Elastic dislocation modelling for prediction of small-scale fault and fracture network characteristics

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• Many active faults slip by repeated earthquakes. The geodetically-measured deformation during the slip event can be well modelled by elastic dislocation methods.

• The accumulated deformation over many seismic cycles represents multiple ‘elastic’ slip events, plus inter-seismic relaxation processes.

• From observations of earthquake events, we suggest that most subsidiary faulting/fracturing is generated during the slip event rather than during the inter-seismic relaxation.

• If so, then modelling the strain and stress changes associated with accumulated slip on large faults may provide a first-order prediction of the distribution and style of minor faults and fractures that are too small to map in the sub-surface.
Introduction to Elastic Dislocation methodology

A ‘fault panel’ is a rectangular dislocation with uniform slip, embedded in an elastic medium.

Using the equations of Okada (1992), the resulting displacement and strain tensor can be computed at any observation point in the medium.

The corresponding stress tensor and failure mode (if any) at the observation point can then be computed using appropriate material properties.

Mapped faults in the subsurface can be approximated by an array of rectangular fault panels, each of uniform slip.

A background bulk strain can also be superimposed.
Neotectonic example:
El Asnam earthquake fault, Algeria
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1980 earthquake fault zone: N-dipping thrust fault with hangingwall anticlinal ridge (topography reflects active structure)

Europe-Africa plate boundary, showing seismic zone and slip vectors – note NNW-SSE convergence direction
Neotectonic example: El Asnam earthquake fault, Algeria

1980 thrust earthquake: extensional surface breaks along hangingwall

Thrust break, 7m slip
Neotectonic example: El Asnam earthquake fault, Algeria

1980 earthquake: en echelon normal faulting on hangingwall of central fault segment: ~N-S trend, not parallel to main thrust fault
Neotectonic example: El Asnam earthquake fault, Algeria

8-panel fault model (based on geodetic net and earthquake source modelling); initial model dip-slip:

Predicted surface deformation, x300:

Predicted area where Coulomb shear stress exceeds failure, 50m depth
Neotectonic example: El Asnam earthquake fault, Algeria

At each observation node, calculated stress tensor is used to predict mode and orientation of likely failure planes.

Dip-slip model predicts strike-parallel subsidiary faults (not observed).

Reverse faults – green
Normal faults - red

S1
S3
conjugate failure planes
Neotectonic example: El Asnam earthquake fault, Algeria

Change slip direction on underlying fault panel from dip-slip to minor oblique-slip – results in rotation of failure planes in hangingwall, matching observed surface breaks.

Conclusion from neotectonic example: elastic dislocation model can give good prediction of subsidiary fractures associated with large faults.
• Elastic dislocation methods are appropriate for modelling the coseismic deformation during earthquake slip events.

• Application to a neotectonic (seismic) example provides a good prediction of associated small-scale faulting (location and mode of failure, orientation of fracture planes).

• Application to a now-inactive geological example shows that the method is able to match many of the mapped small-scale faults, and can be used as a guide to understand and predict the detailed deformation.

• The method can potentially be used to predict fault/fracture distributions for input to reservoir modelling.