A Mechanical analysis of the correlation between forearc morphology and frictional properties of megathrust

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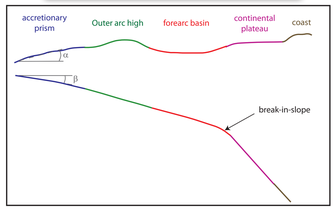
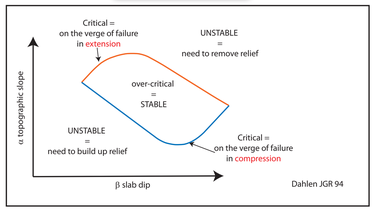
Some recent studies have pointed out to a possible correlation between forearc topography and seismic asperities on megathrust (Song and Simons, 2003; Wells et al., 2003). This correlation suggests that the morpho-tectonic zones could reveal spatial variations in frictional properties of megathrusts. One possible cause would be that the effective friction along megathrust depends on the mode of slip: it would be lower in seismic asperities area due to dynamic weakening during seismic rupture, and larger in area dominated by rate-strengthening friction. In order to assess this correlation, a systematic study of a number of subduction margins has been conducted. The objective is to highlight common features associated to seismic or aseismic areas and weakly or strongly coupled areas and to establish if they can be linked to frictional properties. Forearc topographies and slab geometries are studied based on the critical taper model and on the limit analysis theory. This theory, which is based on the mechanical equilibrium and the theory of maximum rock strength, allows predicting forearc deformation based on the megathrust geometry, forearc topography and frictional properties. More general than the critical taper model, it can be used to retrieve the effective friction on the megathrust, and its eventual variation in space from the localization of active faults.

How does the critical taper theory relate to forearc morphology?

Forearc morphology and segmentation:

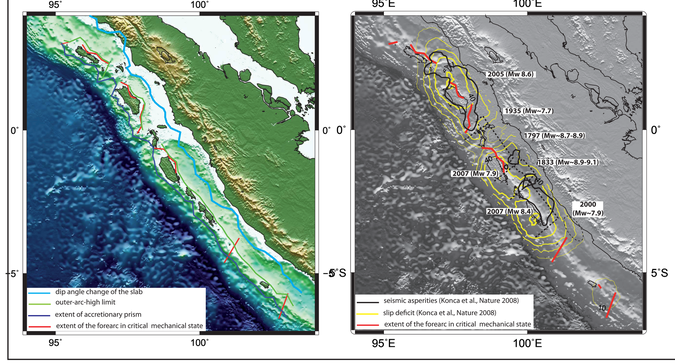


Critical taper theory:



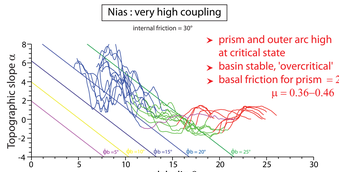
SUMATRA

Localisation of the extent of the critical mechanical state and comparison with seismic asperities and coupling:



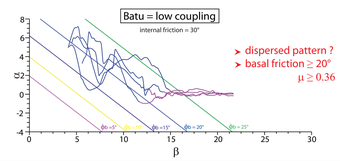
Which parts of the forearc are at critical state?

Nias : very high coupling



- prism and outer arc high at critical state
- basin stable, 'overcritical'
- basal friction for prism = 20–25°
  μ = 0.36–0.46

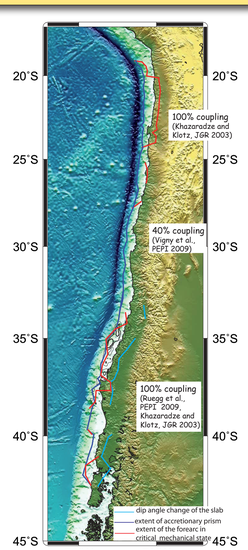
Batu = low coupling



- dispersed pattern ?
- basal friction ≥ 20°
  μ ≥ 0.36

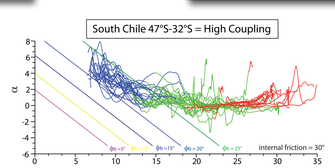
CHILI

Localisation of the extent of the critical mechanical state

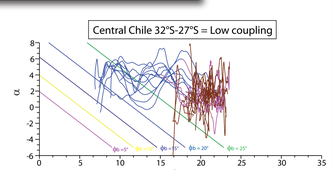


Differences between high coupled and low coupled forearcs ?

South Chile 47°S-32°S = High Coupling

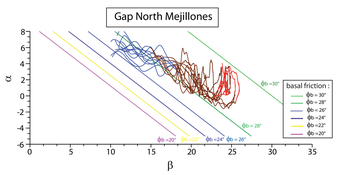


Central Chile 32°S-27°S = Low coupling



SOUTHERN CHILE :
Prism at critical state,
correlation between upper limit of seismogenic zone and exitent of the prism at critical state ?
basal friction = 20–25°
μ = 0.36–0.46

Gap North Mejillones



CENTRAL CHILE :
Whole forearc over-critical,
correlation between over-criticality and low coupling ?
correlation between flat slab and low coupling ?

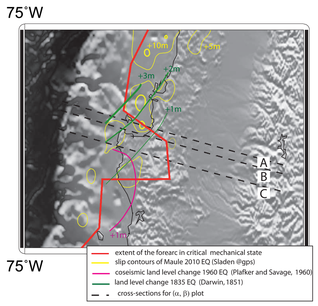
NORTHERN CHILE :
Prism, coast and mejillones peninsula at critical state,
basal friction = 28°
μ = 0.53
Can the critical taper or the limit analysis explain the normal faults of the peninsula ?

Prism and sometimes outer-arc-high are at critical state.
Forearc basins are always stable, only an upper bound for the basal friction can be proposed with the crtitical taper theory.
Criticality suggesting very high friction below prism compared to fold-and-thrust belts, related to rate-strengthening ?
The correlation between the extent of the critical domain and the upper limit of the seismogenic zone is not applicable to Sumatra Islands.
Arauco and Mejillones Peninsulas are also at mechanical critical state, rate-strengthening barriers?

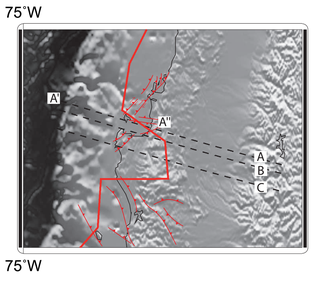
The slab break-in-slope seems to underline forearc basins and seems to mimic the coast.

Arauco Peninsula : a rate-strengthening barrier ?

Comparison of the extent of the criticality with Maule 2010 earthquake slip



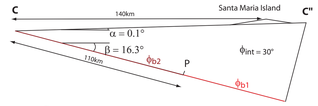
Thrusts and strike-slip faults described by Melnick et al. 2006 and Melnick et al. 2009 :



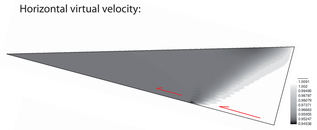
Retrieving basal frictions from the modelisation of the Santa Maria fault thrust with the limit analysis theory :

Numerical external approach of the limit analysis (Souloumiac et al., Comp. Geosc. 2010) used to find the basal frictions reproducing a thrust fault at the same localization and with the same dip as the Santa Maria thrust fault.

sketch:

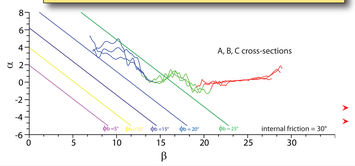


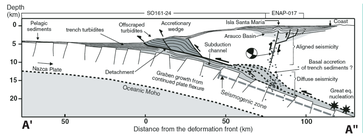
Horizontal virtual velocity:



Vertical virtual velocity:

Research of the basal friction below peninsula :

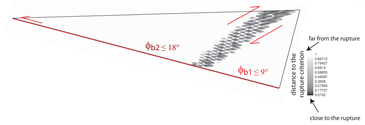




- basal friction below prism : 23°
- basal friction below peninsula : 26°
  Static frictions ?

- Santa Maria thrust : upper limit of the seismogenic zone ?
  Basal frictions needed to create this fault can be assessed with the limit analysis.

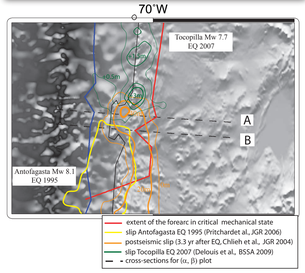
Distance to the coulomb rupture criterion:



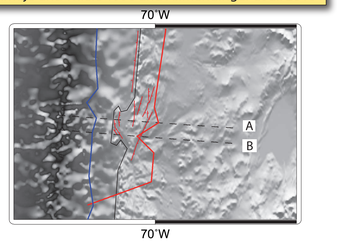
The modelisation requires a basal friction below the seismogenic zone lower than 9° (μ ≤ 0.15) and a friction for the prism ≤ 18° (μ ≤ 0.32), otherwise, a pop-up structure is preferred.

Mejillones Peninsula : how to explain the normal faults?

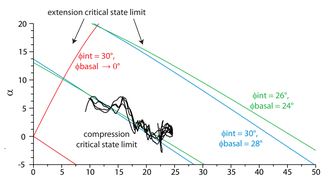
Comparison of the extent of the criticality with slips of Antofagasta 1995 and Tocopilla 2007 EQ



Normal faults described by Armijo and Thiele 1990 and Allmendinger et al. 2010 :

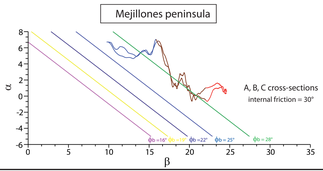


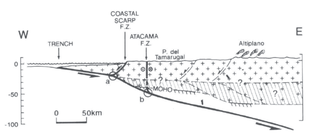
Can the peninsula be at the extensional critical state ?



- Impossible to reach the extensional envelop

Mejillones peninsula





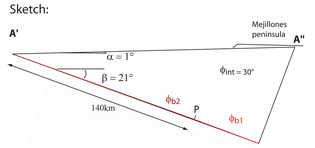
- Which frictional properties could explain these normal faults ?

- basal friction below prism : 26.5°
- basal friction below peninsula : 28°

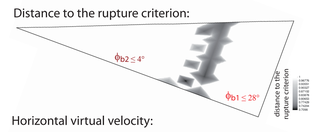
Formation of a normal fault
requires a transition from a first basal friction
ϕb1 ≤ 28° to ϕb2 ≤ 4°
How can we reconcile this change of friction from 28° to 4° ?
28° = static friction whereas
4° = postseismic friction ?

Normal faults = frictional transition ?

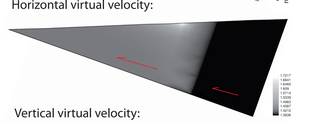
Sketch:



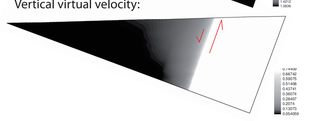
Distance to the rupture criterion:



Horizontal virtual velocity:

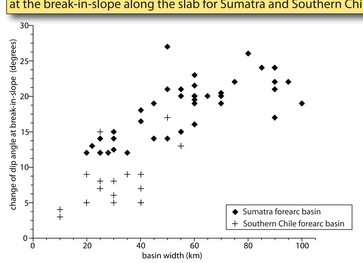


Vertical virtual velocity:

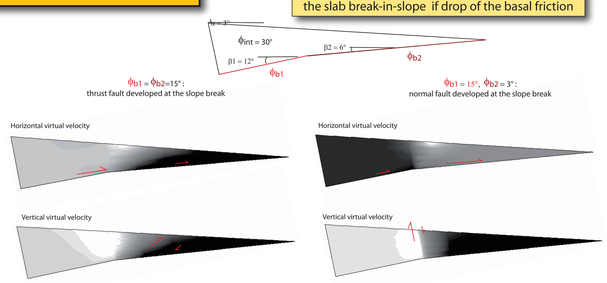


Dip angle change of the slab, correlation with forearc basins?

Correlation between forearc basin width and the change of dip angle at the break-in-slope along the slab for Sumatra and Southern Chile :



Limit analysis : normal fault developped on top of the slab break-in-slope if drop of the basal friction



Some perspectives

Study of flat slab forearcs (Northern Peru, Mexico, Makran) to determine α/β patterns and compare mechanical states.

Study of low coupled forearcs to check if always over-critical.

Other peninsulas considered as barriers (Ilo): also at mechanical critical state with very high basal frictions ?

Normal faults in forearc basins associated to transition of friction or at extensional critical state?

Forearc basins always associated to break-in-slope?