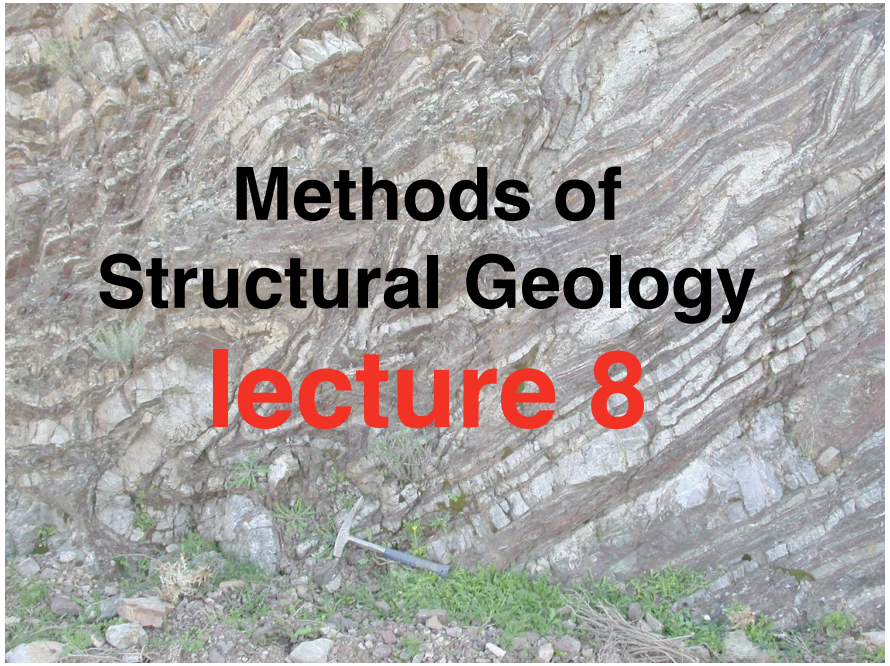
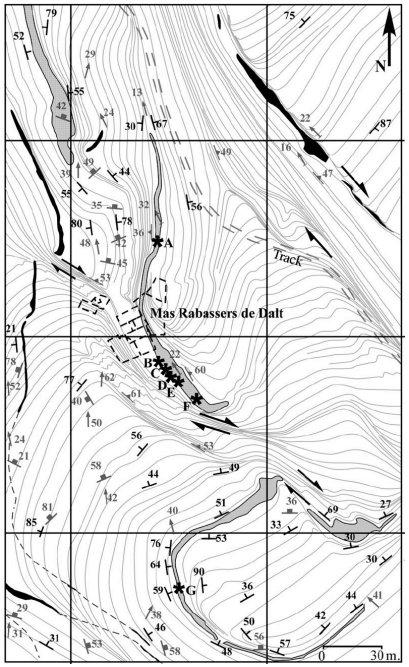


Methods of Structural Geology

lecture 8

This lecture

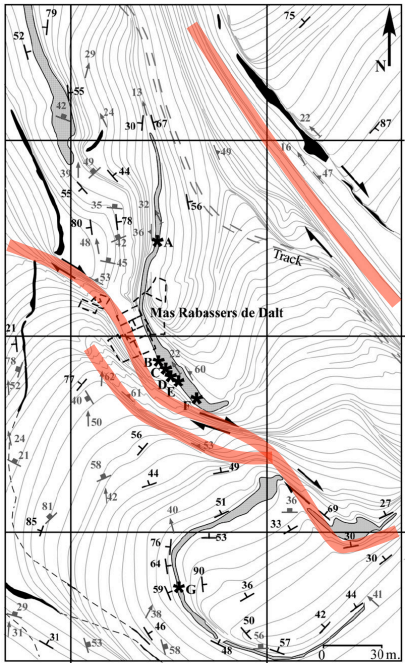
- Discuss the plotting exercise on Mas Rabassers de Dalt
- Look at folding related to shear zones
- Show an example of the application of new theory: Cap de Creus
- Another exercise



Mas Rabassers de Dalt (Spain)

Metagreywackes and metapelites
Pegmatite
Quartzite
Farmhouse ruins (Mas Rabassers de Dalt)

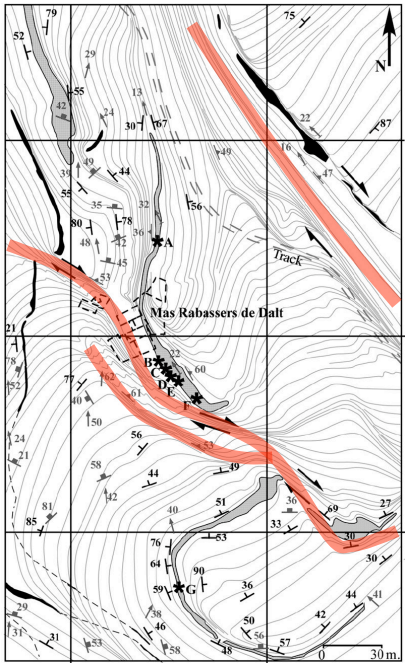
Trace of the main foliation
S_{0-1} foliation orientation
S_2 foliation orientation
S_3 foliation orientation
Fold axis (mainly D_3)



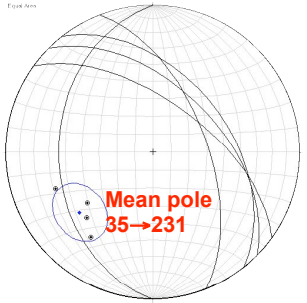
Mas Rabassers de Dalt (Spain)

- Folded main foliation (S_{01})
- S_2 indicates second deformation
- Dextral D_3 shear zones

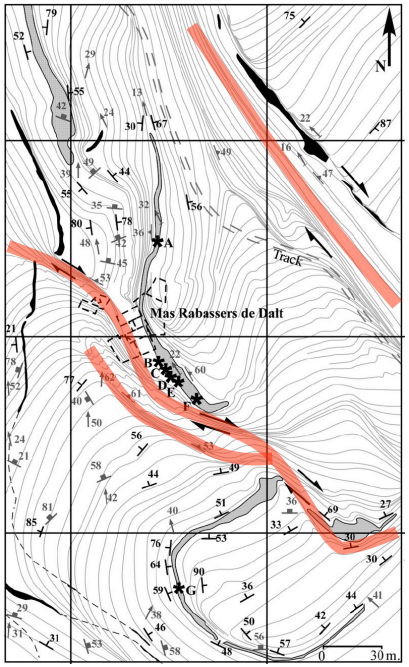
Trace of the main foliation
$S_{0\text{-}1}$ foliation orientation
S_2 foliation orientation
S_3 foliation orientation
Fold axis (mainly D_3)



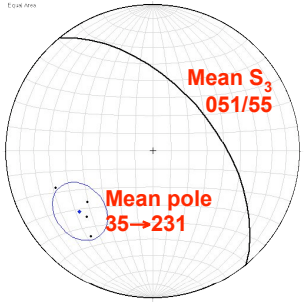
S_3 foliation



- Most S_3 strike NW-SE
  - (one outlier)
- Mean shear zone orientation is 051/55



S_3 foliation



- Most S_3 strike NW-SE
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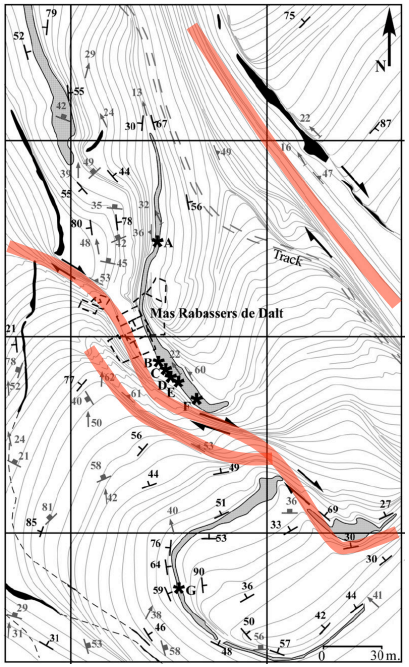
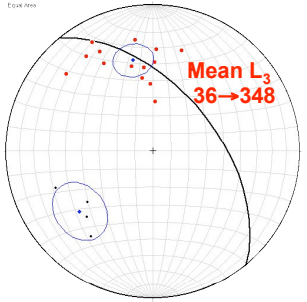
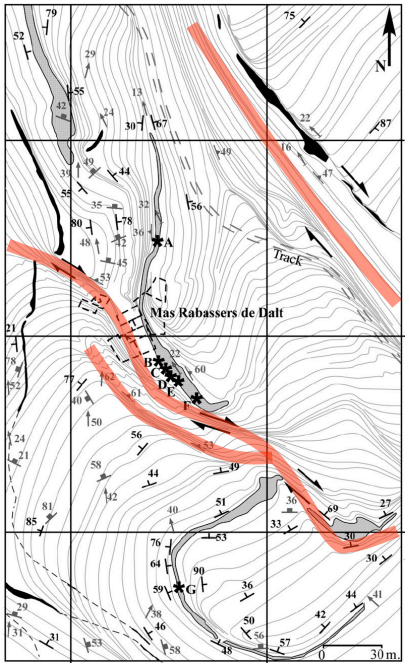


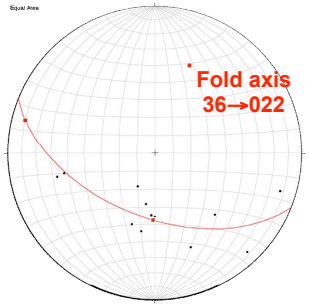
Fold axes (D_3)



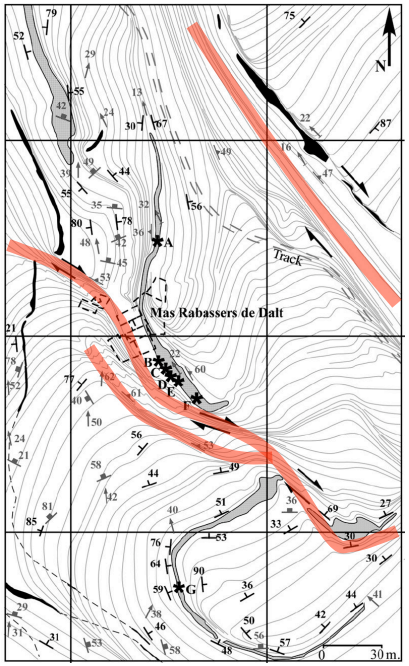
- Mean fold axis lies in plane of shear zones
- Relationship to shearing?



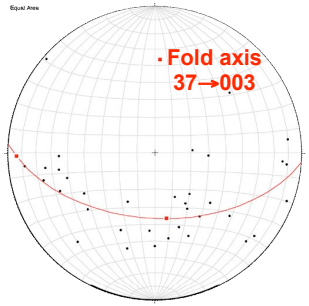
Second foliation (S_2)



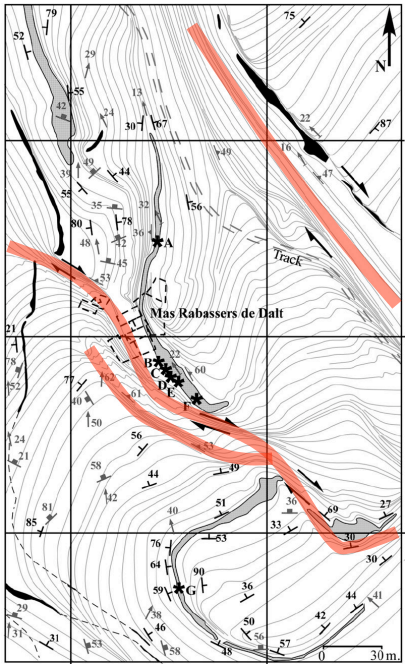
- S_2 foliation forms great circle
- Folding (D_3) around 36→022



First foliation and bedding (S_{01})

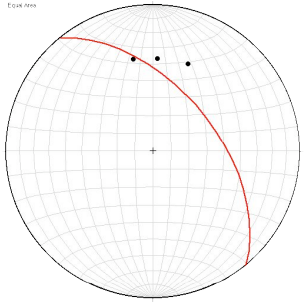


- S_{01} foliation forms rough great circle
  - Much spread: 2x deformed
- Folding (?D_3) around 37→003

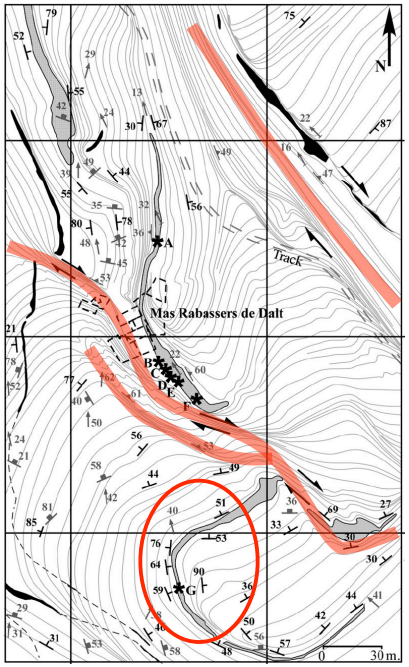


Summary

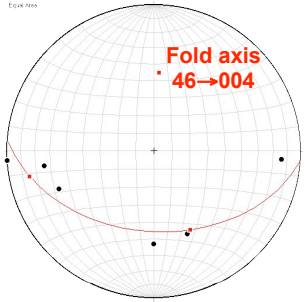
Folding related to D_3 shearing?



- Mean S_3 = 051/55
- Mean D_3 fold = 36→348
- S_2 fold axis = 36→022
- S_{01} fold axis = 37→003



Is fold in south also D_3 fold?

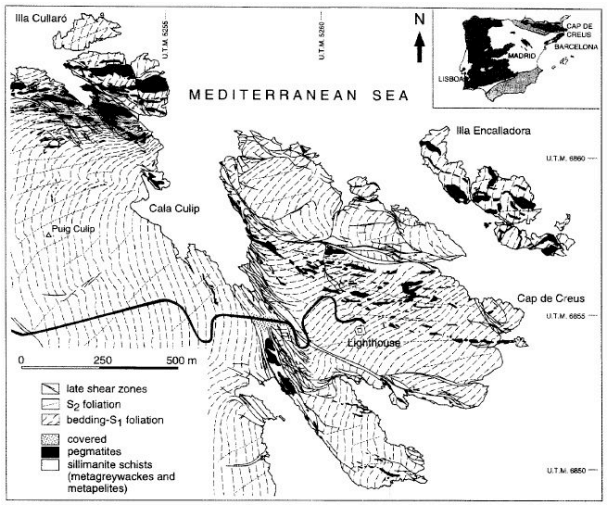


- Fold axis = 46→004
- Close to general fold axis (36→348) in plane of D_3 shear zones

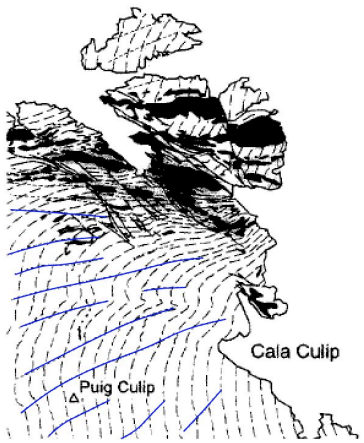
Shear zone-related folds

- Plot an EW-striking, vertical, dextral shear zone in your stereonet
- Stretching direction is horizontal
- What are the XYZ-directions of the <u>incremental</u> strain ellipsoid?
- Shear strain is 2
  - Draw the Mohr circle for strain
  - Plot the XYZ-directions of the <u>finite</u> strain ellipsoid
  - Plot the finite orientations of the planes with original orientation: **270/90; 215/90; 215/45**

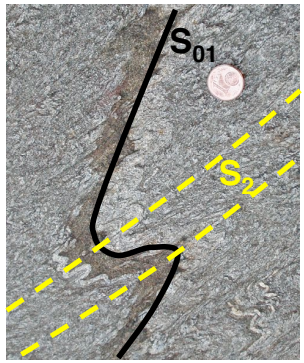
An application at Cap de Creus



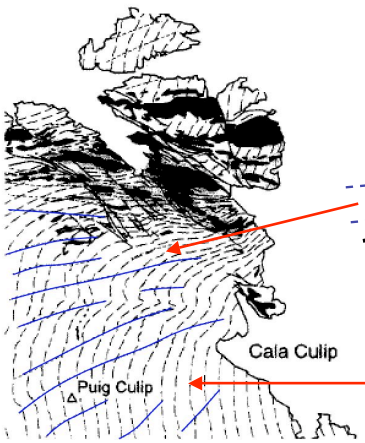
Analysis of the Puig Culip area



- Folded S_{01} (turbidites)
- S_2 crenulation cleavage



Strain gradient on Puig Culip



- Folded S_{01} (turbidites)
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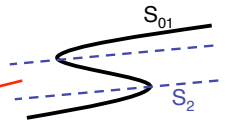
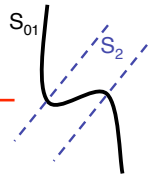
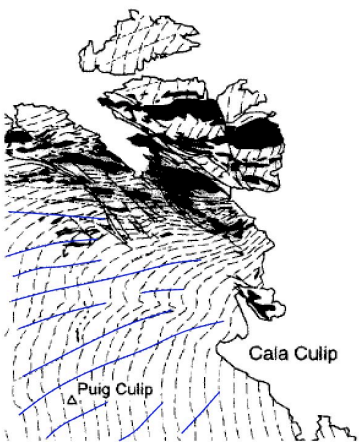


High strain

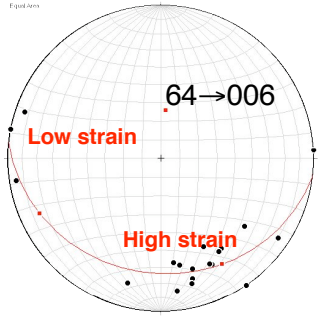


Low strain

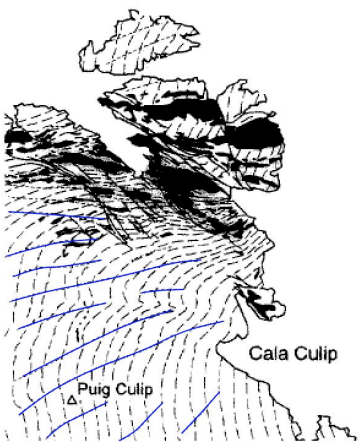
Strain gradient on Puig Culip



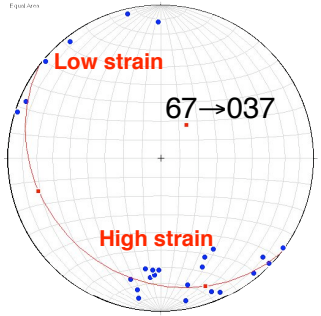
- S_{01} rotates from subvertical NS-striking towards steeply NNW-dipping



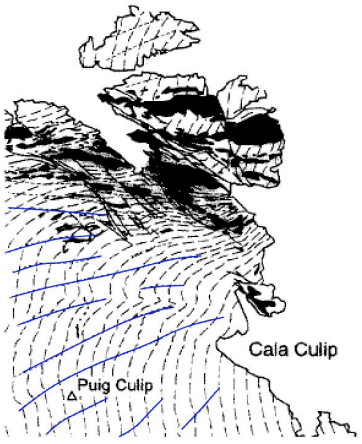
Strain gradient on Puig Culip



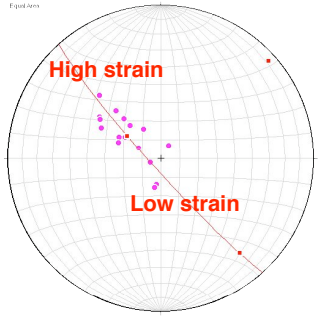
- S_2 rotates from sub-vertical NW-dipping towards steep N-dipping



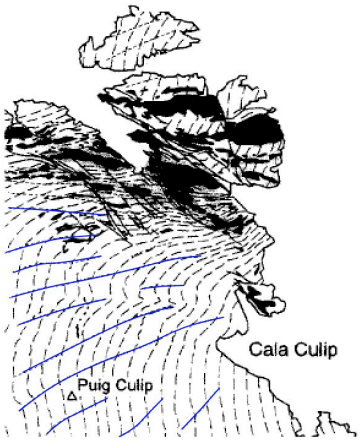
Strain gradient on Puig Culip



- L_2 fold axis rotates from vertical to NW-plunging

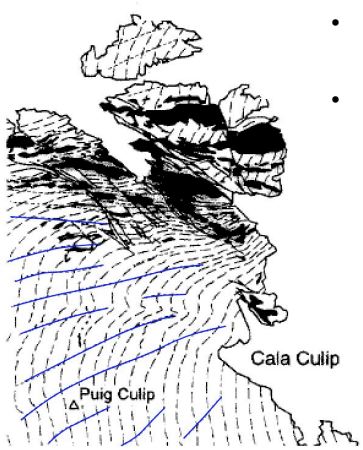


Interpretation of deformation

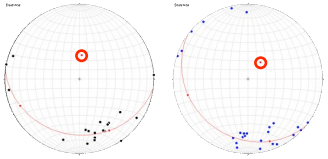


- Model A: 3 events
  - D_1 isoclinal folding
  - D_2 S-shaped folds + S_2 cleavage
  - D_3 dextral shearing
- Model B: 2 events
  - D_1 isoclinal folding
  - D_2 dextral simple shear with shortening of S_{01}, forming folds and S_2 cleavage. L_2 fold axes and S_2 rotate with increasing strain

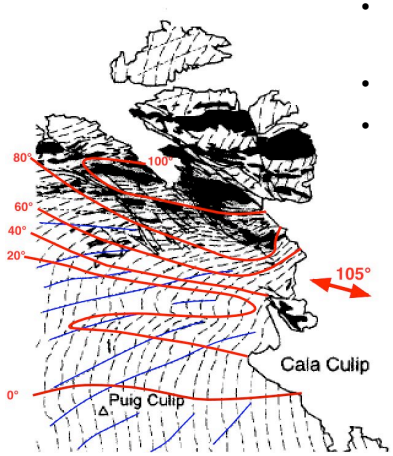
Testing model B: only 2 events



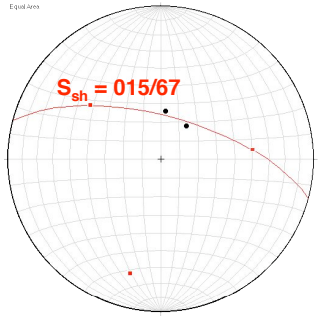
- What is the orientation of the shear zone?
- Fold axes of S_{01} and S_2 very close
  - Not accurate enough with large spread in data



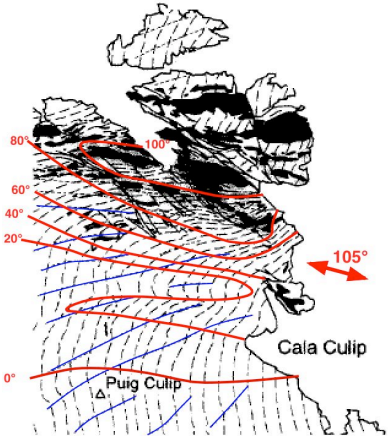
Draw isogons: strike contours



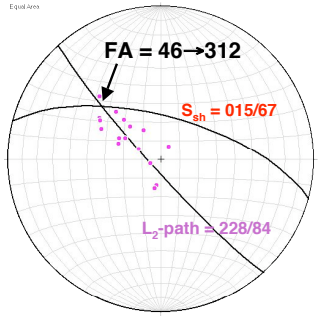
- Isogons define the strike of the shear zone
- The shear zone strikes **105°**
- This gives **S_{sh} = 015/67**



Fold axis rotate towards fabric attractor

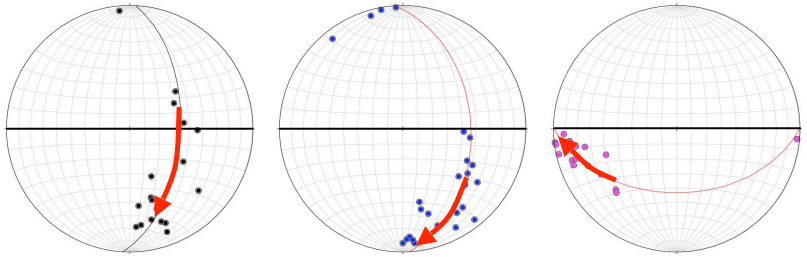


- The fabric attractor (FA) is the intersection between the shear plane and the trend of the rotating L_2 fold axis



Rotate all data to suitable orientation

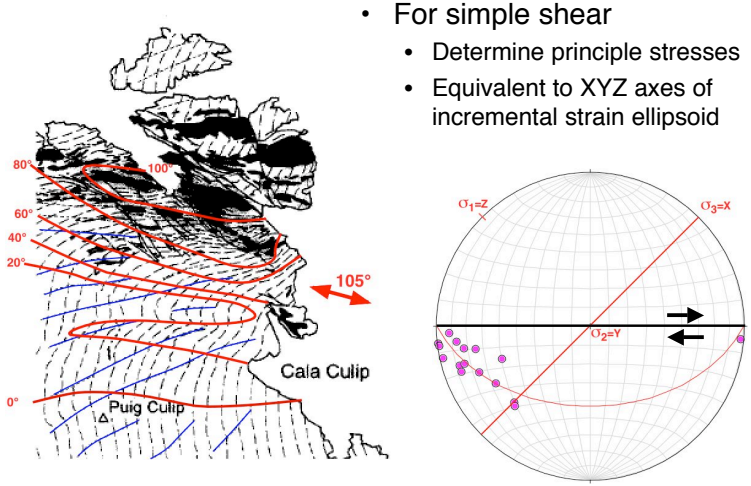
- All data have been rotated to make
  - Shear plane vertical and EW-striking
  - Fabric attractor horizontal



S_{01} poles **S_2 poles** **L_2 fold axes**

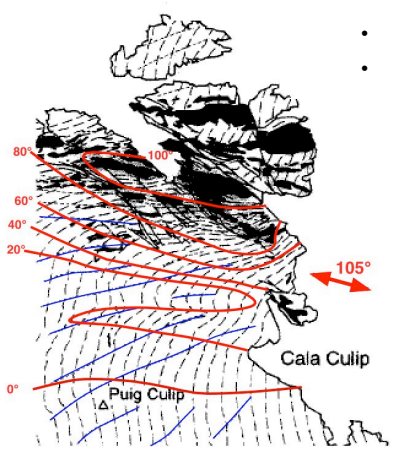
XY-plane of incremental strain ellipsoid

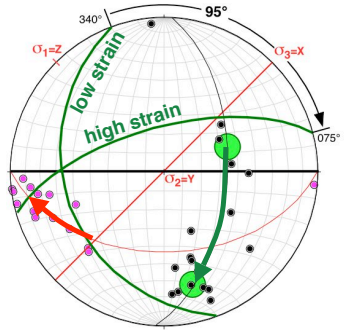
- For simple shear
  - Determine principle stresses
  - Equivalent to XYZ axes of incremental strain ellipsoid



Compare low- and high-strain S_{01}

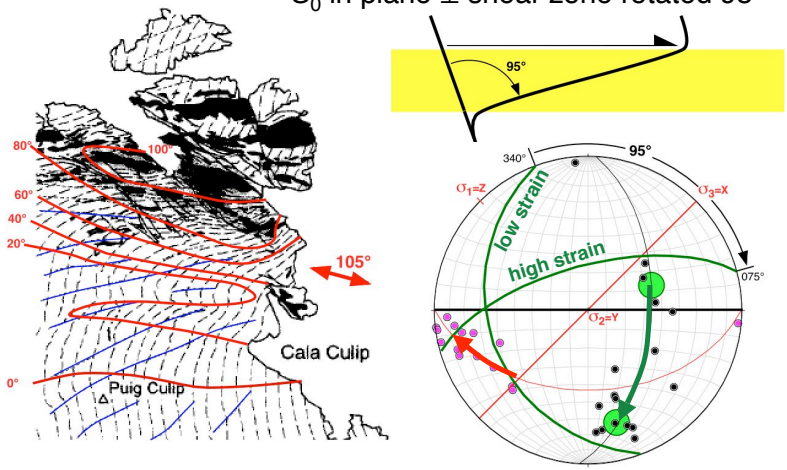
- Low strain $S_{01} \approx 250/35$
- High strain $S_{01} \approx 345/65$
- Low strain S_{01} intersects XY-plane ± where least rotated L_2 fold axes plot





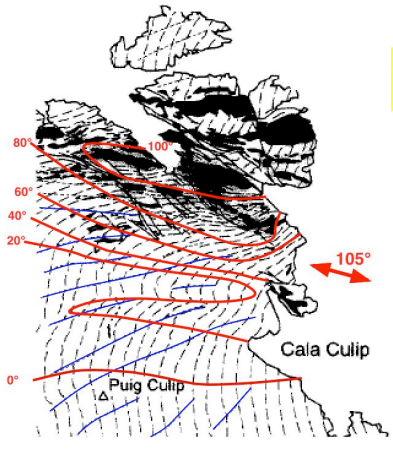
Compare low- and high-strain S_{01}

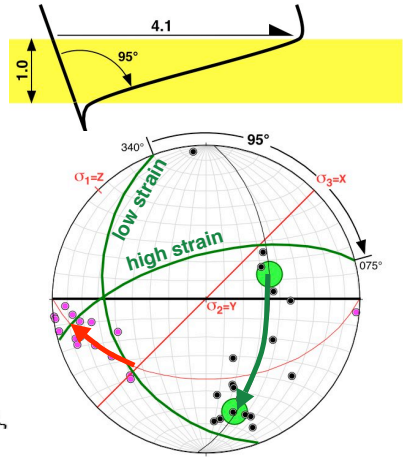
- S_0 in plane ⊥ shear zone rotated 95°



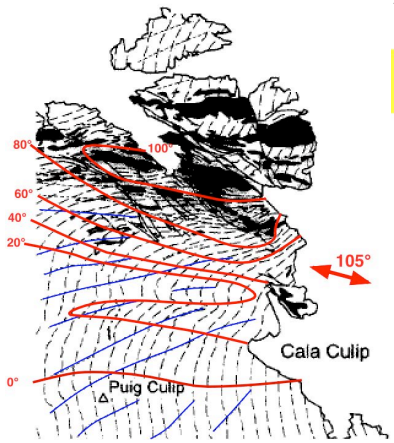
Compare low- and high-strain S_{01}

- The shear strain is 4.1

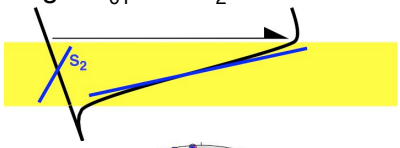


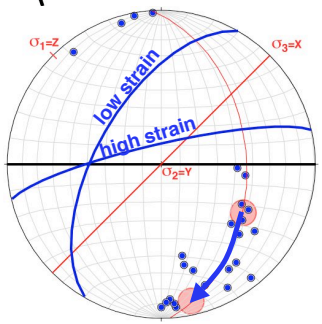


How does this all fit with S_2?

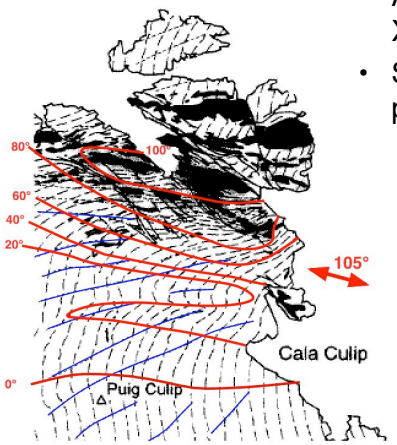


- Angle S_{01} and S_2 decreases

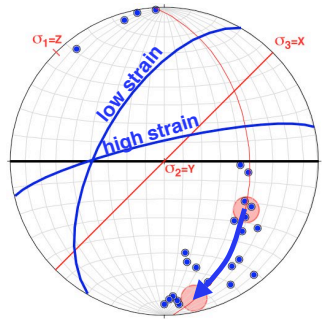




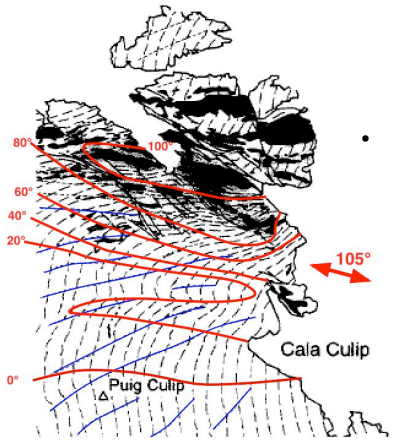
<u>But</u>: original S_2 does not lie in XY-plane



- Angle between original S_2 and XY-plane large
- S_2 probably **<u>older</u>** and not product of shearing event

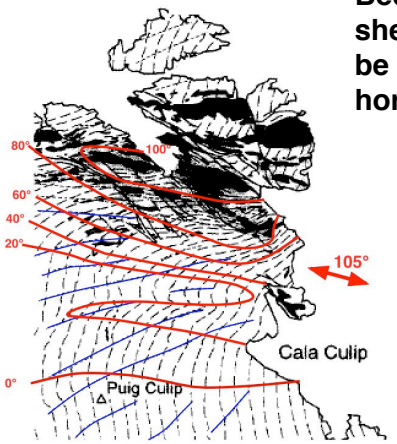


Interpretation of deformation events

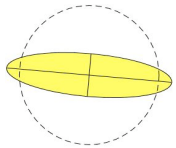


- **D_2 folding**
  - Formation of steep NE-striking S_2
  - Folds with sub-vertical fold axes
- **D3 shearing**
  - Shear plane 015/67
  - Shear direction 46→312
  - Reverse-dextral shearing, $\gamma_{max} \approx 4$
  - Rotation of all D_2 fabric elements
  - No new D_3 cleavage formation, as D_2 structures could be reactivated

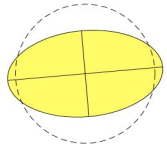
Strain analysis in field



- **Because of the 46° plunging shear direction, there seems to be significant area loss in the horizontal outcrop plane**



High strain (γ=4)
R_f = 3.9
ΔA = -63%



Low strain (γ=1)
R_f = 1.8
ΔA = -31%

An example

- A shear zone (S_{SH}) offsets bedding (S_0)
  - Bedding outside shear zone: S_0 = 224/34
  - Bedding inside shear zone: S_0' = 292/78
  - Stretching lineation in S_{SH}: L_{str} = 37→253
- The bedding inside the shear zone has folds
  - Orientation of fold axis: F = 46→217

- Plot all the data
- What are the orientations of the principal stresses?
- What is the amount of strain in the shear zone?
- What was the original orientation of the folds?