# Textural map units in quartzo-feldspathic mylonitic rocks<sup>1</sup>

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Received April 17, 1986

Revision accepted February 6, 1987

The classical macrotextural subdivision of quartzo-feldspathic mylonitic rocks yields only three rock types: protomylonite, mylonite, and ultramylonite. This restriction impedes detailed mapping of the internal textural transitions common in wide, deep-seated, crustal-scale shear zones, where such transitions may occur over kilometres and involve several clearly mappable textural types. The introduction of two objectively defined field mapping terms, "homoclastic" and "heteroclastic," describing the macroscopic grain-size distribution within the porphyroclast population provides descriptive flexibility without changing the matrix – porphyroclast basis of the established classification. This allows the description of textural paths other than protomylonite  $\rightarrow$  mylonite  $\rightarrow$  ultramylonite and facilitates the consideration of textural paths in terms of strain partitioning between the constituent grains of the deforming aggregate, rather than as a simple function of finite strain.

La classification classique des roches mylonitiques quartzo-feldspathiques ne fournit que trois roches-types : protomylonite, mylonite et ultramylonite. Ceci nuit à la cartographie detaillée du passage progressif d'une texture mylonitique à l'autre qui dans le cas des zones cisaillantes majeures peut s'effectuer sur des kilomètres. On propose ici deux adjectifs, propres à l'étude sur le terrain, qui décrivent la gamme de taille de grain dans la partie porphyroclastique de la roche et qui introduisent une certaine souplesse dans la description sans changer pour autant la base traditionnelle de la classification des mylonites. Ceci doit permettre de décrire d'autres séquences évolutives que protomylonite  $\rightarrow$  mylonite  $\rightarrow$  ultramylonite et de considérer l'évolution des textures mylonitiques en termes de la répartition de la déformation entre les grains de la roche plutôt que de simplement la relier à l'intensité de la déformation finie.

Can. J. Earth Sci. 24, 2065-2073 (1987)

#### Introduction

A map of textural transitions (macrotexture; cf. crystallography "texture") in mylonitic rocks is the first step in the description of the potential paths that evolving mylonitic textures have followed and the elucidation of the processes involved in mylonitization. The setting up of field mapping units necessitates an objective or descriptive classification of the rock types involved. The established textural classification of mylonitic rocks is based upon the simple volumetric ratio of matrix to porphyroclasts. This scheme, however, only yields three rock names, protomylonite, mylonite, and ultramylonite, which are often, perhaps simplistically, equated with lower to higher magnitudes of finite strain, respectively. This limited classification often suffices for mapping narrow (<1 km) belts of mylonitic rocks formed at shallow structural level and at low metamorphic grade. They are relatively sharply bounded and show relatively abrupt internal textural transitions, which may be adequately mapped as simple lines. However, the classification is clearly deficient when mapping in major, crustalscale mylonite zones, tens of kilometres wide, wherein the textural transitions may occur over several kilometres and include several mappable textural types.

Textural variation within the feldspar porphyroclast population of quartzo-feldspathic rock, at the protomylonite – mylonite or the mylonite – ultramylonite transitions, is more apparent to the naked eye than is the more subtle textural variation in the matrix fraction. This contribution proposes a simple modification of the existing mylonite terminology based upon the distribution of grain sizes within the porphyroclast population of quartzo-feldspathic mylonitic rocks, which results in a straightforward six-fold classification. This allows the description of textural paths (i.e., sequences of textural evolution) other than protomylonite  $\rightarrow$  mylonite  $\rightarrow$  ultramylonite and facilitates consideration of textural paths in terms of strain distribution between the constituent grains of the deforming aggregate, rather than as a simple function of finite strain magnitude. The terminology can be further refined by the user using the qualifiers "coarse" and "fine," according to the local geology. The new terms will first be intoduced, then discussed.

#### **Definitions**

In mylonite terminology, "porphyroclasts" are very loosely defined as grains larger than those grains constituting the matrix (Higgins 1971, p. 76). "Matrix" is loosely defined as a finer grained fraction of the rock derived by dynamic grainsize reduction by recrystallization during ductile deformation. Considerable confusion is introduced into the classification by attempts to place an absolute upper size limit on the matrix grain size, because different authorities select different sizes and some even consider size irrelevant to the definition (e.g., Bell and Etheridge 1973; White *et al.* 1980; White 1982). These latter workers, while defining mylonitic rocks as "fault rocks," were still constrained by the tripartite textural classification, whatever the grain size of the matrix.

The purpose of this paper is pragmatic: to propose generally applicable and easily identifiable field mapping units. It is not my intention to enter into the ongoing semantic debate (e.g., Zeck 1974; White 1982; Tullis *et al.* 1982; Wise *et al.* 1984; Mawer 1986) about what should or should not be called a mylonite. However, in a discussion of mylonite classification, a definition of mylonite is necessary. If mylonites are ductile fault rocks and if ductile faults or shear zones are relatively high strain zones (Sibson 1977; White *et al.* 1980), then mylonitization is simply the manifestation of the intensive operation of crystal-plastic strain mechanisms, accommodated principally by recrystallization (Tullis and Yund 1985). I therefore offer the following, borrowed freely from Bell and

<sup>&</sup>lt;sup>1</sup>Geological Survey of Canada Contribution 47086.



FIG. 1. Homoclastic quartzo-feldspathic mylonitic rocks. (A) Coarse, poorly foliated K-feldspar megacrystic granite. Note coarse, nearly isotropic nontectonic matrix to megacrysts. (B) Strongly foliated, finely homoclastic protomylonite tectonically derived from a parent material very similar to (A). (C) Finely homoclastic mylonite. Note increase in matrix/porphyro-clast ratio compared with (B) and abundant attenuated polycrystalline ribbons of feldspar and quartz. (D) Ultramylonite. (A) – (D) represents a progressively developed textural path. Coin, 2.4 cm.



Fig. 2. Heteroclastic quartzo-feldspathic mylonitic rocks. (A) Coarsely heteroclastic protomylonite derived from a parent similar to that in Fig. 1.4. Note low proportion of fine poly-crystalline ribbons of feldspar and quartz between porphyroclasts. (B) Coarsely heteroclastic mylonite. Note variable porphyroclast size and abundant ribbons in volumetrically important matix. (C) Matrix-rich, coarsely heteroclastic mylonite, transitional to heteroclastic ultramylonite. (D) Heteroclastic "sugary" ultramylonite. (A) – (D) represents a progressively developed textural path. Coin, 2.4 cm.

Etheridge (1973, p. 347). A mylonite is a foliated rock, commonly lineated and generally containing porphyroclasts set in a finer grained matrix, which occurs in planar zones. The matrix is an aggregate of daughter grains, the products principally of dynamic recrystallization, which are significantly finer than their parent grains. A grain size reduction of two orders of magnitude is "significant." This definition is not purely descriptive; it is not meant to be. It requires that the geologist can reasonably deduce the order of magnitude of the grain size of the parent material, either from relic coarse grains (hence the inclusion of prophyroclasts in the definition) or by identifying the specimen as part of a progressive textural path leading back towards the parent material (see below).

## Protomylonite, mylonite, and ultramylonite

The textural classification of mylonitic rocks, well established since the early part of the century, has been comprehensively reviewed by Higgins (1971) and White (1982). With the exception of the common term "blastomylonite," it would seem futile to seek to fundamentally change the historically established textural basis of the protomylonite-myloniteultramylonite series (Sibson 1977). Protomylonite transforms to mylonite when the volumetric matrix/porphyroclast ratio exceeds 50%, and mylonite transforms to ultramylonite when the volumetric matrix/porphyroclast ratio exceeds 90% (Higgins 1971; Sibson 1977). Given the greater resolution of the microscope compared with the naked eye or hand lens, field and laboratory estimates of the matrix/porphyroclast ratio may differ significantly. In the absence of an established minimum size for porphyroclasts, I suggest that the names protomylonite, mylonite, and ultramylonite apply primarily to the macroscopic description of mylonitic rocks.

The term "blastomylonite" is an unfortunate legacy of the first half of this century, stemming from the long-held misconception that mylonitic rocks are the product of cataclasis (e.g., Higgins 1971), i.e., fracturing and the rotation of fragments (grinding and crushing). Some mylonitic rocks were shown to have undergone recrystallization (in one sense or another), and a special term was used to designate these "recrystallised mylonites": blastomylonite. Confusion soon took root, since it is often not clear whether the worker using the term implied a syntectonic recrystallization or post-tectonic grain growth (see Zeck 1974, p. 1071). However, since it is now well established (e.g., White 1973; Bell and Etheridge 1973; White et al. 1980) that grain refinement in mylonitic rocks occurs by dynamic primary recrystallization (Hobbs et al. 1976) driven by the reduction of stored strain energy and involving subgrain rotation and bulge nucleation (Nicolas and Poirier 1976; Poirier and Guillopé 1979), it would appear redundant to use blastomylonite to designate syntectonic recyrstallization in mylonites. Furthermore, much statistically homogeneous, straight-banded gneiss may be essentially secondarily recrystallized (Hobbs et al. 1976) mylonitic rock (e.g., Myers 1978; Davidson et al. 1982; Davidson 1984), but such gneisses rarely carry porphyroclasts. Hence they are no longer in themselves identifiable as mylonitic, and unless a textural path can be established, to map them as such is subjective interpretation.

### Homoclastic and heteroclastic

Textural variation in a relatively fine grained matrix fraction is less readily discernible to the naked eye than in a relatively coarse relic porphyroclast population. Two simple adjectives are introduced here to qualitatively describe the grain-size distribution in the porphyroclast population (Fig. 1). I emphasize the qualitative nature of these adjectives and will couch their definitions in pragmatic terms useful in the field situation. "Homoporphyroclastic," readily shortened to "homoclastic," is an adjective applied to a mylonitic rock wherein most (i.e., two thirds by volume) of the porphyroclast population constitutes a self-evident dominant size class (Figs. 1A-1D). "Heteroporphyroclastic" or "heteroclastic" applies where the frequency of porphyroclast size is perceptibly spread across the size range, i.e., either because several size classes dominate the size distribution or because all size classes are equally represented (Figs. 2A-2D). Hence a mylonitic rock (X) comprising of 25% matrix containing 1-20 mm diameter porphyroclasts (75%), of which 75% measure 10 mm is a homoclastic protomylonite. A similar mylonitic rock (Y), with a 1-20 mmporphyroclast grain size that is more evenly spread over the size classes, is a heteroclastic protomylonite. As a second example, a mylonitic rock (V) comprising 95% matrix containing 1-20 mm porphyroclasts (5%), of which 75% measure 10 mm, is a homoclastic ultramylonite, whereas a similar rock (W), with a 1-20 mm porphyroclast grain size that is more evenly spread, is a heteroclastic ultramylonite. Homoclastic and heteroclastic mylonites are defined along the same lines (Figs. 1 and 2). These terms may be further qualified as in "coarsely" or "finely" homoclastic or heteroclastic mylonitic rocks. Coarse and fine here only apply to the porphyroclast population of the rock. They in no way apply to the matrix fraction (see, however, White et al. 1982, p. 46). The absolute limits of coarse and fine must depend upon local conditions. In a given mapping area, if porphyroclasts in protomylonites are commonly larger than 50 mm, then examples of X and Y above might be called finely homoclastic and finely heteroclastic protomylonites, respectively. If, in the same area, porphyroclasts in ultramylonites are rarely larger than a few millimetres, then examples V and W would be coarsely homoclastic and coarsely heteroclastic ultramylonites, respectively. It suffices that the geologist indicate the size limits selected. Again, it is emphasized that "homoclastic" and "heteroclastic" are field terms. Because of greater optical resolution, the porphyroclast population of any protomylonite or mylonite, indeed of many ultramylonites, will be perceptibly heteroclastic under the microscope.

It is sometimes useful to distinguish mylonitic rocks in the field on the basis of matrix-fraction grain size. From experience, I find that two simple objective cases are pertinent here. Either one can or cannot distinguish individual matrix grains. In the former case the matrix is "sugary," and in the latter case it is macroscopically "aphanitic." Use of such terms would avoid potential confusion that might arise from describing the mylonite matrix fraction as "coarse" (e.g., White *et al.* 1982).

#### **Textural paths**

The established protomylonite – mylonite – ultramylonite (PMU) series tacitly implies a sequential macrotextural development from left to right. In the terminology of studies of progressive strain and of cleavage development (e.g., Flinn 1962; Le Corre 1979), this is but one of several possible textural paths commonly observed in the field. It is dependent on the existence of relatively stiff grains, commonly feldspar in quartzo-feldspathic rocks, which undergo dynamic recrystallization less readily than those parent grains, or parts of grains,



grains. Bulk strain was equally accommodated by the parent (pretectonic) matrix grains and megacrysts. (B) Plagioclase-porphyroclast-rich, coarsely heteroclastic mylonite (lower field) juxtaposed by very finely homoclastic mylonite to ultramylonite (upper field). As seen from mapping, both are derived from megacrystic parent rocks. The upper field parent rock was syntectonically intruded into the lower field host, yet grain-size reduction is more advanced in the younger material. The textural evolution of the two rocks was influenced by the higher plagioclase/K-feldspar ratio in the older parent rock. (C) Secondary porphyroclasts in aluminous paragneiss derived by the growth of plagioclase porphyroblasts. (D) Photomicrograph of a plagioclase porphyroclast from (C) with a central core marked by an internal wall of sillimanite (arrows) overgrown by an optically continuous rim. Photo long dimension 3.7 mm (plane-polarized light). Coin in (A) - (C), 2.4 cm. FIG. 3. (A) Relatively low strain ultramylonite. The outlines of the original K-feldspar parent megacrysts are still clearly visible as polycrystalline elongate aggregates of new daughter



FIG. 4. (A) Generalized geology and location of the Great Slave Lake Shear Zone at the boundary between the Slave Craton (ruled) and the Churchill Province (dotted), Canadian Shield.

contributing daughter grains to the matrix fraction (PMU path). However, under P-T conditions of the amphibolite facies and in the presence of sufficient water, both K-feldspar and plagioclase recrystallize dynamically (e.g., Vidal et al. 1980; Tullis and Yund 1980; Hanmer 1982). K-feldspar megacrysts in granite may recrystallize rapidly relative to the strain rate (Fig. 3A) such that no porphyroclasts remain, although the outlines of the K-feldspar parent grains are still readily apparent, i.e., the rock is an ultramylonite. Here, either the PM stage of the PMU series was drastically telescoped into the initial strain increments, or it was never developed (U path). Alternatively, protomylonite can pass transitionally into ultramylonite with no intervening mylonite stage (PU path). For example, after transition from coarsely to finely homoclastic protomylonite, the next textural stage may be the disappearance of the vast majority of the porphyroclasts leading directly to an ultramylonite.

Many permutations are possible and are best described phenomenologically, borrowing once more from the terminology of progressive strain (e.g., Means *et al.* 1980; Lister and Williams 1983), in terms of the partitioning of strain between the matrix and porphyroclast fractions of the rocks. If, as predicted by the general model of strain softening (e.g., Watterson 1975; Poirier 1980; White *et al.* 1980), the bulk imposed strain rate is preferentially partitioned into the finer grained matrix, porphyroclasts may be expected to survive large increments of finite strain (PMU path). In other words, if the strain mechanism is even partly recrystallization accommodated (Tullis and Yund 1985), then the ratio of the local recrystallization rate and the bulk imposed strain rate (recrystallization/strain rate ratio) will be relatively high in the matrix and relatively low in the porphyroclast fraction. The recrystallization/strain rate ratio may vary among the porphyroclast population as a partial function of mineral composition, reflecting the influence of the latter on grain-scale rheology (Fig. 3B). Alternatively, if the bulk imposed strain rate is equally partitioned among the component grains of the rock, regardless of initial grain size or composition, variation in the recrystallization/strain rate ratio may be relatively minor and porphyroclasts would not survive even a moderate increment of finite strain (U paths: Fig. 3A). The above represent two idealized cases or end-member textural paths between which natural examples may fall (e.g., PU path). The factors influencing distribution of the bulk strain rate will include those that are particularly pertinent to dynamic behaviour in the feldspars, i.e., microcracking, space lattice symmetry, phase compositions, porphyroclast spacing as well as pressure, temperature, metamorphic atmospheric composition, strain rate, etc. (e.g., White 1975; Vidal et al. 1980; Tullis and Yund 1980; Hanmer 1982).

It must be emphasised that mapping textural transitions shows that the recrystallization/strain rate ratios, and hence the

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FIG. 4 (concluded). (B) A detail of (A). Broken wiggly lines are observed faults. Location given in (A). See text for discussion.

partitioning of the bulk strain rate between matrix and porphyroclasts, vary during progressive strain. For example, a coarse porphyroclast population may survive a PMU textural path leading to coarsely homoclastic ultramylonite, a progression traceable on the ground over several kilometres; then abruptly (spatially at least) the coarse (several centimetres) porphyroclasts may disappear into the matrix because of dynamic recrystallization. It is not appropriate to speculate here on the causes of such variation in recrystallization/strain rate ratio, though they must concern the factors listed above. Suffice it to reiterate that pertinent study will be best undertaken on samples whose textural context is known from detailed mapping of textural transitions.

### Secondary porphyroclasts

The classical PMU mylonite series implicitly assumes (1) that all of the material now constituting the rock was derived from the parent rock and (2) that the porphyroclast fraction is primary, that is to say, derived only from original grains of the parent rock that initially were at least as coarse as the porphyroclasts now present. Some flexibility with respect to these assumptions is warranted (e.g., Wintsch and Knipe 1983). However, wholesale intrusion and subsequent deformation of

new material, e.g., pegmatite veins, during the development of a mylonitic texture in the invaded rock can abruptly alter the matrix/porphyroclast ratio of the bulk rock. Similarly, the wholesale growth of large (centimetres) feldspar porphyroblasts during the deformation, with or without significant influx of new material, which subsequently undergo strain and grain-size reduction, can increase the porphyroclast fraction of the rock (Figs. 3C and 3D). Such "introduced" porphyroclasts are here termed secondary. Sometimes it is obvious when secondary porphyroclasts are present and (or) volumetrically important, e.g., isolated trains of porphyroclasts derived from pegmatite veins. Very often it is not! Where secondary porphyroclasts are volumetrically important, they can result in a reversal of textural development with ongoing deformation such that an ultramylonite could develop syntectonically into a rock that has the textural attributes of a mylonite or even a protomylonite. I feel that this is so contrary to the general conception of the significance of mylonitic textures that mylonite terminology should not be applied where the geologist is aware of extensive secondary porphyroclast development. A term such as "porphyroclastic gneiss" (e.g., Davidson et al. 1982; Davidson 1984) is perhaps more appropriate.

#### **Texture versus strain**

It follows from the preceding discussion that a map of textural types in mylonitic rocks is not necessarily a qualitative representation of the spatial variation of bulk finite strain. In other words, a protomylonite could represent high bulk finite strains associated with strong partitioning of the strain into the matrix fraction. Similarly an ultramylonite could represent relatively low bulk finite strain associated with equal partitioning of the strain throughout the component grains of the rock. Therefore, textural paths should not automatically be equated with finite strain gradients in the absence of independent strain markers. It should also be noted that the grain-size distribution in the parent material may strongly influence the grain-size distribution in the mylonitic rock derived from it. However, the relationship is not simple, and depending on the nature of the strain-rate partitioning between the grains of the deforming rock, a coarse, equigranular parent rock can transform to a coarsely heteroclastic mylonite as readily as a coarse megacrystic granite can transform to a finely homoclastic mylonite.

By way of an example, Fig. 4 is a map of part of the Great Slave Lake Shear Zone (GSLSZ), a 25 km wide dextral transcurrent structure, located at the boundary of the Slave and Churchill provinces in the northwestern Canadian Shield (Hanmer and Lucas 1985; Hanmer and Connelly 1986). The GSLSZ was active at all metamorphic grades from granulite to lower greenschist facies. Figure 4B illustrates the geology of a section of the greenschist to the lower amphibolite-facies part of the shear zone. The principal features of the map are the following: (1) The generally straight boundaries of the mylonitic map units contrast with (2) the locally highly irregular boundaries of the mylonitic map units southeast of Second Lake. (3) The mylonitic map units are discontinuous along strike. (4) The boundaries of the mylonitic map units are variably transitional; i.e., ultramylonite may be juxtaposed with rocks ranging from homoclastic protomylonite (see northwest of Spike Lake) to texturally diverse mylonite or heteroclastic ultramylonite. Of themselves, these features are not surprising. However, the foliation in the mylonitic rocks (not shown) is everywhere vertical and 060° in strike (i.e., parallel to the Laloche River). If the mylonitic map units were a simple qualitative representation of the variation in strain intensity, then the textural map units should not be straight (cf. (1) above). Furthermore, where the textural map unit pattern is complex, the foliation pattern would reflect this and anastomose (e.g., Bell 1985, Fig. 1).

#### Conclusion

The initial mapping and process-oriented study of the textural evolution of mylonites in wide, deep-seated, crustal-scale shear zones are hampered by the inflexibility of the tripartite textural classification of mylonites. The classical protomylonite  $\rightarrow$  mylonite  $\rightarrow$  ultramylonite textural path is only one of several possible paths. The terms "homoclastic" and "heteroclastic," which refer to grain-size distribution in the porphyroclast population of the mylonitic rock, introduce greater flexibility to the classification without altering its fundamental basis. They allow the description of textural paths other than PMU and enable the map maker to consider the textural development of mylonites in terms of the partitioning of the bulk imposed strain rate between the constituent grains of the rocks, rather than simply as a function of increasing finite strain.

### Acknowledgments

Steve Lucas and Jim Connelly, my field assistants in recent years, provided a foil for ironing out the bugs in practically applying the ideas embodied in this paper. Thanks go to Jack Henderson for critically reading an early version of the manuscript.

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