RENDICONTI Società Italiana di Mineralogia e Petrologia, 38 (1): pp. 27-33
Comunicazione presentata al Congresso SIMP di Cagliari il 16 ottobre 1981

OCCURRENCE OF LATE-HERCYNIAN PERALUMINOUS GRANITES IN THE SOUTHERN ALPS

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RIASSUNTO. — Dopo i graniti peraluminosi a cordierite + muscovite nel massiccio di Bressanone (VISONÀ, 1980), altri S-graniti sono stati ritrovati nelle Alpi Meridionali orientali. Nella parte orientale di Cima d'Asta vi è un piccolissimo corpo di granito muscovitico con pseudomorfi da cordierite. Al Monte Sabion vi è una masserella e minori corpi filoniani di porfidi granitici a muscovite, con relitti di andalusite in via di muscovitizzazione e con granati.

Queste nuove conoscenze definiscono più compiutamente la caratterizzazione ercinotipa dei complessi plutonici sudalpini, caratterizzati in ogni modo da I-graniti ≫ S-graniti.

Esse pongono problemi petrologici relativi alla pratica stabilità della muscovite in condizioni intrusive di piccola profondità, quali sono certamente, su base geologica e petrografico-tessiturale, le condizioni dei plutoni considerati. Il problema non è nuovo e porta a non utilizzare in modo quantitativo il ben noto sistema semplice Ms + Qz (muscovite ideale) alle condizioni compositive complesse di un fuso S-granitico in risalita e cristallizzazione, ma di considerare un probabile allargamento del campo di stabilità della muscovite in fusi persilicici verso più basse *P* e/o più alte *T*.

ABSTRACT. — Following the finding of the cordierite + muscovite peraluminous granites in the Bressanone Massif (VISONÀ, 1980), other few S-granites were found in the eastern Southern Alps. In the eastern area of the Cima d'Asta basement there is a tiny body of muscovite granite containing cordierite pseudomorphics. In the Monte Sabion area there is one small mass and some dykes of muscovite-bearing granite porphyries with minor garnet and andalusite.

These findings confirm the Hercynotype character of the Southern-alpine plutonics, the main feature, however, being I-granites ≫ S-granites.

Petrological problems arise with relation to the practical stability of muscovite in high-level plutonic conditions, which are defined on a geological and petro-textural basis. This is not a new problem; it suggests that the well-known Ms + Qz simple system may not be employed in a quantitative way in a rising and crystallizing S-granitic melt. It could be considered that the muscovite stability field should be extended towards higher temperature and lower pressure.

Introduction

In the pre-Permian basement of the Southern Alps there are granitoid massifs (Cima d'Asta, Bressanone, Ivigna, Monte Croce, Monte Sabion) of the late-Hercynian age (290-275 m.y.), which are described by D'AMICO (1974) and BARGOSSI et al. (1979; see references therein). The granitoid typology is I-type, according to CHAPPELL-WHITE (1974); in fact the association is given by subaluminous granites + granodiorites and metaluminous granodiorites + tonalites + quartzdiorites. Only recently a small body of cordierite and muscovite bearing peraluminous granite has been described (VISONÀ, 1980).

In this paper the finding of other peraluminous granites in the Southern Alps (Cima d'Asta and Monte Sabion areas) is described and some of the problems arising are discussed.

Petrography and chemistry

Peraluminous granite in the Vanoi Valley (Cima d'Asta)

This forms a small outcrop, of a few meters, within the phyllites, at the beginning of the road for the Broccon Pass. It is a very deuterized medium-fine grained, muscovite syenogranite (table 1), with pegmatitic patches and with probable cordierite pseudomorphics. Muscovite is abundant in the pegmatitic patches; it appears to be mainly primary in the texture and is in isolated flakes or, more frequently, interleaved with biotite.

The shape of the pseudomorphics is rather stumpy, irregular or rounded, with a lot of sericite and fewer chlorite. No mineral relics are present. The pseudomorphics can, by probability, be attributed to a previous cordierite origin, but a possible andalusite origin cannot be completely excluded. Around the pseudomorphics,

TABLE 1
Modal composition of the peraluminous granites

	Val Vanoi (Cima d'Asta) (1)	Monte Sabion (11)
Qz	38,2%	34,4%
Kf	39,0	30,1
P	18,1	29,0
Bi	1,7	3,0
Ms	1,4	3,1
And	?	max 1,0
Cdt, ps.	1,6	pr
Gt	-	max 0,5

(1), (11) number of samples.

flakes of intergrowing muscovite and biotite may be found; this indicates of course an early genesis of the cordierite.

The medium-grained texture and the pegmatitic flecks, within such a small mass, suggest a crystallization in the presence of a substantial quantity of water.

The small mass belong to an epiplutonic complex, certainly intruded to a depth of a few km.

Peraluminous leuco-monzogranitic porphyries and micrograntes of Monte Sabion

Near Monte Sabion (Pinzolo, Val Rendena) a complex association of granitoid rocks, described by OGNIBEN (1952), outcrops over an area of a few kilometers, within metapelitic hornfelses. They are sub-metaluminous

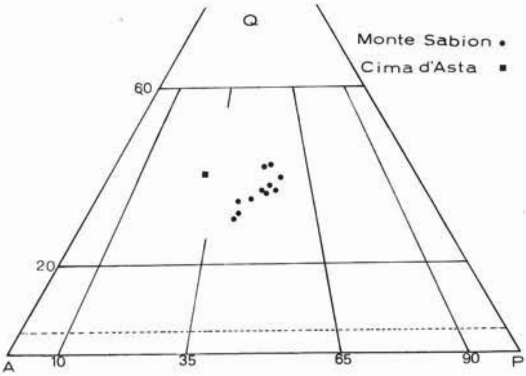

Fig. 1. — *Q-A-P* modal classification of Monte Sabion and Cima d'Asta peraluminous granites.

granites-granodiorites (I-granitoids). To date, peraluminous heterogranular microgranites and leucogranitic porphyries have not been described.

These form a small mass which outcrops discontinuosly over an area of approximately 1/2 km² on the Western slopes of M. Sabion (Malga Cioca area), as well as smaller masses and/or maybe large dykes, which never clearly outcrop. They are porphyritic or heterogranular rocks, with a P.I. average = 18; the groundmass is medium-fine to very fine and also granophyric. The composition is monzogranitic (fig. 1). There is a significant presence of muscovite together with a minor quantity of garnet and andalusite. Pseudomorphics possibly attributable to cordierite are rare.

This paper deals only with the peraluminous character of these rocks, which is not very strong (table 2). A more detailed regional study is under way.

The features to be underlined here, in contrast with the main associated I-granitoids, are:

1) the constant presence of muscovite (100 % of the samples);

2) the frequent presence of andalusite

TABLE 2
Chemical composition of peraluminous granitic porphyries of Monte Sabion

	Leucogranitic porphyries $\bar{X}$(n=4)	SD	Granitic porphyry (n =1)
Wt.%			
SiO_2	75.50	0.77	73.43
TiO_2	0.01_5	0.00_6	0.20
Al_2O_3	13.45	0.18	13.78
Fe_2O_3	0.62	0.03	0.74
FeO	0.44	0.24	1.18
MnO	0.04	0.01	0.04
MgO	0.13	0.14	0.44
CaO	0.51	0.16	1.23
Na_2O	3.88	0.29	3.30
K_2O	4.30	0.48	4.60
P_2O_5	0.06	0.01	0.10
L.O.I.	0.99	0.35	0.96
Na_2O/K_2O	0.91	0.18	0.72
C	1.62	0.57	1.38
ppm			
Ce	20	6	35
La	12	4	24
Ba	69	21	256
Sr	17	8	100
Rb	216	7	161
Li	14	5	32
Y	34	2	26
Zr	42	7	84

$\bar{x}$ = average; n = number of samples; SD = standard deviation; C = CIPW normative corundum.

relics reacting towards muscovite (65 % of the samples);

3) the relatively frequent presence of garnets (40 % of samples) as small, irregular, cribrous grains in the aplitic groundmass;

4) the rare and uncertain presence of pseudomorphics from cordierite.

Petrogenetic problems of the peraluminous minerals

On the basis of their textural relations, the few *garnets* found in the Sabion rocks appear to have crystallized late in the groundmass. A similar crystallization is relatively frequent, for Fe-Mn-garnets, in aplites (e. g. CAWTHORN-BROWN, 1976; CLARKE, 1981; ABBOT, 1981; ALLEN-CLARKE, 1981). The garnets are compatible with a peraluminous composition, but they are not a conclusive proof of a primary peraluminous character; moreover, they cannot supply critical information about the crystallization pressure (e. g. CLEMENS-WALL, 1981).

The *cordierite,* although only inferred from some pseudomorphics, clearly indicates, on the other hand, a primary peraluminosity. The shape of the grains is compatible with a magmatic crystallization (e.g. GREEN, 1976; SPEER, 1981; PHILLIPS et al., 1981; CLEMENS-WALL, 1981); however, a residual origin cannot be excluded; it appears only less probable because the cordierite is in isolated grains, while metamorphic aggregates are lacking. Low pressure conditions, which cannot be better defined, may be inferred from the presence of the cordierite pseudomorphics.

The *andalusite* also indicates a primary peraluminous composition and a low pressure, not quantifiable because of the uncertainty in the system Al_2SiO_5. Andalusite is only found as small, irregular relics enveloped by muscovite. The original shapes are sometimes idiomorphic, but are also irregular when andalusite is associated with quartz. The early formation of both of these shapes is suggested by the fact that they can be found enclosed within subidiomorphic plagioclases.

The idiomorphic shapes are attributed to a magmatic origin; a similar interpretation may be found in D'AMICO et al. (1981), made on the basis of much more significant textures.

The irregular shapes associated with quartz may be, however, anatectic relics; this would imply anatexis at a shallow depth, a problem which can only be discussed after a more detailed regional study.

The textural relationships between andalusite and muscovite are always univocal as a crystallization succession (first andalusite, then muscovite), but correspond to two very different types (fig. 2). The first type (*a* in fig. 2) can be attributed to a discontinuous magmatic reaction, similar to the pyroxene → horneblende reaction (see also CLARKE et al., 1976); the second type (*b* in fig. 2) can be attributed to a subsolidus reaction, comparable to the wellknown pyroxene → uralite reaction. The *b* type aggregates are easily recognized even after complete transformation.

Muscovite is found not only as a product of the andalusite reaction, but more frequently as flakes associated with biotite, feldspars and quartz. It is found in coarser grained aggregates within the heterogranular micrograpites, and in the fine groundmass of porphyritic rocks (fig. 3), and also in the granophyric groundmass. The homogeneity of the distribution, the sizes equal to those of the associated grains, the contact with each one of the other minerals, the not unusual interleaving with biotite, the subhedral and anhedral shapes, the absence of reaction structures are all clear indications that the muscovite crystallized together with the other components. That is, muscovite crystallized from the melt.

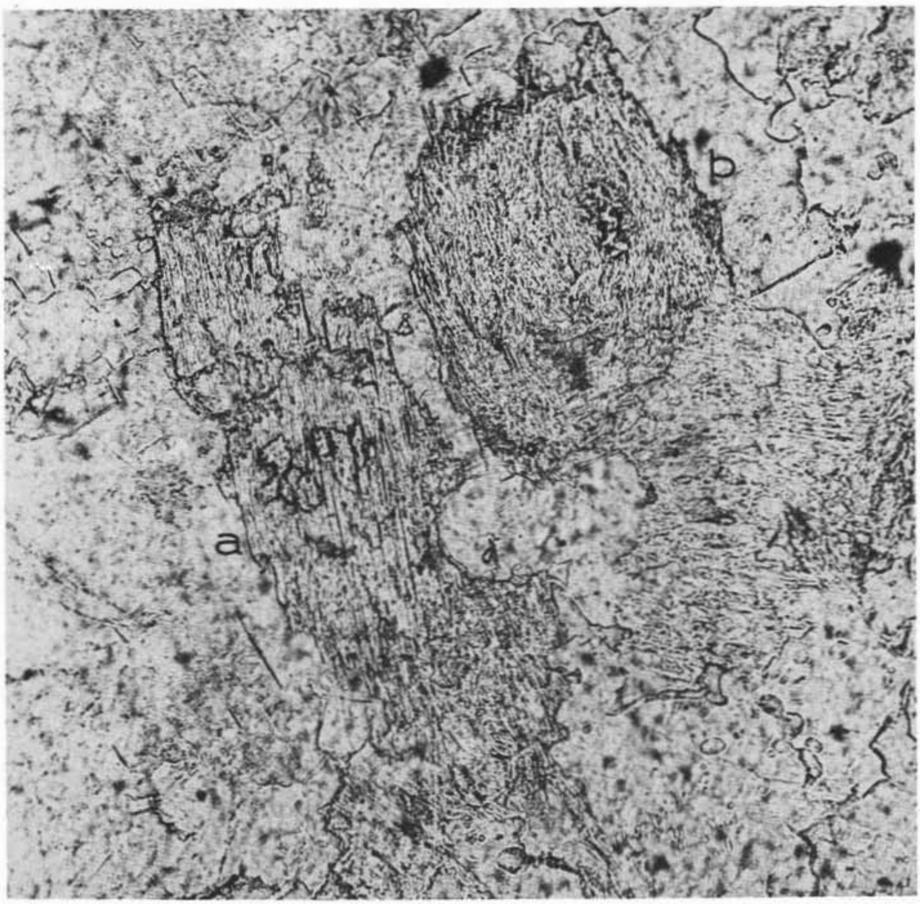

Fig. 2. — Corroded relics of andalusite surrounded by muscovite. Two different textural relationships may be recognized: *a*) subidiomorphic muscovite lamellae enclosing corroded andalusite, which may be attributed to a discontinuous magmatic reaction; *b*) irregular clusters of muscovitic flakes, which may be attributed to a subsolidus reaction. Monte Sabion; one Polar, 85 x.

The crystallization of muscovite from the melt is generally accepted (e.g. HARRIS, 1974; LUTH, 1976; THOMPSON-ALGOR,

1977; WYLLIE, 1977; THOMPSON-TRACY, 1979; MILLER et al., 1981 etc.) and does not, of itself, present any problems. However, to our knowledge, the possible magmatic origin of muscovite in fast cooling porphyritic high level plutonics, has never been discussed: a situation in apparent contradiction with the experimental knowledge of the muscovite stability in persilicic rocks.

According to generally accepted experimental data (EVANS, 1965; ALTHAUS et al., 1970), the muscovite crystallization from persilicic magma would have required a pressure of at least 3.5-4 kb, that is a depth of 13-15 km or more. A similar depth is in complete contrast to all the geological, petrological and textural data and cannot be assumed. The data and some implications are briefy discussed.

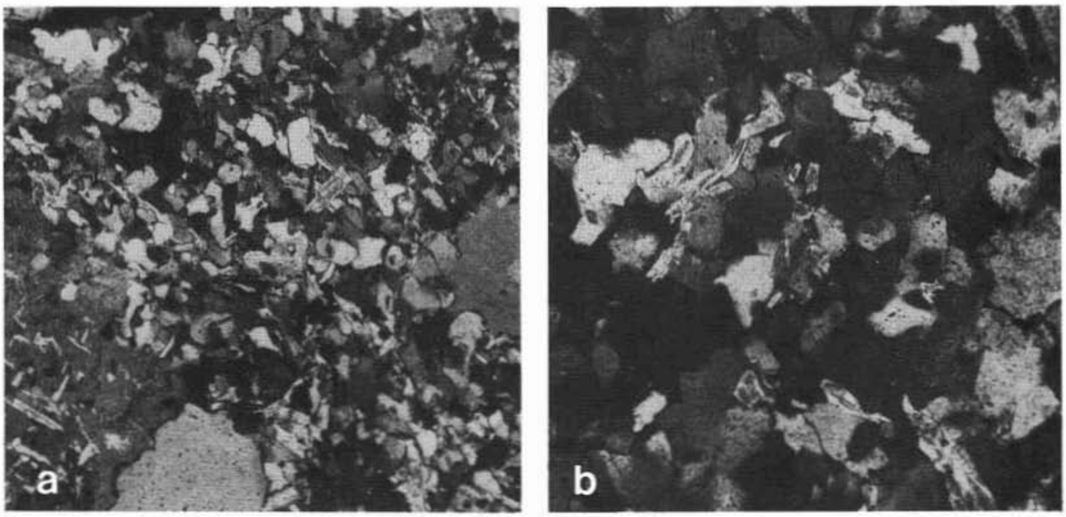

Fig. 3. — Subhedral to anhedral muscovite crystals are distributed homogeneously in the groundmass of the porphyritic S-granites of Monte Sabion. Crossed Polars, 42 x (*a*), 105 x (*b*).

The intrusions of all the Southern Alps plutonics are considered to be high-level, on geological grounds, for the following reasons:

a) intrusion into the basement almost up to the Permian covers;

b) radiometric age very close to that of the Permian volcanics (D'AMICO et al., 1980), which lie stratigraphically only a few hundred meters above the plutonic masses;

c) a possible comagmatic relationship between plutonics and volcanics (D'AMICO, 1964);

d) massive hornfelses presence, giving indications of intrusion into a previous cold (and therefore high) crust;

e) fine-grained and porphyritic textures within the smallest masses, also indicating a cold crust.

D'AMICO (1965) estimated a maximum intrusion depth of approximately 2 km for the Roncegno pluton (Cima d'Asta region).

The plutonic association of Monte Sabion is of exactly the same type. The peraluminous granites present petrographic evidence of rapid cooling after emplacement (porphyritic, heterogranular, granophyric textures) and must obviously be considered high-level intrusions.

For all the above reasons, one cannot accept the deduction of a crystallization depth of 13-15 km, based on the presence of magmatic muscovite and on well-known experimental data.

An important overpressure of water in the mass cannot even be assumed, due to the porphyritic texture of the peraluminous rocks of Monte Sabion. A water overpressure could only eventually be claimed for the small mass in the Vanoi Valley, Cima d'Asta.

So the question must be asked: does the muscovite stability ,in the peraluminous granitic melts extend towards lower pressures? A similar question has been discussed in various papers (SYLVESTER et al., 1978; SWANSON et al., 1978; KEITH et al., 1980; MILLER et al., 1981) and is implicit in others.

This problem has been discussed extensively by D'AMICO et al. (1981). There are two not alternative, but complementary ways to explain the enlargement of the muscovite stability field towards the lower *P* and higher *T*:

1) the complexity of the muscovite solid solution (MILLER et al., 1981; ANDERSON-ROWLEY, 1981);

2) the water undersaturation of the melt (which can be deduced from WYLLIE, 1977, pg. 47-51, fig. 9 *a*).

We feel that the second way is the most important, because it lead to the same constraint for the ascent of the granitic magmas into the crust: that is the water undersaturation.

The case of Monte Sabion has been particularly discussed from a petrographic point of view because it is felt to be, amongst all those discussed in literature, the clearest case of magmatic crystallization of muscovite at relatively shallow depth.

It invites a revision of the applicability, of the most usual Ms-out experimental curves (but not all; see discussion in D'AMICO et al., 1981), to the natural situations, assuming the expansion of the muscovite + quartz stability field towards higher temperatures and lower pressures than those usually accepted. The OH-forming and cation exchange reaction, in the solution of H_2O in aluminosilicate melts, as discussed by BURNHAM (1975), may perhaps provide a clue of solution.

Hercynotype features of the plutonic association

The presence of peraluminous granites is normal in the Hercynotype frame (PITCHER, 1979 a, b) of the Southern Alps. The prevalence of I-type over S-type granitoids in the plutons of the Southern Alps appears to be overwhelming. The ratio is about 10:1 on Monte Sabion, 100 : 1 on Bressanone, 1000:1, or more, on Cima d'Asta. This is an extreme case of the Hercynian typology, where the S-type granites usually have a more important role (e.g. Calabria, French Massif Central, Moldanubikum etc.).

This moderate hercynotypology, with very few or no S-granites, is, however, prevalent in the Hercynian plutons of the Alps (D'AMICO, 1974; BARGOSSI et al., 1979) as well as in Sardinia (DI SIMPLICIO et al., 1975). It is probably not fortuitous that, in these same areas, an important Permian volcanism occurs, on the contrary to other Hercynian areas.

These few considerations reveal that Hercynotype characterization has an internal, very articulate gradualness, and, for this reason, wider and deeper examination is necessary.

Aknowledgements. — This research was supported by the Italian Consiglio Nazionale delle Ricerche, CT 78.00246.05. IGCP Project no. 5.

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