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A comparison of different methods for estimating penetrative strain using natural and synthetic data: A study from the Sikkim Himalaya

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Convergence-related shortening gets primarily accommodated in faults, fault-related folds and penetrative strain in fold thrust belts (FTB). For example, in the Himalayan FTB, ~477-919 km minimum orogen-scale shortening is accommodated by a series of folded, south vergent thrust systems that vary laterally in their geometry resulting in laterally varying shortening distribution. From hinterland to foreland, these major thrust faults are the Main Central thrust, the Pelling-Munsiari thrust, the Lesser Himalayan duplex, the Main Boundary thrust, and the Main Frontal thrust. In the Sikkim Himalayan FTB, the structural geometry of these thrust sheets laterally varies over ~15 km. Based on two regional, transport-parallel balanced cross-sections, ~542-589 km minimum wedge-scale shortening has been estimated. To quantify grain-scale shortening, we analyzed 201 thin-sections cut from 96 quartz-rich samples (sandstone, quartzite, phyllite, schist, and gneiss) and calculated penetrative strain from them. Penetrative strain results indicate that ~25-26% of total Himalayan shortening is recorded at the grain-scale in this section of the eastern Himalaya.

In the internal thrust sheets, the strain magnitude (R_S) remains higher (~1.4-2.43), and it progressively decreases in the frontal thrust sheets (~1.08-1.51). The normalized Fry and the R_f-φ are the two most commonly used graphical methods to estimate best-fit strain ellipse parameters, i.e., R_S and φ (long-axis orientation). However, in thrust sheets with less deformed sandstones, where initial grain shapes were not spherical, these graphical methods do not accurately estimate the best-fit strain ellipse parameters. The central vacancy in the Fry plot was objectively fitted using the enhanced normalized Fry (ENFRY), the point-count density (PCD), the continuous function method (CFM), and weighted least square (WLS) methods. From the R_f-φ data, we calculated the best-fit strain ellipse using the shape matrix eigenvector (SME), centroids of the hyperbolic plot (HP), Elliot's polar graph (EPG), and R_f-φ graph, harmonic mean (HM) and vector mean (VM) methods. In this study, we calculate the accuracy of these strain methods as a function of the strain magnitude and structural position within the orogenic wedge. The SME and HP methods record the lowest bootstrap errors in the strain parameters in the internal thrust sheets. In contrast, R_S and φ values estimated by the WLS method records the lowest bootstrap error in the frontal thrust sheets, followed by the SME, HP, and EPG methods. We also created six synthetic aggregates containing 150-170 random elliptical grains with random long-axis orientations. We deformed these aggregates under pure-shear, simple-shear, and general-shear conditions at various strain increments. We have generated 7560 strain data. To understand the accuracy of these strain methods in estimating penetrative strain, we calculated the Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) for every strain method and every type of deformation. Experimental results indicate that the SME and HP methods record the lowest errors in the R_S and φ values. In low strain conditions (R_S<1.5), the SME, HP, and EPG methods record lower errors in the strain parameters. Therefore, this study shows that the SME and HP methods overall yield a better penetrative strain estimate.