In Memory

Margaret (Mum) and Suzanne

The essence of FIA: A study of the distribution of Foliation Intersection Axes data and its significance from hand sample to regional scales.

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Statement on the Contribution of Others

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R. Ketcham, University of Texas CT Facility, acquired the HRXCT data (including fine tuning the process for this application), and contributed to the description of the HRXCT technique and some aspects of the discussions in chapters 1 and 2. David Donald, James Cook University, collaborated on chapters 3 and 4 with particular regard to the development of the bootstrap statistical techniques.

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Introduction and Thesis Outline

The study of orogenic belts is fundamental to understanding many of the crustal scale processes that control the formation and behaviour of continents. However, the history of orogenic belts is commonly very complicated, with overprinting pulses of metamorphism and deformation that can be diachronous along the length of an orogen. Repeated deformation events overprint or remove the effects of earlier ones. Consequently structures preserved in the rock matrix do not preserve evidence of all the deformation events that the rock has gone through. Combined with deformation partitioning that causes strain to be heterogeneously distributed at all scales, matrix structures cannot be used as a framework for correlating metamorphic events across an orogen.

FIAs are a structure that appears to provide a consistent record through time, allowing the effects of deformation events that may have been destroyed or redistributed in the matrix to be preserved. FIAs are the foliation inflection/intersection axis preserved in porphyroblasts. They are interpreted as being the intersection of successive foliations, or the curvature of one into the next, which have been overgrown by a porphyroblast. They can be equated with the intersection lineation between these two foliations or the fold axis of the second event. An alternative interpretation is that they represent the axis of rotation of a porphyroblast while it was growing. However they are interpreted, they can be routinely measured and used to investigate structural, metamorphic, and tectonic processes

FIAs are most commonly measured using the asymmetry method. This method finds the average FIA orientation for a sample using a series of spatially oriented thin sections. It relies on the fact that a simple asymmetrically folded surface with a sub-horizontal axis will appear to have opposite asymmetries when cut by two vertical planes that strike either side of the fold axis; curved inclusion trails preserved in porphyroblasts are analogous to such a fold.

Questions have been raised about the accuracy of FIA measurements because they are not measured directly. What is the intra sample variation of FIAs, and how reliable are FIA orientations determined by the asymmetry method? Data suggesting that they most likely remain consistently oriented, in spite of the overprinting effects of younger deformations, are difficult for many to accept. These questions have lead to doubt as to the significance of FIAs, and whether they can be correlated between samples and along orogens. This thesis takes a detailed look at FIAs using newly developed techniques in an attempt to address these issues, and to provide an insight into their significance. The four chapters have been written as manuscripts and the first has been accepted for publication as an electronic article in American Mineralogist.

Finding the orientation of a FIA in a single porphyroblast requires the inclusion trails to be viewed in three dimensions, or sectioned in multiple orientations. This is rarely possible in rocks and not possible using two-dimensional thin sections. Virtual models of the inclusion trails can be made using serial grinding or serial thin sectioning. These techniques are time intensive and the orientation of the axes need to be at a high angle to the sections or grinding plane for the geometry of the curved trails to be captured. High resolution X-ray computed tomography (HRXCT) provides an alternate means by which the inclusion trails inside porphyroblasts can be imaged. It enables the internal structure of solid objects to be visualized in three-dimensions. HRXCT is a development of X-ray computed tomography technology developed for medical applications. It measures the attenuation of X-rays as they pass through an object; the amount of X-ray energy attenuated is proportional to its energy, and the density and average atomic mass of the material being analysed. HRXCT is capable of resolutions of less than 10μm. Chapter 1 demonstrates the application of HRXCT to the analysis of the geometry of inclusion trails in garnet porphyroblasts. A background for this technique is provided along with operating parameters suitable for imaging garnet inclusion trails. Techniques for the analysis of the data are also discussed.

The HRXCT technique described in Chapter 1 was used to generate a three-dimensional dataset for a sample of garnet schist from Vermont. This dataset was used to investigate the orientations of FIAs in multiple porphyroblasts from the same sample in Chapter 2. This study allows the intra sample variation of FIA orientations to be determined. This is the first time that FIAs in individual porphyroblasts have been measured.

The asymmetry method does not provide an estimate of the error in the measured FIA orientation. Determining FIA orientations using HRXCT allows the distribution within a sample to be determined, but it is not practical for large numbers of samples because of cost and time issues. Chapter 3 investigates the use of maximum likelihood estimation (MLE) to fit a cyclic logistic regression to asymmetry data, which allows a confidence interval to be determined for the FIA. A resampling method known as bootstrapping is used to obtain more robust estimates of the variability of the model parameters, and the goodness-of-fit, than are achieved using currently available techniques.

The 4th chapter of the thesis looks at how FIA can be correlated between samples and their significance to orogenic processes. Examples of the application of the bootstrapped MLE approach and the correlation of FIA are given for both regional and sample scale problems. The causes of variation of FIA at hand sample and regional scales are discussed in this context. Guidelines for the use of FIA are presented along with a discussion of their significance.