The Deposits of Argentiferous Galena within the Bellerophon Formation (Upper Permian) of the Southern Alps*

Carlo Brusca, Gabor Dessau, M. Leroy Jensen, and *Giuliano Perna*

1. Introduction

During the past several years we have been engaged in the study of the argentiferous galena deposits of the Bellerophon formation. Our main results are included in this paper, while a more detailed paper is in preparation.

There are two main hypotheses on the origin of these deposits: a magmatic-hydrothermal genesis, with metasomatic replacement of a sedimentary matrix (Pošepný, 1880; Andreatta, 1949; di Colbertaldo-Nardin, 1964; Morteani, 1965); and a sedimentary genesis, probably exhalative-sedimentary (Canaval, 1912; Trener, 1914; Tornquist, 1931; Münch, 1958; Maucher, 1959). For the discussion of the literature we refer to a paper by Dessau and Perna (1968).

2. The geological background

In the Bolzano area the "Bozen porphyric platform", a complex series of acid extrusive rocks of Permian age**, rests on the crystalline basement and reaches a thickness of over 2000 metres. At increasing distances from the centre the thickness decreases, as it is evident from the isopach map (Baccos, Brondi, Perna, 1971; from this paper Fig. 1 is reproduced).

The sedimentary series, which lies upon the "Bozen porphyric platform", begins with the "Grödener sandstone" (Middle Permian), which has a greater area and its maximum thickness in the Judicarian Alps to the SW, and in Carnia to the east. Another area where it attains a great thickness is at the centre of the Porphyric platform, where it is depressed because of volcano-tectonic collapse (Baccos, Brondi, Perna, 1971; Fig. 1).

* Research carried out with the financial assistance of the Italian Council of Scientific Research and of the Autonomous Region Trentino-Alto Adige, and of the Laboratory of Isotopic Geology, University of Utah, Salt Lake City, Utah.

** In the following, for the sake of brevity, often called "Porphyric platform", "porphyric rocks" or "Porphyries".

The continental and deltaic surroundings, in which the Grödener sandstone was deposited, change to a partly lagoonal and partly shallow marine environment with the Bellerophon formation (Isopach and ore deposit map, Fig. 2). It reaches its greatest thickness in Carnia, where it is possible to distinguish (S e l l i , 1963) three complexes: the lower one composed of gypsum, argillite, marl, marly breccia, cellular dolomite; the middle one mainly of cellular marly breccia with dolomitic cement and of cellular dolomite with intercalated marly beds; and the upper one of dark grey, slightly bituminous, well stratified limestone. The thickness decreases westward, where it changes to the so-called "Badiota facies" (A c c o r d i , 1958, 1959), composed in its lower part of marl and gypsiferous sandstone, whereas its upper part is of neritic facies, with beds of bituminous limestone, marl, and dark grey limestone.

Towards its western end, where its thickness is decreasing gradually to nil, the Bellerophon formation is of "Fiemmazza facies": above the cellular dolomite and the gypsiferous sandstone of the lower complex, there are thick layers of calcareous dolomite with beds of oölitic texture, deposited in a lagoonal-evaporitic environment, as confirmed by small lenses of gypsum and tiny idiomorphous quartz crystals.

This description, drawn mainly from the geological literature, is very much generalized. There are obviously varieties and exceptions, as can be expected in the case of continental, lagoonal and shallow sea sediments, transgressive over a continent of strong relief. In Chapter 4 we shall describe in detail a local series of reduced thickness, belonging to the "Fiemmazza facies".

3. The ore deposits

Within the boundaries of Italy, rare and insignificant mineral occurrences are known also in places where the Bellerophon formation has considerable thickness. But the two areas of main interest, as the seat of important mining in the past and of recent exploratory activity, are those north-east of Trento (Monte Calisio and Lavís) and of the upper Val di Non, near Provès and Marcena, where the Bellerophon formation, in "Fiemmazza facies", has a thickness of not more than 50 metres (Fig. 2). In Slovenia, mineralization is evident within the Bellerophon formation, and from the limited bibliography we had at our disposal, we estimate that the paleogeographic situation may be similar to that prevailing in the Trento area.

The Italian deposits have been exploited for argentiferous galena, which is accompanied by chalcopyrite, pyrite and marcasite, probably As-rich fahlerz, all very scarce. The sphalerite is always anhedral and sometimes shows concretionary textures. It is characterized by a very low iron content, as revealed by the light-coloured internal reflexes and by the spectrographic analyses. A sulphosalt is found in trace amounts, most probably a lead sulphoantimonite, as confirmed by the optical characteristics and by the trace elements detected when analyzing the galena. Only at Transacqua is a sulphosalt important, which has been

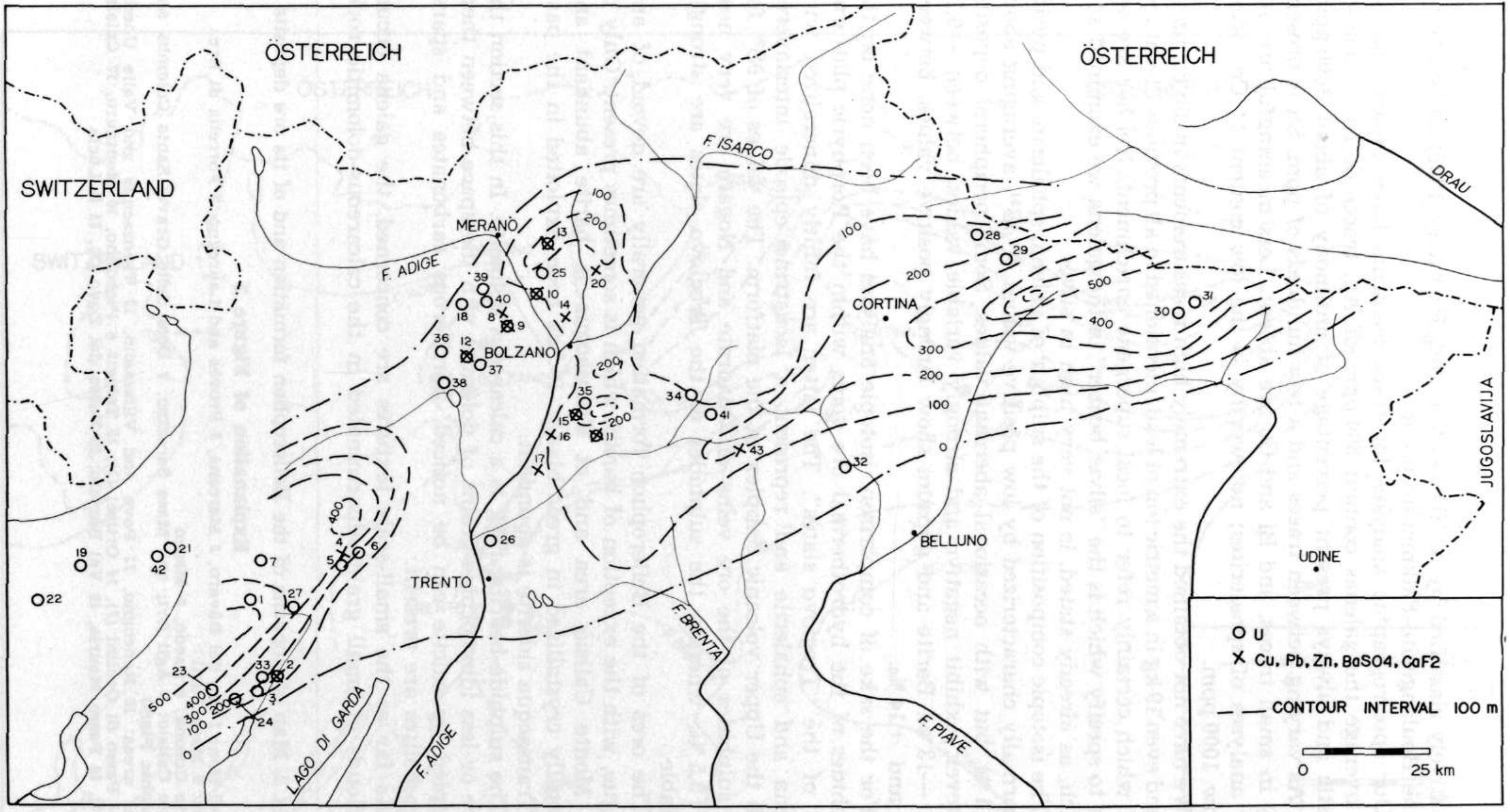


Fig. 1. Isopachs of the "Grödener sandstone" and of its mineral deposits

tentatively classified by us (Dessau and Perna, 1968) as belonging to the Boulangerite-Falkmanite group.

Our spectrographic analyses for trace elements have shown that on the average the galenas contain 800 ppm of Ag, traces of Ni, a characteristic and always present percentage of antimony of about 3000 ppm, and As varying between traces and a few hundreds of ppm. Sn is present only in small traces, and Bi and Co are absent. Less meaningful are our few analyses of sphalerites; noteworthy is the low content of Cd, often below 1000 ppm.

We have not obtained the extremely high measurements in silver, up to 10 and even 19 kg in a metric ton of lead, mentioned in all previous literature, and which certainly refer to local supergene enrichment. Neither are we able to specify which is the "silver bearer" in the galena we examined and which, as already stated, is not very high in silver.

The isotopic composition of the sulphur of galena, sphalerite and pyrite is normally characterized by low positive values of δS^{34}, averaging about +2,5 ‰, but with occasional aberrant values. Some peripheral deposits, however, exhibit negative and strongly variable values, between —0,10 and —13 ‰. Barite and gypsum show strongly positive values, between +9 and +14 ‰.

For the sake of comparison, isotopic analyses have been done on the sulphides of the hydrothermal ore veins within the Porphyric platform, and of the "Tregiovo slates". The latter are faintly mineralized with galena and sphalerite and represent a lacustrine episode interlayered with the Upper volcanic complex of the platform. The values of δS^{34} for the sulphides of the ore veins of Quadrate and Nogarè are very near to +5,5 ‰, whereas the sulphides of the Tregiovo slates are strongly variable.

The ores of the Bellerophon formation generally are devoid of any gangue, with the exception of barite, which is sometimes present. Only in the Monte Calisio area and at Transacqua is barite abundant and generally crystallized in great blades. It has been exploited in the past. At Transacqua siderite is abundant.

The sulphide-bearing rock is a calcareous dolomite. In this section the more or less idiomorphic grains of dolomite vith the space between them occupied by calcite can be noticed. Ferriferous carbonates and sparse large oölites are present.

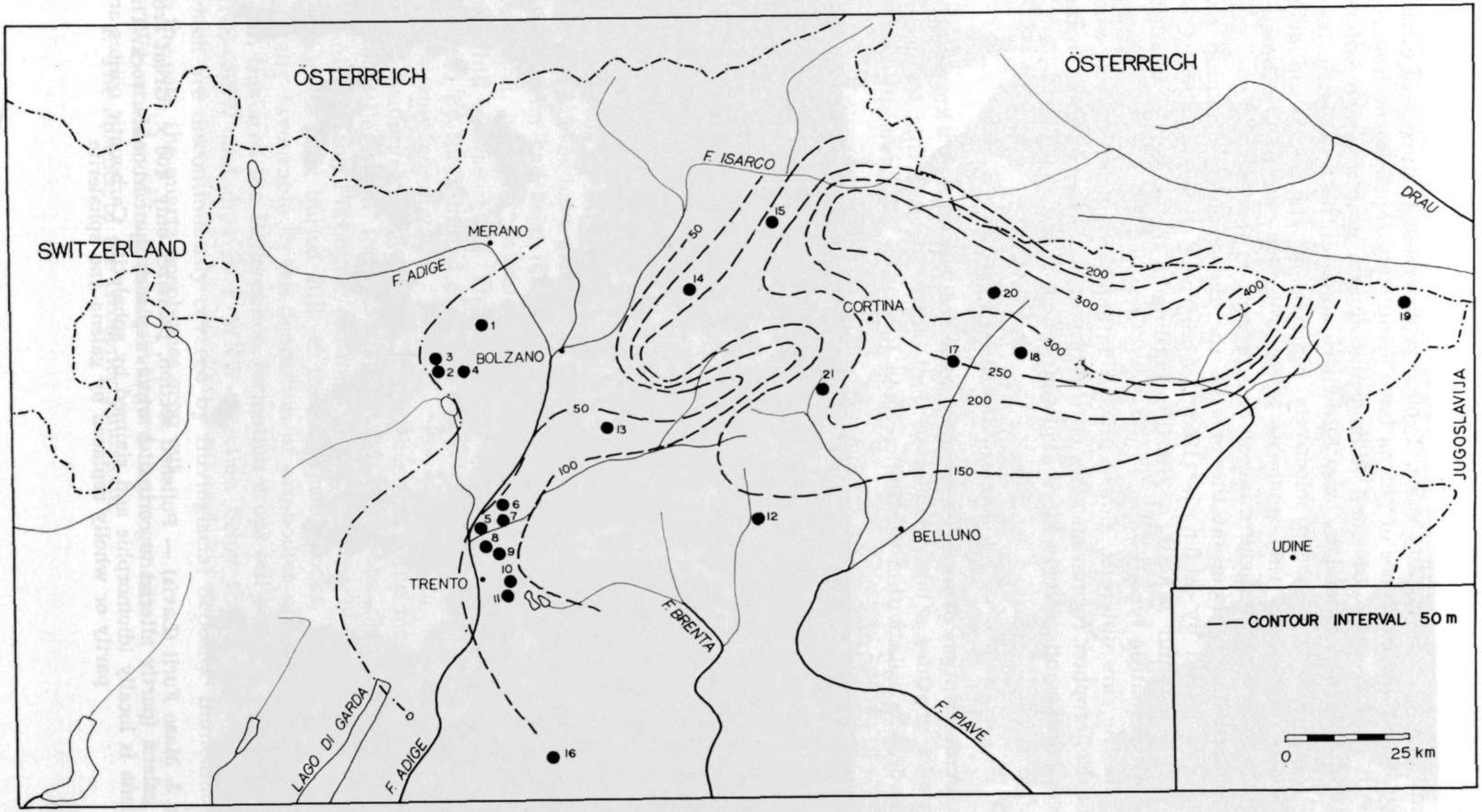
As far as the small-scale textures are concerned, the galena occurs in clouds of small grains disseminated in the calcareous-dolomitic rock,

---

Fig. 2. Map of isopachs of the Bellerophon formation and of its ore deposits

Explanation of Figure 2

Val di Non: *1* Rio del Bàvaro, *2* Marcena, *3* Provès and Lauregno, *4* Forcella di Brez
Lavís: *5* Maso Furli
Monte Corona: *6* Faedo, *7* Masèn
Monte Calisio: *8* Agli Orti and Maso Saracino, *9* Doss delle Grave, Santa Colomba and Monte Piano
Other areas: *10* Roncogno, *11* Povo and Villazzano, *12* Transacqua and Valle Uneda, *13* Passo di Occlini (?), *14* Ortisei (?), *15* Telpeit e Piccolino, *16* Montàuro, *17* Calalzo (?), *18* Passo Mauria, *19* Val Bàrtolo, *20* Passo del Zovo (?), *21* S. Lucia



ÖSTERREICH
ÖSTERREICH
SWITZERLAND
JUGOSLAVIJA
MERANO
BOLZANO
TRENTO
CORTINA
BELLUNO
UDINE
F. ADIGE
F. ISARCO
F. BRENTA
F. PIAVE
DRAU
LAGO DI GARDA
F. ADIGE
50
50
100
150
200
250
300
300
200
400
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
CONTOUR INTERVAL 50 m
0
25 km

and in tiny cross-cutting veins. Typical replacement textures are evident. Relatively big expanses of galena have completely replaced the host rock, with the exception of small idiomorphic quartz grains, which are now completely surrounded by ore. Elsewhere some of the concentric layers of the oölites have been selectively replaced by sphalerite and galena (Fig. 3). Sometimes the sphalerite appears to be definitely subsequent to the galena. Supergene minerals are present in traces.

Microscopic studies on the ores of the Bellerophon formation have been published by Münch (1958), Maucher (1959) and di Colbertaldo and Nardin (1964); according to the latter the sphalerite is of marmatitic type.

In the rare outcrops, almost always without economic interest, where the Bellerophon formation rests on the phyllites of the basement, copper ores seem comparatively more abundant.

4. The ore deposit of Lavís

A description of an area recently explored, near Lavís 9 km south of Trento, provides a better understanding of the characteristic features of the ore deposits within the Bellerophon formation. At Lavís, the Società

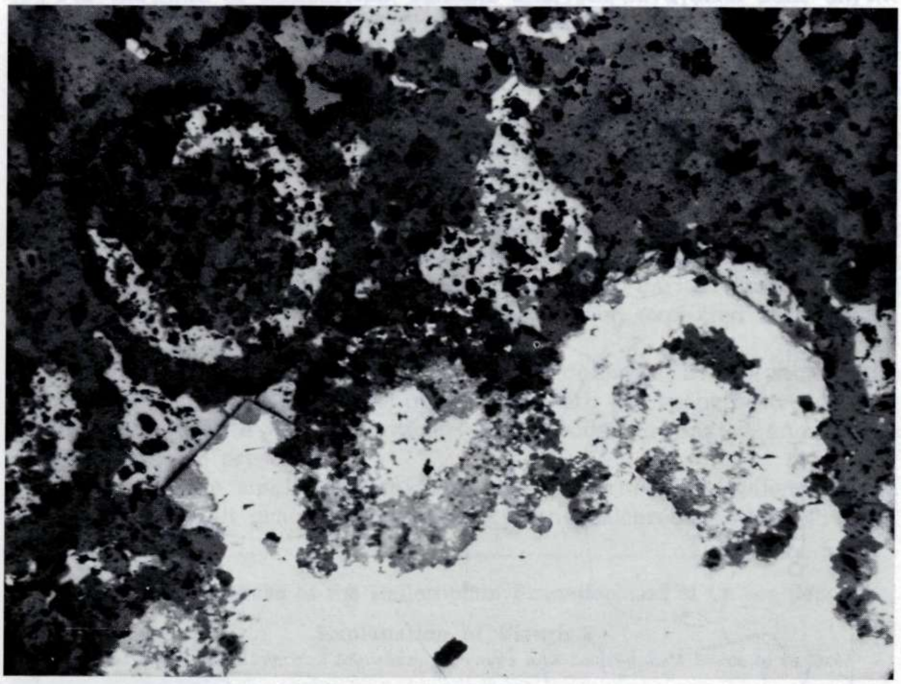


Fig. 3. Maso Furli (Lavís) — Polished section, polarizer only, 100 ×. Great area of galena (partly altered to cerussite) which replaces the carbonatic rock. The galena is locally idiomorphic and rimmed by sphalerite. Carbonatic oölites are partly or wholly replaced by galena and sphalerite

Fig. 4. Monte Rosà — Conglomerate of porphyric gravel cemented by iron-bearing dolomite, and transgressive on the Bellerophon formation

Mineraria e Metallurgica di Pertusola has carried out, during the years 1967 and 1968, a detailed geological survey, followed by a drilling program (14 holes with continuous coring and 27 with recovery of the cuttings), and finally by an ore-dressing test on 200 tons of material. Unfortunately the low reserves have prevented further developments.

Attention had been drawn to this area by an outcrop of Bellerophon formation, carrying galena and sphalerite, on the eastern flank of the small hill of Maso Furli. This area corresponds to a paleogeographic high, disclosed by the thinning of all Permo-Triassic sediments from the transgression surface upwards.

The leading hypothesis has indeed been that the metallic ions found in the Bellerophon formation originated from the degradation of the volcanics of the Porphyric platform; thus the area of Lawís, placed on the border of a buried hill of these volcanic rocks, should have been specially favourable to the deposition of ore-bodies of economic interest.

In this area the Bellerophon formation crops out along a belt striking NNE—SSW and dips in a WNW-direction belov the Werfenian strata, which are discontinuously covered by fluvioglacial deposits. Immediately to the east, the quartz porphyries crop out.

We consider of importance in regard to the genesis:

1. The absence of the Grödener sandstone.

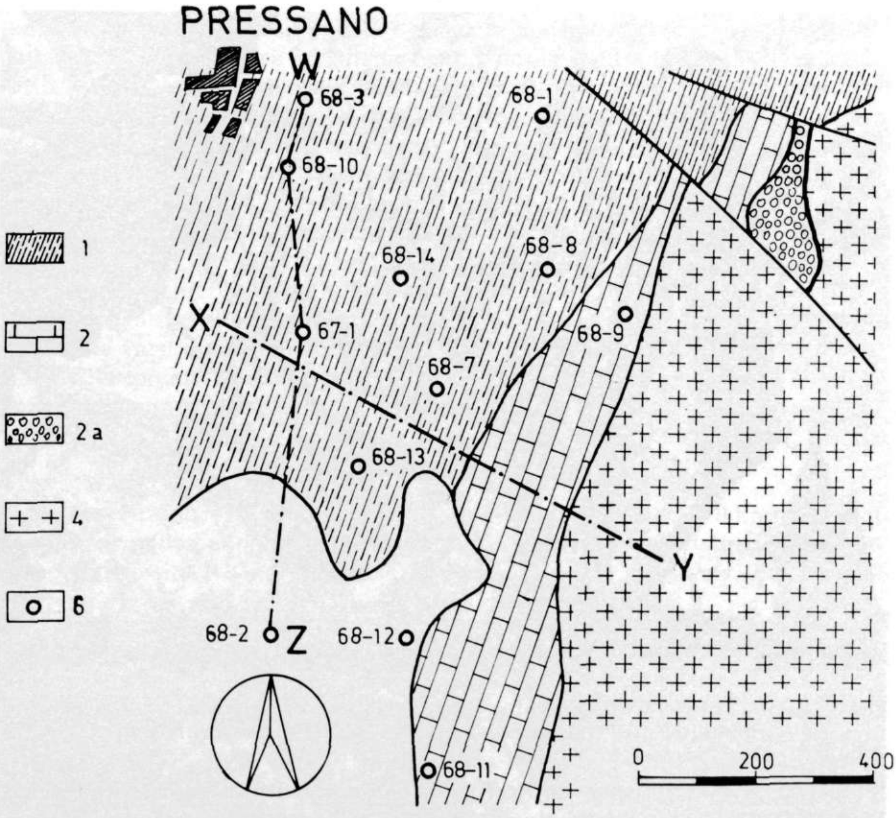


Fig. 5. Geological sketch map of the Lavís area

Explanation of Figures 5, 5a, and 5b

1 Werfenian
2 Bellerophon formation
2a Conglomerate of porphyry pebbles with fossiliferous dolomitic-ferruginous cement
3 "Grödener sandstone"
4 Quartz porphyries
5 Ore body
6 Cored bore holes

2. The local appearance of a conglomerate just below the Bellerophon formation, which in its proximity contains barite. The conglomerate is composed of coarse (1 ÷ 50 cm) rounded porphyry gravel, cemented by an iron-bearing dolomite (Fig. 4) containing fragments of lamellibranchs*.

3. The transgression of the Werfenian, immediately to the north, directly over the Porphyries (Figs. 5, 5a and 5b.

4. The presence, in the Maso Furli hill, of tabular blocks of porphyry buried in the Bellerophon formation (Fig. 6).

* Further to the north-east, on the western slope of Monte Rosà, there is another outcrop of porphyric conglomerate, which however must be of Werfenian age, on account of the presence in the cement of *Holopella gracilior*.

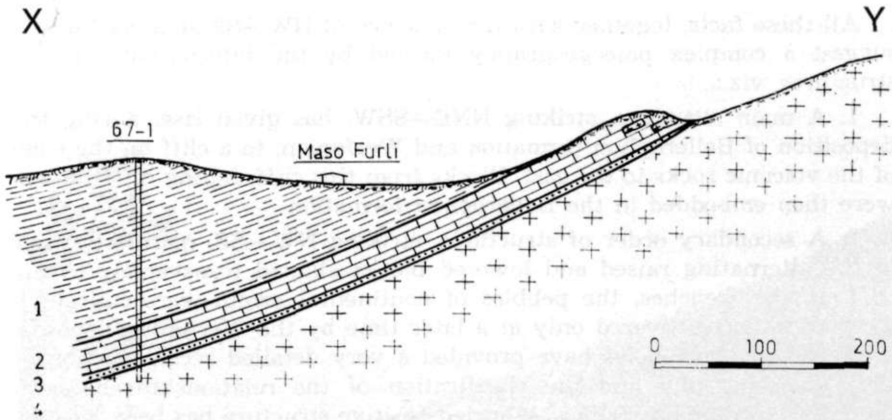


Fig. 5a. Geological section NW—SE of the Lavís area

Please see the explanation on the opposite page

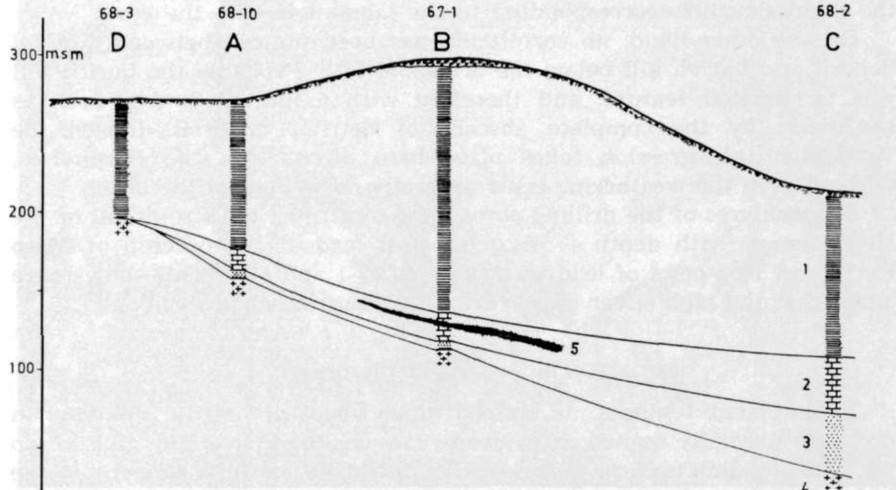


Fig. 5b. Geological section N—S of the Lavís area

Please see the explanation on the opposite page

All these facts, together with the presence of NW—SE striking faults*, suggest a complex paleogeography formed by the interference of two structures, viz.:

1. A main structure, striking NNE—SSW, has given rise, during the deposition of Bellerophon formation and Werfenian, to a cliff on the edge of the volcanic rocks to the east. Blocks from this cliff, falling into the sea, were then embedded in the Bellerophon formation.

2. A secondary order of structures, striking NW—SE, manifests itself in the alternating raised and lowered blocks aligned transversaly to the cliff. In the trenches, the pebbles of continental origin were collecting. The uplifts were covered only at a later time by the Werfenian deposits.

The many bore-holes have provided a very detailed reconstruction of the paleogeography and the clarification of the relationships between the latter and the ore bodies. A buried positive structure has been located, striking NW—SE and therefore parallel to the secondary structures which the mapping had identified. With respect to this buried structure it is possible to distinguish three different facies in the Bellerophon formation (Figs. 7b and 8):

— A barren carbonatic-arenaceous facies, thickness 0—15 metres.

— A mainly carbonatic facies, ore-bearing, thickness 17—35 metres.

— A mainly clayey-marly facies, with only traces of ore, thickness above 35 metres.

The mineral deposit, composed of galena, sphalerite, pyrite, chalcopyrite and barite, either disseminated or in thin veinlets, is arranged on both flanks of the secondary positive structure striking NW—SE (Figs. 5b and 7); the mineral occurrence grows richer in ESE direction, nearing the main structure corresponding to the land-surface to the east.

On the other hand, no correlation has been noticed between mineral deposit and buried hill below the drill-hole 68-3. Probably the buried hill was an isolated feature, and therefore with a limited land-surface, as confirmed by the complete absence of detrital material. Indeed the Werfenian transgression takes place here directly on the Porphyries, without even the weathering crust generally noticeable on the latter.

The analyses of the drilling cores have confirmed the strong fall of the silver assays with depth — 7 kg per t of lead at the outcrop of Maso Furli, and 1 kg per t of lead in drill-holes 67-1 and 68-7. This shows once again that the high silver assays are due to supergene enrichment.

5. **The genesis of the ores**

Replacement textures, as noticed in polished sections of Bellerophon ores, are normally quoted as evidence of hydrothermal origin. But we do not consider this texture to be a sufficient proof, both on account of the lack of other evidence, and primarily because it is probably the result of local migrations in the course of diagenesis.

---

* We recall that also the Montagiù ore vein, cutting through the porphyries near Faedo, follows nearly the same strike (Dessau and Duchi, 1970).

Fig. 6. Maso Furli — Big tabular block of Porphyry embedded in the Bellerophon formation

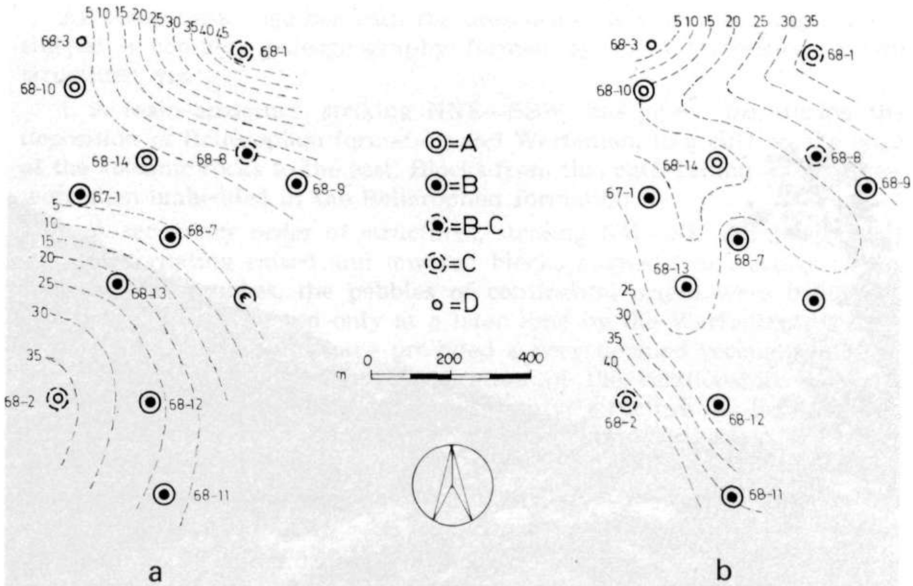


Fig. 7. Isopach maps of "Grödener sandstone" (a) and Bellerophon formation (b) in the Lavís area

Facies of Bellerophon formation as encountered by the bore-holes:
A Carbonatic-sandy facies, barren
B—C Mainly carbonatic facies, ore-bearing
C Transitional facies, ore-bearing
C Mainly marly-clayey facies, practically barren
D Bellerophon formation missing

On the other hand, the regional spread and the stratigraphic persistence of the ore-bearing horizon are considered by us to be a control of a sedimentary deposition. In addition, the lagoonal, moderately euxinic environment, with precipitation of the first terms of the evaporitic series (dolomite, gypsum, anhydrite), seems favourable for the deposition of galena.

What has to be explained, are the sources both of the metallic ions and of the sulphur of the sulphides.

As far as the first are concerned, one can assume either a leaching of the rocks of the Porphyric platform and of their mineral deposits, or a supply by thermo-mineral springs issuing at the bottom of the sea.

In favour of the first hypothesis stands the fact, that there were porphyric land-surfaces (Monte Rosà near Lavís and Monte Luco in the upper Val di Non) during the deposition of the Bellerophon formation, and near to the areas containing metal minerals. Moreover the trace-element content and the δS^{34} composition of the sulphides of the Bellerophon formation show analogies with the corresponding values for the sulphides of the hydrothermal veins in the Porphyries. We, however, do not attribute too much probative value to this control, because of the possibility of changes during solution transport and re-deposition.

In regard to the second hypothesis, there is an equal lack of direct evidence. But an exhalative-sedimentary origin, already suggested by several authors beginning with T r e n e r (1914) and C a n a v a l (1916), would be in agreement with the general characteristics of these deposits and especially with the isotopic composition of the sulphides. At any rate, such an important volcanic activity, as the Permian one in our area, may well have had a long hydrothermal "tail"; it may also be remembered, that in the neighbouring district of Predazzo there has been a resumption of volcanic activity during Triassic times.

For the greater part of the deposits of the Bellerophon formation examined, the δS^{34} of the ores is about $+2{,}5$ ‰, with small fluctuations of this average. This is strong evidence in favour of a direct magmatic origin, at least for the sulphur.

One has, however, still to explain the values of δS^{34} of the ores of the upper Val di Non and of S. Lucia, values which are almost entirely negative, and varying over a wide range. These two features are strongly suggestive of a microbiological origin, through reduction of sulphates by sulphate reducing bacteria. The environment where the last mentioned deposits were formed, some distance from the likely center of activity of the submarine sulphurous springs, was probably out of their reach, and more favourable to the thriving of the sulphate-reducing micro-organisms, on account of lower temperatures and diluted solutions.

Amongst the various hypotheses, while acknowledging the difficulty of a proper choice, we are in favour, as far as the metallic ions are concerned, of an origin by meteoric leaching of the volcanic rocks of the Bozen Porphyric platform. Even disregarding the circumstance, that no feeder channels of the supposed submarine thermo-mineral springs have been found, we consider circumstancial evidence that metallic sulphides appear, even if exceptionally, in the Werfenian where, as for instance to the north of Lavís, it is transgressive over the Porphyries and in the same facies as the ore-bearing horizons of the Bellerophon formation.

As far as the source of the sulphur of the ores is concerned, according to the present state of knowledge about sulphur isotopes, whereas in Val di Non and at S. Lucia it derived from biochemical processes, in the other areas it is of inorganic origin, and most probably supplied to the sedimentary basins by sulphurous springs. It may be noted, that such springs are known in the district even to-day.

6. Acknowledgments

We have made use of unpublished data from the archives of the Bureau of Mines of Trento, and we thankfully acknowledge the permission granted by the Società Mineraria e Metallurgica di Pertusola to disclose information about their exploration work at Lavís.

Explanation of Fig. 8

A Carbonatic-sandy facies, found near to the Permian Quartz porphyry highs
B Mainly carbonatic facies, bordering facies "A"
C Mainly marly-clayey facies, found in depressed or rapidly subsident areas

A-1 Werfenian
A-2 Bellerophon formation: Sandy limestone with detrital elements (quartz and glauconite) and gypsum veins. Sparse nodules of barite
A-3 Red dolomite with glauconite grains. Sparse gypsum nodules
A-4 Cellular grey marly dolomite
A-5 Light grey dolomite containing thin detrital beds with clastic smoky quartz; upwards the rock gradually changes to red sandy marl
A-6 "Grödener sandstone": Red sandy marl alternating with thin sandy layers, green at the bottom
A-7 White sandstone with clastic smoky quartz. This complex grows micaceous and more grey downwards
A-8 Quartz porphyries

B-1 Werfenian
B-2 Bellerophon formation: Grey dolomitic limestone with many thin black marly partings
B-3 Grey dolomite with very abundant grains and veinlets of galena, sphalerite, pyrite and chalcopyrite
B-4 Light grey cellular dolomite, with thin beds of microbreccia, containing small vegetable fragments. These beds bear galena in scattered spots
B-5 Arkose with light-coloured fragments of Porphyries. Downwards the arkose gradually changes to a conglomerate of limestone pebbles
B-6 Sandy altered porphyry
B-7 Quartz porphyries

C-1 Werfenian
C-2 Bellerophon formation: Alternations of intraformational glauconitic breccia and of marl and marly dolomite
C-3 Alternations of grey and pink marly, clayey and dolomitic beds, with nodules, veins and thin strata of gypsum
C-4 Grey, oölithic, quartz- und fossil-bearing dolomite
C-5 Dolomitic breccia and grey clayey and marly beds alternating with a grey arenaceous oölithic dolomite with rare spots of galena
C-6 "Grödener sandstone": Fine-grained micaceous sandstone alternating with grey dolomitic beds; appearance of gypsum nodules and of thin fragmental layers. At the bottom grey marls
C-7 Sandstone composed of porphyric material, with gypsum nodules
C-8 Sandy altered Porphyry
C-9 Quartz porphyries

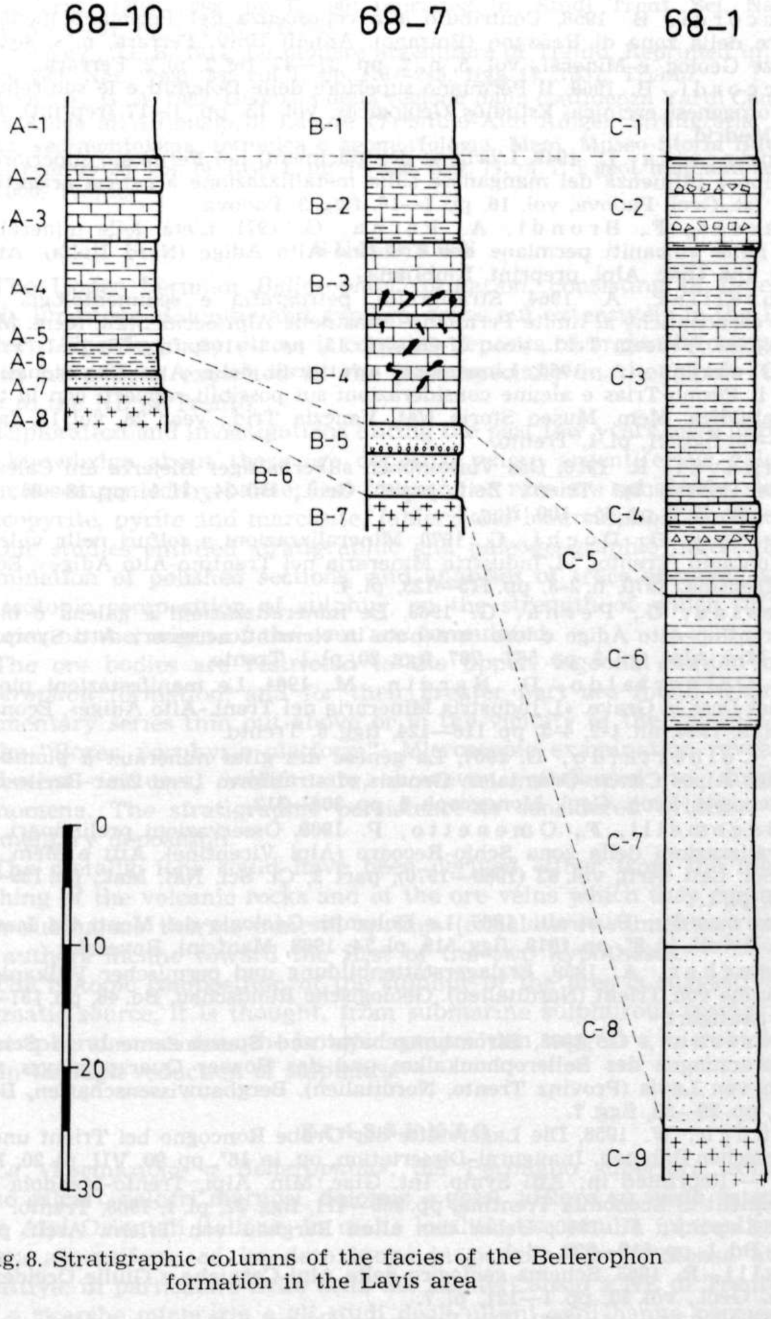


Fig. 8. Stratigraphic columns of the facies of the Bellerophon formation in the Lavís area

Main references

Accordi, B. 1958, Contributo alla conoscenza del Permiano medio-superiore della zona di Redagno (Bolzano). Annali Univ. Ferrara, n. s. sez. IX, Scienze Geolog. e Mineral., vol. 3, n. 2, pp. 37—47, fig. 2, pl. 2, Ferrara.

Accordi, B. 1959, Il Permiano superiore delle Dolomiti e le sue relazioni con l'orogenesi ercinica. Estudios Geologicós, vol. 15, pp. 1—17 (reprint), fig. 1, pl. 1, Madrid.

Andreatta, C. 1949, L'origine dei giacimenti nel Permiano superiore del Trentino e influenza del manganese sulla metallizzazione a galena argentifera. Mem. Ist. Geol. Padova, vol. 16, pp. 1—16, figg. 2. Padova.

Baccos, F., Brondi, A., Perna, G. 1971. L'età delle mineralizzazioni nelle vulcaniti permiane del Trentino-Alto Adige (Nord Italia). Atti II Symp. Int. Giac. Alpi, preprint. Ljubljana.

Bosellini, A. 1964, Stratigrafia, petrografia e sedimentologia delle facies carbonatiche al limite Permiano-Trias nelle Alpi occidentali. Mem. Museo Storia Nat. Venezia Trid., year 27-28, vol. 15, pp. 1—106, figg. 57, pl. 1, Trento.

Bosellini, A. 1965, Lineamenti strutturali delle Alpi Meridionali durante il Permo-Trias e alcune considerazioni sui possibili rapporti con la tettonica alpidica. Mem. Museo Storia Nat. Venezia Trid., year 28, vol. 15, fasc. 3, pp. 1—72, figg. 21, pl. 1, Trento.

Canaval, R. 1916, Das Vorkommen silberhaltiger Bleierze am Calesberg (Monte Calisio) bei Trient. Zeit. prakt. Geol., Bd. 24, H. 1, pp. 18—25; H. 2, pp. 29—38, H. 3, pp. 85—100, figg. 3.

Dessau, G., Duchi, G. 1970, Mineralizzazioni a solfuri nelle vulcaniti del Montagiù (Trento). «L'Industria Mineraria nel Trentino-Alto Adige», Economia Trentina, 1970, n. 2-3, pp. 115—123, pl. 4.

Dessau, G., Perna, G. 1968, Le mineralizzazioni a galena e blenda del Trentino-Alto Adige e loro contenuto in elementi accessori. Atti Symp. Int. Giac. Min. Alpi, vol. 3, pp. 587—787, figg. 20, pl. 1. Trento.

Di Colbertaldo, D., Nardin, M. 1964, Le manifestazioni piombifere del Doss le Grave. «L'Industria Mineraria nel Trent.-Alto Adige», Economia Trentina, 1964, nn. 1-2, 4-5, pp. 116—124, figg. 8. Trento.

Di Colbertaldo, D. 1967, La génèse des gîtes minéraux à plomb-zinc dans les Alpes Centre-Orientales. Genesis of stratiform Lead-Zinc-Barite-Fluorite deposits, Econ. Geol. Monograph 3, pp. 308—312.

Giacomelli, F., Omenetto, P. 1969, Osservazioni preliminari sulle mineralizzazioni della zona Schio-Recoaro (Alpi Vicentine). Atti e Mem. Acc. Pat. Sci. Lett. Arti, vol. 82 (1969—1970), part 2, Cl. Sci. Nat. Mat., pp. 129—149, figg. 3, pl. 1.

Leonardi, P. et alii. 1967, Le Dolomiti. Geologia dei Monti tra Isarco e Piave. 3 voll. in 8°, pp. 1019, figg. 519, pl. 74, 1968, Manfrini, Rovereto.

Maucher, A. 1959, Erzlagerstättenbildung und permischer Vulkanismus im Raume von Trient (Norditalien). Geologische Rundschau, Bd. 48, pp. 131—140, fig. 1, Stuttgart.

Morteani, G. 1965, Strontiumgehalte und Spurenelemente in Schwerspatvererzungen des Bellerophonkalkes und des Bozner Quarzporphyrs nordöstlich von Lavís (Provinz Trento, Norditalien). Bergbauwissenschaften, Bd. 12, n. 1-2, pp. 20—23, figg. 7.

Münch, W. 1958, Die Lagerstätte der Grube Roncogno bei Trient und ihr geologischer Rahmen. Inaugural-Dissertation, op. in 16°, pp. 90, VII, pl. 20, München. — Reprinted in: Atti Symp. Int. Giac. Min. Alpi, Trento-Mendola 1966, supplement to Economia Trentina, pp. 355—411, figg. 32, pl. 1, 1968, Trento.

Pošepný, F. 1880, Ueber den alten Bergbau von Trient. Arch. prakt. Geol., Bd. 1, pp. 519—528, pl. 1.

Selli, R. 1963, Schema geologico delle Alpi Carniche e Giulie Occidentali. Giorn. Geol., vol. 30, pp. 1—121, pl. 7.

Tornquist, A. 1931, Die Vererzungsphasen der jungen ostalpinen Erzlagerstätten. Sitz.-Ber. Ak. Wiss., Math.-naturw. Kl., Bd. 140, pp. 219—229. Wien.

T r e n e r, G. B. *1899*, Le antiche miniere di Trento. XX Annuario Soc. Alpin. Trid., 1896—1898, pp. 27—90; reprinted in: Studi Trent. Sci. Nat., 34, vol. 1, pp. 1—57, fig. 1, 1957, Trento.

T r e n e r, G. B. 1914, Le miniere argentifere di Trento. Reprinted in: Studi Trent. Sci. Nat., year 34, vol. 1, pp. 218—245, figg. 17, 1957, Trento.

V e n z o, G. A. 1962, Geologia della regione dalla confluenza Val di Cembra—Val d'Adige all'Altipiano di Lavazè (Trentino-Alto Adige). Stratigrafia, petrografia, sedimentologia, tettonica e geomorfologia. Mem. Museo Storia Nat. Ven. Trid., year 25-26, vol. 14, fasc. 1, pp. 7—228, figg. 74, pl. 1, 1 geol. map and sections 1:50.000, Trento.

SUMMARY

The Upper Permian *Bellerophon* formation, consisting of limestone, marly limestone, dolomite and gypsum, crops out extensively in the Italian Eastern Alps. In many places it contains deposits of argentiferous galena, which have been exploited in the past, specially in the Monte Calisio area to the NE of Trento.

Exploration and investigations during the past few years have improved our knowledge about these ore deposits, where argentiferous galena is often accompanied by barite; less frequent or rare are sphalerite, siderite, chalcopyrite, pyrite and marcasite, fahlerz and lead sulphoantimonites.

Our studies entailed stratigraphic and paleogeographic investigations, examination of polished sections, and analyses of trace elements and of the isotopic composition of sulphur, on the strength of which different theories on the origin of the ores are formulated.

The ore bodies are restricted to the upper, lagoonal section of the *Bellerophon* formation, and for their greater part are found where the sedimentary series thin out above or in the vicinity of the volcanic rocks of the "Bozen porphyric platform". Microscopic examination reveals replacement textures, which are, however, attributed to diagenetic phenomena. The stratigraphic persistence is considered evidence for a sedimentary deposition.

The metallic ions could have been derived either from the meteoric leaching of the volcanic rocks and of the ore veins which they contain, or from submarine thermo-mineral springs (exhalative-sedimentary origin); the authors incline toward the first of the two hypotheses.

The isotopic composition of the sulphur of the ores is suggestive of a magmatic source, it is thought, from submarine sulphurous springs; only in peripheral areas does the isotopic composition suggest a microbiological origin through reduction of sulphates.

RIASSUNTO

La «Formazione a *Bellerophon*», del Permiano superiore, comprendente calcari, calcari marnosi, dolomie e gessi, affiora su vasta estensione nelle Alpi Orientali italiane. In molte località essa risulta mineralizzata a galena argentifera, ed ha dato luogo in passato ad un'intensa attività estrattiva, in particolare nella zona del Monte Calisio a NE di Trento.

Le ricerche minerarie e gli studi degli ultimi anni hanno permesso di perfezionare le conoscenze sulla mineralizzazione, che è a galena argenti-

fera prevalente, cui si accompagna spesso la barite; più rare e sporadiche sono blenda, siderite, calcopirite, pirite e marcasite, tetraedrite e solfoantimoniti di piombo.

Vengono esposti i risultati degli studi stratigrafici, paleogeografici, minerografici e delle analisi degli elementi traccia dei solfuri ed isotopiche dello zolfo, che hanno portato a formulare differenti ipotesi sulla genesi delle mineralizzazioni.

Queste ultime sono confinate al livello superiore, lagunare, della Formazione a *Bellerophon,* e sono in gran prevalenza concentrate dove la serie si assottiglia, al di sopra o in vicinanza delle vulcaniti della «Piattaforma porfirica atesina». Per quanto studi minerografici rivelino strutture metasomatiche — attribuibili però a fenomeni diagenetici — la costanza stratigrafica viene considerata prova di deposizione sedimentaria.

Gli ioni metallici potrebbero provenire o da dilavamento meteorico delle vulcaniti e dei filoni che queste contenevano, oppure da sorgenti termo-minerali sottomarine (origine esalativo-sedimentaria); ma gli autori propendono per la prima ipotesi.

La composizione isotopica dello zolfo dei solfuri è generalmente a favore di una provenienza magmatica dello zolfo, da sorgenti solfidriche sottomarine; solo in zone periferiche la composizione isotopica suggerisce che lo zolfo dei solfuri abbia origine dalla riduzione microbiologica di solfati.

DISCUSSION

Di Colbertaldo: Se bene ho capito, dal punto di vista genetico, voi siete più propensi a ritenere una origine di questi giacimenti, situati nel Permiano superiore, da lisciviazione della piattaforma porfirica e dei filoni eventualmente presenti nella piattaforma porfirica. Però desidero far osservare che il calcare a Bellerophon non è mineralizzato soltanto in Trentino, dovè ha forse la maggiore estensione, ma anche nella Val Bàrtolo presso Tarvisio. Nella Val Bàrtolo la manifestazione è a piombo, zinco e rame; in vicinanza si trovano anche masse di calcite bianca, spatica, molto fetida, molto odorante di acido solfidrico. In questa zona non esiste alcuna manifestazione eruttiva a cui legare una mineralizzazione. Ora, come nelle Alpi noi abbiamo molti livelli mineralizzati che vanno dal Trentino al confine col Austria, Jugoslavia, e nell'interno di questi due Stati, vien di pensare che per uno stesso livello mineralizzato noi dovremo invocare uno stesso tipo di genesi. Ecco perchè io mi trovo imbarazzato nell'accettare una origine per lisciviazione di mineralizzazioni preesistenti nella piattaforma porfirica Trentina, quando invece nel Tarvisiano mancano questi elementi a cui riferire un analogo tipo di mineralizzazione.

Dessau: I well understand what Professor di Colbertaldo wants to tell us. It is also shown on Fig. 2 of our paper that in Val Bàrtolo, in the vicinity of the boundaries with Austria and Yugoslavia, there is another small ore deposit within the Bellerophon formation; I believe I also mentioned it during my talk. This small deposit is very far away from the Bozen porphyric platform or, more generally, it is far away from outcrops of eruptive rocks. As it is difficult to admit a different origin for this deposit with respect to the other ones of the main area, this would be evidence in favour of the sedimentary origin of all the deposits. My answer to Professor di Colbertaldo is that we really have not been able to make up finally our minds between the two possible origins. We have stressed in our paper that we are still doubtful about this subject, although we give a slight preference to the hypothesis of the origin of the metallic ions from the weathering of the porphyric platform.

Maucher: Wenn ich Sie richtig verstanden habe, dann sind Sie der Ansicht, daß die Erze im Wesentlichen sedimentiert wurden, und daß der Erzbestand aus der Verwitterung der Quarzporphyre kommt. Für diese Hypothese spricht jawohl auch die Zusammensetzung der Schwefelisotope, die auf der einen Seite in der Nähe von Quarzporphyren mehr den Charakter von vulkanischem Schwefel, oder magmatischem Schwefel hat, und je weiter wir uns davon entfernen, um so mehr veränderten S^{34} Gehalt zeigt. Wenn ich Herrn Professor di Colbertaldo richtig verstanden habe, so sagte er, die Erze könnten nicht von den Quarzporphyren stammen, da in diesem Gebiet bei Tarvis die Quarzporphyre fehlen. Nun, ich glaube, man kann folgendes sagen. Das Milieu des Bellerophonkalkes mit seiner salinaren Fazies ist ein Milieu, in dem Metallgehalte, wenn sie ins Meer gelangen, sedimentiert werden. Ob diese Metallgehalte aus der Verwitterung von Quarzporphyren stammen oder aus der Abtragung der Erzgänge im Quarzporphyr, oder ob die Verwitterungslösungen aus den karbonischen Erzgängen stammen, wie Sie ja gerade in den Karnischen Alpen gezeigt haben, ist dafür vollkommen gleichgültig. Ich glaube, wir sollten uns zunächst einmal einfach darüber unterhalten, daß das Sedimentationsmilieu, die Fazies des Bellerophons eine salinare Fazies ist, die gerade für solche Ausscheidungen von Metallen günstig ist. Und zwar eine besondere karbonatische Fazies, in der hauptsächlich das Blei fällt, sehr wenig das Kupfer und sehr wenig das Zink. Erst in dem Augenblick, so war wenigstens unsere Beobachtung, wenn die Kalke etwas mergeliger werden, wenn sie etwas toniger werden, wenn also das Sedimentationsmilieu sich ändert, dann fällt auch mehr Kupfer. Es liegt also nicht nur am Angebot der Metallionen, sondern es liegt an der Fazies, in der sie ausgeschieden werden. Dafür spricht auch Ihre Zinkblende, die kaum Cadmium enthält, während ja Zinkblenden in den Porphyrgängen noch hohe Cadmiumgehalte haben. Die entscheidende Frage ist doch einfach die nach dem Milieu. Der Nachweis, wo die Metallionen hergekommen sind, ob nun aus einer Verwitterung des Grödener Sandsteines, aus einer Verwitterung des Porphyrs, oder aus der des karnischen Gebietes, das, glaube ich, ist sehr schwer zu entscheiden. Das könnte man vielleicht mit Spurenelementen machen, aber auch da ist wieder die Schwierigkeit, daß auch die Spurenelemente nicht nach dem Angebot fällen, sondern nach dem Milieu. Wir müssen uns immer darüber klar sein, daß die Fällungsbedingungen das

Wesentliche sind und nicht das Lösungsangebot allein. Es kann natürlich nur das fallen, was in der Lösung ist, aber es muß nicht fallen, was in der Lösung ist. Insofern ist, glaube ich, die Frage, ob der Porphyr in der Nähe ist oder nicht in der Nähe ist, für die Erz-Ausscheidung als solche gar nicht so wesentlich.

Dessau: Wenn ich in Kürze darf, möchte ich sagen, daß wir einfach mit dem, was Professor Maucher gesagt hat, völlig einverstanden sind. Ich errinere mich an alte Arbeiten über Oberschlesien, wo es bewiesen ist, wie sehr eine Salzzirkulation für den Transport und die Fällung besonders von Bleiglanz wichtig ist. Über den Ursprung der Metallionen sind wir eigentlich zu keinem sicheren Schluß gekommen. Wir haben aber in Betracht gezogen, daß die Zuhörer im allgemeinen doch am Ende wissen wollen »Was denkt Ihr eigentlich darüber?«. Auch für uns sind die Fällungsbedingungen viel wichtiger als die Herkunft. Was die Herkunft betrifft, ist es auch bemerkenswert, daß dort, wo die Porphyre fehlen und die Bellerophon-Formation auf Altkrystallin zu liegen kommt, die Erze kupferreicher und weniger bleihaltig sind, also von dem anstehenden Gestein beeinflußt worden sind.

Mittempergher: I quite agree with the explanation of Professor Maucher, that the Bellerophon beds may be very favourable host rocks; but we have also a lot of geochemical evidence about the backgroung of lead in the quartz porphyry and also in the Carboniferous beds. The Carboniferous beds in the eastern part are very rich in lead and zinc, especially lead. There is a lot of smal' mineralization, but also the background is very high. At the other hand, in the Trento and the Bozen areas, we have the quartz porphyry with very high backgroung of lead, and in the same area we have the lead mineralization not only in quartz porphyry, in the propylitic mineralizations of the Val Sarentino. Terlano, but also in the Tregiovo beds and in the upper part of the Gröden sandstone. Here there are many places where we have syngenetic lead minerals. For this reason I believe that the Permian volcanics and the Carboniferous shales may be regarded partially as sources for the lead and zinc contained in the Bellerophon mineralizations.

Emberger: Une question sur les isotopes de soufre. Dans votre texte vous avez mentionné comme valeurs du rapport isotopique du soufre pour la galène des groupes de chiffres, des valeurs positives faibles et quelques valeurs négatives fortes. Je voudrais savoir si ces valeurs ont été mesurées sur des échantillons présentant des conditions de gisement ou un aspect morphologique identique ou différent?

Dessau: Le collaborateur Professeur Perna confirme que les faciès des échantillons sont exactement les mêmes; mais les échantillons avec les valeurs aberrantes viennent d'une région bien définie.

Emberger: Je vous pose cette question parce que j'ai eu l'occasion de faire des études de ce genre sur des gisements marocains qui appartiennent en fait à la zone alpine et dans lesquelles j'ai constaté que les variations importantes du rapport isotopique peuvent être enregistrées là, où il y avait des minéralisations voisines (à des distances de l'ordre du décimètre ou de la dizaine de mètres), mais présentant des caractéristiques différentes (morphologie, roche encaissante, association minérale...). Les analyses ont parfois donné des résultats très différents. Ainsi, de la galène dispersée en nuage dans le ciment d'un grès montre un δS^{34} négatif très faible tandis que de la galène en remplissage de fissure dans ce même grès montre au contraire une valeur négative très élevée. Cette différence de valeur traduit très probablement des différences dans le mode de formation de ces deux types de galène.