RENDICONTI DELLA SOCIETÀ ITALIANA DI MINERALOGIA E PETROLOGIA, 1984, Vol. 39, pp. 629-648

HERCYNIAN Mo-MINERALIZATIONS OF PORPHYRY-STYLE IN THE SARDINIAN BATHOLITH

A DISCUSSION ON THE GENESIS AND A COMPARISON WITH OTHER DEPOSITS OF THE FAMILY

GIOVANNI GUASPARRI, FRANCESCO RICCOBONO, GIUSEPPE SABATINI
Istituto di Mineralogia e Petrografia dell'Università, via Mattioli 4, 53100 Siena (Italia)

ABSTRACT. — The Mo-mineralizations of the « granitic » batholith of Sardinia are reviewed and some of the most significant of them are described. They are low or very low grade mineralizations, the bulk of the molybdenite being distributed through large rock volumes. The mineralizations occur mainly as molybdenite bearing quartz veins, stockworks, fracture fillings and disseminations. Hypabyssal high silica intrusives (leucogranite-porphyries and fine-grained leucogranites) are always the rocks genetically linked to mineralizations and their commonest host. Extensive hydrothermal halos with propylitic, argillic and phyllic assemblages are associated with the mineralizations which according to their major features are to be considered as porphyry-style mineralizations.

The genesis of these deposits is discussed in the light of the petrology and geostructural evolution of the batholith and particularly as regards the second hercynian magmatic phase to which all the mineralizations are bound.

Comparisons are drawn with mineralizations of other segments of Hercynian chain in Europe, and some comments are made on metallogenesis related to granitic rocks.

RIASSUNTO. — Vengono prese in esame e descritte alcune delle più significative mineralizzazioni a molibdeno associate alle rocce granitiche del batolite sardo. Si tratta di mineralizzazioni a tenore basso o molto basso, essendo la maggior parte della molibdenite dispersa in grandi volumi di roccia.

Il minerale si rinviene principalmente in vene di quarzo, stockworks, come riempimento di fratture o disseminato. Le rocce che sono sempre geneticamente legate alle mineralizzazioni e che comunemente le ospitano, sono rappresentate da ipoabissaliti persiliciche (porfidi leucogranitici e leucograniti a grana fine).

Ampie aureole idrotermali con tipo di alterazione « propilitica », « argillica » e « fillica » sono associate alle mineralizzazioni che per le loro caratteristiche di insieme sono da considerare come manifestazioni del tipo « porphyry ».

Viene discussa la genesi di queste mineralizzazioni alla luce dell'evoluzione petrologica e geostrutturale del batolite riguardante in particolare la seconda fase magmatica ercinica a cui le mineralizzazioni sono legate.

Vengono infine fatti confronti con mineralizzazioni di altri segmenti della catena ercinica europea, nonchè alcuni commenti sulla metallogenesi legata alle rocce granitiche.

1. Introduction

Numerous molybdenum showings, mined in the past but now considered to be of subeconomic value, are known in the Sardinian batholith (see SALVADORI, 1959). A diamond drill program has been recently undertaken by the Progemisa S.p.A. to test the economic potential of some of them.

GHEZZO et al. (1982) have recently emphasized the close association of the Mo-mineralizations with high silica plutonites belonging to the «leucogranitic suite» which represents the exclusive products of the second phase of the hercynian intrusive magmatism (BRALIA et al., 1982; GUASPARRI et al., in press). This statement which is further strenghtened by new available data, can be now extended to the whole metallogenesis bound to the rocks of the batholith.

Of the two phases recognized within the hercynian magmatism only the latest one had emplacement conditions and crystallization history which allowed the development of mineralizing phenomena. This conclusion is based on the recently acquired knowledge on the petrology of the batholith and mainly relies on the metallogenetic interpretation proposed by GUASPARRI et al. (in press).

Referring for details to the aforementioned papers, we need to recall at first, in the interest of the subsequent discussion, some relevant aspects of the petrology of the leucogranitic rocks.

2. Petrological outlines of the leucogranitic rocks

The rocks of the second intrusive phase of the hercynian magmatism in Sardinia always show isotropic structure, their contacts are always sharp and discordant with the foliation in the country rocks; the intrusions follow structural axes which are grossly orthogonal to those of first phase plutonites. These and other characteristics such as intense fracturing, ubiquitous late-magmatic alteration, association with very abundant hypabyssal facies (porphyries and aplites), the frequency of miarolitic cavities, etc. indicate that the leucogranites are decidedly post-tectonic magmas emplaced at relatively high crustal levels in a substantially distensive regime.

Of utmost importance is the complete lack of BMD inclusions and mineralogic disequilibrium phenomena which are ubiquitous in the first phase magmatic products. This indicate that the leucogranitic suite is of exclusively crustal origin (GUASPARRI et al., in press) and particularly excludes interaction processes between basic subcrustal magmas and lower crust partial melts which according to BRALIA et al. (1982) played a decisive role in the genesis of the tonalitic and granodioritic rocks of the first phase.

We wish to emphasize further that the products of the two intrusive phases were clearly emplaced at different levels in the crust despite field observation indicating that the leucogranites are at approximately the same topographic level as the preceding intrusions. In fact, if we take into consideration that the erosion rate for this kind of orogen is fairly rapid (not less than 0.5 km/m.y. according to CLARK and JÄGER, 1972 and ALBAREDE, 1976) and if we reasonably assume that erosion started at least at the time of emplacement of the first phase plutonites, it follows that the 10-15 m.y. younger leucogranites (DEL MORO et al., 1975; GHEZZO et al., 1979) were evidently intruded at much higher levels than the preceding magmatites.

All the leucogranite outcrops, are constituted by numerous composite stocks assembled through multiple intrusion events. Rock textures are highly variable and numerous lithofacies can accordingly be distinguished; they can however be divided into two main groups: medium to coarse grained leucogranites and fine-grained varieties (microleucogranites, aplites) or leucogranite porphyries. The fine grained and porphyritic rocks, constituting about 15-30 % of the whole volume of the suite, are the youngest in the intrusive succession. All the rocks of the suite are usually pervasively altered, though to varying degree. Alteration increases from coarse grained to fine grained or phorphyritic rocks.

The major mineral assemblage of the medium to coarse grained facies is constituted by quartz, K-feldspar, sodic plagioclase and biotite. The normative average proportions of the light minerals are: 34,7 % quartz, 28,7 % K-feldspar, 33,4 % plagioclase, while modal analysis indicates that K-feldspar is always clearly in excess of plagioclase.

Quartz is generally subhedral and lacks ondulatory extinction. K-feldspar is characteristically microperthitic orthoclase and subordinately microcline-microperthite with anhedral to subhedral contours. Plagioclase, which is generally albitic oligoclase, occurs in tabular subhedral grains with poorly developed zoning. Biotite is an iron-rich term and iron ores, apatite, zircon and allanite are ubiquitous accessory minerals. Fluorite is also widespread, generally as inclusions in biotite, frequently also enclosed in feldspars.

The fine grained and porphyritic rocks do not differ in their mineral assemblage from the preceding, differences being merely of structural and textural nature. Bipyramidal quartz, microperthitic K-feldspar and unzoned albitic plagioclase are the common phenocrysts toghether with the less frequent biotite crystals. The groundmass is always holocrystalline and ranges in texture from very fine aplitic to microgranular, almost cryptocrystalline. The phenocrysts/groundmass ratio is highly variable. Contrary to the notable variability in rock texture the chemical composition of the rocks is fairly homogeneous. In table 1 the average composition of medium to coarse grained leucogranites and of porphyries and fine grained varieties are reported together with the ranges of variation for each element. The most striking feature of the major oxide data is the narrow range in oxide abundance as a whole and particularly within the single groups. Nevertheless some significant variation does exist between the two groups. The fine grained leucogranites and leucogranite- porphyries show an increase in SiO_2 and K_2O and a decrease in total FeO, MgO and CaO contents. These variations are in agreement with a fractional crystallization link between the two groups of rocks as strongly indicated by their field relationship.

As regards the other relevant petrologic aspects of these rocks we can synthetize, as follows, the main conclusions reached by GUASPARRI et al. (in press):

1) the leucogranitic rocks derived from notably undersaturated magmas (H_2O content not more than 3 % but likely less) and consequently they could rise to very high levels in the crust.

2) Crystallization is likely to have proceded from the bottom of the magmatic chamber thus largely avoiding settling difficulties which would have arised in a fractionation phenomenon.

3) Quartz, K-feldspar, plagioclase and biotite were liquidus minerals throughout the crystallization of these magmas so that major element fractionation was limited and practically restricted to magnesium and calcium.

4) Strong fractionation was possible for some minor elements such as barium, owing to the high K_D values between bulk solid and liquid in such high silica magmas (EWART et al., 1977; LEEMAN and PHELPS, 1981; MAHOOD and HILDRETH, 1983).

5) Water saturation of the rest melt was probably reached when 70-80 % of the magma was crystallized and second boiling phenomena, due to the shallow level of emplacement, induced pervasive fracturing of the rocks allowing an equally pervasive alteration of the already solidified rocks by the permeating fluids.

6) The abrupt reduction in temperature due to volatile loss is likely to have caused rapid nucleation and/or quenching and consequently porphyritic, microgranular and aplitic textured rocks ensued.

7) The leucogranites are pure minimum melts of crustal anatexis induced by the pressure release caused by drastic erosion of the chain started in coincidence with the emplacement of the first phase plutonites. Their low H_2O content can be explained assuming that an at least partially granulitized lower crust was involved in the anatectic process.

8) The leucogranitic rocks, like the large majority of the magmatites constituting the sardinian batholith, show the mineralogical and geochemical characteristics of « I » type granitic rocks.

3. The Mo-mineralizations of the Sardinian Batholith

As a complete inventory and description of the many Mo-showings known in the Sardinian batholith would be prohibitively long and tedious, we shall limit ourselves to three different districts which well illustrate the main features of the various alteration-mineralization styles of these showings.

However, before going into descriptions of the Mo-mineralizations of the batholith it is opportune to explain the criteria used in describing the hydrothermal alteration assemblages.

It is well known that the variety of mineral assemblages encountered in hydrothermally altered rocks have been grouped or named in different ways by various authors in an attempt to classify the alteration phenomena (SCHWARTZ, 1947; BONORINO, 1959; CREASEY, 1966; MEYER and HEMLEY, 1967; LOWELL and GUILBERT, 1970; ROSE, 1970; ROSE and BURT, 1979) and actually no generally accepted nomenclature yet exists. This is mainly because alteration phenomena can hardly be framed into rigid schemes since even minor differences in the physicochemical characteristics of circulating hydrothermal solutions or of wall-rocks can induce notable variations in the resulting assemblages. Furthermore, as pointed out by CREASEY (1966), one can either adopt long descriptions of the hydrothermal parageneses (with the advantage of no genetic implication) or resort to some compact term (justified in the interests of brevity) in the case of widespread and recurring assemblages.

The latter is of course preferable and prevalent at present but attention is needed as the same term can have different meanings

TABLE 1

Chemical analyses of fresh and altered leucogranitic rocks

	A		B		MS21	MS89	MS30
SiO_2	75,62	(74,02-76,47)	76,56	(75,20-78,32)	77,22	77,41	76,80
TiO_2	0,11	(0,06-0,20)	0,06	(0,02-0,14)	0,05	0,08	0,05
Al_2O_3	12,95	(12,38-13,80)	12,78	(12,00-13,72)	13,46	13,82	13,51
Fe tot. (as Fe_2O_3)	1,41	(1,03-2,15)	1,11	(0,40-1,61)	0,34	0,45	0,80
MnO	0,06	(0,03-0,09)	0,06	(0,01-0,14)	0,01	0,01	0,03
MgO	0,22	(0,02-0,59)	0,08	(0,01-0,24)	0,08	0,06	0,08
CaO	1,01	(0,61-1,33)	0,53	(0,23-0,87)	0,31	0,30	0,27
Na_2O	3,40	(3,00-3,67)	3,32	(2,55-4,06)	1,58	0,27	1,63
K_2O	4,70	(4,21-4,95)	4,95	(4,32-5,65)	5,96	6,16	5,68
P_2O_5	0,06	(0,04-0,12)	0,07	(0,01-0,17)	0,04	0,05	0,04
L.O.I.	0,44	(0,20-0,77)	0,48	(0,35-0,89)	0,95	1,39	1,11

	MS29	MS38	MS33	MS110	MS110	MS78	MS133	MS136
SiO_2	74,34	76,92	81,47	75,32	80,08	74,40	77,08	67,88
TiO_2	0,04	0,04	0,05	0,06	0,07	0,04	0,09	0,11
Al_2O_3	15,23	11,85	10,56	14,01	10,64	14,48	12,35	18,06
Fe tot. (as Fe_2O_3)	1,96	3,71	1,77	0,75	1,95	2,92	2,86	3,63
MnO	0,07	0,16	0,10	0,02	0,09	0,06	0,12	0,18
MgO	0,08	0,05	0,06	0,20	0,11	0,54	0,24	0,38
CaO	0,28	0,72	0,54	0,35	1,00	1,07	0,98	0,47
Na_2O	0,16	0,16	0,12	0,37	0,16	0,03	0,35	0,18
K_2O	5,61	3,90	3,70	7,07	4,38	3,59	3,83	6,36
P_2O_5	0,08	0,05	0,05	0,04	0,07	0,09	0,37	0,31
L.O.I.	2,15	2,42	1,58	1,81	1,45	2,77	1,74	2,44

A) Average (and range of variation) of 23 analyses of unaltered coarse and medium grained leucogranites. *B*) Average (and range of variation) of 25 analyses of unaltered leucogranite-porphyries and fine grained leucogranites (from GUASPARRI et al., in press).

MS-21, altered leucogranite-porphyry (Capo Malfatano); argillic type alteration. MS-89, altered leucogranite-porphyry (Flumini Binu); argillic type alteration. MS-30 and MS-29, altered leucogranite-porphyry (Perda Lada); argillic type alteration. MS-38 and MS-33, altered leucogranite-porphyry (Perda Lada); phyllic type alteration. MS-110*a*, altered coarse-grained leucogranite (Perda e' Pibera); argillic type alteration. MS-110, vein border in coarse-grained leucogranite (Perda e' Pibera). MS-78, the detailed description of this rock is given in the text (Su Laccheddu - Mt. Mannu). MS-133 and MS-136, vein borders in fine-grained leucogranite (Mt. Unne).

according to different authors (ROSE and BURT, 1979) and further, some authors attach more importance to abundance of minerals than to mineral assemblages. Therefore we think it preferable to clearly define the meaning that we attach to the terms adopted in the descriptions of the hydrothermal alteration phenomena.

We shall apply the term « propylitic » to alteration affecting rocks where the original ferromagnesian minerals have been totally or almost totally converted to secondary minerals such as chlorite, epidote and subordinately sericite, and where plagioclase has been transformed to a varying extent to albite + epidote + calcite + sericite. Conversely K-feldspar is found quite fresh and quartz is unattacked. Propylitized rocks have undergone deep mineralogical transformation but there are only very minor gains and losses of cations although H_2O, CO_2 and sulphur may be added.

We shall apply the term « argillic » to alteration affecting rocks where the ferromagnesian minerals are almost completely destroyed and plagioclase is largely replaced by kaolinite, montmorillonite or amorphous clays. The K-feldspar remains fresh or only slightly corroded. The most evident chemical variation is a notable leaching of sodium, calcium, magnesium and a partial leaching of iron.

The transition from an « argillic » to a « phyllic » type alteration is unavoidably arbitrary. It is taken by us to occur when there is an incipient but evident instability of K-feldspar and both feldspars are sericitized. The distinctive character of phyllic alteration consists in a more or less complete replacement of all the fundamental minerals of the rock, except quartz, by sericite (muscovite) or (in agreement with BURNHAM, 1962) biotite. A quartz-mica rock is therefore considered to be the typical product of phyllic alteration. Small quantities of clay may sometimes be included within the phyllic assemblage. A dramatic loss of sodium and calcium is the most relevant chemical feature.

We shall apply the term « potassic » to alteration affecting rocks where secondary K-feldspar participates in the hydrothermal assemblage. As we shall see, potassic assemblages are not frequently observed in the Mo-mineralizations of the Sardinian batholith and are apparently restricted to some veins and envelopes around them.

3.1. The Iglesiente-Sulcis district (SW Sardinia)

In the Iglesiente-Sulcis district (see fig. 1) several felsic stock-like bodies of fine grained leucogranites and leucogranite-porphyries intrude very low grade metamorphic Cambrian to Devonian rocks which appear hornfelsed to variable degree around the intrusive contact. At the southern end of the district several old Mo-prospects and showings are hosted by leucogranite-porphyry plugs and fine grained leucogranite bodies. In the mineralized areas molybdenite is mostly contained in quartz veins of variable thickness which are widely distributed in and near the hydrothermally altered porphyries. Usually the molybdenite bearing quartz veins form stockworks or subparallel swarms (see fig. 2).

The veins are generall only a few centimetres wide and are composed of glassy to milky quartz in which molybdenite occurs as scattered flakes or in ribbon-like textures. In some instances molybdenite streaks ramify through the quartz while in others the mineral forms thin coatings along fractures. Although barren quartz vein systems do exist, microscopic and/or X-ray investigations have revealed that the characteristic dark grey colour of some quartz vein systems, which appear barren to the naked eye, is due to scattered, extremely small sized, molybdenite crystals.

Of the ore minerals which accompany molybdenite the most abundant and widespread is pyrite. It usually occurs both in barren and in molybdenite-bearing quartz-veins and sometimes is also found spotted through the host rock.

Other typically, though erratically, associated minerals are base metal sulphides and wolframite. Sphalerite and galena are variously distributed in molybdenite bearing quartz-veins and sometimes they form sulphide-rich stockworks in heavy altered country rocks along fracturing zones. Country rocks alteration varies considerably in intensity and distribution throughout the district.

Areas of strongest hydrothermal alteration usually overlap mineralized zones of apparently better-grade ore and in turn alteration extent seems to be directly proportional to the intensity of shattering. The most evident consequence of alteration is a notable bleaching of the host rocks. Dark minerals are completely lacking plagioclase assumes a characteristic chalky appearance and local silicification of the rocks is marked by a glassy shine.

Under the microscope the primary paragenesis of the rocks appears heavily corroded and biotite and plagioclase always demonstrate a marked instability. In the areas of most intense alteration the biotite is completely destroyed but often the presence of former biotite can be inferred by clusters of opaque iron minerals and sericite shreds. Plagioclase, usually mantaining its primary boundaries, is largely altered to clay minerals and sericite (see fig. 3). In general K-feldspar and quartz are unaffected by alteration. Compared to the composition of fresh porphyries the major chemical changes (see table 1) consist in a greater or lesser loss of sodium and a relative gain in potassium. Silica, and to a greater extent alumina, show a slight increase; the already very low calcium content is practically halved; iron is consistently leached while the already extremely low magnesium remain substantially constant. The overall alteration pattern is therefore of the « argillic » type

Going toward the fringe zones of mineralized areas the effects of hydrothermal alteration become progressively less evident merging finally into what

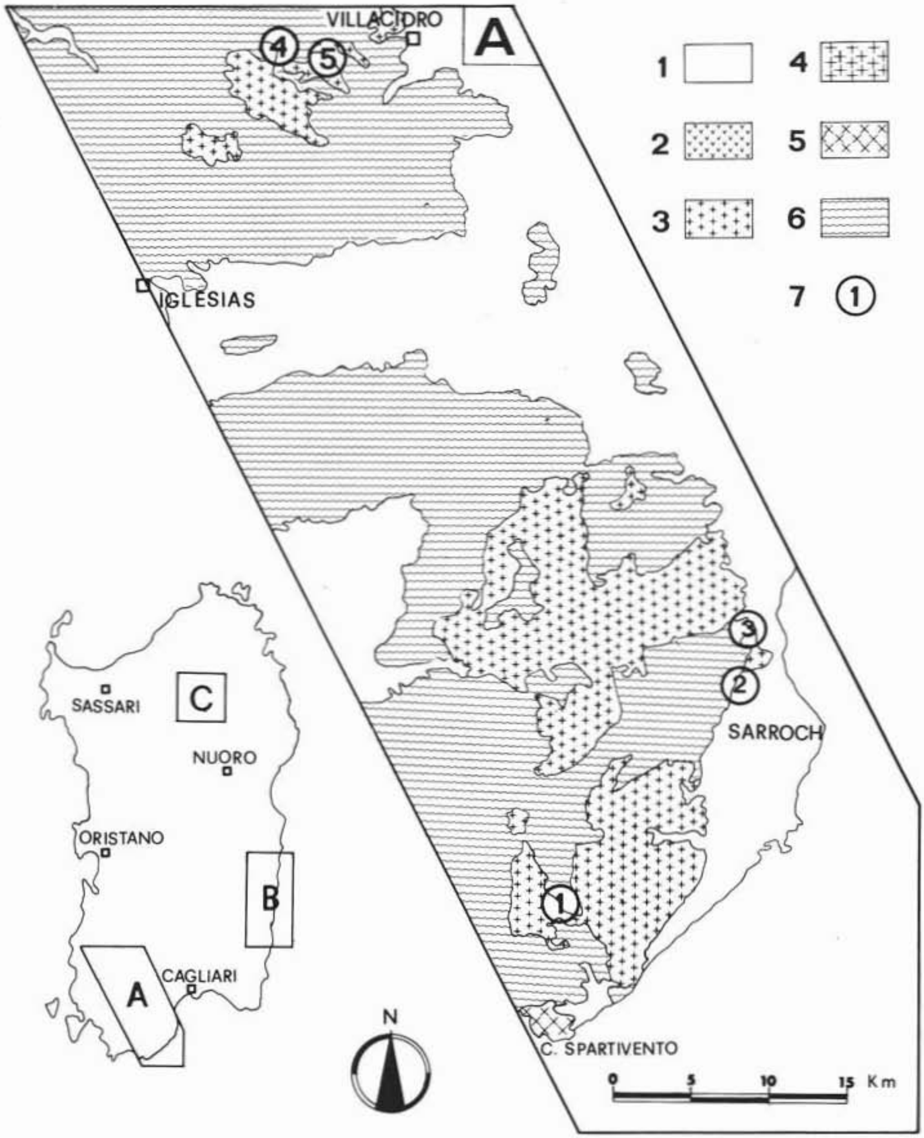

Fig. 1. — Geologic sketch map of the Iglesiente-Sulcis district. - 1) Post-Permian terranes; 2) Late-hercynian volcanics; 3) Rocks of the leucogranite suite; 4) Monzogranites and monzogranitic granodiorites; 5) Granodiorites and tonalites; 6) Metamorphic rocks; 7) Mo-mineralizations: 1 = Capo Malfatano; 2 = Su Seinargiu; 3 = Flumini Binu; 4 = Perda e' Pibera; 5 = Perda Lada.

Fig. 2. — MoS_2 bearing quartz-veins in altered fine-grained leucogranite (Flumini Binu).

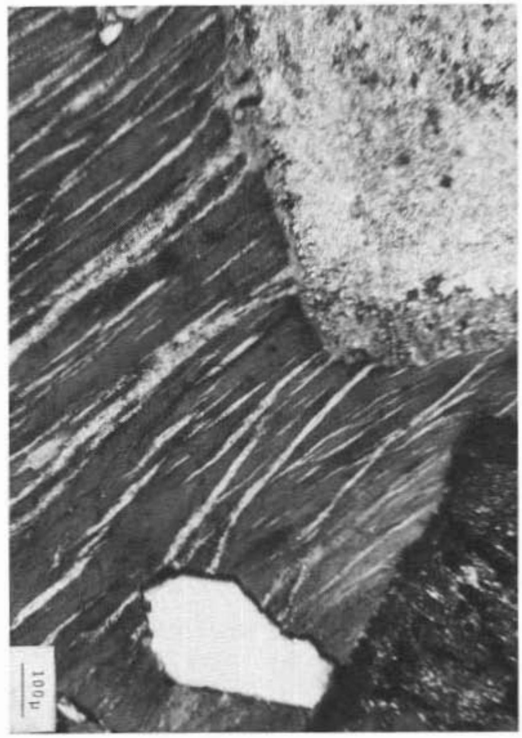

Fig. 3. — Argillic alteration; fresh perthitic K-feldspar crystal in contact with completely altered plagioclase crystals (Flumini Binu).

can be defined as the background alteration of the host leucogranites. This « transiticnal » zone of fleebest alteration affects a much larger area than that occupied by the « argillic » type but is hardly distinguishable to the naked-eye except perhaps for the greenish appearance of the biotite. Seen under the microscope the rock shows that the biotite and, to a much lesser extent the plagioclase are always altered but the alteration character differs somewhat from that formerly described. Biotite, rather than being destroyed, is almost completely replaced by chlorite or chlorite-sericite intergrowths. Plagioclase invariably contains small blades of sericite which preferably develop along the (010) twinning plane. Conversely K-feldspar and quartz appear completely unaffected by alteration.

If we attempt to assign this outer alteration zone to any of the hydrothermal facies of general acceptance some difficulties do arise. Indeed chlorite and sericite are widespread in the peripheral zones of many porphyry-type deposits and chlorite particularly is always included in all assemblages of the propylitic type alteration. However scme perplexities could arise in definying *tout court* as propylitic the alteration of a rock on the basis only of the occurrence of one or two mineral phases instead of considering a mineral assemblage as a whole. We cannot in fact forget that lime-bearing minerals such as epidote and calcite are considered key minerals in defining the propylitic assemblage and moreover that Burnham (1962) proposed epidote as the characteristic mineral for propylitic alteration while, in our case, epidote and carbonates are of such rare occurrence as to be considered accidental rather than a fundamental mineral in the alteration assemblage. On the other hand, if we take into account the extreme acidity of the rocks in question and particularly their very low calcium content, the lack or extreme rareness of lime-bearing minerals is not so surprising even if propylitic conditions were achieved.

Microscopic investigation on propylitized rocks suggest in fact that plagioclase alters to the assemblage albite + kaolinite + Ca-silicates and other Ca-bearing minerals (Creasey, 1966). The albitic nature of plagioclase in our rocks readily explains both its relative stability and the observed lack of calcium-bearing minerals.

Therefore taking into account the gradual nature of the transition from the zone of argillic-type alteration to the outer zone, and the clear chemical constraints seen above, it is not hazardous to attribute to the alteration occurring in the fringe zone of the Mo-prospects in this area the same meaning that propylitic alteration holds for calcium-rich rocks.

3.1.1. *The Perda Lada mineralization*

At the northern end of the district, west of the town of Villacidro, there are numerous Mo-showings and old Mo-prospects in the leucogranitic massif of Mt. Linas (SALVADORI, 1959). Our descriptions will deal with the Perda Lada and the Perda e' Pibera mineralizations which show somewhat different features from those previously described.

The Perda Lada prospect is placed on the southern flank of the San Miali Peaks where in a deep valley cut, a medium-grained pink leucogranite crops out, in turn intruded by a leucogranite-porphyry stock forming the highest elevation of the relief. The porphyry is capped by a strip of metamorphosed lower paleozoic terrane mainly constituted by shales and metasandstones.

The orebody lies entirely in the porphyry, a little below the contact with the metamorphic cover, and consists of a quartz-sericite-sulphide aggregate which has completely replaced the original rock. Outcrops of the mineralized rock are evident from brownish-yellow staining produced by pyrite oxidation. They can be traced over a distance of about a hundred metres, their maximum exposed thickness exceeding ten metres. From the convex attitude of its top it can be inferred that the orebody, although for the most part masked by detritus, have an inverted cup like shape.

Stroked by the hammer the stained surface, the rock reveals a steel grey finely grained aggregate with abundant and well disseminated sulphides. Pyrite and molibdenite are by far the most abundant sulphides with a clear prevalence of the former minerals. Some erratically distributed chalcopyrite and minor wolframite also occurs. Thin sections of typical ore-specimens show that the rock has been so intensely and pervasively altered that no relics of its original texture are retained. A fine grained mosaic of quartz and sericite indicates that neither feldspars nor biotite have escaped alteration. Some very pale pleocroic halos seen around small zircon crystals, sometimes enclosed in sericite flakes, suggest the location of former biotite. Although white mica is usually quite homogeneously scattered throughout the quartzose matrix, local nests of muscovite and even glimpses of vein-like arrangments of this mineral can be found. Very minor quantities of small sized fluorite and siderite crystals complete the non-opaque paragenesis.

Molybdenite generally appears quite randomly distributed except in some instances where an alignment of several lamellae hints at microfracture driven deposition. The presence of frequent intergrowth of sericite and molybdenite flakes suggests that the alteration process and molybdenum deposition overlapped each other at least in part.

The most relevant chemical variations observed in this rock (see table 1), as compared to unaltered leucogranite-porphyries, are the extreme decrease in sodium content on the one hand and appreciable silica increase on the other. The relative gain in CaO is matched by the appearence of fluorite and calcite while K_2O and alumina percentages obviously reflect the proportion of mica to quartz in the rock. In summary, on the basis of the formerly depicted quartz-sericite-pyrite assemblage, the alteration, which has affected the wall rock of the Perda Lada orebody, can be defined of phyllic type.

The top of the strong phyllic alteration zone is rimmed by a pegmatitic band, about half a metre thick, where K-feldspar and quartz are practically the only constituents. Outwards from the ore zone the sourrounding porphyry appears bleached. Microscopic study of numerous specimens collected at increasing distance from the orebody show that K-feldspar relics become more and more frequent until the alteration character merges into a more or less pronounced argillic type.

The still relatively high iron content of the samples (see table 1), coming from the outer zone are related to scattered pyrite. Farther away the rock appears still less severely altered finally fading into the usual background alteration.

3.1.2. *The Perda e' Pibera mineralization*

About 2 km NW of the Perda Lada prospect is situated the old Perda e' Pibera mine.

The surface lithology is largely dominated by continuous outcrops of metamorphosed lower paleozoic terranes within a radius of more than 1 km of the mine; however, a small outcrop (about ten acres) of a medium grained leucogranite is exposed some hundred metres SW of the mine. Quartz-veins with pyrite and sparse molybdenite, cross cut the rock showing thin, symmetrical, dark grey borders. The selvages appear to be zones of heavy phyllic alteration. Close to the veins, in some cases for as much as two or three times the width of the same, the wall-rock is entirely replaced by a fine grained aggregates of quartz and sericite with scattered pyrite, molybdenite and minor fluorite. Farther away and for a variable distance from the veins the rock appears to have undergone rather pronounced argillic alteration. Analyses of the rock affected by argillic and phyllic alteration, coming from the same sample, are reported in table 1. It is quite evident that chemical gains and losses do not differ significantly from the analogous alteration patterns previously discussed.

It should be noted that in the dumps numerous leucogranite-porphyry blocks are also present. Thin sections of several specimens indicate pervasive argillic-type alteration with incipient K-feldspar sericitization and diffuse flaking by coarsely crystalline white mica of the rock.

Mo-mineralizations showing very similar characteristics in alteration-mineralization style are very numerous in the Iglesiente-Sulcis district and as far as we know also dominant in the other areas of the island. Therefore in order to complete the phenomenological picture of Mo-mineralizations in Sardinia we shall now consider, from the remaining two districts, only Mo-mineralizations having some relevantly distinctive features.

3.2. Salto di Quirra-Ogliastra district (SE Sardinia)

The geology of the Salto di Quirra region is largely dominated by extensive outcrops of meta-sandstones and meta-volcanics. In the eastern border of this area some stock-like bodies of coarse grained leucogranites and leucogranite-porphyry intrude the metamorphic sequence giving rise locally to heavy thermal aureoles.

Ore-bearing quartz-veins occur very close to the leucogranitic intrusives.

3.2.1. *The Perda Majori vein*

Among the molybdenite-bearing quartz-veins of the district (fig. 4), the most relevant and by far the best known (DESSAU, 1956; BACCOS, 1968; VENERANDI, 1968) is the Perda Majori vein which lies about 20 km NE of the town of Muravera. This vein which varies in width from few centimetres to more than one metre, was traced for almost 700 m along the strike in proximity to the south western flank of the Mt. Pedrosu leucogranitic stock.

According to DESSAU (1956) this vein, which is enclosed in meta-volcanic rocks at the outcrop, enters the intrusive rock underground.

Several major features exhibited by the Perda Majori vein as regards for instance ore and gangue paragenesis are quite unusual in Sardinia.

The most abundant primary ore minerals in the vein are molybdenite wolframite and pyrite. Very subordinate quantities of base metal sulphides and bismuth-bearing minerals are also present. A complete description of the paragenesis, was given by VENERANDI (1968).

Molybdenite and wolframite are mostly coarsely crystalline and the former seems at least partly of later deposition. Thin microfracture systems developed in wolframite crystals and filled by molybdenite support this conclusion and together with some breccia-like vein specimen show that intermineral tectonic stresses were active.

Quartz and orthoclase form the bulk of the gangue while topaz and fluorite are common accessories. Late sericite appears ubiquitously and mainly as flecks on orthoclase, but sericite also fills fractures throughout the quartz.

The relatively widespread topaz finding in the Perda Majori vein are a good example of the peculiarities that such a vein displays In the writers experience, this mineral is of extreme rareness in the molybdenite bearing quartz-veins and generally in the Mo-mineralizations of Sardinia.

Wall-rocks appear chloritized to different extents and penetrated by quartz-orthoclase-fluorite veinlets or permeated by the same new-formed minerals.

Even as regards the polytypism of molybdenite the Perda Majori vein differs (BRALIA et al., 1983 a) from other Mo-mineralizations. Of the two main molybdenite polytypes occurring in nature, the hexagonal ($2H_1$) and the rhombohedral ($3R$), only the hexagonal type is found in the mineralizations studied except for the Perda Majori vein where pure hexagonal, pure rhombohedral and mixtures with a variable ratio of $2H_1 : 3R$ occur.

3.2.2. *The Goene mineralization*

In the northern side of the district an impressive swarm of NW-SE trending leucogranite-porphyry dykes (not drawn in our simplified sketch map, but reported in the F. 219 « Lanusei » of the Geological Map of Italy) cuts, on a surface of almost 250 km^2, granodioritic and monzogranitic rocks of the first intrusive cycle.

Very old Mo and Cu-Mo (Fe) prospects are known in this area. West of the town of Lanusei some large leucogranite porphyry dykes coalesce to form the crudely star-shaped knob of Mt. Taré [1], not far from which lies the Cu-Mo (Fe) prospect named Goene.

A certain amount of surface trenching was carried out in the past along sulphide-rich fracture zones developed in a biotitic granodiorite. The mineralization is strictly associated to a NW-SE trending fracture system. Sulphides occurs as dissemination or microveinlets close to major fractures along which the granodiorite is heavily transformed. In a typical example considered by us the hydrothermal alteration affects the rock for several metres on both side giving then away to the perfectly unaltered rock.

Under the microscope the samples from the better grade zones reveal that the original granodiorite is completely transformed to an albite-chlorite-quartz-epidote rock. Disseminated chalcopyrite is abundant throughout this rock often reaching several per cent of the total rock volume. Magnetite and sparse molybdenite and pyrite are also present though unevenly distributed. Ore minerals distribution appears to reflect the distribution of altered femics (BRALIA et al., 1983 b).

Microscopic investigations also show extremely intimate fracturing of the rock. A network of hair-like fractures is filled with albite and quartz and the same minerals weld the crystal fragments in the thoroughly crushed portions of the rock of the richest ore zone.

---

(1) In fig. 4 the dimension of Mt. Taré outcrop has been notably exagerated.

The study of a set of specimens collected from the better grade ore zone toward the fresh granodiorite clearly demostrate a gradual but rapide decrease in alteration intensity coupled with a parallel fading of the ore minerals.

In the less altered zones primary quartz and K-feldspar appear untouched while biotite and plagioclase are completely destroyed.

Plagioclase alters to sericite, albite and minor epidote.

Biotite alters to an aggregate of chlorite and epidote which is a prominent mineral. It also occurs in microveinlets, microfracture coatings and in various disseminated forms.

The transition from propylitized to fresh granodiorite is realized in only few metres. This rapid transition, the absolute lack of background alteration in the surrounding intrusive rock and the overall situation clearly indicate the « cold host » role of the granodiorite. On the other hand, it must be noted that the orientation of the fracturing system, with wich the mineralization is connected, is practically coincident with the direction of the spectacular leucogranite-porphyry dykes swarm in this area. This suggests a close relationship with the intrusive event in which the nearby Mt. Taré knob took part.

The intimate shattering affecting the host rock in the Goene area could be related to an explosive sudden release of fluids from a cooling mass of underlying leucogranite magma.

Evidence of explosive activity in this region, during leucogranite-porphyries emplacement, do exist not far from Goene.

A few kilometres east of this locality in the vicinity of the Nuraghe Murta, there are several known Mo-showings close to zones of heavy silicization associated with great leucogranite-porphyry dykes.

In this area many large blocks of intrusive breccia (see fig. 5) can be found around a hillock to the west of the State Road n. 125, midway between the towns of Bari Sardo and Tortolì.

This open-textured breccia consists of angular to subangular fragments of leucogranite-porphyry set in an essentially quartzosa matrix. The fragments from less than 1 cm to more than 10 cm in size, are quite randomly distributed and oriented. They are frequently crossed by a network of thin quartz-veinlets and have undergone a variable degree of alteration. Some porphyry fragments exhibit very heavily sericitized rims, yet, under the microscope, phyllic alteration appears ubiquitous. Very fresh secondary biotite with leafy habitus is spotted within the breccia elements. Dark mica also forms veinlets with quartz or more rarely is scattered throughout the quartzose matrix. It is to note that the relative abundance of biotite, enhancing colour index of the rock, is deceptive as regards the true nature of the breccia fragments.

Sulphides also occur and are mostly contained in the matrix; they are somewhat sparse, however, and always heavily altered.

At the present moment it is impossible to determine the shape and the effective extension of the breccia body owing to the awkward exposures. For the same reason we retain that analogous situations can have been overlooked in the area in the past and will probably be revealed in more detailed future studies.

Also in the light of these phenomena it is quite reasonable to maintain that the Goene mineralization took its origin through a thermal circulation which affected an already cold granodioritic intrusion all along a fracturing zone and that copper was remobilized by this same more basis rock.

3.3. The Oschiri-Alà Mts. district (NE Sardinia)

The largest (about 900 km²) continuous outcrop of leucogranitic rocks of the island occurs in this area in the Pattada-Monti-Tempio Pausania triangle where only small, scattered and often unmappable strips of the metamorphic cover have survived erosion.

Of the numerous Mo-mineralizations known in this area only three (fig. 4) will be mentioned owing to their somewhat peculiar features.

3.3.1. *Mt. S'Abbagana mineralization*

Discovered about twenty years ago during rubble quarry works, this mineralization lies in a zone where a coarse-grained leucogranite stock is intruded by fine-grained leucogranite and leucogranite-porphyry dykes. Molybdenite is widespread all around the pit and mostly found as paints on fracture walls so that its deposition appears strictly controlled by the fracturing system. The host rock (mostly the fine-grained leucogranite) is in general much less intensely altered than in the exemples previously described. The only exception is represented by narrow border along some quartz-filled fractures which under the microscope reveal that quartz and albite were abundantly introduced.

3.3.2. *Su Laccheddu - Mt. Mannu*

The presence of molybdenite showings in this area, not far from the Coghinas Lake north of Oschiri, was first discovered by SOTGIA (1921) along the Rizzolu stream between Sas Conzas Peak and the western flank of Mt. Mannu. Successively very brief descriptions were given by CARTA (1953), CHARRIER (1957) and ZUFFARDI (1953). The continuation of the mineralization in the northern flank of Mt. Mannu was later pointed out by DERIU and ZERBI (1965).

In this area a pink coarse-grained leucogranite, discontinuously capped by small scraps of the metamorphic cover, is intruded by numerous small bosses of fine-grained leucogranite and leucogranite porphyry.

Around the mineralized area all rock types appear weakly to moderately flecked by sericite and alteration rapidely increases toward the ore-zone.

Mineralization consists of molybdenite, with pyrite and minor wolframite and chalcopyrite, disseminated in highly transformed intrusive rocks. The mineralization is arranged in several mineralized sectors as witnessed by the scattered early mining large part of the exposed contact. Actually chlorite with minor calcite constitute about one third of the whole rock volume and together with quartz and sericite represents the alteration assemblage.

Chlorite and calcite prevalently occur intimately associated in square edged aggregates which suggest the complete pseudomorphosis of now indeterminable minerals. In many instances these mostly chloritic pseudomorphs appear to be corroded in turn by white micas.

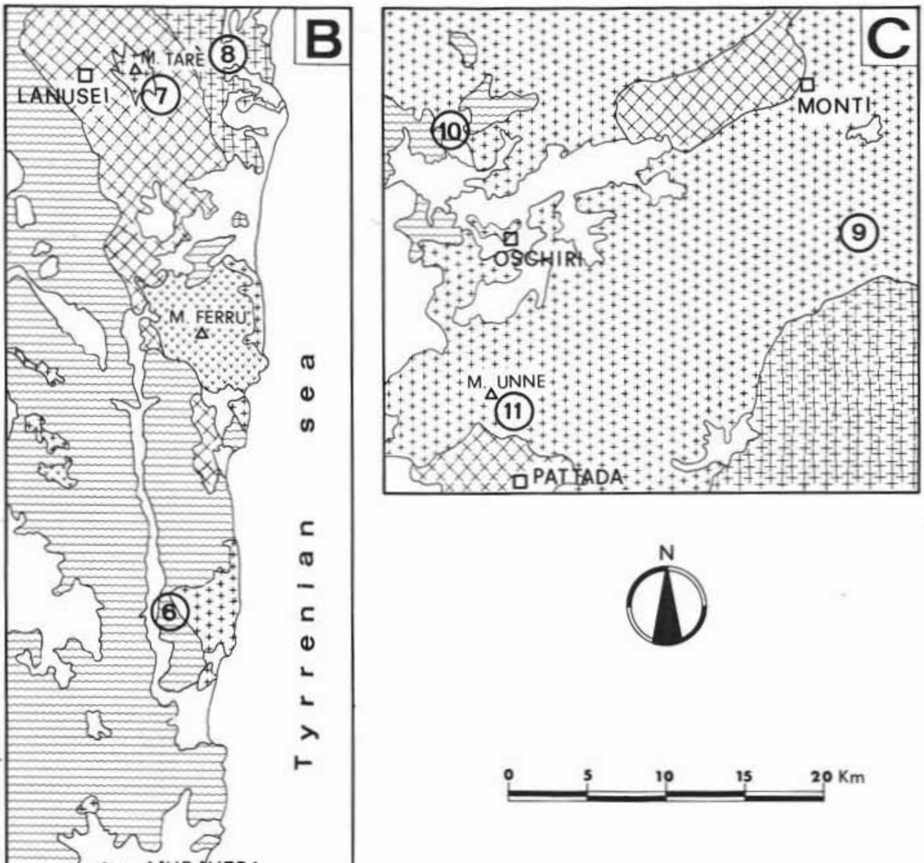

Fig. 4. — Geologic sketch map of the Salto di Quirra-Ogliastra (*B*) and Oschiri-Alà Mts. (*C*) districts. 6 = Perda Majori; 7 = Goene; 8 = Nuraghe Murta; 9 = S'Abbagana; 10 = Su Laccheddu-Mt. Mannu; 11 = Mt. Unne. For legend see fig. 1.

works. Among them the biggest seems to form a flat irregular lens-shaped body up to 15 m thick located in the contact zone between leucogranitic intrusive, and metamorphic cover. All rock types in the ore-bearing areas have been affected by very strong and pervasive phyllic alteration so that quartz-sericite-ores with minor leafy biotite (fig. 6) represent the new mineral assemblage.

However, this holds only partially true as regards a greenish rock interposed between the leucogranitic rocks and the metamorphic cover for a

As regards the original nature of the now chloritized crystals, if we attach diagnostic value to some vestiges of twin planes retained in preferred orientation in the alteration products and to the presence of abundant calcite within many roughly rectangular pseudomorphs, we would be induced to believe that they represent former, relatively Ca-rich, plagioclase crystals.

The chemical analysis reported in table 1 as MS-78 strongly suggest that before the alterative process this rock was more basic than leucogranite.

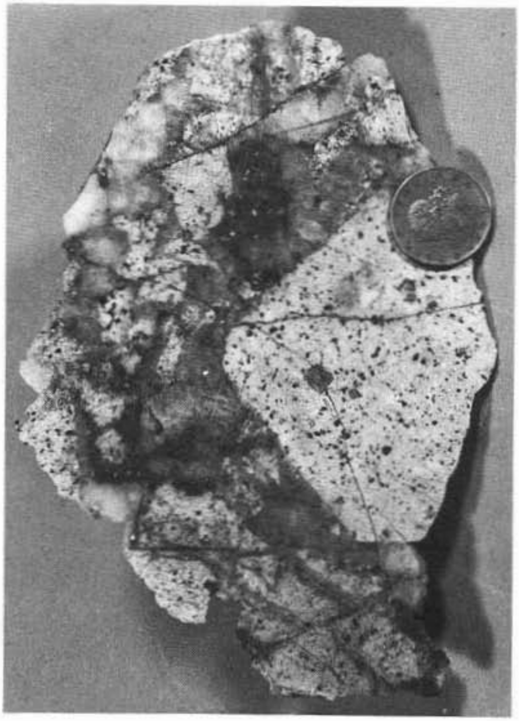

Fig. 5. — Intrusive breccia constituted by fragments of leucogranite-porphyry welded by quartz with sparse sulphides (Nuraghe Murta).

Fig. 6. — Secondary biotite with leafy habitus (Su Laccheddu - Mt. Mannu).

This is further supported by its aspect in the field where its greenish appearance makes it just like a hydrothermally altered granodioritic rock. Therefore we retain that it represents the product of transformation of a rather large fragment of an intrusive of the first phase of the Hercynian magmatism by chance present in this area and involved in the mineralizing processes. Fragments of this kind are actually not uncommon in outcrops of the leucogranitic suite throughout the island.

From microscopic studies it can be inferred that in a first stage a pronounced propylitic alteration, and in a second, together with the emplacement of the ore, a strong phyllic alteration occurred during which propylitic assemblage became unstable and was partially resorbed.

It is worth to underline that this same phenomenon is not revealed by the immediately adjacent leucogranitic rocks though, very likely, they have undergone the same process. This is in agreement with the above inferred different chemical composition of the rocks concerned.

3.3.3. *Mt. Unne*

Not far from the northern contact between the Pattada tonalite and the leucogranitic complex, a new Mo-showing was recently discovered (GHEZZO et al., 1981) in the southern flank of Mt. Unne. In this area a fine grained, intensely fractured, leucogranite is cut by numerous molybdenite bearing quartz-veins distribute over a distance of at least a hundred metres along a new road cut. The wall rock, which often appears relatively fresh to the naked-eye, is intersected by a network of hair-like fractures mainly filled with quartz and sericite. In the wall rock biotite is always largely replaced by chlorite and subordinately by sericite. Feldspars are widely replaced by abundant newformed quartz.

The quartz veins, up to several centimetres thick, exhibit symmetrical borders against the host rock, and here very strong phyllic alteration occurs. Within the borders, which are often much thicker than the veins themselves, the primary paragenesis has been changed to a sugary-textured aggregate of quartz, sericite and subordinately hydrothermal biotite. The latter mineral always appears very fresh and mostly occurs as microscopic nest-like intergrowths where radiated textures are very common. Biotite crystals with leafy habitus have not been found here. Hydrothermal apatite is a relatively widespread accessory mineral in the alteration assemblages. It occurs mostly as relatively coarse, anhedral crystals and its distribution parallels that of secondary biotite.

The notable addition of phosphorous in this environment is evident from the decisive increase in P_2O_5 as shown in table 1 by the MS-133 and MS-136 samples. The different chemistry of the two vein borders mirrors the different ratio of quartz/micas in the two samples, both affected by phyllic alteration.

4. Discussion

The above review of the main features of the Mo-mineralizations of the Sardinian batholith allows the following conclusions to be drawn:

a) Molybdenite is the only primary molybdenum mineral and by far the most abundant of the useful ores. However many mineralizations contain small quantities of other minerals of potential economic interest.

b) The mineralizations are of low or very low grade, the bulk of the molybdenite being distributed through rather large rock volumes.

c) The occurrence of molybdenite varies considerably in attitude. It may occur in quartz vein stockworks, in paints along joints, as fracture filling, in microveinlets and disseminations. The latter two cases are characteristically found close to zones where there is strong (phyllic) hydrothermal alteration of the host rocks.

d) Mo-mineralizations are always directly related to high-silica intrusives emplaced at shallow depth in the crust. Ores and related alteration phenomena are in fact usually centred on stocks of leucogranite-porphyry or fine grained varieties of leucogranites.

e) The mineralizations are associated with extensive hydrothermal halos where propylitic, argillic and phyllic assemblages occur. In some instances these hydrothermal halos are clearly arranged in roughly concentric shells.

f) Close relationships seem to exist between the type of hydrothermal alteration, the type of ore occurrence and the ore paragenesis. Assemblages of molybdenite-chalcopyrite-wolframite-pyrite, in disseminated form, occur within areas of strong phyllic alteration while assemblages of molybdenite-galena-sphalerite-pyrite, in quartz veins and fracture systems, are characteristically present in areas where argillic and propylitic alteration predominates.

g) Extensive crackle zones occur in many mineralized areas and intrusive breccias have also been found.

All these features are very common in porphyry-type deposits (TITLEY and HICKS, 1966; LOWELL and GUILBERT, 1970; SUTHERLAND BROWN, 1976) and some of them are considered distinctive of such deposits so that the molybdenum showings of the Sardinian batholith can be confidently considered porphyry-style mineralizations. Moreover, the results of this survey on the alteration-mineralization features and the geological setting of Mo-mineralizations of the Sardinian batholith strengthen the conclusion already expressed (GHEZZO et al., 1981; GUASPARRI et al., 1981) of a very close genetic link between these mineralizations and the hypabyssal rocks of the leucogranitic suite. The available data, further, strongly suggests that not only the Mo-mineralizations but the whole metallogenesis connected with the Hercynian magmatism is directly linked to the emplacement of the leucogranitic intrusions of the second phase of this same magmatism (GUASPARRI et al., in press). This statement deserves some discussion if we also consider that the tonalitic to monzogranitic plutonites are associated, though rarely, with Cu-Mo (Fe) showings. These are clearly fracture controlled mineralizations. Hydrothermal phenomena are practically limited to alteration envelopes around these fractures or veins and no concentric zoning in alteration or mineralization is evident. The areas affected by hydrothermal alteration vary in shape and extent but always rapidly give way laterally to perfectly fresh rock. The whole picture clearly indicates that the host rocks of these mineralizations cooled well before ore deposition.

The previously described situation at the Goene showing may be considered exemplary of the Cu-Mo (Fe) mineralizations of the first cycle magmatites.

Unambiguous field evidence demonstrates

that the mineralization of Goene, though hosted in biotitic granodiorite, must be genetically related to hydrothermal circulation connected with the intrusion of a system of great leucogranite-porphyry dykes.

It is worth noting that the cold host role played by the rocks of the first intrusive phase does not, in our opinion, mean that these rocks were completely passive. The high copper content of the associated mineralizations may be taken as a strong indication that these rocks contributed Cu to the deposit through leaching.

Future work will deal specifically with this topic.

Evidently some explanation must exist why only the leucogranitic suite and more precisely only the porphyries and fine grained facies of this suite gave rise to mineralizations whereas this « vocation » is totally absent in the first cycle plutonites.

Neither « specialization » nor peculiar differentiation processes (like the thermo-gravitational diffusion of HILDRETH, 1979; SHAW, 1974; SHAW et al., 1976), to which many authors attach a determinant role in metallogenesis, appear able to explain the question (GUASPARRI et al., in press). An unusually high metal content in a given magma may eventually lead to the production of larger and richer mineralizations but cannot trigger the mineralizing process. On theoretical grounds, fractional crystallization could be envisaged as such a reason and this is maintained by some authors (TISCHENDORF, 1977; GROVES and MCCARTHY, 1978) who also regard the same leucogranitic rocks as high silica differentiates of a more basic parent magma. Actually, our mineralizations are linked to fractionated (though slightly) facies of the leucogranite suite, but two different lines of evidence bring us to conclude that fractionation processes cannot have played any major role in determining the mineralizing phenomena. Firstly, the leucogranitic rocks are, beyond any doubt, a direct product of crustal anatexis (BRALIA et al., 1982; GUASPARRI et al., in press). Secondly, despite the much more active fractionation processes (GUASPARRI et al., in press; BRALIA et al., 1982) no sign of mineralization has so far been found linked to the first cycle plutonites even in connection with the highest silica differentiates (the monzo-leucogranites).

The contrasting behaviour of the two magmatic phase plutonites as regards their « metallogenic vocation » must then rely on other intrinsic petrological characteristics.

We have already mentioned that the two suites of rocks were emplaced at quite different crustal levels and that the level of intrusion of the leucogranites was much higher. Depths of emplacement ranging from 3.8 km to less than 1.8 km have been estimated by GUASPARRI et al., in press) for the rocks of this suite. Such shallow crustal levels are likely to be reached only by high temperature magmas with H_2O contents not higher than 2-3 % (BROWN and FYFE, 1970; FYFE, 1970; ROBERTSON and WYLLIE, 1971; LUTH, 1976; WYLLIE, 1979). The decisive relevance to metallogenesis of the low water content of a magma body and its consequent capacity to rise up in the crust to shallow depths has been thoroughly discussed elsewhere (GUASPARRI et al., in press). In such low pressure environments extensive hydrofracturing of wall rocks is easily induced by a second boiling stage of the magmatic body (PHILLIPS, 1973; KOIDE and BHATTACHARJI, 1975; BURNHAM, 1979) and the exolved fluids would be Cl^- rich (HOLLAND, 1972) and most likely subcritical (HOLLAND, 1972; FOURNIER, 1972). The extensive permeability of rocks yielded by brittle failure allow intimate contact between the already crystallized magma and the aggressive high chlorine fluids which, owing to their subcritical state, do not escape from the system but prolong their attack on the preformed minerals so that rock alteration and metal leaching is greatly facilitated. Furthermore, by boiling, these brines may concentrate into small spaces even huge quantities of solutes scavenged from large volumes of rock. There is increasing evidence that these phenomena are involved in and probably essential to porphyry systems (DAVIS, 1974; GUSTAFSON and HUNT, 1975; CUNNINGHAM, 1978).

It should finally be underlined that the heat supplied by the solidifying process, when a magmatic body is emplaced at shallow depth in the crust, offers major possibilities for the establishment of the gigantic hydrothermal circulation systems ([2]) to which many authors attach a determinant role in the formation of a porphyry system.

Rocks of the first intrusive phase were emplaced at a consistently deeper level (RICCI and SABATINI, 1973) partly because of their water content and partly because of the prevailing compressive regime of the orogen, and consequently their crystallization could not give rise to the above described phenomena and mineralizations could not form. A fluid eventually exolved through a second boiling stage would have been Cl^- poor, scarcely aggressive and decidedly supercritical. Such a fluid would have escaped « osmotically » from the rest melt (JAHNS and BURNHAM, 1979), wall rocks, owing to greater pressure, would have expanded in plastic deformation under second boiling so that hydrofracturing would have been precluded and the system would have remained practically impermeable.

The most generalized and characterizing phenomena resulting from the different behaviour of the two suites of plutonites during the late magmatic stage, is that the first phase plutonites are nearly always fresh rocks while the leucogranites are always pervasively altered, though to a variable degree. This means that practically the whole leucogranite suite underwent the afore-described late magmatic processes and was then potentially capable of producing mineralizations.

It has yet to be explained why only a few of the leucogranitic intrusions bear mineralizations and why there is still no evidence that any of the Mo-deposits of Sardinia reach the imposing size of many mineralizations of this type elsewhere. Neither question is easy to answer, and to the first it can only be said that the sites where appreciable concentration of ore occurs were determined by factors which were most likely established by the pre-ore geological framework. As regards the second, we must note that the general situation in which the mineralizations were formed was not the most favourable for the concentration of large quantities of ore. First of all each individual intrusion of the suite is generally very small in size compared to the volume of those which have produced clearly economic porphyry deposits elsewhere, but more significantly the structural framework of a Hercyno-type orogen is so different from, say, an Andino-type orogen (PITCHER, 1979) as to make it much more difficult for a deposit of this kind to reach large dimensions (see GUASPARRI et al., 1981). We refer particularly to the fact that in an Andino-type orogen plutonites are generally able to reach the sedimentary or volcanic cover while this is precluded for plutonites in a Hercyno-type orogen. In the latter practically all products are intruded in metamorphites owing to the very rapid « erosion » of the chain which easily removes the rocks of the surface cover, causing the underlying metamorphosed rocks to crop out. These coheval metamorphites obviously can hardly have constituted a suitable « prepared ground ».

As a matter of fact, many of the Mo-mineralizations of Sardinia lie near the contact of the metamorphic cover and although alteration-mineralization phenomena are widespread in the igneous rocks all around, they scarcely penetrate into the metamorphites. This means that the metamorphic rocks constituted an impervious medium for the ascending fluids and, if so, no large convective circulating system was likely to be active because the participation (in the porphyry system) of percolating ground waters was severely limited.

Apart from the problem of their size or grade (which, anyhow, remains to be ascertained) the Mo-porphyries of the Sardinian batholith certainly have all the fundamental and unifying traits typical of

---

([2]) Indeed the ultimate nature of the hydrothermal fluids is still a much debated problem among specialists since evidence of both magmatic and meteoric water dominated hydrothermal systems have been found (SHEPPARD et al., 1969, 1971; NORTON, 1969; SHEPPARD and TAYLOR, 1974; BATCHELDER et al., 1976; OSATENKO and JONES, 1976; BLOOM, 1981). On the other hand, isotopic data are hardly conclusive and this partly justifies the various models which have been proposed (GUSTAFSON and HUNT, 1975; NORTON and KNIGHT, 1977; HENLEY and MCNABB). However we share the opinion of those authors (e.g. GUSTAFSON and HUNT, 1975) who envisage these systems as evolving in time from a magmatic to a meteoric water dominated circulation; experimental and field data coming from numerous porphyry deposits appears to support this line of thought.

such a family of deposits. We refer for example to the high silica character of the associated intrusives generally fitting the ternary minimum of the granite family, the rather high fluorine of these melts, the shallow level of emplacement reached during a tensional tectonic momentum in the structural evolution of a crustal segment, the evidence of a thickened sialic crust below, etc. On the other hand, apart from diversities in details, the whole class of deposits linked to granitoid rocks shows striking similarities in its essential features and the main petrologic phenomena involved in its genesis. Many authors however, have been more impressed by the differences than by the unifying features of these deposits so that numerous classifications have been proposed. Indeed in classifying the members of the family of porphyry deposits a number of different criteria have been adopted. The porphyry deposits of southwestern North America were firstly subdivided into simple or complex by TITLEY (1966). In relation to complexity and depth somewhat similar terms were then used by SUTHERLAND BROWN (1969). Classification by age was developed by WHITE et al. (1968) while the criterium of correlating the metal content with tectonic setting was proposed by SILLITOE (1972) and in a different way by KESTLER (1973) and KESTLER et al. (1975).

As regards Mo-porphyry deposits, HOLLISTER (1978) made a distinction on the basis of metal and alteration pattern distribution. MUTSCHLER et al. (1981) subdivided Mo-porphyry deposits into granodiorite and granite systems on the basis of the supposed source pluton. SILLITOE (1980) distinguished the subduction-related from the rift-related Mo-porphyry deposits and WESTRA and KEITH (1981) proposed a classification based on magma chemistry. Finally three genera of porphyry deposits were distinguished by SUTHERLAND BROWN (1972, 1976) on the basis of « morphological » characteristics as volcanic, phallic (or hypabyssal) and plutonic deposits.

We wish to stress that especially in areas, such as Sardinia, where the magmatism reveals quite a complex petrologic history, a detailed knowledge, possibly on the regional scale, of the magmatism itself becomes determinant in a correct interpretation of the related metallogenesis on which must obviously rely any well-grounded attempt of classification. For instance, the characteristics distinguishing the aforementioned «plutonic» porphyry deposits (where mineralization is dominantly vein or fracture controlled, host rocks are medium to coarse grained, concentric zoning is unrecognizable and alteration around the veins or fractures rapidly passes into substantially fresh or much less altered rock) are quite similar to those of some mineralizations of the Sardinian batholith already described (i.e. Perda e' Pibera and Goene). These should then be classified as «plutonic» deposits and consequently should be taken as formed at a depth greater than the other mineralizations according to SUTHERLAND BROWN (1976) and NIELSEN (1976). However, this conclusion is disproved both by field and petrographic evidence. It is actually quite clear, at least as far as the Sardinian batholith is concerned, that the mineralizations linked to the hercynian intrusives are directly related to hypabyssal intrusions of leucogranite-porphyries and fine grained leucogranites. Although intrusives of the first magmatic phase or coarse grained leucogranites can be involved in mineralizing phenomena, these rocks invariably turn out to be cold hosts which may have reacted to a variable extent but always suffered events rather than provoking them. We emphasize that a decisive step towards such interpretation of metallogenesis in the batholith was mainly determined by the recognition of two independent magmatic phases within the intrusive hercynian magmatism in Sardinia and the distinctly different levels of intrusion of the respective products.

On the other hand there is evidence that hypabyssal rocks are also related to mineralizing phenomena in by far more famous deposits which according to their major features have been classified as « plutonic » porphyry deposits. For example the main stage of Butte is related to the Modoc quartz-porphyry (BRIMHALL, 1979; BRIMHALL and GHIORSO, 1983) while the proto-ore can reasonably be related to the emplacement of the Steward quartz-porphyry dykes. In the same way aplite, granite-porphyry and quartz porphry dykes intrude the Endako quartzmonzonite within and all around the orebody and these hypabyssal intrusives are the immediate precursor (KIMURA et al., 1976; BLOOM, 1981) and likely trigger the miralizing event(s).

NIELSEN'S (1976) observation that deep drilling in hypabyssal stock-controlled porphyry systems does not substantiate the hypothesis that plutonic porphyries occur deep beneath the former, is therefore not so surprising. On the contrary, we consider that just the opposite could be true, and this is also in agreement with the arguments put forward by GUASPARRI et al. (in press).

Other papers (GUASPARRI et al., in preparation) will be concerned with a more exhaustive testing of these concepts and with the framing of the Sardinian Mo-mineralizations in the metallogenesis of the hercynian orogen. We wish here only to hint at some aspects of this more general argument.

If we compare the Sardinian mineralizations with those related to analogous rocks in the other segments of the hercynian orogen in Europe, some striking differences are evident as regards ore paragenesis and alteration style. Contrary to the rest of Europe where Sn-W (Mo) mineralizations linked to granitic rocks are predominant, there is a decisive prevalence of Mo (W-Sn) in Sardinia; greisen-type alteration is the most frequently encountered in Sn deposits whereas phyllic-type alteration, as previously described, usually accompanies Mo-mineralizations. This situation perfectly matches the definitive prevalence of I type granitoids in Sardinia (BRALIA et al., 1982) and of S (peraluminous) type granitoids in all the other hercynian segments of Europe (PITCHER, 1979).

By definition (see e.g. ROSE and BURT, 1979) a high fluorine activity seems to be determinant in greisen petrogenesis. However no greisen-type alteration is associated with mineralizations linked to the leucogranites of Sardinia despite the fact that these were ensued from fluorine-rich magmas (GUASPARRI et al., in press). It seems then quite likely that the nature of the granitoids involved in the alteration phenomena and namely an Al-rich nature must be a further necessary condition in greisen petrogenesis. If this were true, one of the most striking elements of differentiation between porphyry- and greisen-type deposits (that has historically contributed to a distinction which tacitly implied different genetic mechanisms) could be by-passed and no other serious difficulty would then remain in envisaging all these deposits as the product of substantially the same phenomenon.

As a matter of fact, some authors (HOLLISTER et al., 1974; SUTHERLAND BROWN and CATHRO, 1976) have recently expressed the opinion that at least some of the European greisen deposits could be considered porphyry deposits. This hypothesis is supported, in our opinion, by numerous facts: greisen-type alteration is frequently described in porphyry deposits (e.g. SCHWARTZ, 1947; MCKENZIE, 1970; SHCHERBA, 1970; HOLLISTER et al., 1974; MCMILLAN, 1976; HOLLISTER, 1978); greisen deposits like porphyry deposits are closely linked to shallow emplaced intrusive rocks (ZOUBECK, 1978; TISCHENDORF et al., 1978; BURNOL, 1978; TAYLOR, 1979; COTELO NEIVA, 1972; SIERRA et al., 1972); fluid inclusion studies coming from both types of deposits indicate that boiling of solutions occurred (BURT, 1981); also in greisen deposits evidence exists that convective hydrothermal systems with a notable component of meteoric waters partecipate in the mineralizing phenomena (SHEPPARD, 1977; SIMPSON et al., 1979).

Furthermore, there exists a growing consensus that the differences in metals expressed in the two types of deposit are to be considered as bound to the character of the magma (ISHIHARA, 1980) and probably to some related, as yet unclear, critical interplay between silicate magma, volatile phases and metal complexes in the late stage of the magmatic process (BURNHAM and OHMOTO, 1980). Therefore the differences unquestionably present within the family of mineralizations related to high silica intrusives and more in general to granitoid rocks do not necessarily require that the fundamental genetic processes be different.

On the contrary, we are convinced that the crucial conditions for the triggering of mineralizing phenomena in these kinds of deposits are always the same, as are most of the processes involved in their development. These essentially identical phenomena may well be heavily masked by the somewhat different controls exercized by the nature of the parent magma and the mechanism of emplacement in turn conditioned by the different magmatological and geostructural situations.

Acknowledgements. — We warmly thank P. OMENETTO for stimulating discussion and helpful criticism.

The work was supported by C.N.R. and M.P.I. grants.

REFERENCES

ALBAREDE F. (1976) - *Thermal models of post-tectonic decompression as exemplified by the Haut-Allies granulites (Massif Central, France).* Bull. Soc. Geol. Fr., 1, 1023-1032.

BACCOS F. (1968) - *Osservazioni geologico-minerarie sul giacimento a molibdenite e wolframite di Perda Majori (Sardegna Sud Orientale).* Res. Ass. Min. Sarda, 72 (6), 5-66.

BATCHELDER J., TEODORE T.G., BLAKE D.W. - *Stable isotopes and geology of the Copper Canyon porphyry copper deposits, Lander County, Nevada.* Soc. Mining Engineers - AIME Annual Meeting.

BLOOM M.S. (1981) - *Chemistry of inclusion fluids: stockwork molybdenum deposits from Questa, New Mexico and Hudson Bay Mountain and Endako, British Columbia.* Econ. Geol., 76, 1906-1920.

BONORINO F.G. (1959) - *Hydrothermal alteration in the Front Range mineral belt.* Geol. Soc. Amer. Bull., 70, 53-90.

BRALIA A., GHEZZO C., GUASPARRI G., SABATINI G. (1982) - *Aspetti genetici del batolite sardo-corso.* Rend. Soc. It. Min. Petr., 38 (2), 701-764.

BRALIA A., GUASPARRI G., RICCOBONO F., SABATINI G. (1983 a) - *Polytypism of molybdenite in Mo-deposits of the Sardinian batholith.* Period. Mineral., 52, 235-251.

BRALIA A., DUCHI G., GUASPARRI G., RICCOBONO F., SABATINI G. (1983 b) - *The « anomalous » Mo-mineralizations of the Ogliastra region (east-central Sardinia). The example of Gocne.* Period. Mineral., 52, 219-234.

BRIMHALL G.H. Jr. (1979) - *Lithologic determination of mass transfer mechanisms of multiple-stage porphyry copper mineralization at Butte, Montana: vein formation by hypogene leaching and enrichment of potassium-silicate protore.* Econ. Geol., 74, 556-589.

BRIMHALL G.H. Jr., GHIORSO M.S. (1983) - *Origin and ore-forming consequences of the advanced argillic alteration process in hypogene environments by magmatic gas contamination of meteoric fluids.* Econ. Geol., 78, 73-90.

BROWN G.C., FYFE W.S. (1970) - *The production of granite melts during ultrametamorphism.* Contrib. Mineral. Petrol., 28, 310-318.

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

BURNHAM C.W. (1979) - *Magmas and hydrothermal fluids.* In: « Geochemistry of hydrothermal ore deposits », H.L. Barnes Ed., pp. 71-136. New York: John Wiley & Sons.

BURNHAM C.W., OHMOTO H. (1980) - *Late stage processes of felsic magmatism.* Soc. Mining Geologists Japan, spec. issue 8, 1-12.

BURNOL L. (1978) - *Different types of leucogranites and classification of the types of mineralization associated with acid magmatism in the Northwestern part of the French Massif Central.* In: IGCP symposium MAWAM, Prague 1974, Stemprok M., Burnol L., Tischendorf G., Eds., vol. 3, 191-204.

BURT D.M. (1981) - *Acidity-salinity diagrams - application to greisen and porphyry deposits.* Econ. Geol., 76, 832-843.

CARTA M. (1953) - *Appunti per un piano organico di ricerche e valorizzazione delle risorse minerarie in Sardegna.* Att. Conv. Studi Industr. Sard., vol. 2.

CHARRIER G. (1957) - *Gli scisti cristallini della Sardegna settentrionale - studio geologico e petrografico.* Boll. Serv. Geol. d'It., 79.

CLARK S.P., JAEGER E. (1969) - *Denudation rate in Alps from geochronologic and heat flow data.* Am. J. Sci., 267, 1143-1160.

COTELO NEIVA J.M. (1972) - *Tin-tungsten deposits and granites from northern Portugal.* Internat. Geol. Cong. 24th., Montreal, sec. 4, pp. 282-291.

CREASEY S.C. (1959) - *Some phase relations in hydrothermally altered rock at porphyry copper deposits.* Econ. Geol., 54, 354-373.

CREASEY S.C. (1966) - *Hydrothermal alteration.* In: « Geology of the Porphyry Copper Deposits, Southwestern North America », Titley S.R. and Hicks C.L. Eds., University of Arizona Press, pp. 51-74.

CUNNINGHAM C.G. (1978) - *Pressure gradients and boiling as mechanism for localizing ore in porphyry systems.* U.S. Geol. Survey J. Research, 6, 745-754.

DAVIS J.D. - *Geothermometry, geochemistry and alteration at the San Manuel porphyry copper orebody, San Manuel, Arizona.* Ph. D. Thesis, University of Arizona.

DEL MORO A., DI SIMPLICIO P., GHEZZO C., GUASPARRI G., RITA F., SABATINI G. (1975) - *Radiometric data and intrusive sequence in the Sardinian batholith.* N. Jb. Miner. Abh., 126, 28-44.

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, pp. 381-393.

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

EWART A., OVERBY V.M., MATEEN A. (1977) - *Petrology and isotope geochemistry of tertiary lavas from the northern flank of the Tweed volcano, southeastern Queensland.* J. Petrol., 18, 73-113.

FOURNIER R.O. (1972) - *The importance of depth of crystallization on the character of magmatic fluids*. In: Proceedings of 24th Int Geol. Congr., Montreal, sec. 10, 214 (abstract).

FYFE W.S. (1970) - *Some thought on granitic magmas*. In: « Mechanism of igneous intrusion », Newall G. & Rast N. Eds., Spec. Iss. Geol. J., 2, 201-215.

GHEZZO C., GUASPARRI G., PRETTI S., RICCOBONO F., SABATINI G., URAS I. (1981) - *Le mineralizzazioni a molibdeno associate al magmatismo intrusivo ercinico della Sardegna*. Rend. Soc. It. Mineral. Petr., 38 (1), 133-145.

GHEZZO C., GUASPARRI G., SABATINI G. (1979) - *Late hercynian post orogenic magmatism in the Sardo-Corsican microplate*. Newsletter, 1, 69-91.

GROVES D.I., MCCARTHY T.S. (1978) - *Fractional crystallization and the origin of tin deposits in granitoids*. Miner. Deposita, 13, 11-26.

GUASPARRI G., RICCOBONO F., SABATINI G. (1981) - *Considerazioni sul magmatismo intrusivo ercinico e le connesse mineralizzazioni in Sardegna*. Rend. Soc. It. Min. Petr., 38 (1), 488-490.

GUASPARRI G., RICCOBONO F., SABATINI G. - *Leucogranites of the Sardinian batholith: petrologic aspects and their relevance to metallogenesis*. In press.

GUASPARRI G., RICCOBONO F., SABATINI G. - *Some thoughts on « younger granites » and associated ore deposits*. In preparation.

GUSTAFSON L.B., HUNT J.P. (1975) - *The porphyry copper deposit at El Salvador, Chile*. Econ. Geol., 70, 857-912.

HENLEY R.W., MCNABB A. (1978) - *Magmatic vapor plumes and ground water interaction in porphyry copper emplacement*. Econ. Geol., 73, 1-20.

HILDRETH W. (1979) - *The Bishop Tuff: evidence for the origin of compositional zonation in silicic magma chamber*. Geol. Soc. America, Spec. paper 180, 43-75.

HOLLAND H.D. (1972) - *Granites, solutions and base metal deposits*. Econ. Geol., 67, 281-301.

HOLLISTER V.F. (1978) - *Porphyry molybdenum deposits*. In: « International Molybdenum Encyclopaedia », A. Sutolov Ed., Santiago, Chile, Intermet Pub. p. 270-283.

HOLLISTER V.F., POTTER R.R., BARKER A.L. (1974) - *Porphyry-type deposits of the Appalachian orogen*. Econ. Geol., 69, 618-630.

ISHIHARA S. (1980) - *Significance of the magnetite series and ilmenite series of granitoids in mineral exploration*. Proceedings of the Fifth Quadriennal IAGOD Symposium, Stuttgart, Germany.

JAHNS R.H., BURNHAM C.W. (1969) - *Experimental studies of pegmatite genesis: I. A model for the derivation and crystallization of granitic pegmatites*. Econ. Geol., 64, 843-864.

KESTLER S.E. (1973) - *Copper, molybdenum and gold abundances in porphyry copper deposits*. Econ Geol., 68, 106-112.

KESTLER S.E., JONES L.M., WALKER R.L. (1975) - *Intrusive rocks associated with porphyry copper mineralizations in Island Arc areas*. Econ Geol., 70, 515-526.

KIMURA E.T., BYSOUTH G.D., DRUMMOND A.D. (1976) - *Porphyry molybdenum deposits of the calc-alkalic suite, Endako*. In: CIM, spec. vol. 15, Sutherland Brown Ed., pp. 444-454.

KOIDE H., BHATTACHARJI S. (1975) - *Formation of fractures around magmatic intrusions and their role in ore localization*. Econ. Geol., 70, 781-799.

LEEMAN W.P., PHELPS D.W. (1981) - *Partitioning of rare earths and other trace elements between sanidine and coexisting volcanic glass*. J. Geophys. Res., 86, 10193-10199.

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

LUTH W.C. (1976) - *Granitic rocks*. In: « The evolution of the crystalline rocks », D.K. Bailey & R. MacDonald Eds., London, Academic Press., pp. 335-417.

MACKENZIE W.B. - *Hydrothermal alteration associated with the Urad and Henderson molybdenite deposits, Clear Creek County, Colorado*. Unpublished Ph. D. thesis, University of Michigan, 208 pp.

MAHOOD G., HILDRETH W. (1983) - *Large partition coefficients for trace elements in high-silica rhyolites*. Geochim. Cosmochim. Acta, 47, 11-39.

MCMILLAN W.J. (1976) - *Geology and genesis of the Highland Valley ore deposits and the Guichon Creek batholith*. In: « Porphyry deposits of the Canadian Cordillera », Sutherland Brown A. Ed., CIM Special Vol. 15, 85-104.

MEYER C., HEMLEY J.J. (1967) - *Wall rock alteration*. In: « Geochemistry of hydrothermal ore deposits », H.L. Barnes Ed., New York, Holt, Rinehart and Winston, pp. 166-235.

MUTSCHLER F.E., WRIGHT E.G., LUDINGTON S., ABBOTT J.T. (1981) - *Granite-molybdenite systems*. Econ. Geol., 76, 870-893.

NIELSEN R.L. (1976) - *Recent developments in the study of porphyry copper geology - a review*. In: « Porphry deposits of the Canadian Cordillera », Sutherland Brown A., Ed., CIM Special Vol. 15, pp. 489-500.

NORTON D.L. (1979) - *A hydrothermal convection system related to porphyry copper formation*. Geol. Soc. America, Rocky Mt. Section, pt. 5 (abstract).

NORTON D., KNIGHT J. (1977) - *Transport phenomena in hydrothermal systems: cooling plutons*. Am. J. Sci., 277, 937-981.

OSATENKO M.J., JONES M.B. (1976) - *Porphyry copper and copper molybdenum deposits of the calc-alkalic suite, Valley Copper*. In: « Porphyry deposits of the Canadian Cordillera », Sutherland Brown A., Ed., CIM Special Vol. 15, 130-143.

PHILLIPS W.J. (1973) - *Mechanical effects of retrograde boiling and its probable importance in the formation of some porphyry copper deposits*. Inst. Mining Metallurgy Trans. 81 sec. B.P., B90-B98.

PITCHER W.S. (1979) - *The nature, ascent and emplacement of granitic magmas*. J. Geol. Soc. London, 136, 627-662.

RICCI C.A., SABATINI G. (1973) - *Relazioni fra rocce granitiche e metamorfiche nella Sardegna centro-settentrionale. Nota IV: L'aureola di contatto delle intrusioni di Bono e Anela*. Min. Petr. Acta, 19, 187-194.

ROBERTSON J.K., WYLLIE P.J. (1971) - *Rock-water systems, with special reference to the water-deficient region*. Am. J. Sci., 271, 252-277.

ROEDDER E. (1979) - *Fluid inclusion as samples of ore fluids*. In: « Geochemistry of hydrothermal ore deposits », H.L. Barnes Ed., J. Wiley, pp. 684-737.

ROSE A.W. (1970) - *Zonal relations of wallrock alteration and sulphide distribution at porphyry copper deposits*. Econ. Geol., 65, 920-936.

ROSE A.W., BURT D.M. (1979) - *Hydrothermal alteration*. In: « Geochemistry of hydrothermal ore deposits », H.L. Barnes Ed., New York, Wiley-Interscience, pp. 173-235.

SALVADORI I. (1959) *Segnalazione di una manifestazione a molibdenite nella zona di Villacidro*. Res. Ass. Min. Sarda, 63 (5-6), 5-27.

SCHWARTZ G.M. (1947) - *Hydrothermal alteration in the « porphyry copper » deposits*. Econ. Geol., 17, 319-352.

SCHWARTZ G.M. (1966) - *The nature of primary and secondary mineralization in porphyry copper deposits*. In: « Geology of the porphyry Copper Deposits of Southwestern North America », S.R. Titley & C.L. Hicks, Eds., University of Arizona Press, pp. 41-50.

SHAW H.R. (1974) - *Diffusion of H_2O in granitic liquids: Part I - Experimental data; Part II - Mass transfer in magma chambers*. In: « Geochemical transport and kinetics», A.W. Hoffmann, B.J. Giletti, H.S. Yoder Jr. & R.A. Yund, Eds., Carnegie Inst. Washington Publ., 634, 139-170.

SHAW H.R., SMITH R.L., HILDRETH W. (1976) - *Thermogravitational mechanisms for chemical variations in zoned magma chambers*. Geol. Soc. Am. Abstr., 8, 1102.

SHCHERBA G.N. (1970) - *Greisens*. Intern. Geology Rev., 12, 114-150 and 239-259.

SHEPPARD S.M.F., NIELSEN R.L., TAYLOR H.P. Jr. (1969) - *Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits*. Econ. Geol., 64, 755-777.

SHEPPARD S.M.F., NIELSEN R.L., TAYLOR H.P. Jr. (1971) - *Hydrogen and oxygen ratios in minerals from porphyry copper deposits*. Econ. Geol., 66, 515-542.

SHEPPARD S.M.F., TAYLOR H.P. Jr. (1974) - *Hydrogen and oxygen isotope evidence for the origins of water in the Boulder batholith and the Butte ore deposits, Montana*. Econ. Geol., 69, 926-946.

SHEPPARD S.M.F. (1977) - *The Cornubian batholith, SW England: D/H and $^{18}O/^{16}O$ studies of kaolinite and other alteration minerals*. J. Geol. Soc. London, 133, 573-591.

SIERRA J., ORTIZ A., BURKHALTER J. (1972) - *Metallogenic map of Spain*. Internat. Geol. Cong. 24th Montreal sec. 4, 110-121.

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

SILLITOE R.H. (1980) *Types of porphyry molybdenum deposits*. Mining, Mag.-June, 550-553.

SIMPSON P.R., BROWN G.C., PLANET J., OSTLE D. (1979) - *Uranium mineralization and granite magmatism in the British Isles*. Phil. Trans. R. Soc. London, A, 291. 385-412.

SOTGIU T. (1921) - *Alcune osservazioni sui minerali di molibdeno della Sardegna*. Rass. Min. Met. Chim., 55 (2).

SUTHERLAND BROWN A. (1969) - *Mineralization in British Columbia and the copper and molybdenum deposits*. CIM Bulletin, 62, 26-40.

SUTHERLAND BROWN A. (1972) - *Morphology and classification of porphyry deposits of the Canadian Cordillera*. Proc. 9th Ann. West. Intern. University Geological Conference, Vancouver (Abstr.).

SUTHERLAND BROWN A. (1976) - *General aspects of porphyry deposits of the Canadian Cordillera - morphology and classification*. In: « Porphyry deposits of the Canadian Cordillera », Sutherland Brown A., Ed., CIM Special Vol. 15, 44-51.

SUTHERLAND BROWN A., Ed. (1976) - *Porphyry deposits of the Canadian Cordillera*, CIM Special Vol. 15, 510 p.

SUTHERLAND BROWN A., CATHRO R.J. (1976) - *General aspects of porphyry deposits of the Canadian Cordillera - a perspective of porphyry deposits*. In: « Porphyry deposits of the Canadian Cordillera », Sutherland Brown A., Ed., CIM Special Vol. 15, 7-16.

TAYLOR R.G. (1979) - *Geology of Tin Deposits*. Amsterdam, Elsevier, 544 p.

TISCHENDORF G. (1977) - *Geochemical and petrographic characteristics of silicic magmatic rocks associated with rare-element mineralization*. In: EGCP symposium MAWAM, Prague 1974, Stemprok M., Burnol L., Tischendorf G., Eds., Vol. 2, 41-96.

TISCHENDORF G., SCHUST F., LANGE H. (1978) - *Relation between granites and tin deposits in the Erzgebirge*. In: IGCP symposium MAWAM, Prague 1974, Stemprok M., Burnol L., Tischendorf G., Eds., Vol. 3, 123-137.

TITLEY S.R. (1966) - *Preface*. In: « Geology of the Porphyry Copper Deposits, Southwestern North America », S.R. Titley & C. Hicks, Eds., University of Arizona Press, IX-X.

TITLEY S.R., HICKS C.L., Eds. (1966) - *Porphyry Deposits of Southwestern North America*. University of Arizona Press, 287 p.

VENERANDI I. (1968) - *Il giacimento a molibdenite e wolframite di Perda Majori*. Ist. Lombardo (Rend. Sc.), A102, 678-716.

WALLACE S.R., MUNCASTER N.K., JONSON D.C., MACKENZIE W.B., BOOKSTROM A.A., SURFACE V.E. (1968) - *Multiple intrusion and mineralization at Climax, Colorado*. In: « Ore deposits in the United States 1933-1967 » (Graton-Sales Vol.), Ridge J.D. Ed., New York, Am. Inst. Mining Metall. Petroleum Engineers, pp. 605-640.

WESTRA G., KEITH S.B. (1981) - *Classification and genesis of stockwork molybdenum deposits*. Econ. Geol., 76, 844-873.

WHITE W.H., HARAKAL J.E., CARTER N.C. (1968) - *Potassium-argon ages of some ore deposits in British Columbia*. CIM Bulletin, 61 (679), 1326-1334.

WYLLIE R.J. (1979) - *Magmas and volatile components*. Amer. Miner., 64, 469-500.

ZOUBECK V. (1978) - *Tectonic control and structural evidence of the development of the Krusne hory (Erzgebirge)*. In: IGCP symposium MAWAM, Prague 1974, Stemprok M., Burnol L., Tischendorf G., Eds., 3, 57-76.

ZUFFARDI P. (1953) - *Alcune caratteristiche dei giacimenti minerari sardi*. Atti Conv. Studi Industr. Sard., vol. 2.