ATTILIO BORIANI (*)

BLASTOMYLONITES AND RECRYSTALLIZED MYLONITES

SUMMARY. — Geological evidence points to a formation under metamorphic conditions of an important fault, the « Pogallo Line », cutting the « Massiccio dei Laghi », a high grade metamorphic complex near Lake Maggiore (Northern Italy).

Mylonites from this fault show a more or less developed synkinematic recrystallization in the matrix but not in the porphyroclasts.

The degree of recrystallization depends upon the mineral composition of the rocks affected by the cataclasis.

In the light of these observations, the terminology of blastic mylonites is critically reviewed. The author proposes a distinction between *blastomylonites*, with synkinematic recrystallization only in the matrix, and *recrystallized mylonites*, where recrystallization also affects the porphyroclasts and is essentially younger than cataclasis.

RIASSUNTO. — L'evidenza geologica indica che la « Linea del Pogallo », importante faglia che attraversa le rocce del « Massiccio dei Laghi » in prossimità del Lago Maggiore (Italia Settentrionale), si è formata in condizioni metamorfiche.

Le miloniti di questa faglia mostrano una ricristallizzazione più o meno intensa della matrice ma non dei porfiroclasti.

Il grado di ricristallizzazione dipende dalla composizione mineralogica delle rocce interessate dal fenomeno cataclastico; alla luce di queste osservazioni viene riveduta criticamente la terminologia delle miloniti che mostrano fenomeni di ricristallizzazione.

L'autore propone una distinzione tra *blastomiloniti* che mostrano ricristallizzazione sincinematica soltanto nella matrice e *miloniti ricristallizzate* nelle quali la ricristallizzazione interessa anche i porfiroclasti ed è un fenomeno essenzialmente tardivo rispetto alla cataclasi.

Introduction.

The geological mapping of that part of the « Massiccio dei Laghi » which lies between the Ossola Valley and Lake Maggiore (Northern Italy), revealed the presence of a major structural element: the « Pogallo Line ».

(*) Istituto di Mineralogia, Petrografia e Geochimica dell'Università di Milano. Lavoro eseguito nell'ambito delle ricerche del Centro di Studi sulla Stratigrafia e Petrografia delle Alpi Centrali di Milano del C.N.R.

This fault divides the metamorphic complex in this area into two tectonic units; these do not coincide with the lithologic units commonly distinguished (« Serie dei Laghi » - « Serie Diorito-kinzigitica ») but consist of a southeastern zone, to which the name « Ceneri Zone » of the Swiss geologists can be extended, and of a northwestern zone entirely formed by rocks of the « Serie Diorito-kinzigitica ».

The southern section of that part of the « Pogallo Line » which has been mapped up to now was recently described by BORIANI (1970a). The results of this investigation indicate that this tectonic line is old, certainly pre-Alpine and probably Hercynian. This age can be inferred from the fact that its formation follows the Hercynian folding, since it cuts across the planar and linear structures originated by this folding while it essentially precedes the intrusion of the Granites of the Lakes.

The connection between these late-Hercynian granites and the fault is evident; equally evident appears the connection between the granite formation and the static final phase of the Hercynian metamorphism where anatectic phenomena of great importance are not lacking (BORIANI & PEYRONEL PAGLIANI, 1968).

The geological evidence therefore points to a formation of the « Pogallo Line » under metamorphic conditions; in the structural evolution of the whole complex it seems to represent a phase of uplift of the Hercynian orogenic belt, since the final static metamorphism shows lower pressure characters, demonstrated by the instability of the kyanite-bearing assemblages.

The « Pogallo Line » is marked in the field by a layer of mylonites sometimes reaching the thickness of hundred meters; since the fault plane cuts across the schistosity of the country rocks, the mylonites are derived from a wide range of lithologic types.

Two important conditions are therefore present in these mylonites:

a) formation under metamorphic conditions,

b) wide compositional range of the rocks involved.

To these must be added the almost complete lack of retrogressive reactions or neomineralizations in the mylonites.

A detailed survey of these rocks seemed to me worthy of interest; from the very beginning this study revealed that the terminology of

« mylonites l. s. » is far from being adequate to a non-ambiguous definition of these rocks. The problem is not only restricted to the terminology but also involves the interpretation of the relationships between deformation and recrystallization.

Terminology of the mylonites l. s.

It does not seem necessary to re-examine carefully the terminology of these rocks, since the detailed studies of MALARODA (1946), KNOPF (1931) and others are still completely valid today, especially as regards the rocks where the cataclasis prevails over recrystallization by far. From not always clear and unequivocal sources these authors drew a classification still adequate to the petrographic demands. A confirmation can be obtained from the reading of the recent book of SPRY (1969), on metamorphic textures (p. 229). Spry introduced the amendments of HSU (1955) and CHRISTIE (1963) but essentially accepted Knopf's classification of the mylonites s.s.

Malaroda accepted the two terms « Mylonitgneiss » (QUENSEL, 1917) and « Blastomylonite » (SANDER, 1912) for rocks where recrystallization plays a more important role. Mylonitgneiss was considered synonimous to « augen-schist » (LAPWORTH, 1885) and « flaser rock » (TYRRELL, 1926). For Malaroda the difference between the two types depends on the degree of recrystallization which, in the blastomylonites, also affects the porphyroclasts.

In my opinion the term « flaser rock » is to be preferred to the obsolete « mylonitgneiss » but does not apply to true mylonitic rocks, also in the light of the studies of KATZ (1968) on the formation of the flaser fabric in the granulites of Mont Tremblant Park (Quebec); the process is recognized as essentially crystalloblastic without a true cataclasis. The prefix mylonit- therefore seems unnecessary.

Malaroda's definition of blastomylonite is: (a rock in which) « only minor traces of cataclasis are present while not only the whole matrix, but also the porphyroclasts have been more or less recrystallized.

It is important to observe that while Sander very clearly defined other terms (see for example: « Phyllonit », SANDER, 1911), he did not define the term blastomylonite equally well. Many authors attributed different definitions to Sander or used the term according to their

personal opinion. STAUB (1915) used the term to define rocks in which recrystallization only affected the matrix and not the porphyroclasts. WENK (1934) attributes to Sander the following definition « . . . ganz oder zum Teil regenerierte Mylonit », involving a postkinematic recrystallization of the rock.

SPRY's (1969) definition is rather similar: « Blastomylonite is a mylonite in which late recrystallization is so pronounced that the original cataclastic nature can only be recognized with difficulty, if at all. It is convenient to distinguish between *hartschiefer* in which only matrix has been recrystallized and *blastomylonite* in which both the matrix and lenticles or porphyroclasts have been recrystallized ». It is to be noted that while Spry mentions Knopf in the definition (together with a wrong reference to Sander), KNOPF (1931) says that « the eyes are still cataclastic although the paste has crystallized. A blastomylonite is produced by a deformation which is partly ruptural and partly crystalloblastic, *not by a rehealing crystallization of a previously mylonitized rock* ».

Moreover it seems unjustified to insert the term *hartschiefer* in the table of p. 229 (SPRY, 1969) as intermediate type between mylonites and blastomylonites. The original definition of « hartschiefer » has mainly a textural meaning and refers only in part to a more or less advanced recrystallization.

« Mylonitgneiss » and « Hartschiefer » are therefore rather flimsy and disused terms. It remains *blastomylonite* but its definition is so wide and vague as to be referred to rocks with very different fabric and history.

From the given definitions by the different authors for the term mylonite, and first of all by its creator, LAPWORTH (1885) such a term must be used to indicate rocks connected with non-penetrative discontinuities originated by crushing and milling along horizons of restricted thickness.

Mylonites, though schistose by definition, in contrast with cataclasites, are dark-colored and massive rocks sometimes with a flinty appearance scattered with more or less abundant porphyroclasts and that hardly permit a recognition of the nature of the original rock. The suffix or the prefix -mylonit- must therefore indicate mylonite-like rocks connected with more or less old faults.

Their fabric does not match the concept of a penetrative deformation (in a large domain such as a pre-, para-, or postcrystalline folding). It is in fact known that many rocks originated by regional metamorphism contain relict minerals belonging to older crystalloblastic phases and showing post-crystalline deformations (for example: augen gneisses, flaser gneisses, granulites etc.). I therefore consider it unjustified to call all these rocks blastomylonites.

It is my opinion that a blastomylonite must be intended as « the produce of crushing of preexisting rocks along faults which were active under metamorphic conditions, for example during a static episode following a folding phase with penetratve regional character ».

The crystalloblastic character of such mylonites is therefore essentially synkinematic, even if at the end of deformation the survival of the metamorphic conditions might cause more or less evident equilibrium fabrics in the mylonitic matrix. It is also my opinion that uncertainities in blastomylonite definition were originated by a scanty knowledge of the distinctive criteria between synkinematic and static fabrics; these criteria are now well known from the recent contribution to the interpretation of microstructures supplied by other sciences, such as ceramics and metallurgy.

Given the geologic relevance of the *blastomylonitic character* of the mylonites from the different faults, especially those of regional importance, it seems worth while to consider in detail the various features that characterize and the factors that determine the observable fabrics.

The mylonites of the « Pogallo line ».

The mylonites of the « Pogallo Line » originate from different rock types, the most interesting of which are:

a) augen gneisses,

b) biotite-sillimanite schists,

c) amphibolites.

Augen gneisses. These rocks belong to the « Serie dei Laghi » where they crop out in elongated bodies that are part of folds with very steep axes; till now it was not possible to state if they are in the cores or

in the limbs of these folds, although it seems more likely that they form the cores.

In thin section the mylonites of augen gneiss (Fig. 1) are recognized by the relative scarcity of mica and abundance of feldspar. The matrix is formed by quartz and crushed feldspar with tiny flakes of mica.

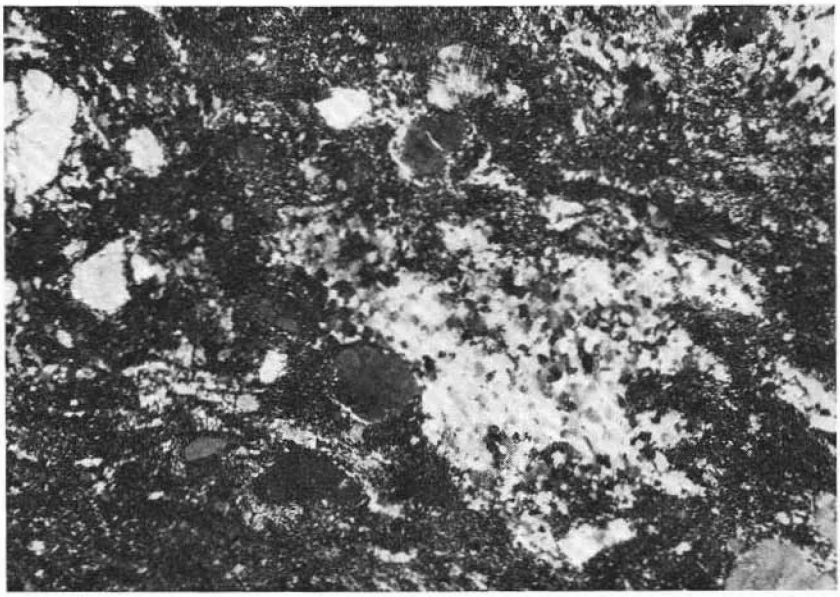

Fig. 1. — Augen gneiss mylonite. Almost polygonal and strongly iso-oriented quartz aggregates (center right), crushed feldspar (fine grained dark part) and mica flakes form the matrix. The porphyroclasts are of microcline and plagioclase. Crossed nicols 35 ×.

Quartz has been entirely recrystallized and shows a rather polygonal fabric; quartz layers are bent around porphyroclasts. The insertion of the quartz plate reveals the strong iso-orientation of this mineral. Recrystallization is therefore synkinematic even if post-kinematic grain boundary migration originated a quasi-polygonal texture.

The crushed feldspar (Fig. 2) shows a grain size smaller than quartz and does not appear to have been recrystallized since the grains show a random optical orientation. Crushed feldspar normally sur-

rounds porphyroclasts. There is no trace of recrystallization in the porphyroclasts, which always show strong post-crystalline deformations.

Biotite-sillimanite schists. This rock type belongs to the « Serie Diorito-kinzigitica » and, in the section of the « Pogallo Line » under consideration, crops out on its western side. In this case porphyroclasts

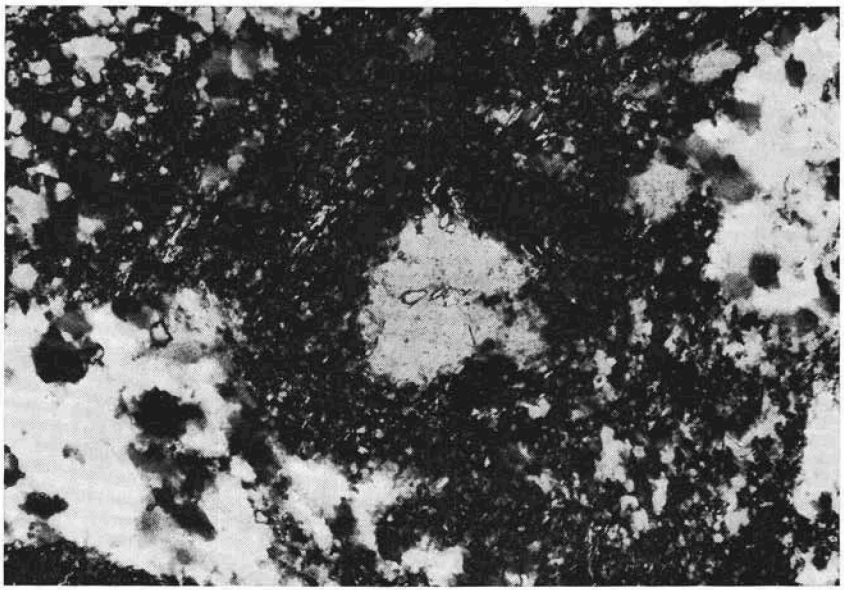

Fig. 2. — Augen gneiss mylonite. A plagioclase porphyroclast surrounded by fine grained feldspar matrix. Quartz has been clearly recrystallized. Crossed nicols 80 ×.

consist of mica, plagioclase, garnet and sometimes staurolite. Quartz, crushed plagioclase and mica flakes form the matrix (Fig. 3).

The presence of mica among the porphyroclasts is due to its great abundance in the original rock. The ratio porphyroclasts/matrix is highly variable and depends mainly upon the relative abundance of plagioclase in the different layers.

Crushed plagioclase is rather scarce in the matrix while quartz is abundant and shows a notable degree of recrystallization and iso-

orientation; in some instances the quartz grains coalesce in broad monocrystalline lenses or ribbons (Fig. 4). Minor recrystallization can be observed also in the mica flakes of the matrix.

Amphibolites. Amphibolites are present in both the units cut by the fault although they are by far more abundant in the schists of the

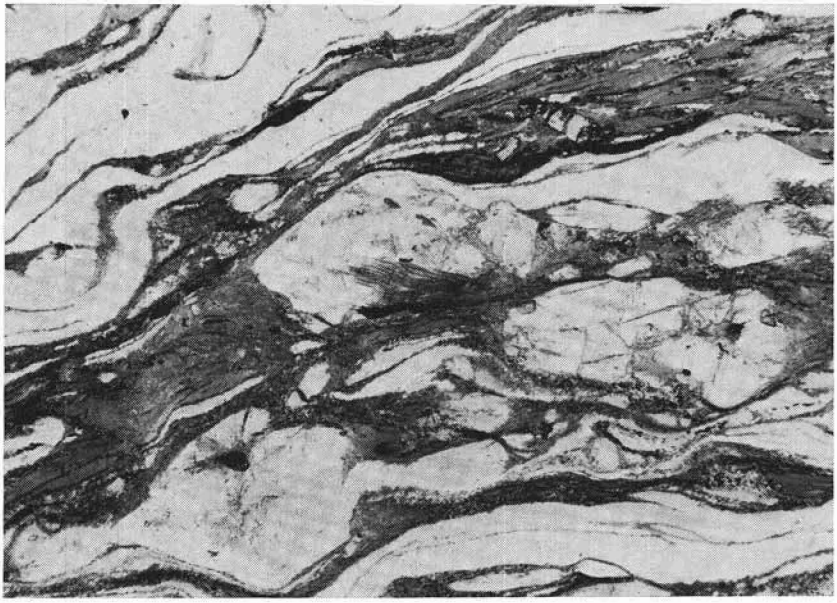

Fig. 3. — Biotite-sillimanite schist mylonite. Note the stability of biotite, sillimanite needles (center), staurolite and feldspar, which shows little, if any, trace of alteration. Plane pol. light 35 ×.

« serie diorito-kinzigitica ». They form intercalatons of limited thickness; mylonites from these rocks can be recognized by their dark green color in contrast to the dark gray or brown of the other mylonites.

In thin section (Fig. 5) they show very peculiar textural characters in which porphyroclasts and matrix are formed by the same minerals, i.e. hornblende and plagioclase. Biotite is very scarce and is present either enclosed in the amphibole porphyroclasts or as tiny flakes in the matrix. Plagioclase is the principal constituent of the matrix

and is completely recrystallized, as is shown also by its rather uniform optical orientation. Recrystallization is clearly synkinematic and boundaries have interlobate shape; also amphibole and biotite in the matrix show traces of syn- and late-kinematic recrystallization (see for example the polygonal arches of hornblende and biotite around the porphyroclasts, Fig. 6).

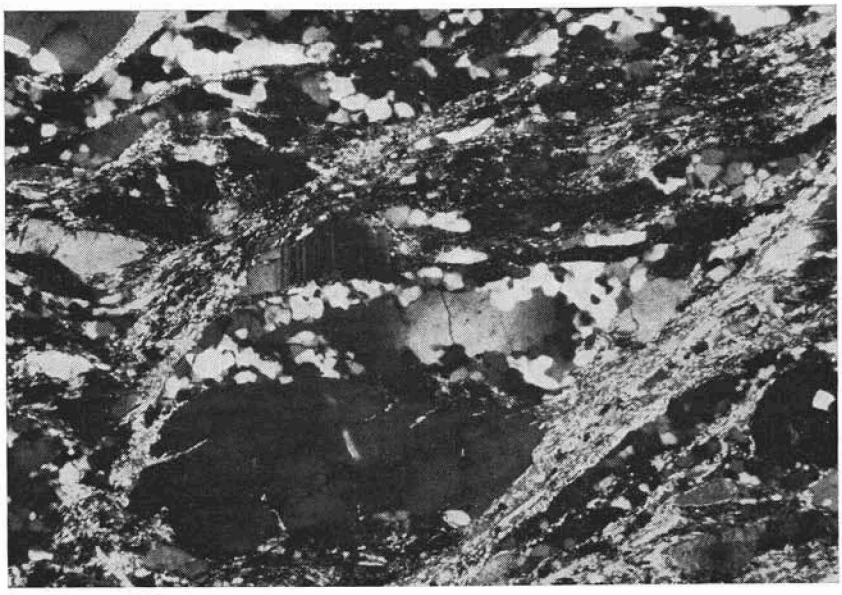

Fig. 4. — Biotite-sillimanite schist mylonite. The recrystallized quartz grains of the matrix sometimes coalesce to form a monocrystalline lens (center). Crossed nicols 60 ×.

The observation of these three mylonitized different rock types enables several conclusions to be reached on the behaviour of minerals during mylonitization under metamorphic conditions.

Spry divides the minerals of crystalline rocks into three groups:

1) brittle minerals such as feldspar,

2) somewhat ductile minerals with some glide properties such as mica, amphibole, pyroxene and olivine,

3) minerals which recrystallize easily, such as quartz and calcite.

It may be shown that in the presence of minerals of group 3) those belonging to groups 1) and 2) behave exactly as anticipated by this classification; feldspars form porphyroclasts or are crushed in a matrix without recrystallization; micas are twisted and frayed and the result-

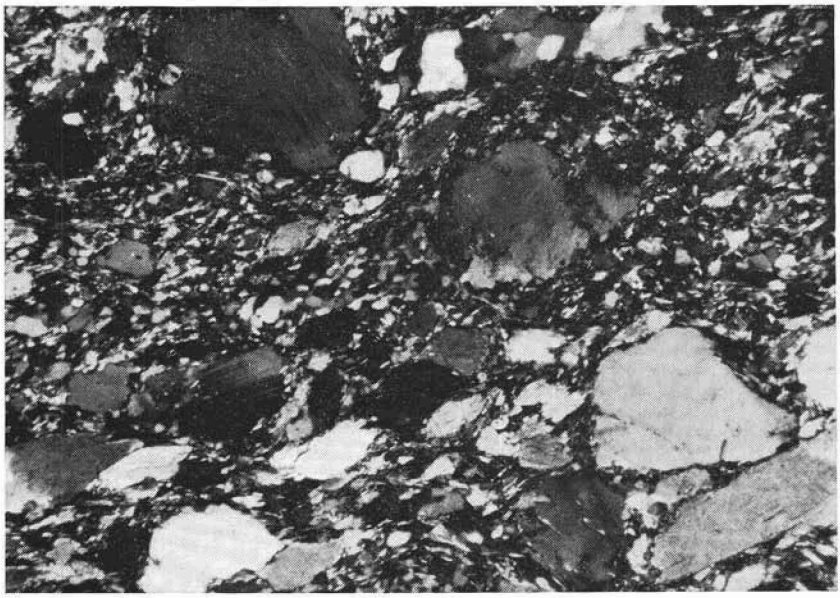

Fig. 5. — Amphibolite mylonite. Porphyroclasts and matrix are formed by the same two minerals, which are present in two generations, a pre-kinematic and a synkinematic one. Crossed nicols 35 ×.

ing tiny flakes are stirred up in lenticular or ribbon-like aggregates together with feldspar grains. Only part of this mica recrystallizes, but when it is particularly abundant it also forms porphyroclasts.

When quartz is absent, such as in the amphibolites, plagioclase must behave, under metamorphic conditions, like a mineral of group 3), i.e. it recrystallizes in the matrix originating a kind of crystalloblastic mortar fabric with porphyroclasts showing post-crystalline deformation surrounded by small grains of synkinematic recrystallization.

From the characters observed it can be concluded that, under sur-

viving metamorphic conditions, as sustained by the geologic evidence and by the absence of retrogressive metamorphism, mylonites are formed whth a synkinematic recrystallization in *the matrix* and that the nature of recrystallized minerals depends upon the relative abun-

Fig. 6. — Amphibolite mylonite. The amphibole has recrystallized (center) as well as plagioclase in the groundmass. Crossed nicols 80 ×.

dance of the species showing different behaviour under a strong deformation.

Porphyroclasts are *never* recrystallized and always maintain the strain energy accumulated during deformation. This character can be defined *blastomylonitic* and its evaluation must be based on the observation of mylonites deriving from different lithologic types.

The geologic relevance of the blastomylonitic character of the mylonites present in a fault is obvious as it enables the unravelling of the connection of non-penetrative tectonic discontinuities with the metamorphic events.

Blastomylonites and recrystallized mylonites.

In contrast with the characters observed in the mylonites of the « Pogallo Line », it was noted that in the mylonites of an auxiliary fault of the « Canavese Line » (NW of the « Massiccio dei Laghi »),

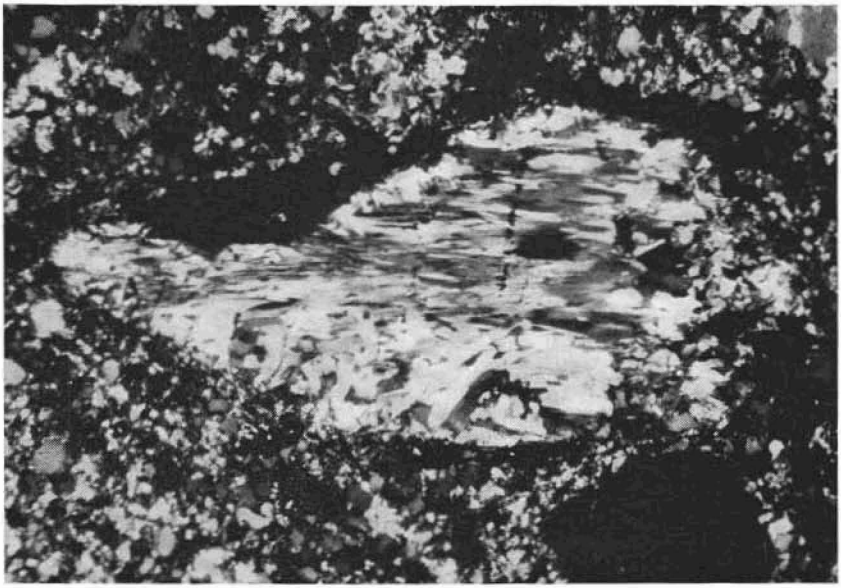

Fig. 7. — Melanocratic granulite mylonite of the « Canavese line » (Finero). A porphyroclast of pyroxene has been replaced statically by a new formed amphibole with decussate texture. Crossed nicols 80 ×.

which suffered a post-kinematic metamorphism under lower metamorphic conditions, several porphyroclasts showed a late recrystallization.

These mylonites, clearly originating from basic granulites of the « Ivrea-Verbano » zone, show porphyroclasts of pyroxene replaced by an aggregate of amphibole with decussate texture; this texture is typically an equilibrium, i.e. a static character (Fig. 7).

I therefore propose to place a limit between *blastomylonites* and *recrystallized mylonites* where the recrystallization either affects or does not affect the strained porphyroclasts.

Blastomylonites or mylonites with more or less pronounced *blastomylonitic character* show an essentially synkinematic recrystallization of the matrix, while *recrystallized mylonites* suffered a post-mylonitic recrystallization which also affected the strained porphyroclasts.

It might be argued against this division that the two terms are equivalent since both mean mylonite with recrystallization. It is my opinion that the term blastomylonite evokes a contemporaneousness of deformation and recrystallization while the second term is more suitable to indicate a succession of the two phenomena. Examples of static recrystallization of strained pre-kinematic minerals are shown by many tectonites such as, for example, the « Cenerigneiss » (BORIANI, 1970b).

Aknowledgements.

The author wishes to express his gratitude to Prof. R. Malaroda and to Prof. H. J. Zwart for their critical reading of the manuscript.

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