DEPARTMENT OF MINES AND ENERGY
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MICROSTRUCTURAL DEVELOPMENT OF MYLONITES NEAR COWELL, EASTERN EYRE PENINSULA, SOUTH AUSTRALIA.

GEOLOGICAL SURVEY

BY

A.J. PARKER
Regional Geology Division

D.M. No.: 68/822

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ABSTRACT

A mylonite zone near Cowell on Eyre Peninsula has developed by progressive deformation and recrystallisation of high grade gneisses during a regional fold event. Within the mylonite zone it is possible to distinguish two groups of rocks, those rocks that still retain much of their original character but which are visibly strongly deformed (mylonitized gneisses), and those rocks in which the new fabric has obliterated most of the original texture and fabric (slaty mylonite). The microstructural development of these particular groups corresponds with, respectively, recrystallisation of mica and recrystallisation of feldspar. It is believed to represent a sequence of recrystallisation starting with quartz outside of the mylonite zone and progressing to mica then feldspar within the zone. The importance of dynamic recrystallisation is emphasized.

INTRODUCTION

By contrast to Lapworth's (1885) definition of mylonite in which the concepts of cataclastic grinding or milling were inherent, recent literature has emphasised the importance of dynamic recrystallisation accompanying ductile deformation (e.g. Bell and Etheridge, 1973; Hobbs et al., 1976; Sibson, 1977). In this paper the microstructural development of a major mylonite zone near Cowell on Eyre Peninsula, South Australia, is examined in detail in order to demonstrate its progressive development, its mode of formation and the timing of that formation.

Mylonites on Eyre Peninsula have not been widely reported in published literature and the only mention of them is by Mawson (1907, p. 74) who noted the presence of "thick strata of highly crushed rock" near Tumby Bay, and by Glen et al. (1977) who record its extensive development along the length of eastern Eyre Peninsula.

This paper represents part of a major structural study by the author in the area west of Cowell (Parker, 1978).

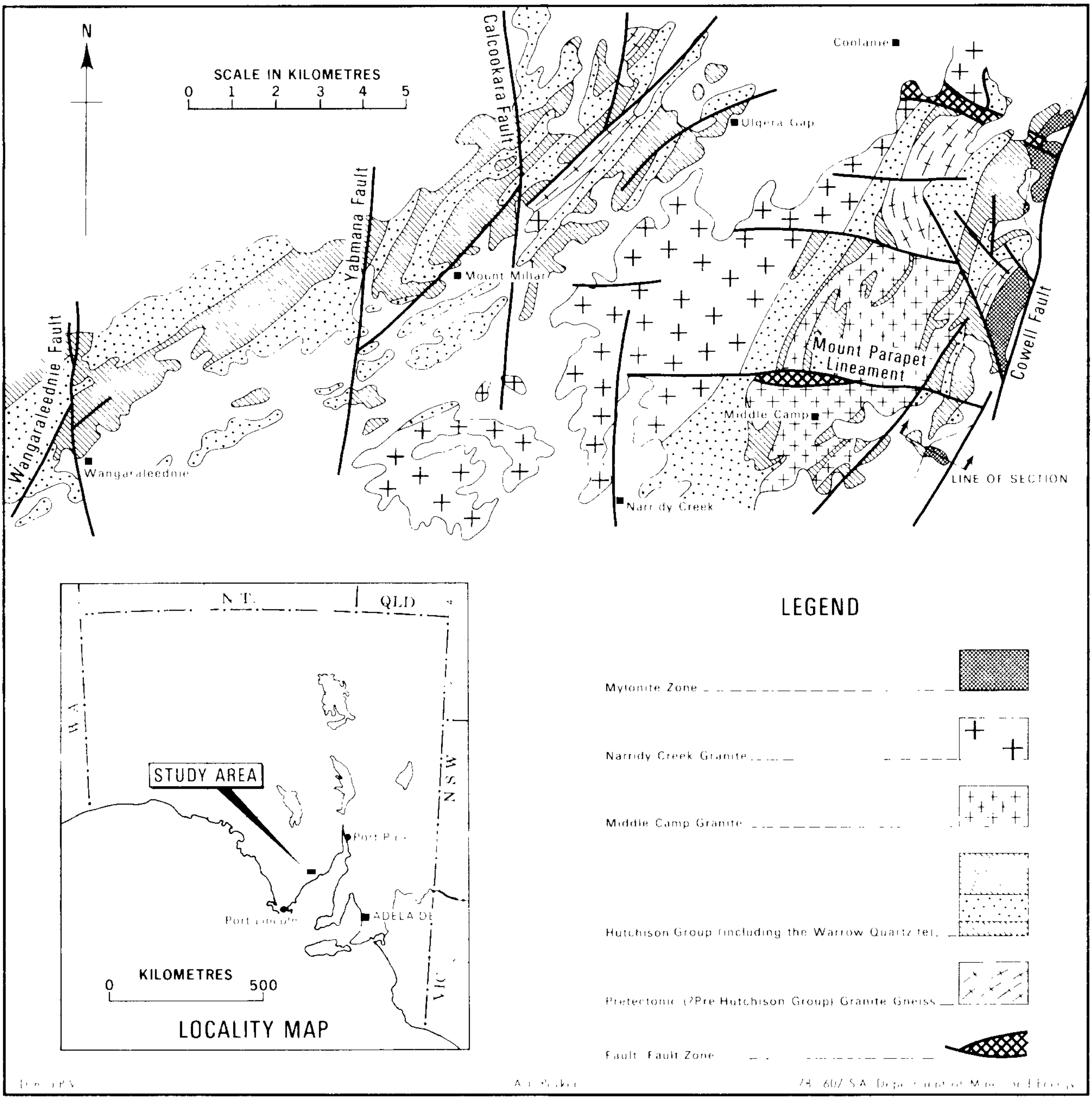


Figure 1

Geological setting of the mylonite zone near Cowell on eastern Eyre Peninsula. The shaded areas are areas of Early to Middle Proterzoic metasediments and granites. They are covered by recent alluvium in the unshaded areas.

GEOLOGICAL SETTING

Mylonitic rocks occur on Eyre Peninsula within a highly deformed and metamorphosed sequence of Early Precambrian granite gneisses, granites and metasediments (Glen et al., 1977). The metasediments and many of the granite gneisses have been metamorphosed to the upper amphibolite facies (sillimanite-orthoclase subfacies) and have been subjected to four main deformations (D_1 to D_4). The main metamorphic event was associated with the first and second deformations while metamorphic conditions during the third and fourth deformations were of lower amphibolite and greenschist facies respectively. The second, third and fourth were all fold deformations - the second producing meso- and macroscopic isoclinal folds, the third producing meso- and macroscopic open to tight folds and the fourth producing local mesoscopic folds - and the development of mylonites accompanied the third.

MESOSTRUCTURE

Although there are several occurrences of mylonite in the area studied, the principal occurrence is in a broad north-north-east trending zone along the eastern edge of the outcropping Precambrian rock (Fig. 1). That zone parallels the regional trend of macroscopic D_3 folds, is buckled and offset by D_4 features, and is truncated along its eastern margin by the Tertiary to recent Cowell Fault. Adjacent to it D_3 folds in migmatite gneisses, dolomites and quartzites become much tighter and almost isoclinal and there appears to be a gradual increase in strain from the west towards the mylonite.

Rocks within the zone itself can be subdivided into two broad categories which merge into each other:

(1) mylonitized gneiss,

(2) slaty mylonite.

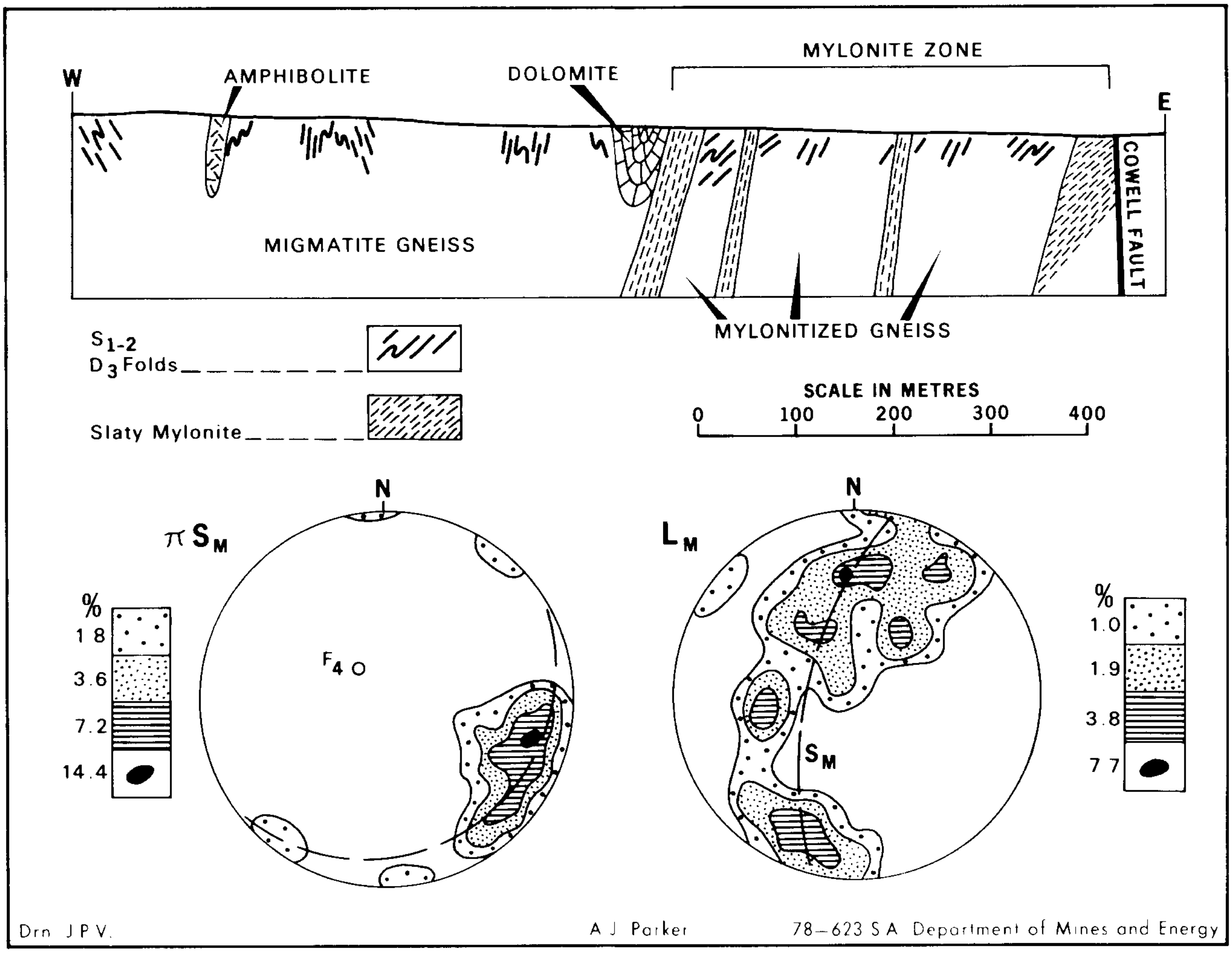


Figure 2

Geological cross-section through the mylonite zone in Mindrow Creek (see Fig. 1), and stereodiagrams of the mylonite fabric elements along that section. Contour intervals are per 1% area.

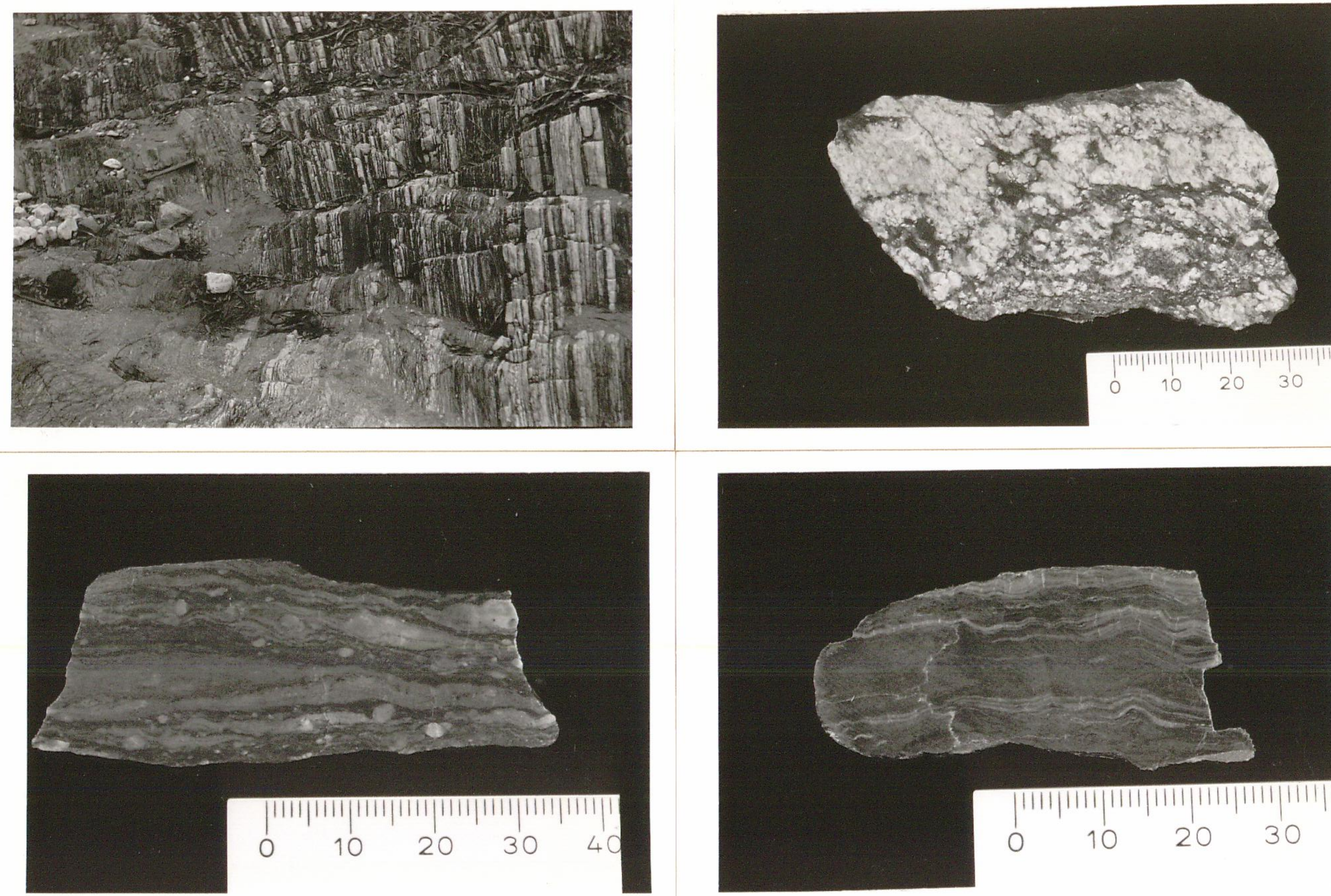


Fig. 3 (a) Outcrop in Mindrow Creek of mylonitized gneiss on the right grading into slaty mylonite on the left.
(b), (c), (d) Mylonitic gneiss specimen MY-1, mylonite specimen MY-4 and slaty mylonite specimen MY-6 collected from the right, the centre and the left, respectively, of the outcrop shown in (a). The scales are in mm.

Most of the zone consists of mylonitized gneiss but there are distinct bands of slaty mylonite developed throughout it (Fig. 2). The bands of slaty mylonite vary from 0.2 m wide up to tens of metres wide and are distinguished from mylonitized gneiss on the basis of texture.

Mylonitized gneisses are medium to fine grained, generally equigranular, and still retain the principal characteristics of the host rocks, that is, the migmatitic layering is still distinct and there are several very tight to isoclinal folds of D_3 form. These folds have a much stronger axial planar fabric than typical D_3 folds outside of the zone and in some cases one limb may be sharply truncated by a narrow band of slaty mylonite. The axial fabric is penetrative and progressively develops into a domainal schistosity which ultimately completely obliterates the original S_{1-2} schistosity.

Slaty mylonite develops from the mylonitized gneiss (Fig. 3). It is typical mylonite with scattered, medium sized, relic clasts of feldspar and long lenticular ribbons of microscopic grained feldspar in a very fine grained micaceous matrix. By contrast with mylonitized gneiss, the original character of the rock is not obvious. Instead the rock has a distinctive slaty appearance and is either massive as in the micaceous rocks or very finely laminated as in the quartzo-feldspathic rocks devoid of mica.

The planar mylonitic fabric (S_M) is the prominent fabric within the mylonite zone and is generally steeply dipping to the northwest though crenulated and buckled by steeply plunging D_4 folds (Fig. 2). However, there is often a strong rod type lineation, L_M, developed in S_M. It is defined principally by very strongly elongate ($>20:1$), cylindrical rods of fine grained feldspar which are often accompanied by a chlorite mineral elongation. L_M is seen best in the early and intermediary stages of slaty mylonite development rather than in homogeneous slaty mylonite.

Throughout both slaty mylonite and mylonitised gneiss there are later veins and pods of quartz and feldspar which have formed either after cessation of or late during the main mylonitisation process. They are relatively undeformed, but they do parallel S_M and occassionally some have a very finely laminated mylonitic texture. These and also the rare isoclinal folds within the slaty mylonite which appear to fold S_M yet have S_M axial planar infer that the process of mylonitisation was a steady, continuously evolving process (cf Bell and Etheridge, 1973).

MICROSTRUCTURE

West of the mylonite zone D_3 microstructures are characterised by microfolds or crenulations of the main S_{1-2} schistosity or layering, and by substantial quartz recovery and recrystallisation. Generally D_3 folds have only an incipient axial planar fabric which is defined by scattered micas and a discrete fracture cleavage (N.B. fracture cleavage is used here in a strictly non genetic way to describe irregular planar surfaces which have the appearance of fractures), while S_{1-2} micas are generally kinked and have recovered to form bands of straight segments with serrated kink band boundaries. There is only minor new grain growth along such band boundaries. Quartz recovery/recrystallisation is important within these rocks and there is a regional increase in recrystallisation from the west towards the mylonite zone. That recrystallisation is manifest as a gradual increase in proportions of new grains to old grains (accompanied by a gradual reduction of grainsize), and by an increase in degree of D_3 microfabric development (Parker, 1978). These textural/microfabric variations combined with the regional tightening of D_3 folds towards the mylonite zone are believed to indicate a regional increase in D_3 strain from west to east.

Figure 4

Deformed S_{1-2} biotite in mylonitic gneiss with newly recrystallised S_M biotites aligned along kink/crenulation band boundaries. S_M is vertical. Field of view is approx. 0.7 x 0.5 mm.

There are two principal stages of fabric development observed in the mylonite zone and these correspond to the progressive formation, firstly, of mylonitized gneisses from migmatite gneisses, and secondly, of slaty mylonite from mylonitized gneiss. They are, respectively, a mica recrystallisation stage and a feldspar recrystallisation stage. The recrystallisation of quartz is obviously an ongoing feature with continual crystallisation and recrystallisation within the zone and is analogous to that described by Bell and Etheridge (1976).

Mica Recrystallisation Stage

While the fabrics and textures of mylonitized gneisses are an extension of D_3 microstructures outside the mylonite zone, in thin section they have several obvious differences. Firstly, D_3 or D_M micro-folds are noticeably much tighter, secondly they have a strong, penetrative axial fabric, and thirdly, there is considerable disruption of layering. The S_M fabric is a logical progression from S_3 fabrics outside the mylonite zone and there are three main features defining it. They are, a fracture cleavage, a mica preferred orientation, and a segregation or domainal schistosity.

S_{1-2} micas in mylonitized gneiss, by contrast with their moderately deformed equivalents outside of the zone, are both highly deformed and strongly recrystallised (Fig. 4). Kinked or crenulated micas have strongly flexed hinges and there is often prolific, very fine new grain growth both along kink band boundaries and wrapping around individual grains. S_M is defined by these new micas, by rotated fragments of old grains and by a dimensional orientation of fine opaque minerals accompanying the new mica growth. Both biotite and chlorite can consitute S_M and S_{1-2} but in by far the majority of specimens the principle micas are chlorite and sericite. Old S_{1-2} micas are still present, but they have been almost completely pseudomorphed by chlorite.

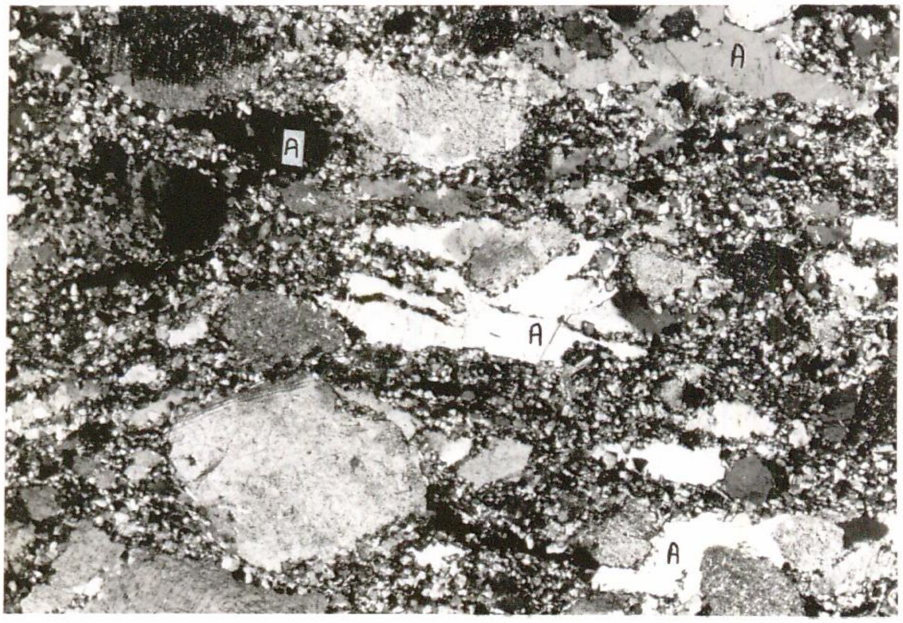


Figure 5

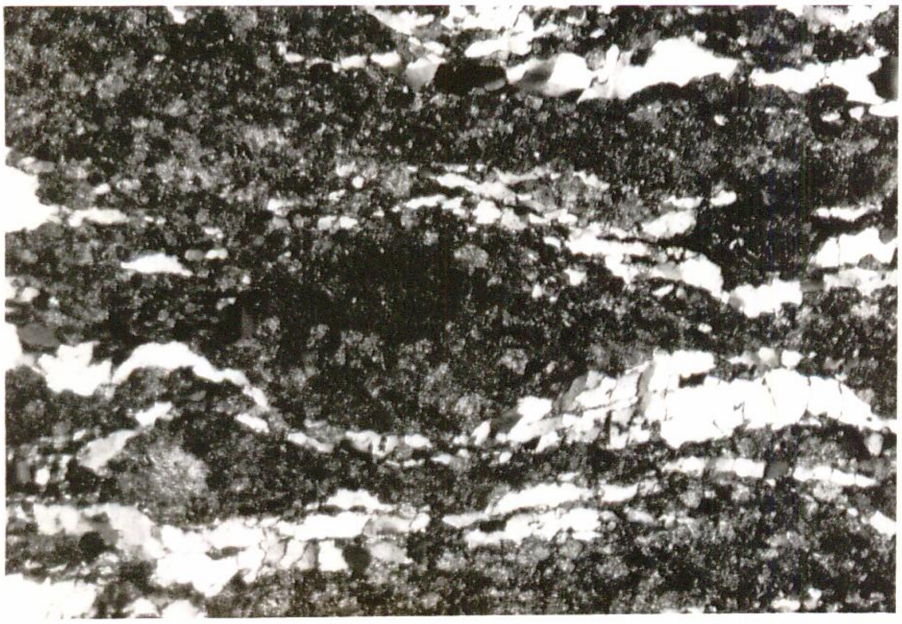
Texture of mylonite gneiss specimen MY-1 with coarse feldspar augen in a fine grained recrystallised matrix of quartz, feldspar and mica. Quartz ribbons overprint the main mylonitic fabric and are very distinctive. Each of the ribbons labelled A, consists of one single unstrained quartz grain with almost perfect optical continuity. Field of view is approx. 4 mm x 2.5 mm.

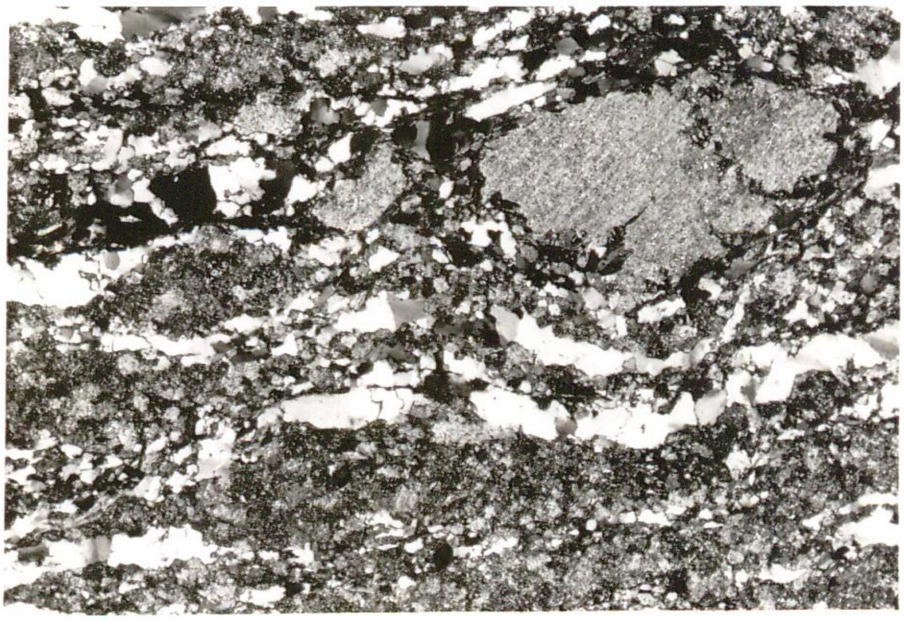
Accompanying recrystallisation of mica, there is concomitant recrystallisation of quartz, retrogression of garnet and incipient alteration of feldspar. The recrystallisation of quartz has led to a variety of fine to medium grained aggregates ranging from subpolygonal and relatively unstrained new grains, to highly undulose and irregularly shaped (?)old grains. Garnets have partially or completely retrogressed to chlorite, and the alteration of feldspar is manifest as a flexuring and kink banding of multiply twinned plagioclase grains, as a partial sericitisation of plagioclase and as an incipient grain boundary recrystallisation of microcline. Neither feldspar, however, is strongly deformed or recrystallised.

Feldspar Recrystallisation Stage

This stage of mylonitic microstructural development corresponds exactly with the formation of slaty mylonite. In the previous stage while the S_{1-2} fabric was largely destroyed, the rocks still retained much of their original character (e.g. layering, medium grain size). However, with the recrystallisation of feldspar that character is obliterated and replaced by a homogeneous slaty fabric. In Figure 3 a broad outcrop and three specimens displaying the progressive development of slaty mylonite from mylonitized gneiss, were illustrated. In this section the microscopic features of those specimens will be described. It should be noted here, though, that all these particular specimens have similar mineral ($Q_{30-40}Pl_{30-45}Kspar_{10-20}Mica_{1-12}$ Acc_{1-5}) and chemical compositions so they are all considered to have been derived from an identical lithology.

Specimen MY-1 (Fig. 3) displays partial recrystallisation of feldspar which is manifest as aggregates of fine to very fine new grains both surrounding old grains and sweeping off into long tails on each end (Fig. 5). Augen development is pronounced and the textures are typically protomylonitic with the augen or clasts still constituting 45-55% of the total rock (Sibson, 1977; Spry, 1969; N.B. protomylonitic is used here in a strictly non-genetic manner





Figures 6 (a) and (b)
Textures of mylonite specimen MY-4 with relic feldspar augen in a strongly foliated (S_M), recrystallised matrix. S_M is horizontal.NB subgrain development around edge of feldsapr augen in (a). Field of view is approx. 4 mm x 2.5 mm.

(as does Sibson) whereas Spry implied that it was a crushed rock rather than a recrystallised rock).

There is a good foliation (S_M) in the rock being defined by mica alignment, quartz ribbons, slightly elongate old feldspars, and trains of newly recrystallised feldspar grains. The micas are mainly fine to very fine grained sericite and chlorite but there are some rare, scattered, medium sized, highly deformed old grains.

The quartz ribbons are very prominent. They often occupy pressure shadow sites, but more importantly, individual ribbons are often interconnected across S_M and form very coarse, relatively unstrained, <u>single</u> grains which anastomose around recrystallised feldspars. In some areas these coarse, often euhedral quartz grains have subgrains locally developed indicating that there was minor, local deformation and recovery postdating the final quartz crsytallisation. Nevertheless though, the quartz crystallisation does postdate the major deformation and feldspar recrystallisation and is a late stage effect.

Associated with the quartz ribbons and associated with the same late stage crystallisation event is the presence of new plagioclase both as overgrowths on old grains and as aggregates of medium/fine grained new grains. In the first case, both the old and new grains are clearly recognised by their sericitised outlines, and the new overgrowths are strikingly <u>euhedral</u> into the quartz ribbons.

The next stage of development represented by specimen MY-4 produced typical mylonite textures with only 10-25% augen remaining in a fine grained, strongly foliated matrix (Fig. 6). The augen are recrystallised with old grain relics in the cores and they have long tails of new grains which are sometimes strongly elongate to define a mesoscopic L_M lineation in S_M.

Figure 7

Slaty mylonite specimen MY-6 in which there are no remaining feldspar augen. This specimen consists almost entirely of very fine grained recrystallised quartz, feldspar and mica. S_M is horizontal. Field of view is approx. 1 mm x 0.7 mm.

Figure 8

Euhedral feldspar overgrowths that have grown on matrix feldspars into a late stage unstrained quartz vein. The matrix in the lower half of the photograph is recrystallised ultramylonite equivalent to figure 7. S_M horizontal. Field of view is approx. 0.7 x 0.5 mm.

Pinkish white quartzo feldspathic bands are characteristic of this stage of development. They consist entirely of alternating ribbons of fine grained highly undulose quartz and fine grained subpolygonal aggregates of recrystallised plagioclase. They contrast against the dark green slaty matrix which consists of fine grained quartz, feldspar, chlorite, sericite, epidote, sphene and opaque minerals with scattered feldspar clasts.

The third stage of mylonitic development is shown by specimen MY-6 (Fig. 7). It has a typical ultramylonitic texture, there being fewer than 5% clasts or augen and the matrix is fine grained with a strong slaty schistosity defined by the preferred orientation of chlorite, sericite, some opaque minerals, and to a lesser extent epidote prisms. Quartz and quartzo feldspathic bands are much less prominent and they have homogenous textures compared with the ribbon textures of MY-4. Micas also are generally homogeneously mixed up in the matrix but some sericite has aggregated in the hinges of post myloni tic, D_4 crenulations to form narrow muscovite films.

Another important observation in specimen MY-6, is the presence of late generation quartz veins which resemble those of MY-1. They are very coarse grained and unstrained and furthermore they have very fine euhdral feldspar overgrowths growing out from matrix feldspars into them (Fig. 8).

Summarising then the transition from mylonitized gneiss into slaty mylonite, the principle features are the gradual reduction in augen or clasts, the corresponding recrystallisation of feldspar, and the progressive mixing up or homogenisation of the fabric. The ultimate slaty mylonite bears little resemblance to the original rock although it is of similar overall composition.

Comparison of Plagioclase and Microcline Recrystallisation

An interesting observation in this recrystallisation sequence is a comparsion of the nature of recrystallisation of plagioclase and microcline. Within the mylonitized gneisses and in the initial stages of slaty mylonite development, recrystallisation of plagioclase was initiated by recovery of flexed twin lamellae to form subgrains which subsequently rotated to form fine/medium grained aggregates of new grains. This is a relatively rapid process compared with microcline and in specimen MY-4 most of the old plagioclases have completely recrystallised to aggregates of fine, subpolygonal new grains. Those old grains that do remain are located in the cores of augen shaped aggregates of new grains. That the new grains have formed from subgrains of the old host grain is evidenced by a progressive misorientation of new grains away from the old grain core.

Microcline behaved quite differently to plagioclase during the development of slaty mylonite. These differences were noted even in the mildly deformed rocks outside the mylonite zone, but are much more obvious here. In the mylonitized gneisses, microcline shows incipient very fine new grain growth along grain boundaries and along (?)fractures within the grains. In the slaty mylonite specimens MY-1 and MY-4 microcline augen show prolific, very fine, grain boundary recrystallisation and it is noteworthy that the majority of augen still remaining in specimens MY-4 and MY-6 are predominantly microcline. Although they have many features in common with plagioclase recrystallisation (old grain cores surrounded by new grain rims with tails of new grains off each end), the size and nature of new grains differ substantially. For example, the new microcline grains are much finer than new plagioclase grains. Because they are finer grained, more energy is necessarily required to completely recrystallise old microline grains than would be required to recrystallise old plagioclase grains of the same size, therefore it is believed that this has influenced the apparently much slower and more restrictive process of recrystallsiation of microcline than for plagioclase.

SUMMARY AND DISCUSSION

It is clear from the above descriptions that the microstructure of the mylonite series of rocks has developed principally from recrystallisation of the various components without significant changes in overall composition. The first evidence of mylonitisation was seen in the country rocks adjacent to the mylonite zone. In these rocks, D_3 features noticeably intensified on approaching the mylonitized rocks, folds became tighter, S_3 became stronger, and there was substantial recrystallisation of quartz.

Within the mylonite zone, it was possible to distinguish two rock groups, those rocks that still retained much of their original character but which were visibly strongly deformed (the mylonitized gneisses), and those rocks in which the new fabric had obliterated most of the original character (slaty mylonite). Furthermore it was shown that these particular groups corresponded essentially with, firstly, recrystallisation of mica, and then secondly with recrystallisation of feldspar. The importance of recrystallisation is emphasised because it was the major mechanism behind the development of the microstructure. Clearly the recrystallisation process was a dynamic process as illustrated by its progressive development, by the strong S_M schistosity in the recrystallised matrix, and by the overprint of late stage quartz veins that have clearly formed subsequent to the main fabric.

Ductile deformation of the rocks is also emphasized by the association of isoclinal folding with the development of the microstructure. No brittle or cataclastic features are present in these rocks and while it may be argued that they have been masked by recrystallisation or neo-mineralisation subsequent to the cataclastic deformation (e.g. see Christie, 1960) all the available evidence supports a ductile event. This is particularly so when the extreme elongation of many recrystallised aggregates is considered. Such features are well known to metallurgists as the result of superplasticity of very fine grained aggregates when two or more mineral phases are present (e.g. Hayden et al., 1972; Ashby and Verall, 1973; Boullier and Gueguen, 1975). Boullier and Gueguen have applied some of the metallurgical concepts to mylonites and rightly consider that the principles of superplasticity can be applied to such rocks.

In concluding that ductile deformation accompanied by dynamic recovery/recrystallisation was the prime process of mylonite microstructural development at Cowell, this study therefore confirms the current views on mylonite development expressed by Bell and Etheridge (1973, 1976), Hobbs et al. (1976), and Sibson (1977). Also, it emphasises the importance of feldspar recrystallisation as the prime factor controlling the development of what are normally considered as typical mylonites (Spry, 1969; Sibson, 1977). Bell and Etheridge (1973) erected a basic four stage scheme for the formation of mylonites. Their scheme is summarised in the table below and compared with the stages identified in this study.

STAGE	Bell and Etheridge (1973)	This study
1	COUNTRY ROCK NOT VISIBLY DEFORMED - quartz recovery/recrystallisation rare feldspar deformation, micas kinked but only incipient recrystallisation	D_3 microstructure quartz recrystallisation
2	COUNTRY ROCK VISIBLY DEFORMED - mylonite schistosity prominent, feldspar deformation common, significant mica recrystallisation	mylonitised gneiss mica recrystallisation stage
3	QUARTZ-FELDSPAR MYLONITE - all remnants of country rock obliterated, feldspar recrystallisation significant	slaty mylonite MY-1 and MY-4 feldspar recrystallisation stage
4	QUARTZ-FELDSPAR PHYLLITE - no country rock grains remain homogeneous fabric	slaty mylonite MY-6

Clearly there is a positive correlation between the microstructural development in their study and that examined here. This correlation is an important correlation because not only does it support the concepts of ductile deformation and dynamic recrystallisation expressed by Bell and Etheridge (1973), but more importantly it emphasises the usefulness of their four stage scheme as a practical microstructural and mesostructural subdivision of the development of mylonitic rocks. While the four stages together represent a continous sequence of progressive recrystallisation of the various components within the rocks, they are distinctly definable stages within that sequence.

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John Parker

AJP:GU

A.J. PARKER

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