Oceanic detachments
Formation & associated deformation

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Oceanic detachments

1. Lithospheric construction, structure and tectonism

2. Detachments: occurrence & characteristics
   - Footwall & fault composition
   - Deformation conditions
   - Seismicity & active faults
   - Models

3. Deformation & composition

4. Conclusions and perspectives
Seafloor morphology: volcanism + tectonism

Ridge segmentation
Volcanism limited to axial zone
Interaction of faulting and volcanism
Modification of oceanic crustal structure by extension

Oceanographer FZ

Rabain et al., EPSL, 2001


~10% Strain by high-angle faulting

AVR, rift

Faults

Sediment

TOBI Sonar, 29°N (CD99)

Sound illumination from W

Searle et al., EPSL, 1998
Escarf et al., JGR, 1999
Outcrop of peridotites on-axis (Cannat, et al.):
Heterogeneous lithosphere (gabbro + peridotite)
Tectonic lift from lithospheric base to seafloor
No expression on seafloor morphology
No images of tectonic structure under axis (faults, etc.)
"Layered" crust

Depth b.s.f., km

0

2

4

6

8

Layer 2

Layer 3

Crust

Moho

Mantle

"Crust"

Mantle

"Heterogeneous" crust

V_p, km/s

0

2

4

6

8

After Cannat [1993; 1995]
After Cannat [1993, 1995]

The diagram illustrates the differences between a "layered" crust and a "heterogeneous" crust. The "layered" crust is characterized by distinct layers, with Layer 2 and Layer 3, and a Moho boundary separating the crust from the mantle. The "heterogeneous" crust shows a more complex structure with a "crust" layer and a serpentinized peridotite at the base of the lithosphere, indicated by the red crosses.

The diagram also includes a depth profile with depth b.s.f. in kilometers (km) on the y-axis and P-wave velocity ($V_p$) in km/s on the x-axis. The layers are labeled as Basalt, Dyke complex, and Gabbro, with a gradient indicating the transition from 100% Basalt to 0% Basalt.

The figure is labeled for the "Layered" crust and "Heterogeneous" crust, with $V_p$ values for each section.
Oceanic low angle faults first identified end of 90’s (speculated in ‘80’s)
New mode of tectonic strain accommodations
Analogues to continental core complexes: key to understand their origin
Oceanic detachments

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Smooth, domed surfaces, with low angle (<20° at termination)
Corrugations parallel to spreading direction
Gabbro and peridotite outcrops along their surface (limited dredging)

First identified:
Cann et al. [Nature, 1997]
Tucholke et al. [JGR, 1997]
30°N detachment, MAR
Fault striations from sonar

ATLANTIS TRANSFORM

42°20'W

42°10'W

42°00'W

41°50'W

TERMINATION

MID-ATLANTIC RIDGE AXIS

B.A.?

BREAKAWAY 1

Lost city

TOBI sonar, ~6x6 km
Cann et al. [1997]
Rifted detachments: 5°S & 35°N, Mid Atlantic Ridge
3. Deformation & composition

Fifteen-twenty detachment (MAR, 15°N):
Bridge Drill sampling, dredging’01, ODP 209’03 geophysics’07

Atlantis (MAR, 30°N):
Geophysics, seismics ‘96-’03, Lost City’09-’05, IODP 304/305, ’04-’05

Interpretation of Tucholke et al.’s [1997; 1999] models;
After continental core complex models
Extension during low-magma supply
Rooting in base of lithosphere - plastic deformation zone
Tectonic window of deep lithospheric levels
Tectonic/passive accretion of mantle to the lithosphere

Interpretation of Tucholke et al.'s [1997; 1999] models;
After continental core complex models
Rooting in brittle - plastic transition

Deformation zone:
- Wide plastic deformation zone (>100 m)
- Overimprinting of semibrittle and brittle deformation
- Progressive strain localization to thin brittle fault (1 m)

Oceanic detachments: New mode of oceanic lithospheric accretion & possible key to continental detachments
Footwall composition - Geological & geophysical constraints

JR63 BGS Wireline drilling
WHOI TowCam

ODP Leg 209 Hole#1275
Dives: MODE’98, FARANAUT
Geological constraints:
Striations and fault surface

From: MacLeod et al. [2002] & Escartin et al.
Geological constraints: Striations and fault surface

From: MacLeod et al. [2002] & Escartin et al.
No evidence of extrusives (pillow basalts, volcanic cones, etc.)

From: Escartin et al. [2003]
<100 m deformation zone with fault rock
Talc, amphibolite & serpentine 'schists', Cl-rich
High-T deformation: Scarce, not clearly associated with fault
Fault rocks:
- Ultramafic protolith (relict spinels, REE)
- Metasomatism: Si from basalt/gabbro
- Focused fluid flow along fault & deformation
Fault zone & rocks:

Thin (~100 m) fault zone
Talc & amphibolite derived from peridotite
Fault-parallel foliations
Coeval with magmatism:
  Chill margins against schists
  Magmatic clasts
Green-schist facies (T<400-500°C)

Similar to:
  MAR : Atlantis FZ (MAR) Detachment
  (Karson, John, Fruh-Green & Co.)
  22°N (Tucholke) & 5°S (Reston et al.).
  Also reported in Atlantis Bank, SWIR (Dick & Co.)

From: Escartin et al. [2003]
Footwall composition:
Seismic reflection & refraction data
IODP Drilling (2 legs, 1.5 km)
Hydrothermal activity related to serpentinization
Peridotite sampling along fracture zone wall
Atlantis - U1309D - Depth (m)

U1309G - Fault rocks at top

Basalt with palagonite

Talc-tremolite schist

Fractured diabase

Rest: Undefomed gabbro (NO peridotite)
Footwall composition (IODP):
100-200 m of fault zone
1.5 km of gabbro (!)
Long story short: tested lithospheric heterogeneity
Geological data not concordant with geophysics
Reflector & velocity gradient at 500 m
Fresh peridotites: Vp>8 km/s at >500m; Lost City site
ODP drilling 2004/05: 1.5 km gabbro
Thin fault zone (~100 m) recording low T/P deformation
Linked fluid flow, magmatism and deformation
No evidence of deep, high T/P deformation
Long-lived structures (~1-3 Myr)
Shallow fault at surface; geometry at depth unconstrained
Recap of observations 2/2

Seismicity at deep levels (~3-8 km, TAG detachment)
Active surfaces over large portions of the MAR (hydrophone)
Aseismic creep in shallow levels:
  Serpentinites, talc, fluids and other weakening processes
  Limit may correspond to alteration front

![Diagram showing breakaway detachment and aseismic creep]
a) Shallow detachment (15°45' N, MAR)
- Breakaway Detachment
- Brittle deformation zone
- Axis
- Alteration front (300-450°C?)
- Transient (after intrusion)
- Brittle-Plastic transition (~750°C)
- Long-term

b) Amagmatic extension
- Magmatic crust ↔ Amagmatic accretion
- Limited melt supply

Escarin et al. [2003]

c) Melt-assisted extension
- Plastic and melt-assisted deformation zone
- Melt-rich zone
- Moho
- Mantle lithosphere
- Asthenosphere
15°45′N, MAR
Atlantic, MAR 30°N
(Kane, MAR 21°N)

Needs modification
to include seismic
constraints

Atlantic Bank, SWIR

a) Shallow detachment (15°45′ N, MAR)

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b) Amagmatic extension

- Magmatic crust
- Amagmatic accretion
- Plastic deformation zone
- Limited melt supply

No

C) Melt-assisted extension

- Plastic and melt-assisted deformation zone
- Melt-rich zone

Escartin et al. [2003]
4. Open questions and perspectives

Contribution of detachments to tectonic lithospheric accretion: are they more pervasive than previously thought? - Need reevaluation of existing data, comparison among sites, and integration of new results

Feedback between detachment-related extension & magmatism - Modelling

Geometry at depth: rooting of faults & deformation conditions - Microseismicity (other than TAG), drill holes, and seismic surveys

Why do they form? Indicators of specific magmatic, rheological and/or tectonic conditions
Rheology of talc (and other alteration products) & fluid interaction
G. Hirth, B. Evans

Tectonic rotations, displacements, and fluid flow (MAR 15°N)
C. MacLeod, J. Carlut, A. McCaig

Nature of seismic reflectors (30°N)
J. P. Canales, S. Singh

Seismic activity & reevaluation (13°N)
D. K Smith, J. Cann, M. Cannat

Numerical modeling
N. Ribe