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Strain estimation from the fabrics of deformed rocks

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The paper presents a simplified method of estimating strain from the fabrics of weakly deformed rocks, where it is difficult to measure the longer and shorter dimensions of deformed objects. In this method, the plot of the average normalized length of deformed objects against the orientation of lines of constant length, at different angular spacing exhibits a sinusoidal curve. The ratio of maximum to minimum length of curve provides strain ratio. Further, the orientation of the maximum and minimum provides the orientation of principal strain axes. The method requires only a few measurements at different angular spacings, resulting into quick estimate of strain.

Keywords: Homogeneous deformation, monomineralic and polymineralic rocks, sinusoidal curve, strain ratio.

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SEVERAL methods of estimating two dimensional strains from the deformed rocks have been proposed[1–10]. The methods require the measurement of longer and shorter dimensions of the deformed objects, called strain markers. It is easy to measure the longer and shorter dimensions of the deformed objects in moderately to highly deformed rocks, whereas it is difficult to identify with precision the longer and shorter axes of individual objects/particles in weakly deformed rocks. The relatively few methods that do not require the identification of longer and shorter axes of particles are centre to centre method[7,11], Fry method[3], regular and inverse SURFOR wheel method[5,6] and intercept method[10].

The centre to centre method[7,11] assumes that the particles are well dispersed and distributed uniformly so that the grain centre approaches an isotropic pattern in the unstrained state. In such distributions, length of the lines '*d*' from the centre of one object to the centre of its nearest neighbour is statistically constant in the initial state. During deformed state, the distance between the centre of randomly deformed particles is systematically altered to '*d*′' in such a way that changes in the distances are related to the direction and amount of strain. On a sheet of tracing paper the centre of all particles are marked. A line is then drawn joining the centre of the nearest neighbour particle. The distance '*d*′' and orientation of the tie from line '∝' from the known reference are determined. The value of '*d*′' and '∝′' are plotted as abscissa and ordinate respectively, to provide a bell shape curve. By measuring the distance between the maximum and minimum values of '*d*′' on the curve of best fit, the ellipticity (*R*) of the strain ellipse can be found from $R = d'_{max}/d'_{min}$.

The Fry method[3] is based on an arguments; when a set of points with statistically uniform distribution are deformed, the average distance between the neighbouring points in any direction increases or decreases in the same ratio as the length of a marker line in that direction[12]. The maximum increase takes place in the direction of longer axis of the strain ellipse. The average distance between the points decreases the most in a direction parallel to the short axis of the stain ellipse. In this method, centre of all the grains are traced on an overlay by keeping the centre of the grain on a central reference point. After tracing several times all the centre points, a vacancy field of ellipsoidal shape gives directly as long and short axes. The orientation of the ellipse also gives the orientation of the strain ellipse.

The SURFOR wheel method[5] (SURFace Orientation) is a computer based method for the estimation of two dimensional strain from the orientation of lines in a plane. The method assumes that the grain boundary surfaces or other surfaces of the undeformed rocks have no preferred orientation. Homogeneous strain of the bulk rock volume is then assumed to produce a preferred orientation. The method involves digitization of outlines by a set of small straight lines on the enlarged photographs. The orienta-

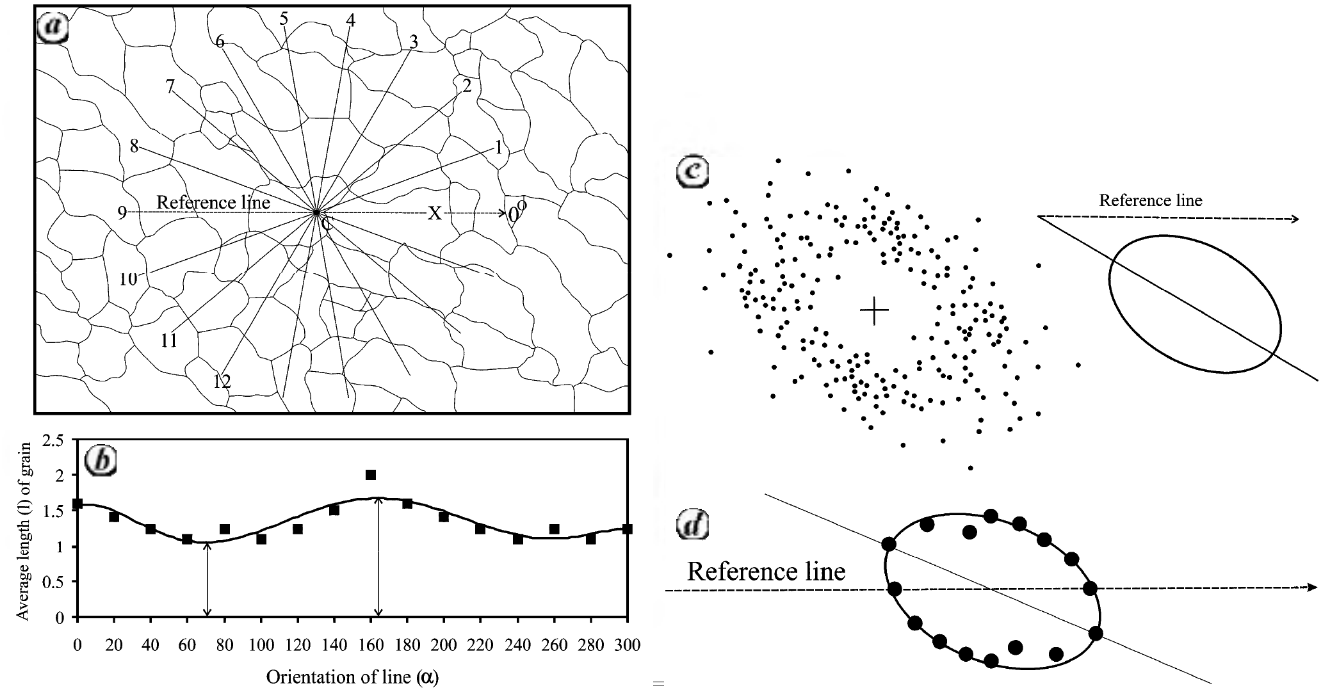

Figure 1. ***a***, Outline of grain boundaries from the thin section of Cambrian quartzite[11]. X is the reference line and C is the centre. Lines 1, 2, 3, 4, 5, . . . represent 20°, 40°, 60°, 80°, 100° . . . respectively; ***b***, Plot of the average grain length (*l*) orientation of line (∝) w.r.t. reference line. From the plot the ratio of maximum to minimum gives the strain ratio and the direction provides the maximum and minimum strain axes. The strain ellipse and orientation of maximum strain in Figure 1 *a* as obtained by (***c***) Fry method and (***d***) Intercept method.

tions of length of the line segments are measured and a histogram of total length per increment of angle is obtained by adding the length of all segments.

The inverse SURFOR wheel method[6] is based on the same assumptions as those of the SURFOR wheel method[5]. However, in the inverse SURFOR wheel method the strain analysis consists of rotating a set of parallel lines of fixed and constant length through 180° at 10° increments. At each position, the intersections of outlines with the lines were counted. The number of intersections plotted against the orientation of the line gives a sinusoidal curve in the deformed state. On the plot, the minimal and maximal intersections represent the orientation of the maximum and minimum principal strain axes.

The intercept method[10] is another method of estimating strain from weakly deformed rocks, based on the fact that the average length of the intercepted grain is constant in an undeformed state with no initial fabric. The average length in deformed state in any direction is the diameter of an ellipse of the same aspect ratio as the strain ellipse. In this method, the average normalized dimension of deformed particles in different directions on a plane defines the shape and orientation of strain ellipse.

The present paper describes an alternative technique[10] for determining the strain in weakly deformed rocks. This method is similar to the inverse SURFOR wheel but differs in the sense that the latter method requires a SURFOR wheel to be placed on the deformed fabric to determine the number of intersections with parallel lines. Further, in the intercept method[10], the average length is plotted on a polar plot as a function of line orientation. However, in the present method, the average length of the grains on a line of constant length is plotted on a simple graph against the orientation of that particular line. The plot gives a sinusoidal curve in the deformed state.

This method is also based on the fact that the average length of the particles/grains is constant in an undeformed rock with no initial fabric. Due to homogeneous deformation, the particles change their length and orientation. Hence, it is proposed that the number of the deformed particles or grain be obtained along fixed length of lines of different orientations passing through the centre of the fabric (Figure 1 *a*). Averages of these measurements (*l*) are then plotted on a simple graph against the orientation of lines (∝) w.r.t. reference line, resulting in a sinusoidal curve. The curve gives the maximum and minimum line length and thus the strain ratio. On the plot, the maximum and minimum lengths also represent the orientation of maximum and minimum principal strain axes.

The procedure is as follows:

1. Trace the grain boundaries (Figure 1 *a*) from the photograph. Choose the point C roughly in the middle of the drawing and a reference line (X) passing through C (Figure 1 *a*).

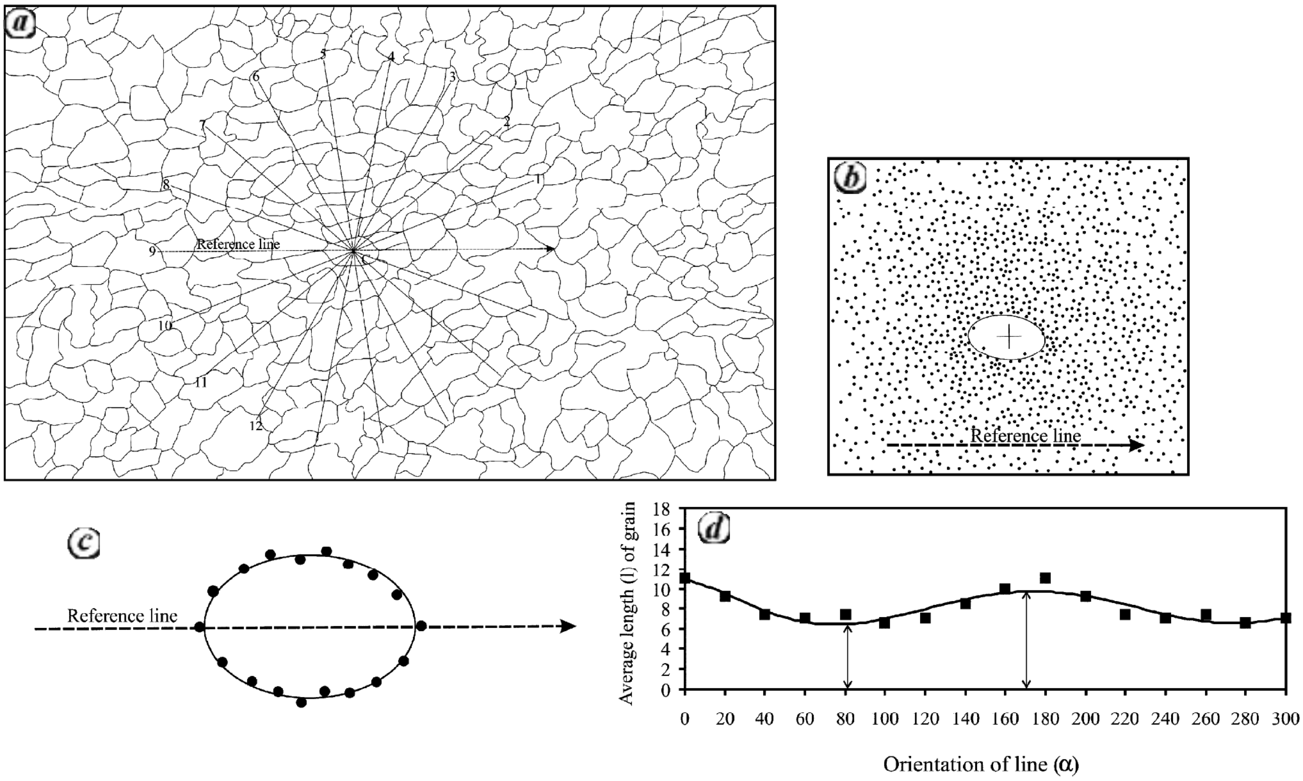

Figure 2. ***a***, Outline of the fabric of thin section from the quartzite of Garhwal Group of Uttarkashi region of Garhwal Himalaya, used for the strain determination by the present method. The strain ellipse and orientation of maximum strain obtained by (***b***) Fry method (***c***) intercept method (***d***) the present method.

Table 1. Comparison of three different methods of strain estimation on Figure 1 *a*

Method	Fabric element	Strain ratio	Orientations
Fry Method[3]	Centre	1.70	152°
Inverse Surfor[6]	Outline	1.27	150°
Intercept Method[10]	Outline	1.77	157°
Present Method	Outline	1.66	164°

Table 2. Comparison of the methods of strain estimation on the fabric of Figure 2

Method	Parameter	Strain ratio	Orientation	Figure no.
Fry Method[3]	Centre	1.61	172°	2 *b*
Intercept Method[10]	Outline	1.51	180°	2 *c*
Present Method	Outline	1.57	172°	2 *d*

2. Draw lines (1, 2, 3, 4 . . . Figure 1 *a*) of equal lengths (5–10 times larger than the average grain size) and at regular angular spacing with respect to the reference line passing through the centre point C. For best results, lines of 20° angular spacing should be drawn.
3. Count the number of grains traversed by the lines of different orientations passing through C. The lines 1, 2, 3, 4, 5 . . . represent 20°, 40°, 60°, 80°, 100° . . . respectively. At the end of the line, half or more than half grain covered is counted as one grain; or may be counted in fractional part for greater accuracy.
4. Since the length of line (L) is known, the average grain length (l) can be obtained by dividing L by number of grains along a particular line passing through point C.

The average length (l) of the grain is plotted against the orientation of line (∝) w.r.t. reference line. On the plot, the minimum and maximum lengths represent the orientation of maximum and minimum strain axes and the ratio between them is the strain ratio.

The present method was applied to two different fabrics of rocks. Figure 1 *a* shows the application of the method on a thin section of Cambrian quartzite[11]. Sufficient published data is available on this fabric; hence it is proposed to use this fabric for the strain estimation by the present method. To determine the strain from this fabric, the present method has been applied and the result is compared with the strain obtained by other methods. Table 1 indicates that there is a small variation in the strain ratios obtained by different methods, which uses different parameters. The results are listed in Table 1 along with the results obtained by other methods performed strain estimation on the same fabric.

Figure 2 *a* is a sketch of the fabric of thin section from the quartzite of Garhwal Group of Uttarkashi region of Garhwal Himalaya, used to demonstrate the present method of strain estimation. A comparison of the results is given in Table 2.

The strain ratios and the orientation of the strain ellipse estimated by different methods (Tables 1 and 2) on the fabrics of deformed rocks (Figures 1 *a* and 2 *a*) exhibit minor variation. This variation in the strain ratio is probably due to the use of different fabric elements[6], i.e. centres of grains vs grain boundaries, or due to the fact that each technique has its own set of assumptions[13]. Like other methods, the present method also assumes a homogeneous deformation and random orientation of grains with no initial fabric prior to deformation. The proposed method will be useful in homogeneously deformed monomineralic rocks where the particle surfaces actually record the strain. Application of this method to polymineralic rocks might be complicated by strain partitioning into the minerals among rheologically different grains[11]. The advantage of this method over the others is that a sinusoidal curve provides the maximum and minimum lengths and the orientation of maximum and minimum principal strain axes. The method also requires only a few measurements for a quick estimate of strain.

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MEETINGS/SYMPOSIA/SEMINARS

National Workshop on Potential Alternatives to Dissection and Experimentation in Life Science (Zoology) involving invasive Animal use and the Practical Curriculum

Date: 19–21 November 2009
Place: Jaipur

Themes include: Making the teaching of life science (Zoology) livelier and career oriented; Psychological impact of killing and collection of animals on the young minds; Curricular transformation and introduction of applied courses/papers; Replacement alternatives to common dissection exercises and experiments involving use of animals namely, study of anatomy/dissection skills (from invertebrates to proto-chordates and fishes to mammals), physiology, biochemistry, cell biology, radiation biology, histology, pathology, embryology and developmental biology, study of museum specimens, permanent preparations of external body parts/internal organs, microscopic slides and osteology; miscellaneous issues and concerns.

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International Conference on Climate Change and Bioresource (ICCCB-2010)

Date: 9–12 February 2010
Place: Tiruchirappalli, India

Themes and objective: There is growing awareness on the imperative need to conserve, protect and manage the various ecosystems and their valuable natural resources. There is a need for the rational exploitation, conservation and sustainable management of diverse and exploited living resources. For the conservation and sustained development, it has became essential to take stock of the species that occur, the nature of their incidence, the environmental and biological characters that govern their life and activities so that we can propose the desired regulatory measures.

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