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Incremental fold test for paleostress analysis using the Hough transform inverse method

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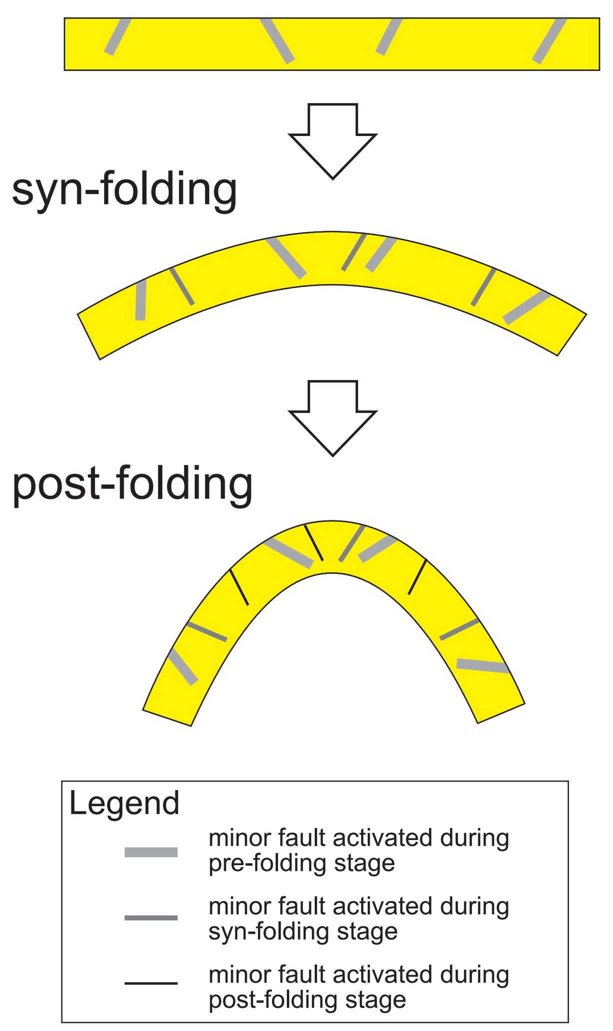
Summary

- We present a method for an incremental fold test for the paleostress inversion
- The point of our method is stepwise backtilting of strata associated with faults
- The experiments using artificial and natural fault-slip data sets validated the method
- This method is probably applicable to investigate spatial and temporal variations of stress field

Introduction

- Paleostress inversion for folded rock masses requires great care.
- In addition, fault-slip datasets are commonly heterogeneous, reflecting fault activity under various stress regimes and at different times.
- We present a method for an incremental fold test, which provides not only the stress regime, but also the relative timing of folding and faulting.



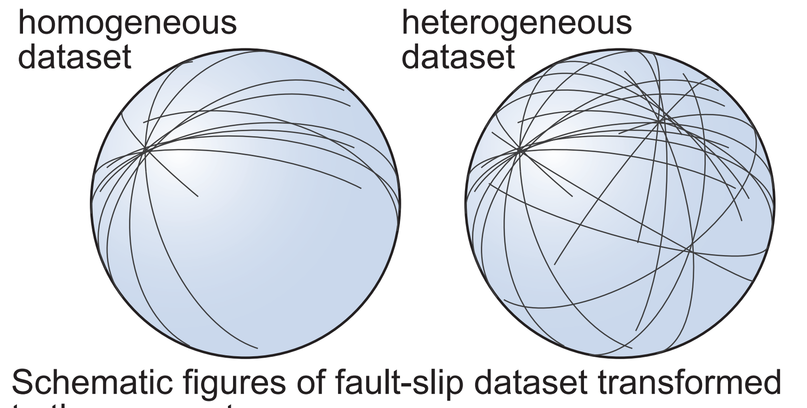
Minor faults activated during the pre-, syn-, and post-folding stages. Note the rotation of early faults during folding.

Method

- The point of our method is stepwise backtilting of strata associated with faults.

Paleostress inversion using the Hough transform (Yamaji et al., 2006)

- The application of HIM (Hough transform Inverse Method) calculates the fitness of all possible stresses to the fault data and detects peaks of the fitness.



Schematic figures of fault-slip dataset transformed to the parameter space.

Objective function of HIM

$$F(\vec{\sigma}) = \sum_{k=1}^{N} f^{(k)}(\vec{\sigma})$$

Fitness function on the parameter space for the kth fault-slip datum

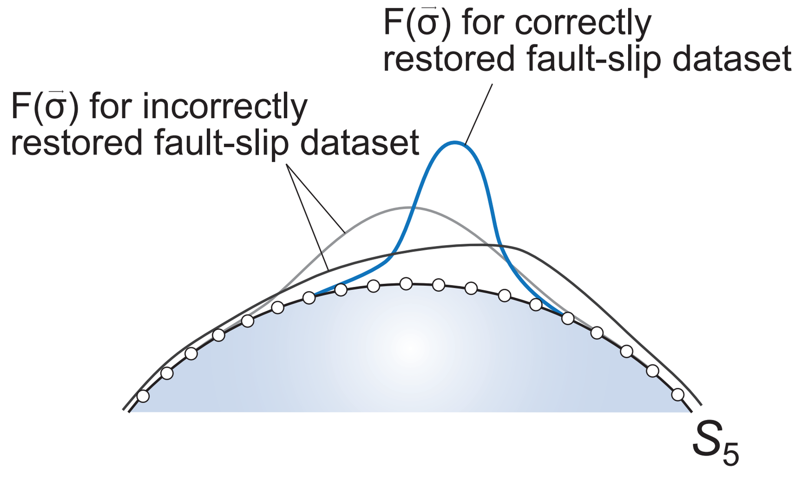
Incremental fold test

- Rotated fault-slip data are analyzed by HIM.
- The peak values of fitness are compared among backtilting steps to find a maximum.

Assumptions

The peaks in $F(\vec{\sigma})$ for a fault-slip dataset for which the attitudes have been correctly restored to those at the time when the faults were activated, are expected to be higher than those obtained for incorrectly restored dataset.

The potential stress solutions derived from incorrectly restored datasets not only have lower values of total fitness, but also deviate from the true reduced stress tensors.

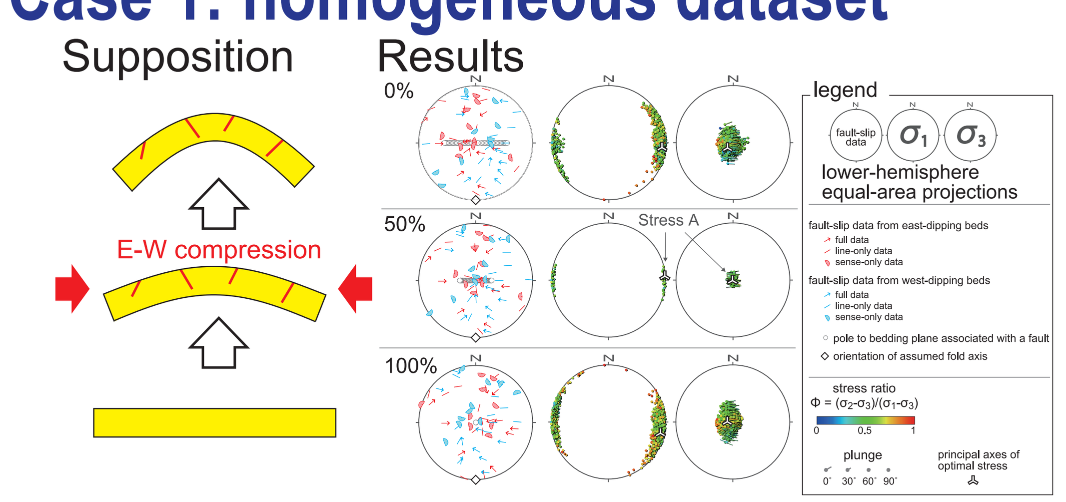


Schematic figure showing the concept of the incremental fold test proposed in this study.

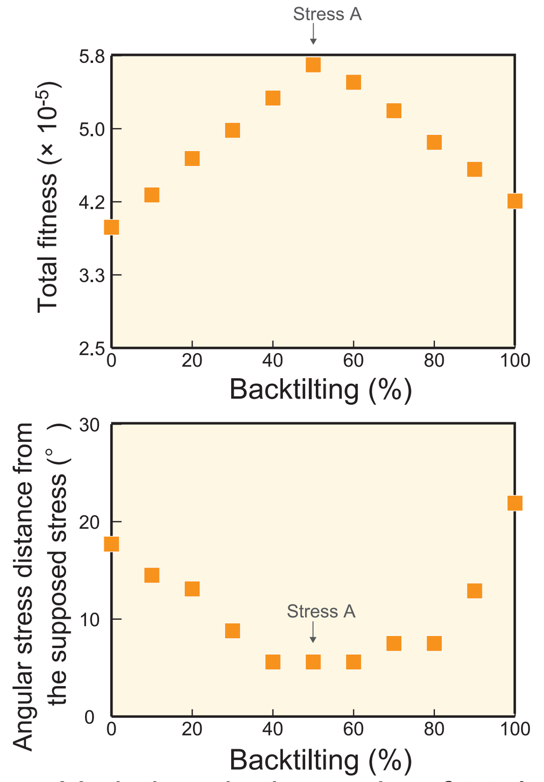
Application to artificial datasets

- We applied the method to two different artificial fault-slip datasets.
- Supposed stresses were successfully detected and the correct timing of faulting relative to tilting were chosen.

Case 1: homogeneous dataset

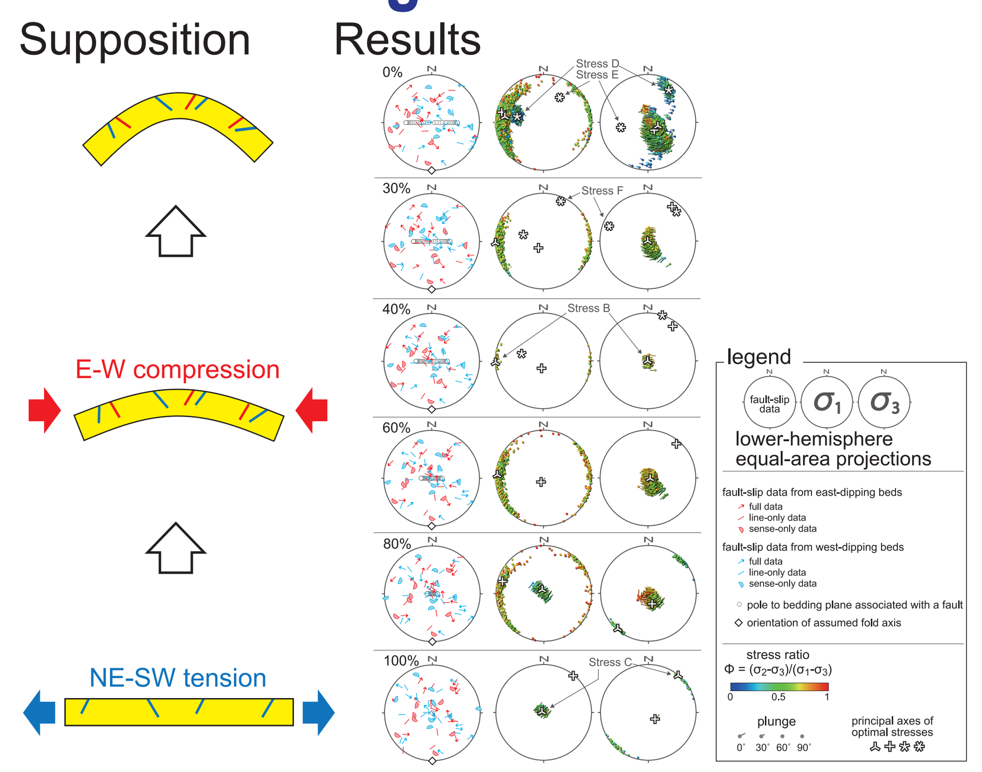


Stereograms showing the artificial fault-slip dataset (left-hand column) and the results of HIM (center and right-hand columns) for Case 1. Left-hand column: the fault-slip data are shown as tangent-lineation diagrams (Twiss and Gefell, 1990). Center and right-hand columns: reduced stress tensors with a relatively high fitness value of $F(\vec{\sigma})$ for the datasets. In the center (right-hand) column, the orientations of σ_1 (σ_3) axes are plotted as small circles, and the lengths and directions of attached bars indicate the orientations of σ_3 (σ_1) axes, as if there were small stereograms around the small circles. Percentage values shown in the upper left corner of each panel indicate the amount of backtilting.

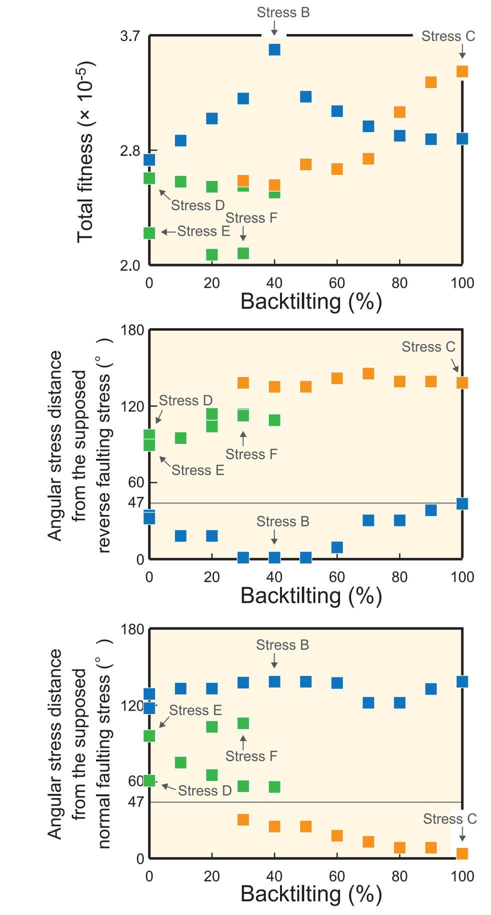


Variations in the peaks of total fitness for the fault-slip dataset of Case 1.

Case 2: heterogeneous dataset



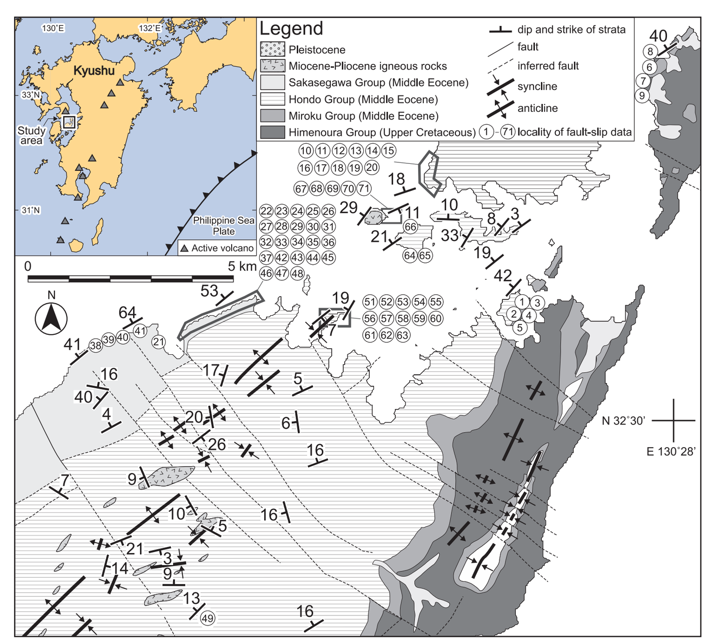
Stereograms showing the artificial fault-slip data and the HIM results for Case 2.



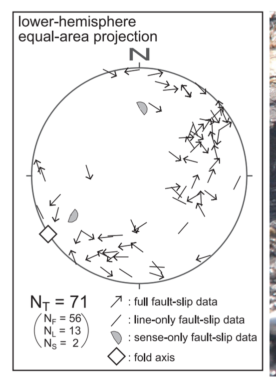
Variations in the peaks of total fitness for the fault-slip dataset of Case 2.

Application to a natural dataset

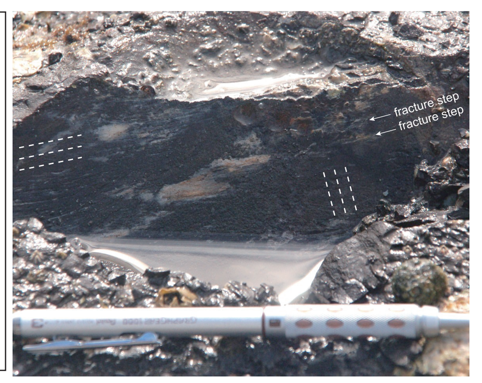
- We applied the test to natural fault-slip data set in an early Middle Eocene sedimentary strata of Kyushu, southwest Japan, which was folded with NE-SW trending fold axes in the Early Miocene.
- The result presented three significant paleostresses.



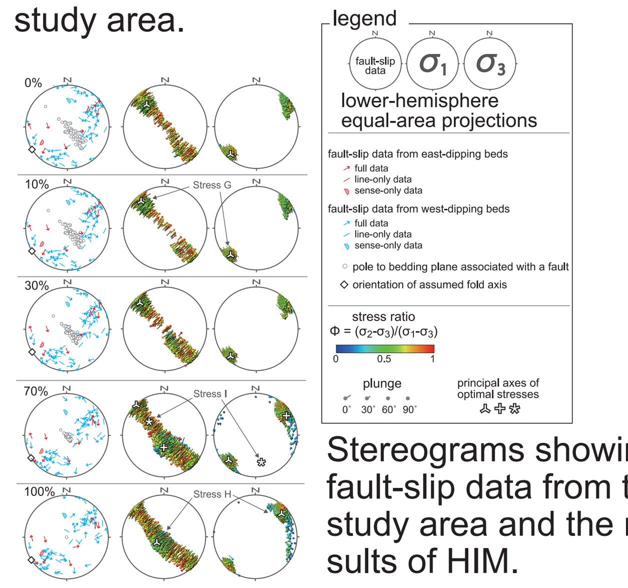
Geologic map of the Amakusa-Kamishima area after Miki (1981).



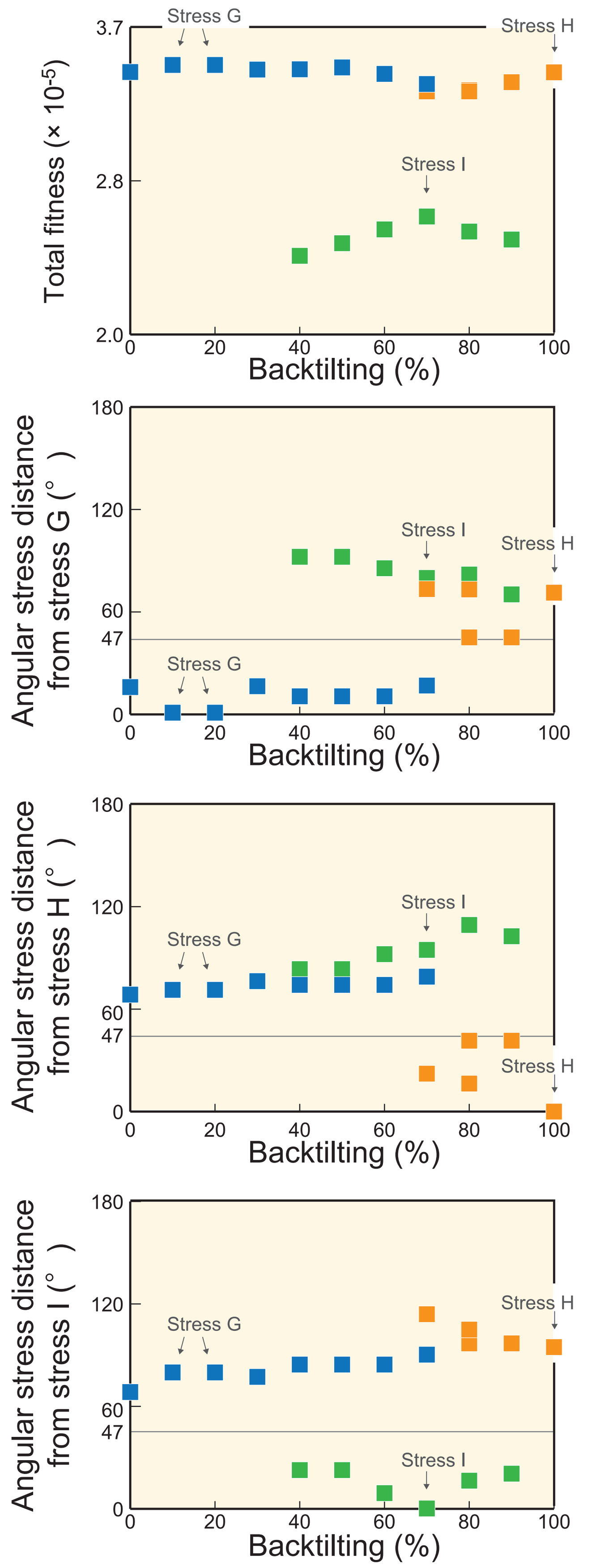
Tangent-lineation diagram of in situ fault-slip data from the study area.



Superimposed slickenlines on a fault plane in the study area.



Stereograms showing fault-slip data from the study area and the results of HIM.



Variations in the peaks of total fitness for a fault-slip dataset from the Amakusa-Kamishima area.