Additional Slides
Ad-hoc melt migration - Sill and dike approximation

Two end-member scenarios

Sill

Dike
Conclusions: Modes of extension & oceanization

- Narrow symmetric
- Asymmetric
- Wide Asymmetric

- Serpentinitised mantle
- Magmatic crust
Conclusions: Modes of extension & oceanization

Wide margin vs Narrow margin:
- Core complex
- Distributed faulting
- Sequential faulting
- Break-up at 49 ma
- Serpentinised mantle
- Magmatic crust

Narrow margin:
- Break-up at 28 ma
- Salt basin
- Continent-ocean transition

San Francisco craton
Congo craton

Salt basin
Continent-ocean transition
**FINITE ELEMENT MODELLING**

- Tracer particles follow Moho & base continental lithosphere.
- Serpentinization occurs when entire crust becomes brittle due to increased hydrothermal circulation. Tracer particles follow serpentine.
- Decompression melting when geotherm crosses solidus.
- At each time step melt produced is focused at rift centre. Subsequently, melt is moved laterally with a velocity $V_x$.

*Perez-Gussinye et al., EPSL, 2006.*
SLOW VELOCITY = 4.2 mm/yr (half extension)
NORMAL MANTLE TEMPERATURE = 1300°C

SERPENTINISATION STARTS BEFORE MELTING
Perhaps forming a barrier for melt to reach surface

Perez-Gussinye et al., EPSL, 2006.
**EXTENSIONAL PROCESSES**

**FAST VELOCITY = 10 mm/yr (half extension)**

**NORMAL MANTLE TEMPERATURE = 1300°C**

**Time**

- Time = 4.6 myr
- Time = 7.6 myr
- Time = 14 myr

**Distance along FEM grid [km]**

- 200 220 240 260 280 300

**Depth [km]**

- 0 10 20 30 40 50

- Moho depth
- Brittle-ductile transition (BDT)
- Zone of melting
- Base continental lithosphere
- Mantle depletion in %

**MELTING STARTS BEFORE SERPENTINISATION**

Perez-Gussinye et al., EPSL, 2006.
1. Past and Current Research:
   Extensional processes.
   Mechanical properties of continents.

2. Future Research
Slow extension velocity \( \sim 4 \) mm/yr

Strong (mafic granulite) lower crustal rheology
Slow extension velocity $\sim 4$ mm/yr
strong (mafic granulite) lower crustal rheology

Effective crustal thinning due to sequential faulting
Slow extension velocity \( \sim 4 \text{ mm/yr} \) weak (wet quartz) lower crustal rheology

NO Effective crustal thinning due to sequential faulting
$v_p/v_S$ is primarily sensitive to quartz content.

After Christensen [J. Geophys. Res., 1996]

$v_p/v_S$ is primarily sensitive to quartz content.

$v_p/v_S$ is primarily sensitive to quartz content.

$v_p/v_S$ is primarily sensitive to quartz content.
After Lowry & Pérez-Gussinyé, 2011

Crustal thickness can be used as a proxy for depth to olivine-dominated lithology...

(Perhaps) crustal $v_P/v_S$ can be used as proxy for quartz-vs feldspar-dominated lithology?
Western US $T_e$:

Generally,

- Low in active deforming zones
- Intermediate in Colorado Plateau and island-arc derived accretionary terranes
- High in stable lithosphere (Wyoming craton & Great Plains)

EXTENSIONAL PROCESSES

MECHANISMS OF CRUSTAL THINNING FROM 30 to < 6 km

Cowie et al., EPSL, 2005

Newfoundland  Break-up margin  Distance [km]  West Iberia

Ranero & Perez-Gussinye, in prep.
Presenter’s notes: In conclusion, by decreasing lower crustal viscosities, we can explain a wide range of extensional styles, going from narrow symmetric margins to extremely wide asymmetric ones. These architectures arise from a combination of extensional modes as the lower crust becomes stronger during extension. Narrow symmetric margins would correspond to the Type I described by Huismans and Beaumont. If there were a further decrease in viscosity, (Presenter’s notes continued on next slide)
wide symmetric margins would form, corresponding to the Type II margins of those authors. Asymmetry arises if sequential faulting modes kicks in during extension. As lower crustal viscosity decreases, so does the mantle uplift velocity and hence the amount of melting and serpentinisation during extension. Along our study area we see these three extensional styles. The continent-ocean transition may consist of exhumed serpentinised mantle and may be wide in the north due to a very slow extension velocity. To the south a small degree of coupling between crust and mantle and higher extensional velocities probably led to an abrupt transition to oceanic crust.
EXTENSIONAL PROCESSES

DEFORMATION OF UPPER AND LOWER CRUST

Pre-stack depth migration, interpretation & wide-angle seismic velocities

Faults exhumate lower crust at shallow levels.

West
Pre-stack depth migration

East

Perez-Gussinye et al., JGR, 2003
Rift duration [Myr] = Extension Factor

- Ductile lower crust
- Whole crust: brittle

**BATHYMETRY OF THE WEST IBERIA MARGIN**

IAP: Iberia Abysal Plain, DGM: Deep Galicia Margin, GIB: Galicia Interior Basin

**West**

Peridotite ridge

**Depth [km]**

- Moho from Line 6 (Whitmarsh et al., 1996)
2. Margin width

Camamu / Sul do Gabão

Aslanian et al. 2009
2. Margin width
2. Margin width

Camamu / Sul do Gabão

Camamu – Sul do Gabão

Campos/Kwanza

Campos-Kwanza

320 Km

490 Km

Aslanian et al. 2009
2. Margin width
Presenter’s notes: I have been focusing in answering the following questions: 1- how do we go from where extension is small and there is no marked asymmetry (the basin stage), to a stage in which break-up has occurred and we are left with two asymmetric margins on both sides of the new ocean. Seismic data also show that these last stages of rifting are associated with the occurrence of detachment-like faults and we want to understand what is their role in generating the asymmetry and in break-up.
3. Transition to oceanic spreading

[Diagram showing transition from continental to oceanic crust with labeled features such as Moho, Serpentinite ridges, and ODP site.]
Rheologic evolution at non-volcanic margins during extension

\[ \beta = \frac{Z_{c0}}{Z_c} \]

Rheologic evolution at non-volcanic margins during extension

\[ \beta = \frac{Z_{c0}}{Z_c} \]

1- Initially the lower crust behaves **ductily**.

2- with increasing extension lower crustal rocks rise to shallower levels and cools and behave brittlely: deformation in upper and lower crust strongly coupled.

3- Eventually **whole crust is brittle** faults bring water to the **mantle** and serpentinize it.

4- Deformation focuses at weak serpentininites: crust separates and mantle is exhumed.

**Perez-Gussinye & Reston, JGR, 2001.**
EXTENSIONAL PROCESSES

WEST IBERIA MARGIN

- SYNRFIT YOUNGER OCEANWARDS
- FAULTED BLOCKS OCEANWARDS
- MOST LOWER CRUST BRITTLE
- FAULTING SEQUENTIAL IN TIME
- EACH NEW FAULT CUTS PRE-THINNED CRUST

BLOCK DIMENSION ~ BRITTLE LAYER THICKNESS ~ CRUST THICKNESS

So how do basins and margins really form?

Let’s look at high-resolution studies of stratigraphy from little extended basins
EXTENSIONAL PROCESSES

East Shetland Basin

The surface represents the basin bathymetry at the end of the Late Jurassic extension. (Cowie et al., EPSL, 2005)

Stage 1
Distributed faulting (167–155 Ma)

Stage 2
Strain localizes onto large inward-dipping fault arrays (155–148 Ma)

Stage 3
Strain migrates toward rift axis (148–140 Ma)

Return to Part 1