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Porphyroblastesis and displacement: some new textural criteria from pelitic hornfels

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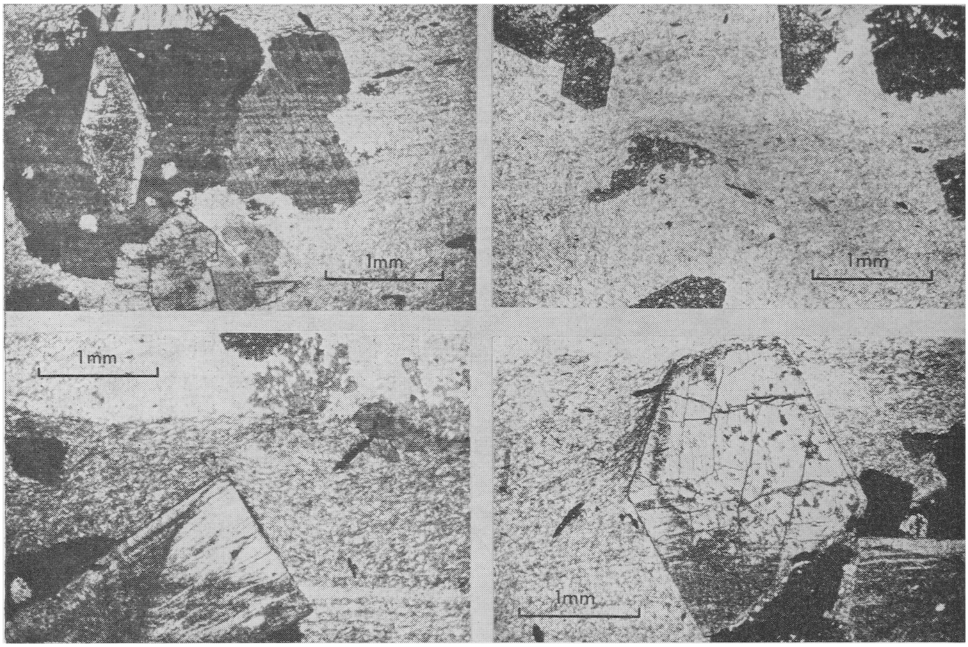
SUMMARY. The formation of porphyroblasts by replacement and displacement of pre-existing *S* surfaces is examined in the light of textural evidence displayed by sediments hornfelsed by the Bushveld Igneous Complex. Helicitic biotite, staurolite, and cordierite all show replacement and displacement textures, the former being more common. The evidence indicates that porphyroblasts are capable of creating local pressure differences that disturb the pre-existing banding, even in hornfelsed rocks that have suffered neither regional metamorphism nor orogenic movement.

THE origin of bowing of *S* surfaces around porphyroblasts has received considerable attention in recent publications particularly by Zwart (1960), Rast (1965), Spry (1969), and again by Misch (1971), Spry (1972), and Harvey and Ferguson (1973). The evidence that a growing porphyroblast or even poikiloblast may push aside adjacent *S* surfaces during growth is not unequivocal and thus prompted Spry to comment, 'that it will be necessary to find a simple example of displacement alone to prove the validity of the hypothesis.... One would presumably look for proof in undeformed types, such as simple thermal metamorphic rocks' (Spry, 1972, p. 1202).

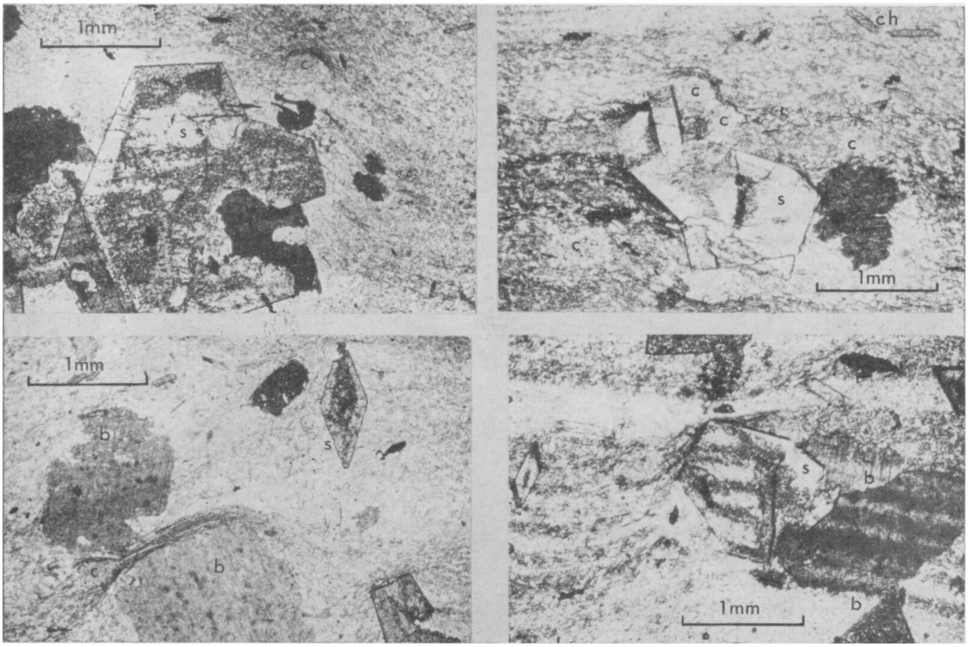
The basal Argillaceous Zone of the Timeball Hill Stage of the Pretoria Series crops out near Penge in the Eastern Transvaal, South Africa, where the rocks dip uniformly towards the south-west at 15 to 20°, parallel to the pseudostratification in the overlying Bushveld Igneous Complex. The entire succession of shale some 580 m thick has been converted into various types of porphyroblastic hornfels, consistent with the chemical composition of individual bands, as result of contact metamorphism due to the intrusion of the Bushveld Igneous Complex. Andalusite, staurolite, garnet, cordierite, and chloritoid-bearing varieties as well as combinations of these minerals have been described by Schwellnus *et al.* (1962, p. 29) and Schwellnus (1969, p. 326). Despite the relatively high grades of metamorphism achieved in these rocks, original bedding and other sedimentary structures are still preserved. Apart from regional tilting and local disturbances associated with faulting, the beds have not suffered any further deformation or alteration that can be attributed to a subsequent regional metamorphic event. Although recrystallization is attributable to pure thermal metamorphism, complexity of crystallization history is indicated by the coexistence of cordierite and staurolite, by zoning of staurolite, and by the existence of a recognizable sequence of crystallization (cordierite–biotite–staurolite–biotite–chloritoid). All *S* surfaces in these demonstrably clastic rocks represent former sedimentary banding. Any disturbance of the *S* surfaces as seen in thin section is nearly always associated with porphyroblastic growth, the finer grained bands tending to show greatest displacement. Rarely micro-shears have disturbed sedimentary banding prior to porphyroblastesis.

A staurolite–biotite–cordierite hornfels is notable for the porphyroblastic development of the three principal minerals, which in thin section are seen to be set in a fine-grained, banded matrix of quartz and sericite. Feldspar, tourmaline, chloritoid, and iron oxides are accessory constituents. Except for the tendency for small cordierite microporphyroblasts to grow with their longer axes parallel to the original bedding no lineation or preferred orientation of any of the other major constituents is noted in thin section. Xenoblastic cordierite was first to form and was succeeded by the growth of biotite poikiloblasts up to 2·5 mm in length and characteristically sieved with matrix inclusions and, or, individual crystals. The cordierite is frequently enclosed by biotite and sometimes replaced by it. Later growth of large staurolite porphyroblasts of similar size to the biotite is witnessed by the replacive relationship of staurolite towards biotite with the biotite containing fewer inclusions.



FIGS. 1 to 4: FIG. 1 (top left). Helicitic biotite enclosing staurolite. FIG. 2 (top right). Disturbed *S* surfaces about an incipient staurolite porphyroblast (S). FIG. 3 (bottom left). Disturbed *S* surfaces about an helicitic staurolite idioblast. FIG. 4 (bottom right). Truncation and disturbance of *S* surfaces by staurolite.

All porphyroblasts have developed later than the *S* surfaces, which abut against the porphyroblasts often with disturbance. In nearly every instance the biotite is helicitic, trains of inclusions marking the original sedimentary banding, passing ghostlike through the crystals without disturbances, pleochroic haloes having a tendency to be concentrated in the darker layers (fig. 1). Helicitic idioblasts of staurolite are common and sedimentary banding often also passes undisturbed through the crystals. Nevertheless in the numerous slides examined by the writer bowing of *S* surfaces has occurred around some staurolites as well as being truncated by the porphyroblasts (fig. 4). S_e passes continuously into one half of the staurolite crystal but is deflected at another face suggesting the two faces either belong to two different forms or similar faces have different surface energies and therefore bear a different relationship to the matrix. Nevertheless, other examples suggest that displacement has resulted from preferential growth of a crystal in one direction and with staurolite most frequently at crystal coigns especially those involving the basal pinacoids, brachypinacoids, and macrodomes. Disturbance is rarely symmetrical and not necessarily in the same sense, growth of different crystals often taking place in opposite directions thereby suggesting that external forces were not responsible for the displacements observed. Staurolite poikiloblasts in the process of growing, as witnessed by the large number of inclusions in the ragged margins of some crystals and by incipient porphyroblastesis, exhibit associated bent *S* surfaces in the matrix. Similarly disturbed *S* surfaces are noted between two developing staurolite crystals and more rarely around biotite where it is



FIGS. 5 to 8: FIG. 5 (top left). Displacement of *S* surfaces about staurolite (S) and cordierite (C). FIG. 6 (top right). Displacement of *S* surfaces about staurolite (S) and cordierite (C). Chloritoid (Ch). FIG. 7 (bottom left). *S* surfaces squeezed between growing biotite (b) and cordierite (C). Staurolite S. FIG. 8 (bottom right). S_i–S_e surfaces increasingly displaced during growth of staurolite (S). Biotite (b).

in the process of replacing staurolite or a biotite crystal growing in proximity to a staurolite crystal. Although tightening of banding in the matrix occurs around porphyroblasts (figs. 6 and 7) no squeezing of displaced '*S*' planes nor disturbed '*S*' planes, which might suggest development of porphyroblasts in association with microfolds, were noted within helicitic crystals. Frequent displacement and bowing of *S* planes occurs around cordierite crystals, the finely banded material being preferentially disturbed (fig. 5), the effect dying rapidly away from the crystal margins. In contrast the chloritoid, which also forms small idioblasts ($< 0{\cdot}3$ mm) of late crystallization, is randomly oriented with respect to *S* surfaces, which it never disturbs (fig. 6). Examination of ten thin sections containing a total of nearly 500 staurolite and biotite porphyroblasts shows that replacement without disturbance is more common than displacement, the ratio being approximately 10:1. Further it was noted that the greatest displacement was often associated with darker bands; a probable consequence of their incompetency.

Specific examples. To indicate the varied nature of the growth of porphyroblasts in the pelitic hornfels from near Penge, Transvaal, a number of examples from thin sections of rock collected by the writer are given below:

Fig. 1 depicts helicitic biotite flakes surrounding staurolite in a matrix of quartz and sericite. Trains of inclusions, marking the origin sedimentary lamination, pass relatively undisturbed through the biotite indicating an original by simple replacement of the matrix. Slight disturbance is suggested by the more widely spaced *S* surfaces in the biotite than in the matrix.

In fig. 2 the bowing and squeezing of *S* surfaces about the incipient porphyroblast of staurolite is obvious; the phenomenon decreases away from the crystal and is absent in the surrounding matrix.

A large idioblast of helicitic staurolite is shown in fig. 3. Primary sedimentary banding represented by *S* surfaces is both truncated without disturbance and bowed over one coign of the staurolite. Bowing of *S* surfaces about an opaque mineral is also visible. A more advanced example of *S* surfaces both truncated without disturbance and bowed by a staurolite idioblast is shown in fig. 4, indicating growth both by replacement and displacement.

Fig. 5 shows disturbance of *S* surfaces about the margins of a staurolite–biotite cluster. Bowing and squeezing is more pronounced against cordierite growing in the immediate environment. Similar squeezing of *S* surfaces and their irregular displacement about staurolite and cordierite are visible in fig. 6. *S* surfaces are not affected by the late growth of idioblasts of chloritoid.

Fig. 7 depicts disturbances of *S* surfaces around porphyroblasts of helicitic biotite, cordierite, and staurolite. The evidence suggests pushing and squeezing of *S* planes about the growing crystals.

Fig. 8 shows disturbance about a porphyroblast of helicitic staurolite. During a period of active blastesis the *S* surfaces became more intensely disturbed as crystallization proceeded, now witnessed by the trains of inclusions through the staurolite.

Conclusions. The evidence given shows that *S* surfaces may pass undisturbed through porphyroblasts, or they may be bowed and truncated by the porphyroblasts. In the first instance the evidence is unequivocal, the porphyroblasts formed later than the *S* surfaces: it is in examples of the second type that controversy has arisen. In the absence of either regional metamorphic imprint subsequent to the development of the hornfels or pre-metamorphic compaction phenomena, it is unlikely that differential flattening or later disturbance of *S* surfaces around previously crystallized porphyroblasts have occurred in the rocks of the present study. Rather the bowing and truncation of the *S* surfaces has been the result of both replacement and displacement by porphyroblastic growth. Such displacement has been confined mainly to the growing staurolite and cordierite, less commonly with biotite and then mainly though not exclusively where it is associated with staurolite, and never with chloritoid. It is the growth of cordierite that provides the unequivocal evidence of bowed *S* surfaces that can only be attributed to their displacement during growth. Disturbances due to porphyroblastesis of staurolite and biotite are, however, equally convincing.

Thus the textural relationships are compatible with a mechanism whereby staurolite, biotite, and cordierite porphyroblasts both replaced the matrix as well as displaced the matrix round them as they grew in a manner similar to that envisaged by Misch (1971) and by Harvey and Ferguson (1973).

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