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MICROSTRUCTURE AND MINERALOGY OF AN ORTHOGNEISS (ANTIGORIO GNEISS - LEPONTINE ALPS) **

ABSTRACT. — The different behaviour of K-feldspar (more brittle) and plagioclase (more ductile) during synkinematic metamorphism, appears to be the principal cause of the augen texture.

The orthogneiss of Antigorio is characterized by the presence of allanite, resulting from the metamorphic transformation of an igneous Fe-richer in a Fe-poorer biotite and the reaction of the released Fe^{2+} with monazite and clinozoisite. The presence of allanite seems to be a distinctive character of the medium grade orthogneisses.

RIASSUNTO. — Il diverso comportamento del K-feldspato (più fragile) e del plagioclasio (più duttile) durante il metamorfismo sincinematico sembra essere la principale causa di formazione della tessitura occhiadina negli ortogneiss granitici.

L'ortogneiss di Antigorio è caratterizzato anche dalla presenza di allanite risultante da trasformazione metamorfica della biotite con impoverimento in Fe e reazione di Fe^{2+} con monazite e clinozoisite. La presenza di allanite sembra essere un carattere distintivo di ortogneiss di medio grado metamorfico.

Introduction

The granite gneiss of the « Antigorio nappe » (Lower Pennidic nappes of the Alps, Ossola region - Italy) is part of the old Pennidic basement consisting of late-to-post Variscan granites intruded into a precarboniferous metamorphic series. Whilst other nappes (i.e. Mt. Leone) preserve the original association of intrusives and country rocks, in the Antigorio nappe only granite is recognized.

During the Alpine orogeny the basement was thrust along shear-planes localized mainly at the contacts of different lithological units and large slabs of basement rocks were thrown into nappes which piled-up rigidly in a more plastic groundmass of Permian and Mesozoic sediments. In this phase synkinematic metamorphism occurred.

After the emplacement of the major nappes the temperature began to rise; the high temperature regime outlasted the main deformation phase causing the almost static reequilibration of the textures.

A discussion of the geological setting of the area exceeds the purpose of the present work which is particularly concerned with the textural and mineralogical evolution of this monometamorphic granite-gneiss, in order to shed light upon the mechanism of formation of the granitic orthogneisses in general.

The Antigorio gneiss

The « Antigorio nappe » is a thick subhorizontal slab of a light coloured gneiss with a foliated, augen texture as the « normal » facies.

The composition ranges from granitic to granodioritic. MILNES (1965) distinguished two colour-facies depending on the biotite content (more or less than 8 % vol.).

From the textural point of view at the present state of knowledge, 3 types, with increasing degree of deformation, are recognized:

1) Nearly undeformed granite, with little or no foliation. This type is present in the higher levels of the orthogneiss body; its characteristics are:
   a) « granitic » relics of plagioclase and K-feldspar are very abundant;
   b) quartz and feldspars show little granulation;
   c) the shape and size of single feldspar crystals or monomineralic aggregates are substantially the same as in an unmetamorphosed, medium-grained, granite.

2) Orthogneiss with a gneissose to augen texture, representing the « normal » facies of the Antigorio gneiss. Feldspatic augen range from 0.5 to 2 cm. This facies is the most widespread and forms most of the Antigorio nappe: its characteristics are:
   a) the K-feldspar is frequent as relict crystals; plagioclase relics are also present but rare;
   b) subgranulation is present in K-feldspar but more evident in plagioclase which is, in many cases, replaced by polygonal aggregates of newly-formed grains;
   c) the K-feldspar aggregates (relics + subgrains) preserve shape and size similar to those of the granitic parent rock, whilst plagioclase aggregates tend to form lenses elongated in the schistosity plane.

3) Strongly foliated, laminated gneiss characteristically fine grained, with regular, parallel foliation.
   This facies is present in zones at the base or on the frontal part of the « Antigorio nappe » and in thin zones of the orthogneiss body probably corresponding to the « shear planes »; its characteristics are:
   a) the relics of K-feldspar are still present but scarce. Plagioclase relics are missing;
   b) aggregates of both K-feldspar and plagioclase are a common feature;

c) monomineralic aggregates are in the form of small, very flattened lenses of polygonal grains; only seldom relict crystals are preserved as core of K-feldspar aggregates.

Common accessories of the Antigorio gneiss are sphene, apatite and zircon. Apatite and sphene are widespread and are usually associated with biotite aggregates. Zircon is present as inclusion in biotite and allanite; no pleochroic haloes are present in biotite. The absence of monazite was verified by electron probe tests, detecting La Lα.

Feldspars

K-FELDSPAR — Microcline (high triclinic according to WENK, 1967) is always present in the Antigorio gneiss. It is very abundant as large grains in the
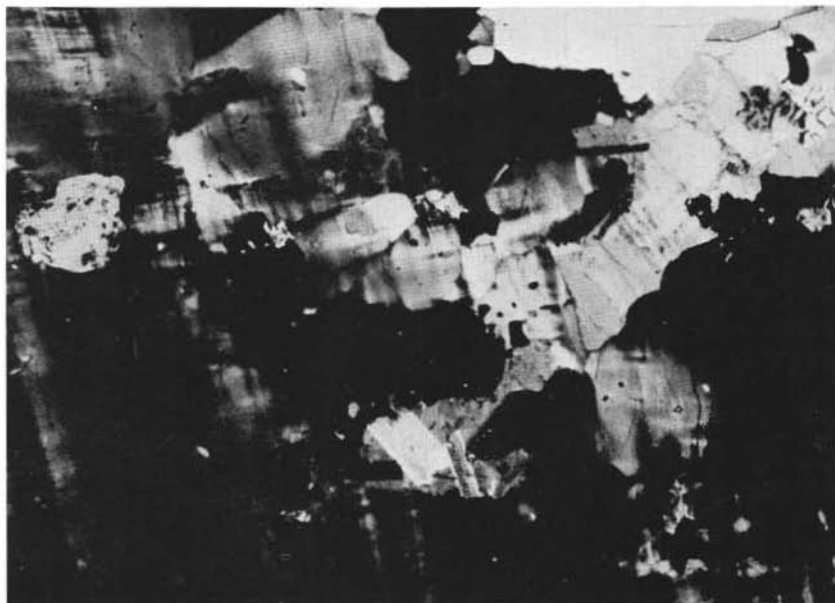

Fig. 1. — Large K-feldspar grain with microcline grid, in a poorly foliated type; the K-feldspar includes small, rarely myrmekitic, plagioclase grains. Sometimes a marginal granulation is present.

less foliated varieties and builds up the augen in the gneissic types. In this case the habit of the crystals is tabular in prisms with subhedral outlines.

The microcline twinning is visible in nearly all the K-feldspar grains, but in many cases also a relict Carlsbad twinning is present.

The largest crystals are generally perthitic; in rare cases it is possible to note small grains of included plagioclase (Fig. 1).

Marginal granulation is a common character; the subgrains are non-perthitic, undeformed and often associated with mirmekitic plagioclase.

In the more foliated varieties the K-feldspar builds up lenses of granoblastic aggregates consisting of non-perthitic and undeformed microcline, and oligoclase (± quartz).

PLAGIOCLASE — The plagioclase generally is present as two generations both in the granitic and in the normally foliated types. The first generation is represented by subhedral crystals of oligoclase with inclusions of muscovite, clinozoisite and biotite; the twinning laws are that of albite-Carlsbad and albite-pericline;

Fig. 2. — Subhedral plagioclase grain of first generation. The arrangement of the muscovite, clinozoisite and biotite inclusions delineates the outlines of a more calcic core.

anthiperthitic intergrowths are common, zoning is not evident (Fig. 2). Moreover plagioclase shows deformation bands or, at the boundaries, the formation of subgrains and of new recrystallized grains crystallographically oriented nearly as the parent grain. With increasing deformation, in the foliated types, the quantity of the relict plagioclase decreases and polygonal aggregates prevail; in the more foliated types only polygonal aggregates of plagioclase are present; characteristic is the presence of individuals with reverse zoning (Fig. 3).

The composition was determined by means of an electron microprobe on the plagioclases of first generation as well as on the polygonal aggregates: the

structural relics show an average An content slightly but constantly higher than that of the unzoned grains of the polygonal aggregates; more evident is the difference of composition between the relict plagioclase and the reverse zoned plagioclase of new generation (see Table 1).

Biotite

Biotite is virtually the only Fe-Mg mineral of the Antigorio gneiss; in fact amphibole-bearing varieties are rare and have not been considered in the present study.
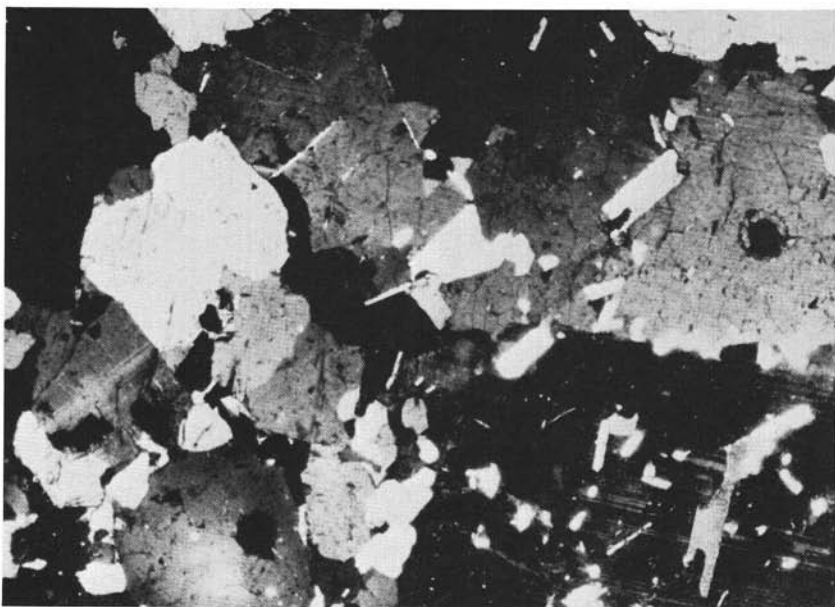

Fig. 3. — Second generation plagioclase subgrains, on the left, surrounding an albite-Carlsbad twinned first generation crystal. Reverse zoned grains are clearly visible (lower left).

The biotite is completely recrystallized and structural relics are missing, although the shape and size of the decussate aggregates of the less deformed varieties could be traced back to that of the biotite of the parent granite; the single lamellae are generally undeformed.

Muscovite, sphene, zircon, clinozoisite-epidote, often with allanite nuclei, are almost constantly present in the biotite aggregates in a very close association, whilst opaques and monazite are absent.

The colour of the biotite (Z) is generally pale, in different shades of light greenish brown or greenish yellow.

XRF determinations of Ti, Fe and Mg were performed on the biotite of different types of Antigorio gneiss (Table 2).

The TiO_2 content ranges from 1.77 to 2.82 %; it must be noted that the Ti content seems to be related to the $Mg/(MgO + FeO_{tot.})$ ratio in the sense that the higher the ratio, the lower is the Ti content of the biotite.

The $MgO/(MgO + FeO_{tot.})$ ratio ranges from 0.44 to 0.59 and is consistently higher than in the biotites from granites or granodiorites (DEER, HOWIE & ZUSSMAN, 1962).
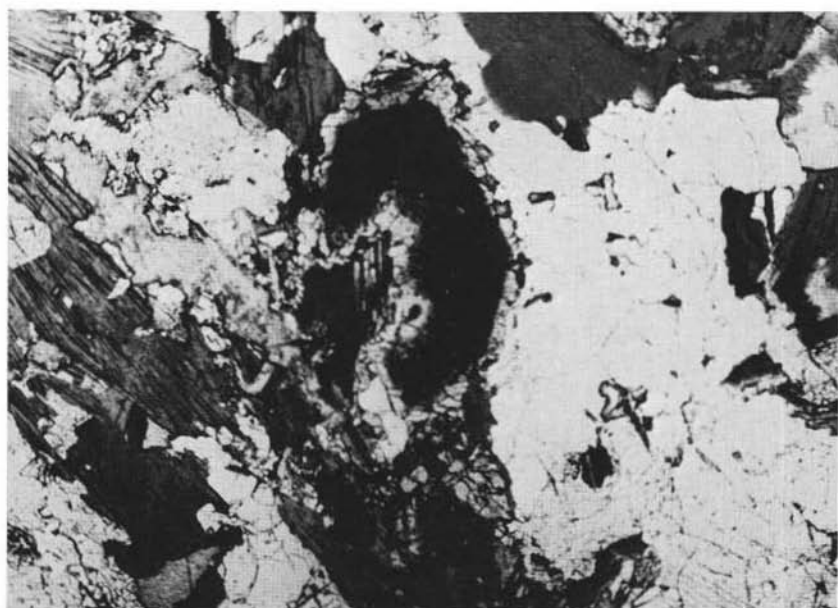

Fig. 4. — Allanite showing epidote rim, associated with biotite on the left.

An electron probe test proved that the composition of the biotite is homogeneous within the single lamellae and that the composition of the different lamellae of an aggregate is the same (less than 1 % variation in MgO and FeO content).

Clinozoisite - Epidote - Allanite

Epidote is a characteristic accessory mineral of the Antigorio gneiss. The most common type present in the rock is a rather Fe^{3+} rich variety with high interference colours, whilst the lower birefringent clinozoisite, with its anomalous interference colours, is rare.

It is possible to distinguish three types of occurrences of epidote:
1) small clinozoisite grains within the large plagioclase individuals;

2) epidote or clinozoisite xenoblasts in the quartz-feldspar aggregates;

3) relatively large grains or idioblasts with or without allanite core in close association with biotite and sphene (Fig. 4). A scan line through a zoned allanite--epidote grain (Fig. 5) shows a progressive decrease in Fe content from the core to the periphery and a sharp jump of composition at the boundary of the idioblastic allanite nucleus.
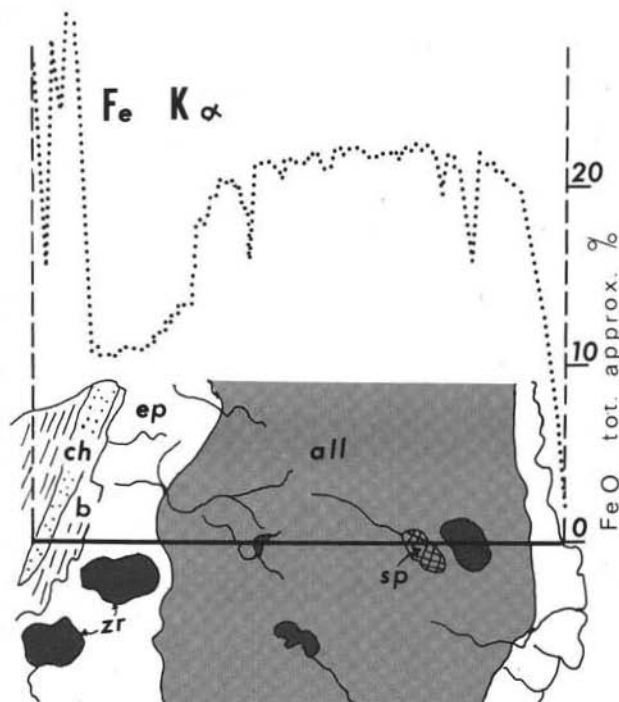

Fig. 5. — Scan-line through an allanite idioblast for $Fe_{tot.}$. Explanation in the text.   (zr = zircon, ch = chlorite, b = biotite, ep = epidote, all = allanite, sp = sphene).

Epidotes are typically undeformed and show no sign of late recrystallization. In the rare cases in which epidote is missing the rock contains opaque mineral grains, that are characteristically absent in the epidote-bearing varieties.

According to MILNES (1965) epidote is not present in the more « granitic » types of the Scheggia di Marsasca zone.

Conclusions

The comparison of the mineralogical and textural characters of the Antigorio gneiss with those of the common granites and granodiorites permits us to draw the following conclusions on the metamorphic transformations that affected the

rock. The first conclusion regards the different behaviour of K-feldspar and plagioclase during synkinematic recrystallization. The difference is that K-feldspar tends to behave more like a porphyroclast than plagioclase. The reason seems to be that recrystallization is caused not only by deformation but also by chemical instability of the parent mineral, during metamorphism.

In the particular case of the plagioclase, as well as in other complex silicates, at least a slight compositional change accompanies the recrystallization because the chemical changes increase the mobility of the dislocations (VERNON, 1976).

TABLE 1

Composition of plagioclases of sample 3966, from « Le Piode », Devero Valley. Electron-probe analysis. (c = centre, i = intermedium, p = periphery)

	SiO_2	Al_2O_3	CaO	K_2O	Na_2O	Tot.%	An %
Granitic relict							
c 62.85	22.59	5.32	.11	8.70	99.57	25.3
i 64.02	21.58	4.35	.18	9.00	99.13	21.1
i 63.34	22.67	5.06	.15	8.74	99.95	24.2
p 63.76	22.53	4.87	.09	8.88	100.13	23.2
p 63.27	22.74	4.88	.10	8.82	99.81	23.4
Zoned grains							
c 67.33	21.47	2.77	.38	9.96	101.91	13.3
i 64.94	22.10	4.13	.31	9.17	100.65	19.9
p 63.76	23.34	5.16	.29	8.54	101.09	25.1
c 66.37	20.51	2.50	.40	9.93	99.70	12.3
i 63.31	22.36	4.69	.28	8.68	99.34	23.1
p 62.41	22.61	5.05	.18	8.52	98.77	24.7

On the other hand, the presence of a high density of dislocations enhances the ionic diffusion (WHITE, 1975).

In other words, while the metamorphic compositional changes of the plagioclase favour the recrystallization, in K-feldspar, under the same temperature and stress field, consistent changes of composition do not occur and part of the strain energy is dissipated in the creation of mechanical twinning. Considered in this light, the different behaviour of plagioclase and K-feldspar appears to be the most important cause of the widespread augen texture of the granite gneisses in which the augen consist almost exclusively of K-feldspar, well beyond the « feldspar isograd » (500° according to VOLL, 1976).

In the case of the Antigorio the question arises as to whether the original granite was directly metamorphosed at the staurolite grade or whether the rock was

subjected to a more or less complete retrogressive transformation before the climax of the Lepontine metamorphism.

According to WENK (1965) the Antigorio gneiss belongs to the area in which the K-feldspar underwent monoclinization and then, on cooling, again triclinization.

As far as K-feldspar is concerned, a polyphase history is not demonstrable, but the lack of relict zoning in the first « granitic » generation of plagioclase could indicate a phase of breakdown of the An molecule previous to the reaching of the present composition. The low-temperature transformation would have been characterized by the replacement of plagioclase by albite + clinozoisite + muscovite.

Another possibility is that the lack of a relict zoning in the plagioclase is dependent on a direct metamorphic homogeneization of the igneous plagioclase.

TABLE 2

Composition of the biotites of the Antigorio gneiss

Sample	Locality	$FeO_{tot.}$	MgO	TiO_2	MgO/MgO+FeO
4386	Piedilago	18.72	8.82	2.82	.46
3999	Le Piode	19.71	9.37	2.47	.46
4343	Le Piode	18.72	10.05	2.37	.49
3996	Le Piode	15.17	12.29	1.77	.59
4001	Le Piode	20.25	9.10	2.54	.44

In any case the plagioclase had reached the present composition of the relict individuals before the main phase of penetrative deformation since the grains of the polygonal aggregates show a slightly lower An content. The only thing we can definitely rule out is that homogeneization took place after deformation because of the presence of small grains with reverse zoning (see analyses in table 1) which, in that case, would have been homogeneizated too.

The conclusion is that a complete reconstruction of the metamorphic path is impossible and only a few points can be stated with certainity.

Among these points we can surely place that regarding the composition of the original plagioclase, which on the average was more calcic than the present one, since abundant clinozoisite and epidote were formed during metamorphism.

As far as allanite idioblasts are concerned we can state that their presence is a common feature of the acid to intermediate orthogneisses but not of the corresponding intrusives. In the case under examination we note that the unmetamorphosed Variscan granites are generally free of allanite and correspondingly rich in monazite and zircon as nuclei of pleochroic haloes in biotites. According to SCHWANDER & WENK (1965) in the Lepontine gneisses no monazite is present in the epidote-bearing types while zircon is present without any pleochroic halo.

Our conclusion is that the allanite idioblasts are the product of a complex metamorphic reaction (probably through step reactions) involving transformation of the igneous iron-rich biotite into a more Mg-rich type; the released Fe^{2+} reacted with monazite and clinozoisite to give allanite. When all the La, Ce and Fe^{2+} were consumed, epidote began to crystallize around allanite taking all the available Fe^{3+}. Zircon, completely restored during metamorphism, probably did not take part in the reactions and remained as inclusion in the new biotite and in allanite. P and Ti in excess gave rise respectively to apatite and sphene, though the latter, as revealed by a semiquantitative probe analysis, is present also in allanite.

Thus, this mineral seems to be a fairly good indicator of the « ortho » origin of gneisses of granitic to tonalitic composition at least at a medium metamorphic grade. Much more work is needed on orthogneisses of different compositions, metamorphic grade and history to test these first ideas on their evolution.

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