	32	100	78	98	92	14	28	36	7	22	23
CO	21	29	23	29	32	7	30	11	11	22	21
CR	301	434	296	396	447	76	176	49	11	148	142
CU	26	17	28	32	27	25	5	19	8	18	23
ZN	80	95	80	86	93	902	111	95	207	296	390
V	148	140	120	134	138	77	153	89	151	178	177
SR	166	79	360	269	78	194	349	78	503	374	394
RB	39	54	80	25	67	149	37	93	123	81	83
BA	782	951	888	530	474	854	1038	468	734	678	711
NB	11	7	10	5	7	5	10	14	3	11	4
ZR	184	170	202	196	170	142	214	324	204	151	144
Y	36	30	30	33	26	26	30	18	35	26	24
LA	23	40	31	24	29	40	40	61	37	28	28
CE	62	45	61	42	49	80	55	137	66	45	51
PB	33	7	3	19	4	81	24	15	16	18	13

Major elements are given as %; the other elements as ppm; *ND* = not detected.

The detailed studies on the tectonic pattern of paramount importance from a mining and ore-prospecting point of view; in fact the Hercynian tectonic stages caused the « splitting » of the ore-bearing horizon and its overthrust towards South or South-West.

Furthermore the isoclinal folds of the first stage might be the cause of the ore-bearing horizon redoubling, thus forming ore bodies of valuable volume (figg. 9 and 12).

3.2.2. *Volcanic trends of central Sardinia*

The Pre-hercynian volcanites of the central Sardinia are represented by acid terms («porfiroidi», metarhyolites, «porfidi grigi e bianchi» Aut.), intermediate (metandesite) and basic ones (metabasalts) (DI SIMPLICIO et al., 1974; GARBARINO et al., 1980; MEMMI et al., 1982).

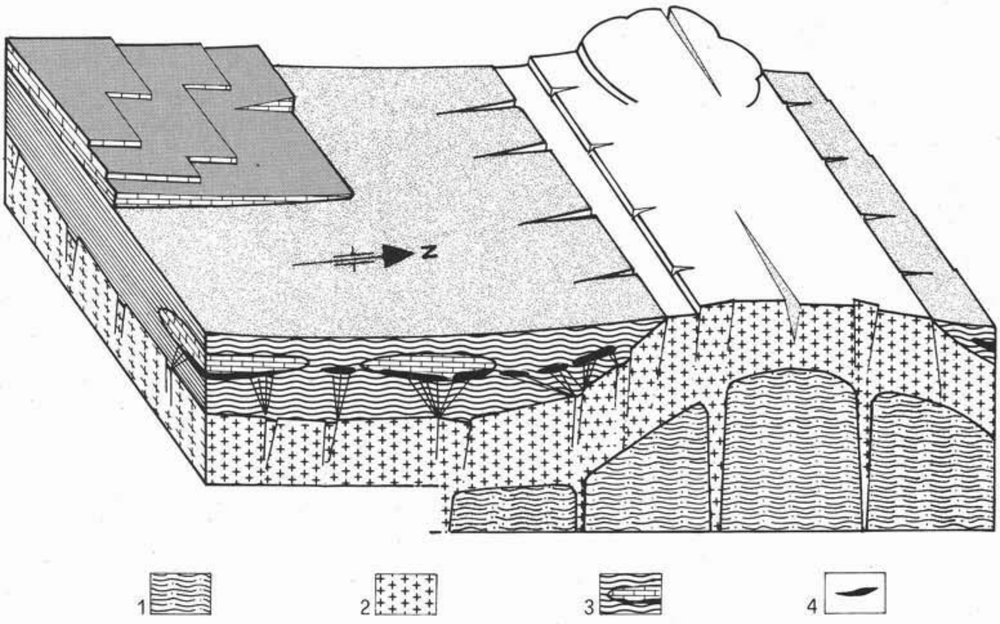


Fig. 13. — Block-diagram showing the hypothesized model of ore forming processes during the Ordovician-Silurian metallogenesis. - 1 = Sandstones and phyllites (« Solanas » formation); 2 = Volcanic cycle (metarhyolites, metandesites, tuffs and tuffites); 3 = black-shales, phyllites and limestones; 4 = ore-bearing horizon.

— The « porfiroidi » consists of sheared porphyries and rhyolites and seem to be attributable to the Precambrian and, at least partly, to the Ordovician (Memmi et al., 1982).

They are similar to the well-known « Ollo de Sapo » porphyries from Spain and for this reason they have been analyzed (tab. 3) and compared with the other volcanites from Sardinia (fig. 10).

— The metarhyolites and their tuffs are composed of a thick cover with evident characters of ignimbrite facies. They could be of Tremadoc-Arenig age as well as the « porfidi grigi e bianchi » (Barca et al., 1981); these latter volcanites outcrop mainly in the Sarrabus area.

— The metandesite consists of dome-shaped bodies and horizons interstratified with phyllites; these volcanic rocks show secondary silicification phenomena.

Their occurrences are localized mainly in the Northern area (Barbagia-Ogliastra) and for this reason their age is still uncertain; in fact even if the whole volcanic cycle seems to be of Pre-caradocian (Barca et al., 1981) it is possible to ipothesize that some volcanic paleoreliefs may range up to the Lower-silurian thus preventing the Upper-ordovician sedimentation (Garbarino et al., 1980).

— Lastly the metabasites made up of small dykes and lenses interbedded with Silurian volcanoclastic sediments.

All these volcanic rocks have been subjected to the Hercynian orogenesis that caused neverthless weak metamorphic phenomena.

The petrographic investigations carried out revealed that the original texture of the metavolcanics is badly preserved.

The quartz and K-feldspar phenocrysts in the acid metavolcanites are fractured and cemented by a quartz-feldspar-sericite microcrystalline matrix, while the plagioclase and mica (biotite) are generally transformed into albite-sericite-epidote and chlorite-epidote respectively.

Evident phenomena of transformations of plagioclases, sometimes with neoformation of calcite, and of mafic minerals into chlorite-epidote are recognizable in the metandesite.

TABLE 6
Analyses of calc-alkaline basalts from central Sardinia

	GU381	GU382	GU367	GU359	GU351	GU360	GU310	V9	FRB2
SIO2	51.69	51.34	46.68	49.20	53.76	53.16	51.49	43.72	53.22
TIO2	.89	.79	1.14	1.28	1.01	.97	.97	1.09	.81
AL2O3	16.00	16.02	16.58	18.68	15.20	15.18	17.17	16.15	12.28
FE2O3	3.06	2.26	7.94	3.33	3.96	2.56	2.28	5.81	3.55
FEO	5.89	6.61	6.75	7.18	7.18	6.68	5.53	8.76	3.83
MNO	.13	.11	.16	.15	.12	.14	.10	.22	.13
MGO	11.36	10.11	9.64	8.59	8.47	9.11	8.01	10.48	9.57
CAO	2.29	4.62	1.51	1.17	1.47	3.42	3.69	4.65	5.56
NA2O	2.54	2.97	2.57	4.91	3.08	4.72	3.99	2.43	1.71
K2O	1.22	1.43	.44	.51	.18	.54	1.44	1.21	.13
P2O5	.26	.24	.20	.35	.23	.20	.23	.24	.18
H2O	4.67	3.50	6.39	4.63	5.04	3.33	5.09	5.26	9.03
NI	170	160	49	19	102	24	117	135	187
CO	37	38	44	24	34	30	34	33	30
CR	528	530	516	113	363	190	461	467	589
CU	3	4	18	10	5	18	51	9	37
ZN	223	178	180	216	107	122	200	646	142
V	180	194	222	234	129	175	149	122	139
SR	305	333	113	179	95	159	242	171	746
RB	69	65	12	10	20	16	39	32	ND
BA	418	335	367	271	194	292	1066	414	72
NB	4	ND	9	14	13	3	8	15	5
ZR	122	113	205	231	208	178	216	196	129
Y	37	17	43	36	49	21	25	35	13
LA	22	7	28	31	48	22	26	21	25
CE	24	16	50	52	32	12	49	50	52
PB	5	15	ND	5	ND	11	70	ND	30

Major elements are given as %; the other elements as ppm; ·*ND* = not detected.

TABLE 7
Analyses of alkali basalts of central Sardinia

	SP1	SP2	PER3	PER4	VILL3
SIO2	43.82	44.85	43.71	43.77	43.26
TIO2	1.85	3.00	1.93	2.16	1.48
AL2O3	15.10	16.11	19.71	19.95	17.67
FE2O3	5.27	12.54	3.51	2.62	4.15
FEO	9.34	5.89	8.12	8.98	8.55
MNO	.19	.23	.15	.14	.25
MGO	6.95	6.34	5.21	4.31	8.63
CAO	9.52	1.48	5.90	5.00	6.30
NA2O	3.40	2.94	3.98	3.60	3.26
K2O	.08	.16	1.34	2.25	.99
P2O5	.59	.70	.38	.30	.48
H2O	3.89	5.75	6.04	6.92	4.97
NI	57	32	16	22	71
CO	54	61	44	47	58
CR	143	38	ND	ND	111
CU	57	72	37	40	16
ZN	240	445	387	261	204
V	280	445	256	316	245
SR	1193	429	1051	510	944
RB	ND	ND	47	84	44
BA	262	199	638	1007	1329
NB	33	47	24	38	20
ZR	183	254	146	158	169
Y	27	38	16	21	28
LA	33	57	18	18	27
CE	44	87	27	43	51
PB	8	6	6	16	3

Major elements are given as %; the other elements as ppm; *ND* = not detected.

The plagioclases of the metabasites are also altered into albite-sericite-epidote, and the mafic minerals consist now of an anhedral association of chlorite-epidote-actinolite and iron ore.

The average chemical composition of 66 samples of Paleozoic volcanites coming from central Sardinia is given in tabb. 3, 4, 5, 6 and 7.

The acid metavolcanics (the « porfiroidi » and metarhyolites) (tabb.: 3 and 4), are included in the classification diagram according to FLOYD and WINCHESTER (1975) in the area of rhyolites and rhyodacites while the intermediate and basic ones (tabb.: 5, 6 and 7) are included in the areas of andesites and basalts respectively (fig. 10). For comparative purpose, the « Ollo de Sapo-porphyroids » (four samples collected by the Authors in the North-Western Spain - tab. 3,

TABLE 8

Lead, zinc and copper contents in the Paleozoic sequence of Central Sardinia

	Pb	Zn	Cu	
$\bar{x}$	20	80	35	"Post-Gotlandiano"
σ	8	40	17	
n	18	50	49	
$\bar{x}$	16	196	43	"Silurian" (including phyllites, black shales, skarn and limestone)
σ	9	246	41	
n	37	98	97	
$\bar{x}$	18	115	30	Volcanites (metandesites, metarhyolites and their tuffs)
σ	9	60	25	
n	28	43	48	

$\bar{x}$ = average content in ppm; σ = standard deviation; n = number of samples. The number of samples « n » is carried out from χ^2 test, which showed different distribution for each element; only samples inside mean $\pm 3\ \sigma$ have been utilized.

samples E 139, E 140, E 142, E 143) and one sample of gray porphyry (« Porfido grigio ») (tab. 3, sample GU 454) from Sarrabus are also reported in the diagram of fig. 9. These rocks show a more pronounced dacitic trend.

Moreover, using the elements believed immobile also during low grade metamorphism (CANN, 1970; PEARCE and CANN, 1973; FLOYD and WINCHESTER, 1977), it has been possible to specify the presence of calc-alkaline basalts and within-plate alkali basalts (tabb. 6 and 7) (fig. 11).

These characteristics are further confirmed by the Y/Nb ratio; this ratio is less than one for the former metabasic rocks and it is equal to four for the latter.

The chemical data moreover indicate how the acid metavolcanites underwent remobilization phenomena of Na, K and Ca while the intermediate and basic ones have been subjected to importance modification in their contents of Ni, Cr and partly Mg, with evident enrichment of LREE.

The presence, in the Lower Paleozoic of Sardinia, of two volcanic families, and namely sub-alkaline and alkaline (DI SIMPLICIO et al., 1975; RICCI and SABATINI, 1978; GARBARINO et al., 1980; BECCALUVA et al., 1981) should denote two different phases of Pre-hercynian volcanic activities. The first, the sub alkaline trend, should be connected to the late stages of Caledonian orogenesis, as well as the similar, mainly acid, occurrences of the Alps and European Continent (BELLIENI and SASSI, 1981; BELOV, 1981; HEINISH, 1981).

The second, the alkaline trend, may be connected to Pre-hercynian rifting phenomena of the paleo-European continental margin (RICCI and SABATINI, 1972; BECCALUVA et al., 1981; BARCA et al., 1981).

3.2.3. *Geochemistry*

About 250 samples have been collected in the Barbagia region (mainly around Funtana Raminosa area), along stratigraphic sequences, from « Post-gotlandiano » formation (phyllites and sandstones), «Silurian» formation (phyllites, black-shales, limestones and «skarnoid» horizon), volcanic formation (metandesites). All the samples have been analyzed for Pb-Zn-Cu by A.A. and XRF.

The geochemical data, reported in tab. 8 lead to the following observations:

I) lead content is rather constant among the three groups of formations, but it shows high variability whithin the same group of formations;

II) copper content is also rather constant and low, apart from small increases in the Silurian formations;

III) zinc content shows the highest values and variability among the three groups of formations.

These remarks are in good agreement with the mineralizing processes model (see later). Taking into account that the highest geochemical anomalies are localized in the « skarnoid » horizon, it is possible to observe, whithin this horizon, great and gentle variations of the metal contents. In fact the contents of the mineralized areas decrease laterally till the regional average, forming along the « skarnoid » horizon a sort of « spots » having high metal content.

Another interesting datum is the following: at a geochemical level the different paragenetic associations are confirmed; as will be described later, two main ore associations prevail: the Fe-Zn-Cu and Pb-Zn. These geochemical analyses revealed as a positive anomaly of Zn and/or Zn-Cu always with very low Pb contents; on the countrary when positive anomaly of Pb and/or Pb-Zn are present the Cu contents are rather low.

3.2.4. *The model of the mineralizing processes*

On the basis of the geodynamic environments described in the foregoing the Authors deemed it expedient to outline the following data in order to depict a general model of the mineralizations in central Sardinia:

I) the presence of an ore-bearing horizon located at the transiction Upper-ordovician - Lower-silurian, or at the bottom of the Devonian;

II) the relationship between the volcanism and the ore bearing horizon;

III) the relationship between the ore associations and the chemism of the volcanism. In fact in the Southern area (Sarrabus-Gerrei) fluorite, galena, sphalerite, arsenopyrite and Ag are prevalent; further North (Barbagia) Fe and Cu assume a more important role.

This is in good agreement with the increase of the intermediate and basic volcanism in a South-North direction;

IV) the primary metal traps seem to be the thick volcanic paleoreliefs; in these paleoreliefs the mineralizations (generally small veins in the volcanic rocks) are very lean. On the contrary the most important mineralizations occur around the paleoreliefs always at the base of the Silurian limestone or in a synchronous stratigraphic level;

V) the role played by Sb is somewhat obscure; recent investigations (CARMIGNANI et al., 1978) ascribe the deposition of Sb mineralizations to Hercynian magmatism. The Authors believe the Sb is connected to the Ordovician-Silurian volcanic cycle, even if strongly remobilized during the Hercynian orogenesis. For this reason Sb has been classified, even if dubitatively, as a product of Ordovician-Silurian metallogenic epoch (tab. 1);

VI) only epigenetic mineralized veins and dykes are present in the « Post-gotlandiano » cover. These mineralizations are clearly associated with the Hercynian metallogenic epoch;

VII) important phenomena of ore remobilization occur in the Ordovician-Silurian ore-bearing horizon. These phenomena are caused by the Hercynian folding and metamorphism; the ore-bearing horizon, folded and faulted by the former events, lost its spatial continuity and has been split and reworked in the nuclei of the folds, giving rise to the typical «sausage» feature (fig. 12).

The latter event transformed the metavolcanites and tuffites of the ore-bearing horizon into a « skarnoid ».

The block-diagram of fig. 13 attempts to synthesize the model of the ore forming processes during the Ordovician-Silurian metallogenic epoch.

It is obvious that this picture represents the scheme of the metallogenesis during the deposition of Devonian carbonatic platform and before the deposition of the « Post-gotlandiano » formation.

Apart from the role of the « porphyroid » basement (Caledonian magmatism?) the Upper-cambrian and the Lower-ordovician are characterized by the deposition of a thick detritical sequence (« arenarie di S. Vito » and « Solanas »).

A great acid-intermediate volcanic cycle follows (meta-rhyolites, meta-rhyodacites and meta-andesite) throughout the whole of central Sardinia.

The sedimentological and geodynamic environments in the Southern (Serrabus) and in the central area (Barbagia) differ.

In the Southern area the rhyolites were covered by the sedimentation of phyllites, sandstones and limestone of Caradocian-Ashgillian, while in the Northern area these sediments seem sometime to be absent.

Even if the most important volcanic cycle was exhausted before the Caradocian-Ashgiallian sedimentation, minor volcanic products were deposited in the Silurian basin.

This, may be proved also by the thin volcanic intercalations in the Silurian and by several dikes (supply channels), now strongly alterated, cutting the terrains below the Lower-ordovician formations.

In the central area (Barbagia), the volcanic paleoreliefs were perhaps prevented the deposition of Caradocian-Ashgiallian and the volcanites are covered directly by the Silurian-Devonian sediments.

The area of Funtana Raminosa mine is rather significant in the understanding of volcanism emplacement and ore deposition. From Meana-Gadoni to Tertenia, along NW-SE direction, the Ordovician volcanites are characterized by variable thickness and different relationship with the Post-ordovician cover; at Meana the metandesite are covered by Silurian limestone and phyllites, at Funtana Cungiada (near Aritzo), the volcanites are very thick and covered directly by the sandstones and phyllites of « Post-gotlandiano » formation.

At Tertenia the « Post-gotlandiano » also lies on the Ordovician metandesite but, in this case, the contact is clearly tectonic rather than stratigraphic.

Important ore deposits occur, along the same NW-SE belt, around the thickest volcanic occurrences; Meana, Giaccuru, Funtana Raminosa, S. Gabriele, Talentino represent the most valuable ore bodies of central Sardinia; the paragenesis is characterized by the presence of Fe, Cu, Zn, Ag and minor amounts of Pb, F.

The mineral composition, as well as the thickness, of the ore-bearing horizon shows significant modification. At Meana the « skarnoid » horizon is composed of quartz, chlorite, epidote, garnets and rare pyroxene; the thickness is reduced to 1-2 meters.

At Funtana Raminosa - S. Gabriele the mineral composition of the « skarnoid » horizon in quite similar but in this area the ore-bearing horizon reaches its maximum thickness, about 10-15 metres.

The structure of the mineralization is to be attributed essentially to concentrations of ores; in fact a fine interpenetration between sulphide and Ca-silicate minerals is present when the ore-content is not very high (fig. 14). In this case the sulphides are of anhedral shape or they are included in the Ca-silicate crystals.

With increasing ore concentration the structure may become massif and mineralization assumes the « massif sulphide » structure as in some stopes of the Funtana Raminosa mine or some lenses of the Sarrabus area.

In this case the ore bed consists almost exclusively of sulphides (and/or magnetite as in Giaccuru); nevertheless a bedding (or a ghost-bedding) can be frequently recognized in the mineralized layers.

On a microscopic scale the mineralizations of the Barbagia area consist of a mixture of sulphides, sulphosalts and oxides; the more common ores are:

I) sphalerite, galena, pyrite, chalcopyrite, magnetite and fluorite;

II) pyrrhotite may be present in the ores where iron mineralization is prevalent;

III) reduced quantities of bournotite, hematite, pentlandite, chromite and arsenopyrite are also present;

IV) Ag is present in the Funtana Raminosa ore production; about 1000 g/ton of chalcopyrite and 1200 g/t of galena;

V) the oxidation zone is not very developed, thus scanty amounts of azurite, malachite, limonite, hydrozincite are visible in the area of ore outcrops.

Exsolutions of chalcopyrite are almost always present in the sphalerite grains.

In the area of Tertenia, the ore deposits of Bau Arenas and Talentinu exhibit different characteristics; they occur as veins and veinlets in the basal metandesites while they exhibit stratiform features in the phyllites. Limestones are absent; the mineral composition of the ore bearing horizon is made up of quartz and chlorite. In these areas dikes of volcanic rocks, strongly altered, are present. These dikes stop at the level of the ore-bearing horizon and they might represent the old channels of volcanic and perhaps mineralization supplies.

Thus the ore-bearing horizon, above the volcanic system and below the Silurian-Devonian sequence, may represent the result of replacement phenomena beneath the sea floor, near the volcanic centres where submarine fumarolic activity was present (OFTEDAHL, 1958; RIDGE, 1973).

This submarine activity should occur more or less at the beginning of the carbonatic Silurian sedimentation, giving rise to the Ca-silicate paragenesis of the « skarnoid » horizon.

The Hercynian orogenesis modified this scheme: in fact according to the results of research on the structural framework of central Sardinia (CARMIGNANI et al., 1982) the difference in thickness of the ore-bearing horizon and Ordovician metavolcanites could be caused by the Hercynian tectonic phases. The stratabound ore-deposits have been reworked and now they exhibit epigenetic features; this is particularly visible in the Southern area (Sarrabus-Gerrei) that represents the front of the folds and overthrusts. The « Filone Argentifero » of the Sarrabus, the ore-deposit of Bacu Locci and Sa Lilla (ZUCCHETTI, 1958; VIOLO, 1966) may represent the result of these remobilization phenomena. These deposits in fact show on a regional scale a close connection to the above mentioned stratigraphic levels, while in detail veins and epigenetic features are prevalent.

Fig. 14. — Ore-bearing horizon made up of garnets, epidotes, quartz. The sulphides are finely disseminated in the rock. Crystallization broadly synchronous with the microfolds are visible. S. Gabriele stope (Funtana Raminosa).

3.3. THE HERCYNIAN METALLOGENIC EPOCH

The well known Hercynian mineralizations have been the subject of several papers and studies by numerous economic geologists. For this reason the Authors deemed it expedient to refer to these previous paper for a detailed analysis of the pneumatolitic-hydrothermal Hercynian mineralizations (ZUFFARDI, 1948, 1953, 1958; URAS, 1951; SALVADORI, 1959; CAVINATO, 1962; ZUCCHETTI, 1965; DERIU and ZERBI, 1965; BACCOS, 1968; NATALE, 1969; SALVADORI and VALERA, 1972; MASSOLI NOVELLI, 1973).

The vein systems of the Arburese (Montevecchio, Ingurtosu, Gennamari), Nuorese (Sos Enattos, Gozzurra) (SALVADORI and ZUFFARDI, 1960; MELIS and SANNA, 1978); Nurra (Argentiera) (BRIGO et al., 1982) have been extensively mined in the past for their Zn-Pb (Ag) ores and they represented an important non-ferrous metal supply for the Italian economy. Currently these mines have been closed, with the exception of Montevecchio whose closure represents a traumatic issue for the regional mining industry.

The Silius mine (NATALE, 1969), a large quartz vein with about 40 % CaF_2 and 1,5 PbS, is still operating in the Sarrabus area and it is believed to be one of the most valuable fluorite mines of Europe.

The Authors aim, in this paper, to furnish data and metallogenic scheme on some lesser known hydrothermal mineralizations in the calc-alkaline plutonites of the Ogliastra (central Sardinia), in order to acquire some knowledge on the correlation between Hercynian magmatic evolution and metal depositions.

In fact even if the mineralizing processes during the Hercynian (or late Hercynian) magmatism seem to have been correctly analyzed, the origin of metals is still obscure and not easily comprensible. Previous authors hypotesized that some ores, present in the hydrothermal veins, may derive from the leaching of Pre-hercynian sediments, by remobilization events closely connected to the last stages of magmatic phenomena (ZUFFARDI, 1968; SALVADORI and VALERA, 1972).

Thus Pb, Zn, Fe, Cu, Ba, F, W and perhaps Sb metals, already present in the preceding metallogenic epochs may have been

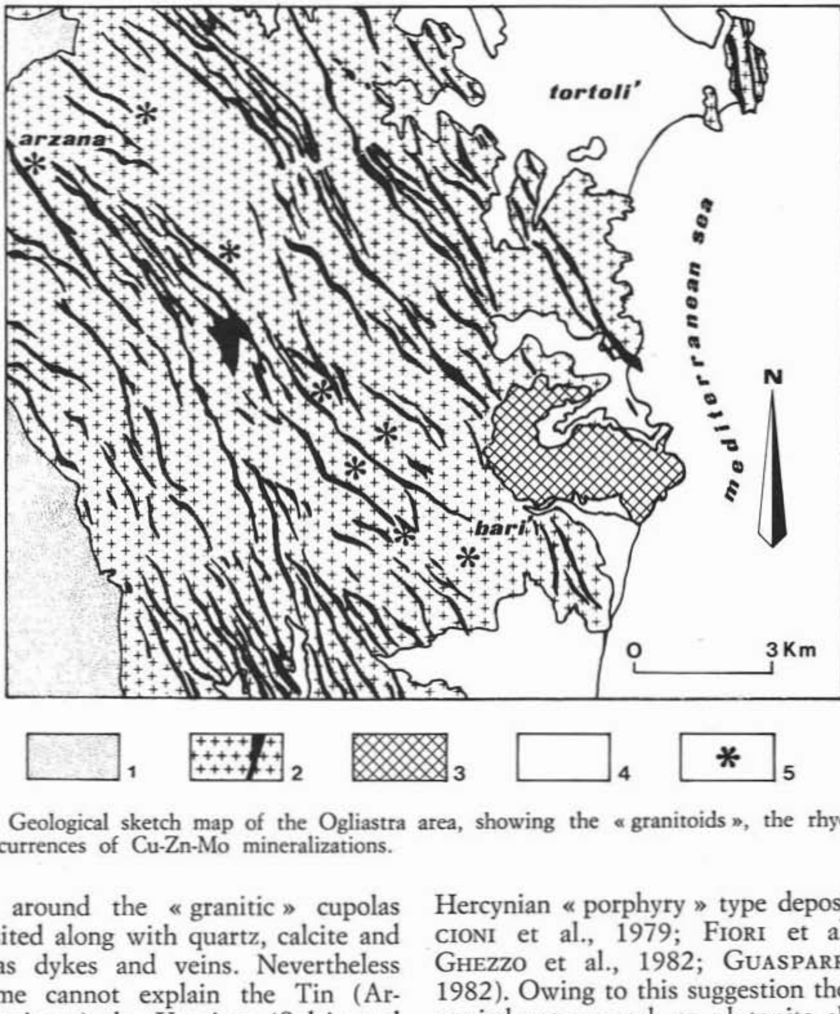


Fig. 15. — Geological sketch map of the Ogliastra area, showing the « granitoids », the rhyolite dykes and the occurrences of Cu-Zn-Mo mineralizations.

reworked around the « granitic » cupolas and deposited along with quartz, calcite and ankerite as dykes and veins. Nevertheless this scheme cannot explain the Tin (Arburese-Fluminese) the Uranium (Sulcis and Gallura) Ni-Co (Linas) and Molibdenum (in several parts of the island) mineralizations; in fact these metals are practically unknow in the previous Cambrian and Ordovician-Silurian metallogenic epochs.

3.3.1. *The Cu-Mo-Zn mineralizations in the « granitoids » of Ogliastra (Central Sardinia)*

The Authors, in the ambit of the Geodynamic project, undertook a study of the mineralizations in the Sardinia plutonites. Several occurrences of Cu, Fe, Zn and Mo, outcrop in the « granitoids » of the Central Sardinia and namely in the Ogliastra region. The ore-association, the structures and the host rocks seem to suggest the presence of Hercynian « porphyry » type deposits (MACCIONI et al., 1979; FIORI et al., 1982; GHEZZO et al., 1982; GUASPARRI et al., 1982). Owing to this suggestion the Authors carried out research on plutonite alterations, geochemical distribution of Cu and Mo, and geophisic anomalies.

About 350 samples were collected from the Ogliastra region at regular intervals of 500 m; the Authors refer to another paper for the complete study of these mineralizations (FIORI et al., 1983). These samples were investigated by microscopic and geochemical analyses carried out by XRF.

The field work revealed the presence of several rhyolite (fig. 15) dykes with NW-SE trend; these dykes are sometimes of considerable size and cut the «granitoid» stocks. These latter consist of a calc-alkaline suite; the more common rocks are represented by tonalite, granodiorite and granite (GHEZZO et al., 1972; DI SIMPLICIO et al., 1974; CONTI et al., 1981).

TABLE 9

Analyses of mineralized « granitoid » rocks from Ogliastra

	PC3	PC30	PC28	PC21	PC18	PC43	PC23	PC14
SIO2	67.99	63.26	60.77	60.60	55.23	47.75	41.12	35.43
TIO2	0.51	0.24	0.69	0.26	0.03	0.11	0.32	0.12
AL2O3	8.91	20.60	18.49	14.46	5.38	15.21	16.71	16.64
FE2O3	10.34	1.88	5.71	5.11	20.52	13.52	26.35	23.06
MNO	0.31	0.05	0.10	0.48	0.35	0.50	0.48	0.69
MGO	3.54	0.96	2.21	1.35	1.82	7.68	2.80	6.94
CAO	2.64	0.40	1.27	6.42	4.61	13.13	6.75	14.87
NA2O	2.28	5.29	5.90	6.58	1.94	0.24	0.53	0.22
K2O	0.13	7.22	3.50	0.16	0.08	0.62	1.23	0.26
P2O5	0.06	0.06	0.13	0.05	0.02	0.03	0.03	0.04
LOI	1.50	0.87	1.32	1.45	3.70	1.04	1.51	1.40
ZN	0.57	0.62	0.02	1.18	6.64	0.13	0.59	0.00
CU	0.41	0.14	0.64	0.01	0.31	0.05	1.71	0.13
NI	3	ND	5	ND	ND	ND	18	ND
CE	29	82	17	130	18	45	6	62
BA	56	926	707	32	23	101	205	67
LA	12	36	20	19	6	21	7	81
ZR	106	114	137	81	6	93	52	128
SR	193	95	139	349	147	431	366	544
RB	16	226	121	20	11	35	71	23
MO	ND	ND	65	ND	89	ND	ND	ND
PB	110	34	39	2.50%	31	–	–	–
F	393	468	586	640	178	–	–	–

Major elements are given as %; the other elements as ppm; *ND* = not detected; — = no data.

The tonalites are composed of plagioclase (35-38 % An) sometimes altered, of biotite and green hornblende; quartz is rare. Epidote is also present, pseudomorph after biotite and plagioclase.

The granodiorites are made up of plagioclase (30-35 % An), perthitic microcline, quartz and biotite sometimes transformed to chlorite; zircon, rutile, apatite, garnet are accessory.

The dykes, barren of copper and molybdenum mineralizations, are characterized by a porphyric texture with quartz and feldspar phenocrysts. Two main trends of sub-volcanic suites are evident from the geochemical analyses (FIORI et al., 1982): a calc-alkaline and an alkaline trends. The alkaline trend is probably connected to Permo-Triassic rift magmatism (BRUNETTON et al., 1976).

The analyses of 23 plutonic rocks and 10 mineralized « granitoids » are reported in tabb. 9 and 10. The diagram of fig. 16 shows the main trends of mineralized and unmineralized granitoid rocks from Ogliastra.

The calc-alkaline plutonites are represented by tonalite and mainly by granodiorite and granite.

The chemical analyses reveal the low content of Cu, Mo and Zn; however, it is interesting to note that in the Ogliastra « granitoid » rocks, as far as Cu and Zn are concerned the average Cu content of granite is higher (roughly twice that of all the other « granitoid » rocks) while average Zn content is maximum in the granodiorites. Unlike these original characteristics of the fresh rocks, the hydrothermally altered rocks, independent of the rock-type, have a higher Cu and Zn content.

The altered granitoid rocks, occurring in the mineralized bodies, show an impoverishment in K_2O, Rb, Ba due to the alteration of K-minerals, mainly biotite and subordinately K-feldspar, to chlorite and epidote. Plagioclase appears to have been more resistant to alteration and, therefore, Na content remains more or less constant, while Ca and Sr increases are connected to the formation of epidote. In conclusion, it is apparent that hydrothermal solutions carried Zn, Cu, Fe, Mo, Mn, Ca and Sr removing K, Rb, Ba and, subordinately, Al.

This kind of alteration is not typical of « porphyry copper » deposits, whereas the hydrothermally altered rocks show a K-rich alteration (LOWELL and GUILBERT, 1970).

The preponderance of Zn over Cu in almost all the samples, is also worthy of note that Zn was more abundant than Cu in the hydrothermal solutions.

Finally the typical zoning of « porphyry copper » deposits, composed of a core of prevalent molybdenite and belts of pyrite-chalcopyrite, sphalerite and galena etc. seem to be absent in the rocks of the Ogliastra.

Neverthless this datum should be analyzed more carefully; in fact the Post-hercynian

TABLE 10
Analyses of « granitoid » rocks from Ogliastra

	PC2	PC34	PC109	PC160	PC178	PC50	PC47	PC52	PC37	PC35
SIO2	67.42	72.88	54.71	72.95	63.98	62.80	63.49	61.30	71.65	70.32
TIO2	0.56	0.22	0.79	0.25	0.78	0.50	0.64	0.60	0.30	0.40
AL2O3	15.68	14.11	12.25	13.76	15.50	13.32	16.57	12.78	12.58	14.98
FE2O3	4.10	1.92	11.65	1.55	5.68	8.64	4.82	9.37	3.95	3.02
MNO	0.05	0.04	0.89	0.02	0.12	0.46	0.08	0.17	0.39	0.06
MGO	1.73	0.56	7..40	0.63	2.94	2.34	2.07	2.49	1.57	0.97
CAO	3.59	0.80	9.74	0.44	2.84	8.49	4.72	9.99	3.56	1.71
NA2O	3.60	3.39	0.30	2.87	2.78	3.08	3.58	0.94	4.32	3.19
K2O	3.13	5.47	0.73	6.04	3.67	0.37	3.60	1.16	1.02	4.75
P2O5	0.12	0.06	0.17	0.09	0.14	0.09	0.16	0.15	0.08	0.14
LOI	0.58	0.47	1.25	0.67	1.45	0.53	0.62	0.91	0.48	0.78
ZN	165	249	763	76	462	553	115	110	229	435
CU	93	ND	125	19	22	11	91	360	46	ND
NI	5	ND	9	ND	6	3	5	ND	ND	4
CE	73	73	107	71	47	83	120	75	98	90
BA	443	647	147	667	775	94	639	214	184	853
LA	42	43	49	40	41	44	64	43	47	45
ZR	139	108	224	115	145	117	131	140	125	150
SR	240	114	428	125	225	380	266	382	247	195
RB	131	196	31	195	127	25	140	49	55	169
PB	29	–	–	–	–	–	–	–	–	–
MO	<2	<2	–	<2	–	–	–	–	<2	<2
F	603	–	–	–	–	375	–	598	–	–

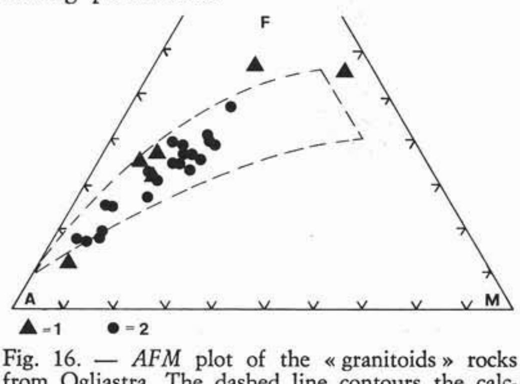
Major elements are given as %; the other elements as ppm; *ND* = not detected; — = no data.

	PC320	PC101	PC219	PC54	PC166	PC141	PC114	PC251	PC188	PC98	PC268	PC108	PC100
SIO2	60.74	66.28	71.85	63.57	70.55	71.41	61.47	68.74	71.25	63.01	55.81	65.53	67.01
TIO2	0.55	0.64	0.28	0.89	0.47	0.27	0.88	0.59	0.27	0.70	1.02	0.74	0.58
AL2O3	16.92	15.06	13.93	16.47	13.91	14.23	16.02	13.47	14.53	14.03	16.67	15.50	15.59
FE2O3	5.80	5.06	2.19	5.84	3.14	2.11	6.43	4.48	1.93	8.56	8.39	5.13	4.76
MNO	0.23	0.12	0.04	0.08	0.04	0.03	0.12	0.09	0.06	0.25	0.27	0.08	0.09
MGO	2.35	2.22	0.98	1.78	0.79	0.89	2.92	1.57	0.75	3.19	7.67	2.05	1.71
CAO	5.25	2.61	1.23	3.74	1.04	1.99	4.42	2.38	0.64	4.57	3.88	3.94	2.14
NA2O	3.74	3.51	3.28	3.25	3.16	3.04	2.89	3.59	3.06	2.44	3.24	2.91	3.18
K2O	4.00	3.27	5.00	3.30	4.93	4.56	3.20	3.49	5.55	2.96	1.86	3.38	3.86
P2O5	0.14	0.14	0.11	0.24	0.17	0.07	0.20	0.11	0.04	0.14	0.14	0.14	0.13
LOI	0.66	1.07	1.24	1.32	1.32	0.81	0.93	0.82	1.30	0.61	1.52	0.72	1.21
ZN	138	118	63	157	50	36	81	77	119	211	233	76	104
CU	20	24	23	23	365	55	10	18	54	9	6	8	19
NI	5	5	ND	4	6	3	7	5	ND	4	9	4	3
CE	50	69	70	71	84	20	66	120	54	81	50	39	57
BA	762	730	613	745	640	465	630	507	609	1672	691	656	695
LA	26	29	38	42	40	7	22	57	42	28	30	2	28
ZR	137	142	109	231	182	70	136	124	104	179	154	132	157
SR	320	216	131	248	76	158	214	130	124	382	230	208	213
RB	133	125	170	146	211	149	139	159	198	87	81	137	138
PB	29	–	–	37	33	48	–	–	–	–	–	–	–
MO	2	<2	<2	<2	2	<2	<2	–	–	–	<2	<2	<2
F	504	–	–	803	560	–	–	–	–	–	–	–	–

erosion may have modified the primary distribution of metals.

The mineralizations consist of small orebodies scattered over the area, according to the main tectonic trends and the alteration is mainly of propylitic type.

In conclusion, on a regional scale these mineralizations may be considered as « porphyry type » deposit according to the following parameters:



▲ = 1 ● = 2

Fig. 16. — *AFM* plot of the « granitoids » rocks from Ogliastra. The dashed line contours the calc-alkaline field (RINGWOOD, 1973). 1 = Mineralized rocks. 2 = « Granitoids » rocks.

I) the geochemical trends of « granitoid » rocks;

II) the geodynamic environment; the area where these mineralizations occur may be included in the North-eastern belt (or along the border) that represents the axis zone of the Hercynian chain. In other words this area might play the role of continental paleomargin subjected to the influence of high-grade metamorphism (« granulitic » facies) (Northern belt) and of mineralized horizon of the Ordovician-Silurian (Central belt). The influence of these two belts might be the cause of a sort of Cu-Mo mixing (and Zn-Pb) giving rise to a new ore association;

III) the ore association (Cu-Mo and Zn, Fe, Pb);

IV) the presence of mineralized skarns in the « granitoid » stocks.

On a local scale and in detail the absence of the typical zoning of the alteration, and mineralization and the very low contents of Cu and Mo, are data in disagreement with the « porphyry » scheme (BURNHAM, 1962; HEMLEY and JONES, 1964; SUTHERLAND BROWN, 1969; CLARK, 1972).

Thus these contrasting parameters seem to give rise to a sort of « aborted » porphyry deposits consisting small bodies of Fe-Cu-Mo-Zn scattered throughout the Hercynian plutonites.

On the other hand the absence of zoning may be caused by the characteristics of these deposits which may be classified as « plutonic porphyry deposits » (NIELSEN, 1976).

It must be remarked moreover that the detailed geochemical researches (FIORI et al., 1983) revealed the presence of a primary geochemical hälo of Cu and Zn around the mineralized bodies.

The mineralizing processes should be interpreted as deposition from hydrothermal fluids along a network of fractures with N-S direction.

Recent researches outlined how the «hercynian type» magmatism is characterised by acid chemism and slow, diapiric uplift of magma toward less shallow — in comparison with the « andean type » — levels of intrusion (ZWART, 1974; D'AMICO, 1974).

These differences of the mechanism of Hercynian magmatic emplacement may furnish an explanation of the low Cu contents and the reduced sizes of ore bodies

3.3.2. *General remarks on Hercynian hydrothermal deposits*

The remobilization and leaching of metals from a more or less deep basement to younger terrains is one of the oldest, most important and most difficult metallogenic problems to explain.

The problem is harder to solve for the old terrains (Paleozoic and Prepaleozoic) where it is almost impossible to find out and analyze the hydrological systems, the composition and the temperatures of geothermal waters.

A comprehensive programme, of isotopic analyses of the main sulphide associations may furnish definite solution to the metal remobilizations from the older metallogenic epochs to the younger ones.

With current knowledge, the Authors can point out some data resulting from the zonal distribution of the mesothermal vein system (Pb, Zn, Cu, F, Ba) (see the schematic map of fig. 17).

The island of Sardinia may be roughly divided into four main areas: the most important from an economic point of view, namely the Arburese-Sulcis and the Sarrabus are characterized by different ore associations; Pb-Zn (and Sn, Ni, Co etc.) are prevalent in the vein systems around the granitoids of the Linas, Oridda and Sulcis (area A), while Pb (Ag), Ba and F assume a great role in Sarrabus region (area B); in the latter area the Silius vein system occurs.

Mo is scattered in several parts of the Island (CABOI et al., 1970, 1978; GHEZZO et al., 1982) while Cu-Mo seem to be concentrated in the plutonites of Central and Northern Sardinia (DESSAU, 1956; SALVADORI, 1959; DERIU & ZERBI, 1965; BAKOS, 1968; CABOI et al., 1970, 1978; GHEZZO et al., 1982), even if in this zone (area C) Pb-Zn veins are also present (Sos Enattos, Gozzura ore deposits).

In the Nurra (area D) a vein NE-SW, mineralized with Pb-Zn-Ag (l'Argentiera) seems to be unconnected with any magmatic stock, even if this may be hypothesized to be at a not great depth (COCOZZA et al., 1974).

The pneumatolitic and hydrothermal mineralizations, related to Hercynian magmatism, are represented by interesting ore-associations even if they seem to be rather poor from an economic point of view.

Tin veins of S.ta Vittoria and Canale Serci (ZUFFARDI, 1958), the narrow quartz veins with molybdenite, arsenopyrite and Ni-Co sulphides (M.te Linas in Arburese area), the U oxides testify the evolution of ore-associations metallogenic epochs to the younger ones; this evolution is represented by the appearance of new metals, as well as Mo, Ni, Co, Sn, U, unknown in the Cambrian and Ordovician-Silurian deposits; thus the presence of these metals seem to be related to the Hercynian magmatism without any leaching and reworking phenomena from the older basement.

4. Conclusions on the Paleozoic metallogenic epochs and discussion of results

The schematic subdivision of the Paleozoic mineralizing processes into three main metallogenic epochs, even if useful for an initial approach to the economic geology of the Sardinia, may introduce some misunderstandings; in fact the mineralizing processes cannot be limited in time, but they are in equilibrium with the geodynamic evolution of the Paleozoic terrains (ZUFFARDI, 1968).

The sulphides, hosted in Cambrian limestone and dolomite, f.i., exhibit several remobilization phenomena; apart from the geochemical concentration during the early diagenesis of limestone (AMSTUTZ et al., 1963) lead, barium and silver are found in the silica horizon that marks the unconformity between Cambrian limestone and Ordovician sandstones and phyllites. The early Caledonian tectonics caused the emersion of the folded Cambrian terrains; the limestone was covered by a thick, probably continental, silica crust along with galena, rich in silver, and barite; these ores were supplied but the erosion of the upper part of the Cambrian limestone and by the freeing of lead and barium metals.

Furthermore remobilizations of Cambrian sulphide occurrence by stresses of Hercynian orogenesis occurred, giving rise to the well known sulphide bodies according to the main Hercynian tectonic trends.

The Hercynian orogenesis was followed by a long period of emersion and erosion activities; the weathering of Cambrian limestone and dolomite lead to the formation of an important karst system, filled by argentiferous galena, barite and more seldom pyrite and sphalerite.

The Triassic peneplanation of the Cambrian terrains and related ore formation by supergene deposition has been investigated in the past and valuable results have been published recently by another Author (BONI, 1979).

Thus, the primary geochemical anomalies of lead, zinc, iron, and barium in the Cambrian sedimentation gave rise, by several phases of tectonic and weathering remobilizations, to ore bodies of different age, structure and ore-association according to the geological evolution of the host rocks.

Another important aspect of the Paleozoic geology of Sardinia is the relationship between the South-Western belt (Cambrian platform), the « internal basin » or central belt (clastic sedimentation and margin volcanism) and North-Eastern belt (axis zone of Hercynian chain).

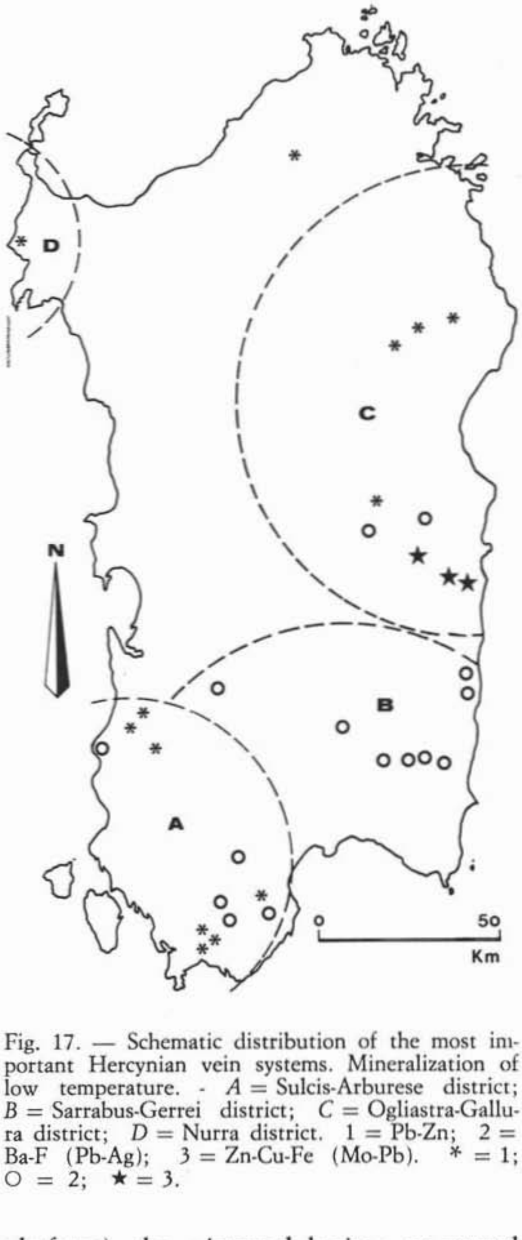


Fig. 17. — Schematic distribution of the most important Hercynian vein systems. Mineralization of low temperature. - A = Sulcis-Arburese district; B = Sarrabus-Gerrei district; C = Ogliastra-Gallura district; D = Nurra district. 1 = Pb-Zn; 2 = Ba-F (Pb-Ag); 3 = Zn-Cu-Fe (Mo-Pb). * = 1; ○ = 2; ★ = 3.

The cross-sections of fig. 18 may furnish an attempt of paleogeographic reconstruction of the environments up to the Hercynian orogenesis, but the data on the Precambrian basement are still meagre. Research carried out on the South-Western and Central Sardinia pointed to some remarkable differences

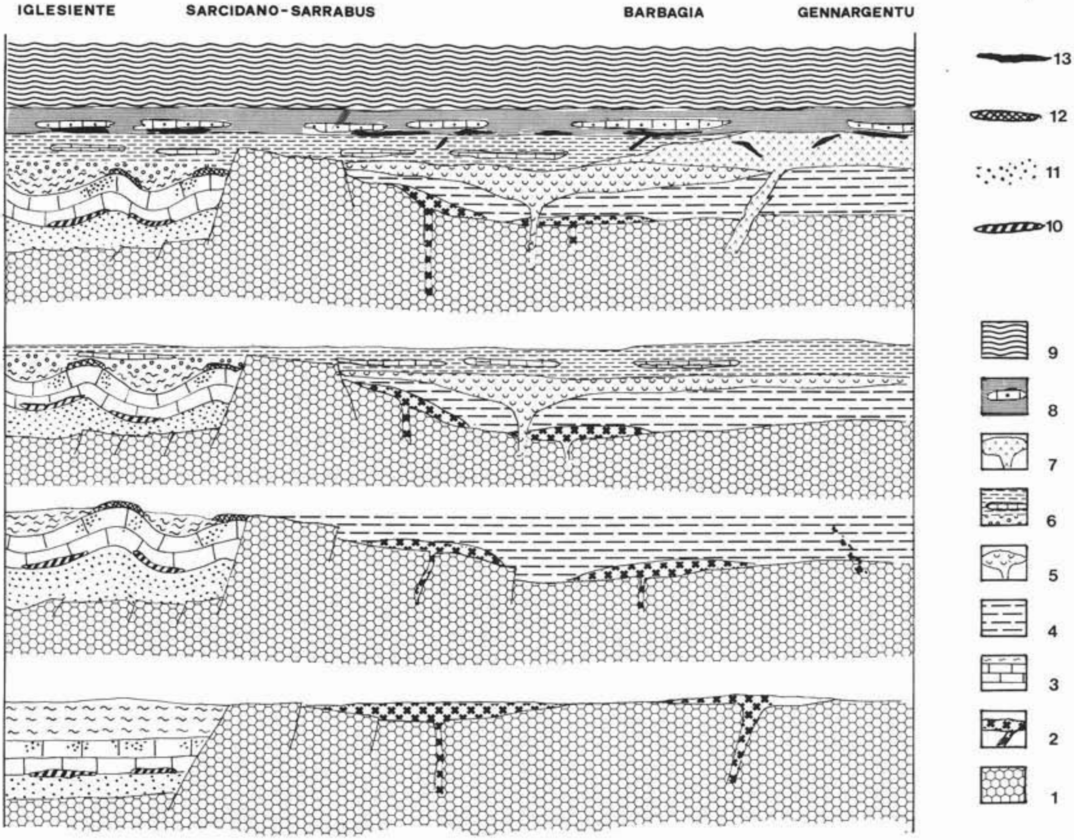


Fig. 18. — Pre-hercynian paleogeographic and metallogenic scheme of central and southern Sardinia. - 1 = Pre-cambrian basement (?); 2 = Porphyroids; 3 = Cambrian sequence; 4 = Upper-cambrian to Lower-ordovician sandstones and phyllites (« Solanas » and « S. Vito » formations); 5 = « Porfidi grigi e bianchi »; 6 = Middle-ordovician conglomerates, sandstones, phyllites and limestones; 7 = Metandesites and tuffs; 8 = Silurian-Devonian black-shales, phyllites and limestones; 9 = Lower-carboniferous (?) phyllites (« Postgotlandiano » formation); 10 = Stratiform deposits of Zn-Fe and/or barite; 11 = Pb-Zn sulphides bodies; 12 = Pb (Ag) and barite mineralization of silica horizon along the Cambrian-Ordovician unconformity; 13 = Ordovician-Silurian ore bearing horizon.

from a geological and ore-deposits point of view.

Around the Cambrian platform the Ordovician and Silurian sediments and volcanics are rather reduced; the strata-bound ore-deposits in Ordovician-Silurian terrains and volcanics, even if present, seem less significant for volume and spatial continuity.

The mineralizations such as Perda S'Oliu (SOLA, 1967; MARINI and MELIS, 1981), S. Leone (VERKAEREN & BURKHARDT, 1970; VERKAEREN & BARTHOLOMÈ, 1979), some stopes of Rosas, all located in the South-Western belt, show ore paragenesis rather similar to those of central Sardinia; they consist of galena, sphalerite, pyrite and/or magnetite and minor amounts of chalcopyrite, fluorite. The presence of metals such as Cu and F is witness to the influence of mineralizing processes in which the volcanic activity begin to play a certain role; these metals in fact are almost absent in the ore bodies hosted by the Cambrian carbonatic platform (PADALINO et al., 1978).

The geological sequence of the central Sardinia shows terrains from upper Cambrian (« Arenarie di S. Vito » and « Solanas ») formations (BARCA and MAXIA, 1982) to Lower-carboniferous (« Post-gotlandiano ») formation with a prevalence of clastic sedimentation and volcanic activity; the carbonatic facies are reduced to thin Ordovician and Silurian lenses and Devonian platform, strongly folded, faulted and eroded.

The stratiform ore-deposits, in the Southern (Sarrabus) as well in as the central area (Barbagia), are located above the thick volcanic cycle of Ordovician-Silurian age; this cycle is characterized by an increase of basic rocks from South towards North and namely from Sarrabus (Rhyolites) to Barbagia-Ogliastra (Andesites). This modification of volcanic chemism affected the composition of ore-associations; in fact Cu is found mainly in the narrow belt NW-SE of the Barbagia (Funtana Raminosa), according to the volcanic occurrence of andesite, while mainly Pb-Zn-Ag (and Sb, As) seem to be related to more acid volcanism, even if the geochemical trend of this volcanism must be analyzed yet.

Thus the spatial zoning of mineralization may be in agreement with the different paleomargin volcanism; this relationship of the ore associations with the geodynamic environment is well known in many ore districts of the world (PELLISSONIER, 1972; SILLITOE, 1972; BOIS et al., 1976; PALOMERO, 1977; JANKOVICH, 1980) but it must be analyzed in detail and by further research in the Sardinian mining district.

The Hercynian metallogenesis confirms the spatial zoning of the preceeding mineralizations, substantisting some heredity phenomena from the Pre-hercynian basement to the Carboniferous-Permian magmatism.

The most important Pb-Zn hydrothermal district occurs in the Arburese, not far from the Cambrian platform; the F mineralization (with minor amount of Ag, Pb, Zn, Ba) occur instead in Sarrabus where the Ordovician sequences is very thick. In fact previous studies threw some light on the role of F in the Paleozoic sequence; the fluoride content increases strongly in the transition from Cambrian to Ordovician slate and sandstones (MAZZELLA et al., 1979); this increase may be due to the beginning of Post-cambrian volcanic activity in the « internal basin » and the Hercynian magmatism might utilize the F content in the Ordovician-Silurian rocks giving rise to the important veins of Silius, M.te Genis, etc.

The Cu-Mo mineralizations of the Ogliastra finally, seem to be located along the border of the old margin, near the Ordovician andesitic belt. In this belt the most important Cu mineralizations of the Sardinian microplate occur, some skarns with Pb-Zn-Cu-Fe mineralizations are included in the Ogliastra granitoid rocks; these skarns may derive from fragments of mineralized Ordovician-Silurian limestones, as can be inferred for the Cuccuroni bodies (DEMURO et al., 1963) near the Arzana village.

Thus from the first metallogenic epoch, the Cambrian one, subsequent mineralizing processes modified the preceeding metallogenic scheme, but each mineralizing stage seems to be, more or less, connected to the preceding ones.

These researches have been carried out with the financial support of the CNR (Consiglio Nazionale delle Ricerche) in the ambit of the « Geodinamica » project, paper n. 528 (U.O. 422 directed by VIOLO); a special grant has been provided by the European Economic Comunity in the ambit of the CREST programme.

SELECTED LITERATURE

The literature on the Paleozoic terrains and ore-deposits of the Sardinia is rather wide.

The Authors named only the more recent papers or those directly connected with the topic of the present paper.

This literature is here divided in four parts: the first three are grouping respectively the references about the metallogenesis of the Cambrian, Ordovician-Silurian and Hercynian epochs. The last part is devoted to the general papers regarding regional, national and international references.

References of the Cambrian metallogenic epoch in Sardinia

ANGELUCCI A. (1970) - *Su alcune strutture sedimentarie nella formazione delle arenarie del Cambrico inferiore dell'Iglesiente (Sardegna Sud-Occidentale)*. Rend. Sem. Fac. Scienze Univ. Cagliari, 40, 3-4, 1-27.

ARTHAUD F. (1963) - *Un example de tectoniques superposées dans le paléozoique de l'Iglesiente (Sardaigne)*. C.R. somm. Soc. Géol. de France, Fasc. 3, 303 pp., Paris.

BENZ J.P. (1964) - *Le gisement plombo-zincifère d'Arenas (Sardaigne)*. Travaux du Lab. Sciences de la Terre Ecole des Mines, Nancy, 126 pp.

BONI M. (1978) - *Considerazioni paleogeografiche su alcune mineralizzazioni a solfuri della Formazione di Gonnesa (Cambrico inferiore edlla Sardegna)*. Mem. Soc. Geol. It., 19, 713-720.

BONI M. (1979) - *Zur Paläogeographie, Mineralogie und Lagerstättenkunde der Paleokosterze in Süd-West Sardinien (Iglesiente - Sulcis)*. Diss. Univ. Heidelberg, 260 pp.

BONI M., MARINELLI P. (1980) - *Analisi stratigrafico-strutturale della zona di Buggerru (Iglesiente) con particolare riguardo alla posizione delle mineralizzazioni nella formazione di Gonnesa*. Boll. Soc. Geol. It., 99, 35-55.

BONI M., GANDIN A., MARINACCI P., STANZIONE D. (1981) - *A paleonvironmental sedimentological and geochemical approach to the Gonnesa Formation (Lower Cambrian) (Buggerru area, SW Sardinia)*. I.A.S. 2nd EUR Mtg. Bologna, Abstract, 14-16.

BRUSCA C., DESSAU G., JENZEN N.L. (1965) - *L'origine dei giacimenti di zinco e piombo nell'Iglesiente alla luce della composizione isotopica dello zolfo nei sulfuri*. Symp. Probl. Geominerari Sardi, Ass. Min. Sarda, Cagliari, Iglesias, 1-30.

BRUSCA C., PRETTI S., TAMBURRINI D. (1967) - *Le mineralizzazioni baritose della copertura di Monte Sa Bagattu (Iglesias - Sardegna)*. Res. Ass. Min. Sarda, LXXII, 7, 89-106.

BRUSCA C., DESSAU G. (1968) - *I giacimenti piombo-zinciferi di San Giovanni (Iglesias) nel quadro della geologia del Cambrico Sardo*. L'Industria Mineraria, 19, 1-53.

BRUSCA C., PRETTI S., TAMBURRINI D., TOCCO S. (1971) - *Su alcune mineralizzazioni a barite e galena insediate nei karst del penepiano ercinico (Iglesiente meridionale - Sardegna)*. Res. Ass. Min. Sarda, LXXVI, 5, 1-25.

CARANNANTE C., COCOZZA T., D'ARGENIO B., SALVADORI I. (1974) - *Caratteri deposizionali e diagenetici della « dolomia rigata » del Cambrico della Sardegna*. Rend. Soc. Ital. Mineral. Petrol., 30, 2, 1159-1173.

CARMIGNANI L., COCOZZA T., GANDIN A., PERTUSATI P.C. (1982) - *Lineamenti della geologia dell'Iglesiente - Sulcis*. Guida alla geologia del Paleozoico sardo. Guide Geologiche Regionali, Soc. Geol. It., 55-77.

COCOZZA T. (1969) - *Slumpings e brecce intraformazionali nel Cambriano medio della Sardegna (nota preliminare)*. Boll. Soc. Geol. It., 88, 71-80.

DI COLBERTALDO D. (1965) - *Osservazioni geologiche-minerarie e genetiche sul giacimento di piombo e zinco di Pira-Roma (Buggerru - Sardegna)*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 41-54.

FANNI S., GANDIN A., GRILLO S.M., LIPPI F., MARRAS G., SALVADORI A., TOCCO S. (1981) - *Piattaforma carbonatica cambrica della Sardegna Sud-occidentale: sedimentazione e deposizioni metallifere*. Mem. Soc. Geol. It., 22, 123-137.

GANDIN A., PADALINO G., TOCCO S., VIOLO M. (1973) - *Un esempio di deposizione stratiforme di barite nella « dolomia rigata » del Cambrico della Sardegna sud-occidentale. Tentativo di correlazione tra l'ambiente di sedimentazione e la precipitazione del solfato di bario. (Nota prima)*. Boll. Soc. Geol. It., 92, 329-354.

GANDIN A., PADALINO G., VIOLO M. (1974) - *Correlation between sedimentation environment and ore-prospecting. Sedimentological and ore-genesis studies of Cambrian « arenarie » and « dolomia rigata » formations (Sardinia - Italy): deposition and concentration of barite in an evaporitic environment*. Rend. Soc. Ital. Mineral. Petrol., 30, 251-330.

JUNKER B., SCHNEIDER H.H. (1979) - *L'infracambriano della Sardegna sud-occidentale*. Mem. Soc. Geol. It., 20, p. 461.

MARCELLO A., SALVADORI I., ZUFFARDI P. (1965) - *Contributo alla conoscenza del Cambrico Sardo. Nota III. Il giacimento di Seddas Moddizzis*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 83-95.

MARCELLO A., VALERA R. (1965) - *Contributo alla conoscenza del Cambrico sardo: nota IV. La zona del Marganai*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 133-154.

MC MOORE H.J. (1969) - *Influence of structures on the base metal deposits of southwest Sardinia, Italy*. Trans. Inst. Min. Metall., Soc. B, 78, 135-147.

PADALINO G., PRETTI S., TAMBURRINI D., TOCCO S., URAS I., VIOLO M., ZUFFARDI P. (1973) - *Ore-deposition in karst formation with examples from Sardinia*. Ore in sediments. Ed. by Amstutz and A.J. Bernard, I.U.G.S., serie A, 3, 209-220.

POLL J.J.K. (1966) - *The geology of the Rosas-Terraseo area (Sulcis South-Sardinia)*. Leidse Geol. Med., 35, 117-208.

PRETTI S., SALVADORI I. (1965) - *Contributo alla conoscenza del Cambrico-sardo: nota IV. La zona di Candiazzus*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 97-132.

PRETTI S., TAMBURRINI D. (1967) - *Le mineralizzazioni di Monte Arcu Sa Gruxi (Sulcis settentrionale - Sardegna)*. Res. Ass. Min. Sarda, 72, 6, 97-140.

PRETTI S., TAMBURRINI D. (1968) - *Le mineralizzazioni a barite della zona di Corona Sa Craba, Serra Lurdagu (Sulcis-Sardegna)*. Res. Ass. Min. Sarda, 73, 7, 13-50.

PRETTI S., SALVADORI I., VIOLO M. (1978) - *A new approach to the investigations on karst and ore-bodies in Cambrian carbonate rocks of Sardinia (Italy)*. Res. Ass. Min. Sarda, 1, 67-85.

SALVADORI I., ZUFFARDI P. (1961) - *Il giacimento di Monte Tamara (Sardegna)*. Res. Ass. Min. Sarda, 65, 7, 53-87.

TAMBURRINI D., URAS I. (1965) - *Contributo alla conoscenza delle mineralizzazioni del Cambrico Sardo: la zona di M.te Flacca*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 293-314.

TAMBURRINI D., VIOLO M. (1965) - *Un esempio di deposito supergenico di galena*. Res. Soc. Min. Sarda, 70, 5, 3-15.

TAMBURRINI D., VIOLO M. (1965) - *Il giacimento a baritina di Monte Barega - Monte Arcau (Iglesiente-Sardegna)*. Ric. Sci., 35, II-A, 814-848.

URAS I. (1951) - *Studi sulla mineralizzazione di Sa Duchessa*. Periodico di Mineralogia, XX, 1-2, 117-134.

VALERA R. (1967) - *Contributo alla conoscenza dell'evoluzione tettonica della Sardegna*. Res. Ass. Min. Sarda, 72, 6, 3-95.

VIOLO M. (1965) - *Contributo alla conoscenza del Cambrico sardo: la zona di M.te Onixeddu - M.te Uda*. Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 191-227.

VIOLO M., ZUFFARDI P. (1971) - *Geochemical metal distribution in the Cambrian system of Sardinia (Italy) and their paleogeographic control*. Proc. IMA-IAGOD Meeting, 3, 160-162.

VIOLO M. (1975) - *La zonalità nei giacimenti metalliferi, una conseguenza delle variazioni paleogeografiche durante la sedimentazione e la diagenesi.* Rend. Soc. Ital. Mineral. Petrol., 30, 1109-1132.

ZUFFARDI P. (1952) - *Il giacimento piombo-zincifero di M.te Agruxiau. Contributo allo studio dei giacimenti e ossidati dell'Iglesiente.* Industria Mineraria, 1, 1-12.

ZUFFARDI P. (1965) - *Strutture sedimentarie in talune mineralizzazioni paleozoiche sarde a solfuri.* Rend. Ass. Min. Sarda, 5, 3-21.

ZUFFARDI P. (1965) - *Contributo alla conoscenza della mineralizzazione del Cambrico sardo. Nota VI. Riassunto ed interpretazioni provvisorie delle conoscenze attuali.* Symp. Probl. Geominer. Sardi, Ass. Min. Sarda, Cagliari-Iglesias, 1-9.

References of the Ordovician-Silurian metallogenic epoch in Sardinia

BARCA S. (1981) - *Contributo alla stratigrafia del Siluriano-Devoniano del Sarrabus (Sardegna sud-orientale).* Boll. Soc. Geol. It., 100, 85-92.

BARCA S., MASCIA M. (1982) - *Assetto stratigrafico e tettonico del Paleozoico del Sarrabus occidentale.* Guida alla geologia del Paleozoico Sardo. Guide Geologiche Regionali, Soc. Geol. It., 87-93.

BECCALUVA L., LEONE F., MACCIONI L., MACCIOTTA G. (1981) - *Petrology and tectonic setting of the Paleozoic basic rocks from Iglesiente-Sulcis (Sardinia, Italy).* N. Jb. Miner. Abh., 140 (2), 184-201.

CARMIGNANI L., CORTECCI G., DESSAU G., DUCHI G., OGGIANO G., PERTUSATI P., SAITTA M. (1978) - *The antimony and Tungsten deposits of Villasalto in south-eastern Sardinia and its relationship with Hercynian tectonics.* Schweiz. Mineral. Petrogr. Mitt., 58, 1/2, 161-188.

CARMIGNANI L., MINZONI N., PERTUSATI P.C. (1982) - *Lineamenti geologici principali del Sarcidano-Barbagia di Belvì.* Guida alla geologia del Paleozoico Sardo. Guide geologiche regionali, Soc. Geol. It., 119-125.

DEMURO P., URAS I., VIOLO M., ZUFFARDI P. (1965) - *Considerazioni genetiche sui giacimenti sardi a solfuri: nota 2ª. Alcuni giacimenti della zona di Arzana (Ogliastra).* Symposium Ass. Min. Sarda, Cagliari-Iglesias, 343-368.

DESSAU G. (1937) - *Studi sulla miniera di Funtana Raminosa.* Per. Miner., 8, 2, 175-215.

FRANCESCHELLI M., MEMMI I., RICCI C.A. (1982) - *Zoneografia metamorfica della Sardegna settentrionale.* Guida alla geologia del Paleozoico sardo. Guide geologiche regionali, Soc. Geol. It., 137-149.

GARBARINO C., MACCIONI L., MINZONI N., PADALINO G., TOCCO S., VIOLO M. (1980) - *The strata-bound copper-lead-zinc mineralization of the Sardinian microplate (Italy).* Intern. Symposium « The European Copper Deposits », S.G.A., Bor (Yugoslavia), 251-260.

HALL A. (1975) - *Regional variation in the crustal abundance of minor elements: evidence from the granites of Sardinia.* Miner. Magazine, 40, 293-301.

MARINI C., MELIS M.F. (1981) - *Le mineralizzazioni stratiformi a solfuri misti della serie paleozoica del Fluminese (Sardegna sud-occidentale). Nota 1ª.* Rend. Soc. It. Min. e Petrol., 37, 541-555.

MAZZELLA A., MELIS M.F., PORCU R., RIVOLDINI A., VIOLO M. (1979) - *La distribuzione geochimica del fluoro nella sequenza ordoviciano-siluriana della Sardegna.* Ass. Min. Sarda, 2, 39-62.

MEMMI J., BARCA S., CARMIGNANI L., COCOZZA T., FRANCESCHELLI M., GATTIGLIO M., GHEZZO C., MINZONI N., NAUD G., PERTUSATI P.C., RICCI C.A. (1982) - *Il magmatismo pre-ercinico della Sardegna.* Guida alla geologia del Paleozoico sardo. Guide geologiche regionali, Soc. Geol. It., 157-164.

MINZONI N. (1975) - *La serie delle formazioni paleozoiche a Sud del Gennargentu.* Boll. Soc. Geol. It., 94, 347-365.

PADALINO G., TOCCO S., VIOLO M. (1978) - *Present hypothesis on the correlation between paleogeographic environments and ore deposits. Examples from Sardinia Mining district (Italy).* Mem. Soc. Geol. It., 19, 721-725.

SOLA L. (1967) - *Studio geogiacimentologico della zona di Perda S'Oliu.* Rend. Assoc. Min. Sarda, 31, 11-18.

VAI G.B. (1982) - *Fasi di « rifting »: nuovi dati stratigrafici e conseguenze paelogeografiche nel Paleozoico inferiore.* Guida alla geologia del Paleozoico sardo. Guide geologiche regionali, Soc. Geol. It., 193-195.

VERKAEREN J., BURCKHARDT G.E. (1970) - *Les skarns a magnetite de S. Leone (Sardaigne SW).* C.R. Ac. Sc. Paris, 270, 3-6.

VERKAEREN J., BARTHOCOME P. (1979) - *Petrology of the S. Leone magnetic skarn deposit (SW Sardinia).* Econ. Geol., 74, 53-66.

VIOLO M. (1966) - *Contributo alla conoscenza dei giacimenti stratoidi polimetallici in area metamorfica. Il giacimento di Sa Lilla (S. Vito, Cagliari - Sardegna).* Res. Ass. Min. Sarda, 8, 1-110.

ZUCCHETTI S. (1958) - *Il caratteristico deposito a solfurati di Piombo e Arsenico di Bacu Locci (Sardegna).* Boll. Serv. Geol. It., LXXX, 2-3, 275-301.

References of the Hercynian metallogenic epoch in Sardinia

BAKCOS F. (1968) - *Osservazioni geologico-minerarie sul giacimento a molibdenite e wolframite di Perda Majori (Sardegna Sud-Orientale).* Res. Ass. Min. Sarda, v. 72 (VI), 5-66.

BRIGO L., FERRARIO A., MARCCELLO A., NATALE P., OMENETTO P., PADALINO G., SALVADORI I., TOCCO S., URAS I., VALERA R., ZUCCHETTI S., ZUFFARDI P. (1982) - *Gîtes filoniens Pb, Zn, F, Ba de basse température du domaine varisque d'Italie.* Bull. du BRGM (2), II, 2, pp. 195-206. Symposium Orleans.

BRUNETTON P., BRINET F., COCHEME J.J., ORSINI I., VELLUTTINI P., VINCENT P.M. (1976) - *Présence d'une structure anulaire en Gallura (Sardaigne septentrionale).* C.R. Acad. Sc. Paris, t. 282, 2127-2130.

CABOI R., CONDRÒ A., MASSOLI-NOVELLI R. (1970) - *La mineralizzazione a molibdenite di Monte S'Abbagana.* Rend. Sem. Fac. Sc. Univ. Cagliari, v. 40 (III-IV), 373-424.

CABOI R., MASSOLI-NOVELLI R., SANNA G. (1978) - *La mineralizzazione a molibdenite di P.ta Su Seinargiu.* Rend. Soc. It. Min. Petr., 34 (1), 167-186.

CAVINATO A. (1972) - *La fluorite in Sardegna.* Mem. Ist. Geol. Univ. Padova, 34 pp.

CONTI L., MACCIONI L., PILI P. (1981) - *Petrologia del nucleo cristallino di Villanova Strisaili (Sardegna centro orientale).* Per. di Min., 5, 283-304.

DERIU M., ZERBI M. (1965) - *Notizie preliminari sul rilevamento geopetrografico e sulle ambientazioni petrogenetiche relative al giacimento di Molibdenite di M.te Mannu (Oschiri).* Symp. Probl. Geomin. Sardegna, Cagliari, 381-393.

DESSAU G. (1956) - *Cenni sul giacimento di tungsteno e molibdeno di Perda Majori.* Boll. Soc. Geol. It., 75, 239-250.

FIORI M., GARBARINO C., MACCIONI L., PADALINO G., VIOLO M. (1983) - *Evoluzione delle mineralizzazioni metallifere della Sardegna (Italia) in funzione dei parametri geodinamici.* Industria Mineraria, 3, 33-42.

GHEZZO C., GUASPARRI G., SABATINI G. (1972) *Lineamenti geopetrologici del cristallino sardo. Le plutoniti e la loro successione negli eventi intrusivi.* Miner. Petr. Acta, 18, 205-234.

GHEZZO C., GUASPARRI G., RICCOBONO F., SABATINI G., PRETTI S., URAS S. (1982) - *Le mineralizzazioni a molibdeno associate al magmatismo intrusivo ercinico della Sardegna: i rapporti con le plutoniti e i fenomeni di alterazione-mineralizzazione.* Rend. Soc. It. Min. e Petr., 38, 1, 133-145.

GHEZZO C., MEMMI I., RICCI C.A. (1982) - *Le granuliti e le eclogiti della Sardegna nord-orientale.* Guida alla geologia del Paleozoico sardo. Guide geologiche regionali, Soc. Geol. It., 151-156.

GUASPARRI G., RICCOBONO F., SABATINI G. (1982) - *Considerazioni sul magmatismo intrusivo ercinico e le connesse mineralizzazioni in Sardegna.* Rend. SIMP, 38, 1, 488-490.

MACCIONI L., PADALINO G., TOCCO S., VIOLO M. (1979) - *I giacimenti del tipo «porphyry copper»: una grande prospettiva per i metalli di base. Ipotesi e possibilità in Sardegna.* Ente Min. Sardo, 1/2, 45-54.

MASSOLI-NOVELLI R. (1973) - *Contributo allo studio genetico del talco di Orani (Nuoro). Nota 1ª: il giacimento di Sa Matta.* Ass. Min. Sarda, 74, 9-39.

MELIS M.F., SANNA M. (1978) - *Le mineralizzazioni piombo-zincifere del campo filoniano di Arghentaria - Guzzurra - Su Ergiolu (Lula, Sardegna nord-orientale). Ipotesi sul meccanismo di formazione e di rimobilizzazione dei metalli del ciclo magmatico ercinico.* Atti Fac. di Ingegneria di Cagliari, 2, 115-135.

NATALE P. (1969) - *Il giacimento di fluorite di Silius nel Gerrei.* Boll. Ass. Min. Subalpina, 6, 1-35.

SALVADORI I. (1959) - *Segnalazione di una manifestazione a molibdenite nella zona di Villacidro.* Res. Ass. Min. Sarda, 63, V-VI, 5-27.

SALVADORI I., ZUFFARDI P. (1960) - *Il campo filoniano di Sos Enattos.* Res. Ass. Min. Sarda, 65, 5-47.

SALVATORI I., VALERA R. (1972) - *Principi e metodi di ricerca delle mineralizzazioni fluoritico-baritiche nel Sarrabus (Sardegna sud-occidentale).* Ass. Min. Subalpina, 4, 533-548.

URAS I. (1956) - *Il giacimento fluoritico di Monreale.* Per. di Mineralogia, 20, 1-42.

VENERANDI I. (1968) - *Il giacimento a molibdenite e wolframite di Perda Majori.* Ist. Lombardo (Rend. Sc.), A 102, 678-716.

ZUCCHETTI S. (1965) - *Segnalazione di un sistema di filoni di tormalinite nei dintorni di Busachi (Cagliari).* Res. Ass. Min. Sarda, 6, 3-11.

ZUFFARDI P. (1948) - *Il giacimento piombo-zincifero di Montevecchio (Sardegna).* Atti « Congresso Minerario Italiano, 17 pp.

ZUFFARDI P. (1953) - *Primi risultati delle ricerche sulla profondità delle mineralizzazioni e sull'imbasamento granitico di Montevecchio.* Res. Ass. Min. Sarda, 58, 5-39.

ZUFFARDI P. (1958) - *Su una nuova segnalazione di cassiterite in Sardegna e sulle presenze di tracce di stagno in alcuni adunamenti idrotermali sardi.* Res. Ass. Min. Sarda, 63, 27-38.

General literature

AMSTUTZ G.C. (1958 b) - *Syngenetic zoning in ore deposits.* Proc. Geol. Ass. Con., 11, 95-113.

AMSTUTZ G.C. (1962) - *L'origine des gîtes minéraux concordants dans les roches sédimentaires.* Chron. Min. Outre Mer Rech. Minière, 308, 115-126.

AMSTUTZ G.C. (1963) - *Space, time and symmetry in zoning.* Symp.: « Problem of post-magmatic ore-deposition », Prague, vol. 1, 33-37.

AMSTUTZ G.C., RHAMDOHR P., EL BAZ F., PARK W.C. (1963) - *Diagenetic behaviour of sulphides.* Develop. in sedimentology, 2, 65-90.

AMSTUTZ G.C. (1971) - *Observational criteria for the classification of Mississippi Valley - Bleiberg - Silesia type of deposits.* Proced. of the 2nd Int. Symp. on the Mineral deposits of the Alps, Bled, 207-215.

BARCA S., CARMIGNANI C., COCOZZA T., GHEZZO L., MINZONI N., PERTUSATI P.C., RICCI C.A. (1981) - *Geotraverse B in Sardinia: stratigraphic correlation forms.* IGCP Project n. 5, Newsletter, 3, 7-21.

BATHURST R.G.C. (1981) - *Carbonate sediments and their diagenesis.* Dev. Sediment., 12, 620 pp., 359 figs., Amsterdam, Elsevier.

BELLIENI G., SASSI F.P. (1981) - *New chemical data and a review on the South Alpine « Pre-Hercynian rhyolitic plateau » in the eastern Alps.* IGCP Project n. 5, Newsletter, 3, 22-28.

BELOV A.A. (1981) - *The main development stages and epochs of tectonic activity in the Mediterranean - Alpine folded area in Paleozoic.* IGCP Project n. 5, Newsletter, 28-35.

BENCINI A., TURI A. (1974) - *Mn distribution in the Mesozoic carbonate rocks from Lima Valley Northern Appennines.* Jour. Sed. Petrology, 44, 774-782.

BERNARD A.J., LELEU M.S. (1967) - *A propos de la concentration résiduelle de la blende et de la galène.* C.R. Accad. Sc. Paris, t. 265, 729-732, Paris.

BERNARD A.J. (1971) - *Metallogenic processes of intra-karstic sedimentation.* Ore in sediments, VIII Int. Sed. Congr. Heidelberg, 43-57.

BOIS J.P., POUIT G. (1976) - *Les minéralizations de Zn (Pb) de l'anticlinorium de Pierrefitte: un exemple de gisements hydrothermaux et sédimentaire associés au volcanisme dans le Paléozoique des Pyrénés centrales.* Bull. BRGM, 6, 543-568.

BURNHAM C.W. (1962) - *Facies and types of hydrothermal alteration.* Econ. Geol., v. 57, 768-784.

BURT D.M. (1977) - *Mineralogy and petrology of skarn deposits.* Rend. Soc. It. Min. Petr., 33, 859-873.

CANN J.R. (1970) - *Rb, Sr, Y, Zr and Nb in some ocean-fluor basaltic rocks.* Earth Plan. Sc. Letters, 10, 7-111.

CARANNANTE G., COCOZZA T., D'ARGENIO B. (1981) - *Tectono-sedimentary trends and paleogeography of Sardinia. During late Pre-cambrian and Cambrian.* I.A.S. 2nd Eur Mtg. Bologna, 227-230.

CARMIGNANI L., COCOZZA T., MINZONI N., PERTUSATI P.C., RICCI C.A. (1979) - *È la Corsica il retropaese della catena ercinica in Sardegna?* Mem. Soc. Geol. It., 20, 47-55.

CARMIGNANI L., COCOZZA T., GHEZZO C., PERTUSATI P.C., RICCI C.A. (1982) - *Lineamenti del basamento sardo.* Guida alla geologia del Paleozoico sardo. Guide Geol. Regionali, Soc. Geol. It., 11-23.

CHILINGAR G.V., BISSEL H.J., FAIRBRIDGE R.W. (1967 a) - *Carbonate rocks: origin, occurence and classification.* Dev. Sediment., 9A, 471 pp., 131 figs., Amsterdam, Elsevier.

CHILINGAR G.V., BISSEL H.J., FAIRBRIDGE R.W. (1967 b) - *Carbonate rocks: physical and chemical aspects.* Dev. Sediment., 9B, 413 pp., 80 figs., Amsterdam, Elsevier.

COCOZZA T., JACOBACCI A., NARDI R., SALVADORI I. (1974) - *Schema stratigrafico strutturale del Massiccio Sardo-Corso e minerogenesi in Sardegna.* Mem. Soc. Geol. It., 12, 85-186.

COCOZZA T., MINZONI N. (1978) - *Osservazioni sul vulcanismo paleozoico sardo.* G.L.P. 2, G.B. Vai ed., 25-29.

COCOZZA T. (1979) - *The Cambrian of Sardinia.* Soc. Geol. It., 20, 163-187.

COOK P.J. (1973) - *Supratidal environment and geochemistry of some recente dolomite concretions, Broad Sound, Queensland, Australie.* Jour. Sed. Petrology, 43, 998-1011.

D'AMICO C. (1974) - *Hercynyan plutonism in the Alps. A report 1973-1974.* Mem. Soc. Geol. It., 13 (1), 49-118.

DEBRENNE F. (1964) - *Archeocyata contribution à l'étude des faunes cambrienne du Maroc, de Sardaigne et de France.* Notes et Mem. Serv. Jeol. du Maroc, 179, 265 pp.

DE LA ROCHE H., LETERRIER J., GRAND CLAUDE P., MARCHAL M. (1980) - *A classification of volcanic and plutonic rocks using R_1-R_2 diagram and major element analyses. Its relationships with nomenclature.* Chem. Geol., 29, 183-210.

DIETRICH R.V., HOBBS C.R.B., LOWM W.D. (1963) - *Dolomitization interrupted by silicification.* Jour. Sed. Petrology, 33 (3), 646-663.

DI SIMPLICIÒ P., FERRARA G., GHEZZO C., GUASPARRI G., PELLIZZER R., RICCI C.A., RITA F., SABATINI G. (1974) - *Il metamorfismo e il magmatismo paleozoico nella Sardegna.* Rend. SIMP, 30, 979-1068.

DUNHAM J.B., OLSON E.R. (1978) - *Diagenetic dolomite formation related to Paleozoic paleography of the Cordilleran miogeo-sincline in Nevada.* Geology, 6, 556-559.

ESTEBAN MATEO C. (1976) - *Vadose pisolite and caliche.* Geologic Notes, 2048-2057.

FLOYD P.A., WINCHESTER J.A. (1975) - *Magma type and tectonic setting discrimination using immobile elements.* Earth Planet. Sc. Letters, 27, 211-218.

FRIEDMAN G.M., SANDERS J.E. (1967) - *Origin and occurence of dolostone.* Dev. Sediment., Amsterdam, Elsevier.

FRITZ P., KATZ A. (1972) - *The sodium distribution of dolomite crystals.* Chem. Geol., 10, 237-241, Amsterdam.

GALKIEWICZ I. (1967) - *Genesis of Silesian Cracovian zinc-lead deposits.* Monography 3, Econ. Geol., 156-168.

GANDIN A., PADALINO G., TOCCO S., VIOLO M. (1974) - *Correlation between sedimentation environment and ore prospecting.* Fourth IAGOD Symp. Varna, II, 377-383.

GARRELS R.M. (1954) - *Mineral species as functions of pH and oxidation-reduction potentials, with special reference to the zone of oxidation and secondary enrichment of sulphide ore deposits.* Geoch. Cosmochim. Acta, 5, 153-168.

GOLDIE R., KOTILA B., SEWARD D. (1979) - *The Don Rouyn Mine: archean porphyry copper deposits near Noranda, Quebec.* Econ. Geol., 74, 1680-1684.

GRUSZCZYK H. (1967) - *The genesis of the Silesian-Cracow deposits of lead-zinc ores.* Econ. Geol. Monography 3, 169-177.

HARANCZYK CZ. (1980) - *Paleozoic porphyry copper deposits in Poland.* European Copper Deposits, Symp. Belgrado-Bor, 89-95.

HEINISH H. (1981) - *Preliminary report on early Paleozoic acid volcanism in the eastern and southern Alps.* IGCP Project, n. 5, Newsletter, 80-89.

HEMLEY J.J., JONES W.R. (1964) - *Chemical aspects of hydrothermal alteration with emphasis on hydrogen metasomatism.* Econ. Geol., 59, pp. 538-569.

IRVINE T.N., BARAGAR W.R.A. (1971) - *A guide to the chemical classification of the Common volcanic rocks.* Can. Jour. of Earth Sc., 8, 523-548.

JANKOVIC S. (1980) - *Ore deposit types and major copper metallogenic units in Europa.* European Copper Deposits, 9-25, Belgrade, Bor.

LAGNY PH., ROUVIER H. (1976) - *Les gisements Pb-Zn en roches carbonatées sous inconformité: gisements paleokarstiques ou gisements dans des paléokarst?* Mem. h. ser. Geol. France, 7, 5-69.

LAND L.S., HOOPS G.K. (1973) - *Sodium in carbonate sediments and rocks: a possible index to the salinity of diagenetic solution.* Journ. Sed. Petrology, v. 43, 614-617.

LARSEN G., CHILINGAR G.V. (1967) - *Diagenesis in sediments.* Dev. Sediment, 8, 551 pp., Amsterdam-London-New York, Elsevier.

LELEU M. (1965) - *Les gîtes plombo-zincifères du*

Laurium (*Grèce*). Thèse Doct. Ing. Fac. Sc., Nancy.

LELEU M. (1966) - *Le karst et ses incidences métallogéniques*. Sc. Terre, Nancy, 11 (4), 385-413.

LOWELL J.D., GUILBERT J.M. (1970) - *Lateral and vertical alteration-mineralization zoning in porphyry ore deposits*. Econ. Geology, 65, 373-408.

MAUCHER A., SCHNEIDER H.J. (1967) - *The Alpine lead-zinc ores*. Geol. Monography, 3, 71-86.

NICOLINI P. (1970) - *Litologie des concentrations minérales stratiformes*. Paris, Gauthier-Villars, 769 pp.

NIELSEN R.L. (1976) - *Recent developments in the study of porphyry copper geology. A review*. Porphyry Deposits of the Canadian Cordillera, Southerland Brown A. (Ed.), Spec. Vol. 15, 487-500.

OFTEDAH G. (1958) - *A theory of exalative sedimentary ores*. Geol. Foien. Stockholm Forb, 80, 1-119.

PALOMERO G.F. (1977) - *Caractéres geologicos y relaciones morfologicas y geneticas de la mineralizzaciones del « Anticlinal de Rio Tinto »*. Acta Jalmantiensia, Salamanca, 24 pp.

PEARCE J.A., CANN J.R. (1973) - *Tectonic setting of basic volcanic rocks determined using trace element analyses*. Earth Planet. Sc. Letters, 19, 290-300.

PELLISSONNIER H. (1972) - *Les dimensions des gisements de cuivre du monde. Essai de métallogénie quantitative*. Mem. du B.R.G.M., 57, 405 pp.

PURSER B.H. (1973) - *The Persian Gulf Holocena carbonate sedimentation and diagenesis in a shallow epicontinental sea*. Springer-Verlag, Berlin Heidelberg - New York, 471 pp.

RAO C.P., NAOVI (1977) - *Petrography, geochemistry and factor analysis of a lower Ordovician subsurface sequence Tasmanie, Australia*. Journal of Sedimentary Petrology, 47, 1036-1055.

RAO C.P. (1981) - *Geochemical differences between tropical (Ordovician) and subpolar (Permian) carbonates, Tasmania, Australia*. Geology, 9, 205-209.

RICCI C.A., SABATINI G. (1978) - *Petrogenetic affinity and geodynamic significance of metabasic rocks from Sardinia, Corsica and Provence*. N. Jb. Miner. Mh., H. 1, 23-38.

RIDGE J.D. (1973) - *Volcanic exhalations and ore deposition in the vicinity of the sea-floor*. Miner. Deposita, 8, 322-348.

RINGWOOD A.E. (1975) - *Composition and petrology of the earth's mantle*. Mc Graw Hill Inc., New York, 618 pp.

SILLITOE R.H. (1972) - *A plate tectonic model for the origin of porphyry copper deposits*. Econ. Geol., 67, 184-197.

STRAKHOV V.M. (1965) - *Principles of lithogenesis*. Edinburgh, Olivier and Boyd, 245 pp.

SUTHERLAND BROWN A. (1969) - *Mineralization in British Columbia and the copper and molybdenum deposits*. Canadian Mining Metall. Bull., 62, 26-40.

SUTHERLAND BROWN A. (1976) - *Metallic mineral resources of canadian Cordillera*. Circum. Pacific. Energy and Mineral Resources, 25, 503-508.

THORPE R.S. (1972) - *Ocean floor basalt affinity of Precambrian Glaucophane schist from Alglesey*. Natur Phys. Sc., 240, 164-166.

TUREKIAN K.Y. & WEDEPHOL K.H. in MACQUAR J.CL. & LAGNY P.H. (1981) - *Mineralizations Pb-Zn sous inconformité des series de plates formes carbonatées. Exemple du gisement de Trèves (Gord, France). Relations entre dolomitizations, dissolutions et minéralizations*. Mineral. Deposita, 16, 2, 283-307.

VERRAES G. (1979) - *Contribution à l'étude de la province métallogénique sous Cevenale: les gîtes Pb-Zn de Montdardier, la Sanguinade et 102, district des Malines (Gord, France)*. Memoire du Centre d'Etudes et de Recherches Géologiques et Hydrologiques. C.E.R.G.A., Montpellier, 17, 1-269.

ZAMAREÑO I. (1972) - *Les litofacies carbonatadas del cambrico de la zona cantabrica (N.W. España) y su distribucion paleogeografica*. Trabajos de Geologia, 5, 3-118, Oviedo.

ZUFFARDI P. (1968) - *Trasformism in the genesis of ore deposits: examples from Sardinia lead-zinc deposits*. XXIII Int. Geol. Congress, 7, 137-149.

ZUFFARDI P. (1969) - *La metallogenèse du plomb, du zinc e du baryum en Sardaigne: un example de permanence, de polygénètisme et de transformisme*. Annales de la Soc. Géologique Belgique, 92, 3.

ZWART M.J. (1974) - *L'Orogene ercinico in Europa*. Mem. Soc. Geol. It., 13/1, 3-5.

WILSON J.L. (1975) - *Carbonate facies in geologie history*. Springer-Verlag, Berlin Heidelberg - New York, 411 pp.

WINCHESTER Y., FLOYD P.A. (1977) - *Geochemical discrimination of different magma series and their differentiation products using immobile elements*. Chem. Geol., 20, 325-343.