

TS3.1:
*Faults and fractures in rocks:
mechanics, occurrence, dating, stress history and fluid flow*



Strain Analysis of Transfer Faults in Extending Regions: Inferences from Micropolar Theory

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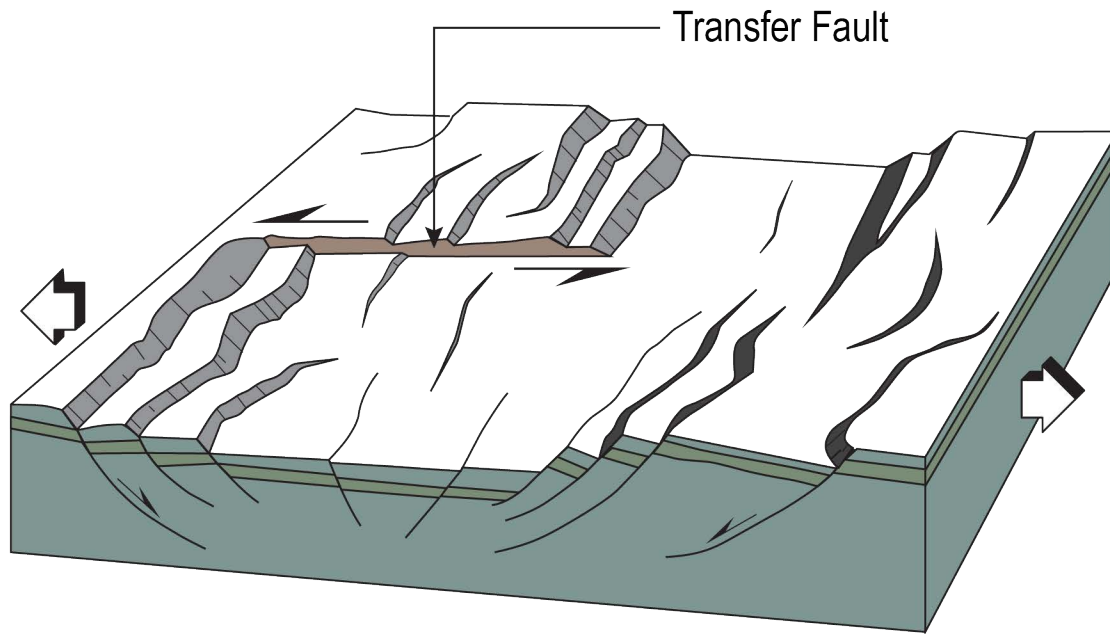
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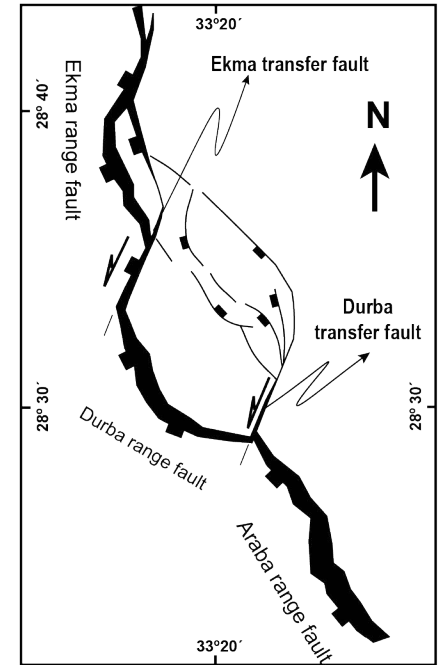
Motivation



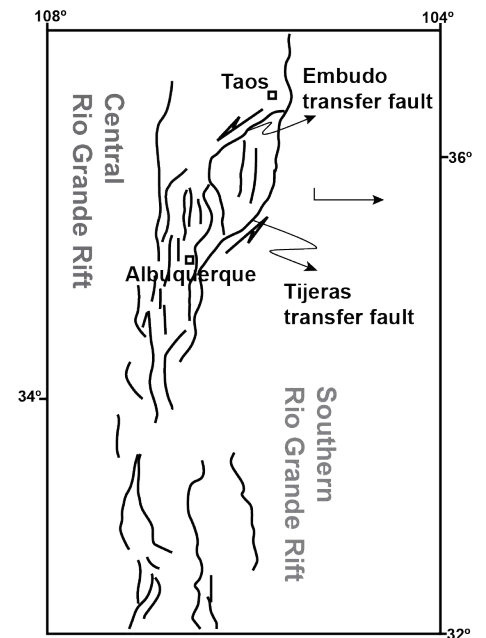
Schematic diagram showing transfer fault linking normal faults in an extending region.⁽²⁾

In this study, the following questions are addressed:

- 1) How could the place of transfer faults linking normal faults be defined in extensional deformation by its rotation and strain components?
- 2) What is the relationship between trend of transfer fault and regional extension direction?



East side of the Gulf of Suez⁽⁴⁾

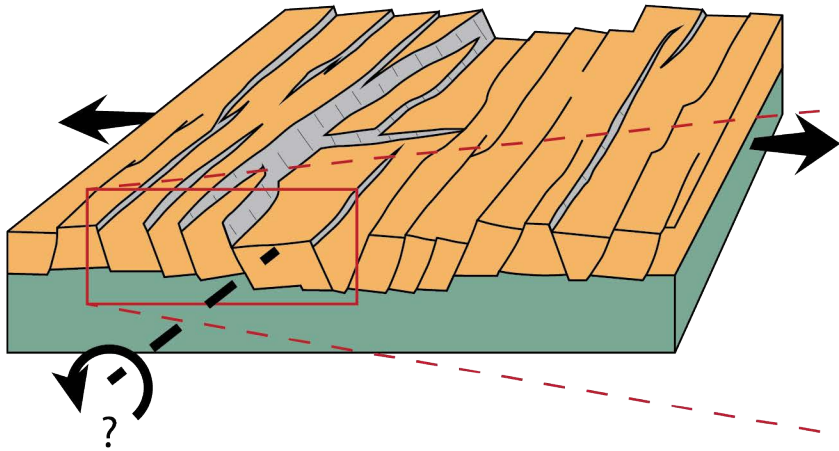


Rio Grande Rift Zone⁽³⁾

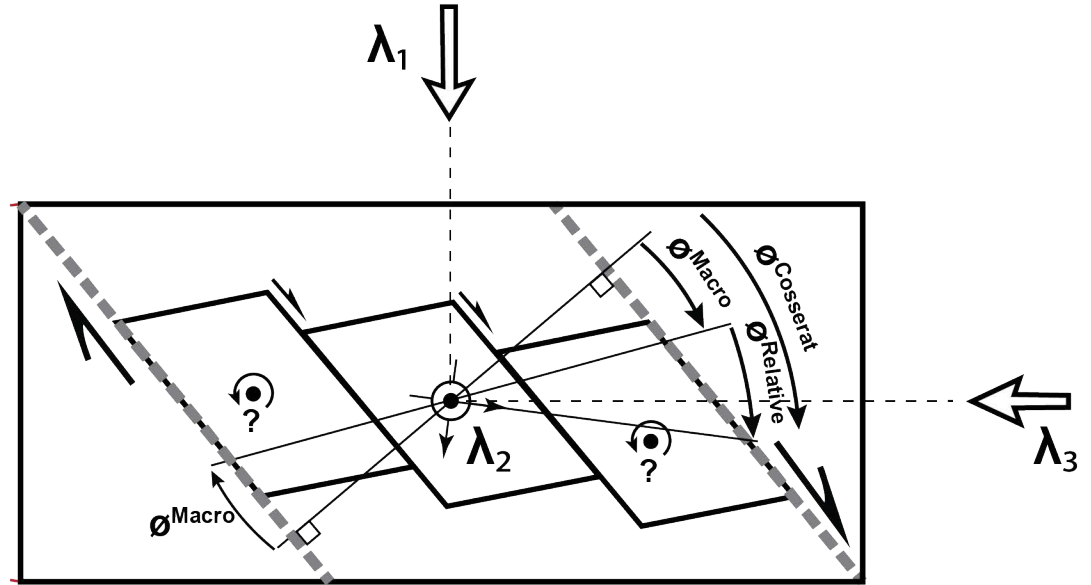
Examples

Methodology

Micropolar theory extended by J-2 plasticity⁽⁶⁾



Block diagram indicating fault segments in a rift zone.⁽⁵⁾



Simplified conceptual model of the micropolar theory in a medium deformed by normal faulting

Assumptions

- Numerous shear planes with different orientations creating rigid blocks host brittle deformation distributed widely.
- Strain is infinitesimal.
- No volume changes.
- Deformation throughout a medium is homogenous.
- Macromotion and micromotion are independent of each other.

Methodology

Micropolar theory extended by J-2 plasticity⁽⁶⁾

$$\mathbf{e} = \mathbf{u} - \mathbf{W}^C = \mathbf{u}^{(S)} + \mathbf{u}^{(a)} + \mathbf{W}^C = \mathbf{u}^{(S)} + \mathbf{A}$$

$\mathbf{e}$: the Cosserat strain tensor

$\mathbf{u}$: macrodeformation tensor

$\mathbf{u}^{(S)}$: macrostrain

$\mathbf{u}^{(A)}$: instantaneous macrorotation

$\mathbf{W}^C$: the Cosserat microrotation (micropolar) tensor

Constitutive equation

$$\boldsymbol{\sigma} = p_r \mathbf{1} + a \mathbf{u}^{(S)} + b \mathbf{A}$$

$\boldsymbol{\sigma}$: stress tensor depending also on frictional condition of Amontons' law in micropolar (Cosserat) continuum.

Values of input parameters

$$30^\circ \leq \alpha \leq 90^\circ \text{ (interval of } 30^\circ \text{)}$$

$$30^\circ \leq \beta_{NF} \leq 90^\circ \text{ (interval of } 10^\circ \text{)}$$

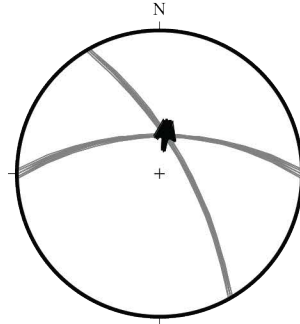
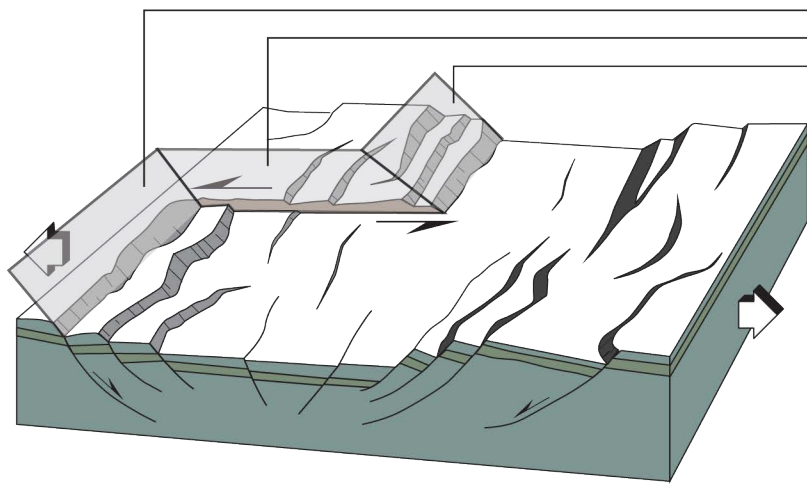
$$60^\circ \leq \beta_{TF} \leq 90^\circ \text{ (interval of } 10^\circ \text{)}$$

Parameters

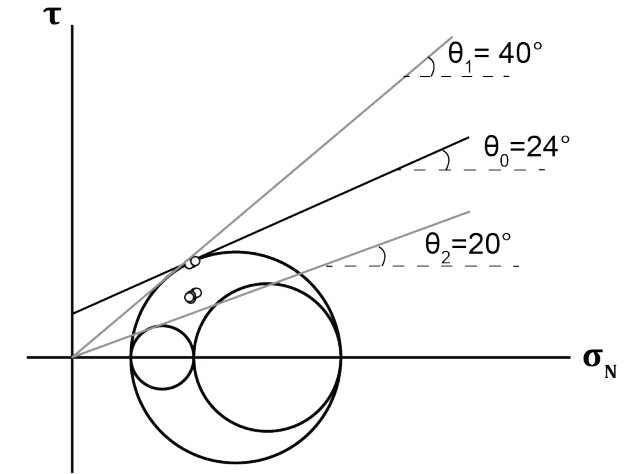
β_N	Dip amount of normal faults	INPUT
β_T	Dip amount of transfer faults	
ξ_N	Rake of slip vector on normal faults	
ξ_T	Rake of slip vector on transfer faults	
α	Acute angle between strikes of intersecting faults	
θ_1	Maximum possible angle of internal friction for reactivation of pre-existing fault (°)	
θ_2	Minimum possible angle of internal friction for reactivation of pre-existing fault (°)	OUTPUT
a, b	Constitutive parameters*	
$\lambda_1, \lambda_2, \lambda_3$	Kinematic axes of the macrostrain tensor	
$\vec{\lambda}_1, \vec{\lambda}_2, \vec{\lambda}_3$	Principal strains (eigenvalues) of the macrostrain tensor*	
C_{macro}	Regional macrorotation*	
$C_{Cosserat}$	Micropolar (Cosserat) microrotation*	
C_{rel}	Relative microrotation*	
$\vec{\phi}_{macro}$	Regional macrorotation vector	
$\vec{\phi}_{Cosserat}$	Cosserat (Micropolar) microrotation vector	
$\vec{\phi}_{rel}$	Relative microrotation vector	
θ_0	The angle of internal friction for intact rock	
D	Shape of instantaneous strain ellipsoid	
p_r	Hydrostatic pressure*	
δ_{rel}	Misfit Angle (°)	
γ_{rel}	Relative Misfit (%)	

* The values in parameters refers to normalized ones between 0 and ± 1 .

Methodology

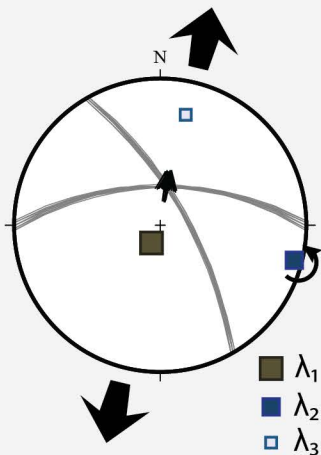


Each fault group (normal and transfer faults) contain 20 fault planes with common slip direction parallel to intersection direction.

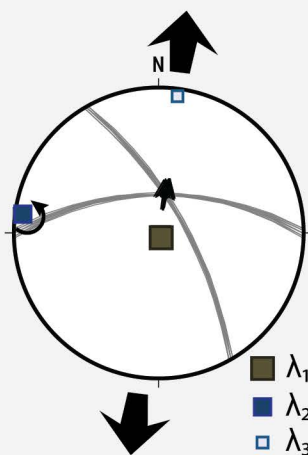


Optimization of internal friction angles (θ_1 and θ_2) for both faults

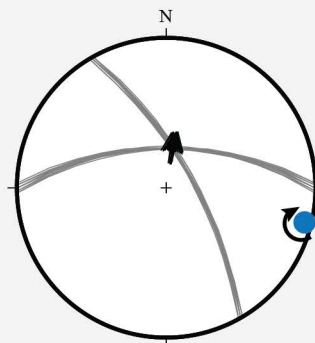
RESULTS



Circular arrow around λ_2 represents direction of macro-rotation, $\vec{\phi}^{\text{macro}}$



Circular arrow around λ_2 represents direction of relative micro-rotation, $\vec{\phi}_{INV}^{\text{rel}}$



Circular arrow around blue axis represents direction of relative micro-rotation, $\vec{\phi}_{MSM}^{\text{rel}}$

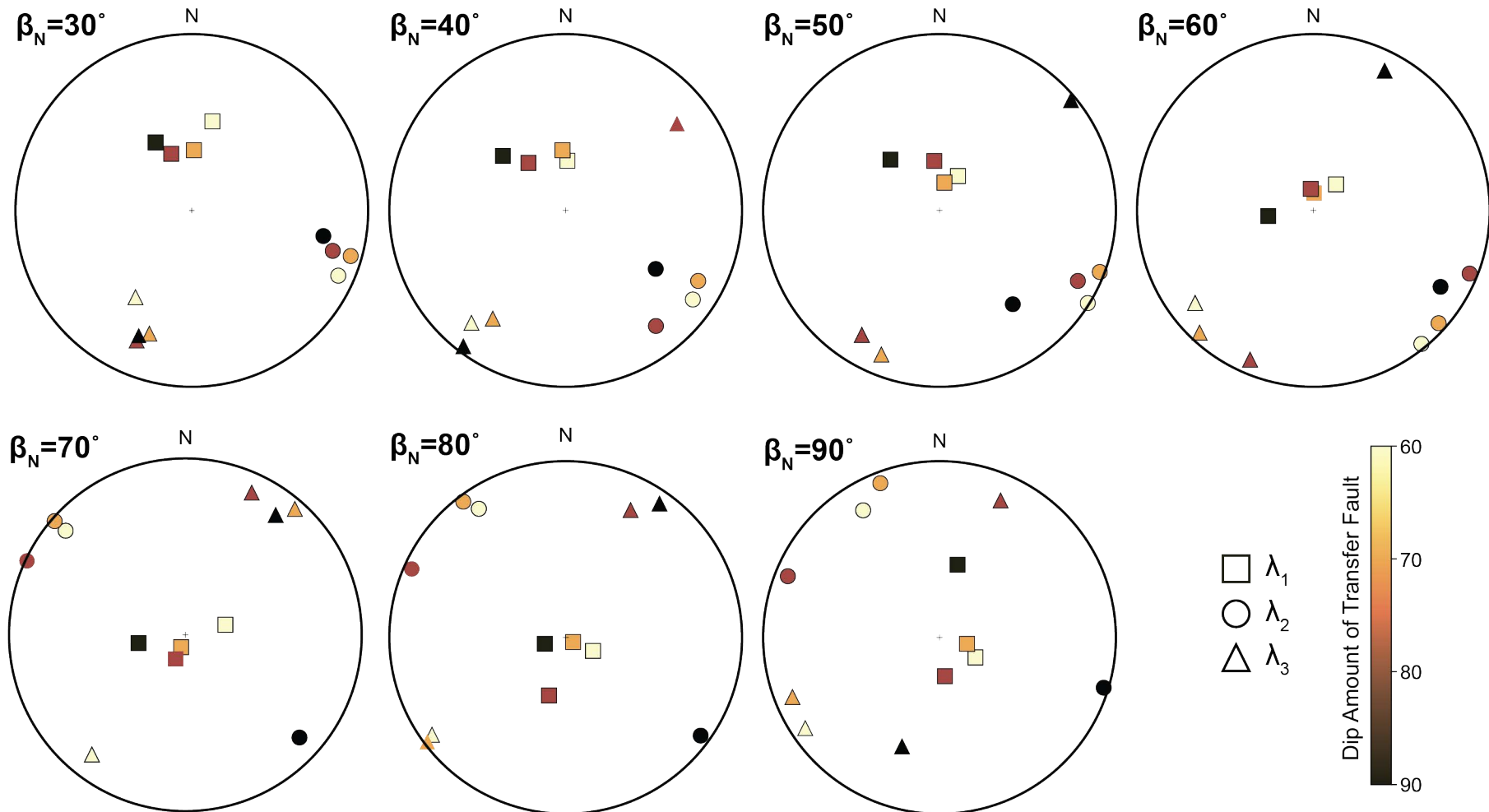
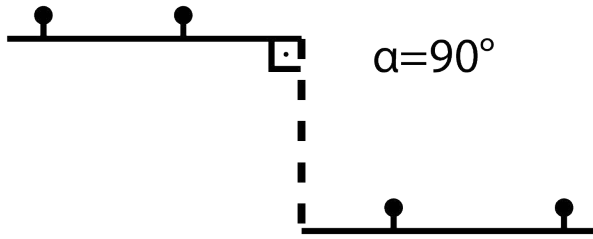
Application of Inverse Method (INV) and Multiple-Slip Mechanism (MSM)

Comparison of results from two different methods, which calculate Cosserat strain in different ways, to measure their reliabilities.

$$\delta_{rel} = \frac{1}{2} \| C_{INV}^{rel} \vec{\phi}_{INV}^{rel} - C_{MSM}^{rel} \vec{\phi}_{MSM}^{rel} \| = \min$$

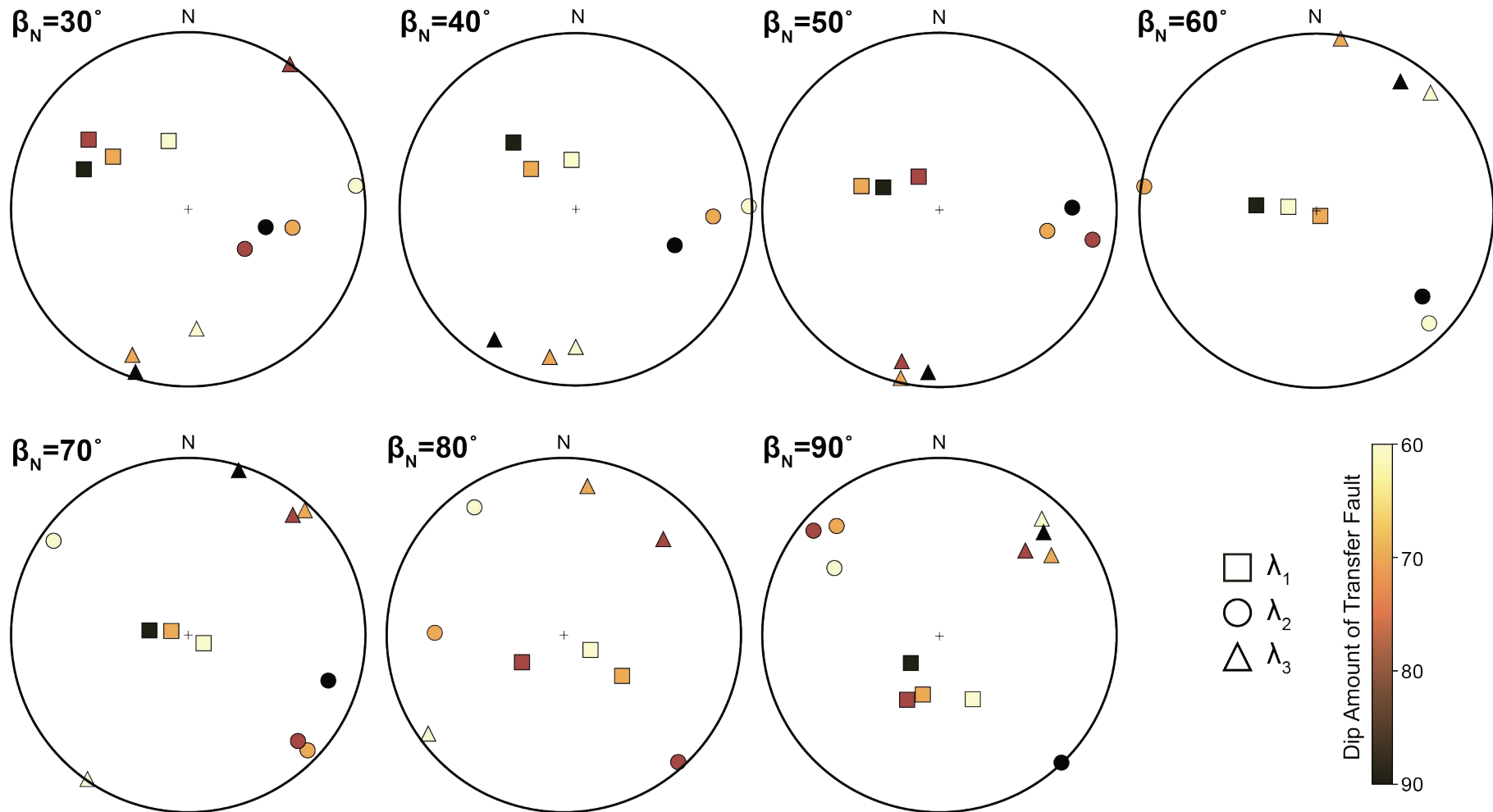
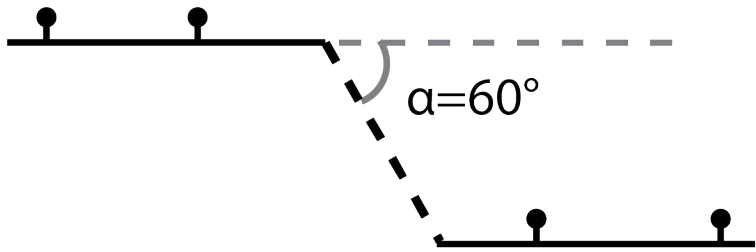
$$\gamma_{rel} = \cos^{-1} \frac{\vec{\phi}_{INV}^{rel} \vec{\phi}_{MSM}^{rel}}{\phi_{INV}^{rel} \phi_{MSM}^{rel}} = \min$$

Results



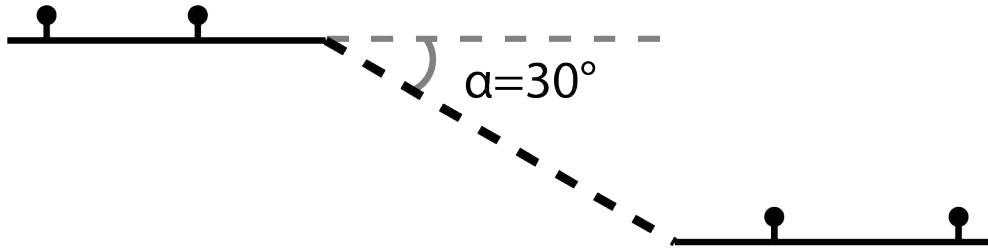
β_N = Dip amount of Normal fault

Results



β_N = Dip amount of Normal fault

Results



No reliable results could be obtained from the analysis for this case !

This is probably due to lack of faults with different orientation and kinematics to be able to accommodate the complete regional deformation in fault sets analysed.

Then, it is required to determine maximum obliquity (up to $\alpha=40^\circ$ or $\alpha=50^\circ$) in trend of linkage between normal fault segments.

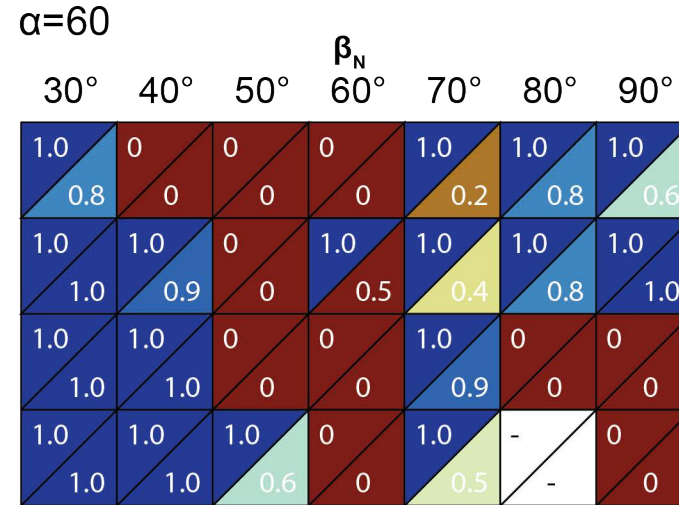
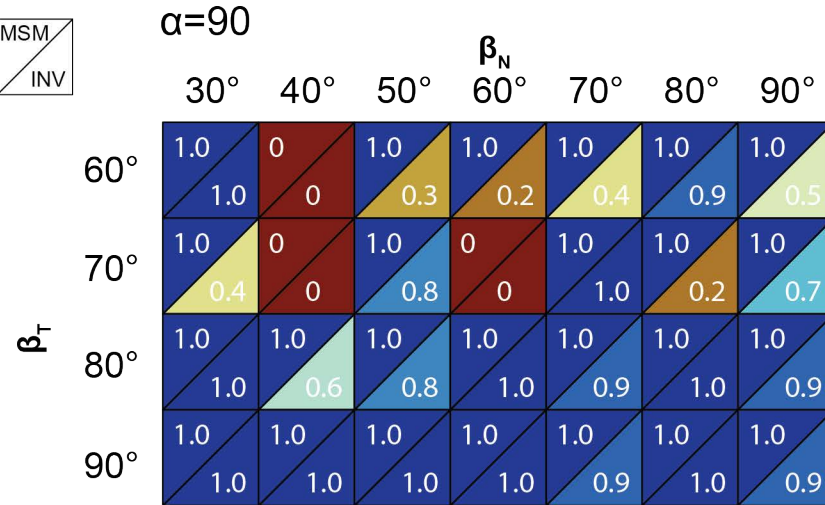
Is there a threshold in obliquity of linkage by transfer faults between normal faults in extensional domains?

Future Studies

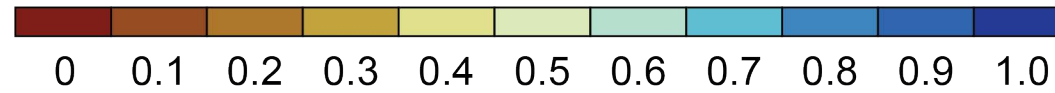
Results

C_{rel} 

Relative
microrotation

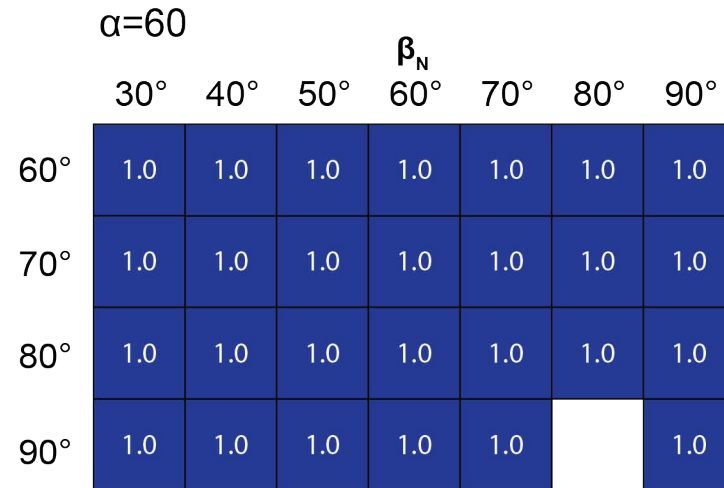
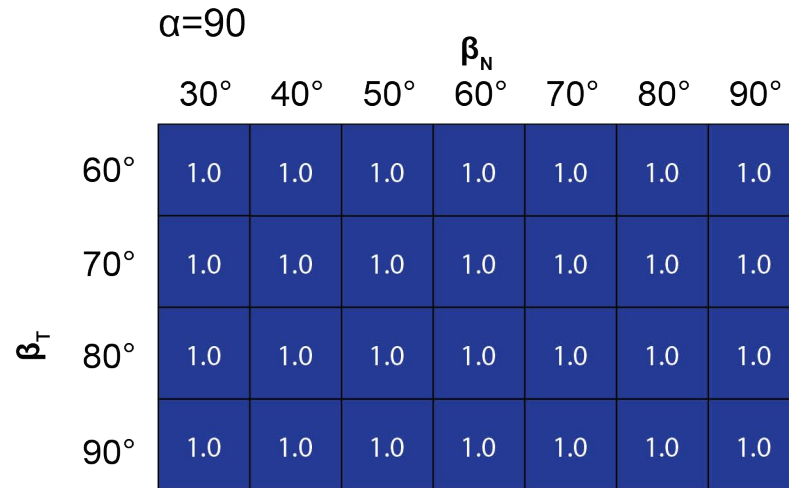


C_{rel}



C_{macro}

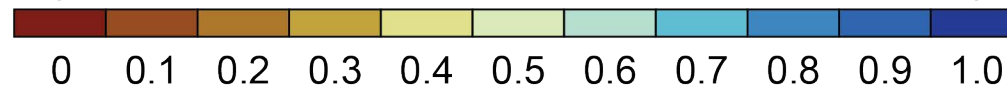
Macrorotation



Pure Shearing

C_{macro}

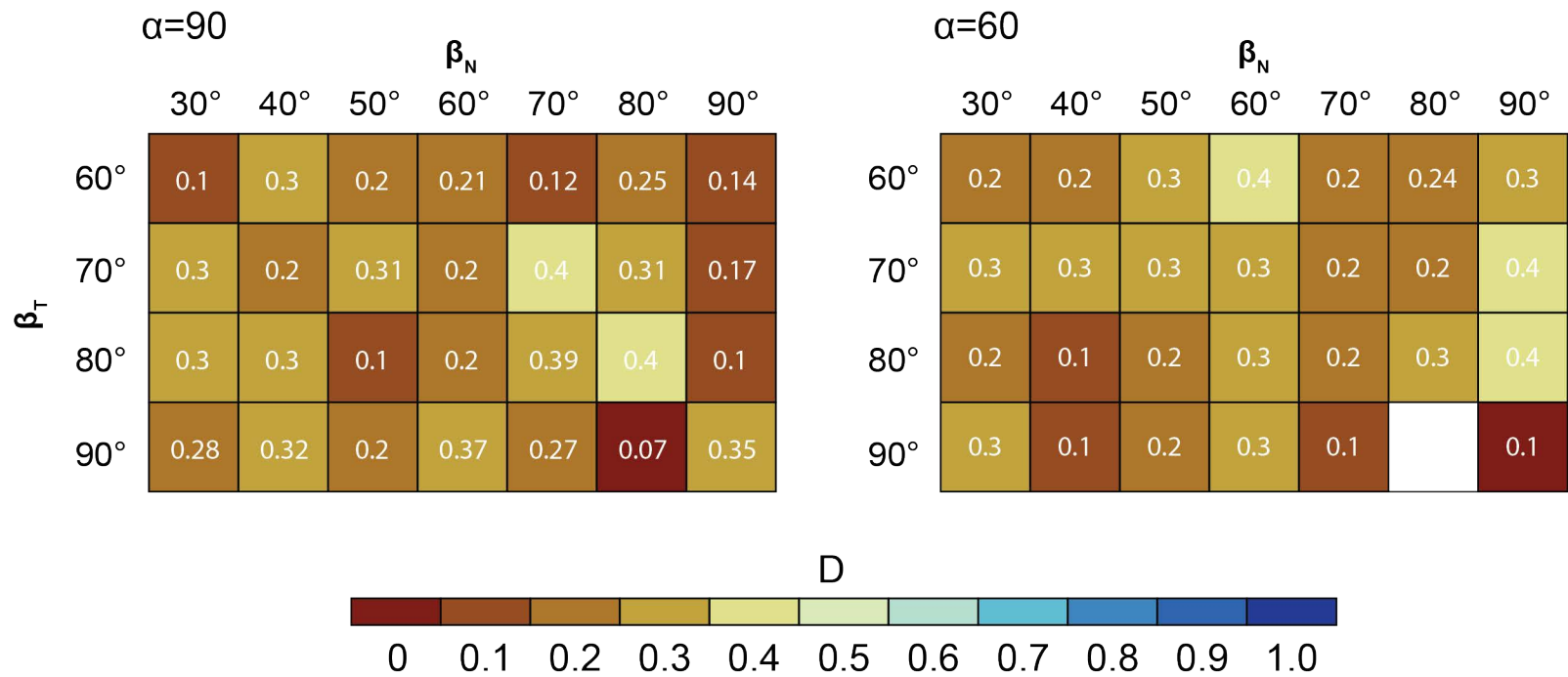
Simple Shearing



Results

D

$$D = \frac{\lambda_2 - \lambda_3}{\lambda_1 - \lambda_3}$$



Conclusions

- 3D strain field is mostly observed in orthogonal and oblique linkage cases. A few cases exhibit plane strain.
- All cases are subjected to simple shearing.
- In cases of orthogonal linkage, extensional direction is predominantly oblique to the strike of the normal fault.
- Many of these cases have no block rotation (microrotation) independent from macrorotation.
- No particular relationship between changing dip amount of faults and direction of extension is observed.
- In cases of oblique linkage, (sub)orthogonal direction of extension appear in nearly half of experiments, especially those including normal faults dipping less than 60° .
- The frequency of non-zero microrotation is seen apparently more than that in orthogonal linkage cases.

References

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- (2) Liggett, M.A. and Ehrenspeck, H.E. (1974) Pahrnagat Shear System, Lincoln County, Nevada: U.S. National Aeronautics and Space Administration Report CR-136388, 10 pp.
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