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Microstructural and Fabric Heterogeneities in Fault Rocks Associated with a Fundamental Fault [and Discussion]

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Phil. Trans. R. Soc. Lond. A 1986 **317**, 99-109
doi: 10.1098/rsta.1986.0027

Phil. Trans. R. Soc. Lond. A **317**, 99–109 (1986) [99]
Printed in Great Britain

Microstructural and fabric heterogeneities in fault rocks associated with a fundamental fault

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[Plates 1 and 2]

The Redbank Deformed Zone of Central Australia displays heterogeneous deformation on all scales. Microstructural and fabric observations indicate that the heterogeneities arise not only from inhomogeneous deformation during individual tectonic events, but also as a result of fault reactivation. Superimposed fabrics from different deformation events can either cause the intensification of an earlier l.–s. tectonite fabric or locally produce linear-type fabrics. Fault reactivation is preferentially localized in those regions where the superimposed fabrics are parallel or sub-parallel to the original fabric. Early foliations that are unfavourably oriented in relation to later superimposed fabrics, may be left as relatively less deformed pods or lenses in the centre of the fault zone.

Quartz *c*-axis fabrics show systematic variations with the type of fault rock, forming both symmetrical and asymmetrical girdles with respect to the foliation. Zones of high strain, where grain refinement has been greatest, display characteristic asymmetrical fabrics. Those areas in which grain refinement has been less intense and retrogression least noticeable, generally exhibit symmetrical fabrics.

1. Introduction

A common feature of many deep-level fault systems now exposed at the Earth's surface is the heterogeneity of deformation. This may in part be a result of the longevity and persistence of deformation within these zones. For as Watson (1980) points out, many of these fault systems were initiated during the Precambrian, but with later reactivation, continued to influence crustal deformation throughout geological time. The different deformation events tend to be localized heterogeneously within a broad mobile zone. But of equal importance is the heterogeneity of deformation during individual tectonic events, caused by spatial variations in such parameters as strain intensity, the deformation régime (coaxial or non-coaxial) and the conditions of metamorphism. As a consequence, a considerable diversity in the type of fault rock and associated microstructure and crystallographic preferred orientations of constituent minerals may develop. To establish the structural history of ancient fault systems, the heterogeneities brought about through reactivation and those produced during single episodes must be identified and differentiated.

Along many faults, reactivation may be relatively easy to determine by using field and microstructural observations. For example, a reverse fault that reactivates with an extensional component may be distinguished by using sense of shear criteria (White *et al.*, this symposium) or the displacement of the stratigraphy. Alternatively, a strike-slip fault which reactivates with a reverse or normal movement may be identified with reference to the orientation of the extension lineation. More problematical, however, are those faults which initiate as a reverse fault and then continue to reactivate over an extended period of geological time with a similar sense of movement, and maintain a constant orientation of the displacement vector. The individual phases of movement become difficult to separate, especially if earlier mylonitic fault rocks are reworked by later mylonite fabrics. The Redbank Deformed Zone, a fundamental fault in the Precambrian continental crust of Central Australia (Marjoribanks 1974), is an example of such a fault system. In this contribution it is shown that the observed heterogeneities in the Redbank Deformed Zone are the result of inhomogeneous deformation during individual tectonic events combined with the effects of fault reactivation. It will also be shown that heterogeneities can exist on all scales. To illustrate these points, variations in microstructure and fabric will be described in detail.

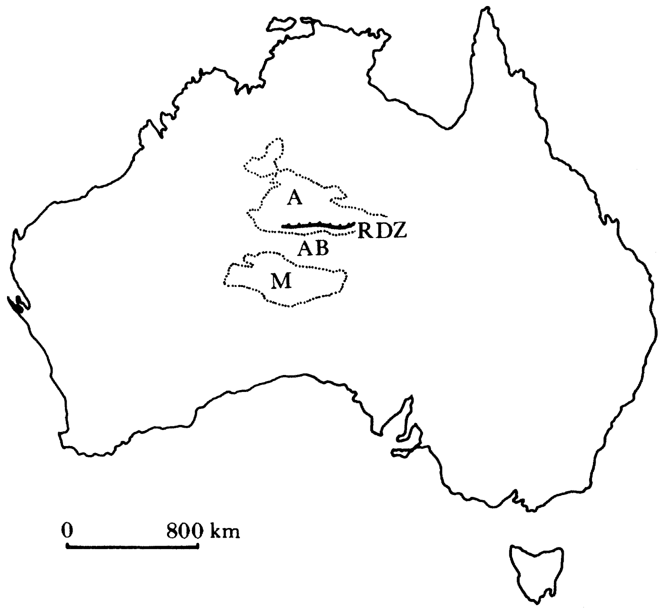

Figure 1. Location map of the Redbank Deformed Zone. A, Arunta Block; M, Musgrave Block; AB, Amadeus Basin; RDZ, Redbank Deformed Zone.

The Redbank Deformed Zone (figure 1) is an east–west trending belt of highly deformed rock separating generally granulite facies rocks to the north from amphibolite grade rocks to the south. This zone of deformation, which can be traced for at least 350 km along strike (Marjoribanks 1974), is marked by a steep northerly dipping mylonitic foliation with a down-dip plunging extension lineation. It was interpreted as a major thrust zone by Forman & Shaw (1973) and was considered to have initiated at about 1600–1700 ma (Marjoribanks & Black 1974). Major reactivation occurred in the early Carboniferous (Armstrong & Stewart 1975) during the Alice Springs Orogeny, and created the pervasive fabrics that are evident at most exposures.

The observations cited below are based on field work along a 70 km segment of the Redbank Deformed Zone, in close proximity to Alice Springs. Detailed field maps were compiled at regular intervals along strike to record any heterogeneity in the deformation. In between mapping areas, traverses across the width of the zone ensured significant coverage of the fault system. These are discussed in more detail in Obee & White (1985).

2. Field description of the Redbank Deformed Zone

The published B.M.R. (1:100000) geological map of the Alice Springs region (sheet 5650) shows that the maximum width of the zone is about 3.5 km, but with considerable variations along strike. Field observations indicate that the zone has diffuse boundaries, so that large areas of gneisses on either side have similar mylonitic fabrics but with decreasing intensity outwards. These marginal areas provide important information on earlier deformation phases and illustrate how earlier fabrics become modified by later tectonic events. Likewise the less deformed pods and lenses within the centre of the zone, which are surrounded by anastomosing regions of high strain, provide useful data on earlier events. Within these pods it can be established that early strongly banded gneisses with a well developed extension lineation were invaded by mobilizate during a migmatization event. But all evidence for the early history of the zone becomes completely obliterated on approaching a zone of high strain, where mylonitic fabrics overprint and destroy any existing fabrics.

Figure 2*a*, plate 1, illustrates a relatively less deformed part of the zone, recording veins of mobilizate streaked out during mylonitization. Open-style folds then disrupt this fabric. Figure 2*b*, however, shows how all trace of an earlier history has been destroyed with the formation of a well developed mylonite foliation.

Typical fault rocks of the Redbank Deformed Zone include mylonites, mylonitic gneisses (figure 2*c*), phyllonites and ultramylonites (figure 2*d*), along with minor amounts of pseudotachylyte, some of which has been foliated (figure 2*e*). The characteristics of each of these have been described by Obee & White (1985).

The grade of metamorphism of the fault rocks ranges from lower amphibolite and upper greenschist facies down to lower greenschist facies. Deformation mechanisms involve brittle fracture of the more competent mineral phases, along with dislocation processes, diffusion, and possibly grain boundary sliding in the ultrafine-grained ultramylonites. The distribution of the different types of fault rocks is heterogeneous. Gradations from mylonitic gneiss into platy mylonites are common, whereas ultramylonite zones have sharp boundaries irrespective of the bordering fault rock. Cross-cutting relations are rare, although at a few localities zones of phyllonite cross-cut platy mylonites or mylonitic gneisses and clearly demonstrate reworking. reworking.

3. Heterogeneously developed tectonite fabrics within the Redbank Deformed Zone

The dominant fabric within the Redbank Deformed Zone, as previously stated, consists of a strong planar mylonite foliation with an associated extension lineation (i.e. an l.–s. tectonite fabric of Flinn (1965)), and similar to that widely reported in fault systems throughout the world. In addition to this fabric there is a local development of a linear type fabric (l tectonite fabric), defined by the elongation of feldspar porphyroclasts and the preferred orientation of mica and quartz lenses. There is an absence of any planar feature within rocks with an l-fabric.

The formation of the l-fabrics is best observed at the margins of the fault zone or within the relatively less deformed pods in the centre of the zone. Field and microstructural observations suggest that these linear fabrics do not result from prolate strain during one phase of deformation, but are formed through the superimposition of two deformation events. It must be emphasized that these fabrics are different from linear intersection fabrics in that they are the product of stretching. The important factors controlling their development are (i) the previous history of the fault system, which influences the orientation of a pre-existing l.–s. tectonite anisotropy and (ii) the intensity and orientation of a superimposed l.–s. tectonite fabric.

Figure 2*f* shows a field photograph of a linear fabric and illustrates how these rocks are formed. A strong lineation can be seen on all surfaces except those perpendicular to the lineation. Field relations indicate that this rock was formed by the superimposition of a later mylonitic fabric sub-perpendicular to an earlier strongly banded mylonitic gneiss with an associated extension lineation. This conclusion is reached by tracing an older gneissose foliation into a zone of high strain. Away from the zone of high strain, the l.–s. fabric of the mylonitic gneiss is dominant in the rock, but with increasing strain this older foliation becomes progressively 'chopped up' until a linear fabric is formed. Figure 3 schematically illustrates the formation of such a fabric.

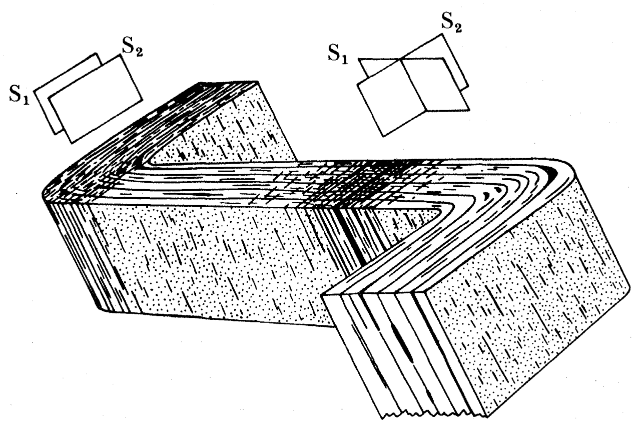

FIGURE 3. Schematic diagram to illustrate the formation of a linear-type fabric. Where the two contributing fabrics (S_1 and S_2) are superimposed in a parallel sense, then an intensification of the earlier fabric results. These regions are preferentially exploited during fault reactivation. Where the two fabrics are perpendicular (and with the X-direction coincident), linear-type fabrics can develop by the progressive 'chopping up' of the earlier foliation. If the intensity of the late fabric is too great, a linear fabric will not develop, and only the late l.–s. tectonite will be recorded in the rocks. The perpendicular relation between the two contributing fabrics may be brought about through large-scale folding, as shown in the diagram, so that locally tens of metres of linear-type fault rock may be generated.

It is apparent that a linear rock will only develop if the two contributing fabrics are superimposed in the correct orientation. In the example depicted in figure 3 the extension direction in the earlier gneisses is coincident with the extension direction of the later mylonite fabric. However, because of prior folding of the gneissose foliation, it is locally parallel and perpendicular to the XY-plane associated with the later mylonite (the XY-plane is assumed to be parallel to the foliation surface). Where the foliation of the earlier gneisses is parallel to the later mylonite foliation, the net result is an intensification of the original l.–s. tectonite fabric. But where the new mylonitic foliation is perpendicular to the old foliation a linear fabric develops.

An important implication from the above observations is for the localization of reactivation in a fault system. Deformation will preferentially concentrate in those regions where the

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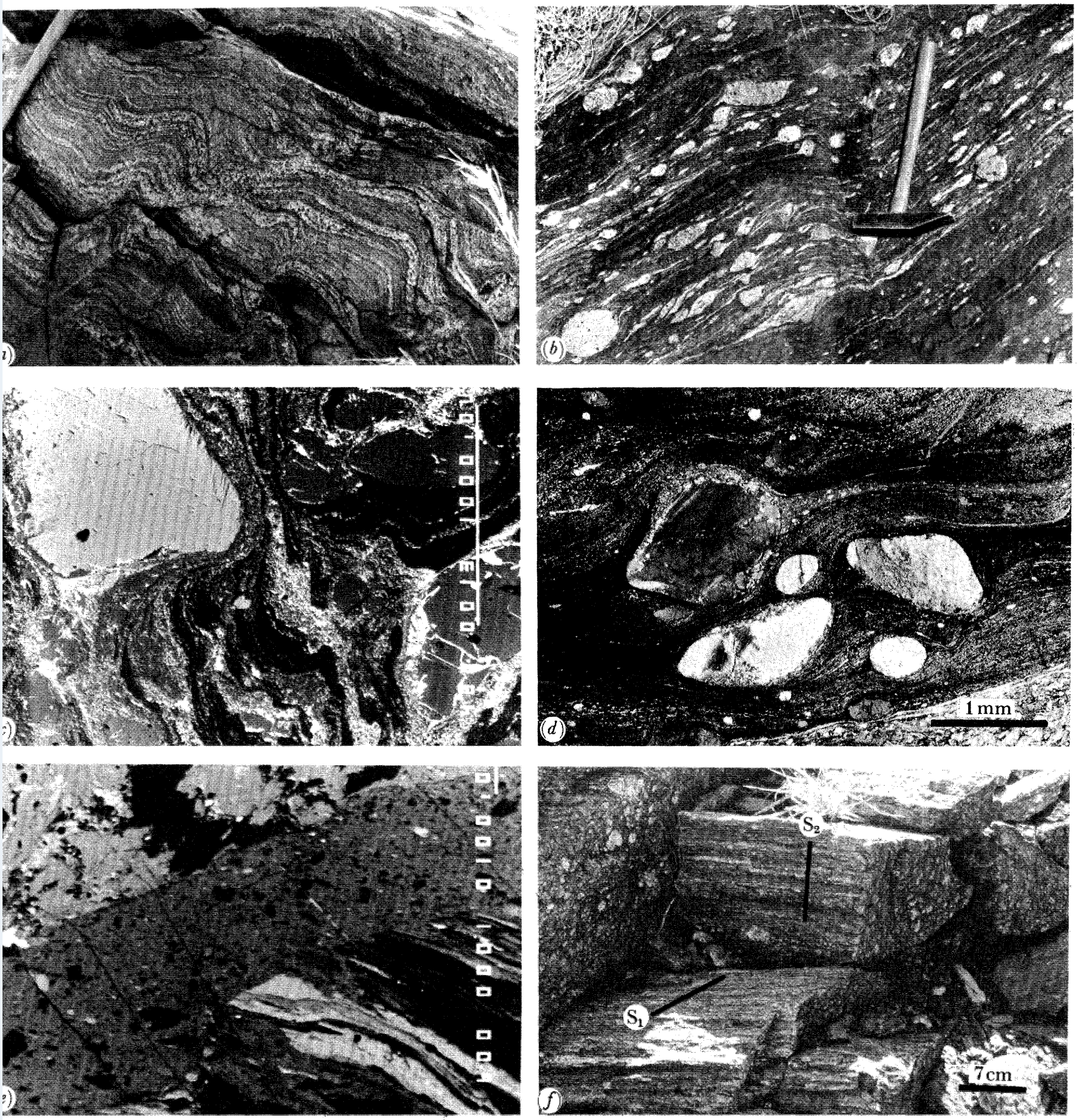

FIGURE 2. Characteristic fault rocks of the Redbank Deformed Zone. (*a*) Mylonitized veins of mobilizate from a relatively less deformed pod within the centre of the zone. (*b*) Strong mylonite foliation containing large porphyroclasts of feldspar. (*c*) Back-scattered electron micrograph of mylonite microstructure. Note complex folding of recrystallized matrix in the vicinity of feldspar porphyroclasts (scale bar 1 mm). (*d*) Ultramylonite containing feldspar porphyroclasts undergoing dynamic recrystallization within grain mantles. (*e*) Pseudotachylyte vein within granulites (scale bar 100 μm). The host rock on the bottom margin of the vein displays a strong foliation which continues into the vein, while the host rock on the top margin remains essentially undeformed. The pseudotachylyte vein has provided the site for localization of later deformation. (*f*) Linear-type fabric developed by the superimposition of two sub-perpendicular foliations (S_1 and S_2). Note the absence of any foliation in this rock.

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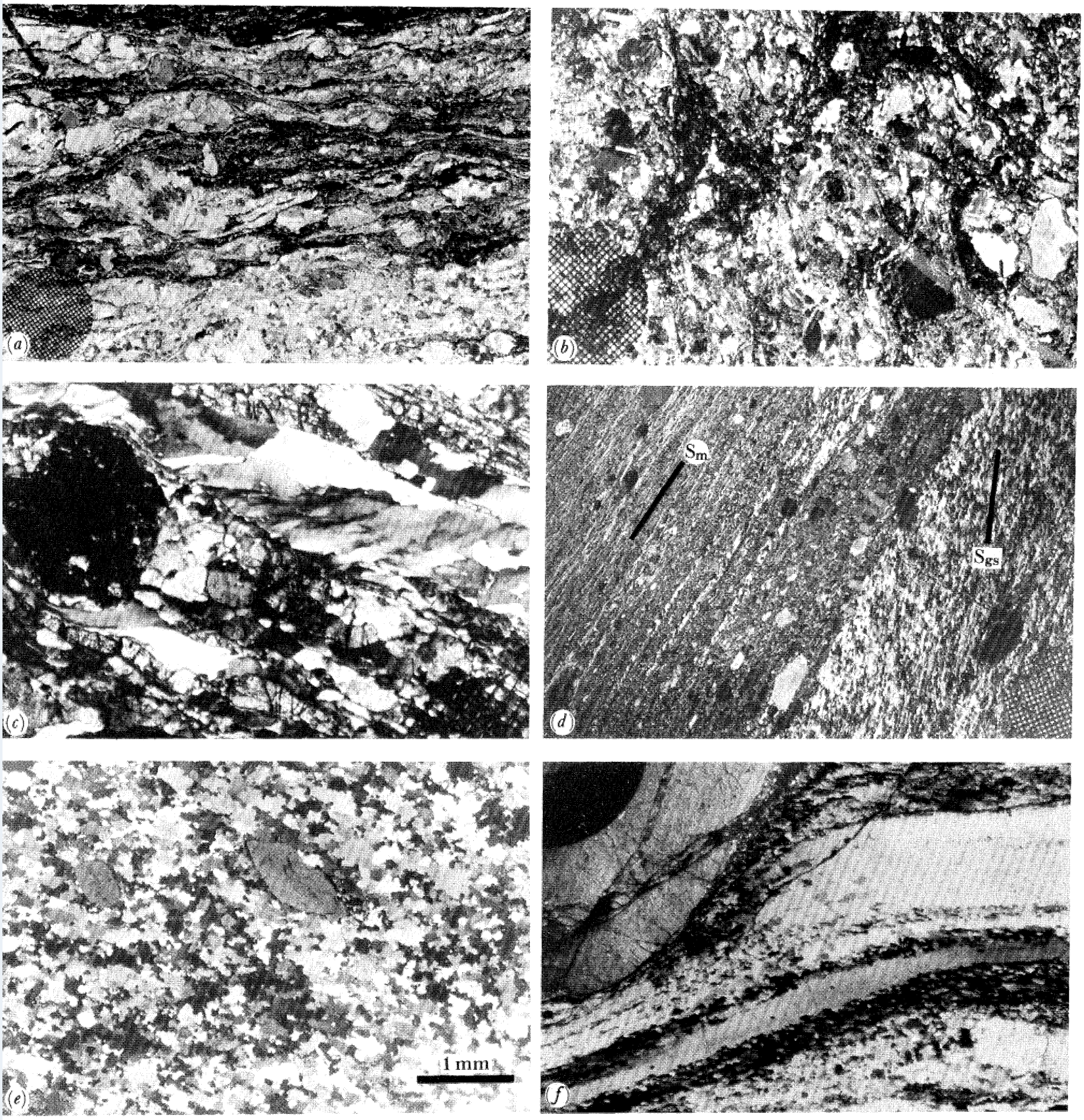

FIGURE 4. Fault rock microstructure (*a*) Optical view of linear-type fabric, parallel to the lineation (scale grid diameter 3 mm). Note domains of quartz–feldspar and micaceous regions. Also note long lenses of quartz and both recrystallization and fracture of feldspar porphyroclasts. (*b*) Linear-type fabric perpendicular to the lineation. Note the absence of any foliation, and the narrow zones of recrystallization containing abundant mica. (*c*) Quartz ribbons with oblique deformation bands in a sillimanite–garnet-bearing mylonitic gneiss (scale grid in bottom right corner). (*d*) Ultramylonite displaying an oblique grain-shape fabric (S_{gs}), with respect to the mylonite foliation (S_m), in a quartz band. (*e*) Relaxed microstructure showing some grains with lobate grain boundaries. Elongate deformed feldspar porphyroclast defines the old foliation orientation. (*f*) White ribbon grain undergoing recrystallization in close proximity to a large feldspar porphyroclast (scale in top corner: radius 1.5 mm).

superimposed fabrics are parallel or sub-parallel and less so in the unfavourably orientated regions. Therefore, it might be expected that some of the less deformed pods within a fault system are the result of unfavourable orientated initial fabrics in relation to later superimposed fabrics. This is consistent with field observations within the Redbank Deformed Zone.

A further control on the development of a linear fabric is the intensity of the second phase of deformation. If the late mylonitization is strong then it will tend to obliterate all evidence of earlier fabrics within the rock. Therefore, these fabrics are best observed at the margins of the fault system or within the less deformed pods.

The microstructure of the linear rocks in sections cut parallel to the lineation appears domainal, with alternating quartz-feldspar and mica-rich zones. The feldspars commonly remain as large porphyroclasts and exhibit deformation twins. Those feldspars that have undergone recrystallization display ghosts of their original elongated grain shape. Quartz tends to form extended lenses that wrap around the porphyroclasts. Grains exhibit undulose extinction and are usually 100–250 μm in size. Grain shapes are varied, although a high percentage of oblong-shaped grains exists within the lenses. The micaceous domains are made up of fine-grained biotite with minor quantities of epidote and recrystallized quartz and feldspar (less than 100 μm in size).

In sections cut perpendicular to the lineation the feldspars appear equidimensional and are surrounded either by rings of quartz or by a complex network of zones where recrystallization has been more intense. By using low-magnification optical microscopy, two dominant orientations of recrystallized zones have been observed, usually perpendicular to each other, but this relation is destroyed where the two zones mutually interfere. Some of the characteristics of these rocks are illustrated in figures 4*a*, *b*, plate 2.

The development of linear-type fabrics within the Redbank Deformed Zone illustrates how heterogeneities may form through reactivation, so that earlier phases of deformation become superimposed by later events. In the following section it is shown that heterogeneities can develop through inhomogeneous deformation during a single tectonic event.

4. Quartz *c*-axis fabrics

The previous section considered variations in the bulk fabric within the Redbank Deformed Zone, while this section is concerned more specifically with variations in the crystallographic preferred orientation of quartz. To determine any systematic variation in *c*-axis fabrics, samples were collected from localities along 70 km of the fault system, both parallel and perpendicular to the strike. All types of fault rock were taken in to consideration, from the relatively coarse-grained mylonitic gneisses to the highly strained ultramylonites.

Faults to the south of the Redbank Deformed Zone were also sampled for comparative purposes. All thin sections were prepared by cutting samples parallel to the lineation and perpendicular to the foliation, and mounted so that viewing was to the east. Linear-type rocks, described in the previous section, were cut parallel to the lineation and perpendicular to the *XY*-plane of the late mylonitic fabric. Quartz *c*-axis fabrics from all of the fault rocks are presented in figure 5 and their descriptions follow below.

Samples taken from the northern margin of the Redbank Deformed Zone, within sillimanite-bearing gneisses, have weak mylonitic fabrics (see figure 4*c*). The quartz grains are pulled out into ribbons or, more commonly, form extended lenses. Grain sizes are varied (200 μm to 5 mm)

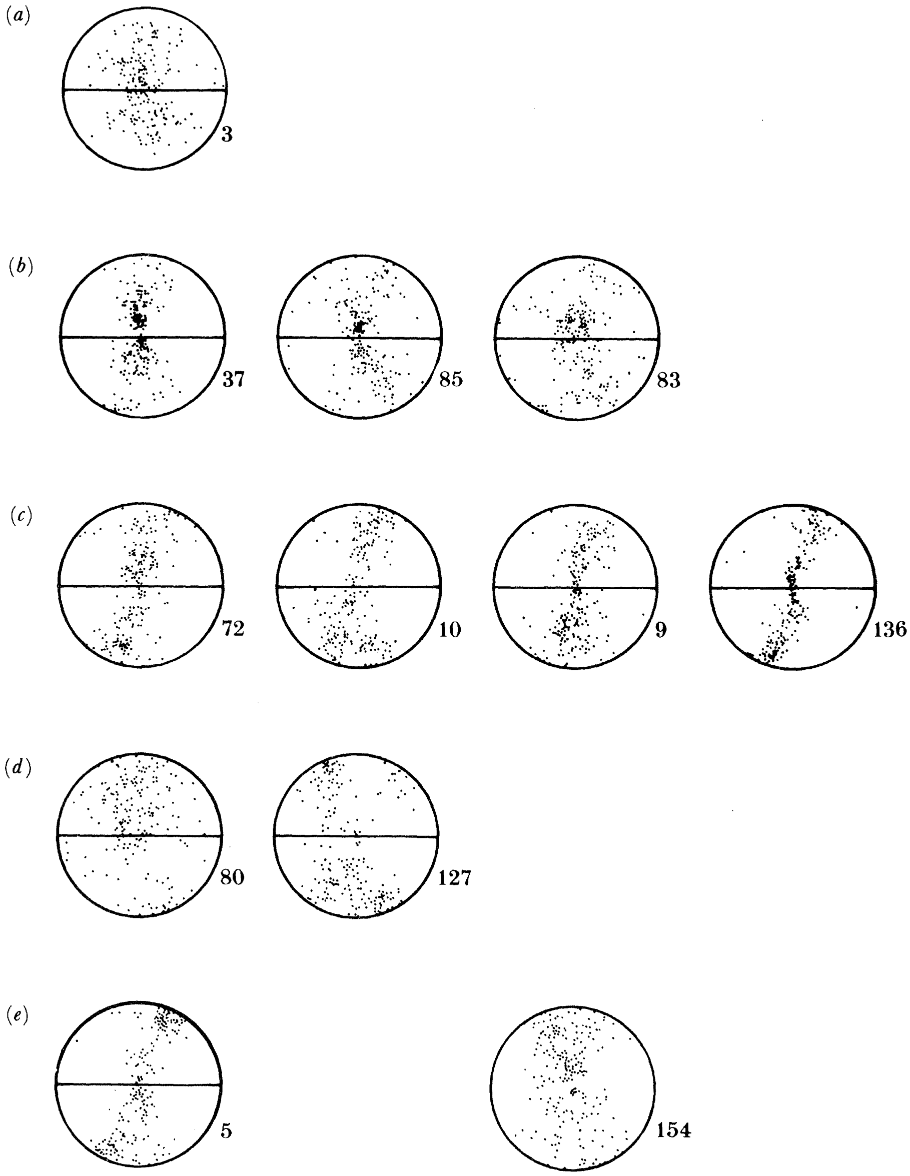

FIGURE 5. Quartz *c*-axis fabrics. (*a*) Sillimanite-bearing mylonitic gneiss. (*b*) Mylonites and mylonitic gneisses containing garnet and relict hornblende. (*c*) Ultramylonites and platy mylonites: generally lower greenschist facies assemblages. (*d*) Platy mylonites with relaxed microstructures. (*e*) specimen 5; mylonitic fault rock south of the Redbank Deformed Zone; specimen 154; fault rock containing linear-type fabric (see text for explanation). Fabrics prepared so that viewing is to the east. The extension lineation plunges to the north (i.e. left side of diagrams).

and optical strain features include undulose extinction and deformation bands. Recrystallization of quartz occurs around grain boundaries. Garnet and sillimanite in these rocks developed fractures while the feldspar underwent dynamic recrystallization. The quartz *c*-axis fabrics from these high-grade gneisses display single cross-girdles which appear symmetrical with respect to the foliation. As can be seen in figure 5*a* the fabric appears somewhat diffuse, but nevertheless strong concentrations are observed. A strong cluster of *c*-axes occurs about the *y*-axis on the fabric diagram and the perimeter is essentially devoid of any orientations. This cluster is composed of prism and rhomb elements (Bouchez & Pecher 1981).

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The *c*-axis fabrics of samples collected from the characteristic mylonites and mylonitic gneisses which make up a significant proportion of the fault rocks within the zone are shown in figure 5*b*. The mineralogy of these rocks comprises garnet, biotite, quartz and feldspar and generally includes relict hornblende. The modal abundance of quartz is considerably varied but it is usually present in significant concentrations suitable for *c*-axis measurements. The quartz grains typically form ribbon textures and have length to width ratios of 3:1. The average width of the grains is about 2 mm. Within the ribbon grains deformation bands are numerous and are usually inclined in the direction of shear for the fault system. The deformation bands commonly form an angle of 55° to the foliation, but where the quartz grains become wrapped around porphyroclasts of garnet or feldspar the angle of inclination is reduced to about 25–30°. At the margins of the quartz ribbons, small-scale recrystallization develops and again this is most pronounced in those ribbons which have become wrapped around prophyroclasts (figure 4*f*). Similar observations were made by Etheridge & Wilkie (1979), who explained the recrystallization as a result of increased stress due to the constraining effects of adjacent porphyroclasts. Sense of shear indicators from the mylonitic gneisses are confusing and often contradictory. The bulk of the shear-sense criteria indicate a reverse displacement, although opposite examples do exist.

The characteristic *c*-axis fabric from the above described rocks is a single type 1 crossed-girdle (Lister 1977) which is symmetrical with respect to the foliation. Again there are strong concentrations about the *Y*-axis, but unlike the sillimanite-bearing gneisses there are more *c*-axes on, or close to, the perimeter of the diagram (basal elements of Bouchez & Pecher (1981)). Although these symmetrical fabrics are considered the norm for the mylonites and mylonitic gneisses, they are not obiquitous. Less common asymmetrical fabrics are observed, along with fabrics that display uneven distributions of *c*-axes within the girdles.

Fabrics of those specimens collected from the platy mylonites and ultramylonites which are considered zones of higher strain where grain refinement has been at an optimum, are illustrated in figure 5*c*. The grain size of these fault rocks ranges from 1–200 μm and they tend to be the most retrogressed fault products. When quartz occurs in significant concentrations, oblique grain-shape fabrics develop. The inclination of the long axes of the grains, like the inclination of the deformation bands in the unrecrystallized grains, is consistently in the direction of shear (figure 4*d*). In some of the relict grains it can be seen that the asymmetric grain-shape fabric has developed from the recrystallization of elongated sub-grains along the deformation bands. Sense of shear criteria within the platy mylonites and ultramylonites is both plentiful and non-contradictory.

The quartz *c*-axis fabrics are characteristically asymmetric type 1 girdles with respect to the foliation (Lister 1977), and the sense of asymmetry is consistent with a reverse movement in the fault system. The distribution of *c*-axes in the girdles is more evenly spread about the basal, prism and rhomb elements than in the previous diagrams. The quartz fabrics generated in these rocks are comparable with those of faults south of the Redbank Deformed Zone. The main difference is a greater concentration of basal elements and more 'dog-leg'-shaped girdles in the southern faults, although a similar sense of asymmetry is noted (see figure 5*e*). Obee & White (1985) have shown that these more southern faults were active at a shallower crustal level.

Some of the platy mylonites within the Redbank Deformed Zone exhibit relaxed microstructures and occasionally metamorphic lobate grain boundaries have developed (figure 4*e*). The *c*-axis fabrics of these rock are weak, although relict fabrics may sometimes be determined (figure 5*d*). The interpretation of these microstructures and fabrics is that certain areas or pods within the active high-strain zones become non-active and relaxed while deformation proceeds elsewhere. The maintenance of relatively high temperatures encouraged grain growth and allowed the development of lobate boundaries in the quartz.

The *c*-axis fabric from a rock possessing a bulk linear fabric, as described in the previous section, is shown in figure 5*e*. Measurements were taken from quartz-rich domains which had undergone more intense recrystallization. The fabric forms a broad girdle that appears symmetrical about the *XY*-plane in the diagram (note there is no foliation in this rock). The fabric is considered similar to those presented in figure 5*b*, but with a wider and more diffuse girdle. The reasons for this may be that an earlier l.–s. tectonite fabric is exerting some control on the orientation of the quartz during the later mylonitization. Also, as previously noted, to produce a linear-type rock the intensity of the late mylonite fabric must not be too great. Therefore it might be expected that a strong girdle would not develop. However, the symmetry and distribution of the *c*-axis fabric is largely attributed to the last phase of deformation.

5. Discussion of the quartz *c*-axis fabrics

The microstructures and quartz crystallographic preferred orientations show consistent variations within the Redbank Deformed Zone. Two main groups of *c*-axis fabrics are observed and these can be related to different types of fault rock. The symmetrical fabrics tend to be related to the higher temperature mylonites and mylonitic gneisses which are generally coarser grained and show less evidence for grain refinement. The asymmetrical fabrics are related to zones of more intense deformation where the grain size is finer and retrogression has been more extensive. This relation is schematically illustrated in figure 6. Although this relation between fault rock type and *c*-axis fabric is considered the norm, it must be emphasized that it is not universal.

Computer simulations of Lister *et al.* (1978) suggest that symmetrical quartz *c*-axis fabrics are indicative of coaxial deformation, and asymmetrical fabrics representative of non-coaxial deformation. Furthermore, studies undertaken by Law *et al.* (1984) within thrust sheets of the Moine Thrust Zone have revealed symmetrical quartz fabrics which, combined with other microstructural data, they have interpreted as representing a coaxial deformation history. Similarly the asymmetrical fabrics they considered representative of a non-coaxial deformation history. If a similar reasoning is applied to the present study, then it might be suggested that significant areas of the Redbank Deformed Zone, represented by the schistose mylonites and mylonitic gneisses, have undergone dominantly coaxial deformation during the late mylonite event. Within these fault rocks localized zones have followed a dominantly non-coaxial deformation path. If this is so then it might be argued that bulk deformation in the lower crust initiates by following a coaxial deformation path, until strain-softened zones develop and allow a non-coaxial deformation path to proceed in more localized regions.

However, it is uncertain whether such an interpretation is realistic. Evidence to support non-coaxial deformation paths in the high-strain zones comes from single sets of shear bands and asymmetric grain-shape fabrics, along with asymmetric recrystallized tails on feldspar porphyroclasts, all of which appear remarkably consistent.

But there is little evidence to support a coaxial deformation path in the mylonites and mylonitic gneisses, and as mentioned earlier, the quartz fabrics are not consistently symmetrical. Therefore the favoured interpretation of the microstructural and *c*-axis data is that large areas of the fault system are domainal on a small scale (thin section level), so that regions are either dominated by coaxial deformation, non-coaxial deformation, or a combination of both. As deformation becomes localized, as a result of strain-softening mechanisms, the non-coaxial domains expand and become dominant, giving rise to the platy mylonites and ultramylonites. This interpretation therefore emphasizes the heterogeneity of deformation on a small scale.

The distribution of data on the fabric diagrams shows a systematic relation with the type of fault rock. The granulites are dominated by prism and rhomb elements, and likewise the mylonitic gneisses which contain garnet and relict hornblende. In contrast to this are those zones possessing lower greenschist facies assemblages and which are considered more highly strained. The fabrics from these rocks display more basal elements in conjunction with prism and rhomb. This relation between fabric element, mineral assemblage and microstructure may indicate a temperature and strain-rate control on the slip systems similar to the experimental observations of Tullis *et al.* (1973), and the naturally deformed examples of Wilson (1975).

The variation in quartz *c*-axis fabrics described above can occur either from composite deformation events or from inhomogeneous deformation during a single tectonic event. The former case would be difficult to distinguish, as the later superimposed event had a deformational framework similar to the earlier. The latter is favoured because the crystallographic preferred orientation of quartz appears very sensitive to deformation and can be easily modified. This is illustrated by some of the platy mylonites with relaxed microstructures, whose fabrics were weakened or totally destroyed as deformation proceeded in other parts of the zone. Also, the quartz *c*-axis fabrics from fault rocks with bulk linear fabrics show a relation with the late superimposed mylonitic foliation and not the earlier mylonitic gneiss foliation.

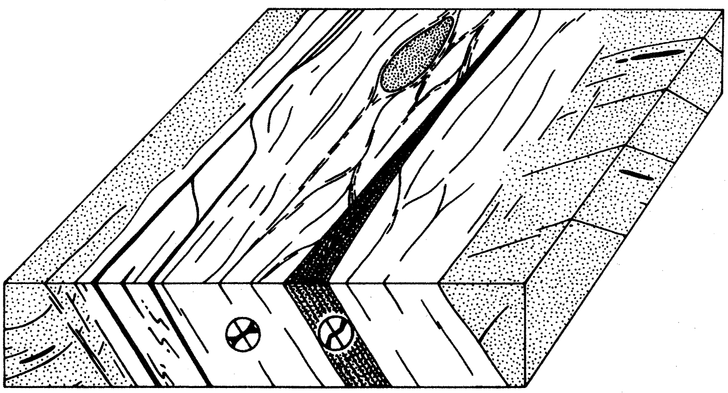

FIGURE 6. Schematic representation of some of the large-scale heterogeneities within the Redbank Deformed Zone. Included are high-strain zones, undeformed pods or intrusions, superimposed fabrics at margin of zone, cross-cutting relations, anastomosing and ordered networks of ultramylonites, systematic variations in quartz *c*-axis fabrics (viewing towards the west).

6. CONCLUSIONS

The Redbank Deformed Zone displays marked heterogeneities on all scales. They are particularly noticeable in the type of fault rock, microstructure, and the crystallographic preferred orientation of quartz. (Some of the large-scale heterogeneities are summarized in figure 6). Microstructural and fabric data have shown that a single deformation event can induce heterogeneities into a fault system. But these heterogeneities can then be impressed upon the products of earlier events, which gives rise to a complex picture. Also, during progressive uplift, not all of the earlier generated fault rocks are reworked because intense zones of deformation become narrower at higher crustal levels. Therefore, ancient fault systems exposed at the Earth's surface may display juxtaposed fault rocks from different events and different depths. If the foliations of different fault deformation events are superimposed parallel to each other, then the early history may not be recognized. But if after folding or a change in the movement direction the foliations are superimposed sub-perpendicular, then a more complete history may be recorded.

Fault reactivation will tend to localize preferentially in those rocks where pre-existing planar fabrics are parallel to later superimposed fabrics, whereas the unfavourably oriented regions may remain as relatively less deformed pods or lenses. Within the unfavourably orientated regions linear-type fabrics may be generated locally, depending on the intensity of late mylonitic fabric.

In many fault systems reactivation may not have taken place, but in those which have undergone more than one phase of movement, certain features, although not diagnostic, might suggest reactivation: cross-cutting relations, major variations in the orientation of the extension lineation, intrusions separating deformation events, and the superposition of profoundly different types of fault rock, for example, the cataclasis of mylonites. Therefore great care must be taken in the interpretation of heterogeneities within ancient fault systems.

H.K.O. gratefully acknowledges financial support through an N.E.R.C. postgraduate studentship and S.H.W. thanks the Royal Society for support through an Anglo-Australian Fellowship and the University of Melbourne for a Visiting Fellowship.

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Discussion

J. G. Spray (*Department of Earth Sciences, Cambridge University*). Mr Obee mentioned the presence of pseudotachylytes within the Redbank Deformed Zone. Could he elaborate on their distribution within the fault complex? Are they, for example, restricted to certain lithologies, do they occur more frequently where individual faults change direction or splay and do they show evidence of multiple injection?

H. K. Obee. I thank Dr Spray for his interest in the pseudotachylytes of the Redbank Deformed Zone. This group of fault rocks is distributed throughout the length of the zone in the Alice Springs region, although they account for less than 1% of the total fault products. (Their microstructure has been described in more detail by Obee & White (1985).)

The pseudotachylyte generally occurs as narrow veins which appear both concordant and discordant with the host rock foliation. The localization of pseudotachylyte generation appears intimately related to variations in host rock composition, i.e. it is often observed at the margins of more basic, competent layers within the gneisses, or close to the boundary between two different types of fault rock such as ultramylonite and mylonitic gneiss. More rarely, though, it occurs close to the bifurcation point of anastomosing high-strain zones.

As mentioned in the paper, most of the pseudotachylyte within the Redbank Deformed Zone has subsequently been foliated after its generation. Further deformation is apparently preferentially localized within the veins rather than in the coarser grained host rock. Obee & White (1985) suggested that these foliated pseudotachylytes may represent episodes of seismogenic slip during aseismic shearing within the deep crust. Examples of unreworked pseudotachylyte (sometimes as multiple generation veins) are best observed along faults south of the Redbank Deformed Zone, where their localization is related to the boundary between the regional gneisses and the main fault rocks.

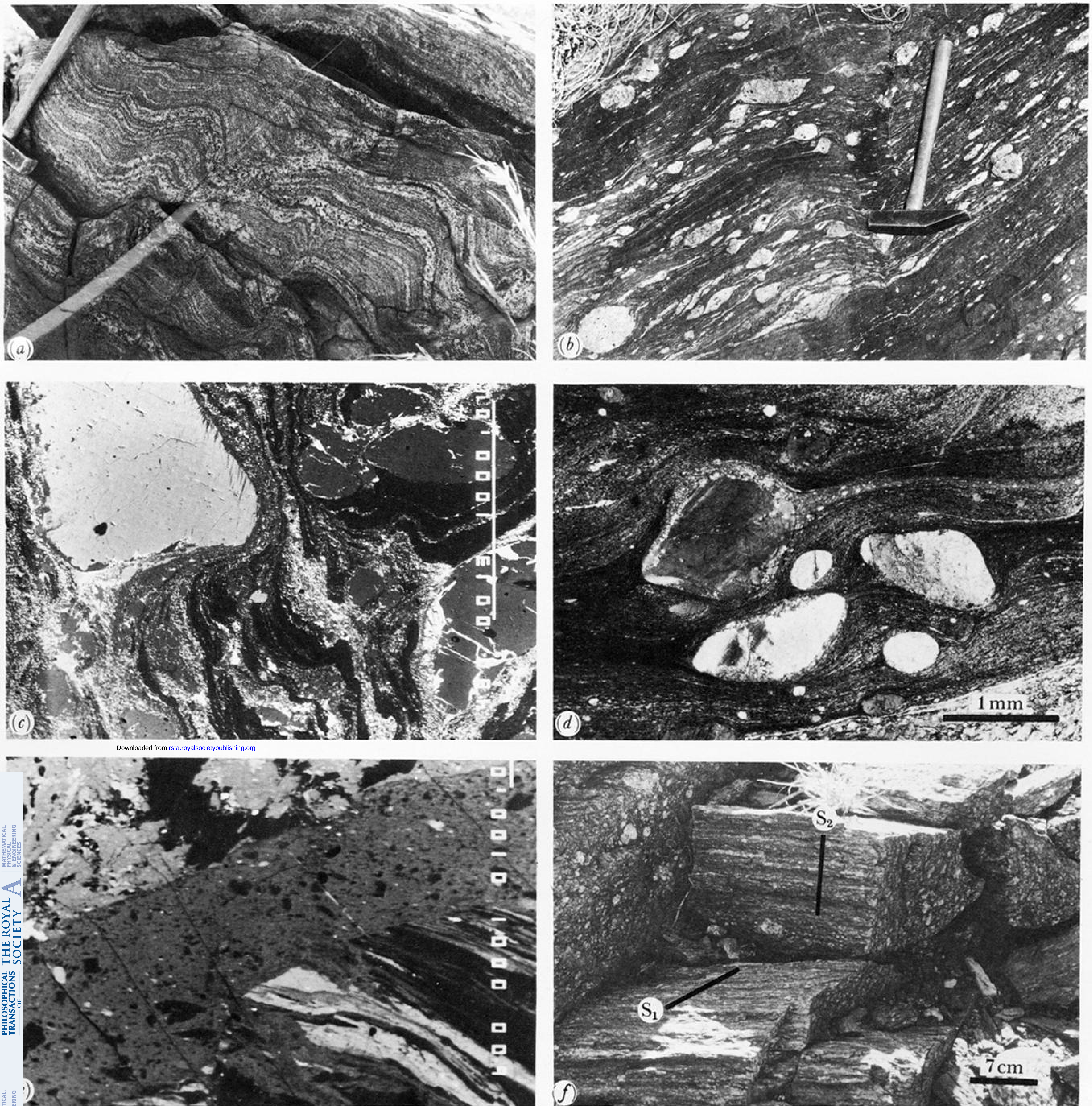

FIGURE 2. Characteristic fault rocks of the Redbank Deformed Zone. (*a*) Mylonitized veins of mobilizate from a relatively less deformed pod within the centre of the zone. (*b*) Strong mylonite foliation containing large porphyroclasts of feldspar. (*c*) Back-scattered electron micrograph of mylonite microstructure. Note complex folding of recrystallized matrix in the vicinity of feldspar porphyroclasts (scale bar 1 mm). (*d*) Ultramylonite containing feldspar porphyroclasts undergoing dynamic recrystallization within grain mantles. (*e*) Pseudotachylyte vein within granulites (scale bar 100 μm). The host rock on the bottom margin of the vein displays a strong foliation which continues into the vein, while the host rock on the top margin remains essentially undeformed. The pseudotachylyte vein has provided the site for localization of later deformation. (*f*) Linear-type fabric developed by the superimposition of two sub-perpendicular foliations (S_1 and S_2). Note the absence of any foliation in this rock.

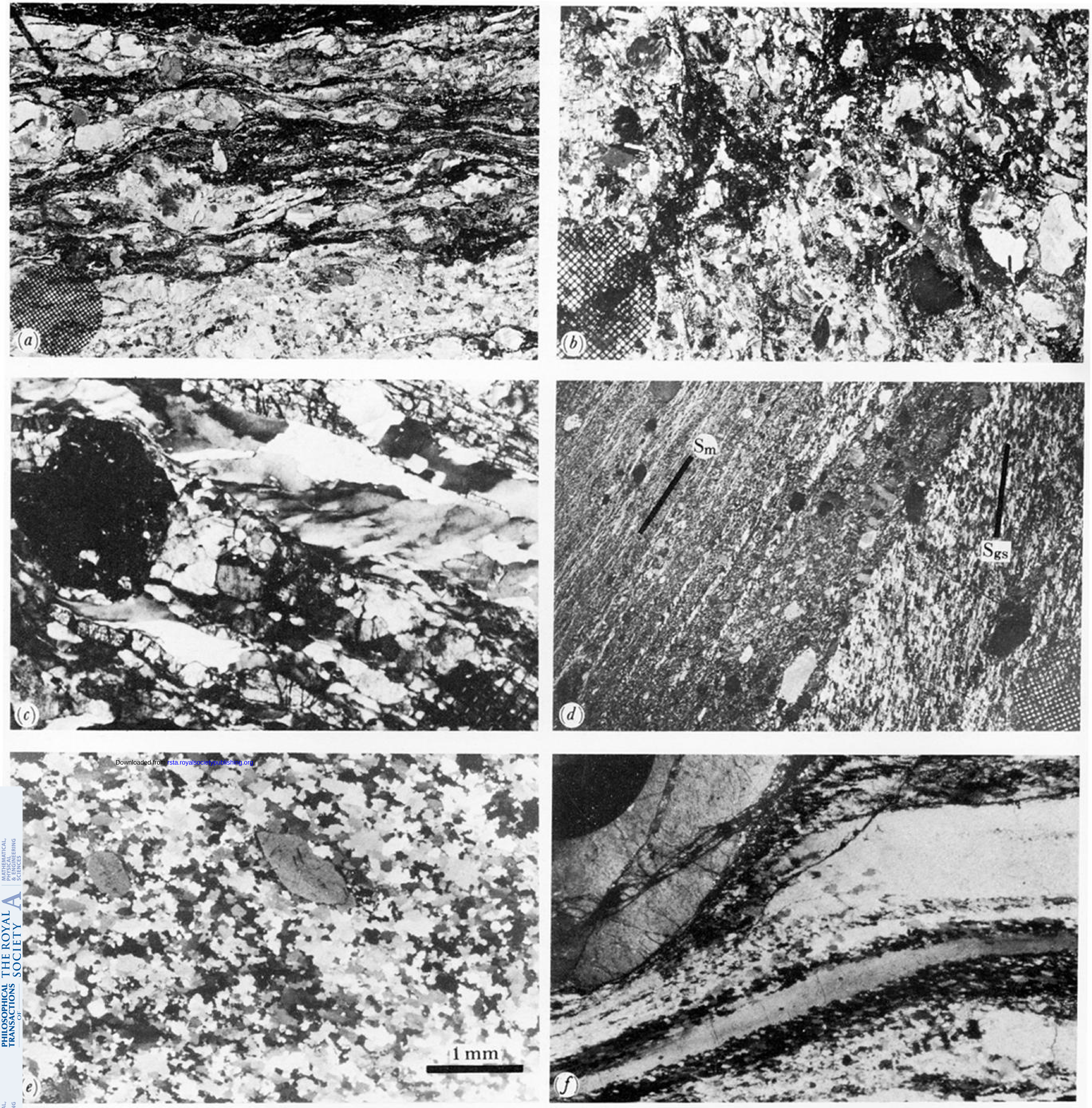

FIGURE 4. Fault rock microstructure (*a*) Optical view of linear-type fabric, parallel to the lineation (scale grid diameter 3 mm). Note domains of quartz–feldspar and micaceous regions. Also note long lenses of quartz and both recrystallization and fracture of feldspar porphyroclasts. (*b*) Linear-type fabric perpendicular to the lineation. Note the absence of any foliation, and the narrow zones of recrystallization containing abundant mica. (*c*) Quartz ribbons with oblique deformation bands in a sillimanite–garnet-bearing mylonitic gneiss (scale grid in bottom right corner). (*d*) Ultramylonite displaying an oblique grain-shape fabric (S_{gs}), with respect to the mylonite foliation (S_m), in a quartz band. (*e*) Relaxed microstructure showing some grains with lobate grain boundaries. Elongate deformed feldspar porphyroclast defines the old foliation orientation. (*f*) White ribbon grain undergoing recrystallization in close proximity to a large feldspar porphyroclast (scale in top corner: radius 1.5 mm).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES