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The relationship between foliation and strain: an experimental investigation: discussion

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Abstract—The account of the relationship of foliation and strain in a salt-mica experiment by Hobbs, Means and Williams is criticized for two reasons. Firstly, the scales of the experimental material and the finite elements measured are considered inappropriate. Secondly, the strain data presented is actually the tectonic, not finite, strain. Both criticisms restrict the application of the experimental results to foliation and strain in rocks.

INTRODUCTION

IN A RECENT paper in the *Journal of Structural Geology*, Hobbs, Means and Williams (1982) provided evidence in a salt-mica experiment that foliations are not necessarily parallel to the principal strain plane ($\lambda_1\lambda_2$ or XY). Two kinds of foliation were produced: domainal, defined by axial surfaces of kink folds, and a preferred mica fabric. The strain was computed in small elements treated as homogeneous, defined by a distorted grid. On the fold limbs the two foliation types were mutually oblique and each was oblique to the local computed $\lambda_1\lambda_2$ plane. Hobbs *et al.* (1982, p. 411) concluded: "In rocks where the foliation has developed by processes similar to those recorded here, large angular divergencies between the foliation and the principal plane of strain should be expected as the rule."

The relationship of foliation and strain has been debated by geologists for more than a century and few can surely claim to be impartial [compare the reviews of Williams (1976) and Hobbs *et al.* (1982) with Treagus (1983)]. The experimental evidence of Hobbs *et al.* (1982) may thus be welcomed by some readers and cited as new evidence that foliation is not generally parallel to the principal plane of finite strain. The purpose of this discussion is to question the evidence by drawing attention to two aspects of the experiment which I believe restrict its application to rocks.

SCALE

The account by Hobbs *et al.* (1982) of their experiment was presented in the context of foliations in rocks. It is reasonable, therefore, to assume that the authors considered the experiment a valid model for rocks despite there being no explicit justification. Strictly, all the experimental parameters should be scaled (see Hubbert 1937) and *similarity* established; for the purpose of the present discussion, only the length scale will be considered.

The grain sizes of the materials in the salt-mica experiment are 100 μm for the salt and 150–500 μm for mica (Williams *et al.* 1977, Hobbs *et al.* 1982). The *model length ratio* will depend on the grain sizes in the rock which the model is intended to simulate. Rocks with foliations of the two types produced experimentally have a wide range of grain size. If analogies are to be made with slaty cleavage and crenulation cleavage (the analogies of Hobbs *et al.*) the grain sizes for slates and schists must be used for scale. Phyllosilicates in the slates studied by Knipe & White (1977) and White & Knipe (1978) are up to 10 μm in size; those from Roy (1978) are 10–40 μm. Finding comparable mica sizes in schists is more difficult, for these are so dependent on the type of schist; however the range 0.2–2.0 mm is probably reasonable for low–medium metamorphic grade schists with foliations of the type under discussion.

The ratio of the model mica lengths and the phyllosilicate or mica flake lengths in the rock is the model length ratio. For *slate* this is found to be approximately 10; that is, the model is ten times larger than its natural analogue. For *schist* (scaling the comparable limits of the grain-size ranges) the model length ratio ranges from 0.25 to 0.75; for convenience take the mean of 0.5 which is a model of half the scale of nature.

The values of the length scale ratios derived for slate and schist may now be applied to the scale of strain computation. The model cross-section was divided into 720 triangular elements with average areas of about 3 mm^2. In the slate these areas would scale to about 0.03 mm^2; in the (mean) schist to 12 mm^2. Only for the schist will these strain elements be comparable to the scale of strain data found from small deformed objects such as ooids. In slate, where much of the discussion of foliation is focused, a comparison of foliation orientation with strain at this pin-point scale would only be meaningful if strain in rocks was measurable on this scale. The result should not be applied to foliation and strain in slate at the hand-specimen scale.

Another way to examine the validity of the model experiment is to compare the scale of the foliations and the scale of the strain elements. Hobbs *et al.* (1982, p. 415) stated: "Calculation of the principal strains λ_1 and λ_3 assumes that the strain field is homogeneous on the scale of each triangle". Is this a reasonable assumption?

Consider the size of a triangle (Hobbs *et al.*, fig. 4); the base may be about 1.7 mm real length, measured on the layering plane, and the height about 3.5 mm. The triangle is composed of mica flakes 0.15–0.5 mm length and salt grains 0.1 mm, initially crudely aligned in layering, and microfolded during model deformation to form kink folds. These kink folds define the two foliation fabrics; their axial planes define the domain-boundary fabric and the limbs the preferred mica fabric. Both fabrics have lateral spacing approximately equal to the kink axial-plane spacing. The distribution of kink axial planes is shown in Hobbs *et al.*, fig. 7(a). The spacing is variable but commonly 0.5–1.0 mm real scale. Thus, each strain element (triangle) may consist of one or two kink folds defining distinct fabric domains. If the fabric is not homogeneous, the strain should not be homogeneous. To assume homogeneity of strain on this scale is as unjustified as to assume homogeneity of the strain at the whole model-fold scale.

Because the array of data provided by strain analysis of deformed elements by modern computers is impressive, there is a danger that its true meaning may be obscured. The real meaning of the strain data of Hobbs *et al.* (1982) is that the strain computation depended on the assumption of homogeneity on the very scale shown to be inhomogeneous by the foliation data. The authors have not, therefore, documented the relationship of foliation and strain.

STRAIN—TECTONIC OR FINITE?

The strain distribution computed by Hobbs *et al.* (1982) was generally referred to, loosely, as principal strains λ_1, λ_2 and λ_3 or the principal $\lambda_1\lambda_2$ plane. At least twice, however, (pp. 415 and 418) the authors used the words "finite strain". Moreover, the results are clearly applied to the relationship of finite strain and foliation in rocks. I consider this analogy is incorrect and that the strain data of Hobbs *et al.* is *tectonic strain*. The reason lies in the experiment procedure.

The method of preparation and assembly of the salt-mica experiment described by Hobbs *et al.* (1982) closely follows the authors' previous experiments (Means & Williams 1972, Means 1975, Williams *et al.* 1977). The multilayer is made up of separately prepared layers, each having been compacted at 360 MPa (3600 bars), marked with a rectilinear network of lines and finally stacked together. The compaction was sufficient to generate a strong layer-parallel foliation, described fully in Williams *et al.* (1977). It is this which subsequently kinked giving rise to the foliations described by Hobbs *et al.* (1982). This compactional foliation resulted from the *compactional strain*. In the experimental descriptions of the authors I can find no data on the amount of compaction and volume loss, only the compaction pressure.

The strain distribution computed for the experiment was derived from analysis of the distortions of the grid which was applied after layer compaction but before the multilayer assembly. It is thus the post-compactional or *tectonic strain* in the model, not the finite or total strain.

A simple estimate of the compactional strain may be made from the data in Means & Williams (1972) and some density estimates. A figure of 20–30% volume loss is found, equivalent to a strain ellipse in the experiment cross section of 1.0 : 0.8 to 1.0 : 0.7 (axial ratios 1.25–1.43) with the apparent elongation parallel to layering. Clearly, the finite strain in each model element will result from the superposition of the tectonic strain computed by Hobbs *et al.* on the compaction strain ellipse; its exact size and orientation will depend on the history of the tectonic strain increment and its rotational element. On the fold limbs of the experiment, the orientation of the finite λ_1 direction is expected to be measurably different from the tectonic λ_1 (given in Hobbs *et al.* 1982, fig. 4), and at a more acute angle to layering. Using the method of Elliott (1970) as one way to superimpose the strains, I find angular differences of 2.5 and 4.5° for points A and B of Hobbs *et al.* with 20% volume loss, and 7 and 12° for 30%. Thus the *finite* λ_1 directions will be measurably less oblique to the foliations produced on the fold limbs than the λ_1 (tectonic) direction of Hobbs *et al.* (1982, figs. 8 and 10). It is probable that the angle between the finite $\lambda_1\lambda_2$ trace and the domain-boundary foliation may turn out to be insignificant.

CONCLUSIONS

The data provided by the salt-mica experiment of Hobbs *et al.* (1982) have been criticised for two separate reasons. First, by scaling the experiment to comparable foliated rocks, and scaling the strain elements accordingly, it is found that the element size is inappropriately small in the rock (particularly slate). The presence of microkinking within each element, giving rise to the two types of foliation fabric described, is, I consider, evidence that the element is inhomogeneous and therefore should not be considered homogeneous for the purpose of strain computation. Secondly, the strain computed in each model element is not a finite strain but a tectonic strain. The accurate data provided by Hobbs *et al.* (1982) on the relative orientations of two foliation types to the $\lambda_1\lambda_2$ traces should not, therefore, be compared with the relationship of foliation and finite strain in rocks.

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