ATTILIO BORIANI (*)

THE MICROSTRUCTURE OF « CENERIGNEISS »

RIASSUNTO. — Il « *Cenerigneiss* » litotipo assai diffuso nella « Serie dei Laghi » (Lago Maggiore, Italia settentrionale), è una migmatite gneissica la cui microstruttura permette una dettagliata ricostruzione degli eventi geologici ai quali fu sottoposta dopo l'anatessi. Nei singoli minerali è chiaramente registrata una intensa deformazione seguita da una parziale ricristallizzazione statica. Ad eccezione del quarzo, tutti i componenti sono presenti in una generazione precinematica ed in una postcinematica; il plagioclasio postcinematico presenta una struttura granoblastica poligonale mentre nelle miche la struttura è decussata. Anche in assenza di peciloblasti è possibile una dettagliata ricostruzione della storia della roccia grazie alla sua microstruttura particolarmente significativa. L'analisi con microsonda elettronica rivela che il plagioclasio di prima generazione presentava una zonatura normale.

SUMMARY. — The « *Cenerigneiss* », a very widespread rock type of the « Serie dei Laghi » (Lake Maggiore, Northern Italy), is a gneissic migmatite in which the microstructure permits a detailed reconstruction of the various phases to which this rock was submitted after anatexis. A strong deformation and a successive partial recrystallization are clearly recorded in the texture of the single minerals. With the exception of quartz, these are present in a pre-kinematic and in a post-kinematic generation, the latter showing a granoblastic polygonal (plagioclase) or a decussate (micas) texture. Even in the absence of poikiloblasts, a detailed reconstruction of the metamorphic history of the rock was possible due to its very specific and significant microstructure. Electron microprobe analysis reveals that the original plagioclase had a normal zoning.

The « *Cenerigneiss* » (BÄCHLIN, 1937; REINHARD, 1964; BORIANI, 1968) is an important member of the « Serie dei Laghi », one of the two units in which the « Massiccio dei Laghi » is divided, the other

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being the well-known « Serie dioritico-kinzigitica Ivrea-Verbano ». This gneiss occurs on both sides of Lake Maggiore in continuous elongated bodies interbedded into the paragneisses of the « Paragneiss e migmatiti della Serie dei Laghi » formation (BORIANI, 1970).

The mesoscopic appearance of these rocks is remarkable for the presence of abundant xenoliths, ranging in composition from fine-grained gneisses to calc-silicate fels, of various shapes and dimensions; lineation is often very strong but schistose, non-lineated types are also found.

Their mineral assemblage consists of: quartz-plagioclase-biotite-muscovite ± K-feldspar ± garnet ± Al-silicates (kyanite and/or sillimanite). Accessory minerals are: zircon, apatite, ores.

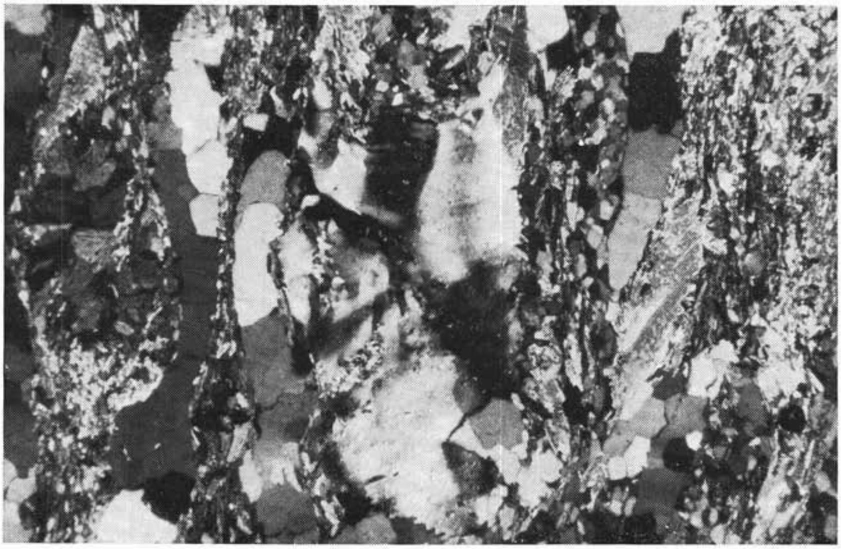

Fig. 1. — Typical texture of a « *Cenerigneiss* » of the 2nd level from the Pogallo valley. Large lamellae of deformed mica (center) are bordered by tiny undeformed lamellae and by granulated plagioclase. On the left an aggregate of myrmekitic plagioclase. Crossed nicols 40 ×.

A feature of the microstructure of « *Cenerigneiss* » (Fig. 1) is the presence of two generations of the fundamental minerals, with the exception of quartz. *Plagioclase* is mostly present in the form of lenses or cylindrical aggregates of nearly polygonal small grains, with intergranular muscovite lamellae, sometimes surrounding relics of deformed plagioclase. *Micas* form aggregates showing a decussate texture; in the center of these aggregates a broad deformed lamella is often present, clearly replaced by the new generation of mica.

Quartz appears in only one generation in the form of flattened phacoids or thin beds showing a transversal division into subgrains.

Garnet is present in the form of inclusions in biotite or in small round grains in a fine grained muscovite matrix, often associated with *kyanite* (the most widespread Al-silicate).

K-feldspar, when present, is in the form of relic augen replaced more or less completely by myrmekitic plagioclase, plagioclase-muscovite-quartz aggregates or by granulated polygonal microcline.

The origin of « *Cenerigneiss* » was explained in several ways by the various authors. Bächlin (1937) grouped them among « *Mischgneise* » with prevailing sedimentary material, recognizing their migmatitic and para-derivate character. Their texture, though compared with the glomerogranular, is explained by a sort of unspecified blasto-cataclastic process.

Reinhard (1964) regards these rocks as true paragneisses and explains their texture as the result of a metamorphic recrystallization « frozen » in its initial stage.

Boriani (1968) explained the non-equilibrium paragenesis and the presence of xenoliths with a differential anatexis and tentatively referred the « glomerogranular texture » to a slow process of crystallization from the anatectic melt and the granulation of plagioclase to the restored metamorphic conditions after anatexis.

Plagioclase.

Four types of plagioclase may be distinguished:

1) Granulated *Polygonal plagioclase* with intergranular muscovite.
2) *Relic plagioclase.*
3) *Myrmekitic* (granulated non-polygonal) *plagioclase.*
4) *Plagioclase* in *plagioclase-muscovite-quartz aggregates.*

The granulation of plagioclase is certainly the most striking feature of these rocks and can be found, with very rare exceptions, only in « *Cenerigneiss* ». The individual polygonal grains range in diameter from 0.1, or less, to a maximum of about 0.5 mm and their polygonality decreases with increasing size. They are generally slightly zoned and untwinned except for some grains showing rare twin lamellae; these may be interpreted as *annealing twins.*

The relic plagioclase is only seldom found in the granulated polygonal areas and is more frequent (BORIANI, 1968) near the northern boundary of the main « *Cenerigneiss* » level in the Ponte Casletto (Val Grande) zone. Relics are generally untwinned and show clear signs of deformation. Their replacement by the recent polygonal plagioclase proceeds inwards from boundaries and fractures (Fig. 2).

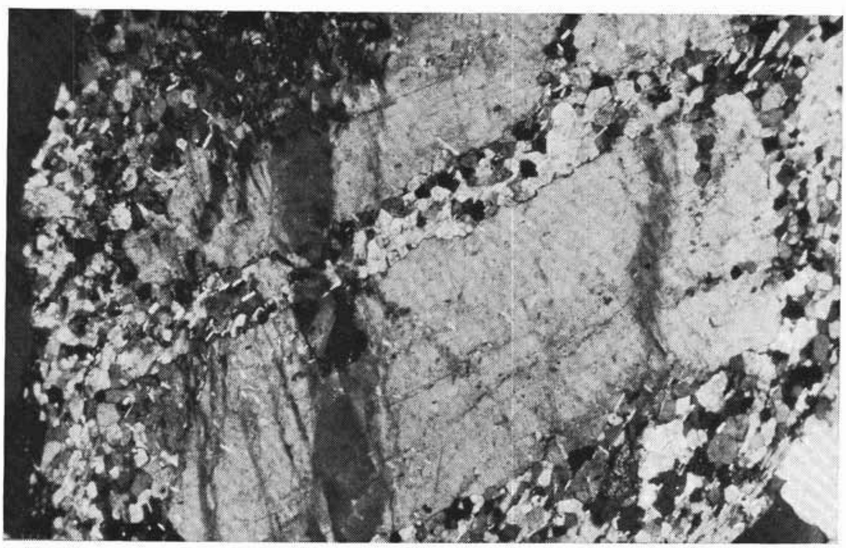

Fig. 2. — Replacement of the relic deformed plagioclase by a new generation of granulated plagioclase, showing a granoblastic polygonal texture. Crossed nicols 120 ×.

Electron microprobe analysis of An and Or content (Tab. 1 e 2) on relic and polygonal plagioclase shows a marked decrease of An-content from the relic towards the small grains, while the same thing seems to happen for Or.

The origin of this structure may be traced back to a process of thermal (static) metamorphism which followed a strong deformation

TABELLA 1.

Microprobe analysis of a « *Cenerigneiss* » plagioclase (relics surrounded by small polygonal grains). S. Ci 7 (co-ord. 60399401) near Cicogna.

	CaO	Na_2O	K_2O
relic 1	4,54	8,91	0,23
	(4,67-4,36-4,65-4,48)	(8,87-9,13-8,83-8,80)	(0,19-0,26)
polygonal grain 1a	4,49	9,08	0,17
1b	4,10	9,40	0,17
1c	3,84	9,48	0,17
1d	2,94	9,96	0,17
relic 2	3,58	9,62	0,21
	(3,52-3,61-3,59-3,59)	(9,60-9,71-9,75-9,42)	(0,21)
polygonal grain 2a	3,97	9,46	0,14
2b	3,80	9,44	0,14
2c	2,63	10,23	0,14
2d	2,55	10,27	0,14
relic 3a	3,91	9,27	0,14
	(3,78-4,04)	(9,43-9,12)	(0,14)
relic 3b	4,67	8,96	0,16
	4,81-4,52)	(8,83-9,09)	(0,16)
polygonal grain 3a	3,08	10,07	0,10
	2,48	10,27	0,09
	(2,59-2,36)	(10,31-10,22)	(0,09)

The second decimal is only added. Underlined values are averages of the various measuring-points (in brackets) in the same grain; the relic plagioclase 3, showing distinct variations, was measured in two (a and b) places. Standards were: Ca = wollastonite, Na = albite, K = orthoclase. All elements were measured at 20 KV; rough percentages were corrected with the modified Springer program, using code KF 11. Polygonal grains are arranged with increasing distance from the relic.

TABELLA 2.

Mol. % end members:

	An	Ab	Or
relic 1	35,7 (34,2-36,6)	63,3 (62,4-64,8)	1,0
polygonal grain 1a	35,1	64,1	0,8
1b	32,3	66,9	0,8
1c	30,7	68,5	0,8
1d	24,4	74,8	0,8
relic 2	28,9 (27,9-29,5)	70,1 (69,5-71,1)	1,0
polygonal grain 2a	31,6	67,9	0,7
2b	30,6	68,7	0,7
2c	22,0	77,3	0,7
2d	21,4	77,9	0,7
relic 3a	31,6 (30,5-32,6)	67,7 (66,7-68,8)	0,7
relic 3b	36,6 (35,2-37,3)	63,0 (62,0-64,0)	0,7
polygonal grain 3a	25,1	74,4	0,5
	21,0 (20,2-21,8)	78,6 (77,8-79,4)	0,4

Note: A relative error of maximal 2% should be considered.

of the rock; relics represent the central, less deformed, part of the original grains which escaped recrystallization. It is possible to explain the An decrease towards the periphery of the granulated plagioclase areas in two ways:

a) The original plagioclase had a normal zoning and the formation of the equilibrium texture resulted in a lattice reorientation of the mechanically polygonized grains respecting compositional differences.

b) The original plagioclase was unzoned, static metamorphism was prograde and recrystallization took place with increasing temperature. The presence of muscovite lamellae and the lowering of Or-content in the polygonal grains seem to favour this second hypotesys, but the constant size of the individual polygonal grains speaks in favour of a constant temperature during the process.

Nevertheless it must be noted that in some relic plagioclases several muscovite lamellae may be seen oriented in the same directions as those present in the surrounding grains; it is possible that the sometimes parallel arrangement of these lamellae in the polygonal areas lacking of the central relic might be traced back to the crystallographic orientation of the original plagioclase.

In the investigated area it may be seen that the polygonal « *Cenerigneiss* » plagioclases increase in size towards NW, i.e. with growing metamorphic grade (Fig. 3). This circumstance suggests a more com-

Fig. 3. — Second generation plagioclase of a « *Cenerigneiss* » of the 2nd level. Grain size is bigger than in the 1st level and not very different from that of quartz (bottom). Crossed nicols 50 ×.

plete (static) recrystallization at higher temperature. As it was previously noted, the size increase entails a decrease in polygonality: boundaries become curved and angles at triple points tend to differ more and more from 120°. This leads to a progressive disappearance of the most striking feature of « *Cenerigneiss* » texture.

Plagioclase is present in big grains in the « *Cenerigneiss* » at the top of M. Zeda, without any trace of deformation or polygonization.

The nature of the rock can be identified only by the presence of Ca-silicate xenoliths and by following step by step the evolution of « *Cenerigneiss* » microstructure towards NW.

The *myrmekitic plagioclase* forms rims around the K-feldspar relics; often the K-feldspar is lacking and completly replaced by the granulated non-polygonal myrmekitic plagioclase (Fig. 4). As its derivation from the replacement of K-feldspar is certain, and its post-kinematic age is equally sure, what is the reason for its lack of polygonality in comparison with the non-myrmekitic plagioclase? It must not be forgotten that replacement of K-feldspar by plagioclase and quartz is not a simple process of recovery, but involves some exchange of ions between feldspar and the surrounding environment.

Furthermore, it is well-known in metallurgy (BÉRNARD J., MICHEL A., PHILIBERT J. & TALBOT J., 1969) that recrystallization temperature is as much lower as the purity of metal is higher; if the same rule can be applied to minerals it is possible that the presence of quartz inclusions will affect the grain boundary energy of myrmekitic plagioclase.

Fig. 4. — Myrmekitic plagioclase originated by replacement of an original K-feldspar. Note the curved interfaces and the non-equilibrium angles at triple points. Crossed nicols 60 ×.

Until now it has not been possible to state the exact composition of this plagioclase, but the extreme fineness of the quartz worms suggests a very low An-content.

The other type of plagioclase present in the « *Cenerigneiss* » is much rarer than those considered above, and often grades into the myrmekitic type. Xenoblasts of plagioclase are intergrown with quartz and muscovite as alternative replacement product of K-feldspar. It is possible that the reaction between K-feldspar and Al-silicate is involved in this type of transformation.

K-feldspar.

This mineral, almost always showing microcline grid and perthitic structure, is not always present in « *Cenerigneiss* » and it is impossible to see any distinctive trend in its distribution. In a series of specimens through the main horizon its presence was noted in the southern as well in the northern part while it is absent in the central.

Even if the K-feldspar may be lacking, its products of transformation are almost always present, i.e. myrmekitic plagioclase or the plagioclase-muscovite-quartz aggregates described in the preceding paragraph (Fig. 5).

Fig. 5. — Among the replacement products of K-feldspar, besides the myrmekitic plagioclase (center), plagioclase-muscovite-quartz aggregates (top) may be also found. Crossed nicols 60 ×.

It is noteworthy that a marginal replacement of the K-feldspar relics by small polygonal grains of the same mineral may be observed in some rare circumstances (Fig. 6). In contrast this is very common in the « *flaser gneiss* » (BORIANI, 1970) and demonstrates that the latter is even more extremely deformed than « *Cenerigneiss* ». The K-feldspar was not found in the northernmost horizon.

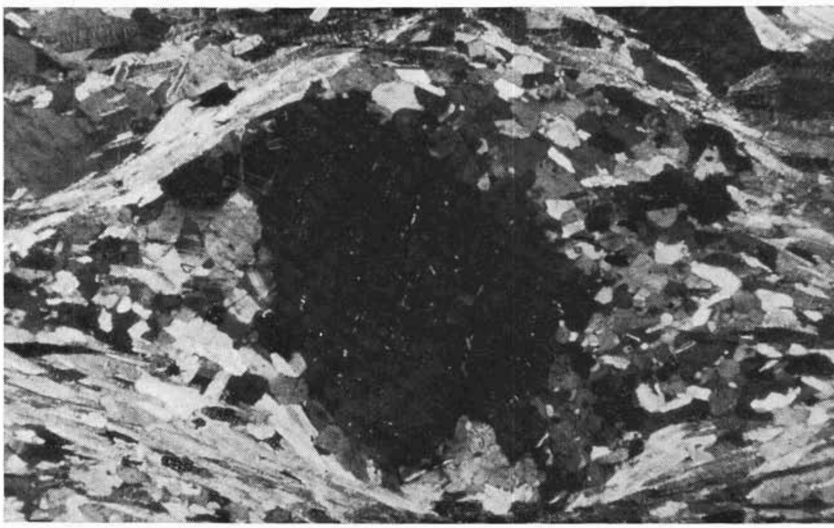

Fig. 6. — Pre-kinematic K-feldspar replaced by granoblastic polygonal K-feldspar of 2nd generation. This type of replacement is rather uncommon in « *Cenerigneiss* ». Crossed nicols 60 ×.

Micas.

Micas are also present in two generations; though biotite and muscovite show more or less the same features it is worthwhile considering their behaviour separately.

Biotite. This is present almost everywhere as aggregates showing a decussate texture, i.e. without any particular orientation except in the more schistose varieties in which this feature may be considered as *mimetic*. In the center of these aggregates relics of deformed biotite of first generation may sometimes be seen. Since the quantity of recrystallized mica, at constant temperature, depends upon the amount of deformation, the frequency of distribution of relic biotite is significant. This is a maximum in the northernmost part of the main level, analogously to what may be observed in the case of plagioclase. It is therefore highly probable that this part was the less intensely deformed. Relics are also very frequent in the more schistose varieties of the second level; this may be attributed to a partial syn-kinematic

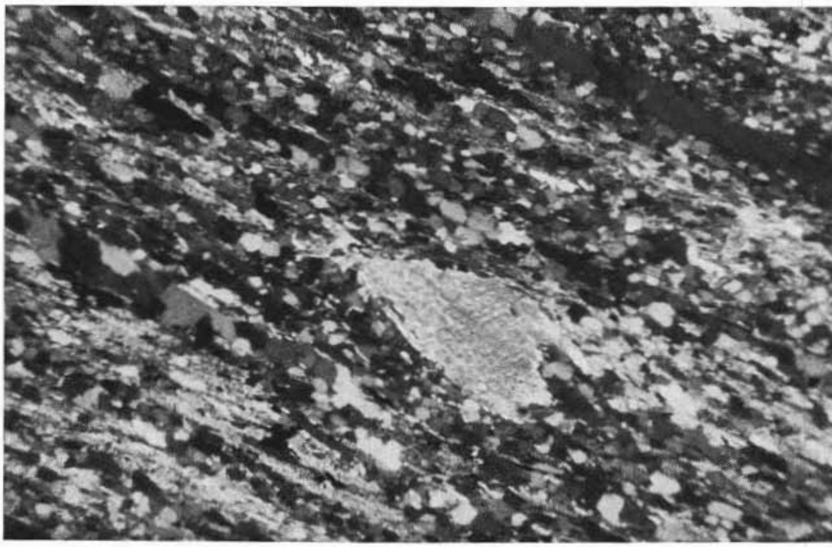

Fig. 7. — Broad pre- (syn- ?) kinematic lamella of muscovite in a schistose « *Cenerigneiss* ». Note the narrow and continuous layers of quartz alternating to the granoblastic polygonal plagioclase layers containing 2nd generation micas. Crossed nicols 60 ×.

recrystallization of biotite during the deformation of these « *Cenerigneisses* » at higher metamorphic grade.

Muscovite. The distribution of relic muscovite (Fig. 7) shows an inverse pattern in comparison to that of biotite, i.e. it is more abundant in the southern than in the northern part of the main level. The different behaviour of muscovite might alternatively traced back to:

a) late (pre-, syn-kinematic) recrystallization of muscovite, compared with that of biotite, in the southern part;

b) different behaviour of this mineral to the recovery process even at slightly different temperatures. Since during the static phase the temperature seems to increase towards NW, it is reasonable that the recovery process was more intense to the N than to the S.

It must be noted that muscovite is more abundant in the southern than in the northern part, whatever its texture and origin. In addition to the relics and the new muscovite with decussate texture, muscovite is also present originated by replacement of K-feldspar or due to the reaction: K-feldspar + Al-silicate + $H_2O \leftrightharpoons$ muscovite + quartz. *Kya-*

Fig. 8. — Small kyanite idioblasts in a matrix of 2nd generation biotite showing decussate texture. Plane pol. light 100 ×.

nite is sometimes still present, together with *garnet*, in this new-formed muscovite; more frequently (BORIANI, 1968) kyanite is found in biotite and garnet in muscovite (Figg. 8 and 9).

In the northernmost horizon in muscovite contorted swarms of *fibrolite* (*sillimanite*) appear, and these must be considered of late formaion (static phase); it must be remembered that in these rocks relic kyanite is often coexistent with sillimanite.

Quartz.

This is the only mineral present in a single generation (with the exception of that formed by reaction in the replacement products of K-feldspar) in the form of large grains or flattened phacoids divided into subgrains wiht slightly disoriented optical orientation. A preliminary survey on quartz microtectonics shows an intense preferential orientation of [0001] as confirmation of its synkinematic recrystallization. Division into subgrains may be considered as having occurred in the static phase.

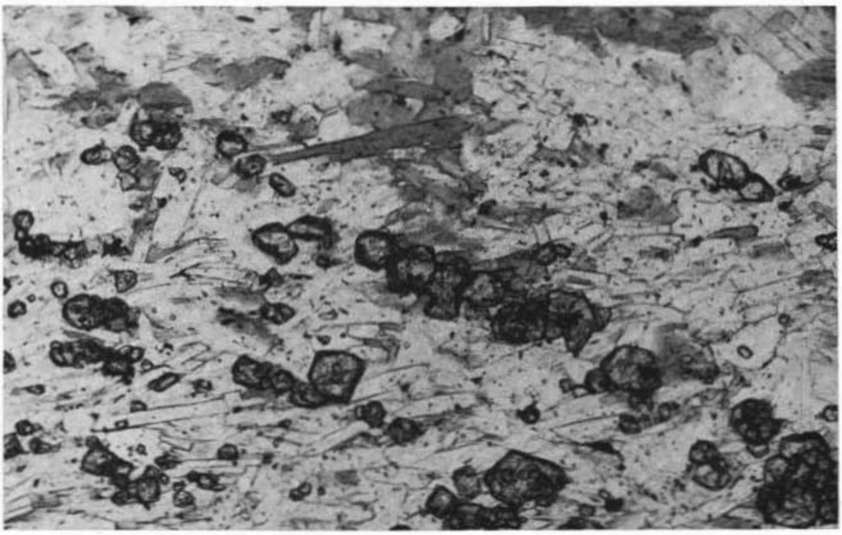

Fig. 9. — Small garnet grains in a fine grained muscovite matrix with minor biotite. Plane pol. light 100 ×.

Conclusions.

The mesoscopic and microscopic characters of the « *Cenerigneisses* » point to the following evolution of the tectonic and metamorphic processes:

1) Anatexis of a paragneiss derived from a series of graywackes with marl intercalations. Crystallization from the melt of a rather coarse-grained migmatitic rock of unknown texture with calc-silicate xenoliths (Boriani A. & Clerici Risari E., 1970).

2) Extreme deformation of the rock in a phase of folding (or re-folding) of the whole complex; the folding caused the reiteration of several layers of « *Cenerigneisses* » throughout the present series. During this phase new schistosity and lineation were created (S_2 and L_2 when referring to the whole zone). The intensity and the type of

deformation in the various parts of their zone of occurrence determined the new texture to be more or less schistose or lineated. To this kinematic phase may be attributed the syn-kinematic recrystallization of quartz, and probably of part of the micas. Quartz in nearly monocrystalline layers, flattened lenses, or cylindrical bodies divided into strongly iso-oriented subgrains was certainly recrystallized during this phase.

3) Static phase which determined the process of recovery with formation of equilibrium textures in the recrystallizing minerals of 2nd generation starting from the strained pre- (and partially syn-?) kinematic crystals. During this phase the temperature was increasing towards NW and recrystallization was less complete in the southern than in the northern part. In the latter the pre-kinematic crystals were almost completely cancelled while elsewhere they were at least partially preserved, especially in the less deformed portions. The granoblastic polygonal plagioclase and the decussate micas belong to this phase; also transformations like replacement of K-feldspar by myrmekite or plagioclase-muscovite-quartz aggregates must be related to this event.

Though the relic plagioclase does not show any trace of zoning, this could be detected by means of electron microprobe analysis of the polygonal grains surrounding relics of pre-kinematic plagioclase. In fact, the decrease observed in An- (and Or-?) content from the relic towards the periphery of the polygonal aggregates may be referred to a pre-existing zoning in the original grain.

The metamorphism during anatexis and successive crystallization was of *kyanite type*, while during the last static phase it turned to a *lower pressure type* as can be sustained by the instability of K-feldspar and the presence of new-formed sillimanite needles in muscovite in a kyanite-bearing rock.

The age of anatexis is thought (Boriani, 1970) to be Caledonian, while the static phase, and probably also the intermediate kinematic phase, are referred to the Hercynian orogeny.

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