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Minimum strain from conglomerates with ductility contrast

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Abstract—An approximate estimate of the minimum strain ellipsoid for rigid clasts in a ductile matrix may be made using the shapes of the most eccentric and least eccentric clast. Further, a minimum strain estimate for the matrix may be made using the curvature of strain shadows of cleavage.

INTRODUCTION

IN THE last thirteen years great advances have been made in developing approaches to strain analysis of conglomerates. Ramsay's (1967, p. 216) concept of combining clast ratio, fluctuation and original fabric, the R_f/ϕ technique utilising fluctuation in particular (Dunnet 1969, Dunnet & Siddans 1971, Siddans 1980), and a much more widely applicable, ingenious technique of Robin (1977) have all added greatly to our understanding of ways of estimating the strain of suites of ellipsoidal markers. More recently, Lisle (1977, 1979) showed that where fluctuation was low and strain at least moderate, the strain of randomly oriented particles was simply approximated by the harmonic mean of the shapes of the clasts. However, all of these methods may only be applied to conglomerates where the ductility contrast between pebbles and matrix is minimal. The necessary premise for all the methods is that the particles behave completely passively.

The purpose of this note is to suggest pragmatic procedures, the first partly related to the earlier methods above, as well as to the method of Gay (1968), which will apply to deformed clasts which are uniformly rigid with respect to their matrix. The techniques provide at least first-order-of-accuracy methods for working with the many real conglomerates which display a marked ductility contrast between pebbles and matrix.

THE FIRST METHOD

The procedure is analysed initially in two dimensions (Fig. 1). Whether or not a preferred orientation exists the clasts will align with low bulk strains, and therefore relatively quickly, close to the maximum extension direction (Figs. 1a & b). The alignment may not be by a direct route but may involve some 'turbulent' orbiting.

The strain ellipse (axes X_t, Y_t: axial ratio $a_t = X_t/Y_t$) is now coaxial with the pebbles and the pebble orientations will be stable if the strain history is not markedly non-coaxial. The least eccentric pebble has initial axial ratio $a_{0\ min}$. It deforms to become the least eccentric deformed pebble with the axial ratio

$$a_{0\ min} \cdot a_t. \tag{1}$$

Similarly, the most eccentric deformed pebble has an axial ratio

$$a_{0\ max} \cdot a_t. \tag{2}$$

Therefore, by searching for the most and least eccentric deformed clasts of a uniformly rigid type we can establish the two quantities.

In the three-dimensional case, the same arguments apply to the YZ plane so that the least eccentric deformed pebble has an axial ratio

$$b_{0\ min} \cdot b_t, \tag{3}$$

and the most eccentric deformed pebble has an axial ratio

$$b_{0\ max} \cdot b_t. \tag{4}$$

For an undeformed suite of pebbles from a monomict conglomerate choose the extreme a_0 and extreme b_0 ratios. For example, 697 undeformed quartz sandstone pebbles (from a Triassic fluvial conglomerate in Spain) measured by Warner ten Kate and Borradaile (unpublished work) showed the following range of axial ratios.

$$a_{0\ min} = 1.0$$
$$a_{0\ max} = 2.47$$
$$b_{0\ min} = 1.0$$
$$b_{0\ max} = 3.44.$$

If these data are applicable to the pebble lithology in the deformed conglomerate then the values can be divided into the appropriate quantities (1)–(4) above to give a maximum and minimum value for a_t and b_t.

This approach will yield a minimum estimate of the strain ellipsoid for the whole rock because: (a) some strain is responsible for aligning the pebbles and may not be recorded directly in the pebble shape; and (b) the strain of the pebbles is less than that of the matrix because the pebbles are more rigid.

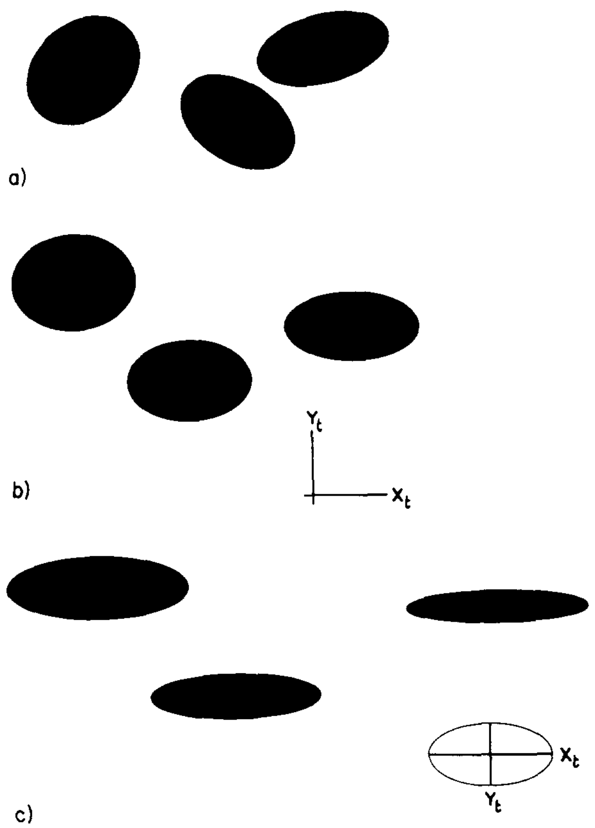

Fig. 1. (a) Suite of elliptical clasts with random orientation. (b) Initial strain with axes X_i, Y_i aligns the ellipses to a stable coaxial position if the strain history is not too rotational. (c) Ensuing tectonic strain (ellipse X_t : Y_t) deforms clasts. From the least eccentric and most eccentric deformed clasts, knowing the extreme initial pebble shapes, it is possible to ascertain the X_t/Y_t ratio.

THE SECOND METHOD

The second method has not been rigorously analysed, but intuitively, and from the work of Shimamoto (1975) it appears to merit attention. There is, as Ramsay (1967, p. 180) implied in his discussion of schistosity and cleavage a strong similarity between the orientations of finite strain in a ductile matrix around a rigid object and the pattern formed by schistosity in a strain shadow region. Shimamoto (1975) used a finite element approach to predict the orientations of local finite strain axes around a rigid particle in a less viscous matrix. There exists a correlation between the bulk shortening of his system and the deviations of the principal-strain trajectories about the more rigid particles (Shimamoto 1975, figs. 4–6). If under certain conditions schistosity does track the XY principal strain orientations (the $\lambda_1\lambda_2$ plane) of the finite strain ellipsoid, the pattern of distortion may relate approximately to the bulk strain by analogy with the figures cited from Shimamoto.

Consider Fig. 2: this is a sketch of a clast exposed on a surface parallel to the XZ principal plane. In terms of the quadratic elongations the axes of the strain ellipse are $\sqrt{\lambda_1}$ and $\sqrt{\lambda_3}$. The schistosity surfaces which just graze the edge of the rigid clast, swing into the strain shadow region when traced past the clast. From the curvature of the trace it is possible to evaluate the $\sqrt{\lambda_3}$ strain as indicated in Figs. 2(a) and 3.

The assumption that cleavage or schistosity is a finite strain trajectory is open to question in some instances (Borradaile 1977, Williams 1977), particularly if the bulk strain accumulates during a 'non-coaxial' (Means 1976, p. 236) strain history. Otherwise, the method offers at least an approximate evaluation of the strain state. The strain determined is the bulk strain for the ductile matrix if the clasts are perfectly rigid.

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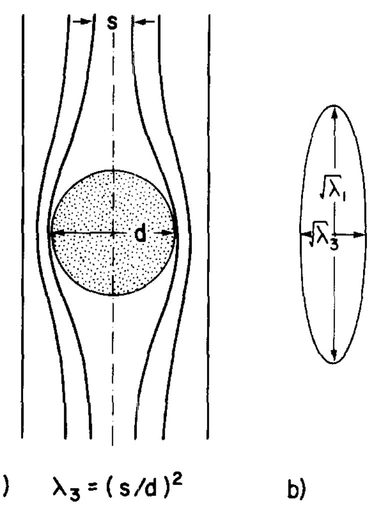

Fig. 2.(a) Rigid round clast (stippled) and deflected cleavage planes around the clast in a ductile matrix. (b) Strain ellipse responsible for strain.

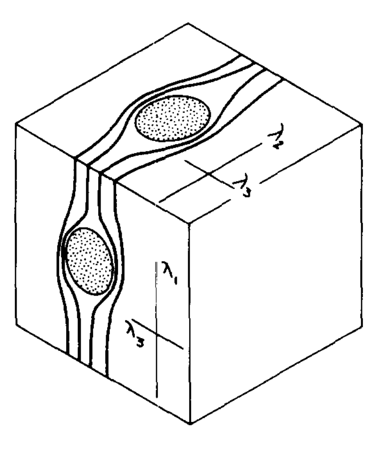

Fig. 3. Three-dimensional configuration of strain shadows around a rigid clast on surfaces parallel to the principal planes.

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