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A statistical examination of the Fry method of strain analysis

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ABSTRACT

The statistics of the Fry method of strain analysis are examined in this paper. Point objects in the pre-deformed state are assumed in the Poisson distribution that is truncated at the maximum probability density function (PDF) of a certain point object. The mean log likelihood function (MLLF) is defined as the average sum of the log PDF of each individual point in the deformed state, and is maximized by use of a grid search to solve for unknown parameters, strain and cutoff radius. In order to demonstrate the feasibility of the new strain method, it is applied to artificial sets of point objects generated at the prescribed parameters. Results deliver a very high accuracy of the strain estimate even for artificial sets with many less packed point objects. Increasing the number of point objects in the MLLF tends to give a higher accuracy of strain estimate, particularly for a smaller point number, less than 60 in this case. A deformed conglomerate is analyzed to illustrate the new approach. A probable spurious point in these data is identified using the detection method proposed in this paper. Its removal leads to a more robust estimate of the strain.

1. Introduction

Although similar to the classical center-to-center method (Ramsay, 1967) in dealing with the points or centers of deformed objects, the ingenious Fry method (Fry, 1979) is more flexible in taking the distribution of objects into account, and requires no knowledge of the nearest neighbour points. These strengths, as well as the fact that deformed objects exposed at outcrop and/or under the microscope are generally not good strain markers on account of their unknown shapes in the pre-deformed state, make the Fry method applicable as a simple and powerful tool to quantify homogeneous deformation recorded by the distribution of points in rocks of variable kinds (e.g., Hanna and Fry, 1979; González-Casado et al., 1983; Crespi, 1986; Onasch, 1986; Ghaleb and Fry, 1995; Genier and Epard, 2007), and even the spatial distribution of mineralization (Vearncombe and Vearncombe, 1999).

The Fry method was devised to graphically extract strain from object–object separations in deformed rocks (Fry, 1979). For point objects that possess an isotropic anti-clustered distribution and then undergo homogeneous deformation, an elliptical vacancy or void is surrounded by points near the center of the Fry plot, that is an analogue of a finite strain ellipse. Theoretical improvements mainly concentrate on the subjectivity and reproducibility of the strain ellipse estimated by use of the Fry method (Ailleres and Champenois, 1994). The uncertainty in defining the finite strain ellipse near the central vacancy is due to the deviation of real point distributions from Fry's (1979) assumption of an anti-clustered distribution. For objects of strongly variable sizes that appear less anti-clustered, Erslev (1988) developed a normalized Fry method that modified each object–object separation according to the shapes and sizes of the two neighbouring objects. Erslev (1988), Dunne et al. (1990) and McNaught (1994) examined how the way of defining object centers affects the estimated finite strain ellipse from a practical viewpoint. Erslev and Ge (1990) later developed a least-squares method to determine the best-fit strain ellipse from nearest neighbour points in the normalized Fry plot. Fry (1999) claimed that the use of the first or second summed moments in estimating strain from some or all parts of points in the Fry plots is unjustified. Waldron and Wallace (2007) attempted to determine the strain ellipse in the non-normalized or normalized Fry plot by locating the locus of the observed maximum point-density gradient that best fits the calculated point density within a central elliptical domain.

In practice, the distribution of points in the Fry plot is influenced by factors such as the distribution of point objects in the sampled area, the shape and the size of the sampled area, and deformation.

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The second factor can be neglected only if a large circular sampled area is chosen. In the absence of the second factor, outside the central vacancy field, points tend to decrease their density outwards from the center, and to be evenly distributed in all directions (Fig. 1c). This is probably the simple reason that most structural geologists have chosen to extract strain only from the points near the center, using some improved Fry methods. Disregarding most points in the Fry plot in this way certainly weakens the claim of obtaining the strain from all separations between objects rather than those lying closest to the center, as Fry (1979,1999) believed. This makes apparent an unclear issue about whether or not all object separations in the Fry plot can be used for strain analysis.

In this communication, we examine some statistical aspects of the Fry method, including the randomness and the truncation of point distribution. The probability density function of distance between the k-th nearest neighbour points is then formulated, from which we define the likelihood function. The mean log likelihood function is then maximized using a grid search to solve for strain, which provides us with a new method of determining strain from point distribution. This method is validated and illustrated by applying it to artificial sets and a real set.

The symbols used in this paper are listed and defined in the Appendix.

2. Strain analysis using the Fry plot

It is necessary to rehearse the procedure for making the Fry plot (Fry, 1979; Hanna and Fry, 1979) before we make some theoretical investigation of it. Let us take a template made up of the positions of n the centres of deformed objects (Fig. 1b). Move this template without any rotation to a new plot so as to locate one of the points at the origin, and then mark other points from the template onto the plot. This process is repeated until all the points in the template have been used up. The map of all marked points, $n(n-1)$ in number, is called the Fry plot (Fig. 1c).

In essence, the Fry plot is a realization of $n(n-1)$ points around a fixed point (origin) in a way peculiar to it of repeating the same random point pattern within the same domain but at differing locations. This peculiarity never violates the assumption of a statistically homogeneous or Poisson distribution of the point objects in the sampled area (Fry, 1979). The density of marked points in the Fry plot depends upon the cumulative occurrences of

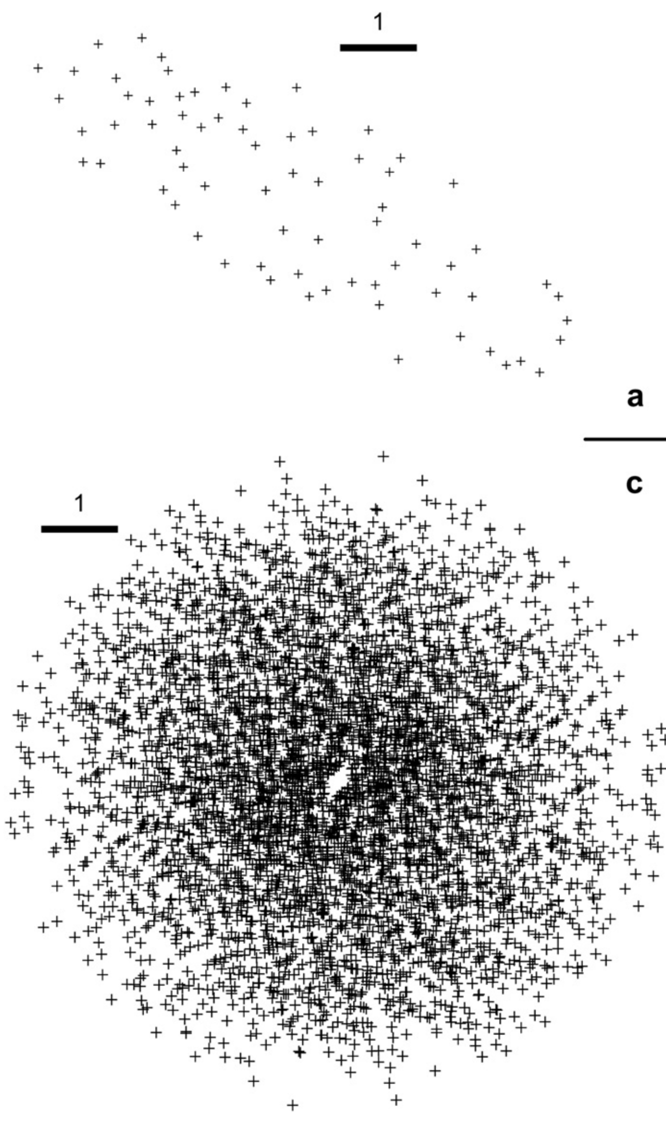

Fig. 1. An artificial set of 70 points in the pre-deformed state (a) and in the deformed state (b). Fry plot of the set in the deformed state (c), and the best fit elliptical void in the center of the plot (d). All points are marked by “plus”. See Section 4.1 for information on data generation. The best fit elliptical void, as well as the first nearest neighbour points in the pre-deformed state is determined by using the proposed method in the case of one outcome ($k = 1$).