Shear-Fold-like Structures Developed by Progressive Deformation of Initial Buckle Folds

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Examination of minor folds in the Precambrian basement of SE Norway has shown that shear-fold-like structures are developed in incompetent basic material during progressive homogeneous deformation of initial buckle folds to which the incompetent material has adjusted itself.

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During the mapping of the Precambrian basement between Moss and Son, SE Norway, it has been possible to demonstrate the progressive development of shear-fold-like structures by homogeneous deformation of initial buckle folds.

These folds were formed during the younger of two deformation phases D_1 and D_2, or V_1 and V_2 according to Berthelsen (1967a, 1967b). The D_2 folds are tight to isoclinal with axial surfaces inclined gently to moderately (15°–40°) to the west; since the fold axis plunges to the west, the folds are reclined. The classification and description of the folds are based on Fleuty (1964).

Development of the shear-fold-like structures

Though the D_2 deformation is generally of a strong flattening type, it has been possible to study the progressive deformation of metabasic rocks which provide the main means of recognizing the fold structures. In agreement with the relations between competence and layer thickness, the thicker and more competent metabasite layers were folded and later boudinée, or only boudinée, during the progressive deformation, depending on their orientation in the stress field. The thin layers on the other hand reacted incompetently during the folding, and it is in this situation that the shear-fold-like structures were developed.

It is characteristic that the incompetent basic material shows concaviform fold curves (seen from the basic rock) and that the opposite fold curves of the layer are often disharmonical. These relations appear in Fig. 1, where it is clearly demonstrated that the incompetent basic material adjusted itself to the buckle folds in the gneiss.

Quite analogous are the folds in Fig. 2A, where it is evident firstly that the basic material reacted incompetently and was adjusted to the concentric

Fig. 1. Disharmonic buckle folded, branched metabasite apophysis. The basic material adjusted itself to the gneiss buckle folds. Section normal to the fold axis.

buckle folds, and secondly that the foliation in the basic material was developed in agreement with the 'zone of contact strain' (Ramsay 1967) of the competent gneiss; that is to say that the foliation in the basic rock converges towards the concave side and diverges towards the convex side of the gneiss buckle folds.

If the compression and the amount of homogeneous strain are increased, folds like those in Fig. 2B are developed. The gneiss foliation is now mainly transposed to parallelism with the axial surface, but buckling is still visible in the immediate surroundings of the basic layer. In this layer also the foliation is mainly expressed as axial-plane foliation but convergence and divergence are recognizable. On the right of the figure the basic layer is

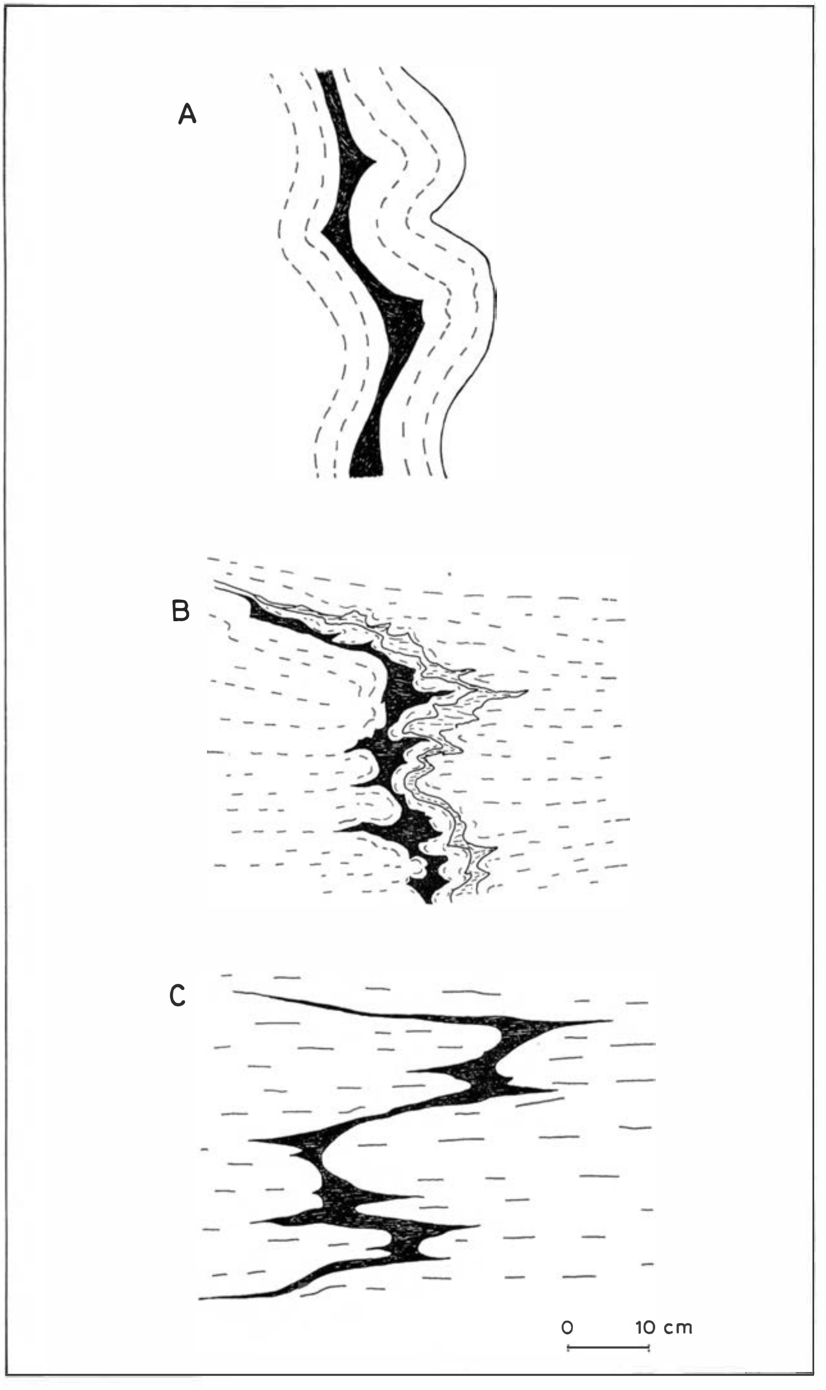

Fig. 2A, B & C. Progressive development of the shear-fold-like structure (C). All sections are normal to the fold axis.

bounded by a thin buckle-folded gneiss layer, while the left side shows a 'contact surface folding' of the style known from mullions or 'Halbboudins' in the sense of Brühl (1969).

These structures were deformed by increasing amount of homogeneous deformation to shear-fold-like structures (Fig. 2C), where the foliation in the gneiss as well as that in the basic layer is parallel to the axial surface. The broad gneiss lobes separated by pinches indicate the incompetent behaviour of the basic material during the initial buckling. Fold structures like those seen in Fig. 2C and in more compressed situations might be erroneously classified as shear structures on account of the approximate similar style, the axial-plane foliation, and a zig-zag trend like that in structures developed by non-affine shear.

Concluding remarks

The progressive development of the shear-fold-like structures is not connected to a shear mechanism and for that reason the term 'shear-fold-like' is only used descriptively. This term is permissible because the resulting structures are of a type traditionally interpreted on the theory of shear-folding. The role of the shear mechanism in the formation of similar-type folds has been much criticized in the last decade by among others Flinn (1962), Ramberg (1965), and Gonzalez-Bonorino (1960) who concluded: 'There is hardly a better example of an erroneous concept in the geologic literature by stereotyped repetition in textbooks, than that of shear- of cleavage-folding' (op. cit. p. 306). Flinn, Ramberg and Gonzalez-Bonorino all state that the similar folds may develop from buckle folds.

According to Flinn the progressive deformation may result in the development of tight similar-type folds from open buckle folds, without any further buckling. The progressive development shown in this note is in agreement with Flinn's assumptions, but what is confusing is that the formation of the shear-fold-like structures of approximate similar type depends initially on the gneiss buckling, evidence of which is generally restricted to broad lobes separated by pinches. The gneiss foliation shows the buckling only in a few cases, since it is generally completely oriented parallel to the new axial surface by transposition.

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