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Skarn Related Mineralization in the Magnetite-Pyrite-Hematite Deposit of Brosso (Ivrea, Italy)

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With 8 figures

Schlüsselwörter

Italien: Aostatal: Brosso
skarnähnliche Vererzungen
Magnetit-Pyrit-Hämetit-
Erzlagerstätten
Traversella Pluton
Sesia-Lauro Zone
Metallogenese

Index

Riassunto

La miniera di Brosso, situata allo sbocco della Valle di Aosta, è stata coltivata in passato per galena argentife ra poi per ossidi di ferro ed infine per pirite. Le mineralizzazioni si trovano lungo il margine orientale del plutone di Traversella intruso nelle formazioni metamorfiche della zona Sesia Lanzo, subito a nord della linea del Canavese.

L'intrusione, di età Alpina, ha ripiegato e metamorfosa to per contatto sia le metamorfiti della Zona Sesia-Lanzo che i filoni di porfirite, intrusi negli scisti.

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Nella zona sono state riconosciute mineralizzazioni di tre tipi diversi, le differenze essendo apparentemente legate al tipo di roccia incassante e alla distanza dal plutone:

1. Vene a quarzo e arsenopirite negli scisti
2. Lenti di ematite e pirite nei marmi
3. Masse di skarn a magnetite e pirite nei marmi in prossimità del contatto.

Un dettagliato studio di queste ultime, basato sulla distribuzione dei diversi minerali nel corpo mineralizzato, permétte di individuare tre distinte associazioni di minerali che sembrano rappresentare, in base alla loro distribuzione nel volume di roccia considerato, tre stadi diversi del processo mineralizzante:

Stadio 1 – si formano borati e silicati di Fe e Mg con minori quantitativi di brucite. Segue, senza soluzioni di continuità, la formazione di grafite e magnetite e l'idratazione dei borati e dei silicati.

Stadio 2 – In due bande ristrette e ben definite che tagliano l'associazione preformata in linea retta, cristallizzano a spese dei minerali precendenti pirrotina e silicati idrati di Ca, Mg e Al. Scompaiono i borati e la paragenesi è completata da molibdenite, bismuto, calcopirite, ilmenite, oro, arsenopirite, blenda, galena etc.

Stadio 3 – Lungo una larga fascia che taglia le associazioni preformate diagonalmente in linea retta, si formano nuovi minerali a spese dei percendenti. La nuova associazione è costituita principalmente da quarzo, carbonati, apatite e silicati idrati di Ca, Mg, Al e Fe, associati con pirite, pirrotina, ematite, calcopirite, blenda, galena, titanite, scheelite etc. Solo in questo stadio è possibile distinguere una distribuzione zonale dei diversi minerali, disposti a bande trasversali alla fascia e parallele alle bande a metamorfismo decrescente che si osservano negli scisti a contatto col plutone.

I rapporti tra le diverse associazioni di minerali riconosciute nègli skarn permettono di ipotizzare che le associazioni formatesi nel secondo stadio siano geneticamente legate alle vene a quarzo e arsenopirite osservate negli scisti e quelle del terzo stadio alle lenti di ematite e pirite che si trovano nei marmi.

Le relazioni esistenti tra la genesi, la messa in posto e la cristallizzazione del plutone e il processo metalizzante sono difficili da stabilire con sicurezza ma i dati raccolti permettono di avanzare una ipotesi interpretativa.

In base a questa ipotesi i tre stadi di deposizione sono da riferire ad altrettante fasi di cristallizzazione del magma rispettivamente prepegmatitica, pegmatitica e postpegmatitica.

Infine, tenendo conto delle caratteristiche minerogenetiche, dell'esistente controllo geotettonico, dell'età, dell'evoluzione e del carattere geochimico del ciclo intrusivo ed effusivo, riteniamo che le mineralizzazioni note a Brosso debbano essere considerate come appartenenti alla cintura metallogenica della Tetide Eurosiatica, con forti analogie con le mineralizzazioni a skarn associate a molti dei giacimenti tipo Porphyry Copper che in essa si osservano.

Abstract

The Brosso ore deposit, located at the lower end of the Aosta Valley, in the past was at first mined for galena and silver, then for iron oxides and more recently for pyrite.

The mineralization occurs along the eastern border of the Traversella pluton intruded in the metamorphic formations of the Sesia-Lanzo Zone, just to the north of the Canavese Line.

The intrusion, of Alpine age, has tilted and metamorphosed both the schists and dolomitic marbles of the Sesia-Lanzo zone and the porphyritic dykes cutting the metamorphic formations.

Three different types of mineralization are known, the differences being apparently related to the host rock and to the distance from the intrusive body:

1. Quartz arsenopyrite veins in the schists
2. Hematite- pyrite lenses in the dolomitic marbles
3. Magnetite-pyrite bearing skarn masses in the marbles inside the contact zone.

A detailed investigation of the latter, based on the distribution pattern of the ore and skarn minerals in the ore body, suggests the existence of three distinct mineral assemblages that appear, from their spatial relationships, to be representatives of three distinct stages of the mineralizing process:

Stage 1 – Mg-Fe borates and silicates are formed, along with minor amounts of brucite, from a dolomitic marble. Formation of magnetite and grafite and hydration of borates and silicates follow without interruption.

Stage 2 – In two well defined and narrow bands cutting the former assemblage along straight lines, pyrrhotite and hydrated silicates of Ca, Mg, Al are formed from the preexisting minerals. Borates disappear and the paragenesis is completed by molybdenite, bismut, chalcopyrite, ilmenite, gold, arsenopyrite, sphalerite, galena, etc.

Stage 3 – In a wide band, cutting again the two former parageneses which are almost completely cancelled, a new mineral assemblage is formed consisting mainly of quartz, carbonates, apatite and hydrated silicates of Ca, Mg, Fe, Al associated with pyrite, pyrrhotite, hematite, chalcopyrite, sphalerite, galena, titanite, scheelite, etc. Only at this stage it is possible to observe a distinct zoning in the mineral assemblage, clearly related to the distance from the intrusive body and parallel to the contact zoning in the surrounding schists.

The relationships between the mineral assemblages observed in the skarn and the other mineralizations known in the area suggest that Stage 2 mineralization is possibly connected to the quartz arsenopyrite veins in the schists and Stage 3 to the pyrite-hematite ore bodies in the marbles.

The existing relations between genesis, emplacement and crystallization of the pluton and ore deposition are difficult to state but a tentative hypothesis can be advanced. In the light of this hypothesis, the three recognized stages of ore deposition could be referred respectively to prepegmatitic, pegmatitic and postpegmatitic stages of crystallization of the magma.

Finally taking into account the minerogenetical character of the ore deposit, the existing regional geotectonical control, the age, evolution and geochemical character of the effusive and intrusive cycle, the ore mineralization of Brosso should be considered as belonging to the Tethyan Eurasian Metallogenic Belt with a striking resemblance to the skarn ore associated with many of the porphyry copper deposits occurring along this belt.

Introduction

The Brosso ore deposit is located at the lower end of the Aosta Valley on the right side of the Dora Baltea river, 6 km northwest of the town of Ivrea (Piedmont, Italy). Like the more famous Traversella mine, belonging to the same district, Brosso has been historically mostly an iron ore producer.

Mining in the area began many centuries ago with the production of silver-lead ore and possibly gold, coming from small individual quartz veins containing sulfides. The first recorded iron ore production dates back to the 11th century (SQUARZINA 1960) and was maintained, with several interruptions, up to the second half of the 18th century when the main product, at least at the Brosso mine, gradually became pyrite (BONACOSSA and SCLOPIS 1900). Unlike the Traversella deposit, belonging entirely to the tactite zone of the Traversella pluton (MÜLLER 1912, COLOMBA 1915, KENNEDY 1931, ZUCCHETTI 1966a, 1966b, TORTI 1973) the Brosso ore bodies mined in that period consisted of hematite-pyrite lenses included in the dolomite marbles outside the contact zone (NOVARESE 1901).

Magnetite-pyrite ore bodies belonging to the tactite zone have been explored and mined at Brosso only since 1910 and the existing studies on those mineralizations are far from complete (FENOGLIO 1961) or present little more than mineralogical interest (GIUSSANI and VIGHI 1964).

To fill this gap the present study was completed between 1962 and 1964; since then no additional exploration and mining has taken place at Brosso.

Regional Geological Setting

The region between the town of Ivrea and the beginning of the Aosta Valley is covered to a great extent by the high morainic ridges forming the northern part of the Ivrea Amphitheater.

The underlying rocks belong to the Australpine unit and are represented by the Permian-Cretaceous sequence of the Canavese Zone forming a narrow belt wedged beetween the Sesia-Lanzo metamorphic formation (Micascisti eclogitici Auct.) and the Ivrea-Verbano ultramafics and metasediments. The Sesia Zone is separated from the Canavese and the Ivrea Zone by a major fault system, the Canavese line, representing the boundary between pre-Alpine metamorphic rocks to the south and prevailing Alpine metamorphism to the North (AHRENDT 1972, HUNZIKER 1974).

The relationships between the Canavese line and the Tonale Centovalli, Cremosina, Engadina and Sestri-Voltaggio lines are still a matter of discussion (GANSSER 1968, DAL PIAZ and others 1972, BORIANI and SACCHI 1974, TRUMPY 1973) and a satisfactory model of the role played by the "Insubric" fault system in the genesis of the Alpine orocline is far from being complete and entirely accepted.

The Sesia high pressure-low temperature Alpine metamorphism is generally related to subduction of a northern lithospheric slab under the Ivrea block (ERNST 1970, DAL PIAZ and others 1972, HUNZIKER 1974) but in any case it is probably true that the Canavese line has assumed at different stages of the Alpine orogenesis different significance as a geosuture, a transform fault and a vertical fault (STURANI 1973).

Closely related to the presence and the evolution of this tectonic boundary are the intrusive and extrusive igneous rocks occurring on both sides of the Canavese line. Volcanic rocks mainly of andesitic composition (ARHEND 1972), once described as porphyrites (NOVARESE 1929, BIANCHI e DAL PIAZ 1963), occur as lava flows and tuffites (Biella sector) or dykes roughly parallel to the regional tectonic trend. Two intrusive bodies, the Biella and Traversella plutons, ranging in composition from monzodiorite to granodiorite and granite (COLOMBA 1912, NOVARESE 1943, CANEPARI and FIORENTINI POTENZA 1961, FIORENTINI POTENZA 1968, CESANA and others 1976) form small ellipsoidal stocks intruded at shallow depth, approximately perpendicular to the Canavese line, in the Sesia Zone metamorphic rocks.

Both extrusive and intrusive igneous rocks are of Alpine age (HUNZIKER 1974) and belong to the same magmatic cycle.

Geology of the Mining Area

The Brosso mine is located along the southeastern margin of the Traversella pluton, just to the north of the Canavese line.

The widespread morainic cover existing in the area prevents in many cases the direct observation of the relationships between the pluton and the country rocks or the tectonic lineaments.

The data available from the mine permit however a good reconstruction of local stratigraphical and structural features (see fig. 1 und 2).

a) Structural setting

The Traversella intrusive body consists of an irregular dyke 6 km long and 1 km wide with an approximate trend N 30° W perpendicular to the Canavese line and to the regional tectonic trend of the surrounding schists of the Sesia Zone.

The schists, forming a slightly ondulated monocline directed N 70° E and dipping south from 10° to 50°, seem to cover the northern and upper end of the pluton. However towards the south, where the erosion has exposed the lower part of the intrusion, the contact appears to be vertical or dipping steeply inwards and the schists show a gradual bending becoming eventually almost parallel to the contact (see fig. 3).

The intrusion has also tilted and bent an older tectonic contact along which several porphyritic dykes occur. The fault zone, 400 m wide and roughly parallel to the Canavese line, divides in two parts the micaschist formation but does not cut the intrusive rocks. However in correspondence with the tectonic accident the contact is bent inwards for more

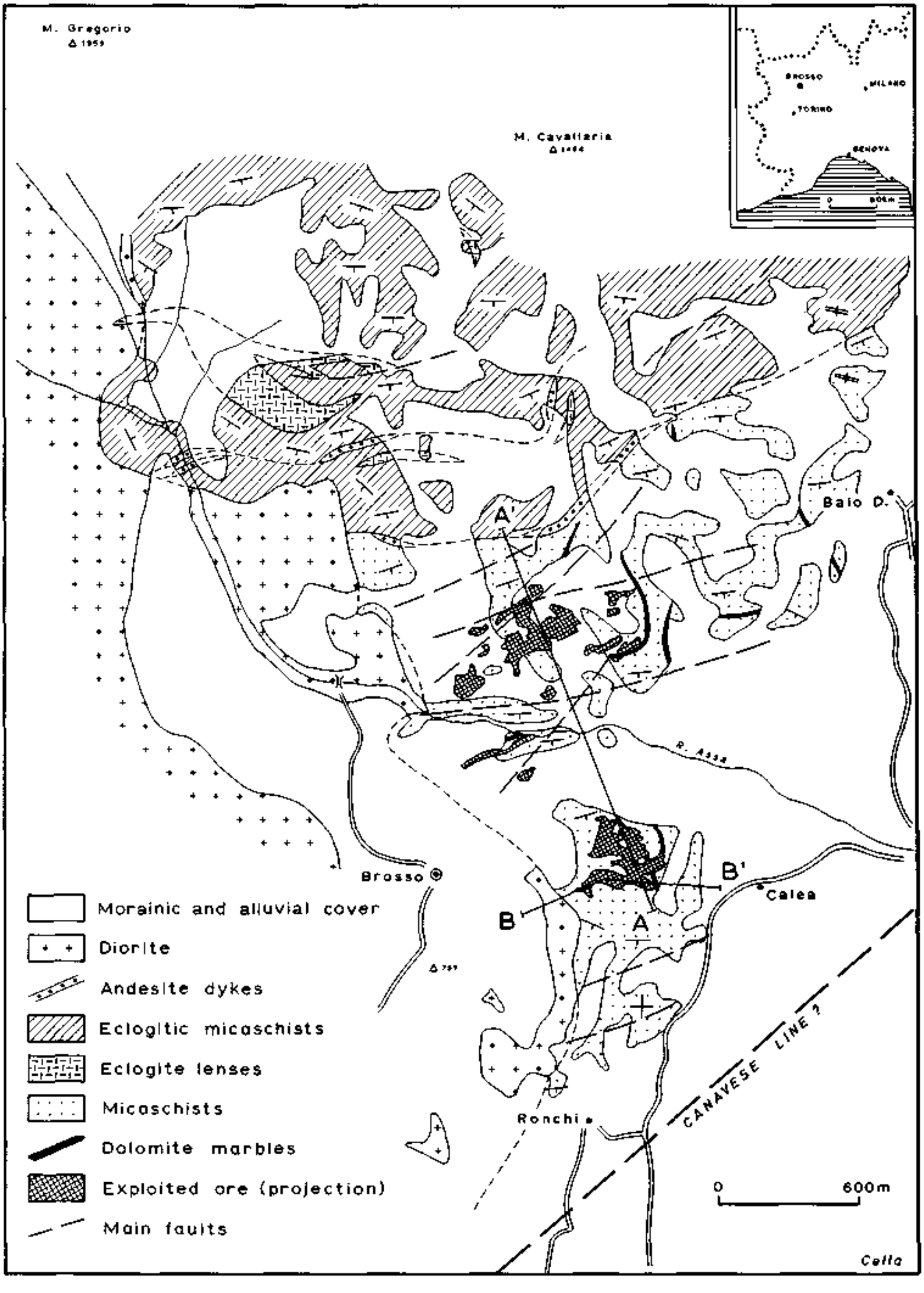

Fig. 1: Geological map of the Brosso mining area.

than 1 km possibly because of differences in lithology between northern and southern blocks or isochronism of tectonic movements and emplacement of the pluton.

Several small faults, often mineralized, belonging to two main sistems N 70° E and N 45° E are on the contrary clearly younger than intrusion and cooling of the pluton.

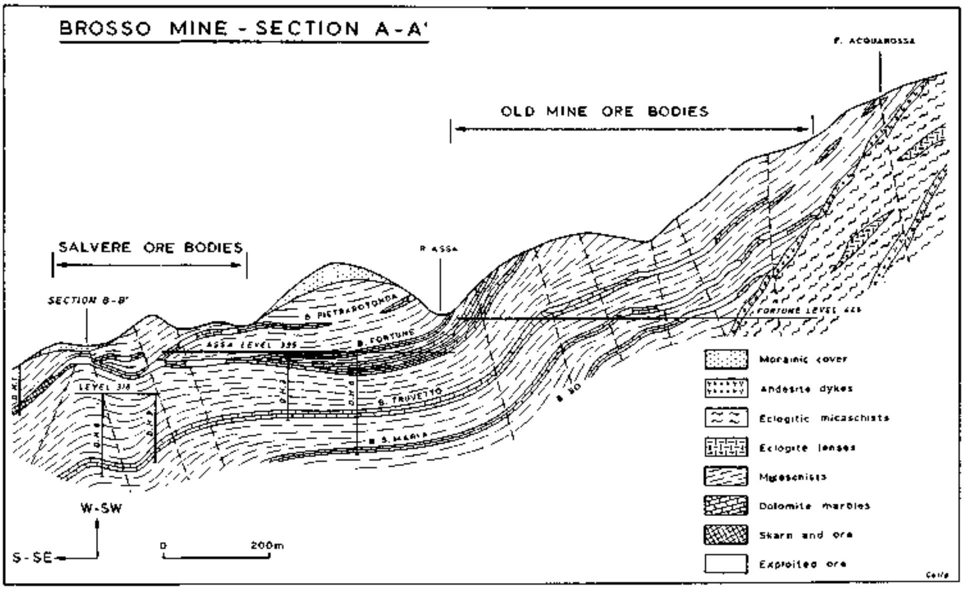

Fig. 2: Generalized cross section through the Brosso mine.

b) Igneous rocks

The intrusive rocks of the Traversella pluton have been described as syenites (Traverso 1894, Novarese 1901), as diorites (Colomba 1912, Novarese 1943) and more recently as monozodiorites.

The mineral assemblage, as remarked by Kennedy (1931), shows a continous variation between a diorite and a quartz monzonite type so that a satisfactory classification is difficult to attain.

The fundamental assemblage is of dioritic composition but irregular patches characterized by the pressence of orthoclase and quartz, sometimes very abundant, are widely distributed in the igeneous body.

Mafic inclusions and peripherical differentiations are also common, while aplitic and pegmatitic veins are not frequent.

The fundamental lithologic type is represented by a fine to medium grained grayish rock formed mainly by plagioclase of labradoritic to andesitic composition, associated with biotite and clinopyroxene, commonly surrounded by green hornblende.

Minor amounts of quartz and K-feldspar are always present, while the common accessory minerals are represented by apatite, zircon, magnetite, ilmenite. With the increase of quartz and K-feldspar the original association is deeply modified: The rock assumes a white-greenish colour due to the deep alteration of plagioclase, biotite and pyroxene.

The plagioclase is transformed, often completely, in a sericite-epidote aggregate surrounded by K-feldspar, while biotite and pyroxene disappear and are replaced by chlorite and amphibole.

Titanite, epidote, pyrite and magnetite are very common in addition to the usual accessory minerals and often form, in association with quartz and K-feldspar, small veins irregularly distributed in the altered rock. An allanite core is often present in the epidote of the veins where pyrite, chalcopyrite, quartz and orthoclase are also found in small geodes (COLOMBA 1912). The presence of K-feldspar of late formation together with the transformation of pyroxenes into hornblende or into magnetite-biotite aggregates and the presence of thin biotite veins (KENNEDY 1931) seems to be related to the development of a residual gas phase rhich in potassium[1]).

The K-feldspar zones are very extended and apparently irregularly scattered in the igeneous body. They seems to show no relation to zoning or to structural features, but a more extended survey would be necessary to establish this point.

The peripheral facies of the pluton are on the contrary clearly affected by proximity and nature of the surrounding rocks.

Near the contact with the micaschists the typical paragenesis is often enriched, at least in the last two meters, by the presence of elongated crystals of orthopyroxene together with small muscovite flakes. Spatially related to the presence of wollastonite-garnet-pyroxene skarn are peripherical facies formed essentially by plagioclase of labradoritic composition, while a plagioclase clinopyroxene association forms the transition zone between the normal diorite facies and the contact rocks of Casebelle (q. 1200 a. m. s. l.), formed essentially by scapolite, near to marialite in composition, with minor amounts of calcite, pyroxene, actinolite, chlorite, sphene, apatite.

Roughly perpendicular to the diorite body, several andesite porphyrite dykes occur along the already mentioned tectonic contact dividing into two parts the micaschists formation.

The individual dykes vary in thickness from 0.1 to 2.5 m and reach a maximum length of 300 m.

The mineral assemblage is rather uniform and it consists mainly of andesitic plagioclase and green hornblende both forming also small phenocrysts disseminated in a very fine grained ground mass.

Plagioclase and amphiboles are deeply altered to sericite, epidote and chlorite and small pyrite crystals are always present and locally very abundant.

Within the contact aureole, at a distance of less than 100 m from the pluton, the porphyritic dykes appear to be deeply metamorphosed with formation of biotite in small flakes, clearly derived from sericite, and in bigger crystals disseminated in the ground mass around the opaque minerals. Associated to the biotite are quartz and albite.

The existence of contact phenomena in the andesite dykes near the pluton and their location along and old tectonic contact tilted and folded by the intrusion seem to demonstrate that the effusive cycle was earlier than the intrusion.

Anyway both the intrusive and the extrusive rocks were not affected by the last regional metamorphic event (ZING and others, 1976) so that the interval between the two magmatic episodes should have been rather short, as it appears also from RB-Sr and K-Ar age determinations (HUNZIKER 1974) giving 29–33 m. y. for the andesites and 28–31 m. y. for the Biella and Traversella plutons.

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[1]) The ring differentiation of the Biella pluton was ascribed to a similar phenomenum, a late "pegmatitic" feldspathization of an original diorite (FIORENTINI POTENZA 1961a, 1961b and 1961c).

c) Metamorphic rocks

Between Mount Gregorio and Lessolo, along the eastern border of the Traversella pluton, the metamorphic formations of the Sesia Lanzo zone are represented by an argillaceous sequence of gray, thin splitting micaschists presenting gradual transition towards more arenaceous types, due to an increase in quartz content, sometimes resembling original graded beds. The typical mineral association is quartz, white micas and albite with small scattered porphyroblasts of garnet and locally minor amounts of chlorite, actinolite and clinozoisite. In the typical micaschists paragenesis no omphacite and glaucophane are present. As mentioned before, a sharp tectonic contact, marked by porphyritic intrusions and roughly parallel to the Canavese line, divides the micaschist formation into two parts (see fig. 1). The northern part is characterized by the presence, within the micaschists, of eclogitic rocks forming nodular to lenticular intercalations ranging in thickness from 20 m to less than 1 m and extending in direction up to 600 m. The eclogite lenses, very seldom perfectly concordant to the micaschist bedding, are usually formed by a wide range of combinations between the following three fundamental mineral assemblages:

1. omphacite, garnet, white micas
2. glaucophane, epidote, garnet, white mica, albite, calcite, quartz
3. albite, quartz, white micas, garnet, actinolite, epidote, chlorite and calcite.

According to Dal Piaz, Hunziker, Martinotti (1972) the former two high pressure-low temperature parageneses were developed during an Eoalpine metamorphic event; the third one, belonging to a separate more recent Eocene event, was superimposed on the others.

In the southern part of the micaschists formation no eclogitic schists are to be found but several marble intercalations are known.

The typical mineral association of the marbles is represented by dolomite with minor amounts of sericite, calcite and chlorite.

White mica is also rather common near the contacts with the schists.

Six carbonate horizons[2]), formed by one or more banks, have been recognized in the area mainly by underground exploration (see fig. 1 and 2). Their maximum thickness is around 30 to 40 m and the known areal extension is, at least in one case, more than 1 square km.

The interval between the different horizons varies from 40 to 300 meters and the total thickness of the series is more than 1.000 m.

No traces of high pressure low temperature mineral assemblage are to be found in the marbles.

In some instances however the dolomite is replaced by irregular masses of crystalline quartz, similar to the ones existing in the eclogite schists and in the eclogite lenses and clearly formed before the last metamorphic event.

d) Contact aureola

The nature and the extension of the contact phenomena induced by the intrusion are mainly related to the lithology of the surrounding rocks.

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[2]) The miner's denomination for the dolomitic marble horizons was "giacimenti" of "banchi" and all of them have received one or more names. From top to botton they are:

1. Salvere (or Fortune) and Pietrarotonda.
2. Truvetto (or S. Eugenia).
3. S. Maria.
4. Bo.
5. Lavassetto and Montefiorito.
6. Baio.

Contact mineral assemblages in the micaschists show a regular variation with the distance from the intrusion and maintain almost the same composition and extension all along the pluton.

On the contrary within the dolomitic marbles the mineral associations are very variable, the varations depending more on structural controls than on the distance from the pluton.

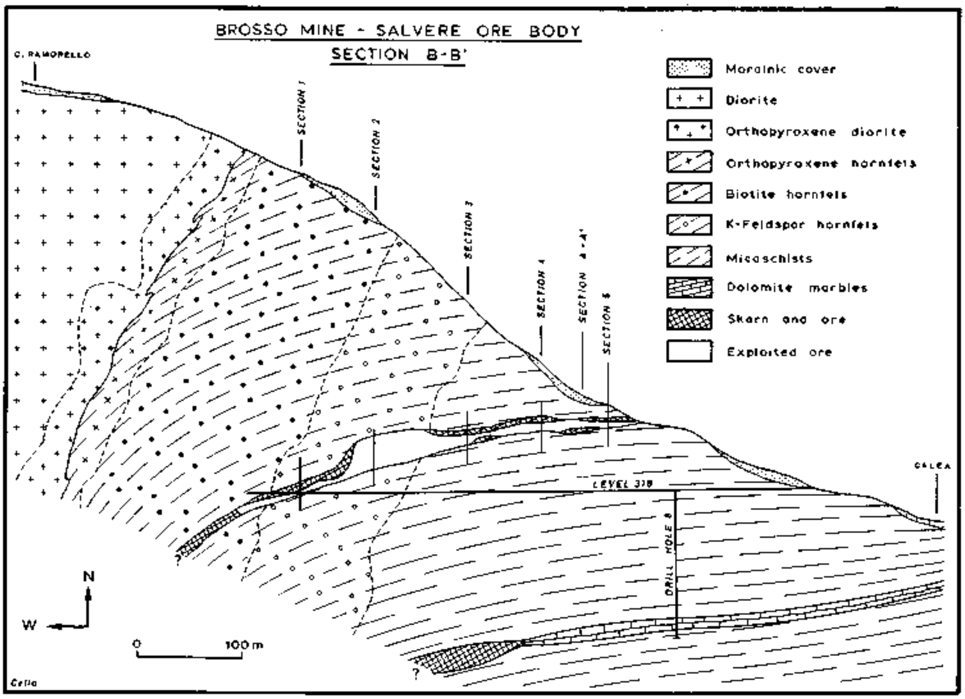

Fig. 3: Cross section parallel to the axial plane of the anticline in the Salvere orebody.

In the micaschists, at a distance of about 300 m from the pluton, the usual mineral assemblage formed by quartz, white mica, albite and garnet begins to change with a rapid increase in feldspar content (perthitic orthoclase, microcline, albite) in replacement of garnet and white mica.

Apatite and zircon become more abundant and tourmaline is sporadically present.

At about 200 m from the contact small biotite flakes appear, gradually increasing in size and frequency towards the contact.

With the increase of biotite content in the rock, the potassium feldspar becomes less frequent and disappears. At about 100 meter from the contact oligoclase is formed together with small scattered garnet crystals. Banded structures and schistosity begin to disappear. At immediate contact with the pluton, in a band 5 to 10 m wide, no more oriented structures are visible and andesine, hornblende and orthopyroxene are formed, together with biotite, while quartz and white mica become very scarce.

While it is possible to follow all the variations in the mineral assemblages within the micaschists, in the dolomite marbles the data are largely incomplete, at least in the Brosso area.

Apart from a small lense of wollastonite-pyroxene skarn occurring in the immediate proximity of the contact in the Assa Valley (q. 1000 a. m. s. L.), no skarn or marble are exposed near the pluton. Moreover the underground exploration of the carbonate horizons was pushed only to a minimum distance of about 200 m from the contact that is to the outer limit of the biotite zone in the micaschists (see fig. 3).

Therefore all the skarn known at Brosso belong to the outer contact aureola.

Nevertheless the contact phenomena in the dolomite marbles seem to be controlled more by local structural conditions than by the distance from the pluton.

Within the skarn zone the mineral assemblage varies to great extent, the variation being related to distinct tectonic and mineralizing episodes.

Because of the intimate genetic relationship, the resulting skarn and ore paragenesis will be described together.

The Ore Deposit

The ore mineralizations known and exploited in the Brosso area show distinctive features apparently dependent on the nature of the host rock and the distance on the pluton.

The following three types of ore, differing in structure, morphology and paragenesis, are present in the area:

1. quartz-arsenopyrite veins, with various amounts of associated sulfides, in the schists,
2. hematite-pyrite lenses in the marbles,
3. magnetite-pyrite bearing skarn masses in the marbles of the contact aureola.

The structural and morphological characters of the former two have already been described (Matteucci and Zucchetti 1962) (Bonacossa and Sclopis 1900, Novarese 1901) so that in this paper more attention is given to the latter and to the processes involved in ore deposition.

a) Quartz arsenopyrite veins

Several occurences of quartz-sulfide veins are known in the area of the Traversella pluton.

Two of them, mentioned by Novarese (1901) and Colomba (1915), are located within the intrusive body, near Vico Canavese, the others occurr in the micaschists surrounding the pluton especially in the north eastern sector, between Tavagnasco and Baio Dora, up to a distance of 4 km from the igneous stock.

In the Brosso mining area the most important mineralization of this type is the one called "Dey Mars", located 500 m to the east of Pratorotondo at 975 m a. m. s. l. and consisting of a network of small subvertical veins, directed N 70° E, and dipping to the north.

Quartz and arsenopyrite are the main constituents of the veins which often show a central band formed by siderite and calcite.

Associated with and often included in the arsenopyrite crystals are minor amounts of pyrite, sphalerite, galena, pyrrhotite, chalcopyrite, bournonite, tennantite and gold (Au 1.2 g/t, Ag 4 g/t in one sample).

The quartz sulfide veins occurring in the Montefiorito bank, near Baio Dora, 360 m a. m. s. l., show a similar paragenesis with the addition of bismuth.

The mineral assemblage is again the same in the Bariasso-Aquila deposit, near Tavagnasco, described by Matteucci and Zucchetti (1962).

In the authors'opinion the observed paragenesis indicates a hydrothermal origin of the deposit and a close genetic relationship to the Brosso and Traversella mineralizations. Setting aside for the moment the problem of the ore genesis, it should be noted that the most striking feature shown by the vein mineralizations is the absence of any significant variation in the observed paragenesis all over the area. All the ore mineralizations, independently from the distance from the pluton, appear to be formed during a single, well defined, mineralizing event occurrend in the same environmental conditions.

b) Hematite-pyrite lenses

The hematite-pyrite lenses scattered in the dolomite marbles intercalated in the micaschists formation have been the main ore exploited in the Brosso mine.

The ore bodies consist of irregular lense shaped masses especially extended along the contact between marbles and micaschists and reaching the maximum thickness and extension in correspondence of small faults directed from N 70° E to N 45° E and dipping towards the north (see fig. 1 and 2). The close relation between faulting and mineralization has been already recognized by the old miners who gave to any individual mineralizing fault a proper name and considered them as the best guide to mineralization³).

Bonacossa and Sclopis (1900) and Novarese (1901) describing in detail the relations between faults and ore bodies, confirmed the miners'opinion stating that the existence of a system of small faults cutting the carbonate horizons had been the main controlling factor in the mineralizing process. Very little can be added to the detailed description given by those Autors.

Since their time the hematite-pyrite ore bodies were worked out and many of them are now inaccessible for investigation. The few ore masses surveyed and sampled afterwards belong to the Salvere Ore Bodies (see. fig. 2) and show in any case identical morphology and structure as those described in the old mine.

The main constituents of the mineral assemblage are pyrite, hematite and quartz. Hematite is the first formed mineral and has later been partially replaced by magnetite (Mushketovitization).

Pyrite crystals seem to be grown around and inside the hematite plagues and show always small inclusions of pyrrhotite, chalcopyrite, sphalerite and galena. Sericite is commonly present in association with pyrite; hematite is, on the contrary, always associated with iron chlorite. Sphene is rather frequent, while scheelite is present only in traces.

Quartz forms often big euhedral crystals showing no traces of successive deformations.

All these minerals replace dull and deformed dolomite crystals associated with minor amounts of white micas, while calcite and siderite are the main constituents of the late formed carbonate veins cutting the ore.

Several other minerals described at Brosso (barite, Colomba 1906; fluorite, Peretti 1962; bismutinite, Artini 1915; bournonite, Grill 1914; etc.) probably belong to this paragenesis but were not observed in the studied samples. As for the vein mineralization, the main characteristic of the hematite-pyrite ore bodies is again the uniformity of paragenesis, structure and morphology all over the mining area, at least outside the contact aureola.

The areal dispersion of the ore bodies is limited by the reduced extension of the carbonate horizons, but in any case the occurrence of the ore within the individual dolomite marble banks is restricted to a rim of less then 0.7 km around the pluton.

It is again possible to postulate a single stage well defined mineralizing event but the environmental conditions seem to be very different from those existing during the formation of the quartz-arsenopyrite veins.

The more restricted distribution of the ore seems actually to point to the existence of a rather steep physico-chemical gradient between the pluton and the surrounding rocks.

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³) In the "old mine" (see. fig. 2) the names of the mineralizing faults were, from north to south, the following: Dey Mars, Quarziti, Tamolin o Tremolin, Bo, Dey, S. Giuseppe, Fortune, S. Maria.

Only some of them are represented in fig. 1 and 2.

c) Skarn related mineralization

As mentioned before, nearly all the recognised skarn occurrences are restricted the outer contact aureola and to the southern part of the Brosso mining area, where the underground exploration was pushed near to the contact with the intrusive.

In this area, within the "Salvere" carbonate horizon, ore and skarn minerals fully replace the dolomite marbles along the southern limb and along the axial zone of a small anticline, dipping towards the pluton (see fig. 3 and 4).

The skarn and ore masses are composed by a great number of minerals (over 40), belonging to superimposed mineral assemblages formed in different times and conditions. The resulting rocks are very complex and the minerographic study of the textural relations of the constituents is, alone, of little help in distinguishing the mineral assemblages formed at the various stages of the mineralizing process and in establishing their paragenetical sequence[4]).

Having in mind that any mineralizing episode should have had a proper structural character corresponding to proper environmental conditions, an attempt was made to study the distribution of any individual mineral in the tactite bank. To this purpose the whole thickness of the mineralized bank was sampled in a selected area roughly parallel to the anticline axis and to the contact between skarn and marbles.

Samples were collected along four sections, the first corresponding to the excavation front, the others to section 1, 2 and 3 shown in fig. 3.

The total area covered by sampling is about 120 m wide and 240 m long.

The scarce thickness (20 to 40 meters) and the regularity of the carbonate horizon proved to be an advantage allowing to plot the distribution patterns of the minerals on a two dimensional diagram simplifing the interpretation and the understanding of the results. The comparison between the distribution patterns so obtained for each mineral shows immediately that three distribution groups are present. Each group represents a distinct mineral assemblage with its own stability field and it is related to particular structural features.

Fortunately, direction and characteristics of the structures are different, the related mineral assemblages being only partially superimposed. Tectonic and mineralizing stages clearly show a temporal succession, the early formed assemblages being replaced by the subsequent ones.

The stability field of the various minerals of the same assemblage is often different, reflecting the variation of environmental conditions both in the same mineralizing stage and in the following ones.

The first mineralizing stage

The typical mineral association of the first mineralizing stage is formed by antigorite, brucite, chrysotile, graphite, humite, ludwigite, magnetite, olivine, pyrite I, szaibelyte.

The distribution fields of the main consituents of this assemblage are represented in fig. 5.

It can be noted that the original associtaion is preserved only on the southern limb and in the eastern part of the anticline while in the rest of the surveyed area it is completely or partially replaced by later formed mineral associations.

The folding of the marble bank seems to be the only tectonic feature conditioning the distribution of the minerals during the first mineralizing stage, the axial plane of the anticline being actually parallel to the contact between marble and skarn.

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[4]) Inadequacy of the textural relations between minerals, as shown in random sections of rocks, to express a significant paragenetical sequence was pointed out firstly by SHAND (1943).

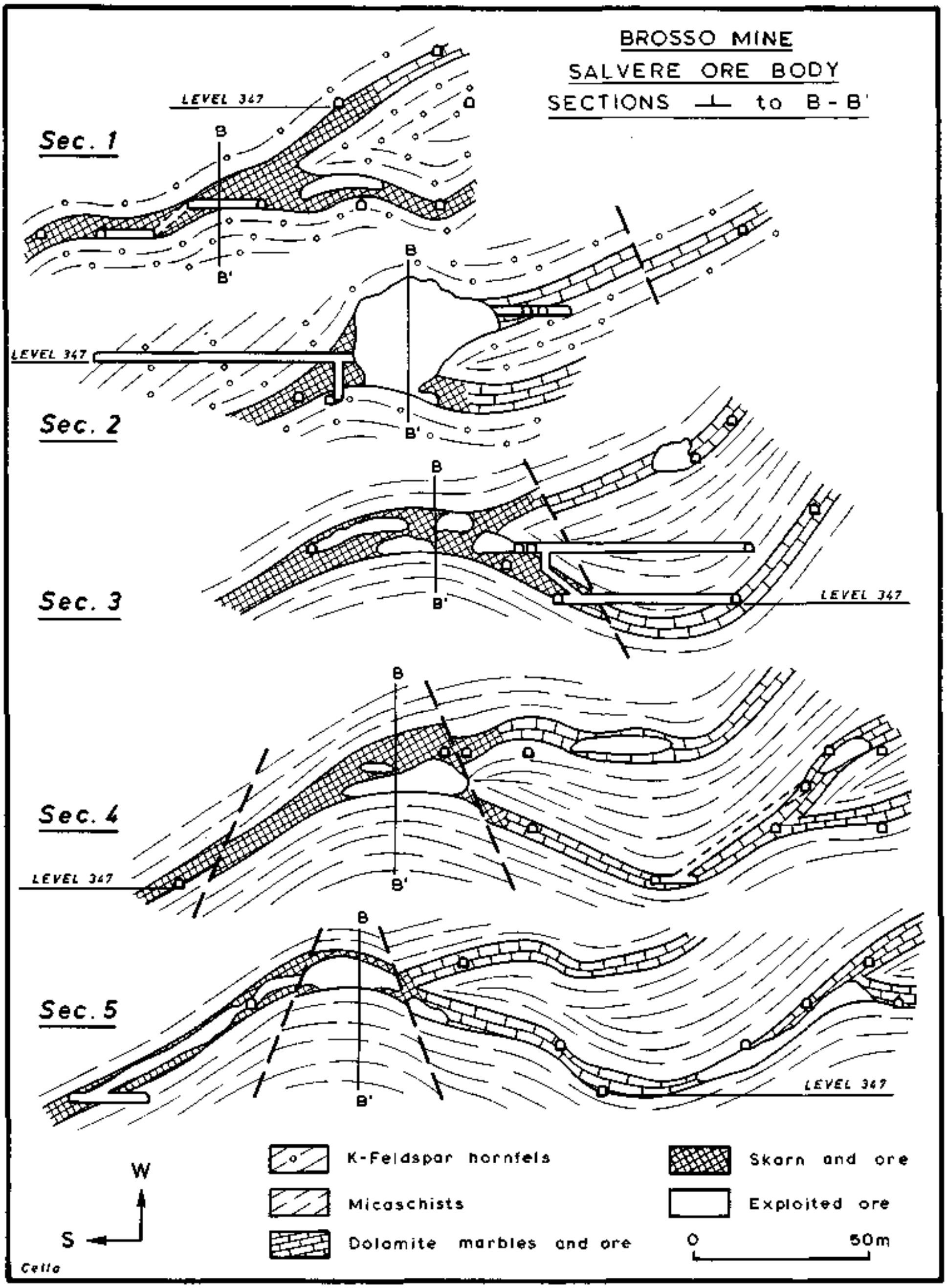
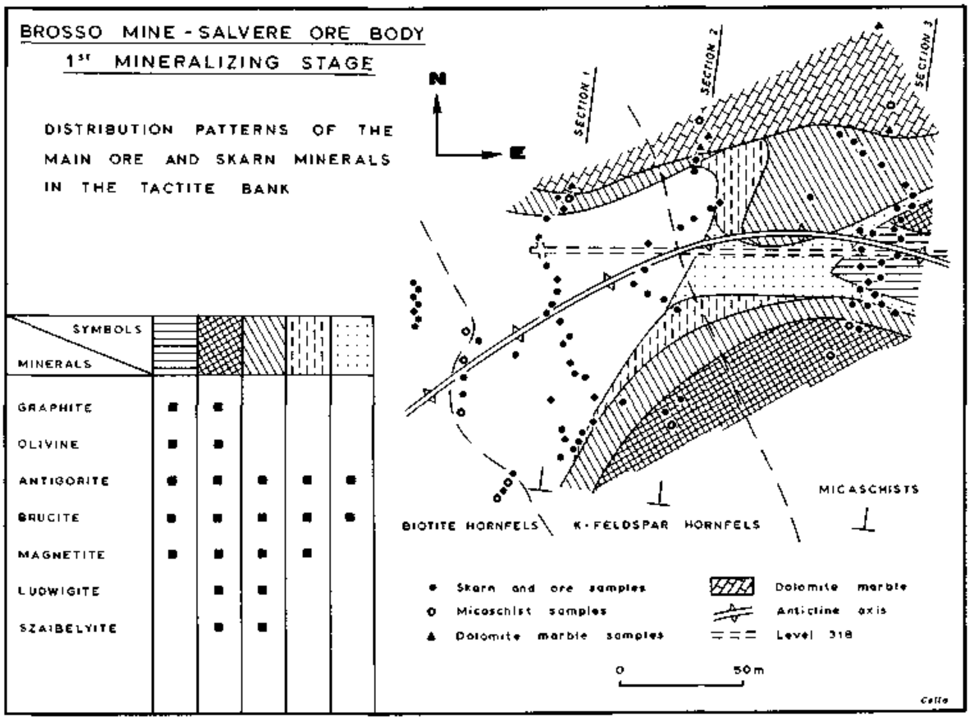


Fig. 4: Parallel cross section through the Slavere anticline.

The textural relationships shown by the ore and skarn minerals replacing the original dolomite allows the reconstruction of a good paragenetical sequence. Among the first formed minerals, olivine, ludwigite and brucite are the more abundant, a coloured variety of humite being only sporadically present.

Olivine is in composition near to forsterite and the central core of the ludwigite crystals is also formed by a nearly pure Mg borate while in the peripherical zone ferroludwigite (Mg 0.75, Fe 0,25) is present[5]). The large and tabular brucite crystals seem to be formed later than olivine and ludwigite. No trace of periclase relicts are to be found, the brucite appearing to have resulted from the direct conversion of dolomite.



SYMBOLS / MINERALS	▤	▦	▨	▥	⬚
GRAPHITE	■	■			
OLIVINE	■	■			
ANTIGORITE	■	■	■	■	■
BRUCITE	■	■	■	■	■
MAGNETITE	■	■	■	■	
LUDWIGITE		■	■		
SZAIBELYITE		■	■		

Fig. 5: Distribution patterns of the mineral assemblage of the first mineralizing stage.

Antigorite and szaibelyte are formed by hydration of olivine and ludwigite respectively. The hydration takes place together with the formation of magnetite.

Small amounts of chrysotile and pyrite are also formed at this point but the dominant mineral is magnetite which forms large plagues of zoned crystals often showing peripherical rythmic intergrowths with antigorite and szaibelyite.

Thin graphite flakes are commonly associated with the magnetite crystals or included along the ludwigite cleavage planes.

Two main steps, linked by gradual transformation of the environmental conditions, can be distinguished in the paragenetical sequence.

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[5]) More details on the mineralogy of the borate minerals have been given in a previous paper (GIUSSANI and VIGHI 1964).

At first, along a sharp boundary like the one dividing skarn and marbles, a rapid and total dissociation of the original dolomite has probably occurred by means of pore solutions in supercritical conditions carrying mainly silica, boron and iron.

The hydrodynamic pressure gradient estabilished when the gas rich igneous melt got in touch with the highly transmissible carbonate horizons could justify the migration of the solutions along the hinge of the folds to a great distance from the pluton, but concentration and chemical potential gradients were probably even more effective.

Crystallization of anhydrous Mg borates and silicates occurred simultaneously in a rather reducing environment. As temperature and/or pressure slowly decreased more Fe^{+2} entered in the borate structure and hydrated minerals such as brucite and humite were formed.

At this stage only less than one half of the original volume was occupied by a stable solid phase the rest being probably represented by metastable calcite, while CO_2 and possibly CO were removed.

A deep change seems to have taken place at this moment, suggesting that the critical point of the solutions could have been reached.

Large amounts of magnetite were formed while olivine and ludwigite did not appear to be any more stable in the new environmental conditions and were replaced by hydrated minerals such as antigorite and szaibelyte. The dissociation of the residual carbonate, represented by calcite, brought to the formation of graphite indicating that strongly reducing conditions existed. At the end of the process the new mineral assemblage, with a mean density of about 4.0, replaces entirely the dolomite ($d = 2.87$).

No apparent change in volume has occurred.

B, Fe, Si, S and traces of F were added; Ca and CO_2/CO were removed in solution.

The uniformity of the assemblage in the tactite bank and the isovolumetric character of the replacement seem to indicate that no effective temperature and pressure gradient existed at this stage around the pluton, the environmental conditions being similar to the one existing at rather high depth.

The second mineralizing stage

The main consistuents of the typical mineral association of the second mineralizing stage are, in order of abundance, pyrrhotite, hornblende, pyroxene, talc, amesite, chalcopyrite and sphalerite.

Minor amounts of ilmenite, penninite, galena and arsenopyrite are also nearly always present while bismuth, gold and molybdenite were only sporadically observed. The typical mineral assemblage is preserved only in the eastern part of the surveyed area (see fig. 6) while in the western part it has been almost completely replaced by later formed minerals. It can be noted that, wherever the assemblage is present, it clearly replaces completely the minerals formed during the first mineralizing stage with the exception of antigorite and brucite which appear to be more stable in the new environmental conditions than ludwigite, olivine, graphite, szaibelyte and magnetite.

The distribution patterns of the new formed mineral assemblage, with the addition of antigorite and brucite relicts, is restricted to two almost vertical narrow zones, few meters wide, cutting the whole thickness of the tactite bank but apparently not breaking through the surronding micaschists.

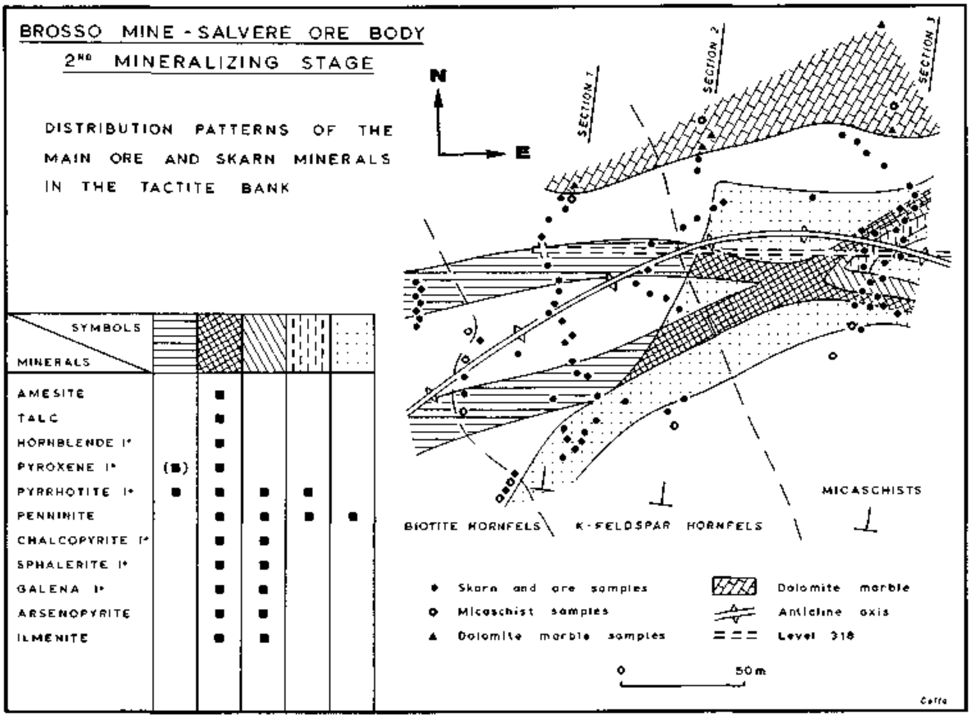
The continuity of the two zones in the western part of the area is marked by the presence of pyrrhotite and prismatic relicts of pyroxene included in the later formed quartz (see fig. 6).

The two mineralized zones seem to show a characteristic vein structure and to occurr along fractures oriented like the quartz-arsenopyrite veins known in the area.

However no defined boundaries are observed and the transition from the first mineral assemblage to the second one is gradual.

The textual relations between the various minerals show that sulfides and silicates were practically formed together.

In the central part of the vein-like zones a network of well formed prysmatic crystals of pyroxene is always present together with radial groups of elongated crystals of hornblende.



MINERALS \ SYMBOLS	▤	▩	▧	┆	⁚
AMESITE		■			
TALC		■			
HORNBLENDE I°		■			
PYROXENE I°	(■)	■			
PYRRHOTITE I°	■	■	■	■	
PENNINITE		■	■	■	■
CHALCOPYRITE I°		■	■		
SPHALERITE I°		■	■		
GALENA I°		■	■		
ARSENOPYRITE		■	■		
ILMENITE		■	■		

Fig. 6: Distribution patterns of the mineral assemblage of the second mineralizing stage.

Pyroxene is colourless, has rather large optic axial angle and high extinction angle and probably represents a magnesium rich member of the augite-diopside series. Hornblende is also colourless, optically negative, with a large axial angle and probably belongs to the tremolite-edenite series representing again a magnesium-aluminium rich variety.

Talc and a blueish green, strongly pleocroic and highly birefrigent variety of chlorite, near to amesite in composition, form large plagues grown around and clearly replacing antigorite and brucite.

Associated with talc and amesite are sometimes rounded individual crystals of a colourless mineral, which by its optical properties (2 V_z small, negative elongation, low birefrigence, good (001) cleavage, high refractive indices) could be doubtfully identified as topaz. Massive sulfides, represented mainly by pyrrhotite and chalcopyrite, form the ground mass in which the silicates are immersed.

Minute starlike particles of exsolved sphalerite are often present in the twinned chalcopyrite plagues. Fine equigranular intergrowths of pyrrhotite and sphalerite with associated galena and bismuth are rather frequent.

Arsenopyrite forms small idiomorphic crystal nests in the pyrrhotite mass in which isolated twinned grains of ilmenite are also present.

Gold-silver particles and molybdenite lamellae are very scarce but their presence was confirmed in some samples by analytical tests.

In the peripherical part of the vein-like zones, no horneblende, pyroxene and amesite are to be found. Pyrrhotite associated with small amounts of other sulfides forms an irregular rim around the magnetite crystals and penninite is formed around the brucite plagues as far as 20 meters from the vein-like zones. The total replacement of the mineral assemblage in equilibrium at the end of the first mineralizing stage is actually limited to narrow zones corresponding to fractures probably formed well after the end of the first mineralizing process.

The fracture zones, apparently limited to the tactite bank, are oriented along directions reflecting the post magmatic tectonic trend existing in the area. The migration of solutions has taken place mostly along the fracture zones and pore migration has been rather limited.

The new formed mineral assemblage shows that addition of Si, Al, Ca, Na, Pb, Zn, Cu and S plus minor amounts of Mo, Au, Ag, Ti, Bi has occurred while B and CO_2 were completly removed and some Fe was also probably driven away possibly in an oxidized form.

Again the transformation has taken place without significant change in volume.

The observed paragenesis suggests that crystallisation occurred in pneumatolytic conditions, the migrating fluids being probably again above the critical point. The absence of any subsequent trasformations of the new formed silicate minerals, the reduced extension of the penninite and sulfides halo around the fracture zones and the limited amount of ore formed at this stage, seems to point to a rapid evolution and exhaustion of the mineralizing phenomenon.

The third mineralizing stage

The former two mineralizing stages are characterised by the formation of mineral assemblages that appear to be, at least at the end of each stage, almost uniform all over the surveyed area.

The mineral assemblage formed during the third and last mineralizing stage is on the contrary very variable, the variations being in connection to the development of the contact aureole in the micaschists.

The distribution patterns of the minerals show that they are arranged along a wide belt directed to the north east and probably corresponding again to a fracture zone parallel to the local post magmatic tectonic trend. Inside that zone, calcite, dolomite, hematite, pyrite, chalcopyrite, sphalerite, galena and marcasite are ubiquitous.

Quartz, apatite, titanite and Fe-chlorites show on the contrary distribution patterns restricted to the central and western part of the belt (see fig. 7).

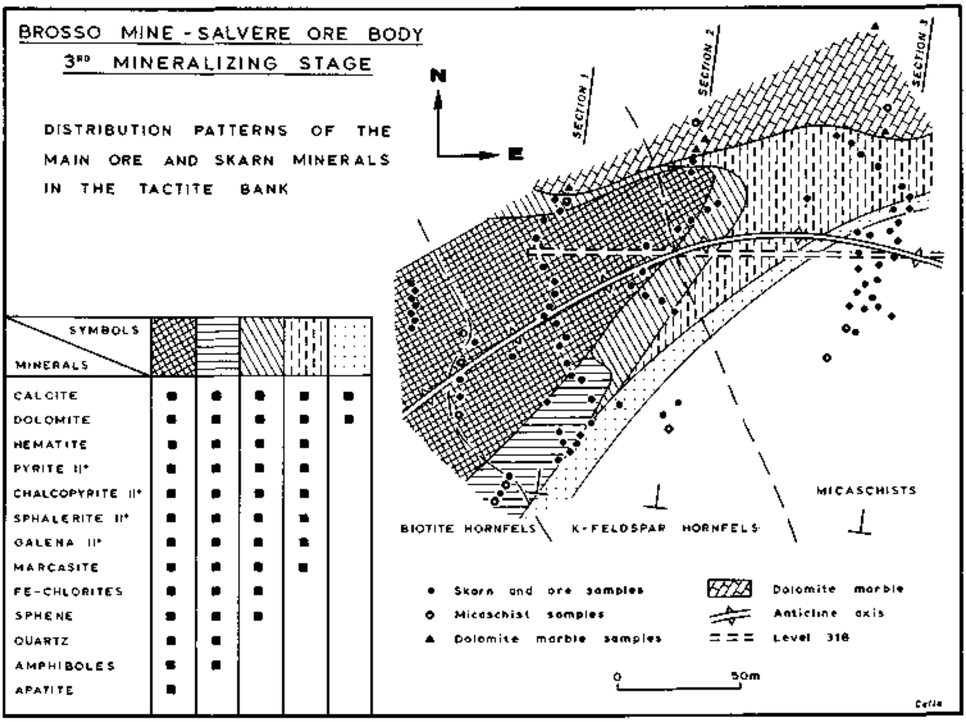
Pyroxene, garnet, epidote and different minerals of the amphibole group are associated with quartz, but they are clearly distributed within the quartz zone along bands parallel to the contact zoning in the micaschists (see fig. 8).

Small fibers of actinolite are disseminated all along the quartz zone and often immersed in the later formed sulfides.

A colourless orthorombic amphibole, probably near to gedrite in composition, forms radial aggregates of thin fibers, associated with actinolite all over the area with the exception of the extreme eastern portion, roughly corresponding to the limit of the contact aureola in the micaschists.

Epidote, near to pistacite in composition, is present in the western half of the quartz zone where it forms large plagues often in association with apatite and titanite.

Green hornblende, in stumpy prysmatic crystals, and altered crystals of pyroxene, probably a member of the augite-diopside series, are present in the western part of the quartz zone. The presence in the tactite bank, of new formed crystals of pyroxene and hornblende corresponds to the appearence of small biotite flakes in the surrounding schists and to the formation of garnet crystals near the contact tactite/micaschists. The dominant chlorite associated with the amphiboles in the quartz zone is represented by a yellow green pleochroic variety, optically negative, with anomalous blue-violet interference colours, probably indicating a rather high iron content.



MINERALS \ SYMBOLS	▩	▤	▧	▥	⁙
CALCITE	■	■	■	■	■
DOLOMITE	■	■	■	■	■
HEMATITE	■	■	■	■	
PYRITE II°	■	■	■	■	
CHALCOPYRITE II°	■	■	■	■	
SPHALERITE II°	■	■	■	■	
GALENA II°	■	■	■	■	
MARCASITE	■	■	■	■	
FE-CHLORITES	■	■	■		
SPHENE	■	■	■		
QUARTZ	■	■			
AMPHIBOLES	■	■			
APATITE	■				

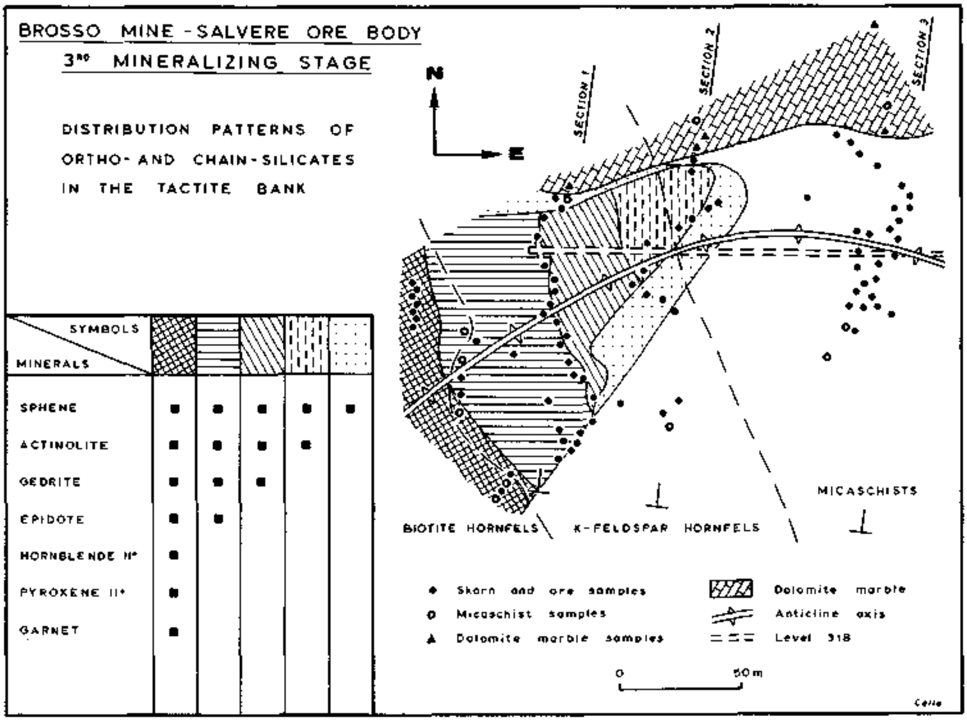
Fig. 7: Distribution patterns of the mineral assemblage of the third mineralizing stage.

A less coloured variety, weakly pleocroic, optically positive, with anomalous brown to red-violet interference colours, is often associated to the former expecially in the epidote zone.

The peripherical part of the quartz zone is characterised by the presence of a colourless chlorite, optically positive, showing olive-green to brown anomalous interference colours, probably representing a variety with a low iron content.

All the iron chlorites replace the early formed antigorite, brucite and penninite and are always associated with quartz and carbonates. Apatite and sphene are widespread in the assemblage, the former being often represented by fairly large idiomorphic crystals. The sulfides present in the quartz zone are represented mainly by pyrite in large zoned crystals, sometimes cataclastic, full of small inclusions of hematite, pyrrhotite, galena and chalcopyrite.

All the sulfide crystals show always a narrow peripherical rim formed by calcite and quartz and less frequently by dolomite or chlorite and they never appear to be in direct contact with the early formed pyroxene and amphiboles, with the only exception of actinolite.



MINERALS \ SYMBOLS	▩	☰	▨	⦙	⁚
SPHENE	■	■	■	■	■
ACTINOLITE	■	■	■	■	
GEDRITE	■	■	■		
EPIDOTE	■	■			
HORNBLENDE II°	■				
PYROXENE II°	■				
GARNET	■				

Fig. 8: Mineralogical zoning in the mineral assemblage of the third mineralizing stage.

Magnetite and brucite are the only minerals among the ones formed during the first mineralizing stage to be still present sometimes as relics or inclusions in the pyrite crystals of the quartz zone.

Some of the minerals formed during the second mineralizing stage are also present as relics.

Among them, the most significant are the skeletal prismatic relics of pyroxene crystals included in the quartz and dolomite plagues and the idiomorphic tables of ilmenite included in the pyrite crystals often only partially replaced by sphene and titanium oxides.

The distinction between the different generations of pyrite, pyrrhotite, chalcopyrite, sphalerite and galena is not always easy to attain.

The determination of the paragenetical sequence only based on textural relations actually gives doubtful results.

Pyrrhotite for instance appears to be replaced by and included in the pyrite crystals but it is also present, together with calcite, galena, marcasite, hematite and sometimes also magnetite, in the last formed veins cutting the cataclastic pyrite crystals.

Chalcopyrite formed during the third mineralizing stage can be distinguished from the one formed before by means of small inclusions of cubanite often present at least in the garnet pyroxene zone and by the few sphalerite exolutions and twinning lamellae. Hematite is rather scarce, only present as inclusion in the pyrite crystals or as filling of the later formed fractures and it is quite often partially transformed in magnetite.

Traces of scheelite are also present, but only in the quartz zone, that is in the central part of the assemblage.

The carbonates are the only gangue minerals present outside the quartz zone.

They are disseminated, together with the ore minerals, along the border and in the north eastern part of the area occupied by the third stage mineral assemblage and appear to be always associated with most of the minerals formed during the first mineralizing stage (see fig. 5 and 7).

Only olivine and graphite do not appear to be stable in the presence of the carbonates. Ludwigite, szaibelyte, magnetite, antigorite and brucite are on the contrary only partially replaced, the ludwigite crystals being often transformed into szaibelyte[6]). A partial recrystallization of the early formed magnetite has also probably occurred at this stage together with the formation of large and limpid dolomite crystals. The typical rim of calcite, dolomite and quartz surrounding the ore minerals in the quartz zone is present also in the carbonate zone but szaibelyite is present in replacement of quartz.

Considering for simplicity only the western and central part of the third stage mineral assemblage, the following considerations can be drawn:

– the replacement of the early formed mineral assemblages has been total, no one of the ancient minerals appearing to be stable in the new evironmental conditions,

– addition of Fe, Cu, Zn, Ca, Al, Si, CO_2 and S has probably occurred with removal of some B and may be also Mg,

– if no magnesium has been removed in solution, a great increase in volume, ranging from 100% to 140%, should be expected.

The comparision between the shape of the tactite bank shown in fig. 3 and 4 and the distribution patterns of the third stage minerals seems to confirm this assumption, at least partially,

– silicates like pyroxene, garnet and amphiboles seem to have been formed before the ore minerals and together with the hornfels minerals such as biotite and K-feldspar,

– the mineral zoning and the volume increase observed during the last mineralizing stage suggest the existence of an effective pressure and temperature gradient between the pluton and the surrounding rocks such as the one that could be expected at shallow depth.

The existence of fracture zones seems to be an essential factor conditioning the migration of the mineralizing fluids, but the mineralizing phenomenon appears to have persisted over a long period of time allowing also pore migration of the solutions in a wide zone around the fractures.

Ore Genesis in Relation to Orogeny and Magmatic Evolution

The study of skarn and ore paragenesis based upon the distribution patterns of the various minerals has yielded much information as to the order in which mineral assemblages were formed during the mineralizing process. The early formation in the tactite bank of silicates of Mg and Fe, then of silicates containing Ca, Al, and Na and finally of free silica

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[6]) The process of transormation of the ludwigite crystals into szaibelyite, camsellite, hematite, magnetite and brucite, that has been previously described in detail (Giussani and Vighi 1964), seems to occurr during the third mineralizing stage.

reminds us of the classical Bowen'series of crystallization arranged in order of increasing silica content and points to the existence of a direct genetic link between fractional crystallization of the magma and ore mineralization.

On the basis of the existing data a partial reconstruction of the relations between emplacement and cooling of the pluton and mineralizing phenomena may be attempted. Furthemore, the rather well known regional geological and structural setting and the geochemical investigations carried out on the Biella and Traversella plutons mainly by Fiorentini Potenzá, allow us to advances some hypothesis on the genesis of the magmatic rocks in relation to the orogenetic evolution of the Alpine belt.

A critical revision of the existing literature and a discussion of the last tectonic models of the Sesia-Lanzo zone metamorphism has been recently presented at the Genova meeting on the high pressure low temperature metamorphism of the oeceanic and continental crust in the western Alps (see COMPAGNONI and others 1977).

The conclusions drawn by the Anthors reflect the present rapid evolution of knowledge on the distribution and characteristic of Alpine metamorphism.

The related geodynamic models of the Alpine orogenic hystory appear in turn to be "... too simple to explain the complexity of the Alpine tectonic and metamorphic evolution" (COMPAGNONI and others 1977).

For what concerns the geodynamic significance of the Alpine magmatism in the western Alps, many problems are still unsolved and more work on geochemistry and geochromology of the intrusive and extrusive Alpine igneous rocks is needed.

The existing data suggest a close relation between the genesis of the magma and the subduction of the oceanic crust formed in the Piedmont basin, the magma possibly resulting from partial melting of the upper mantle material overlying the Benioff plane.

The geochemical character of the Biella and Traversella plutons seems to suggest a possible derivation from a parent magma of similar origin[7]).

However the distribution of the intrusive and extrusive igneous rocks on both sides of the Canavese line[8]) is still a major tectonic problem.

This peculiar distribution could be related to the reversal of the subduction movements that dragged back towards the surface the high pressure low temperature mineral assemblages of the Sesia-Lanzo Zone (HUNZIKER 1974) but also to an Oligocene subduction phase of a more external basin. In any case the rise of the magma and the emplacement of the plutons has probably occurred during the last metamorphic event, in coincidence with the extensive folding of the nappe pile.

Later on, since Oligocene, a general uplift of the northern block occurred along a plane represented by the Canavese Line.

As a consequence of uplift and erosion, the intrusive melts were rised towards the surface and transferred to mesoepyzonal conditions where the cooling of the magma began. The distensive tectonic phase allowed the extrusion along tectonic boundaries of the andesite lavas actually represented by the Biella effusive series and by the porphyrite dykes clearly formed before the emplacement and cooling of the plutons.

The absence of any trace of metamorphic adjustment both in the effusive and in the intrusive rocks seems to show that no further significant movements have taken place after-

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[7]) In the opinion of CESANA, DEMONTE and VENEGONI (1976) the association in the Traversella and Biella plutons of large cations like Ba, Pb and Rb with K-feldspar, U and Th indicates "... an undoubted character of residual system ... of an hybrid magma" derived from partial mixing between light alkaline and basaltic melts.

[8]) The presence of an Alpine Tonalite south of the Canavese line is described by CARRARO and FERRARA (1968).

wards, apart from a gradual general uplift accompanied by a late postmagmatic distensive faulting.

Nevertheless the upwards movement of the magma went on also after the extrusion and cooling of the andesite dykes, probably mainly by means of assimilation and digestion of the surrounding rocks (FIORENTINI POTENZA 1969). Assimilation and contact metamorphism of the andesite dykes itself have been actually observed.

The contact aureola around the pluton should have been at this stage restricted to a very narrow zone, the low termal conductivity and scarce permeability of the micaschists, combined with the assimilation rate, being the main limiting factors. As the igneous melt got in touch with the highly transmissible carbonate horizons intercalated in the micaschists, a physicochemical gradient was estabilished and the first mineralizing stage began.

At this point the crystallization of the igneous melt was certainly far from complete and the first mineral assemblage formed in the marbles was probably limited to a narrow reaction rim of pyroxene-wollastonite-garnet skarn like the ones found at immediate contact with the pluton in the Assa valley.

Later on, the peripherical part of the pluton began to crystallize and a residual gas phase, slowly migrating along the top of the structures in the carbonate horizons, was developed.

Pore migration and dissolution of the carbonates are the main processes that can be envisaged to explain the ion transfer taking place during the first mineralizing stage. Confining pressure seems to have had a minor role in the migration of fluids, the ion exchange being probably controlled by the existence of stark concentration and chemical potential gradients between the components of the igneous melt and the ones of the high transmissible carbonate horizons.

The composition of the first formed mineral assemblage suggests that the migrating solutions were in supercritical conditions, the critical temperature being possibly reached only towards the end of the process.

Strongly reducing conditions and total absence in the paragenesis of rare metals are characteristic of the first mineralizing stage and seem to suggest that a scarcely differentiated fluid phase existed at this point in equilibrium with the partially consolidated magma, at least near the border of the intrusion.

Furthermore the apparent lack of influence of pressure and temperature gradient suggests that the mineral assemblage was formed at rather high depth but in the absence of data on the inner contact zone this hypothesis is not sufficiently supported by evidence.

The end of the first mineralizing stage was probably brought about by the total consolidation of the peripherical part of the pluton no further exchange being possible between the molten core of the intrusion and the surrounding rocks. The crystallization of the magma in the inner part of the pluton⁹) brought to the successive development of a low melting liquid fraction in which volatile components and rare elements were contained.

The cooling of this fraction originated a sequence of overlapping phenomena depending upon the development of a succession of changing fluid phases. The formation of aplites and pegmatites, the late K-Na feldspathization of the early formed intrusive facies, possibly occurred along with U and Th mineralization (FIORENTINI POTENZA 1959 a 1959 b), the metasomatic exchanges between the pluton and the country rocks along fracture zones and all the related phenomena (FIORENTINI POTENZA 1960, 1961 d) could have occurred at this stage of the magmatic evolution.

Much more detailed investigations are needed to fully understand the relations between the metasomatic phenomena and the ore mineralizations formed in this phase.

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⁹) The existence in the central part of the Biella pluton of "an ummixed granitic melt" has been postulated by CESANA and other (1976) also on the basis of geochemical evidences.

In any case both the second mineralizing stage in the tactite bank and the quartz-arsenopyrite veins in the intrusive body and in the micaschists clearly belong to a probably late stage of this phase of the magmatic evolution. The most significant factor supporting this attribution is the presence of rare metals in both parageneses but also the wide areal dispersion, the pneumatolytic character and the apparently short time of formation of the mineral assemblages seem to relate the ore mineralizations to a sudden liberation of residual solutions contained at high confining pressure in the igneous body. The establishment of a tension field in the area and the consequent formation of distensive fractures has been apparently the direct cause of the release of the mineralizing fluids. Strongly oxidizing conditions and presence in the mineralizing fluids of metal like Cu, Zn, Pb, Bi, As, Ti, Mo, Au, Ag are actually characteristic of the second mineralizing stage in the tactite' bank.

A remarkable feature is also the nearly total absence of iron in the silicates, represented by Na, Ca, Mg, Al varieties.

The silicates were formed well beyond the limits of the contact aureola, still slowly developing in the micaschist, but were not observed in the ore veins, where only free silica is present.

The differences between skarn and vein parageneses seem to prove the existence, during the second mineralizing stage, of an effective thermal gradient. The rocks surrounding the pluton were subjected to a relatively rapid cooling as the depth gradually decreased, while convection movements kept the temperature to a high level within the pluton.

The difference in temperatures seems to have been even exalted during the third mineralizing stage.

The last mineral assemblage formed in the tactite bank shows actually a clear mineral zoning, parallel to the one existing within the micaschists inside the contact aureola.

The comparable exstension of the effect of the thermal gradient both in the micaschist and in the tactite bank seems to indicate that the present extension of the contact aureola was reached only at this stage or shortly before.

Outside the contact zone pyrite-hematite mineralizations were formed at the same time as the third mineral assemblage in the tactite bank, the ion transfer involved in the replacement being in both cases almost the same.

Hydrotermal solutions, slowly migrating along new formed fractures and permeating to a certain extent the surrounding rocks, have been in both cases the mineralizing agent. The perfect adjustement of the thermal state of the fluids to the one existing in the country rocks seems to indicate a slow migration rate and a far origin of the hydrothermal solutions.

The last mineralizing process appear to be in some way more related to the evolution of crystallization in the deepest part of the intrusion than to a final stage of crystallization of the apical zone.

The presence of scheelite in both the final parageneses, seems to support this interpretation, the W being possibly derived from leaching of Paleozoic horizons existing at depth (MAUCHER 1965, BRIGO and OMENETTO 1974).

The source of the main ore metals should on the contrary be related to the origin of the magma, probably derived from melting of primary upper mantle material.

In this respect the ore mineralizations in the Brosso and Traversella area and the one lesser known related to the Biella pluton [10]) may be considered as belonging to the Tethyan Eurasian Metallogenic Belt recently recognized and described by JANKOVIC (1977).

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[10]) The presence of Cu-Mo deposits inside the Biella pluton was first mentioned to my knowledge by FIORENTINI POTENZA (1959) but it was not object of any specific study.

The minerogenetical character of the ore deposits, the existing regional geotectonical control, the age, evolution and geochemical character of the intrusive and effusive cycle prove to my opinion beyond any doubt the validity of this attribution.

On that basis it could be assumed that the metallogenic belt is extended from the Carpatian Province through the Alpine one and probably also further to the south, through Tuscany.

The economic implications of this assumption are not to be underestimated.

Mining explorations methods and objectives should be reconsidered in the Alpine region as a whole. For instance in the light of this hypothesis, the Tertiary basic volcanic province, generally extending on both sides of the Insubric Line, assumes a new significance.

For what concerns the Traversella pluton it should be noted that many of the observed features like the low grade hydrothermal alteration of some intrusive apophysis (Canepari and Fiorentini Potenza 1961) and the late K-feldspar formation accompanied by hydrothermal alteration phenomena, show a striking resemblance to the argillitic and potassium silicate alteration accompanying many of the known porphyry copper deposits (Lowell and Guilbert 1970; Sillitoe 1973).

No reliable data are now available on the possible existence oflow grade ore in this area, but the need of more detalied investigations and exploration is in my opinion largely justified on the basis of the existing data.

Conclusion

In the proposed model of the evolution of the orogenic and magmatic cycle and of the formation of the related ore mineralizations, the questions posed are much more than the answers given.

Many of the advanced interpretations, as for instance the one relating the genesis of the metasomatic magnetite ore bodies to a "prepegmatitic" mineralizing stage, could be discussed adequately only in the light of estabilished chemical and thermodynamical principles and of experimentally determined data.

This was clearly beyond the original purpose of the present study that was oriented to the collection of all the data needed to open possibly new perspectives to mining exploration in the area.

I hope to have accomplished at least this task.

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