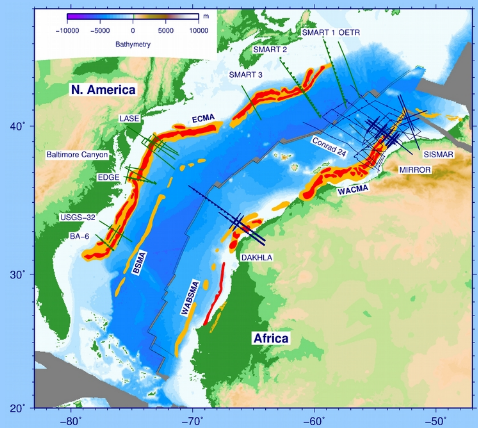
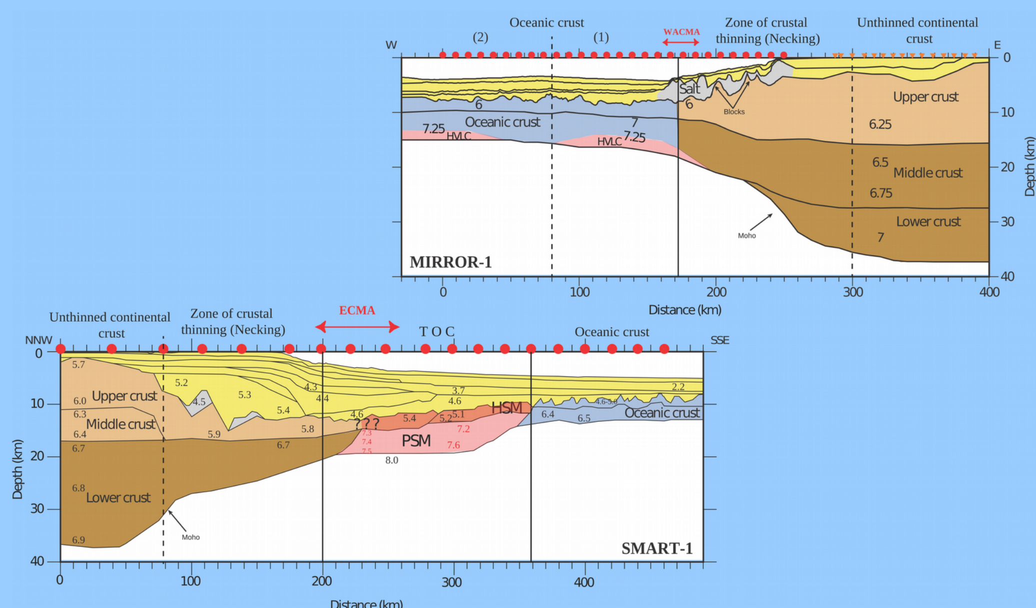
Opening of the Central Atlantic Ocean: implications for geometric rifting and asymmetric initial seafloor spreading after continental breakup.

F. Klingelhoefer, Y. Biari, M. Sahabi, T. Funck, M. Schnabel, M. Benabdellouahed, L. Matias, C. Reichert, M.A. Gutscher, A. Brenner, J.A. Austin

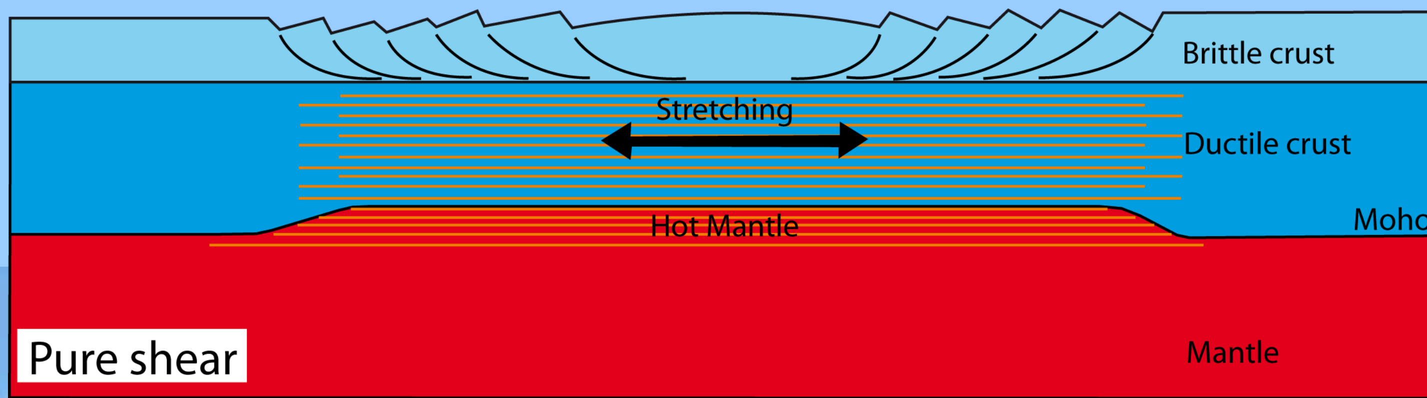


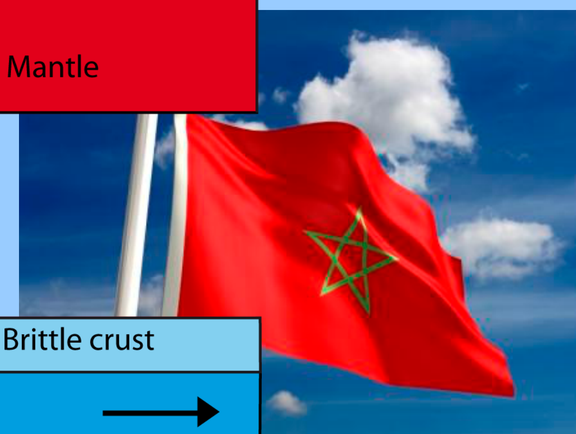
- Introduction
- Deep structure of the Moroccan Margin
- Comparison of the conjugate margins
- Opening mechanism
- Conclusions

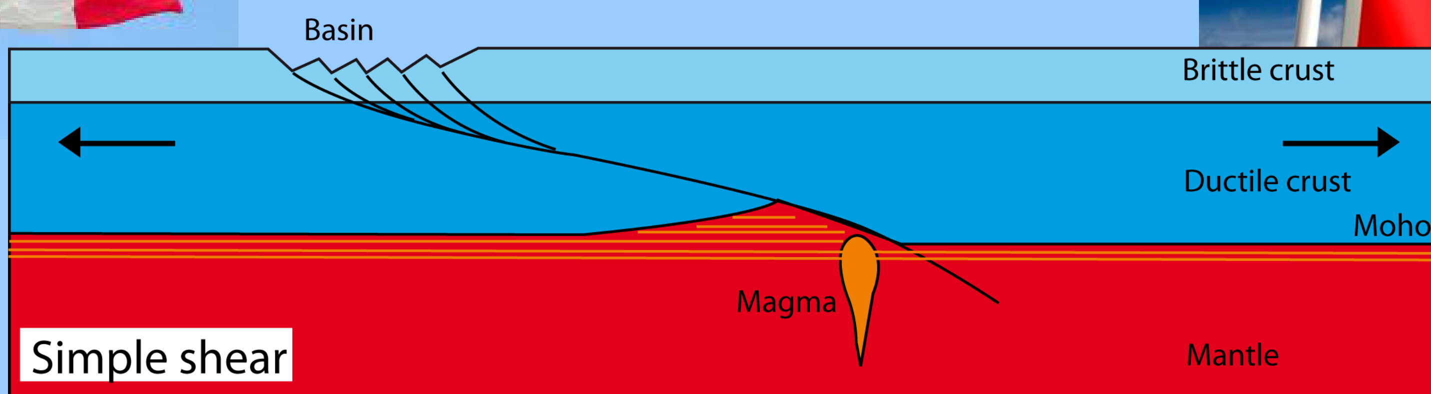


Why conjugate margins ?

Pure shear, McKenzie, 1978

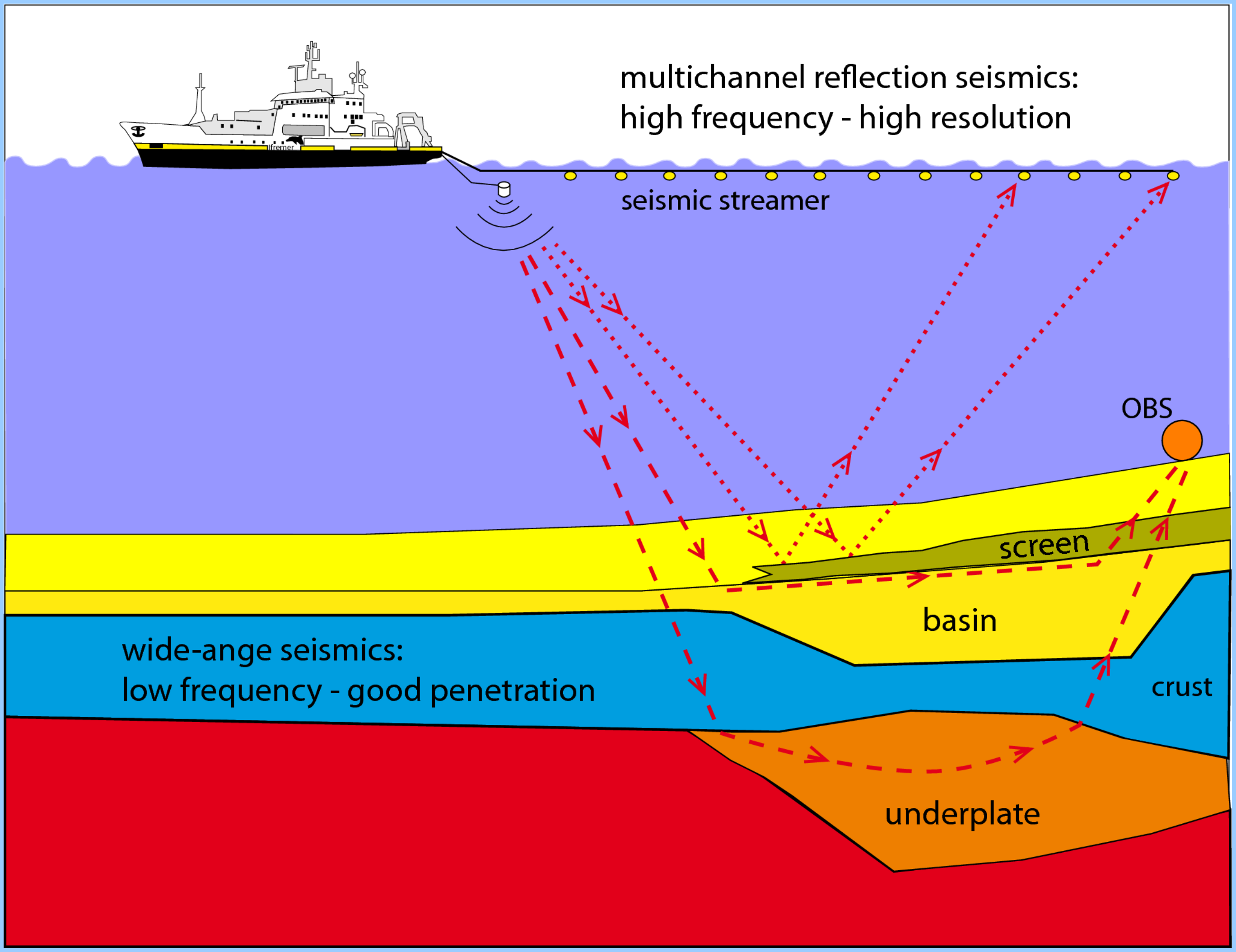






Simple shear, Wernicke, 1985

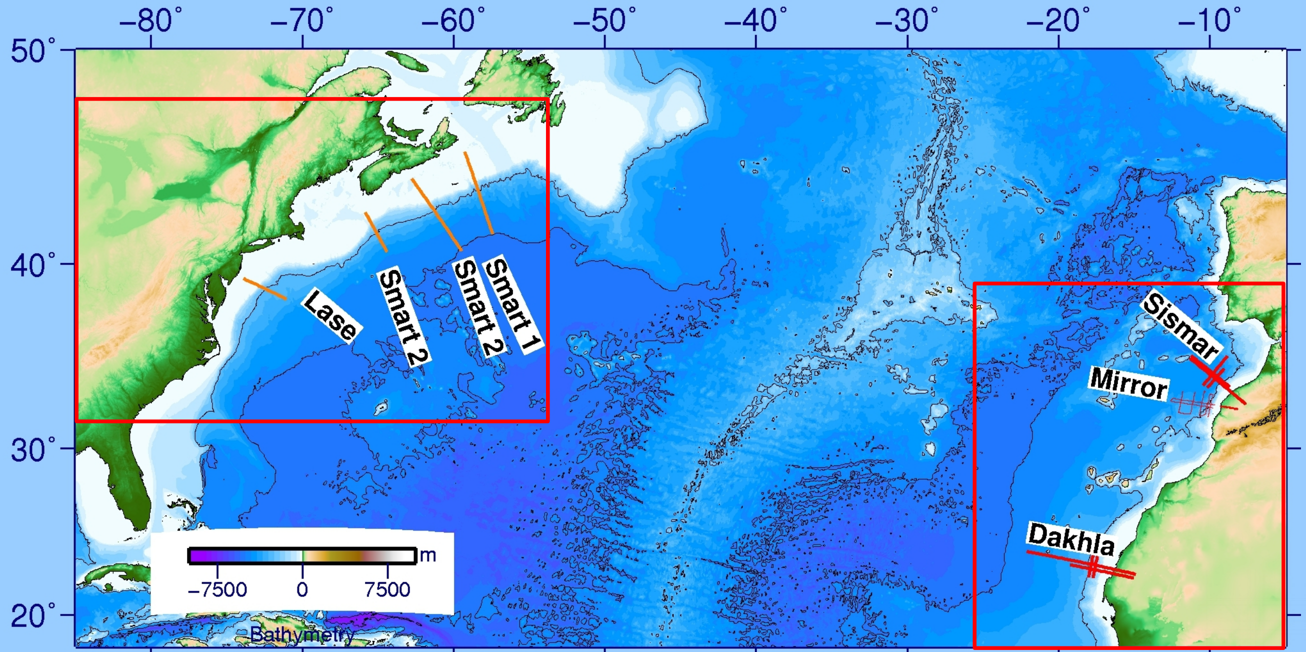
Why OBS



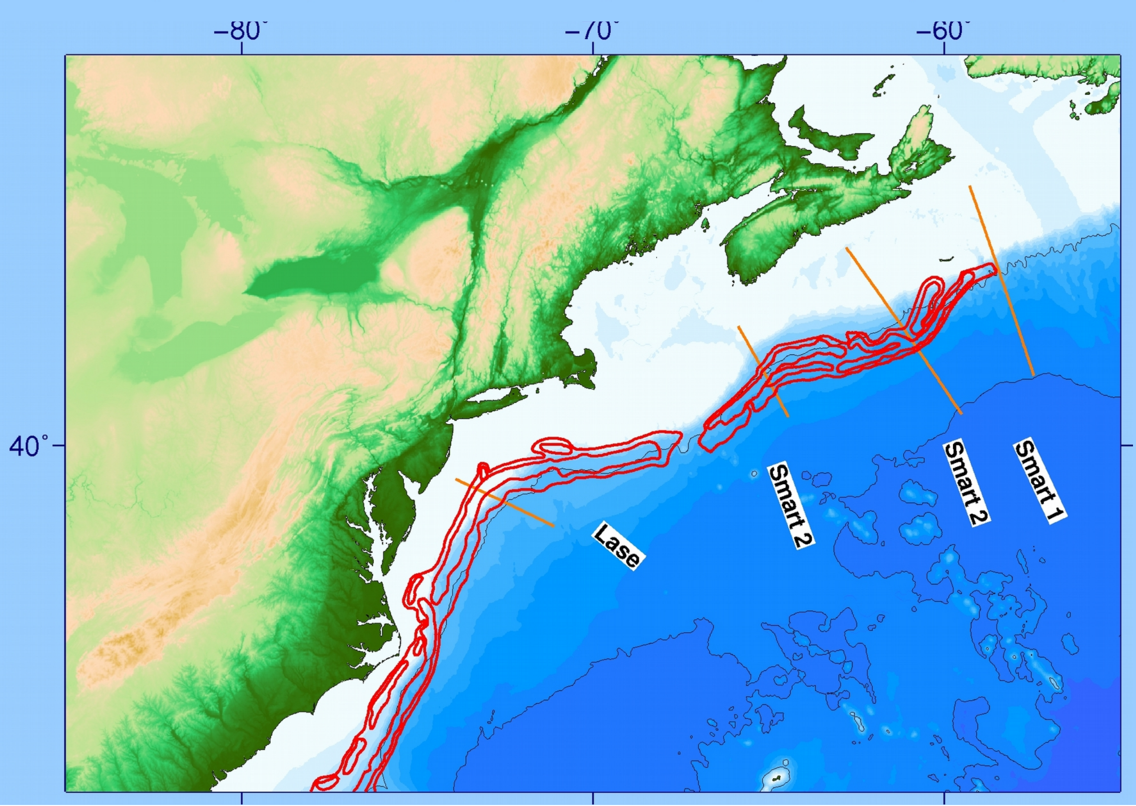
- Imaging below screen (basalt, salt)
- True geometry
- Lithology

eg. underplate, crustal nature

The Morocco-Nova Scotia margin pair



- Opening about 200 Ma in the late Sinemurian
- Existing conjugate mag. anomalies allow reconstruction



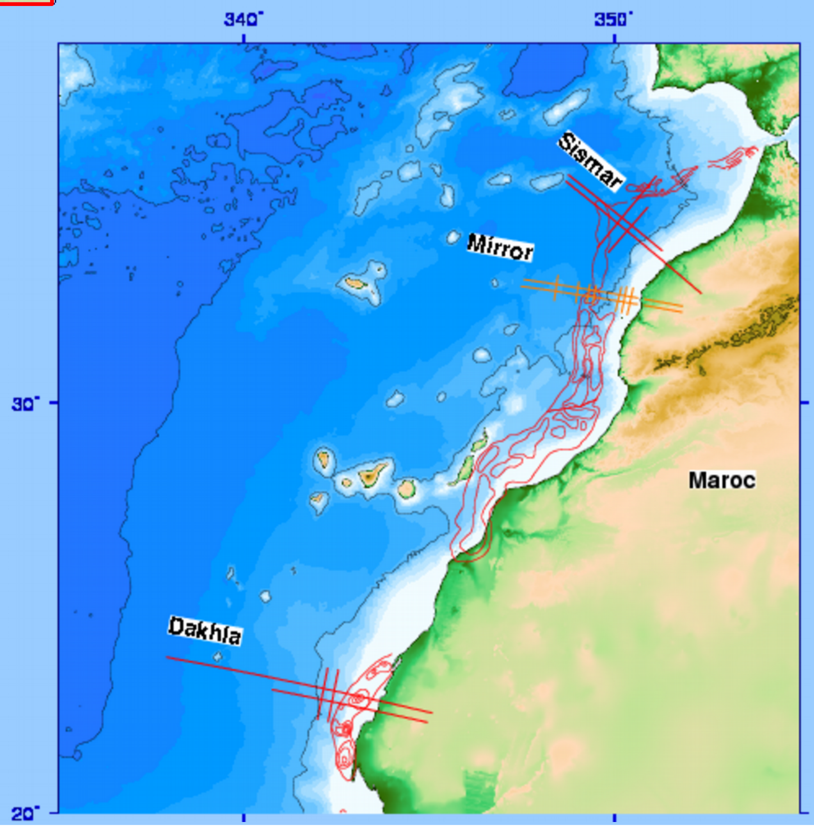
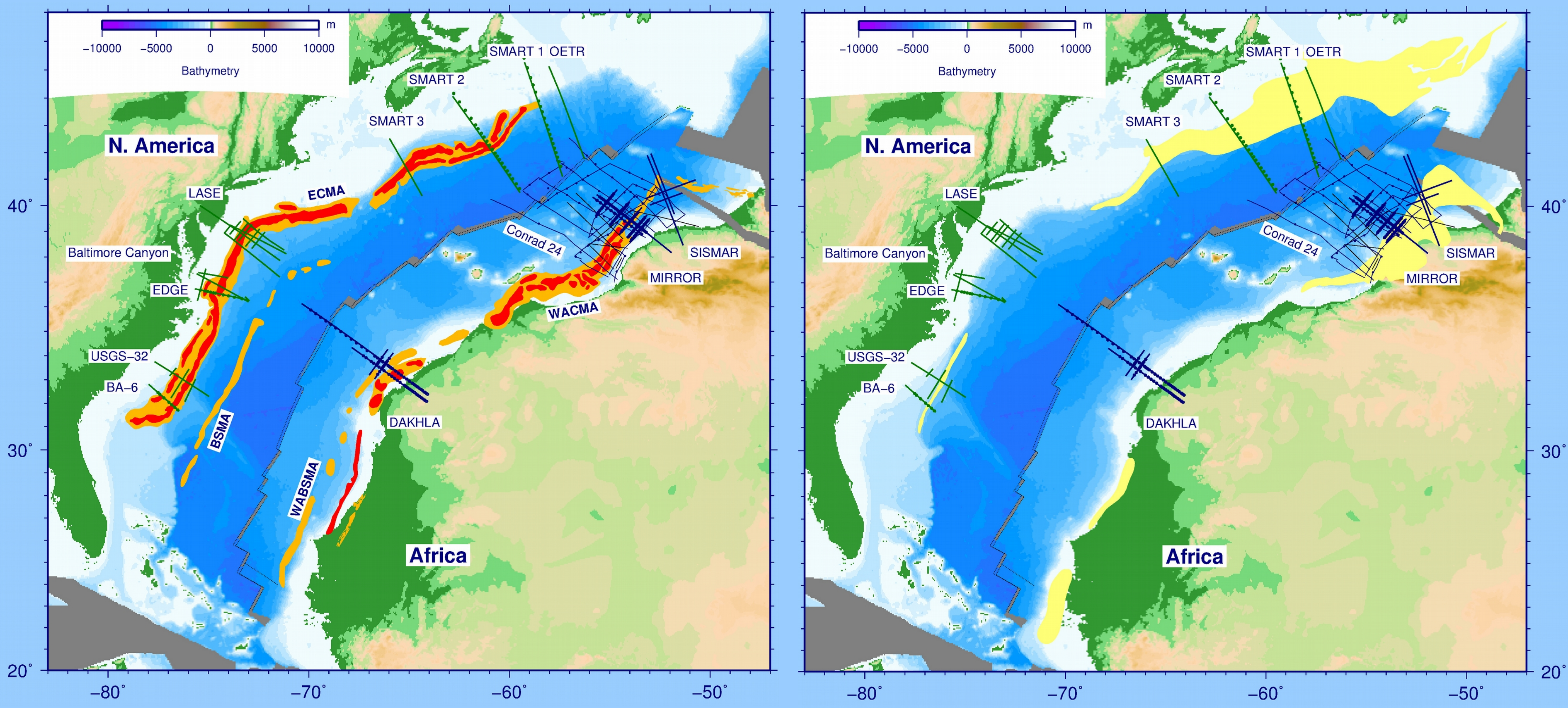


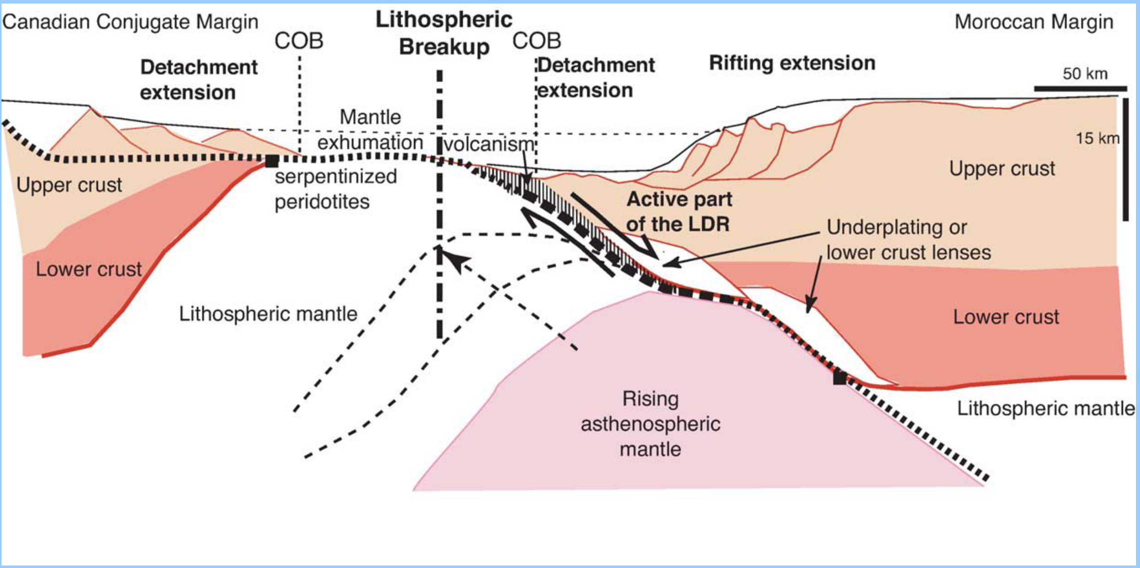
Plate kinematic reconstruction at M25

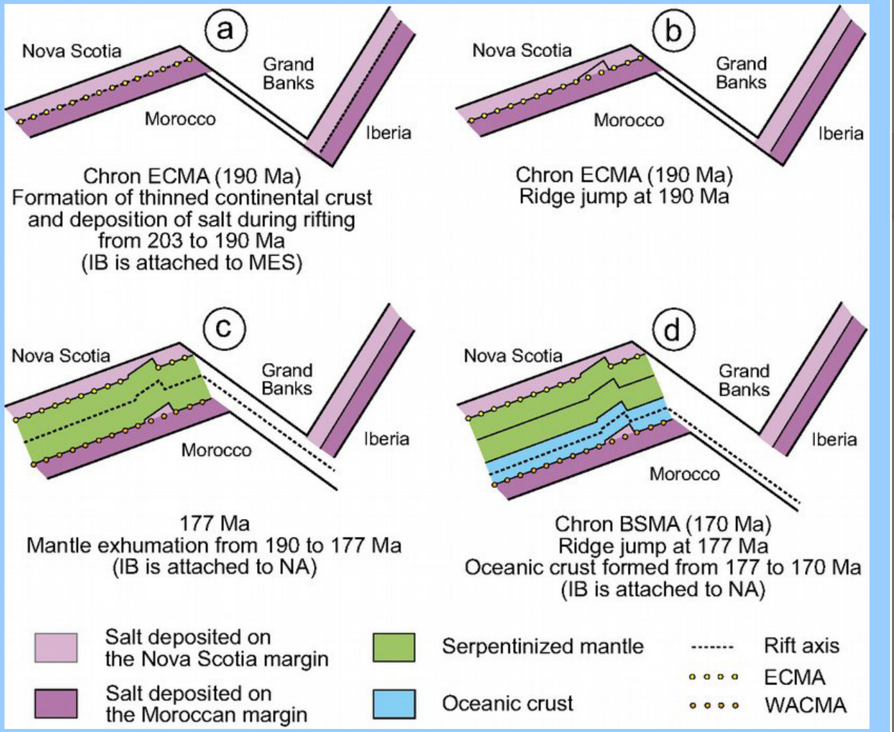


Reconstruction at M25 after Sahabi *et al.*, 2005

Opening mechanism

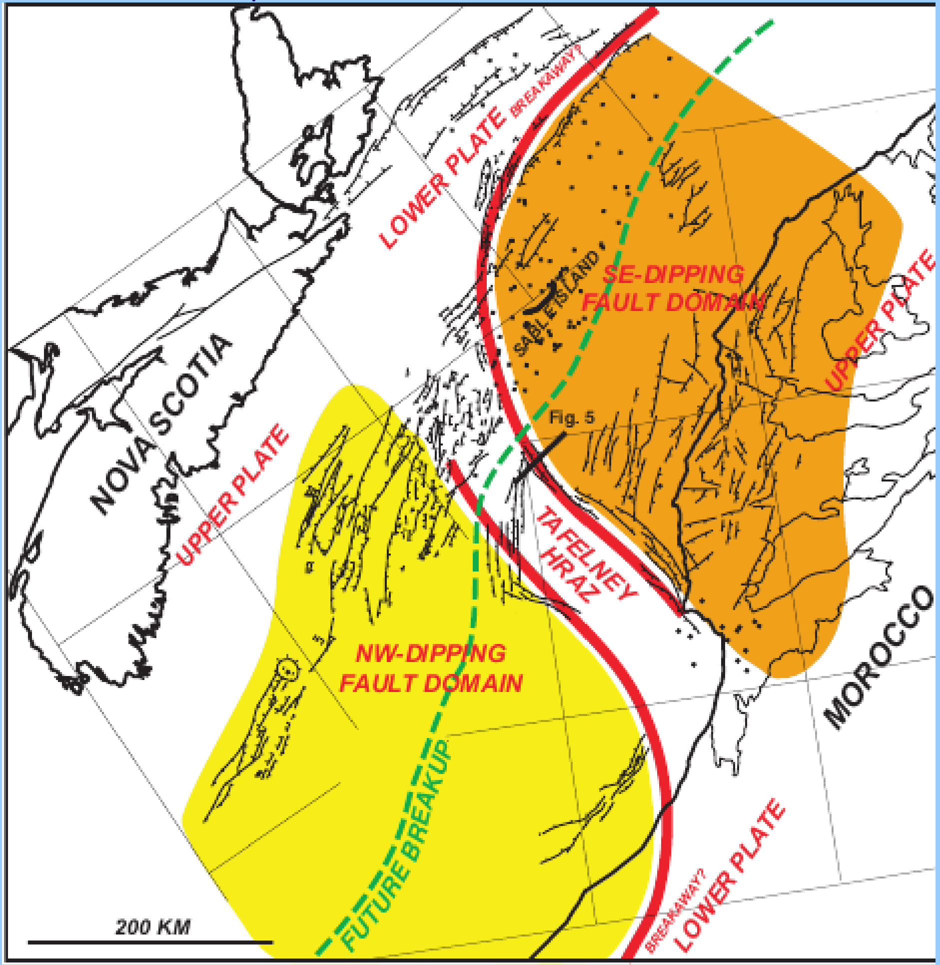
Maillard et al., 2005



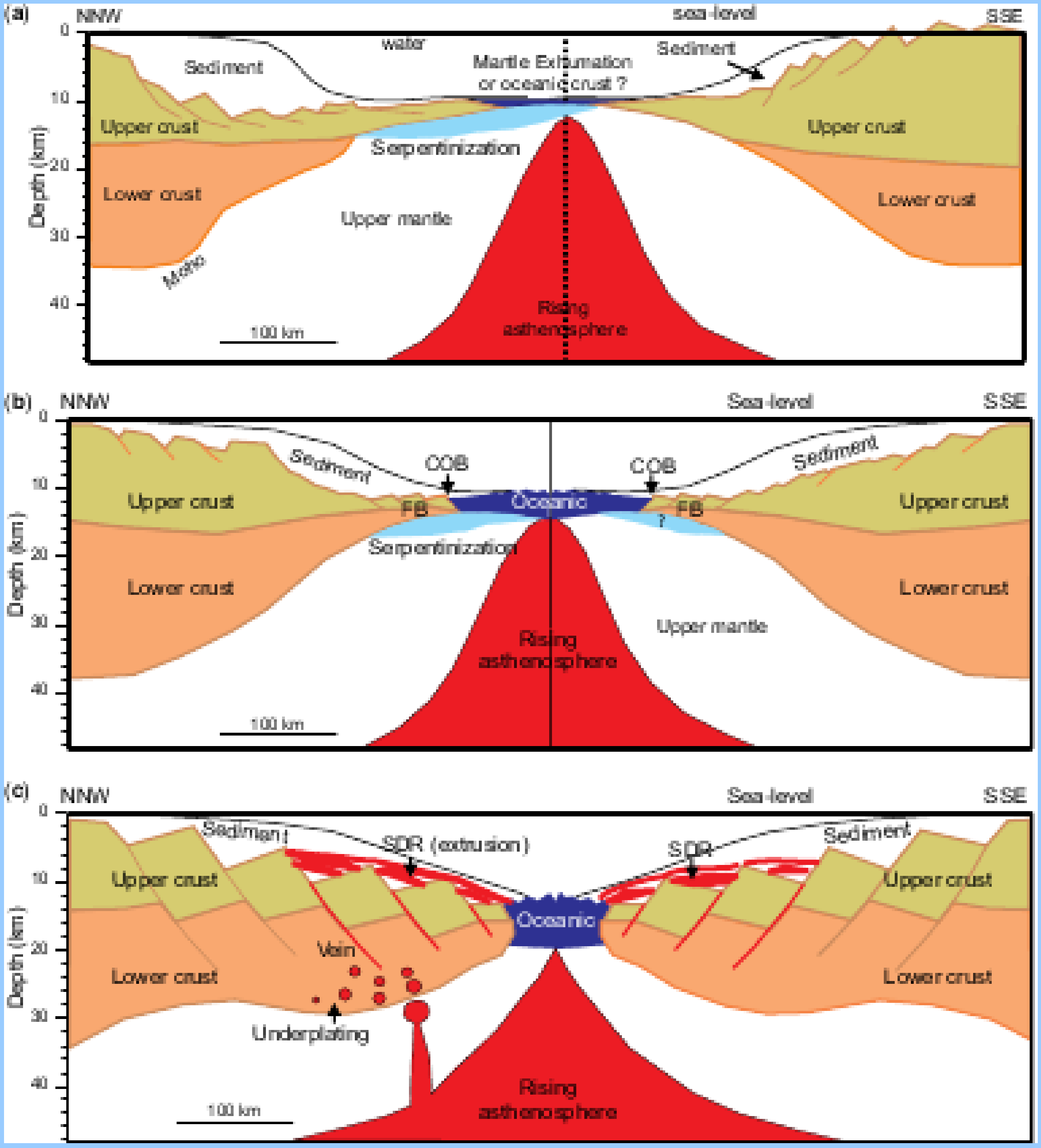


Sibuet et al., 2012

Tari and Molnar, 2006



Volcanism at opening



Non-volcanic

Exhumation of upper mantle material

Transition

Reduction of volcanism

Volcanic

SDR, Underplating

Louden et al., 2012

The NW-African continental margin

Wide-angle seismic data

· SISMAR (2001)

· DAKHLA (2002)

· MIRROR (2011)

Additional multi-channel seismic data from BGR

· ME54

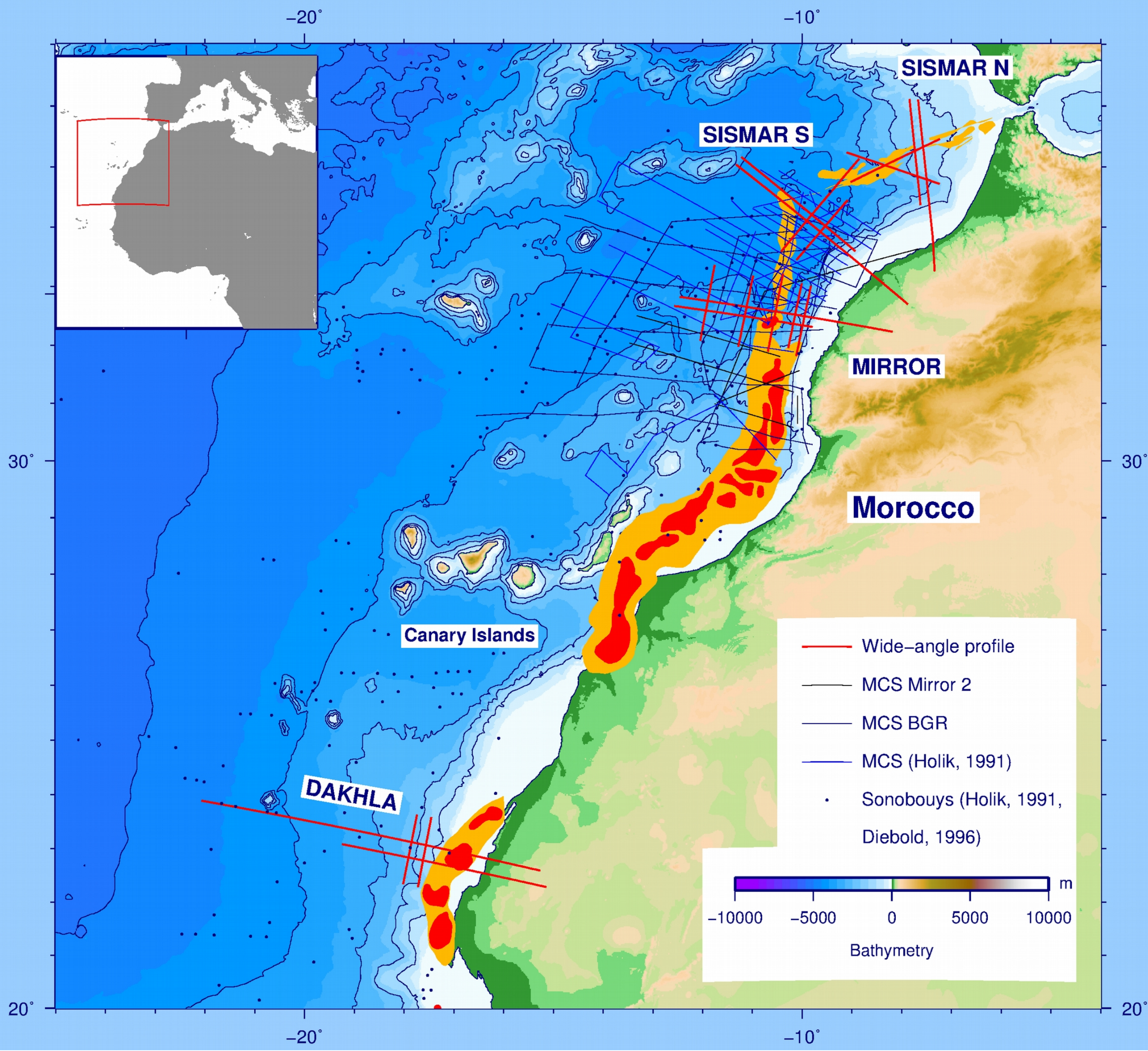
· ME67

· M204

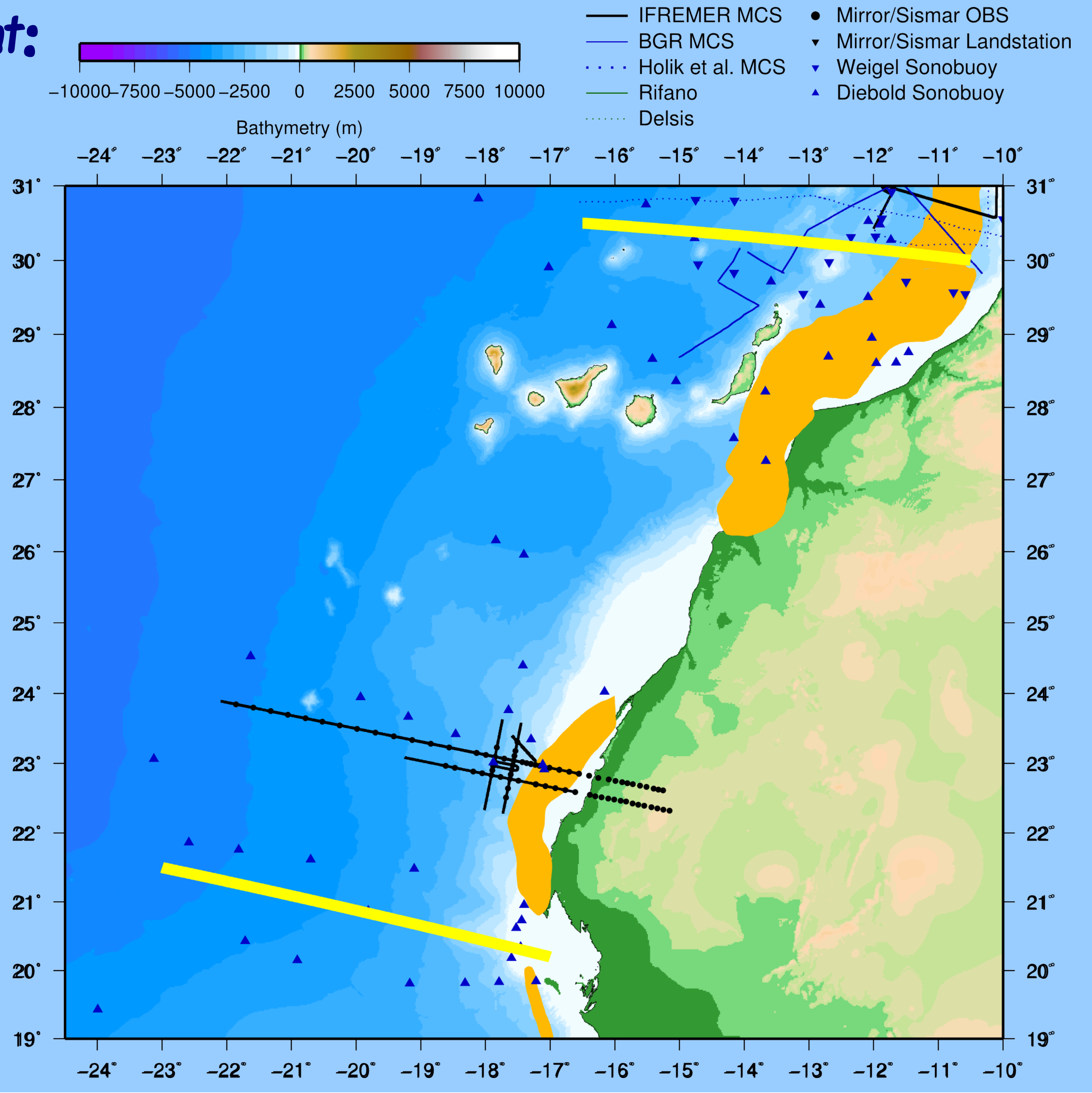
Existing sonobuoy data

· Holik et al., 1991

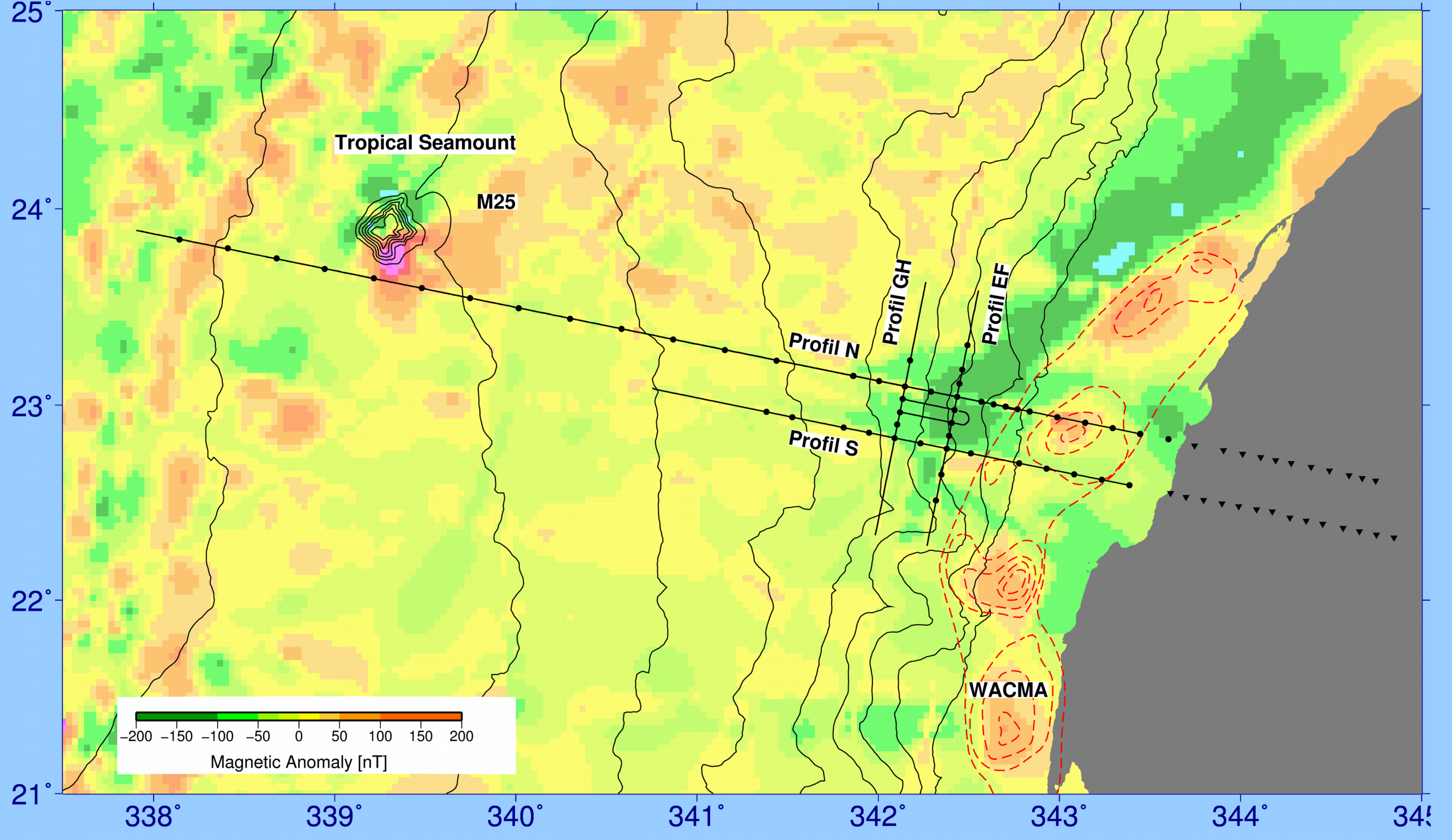
· Diebold, 1996



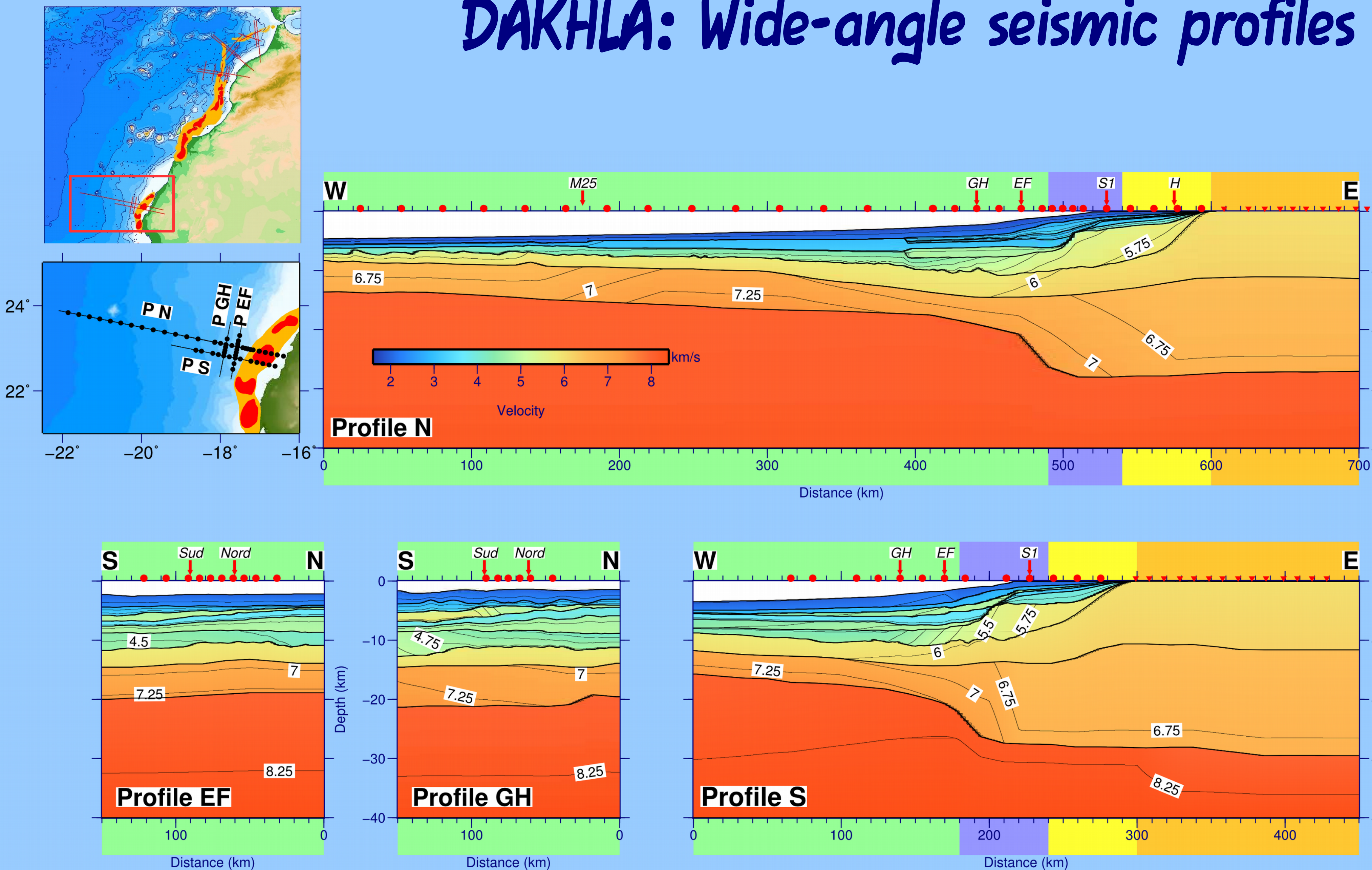
Southern segment: existing data



DAKHLA: magnetic anomaly

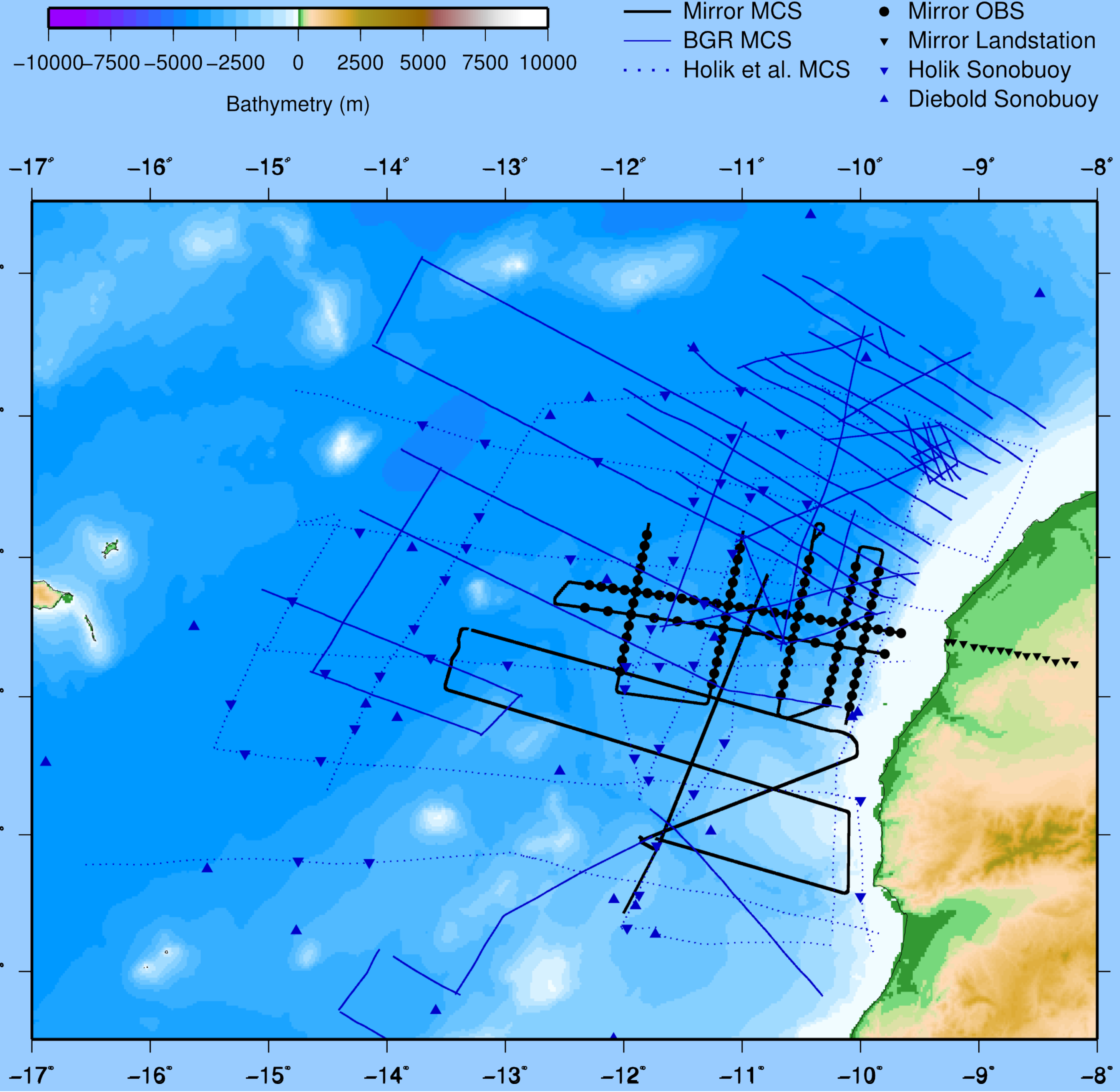


DAKHLA: Wide-angle seismic profiles

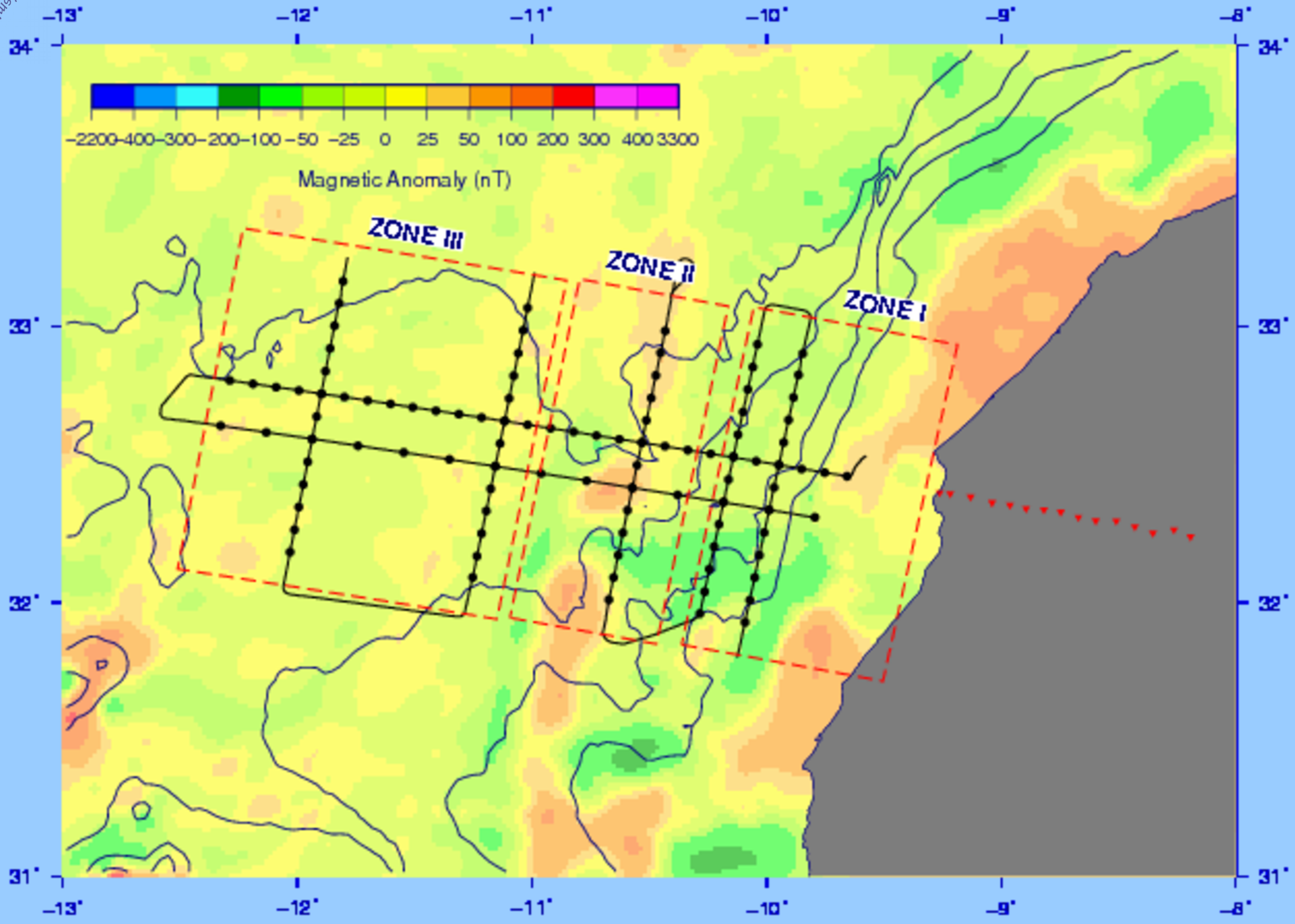


Oceanic
OCT
Thinned cont.
Continental

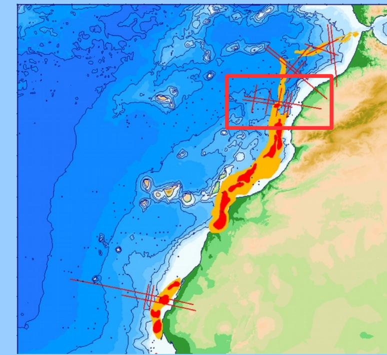
Central segment: existing data

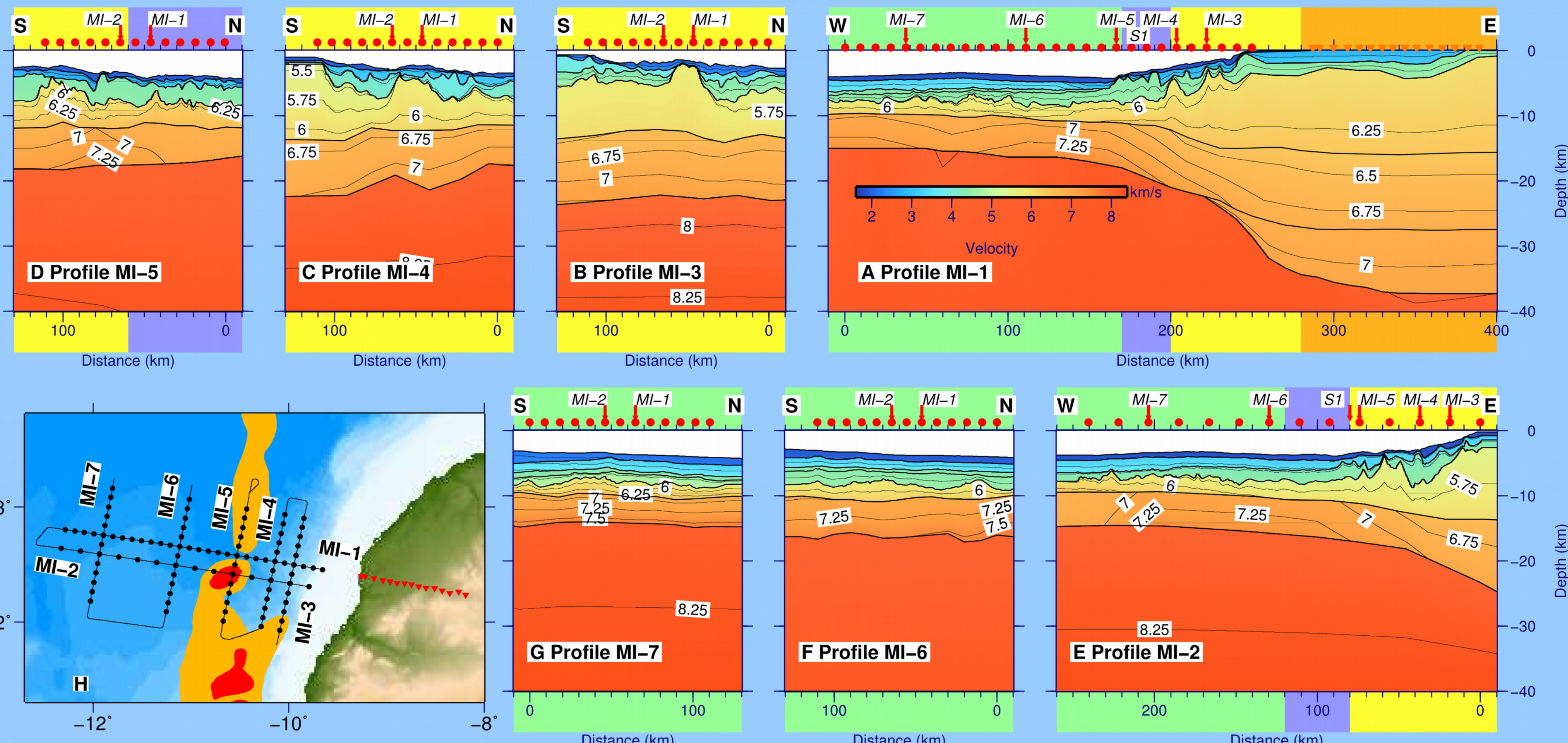


MIRROR: OBS/MCS locations



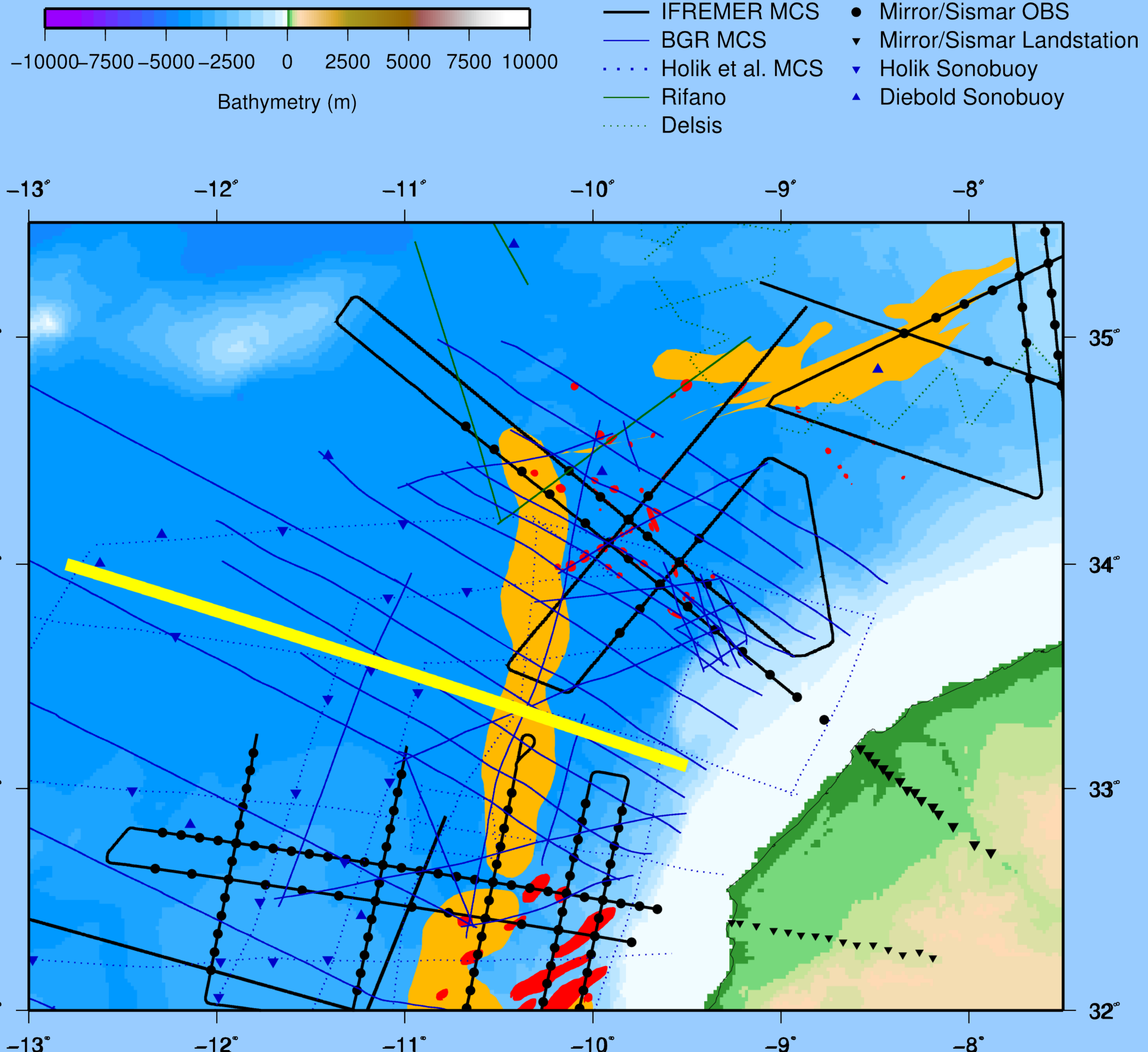
MIRROR:
Wide-angle seismic profiles



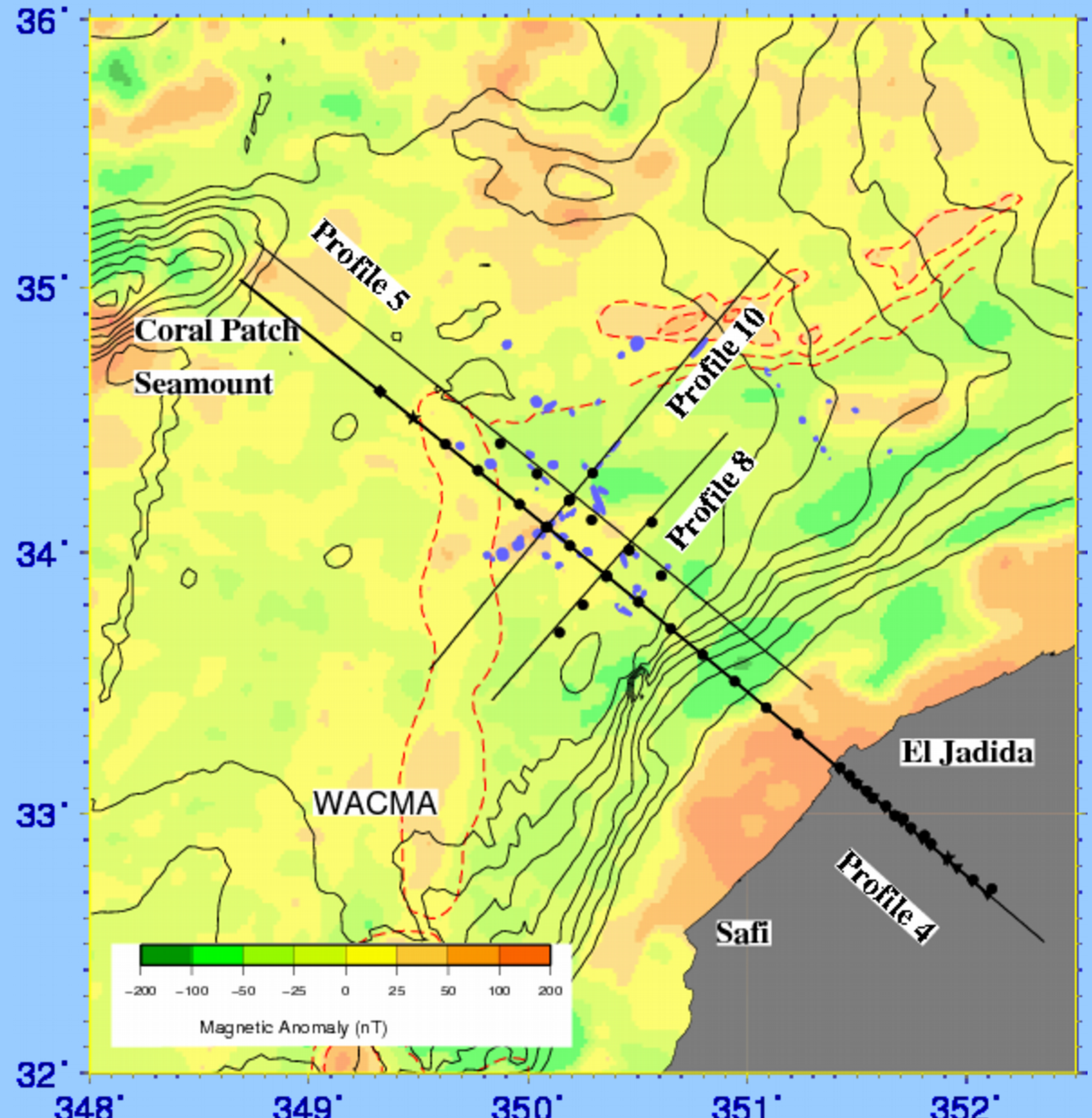


Oceanic OCT Thinned cont. Continental

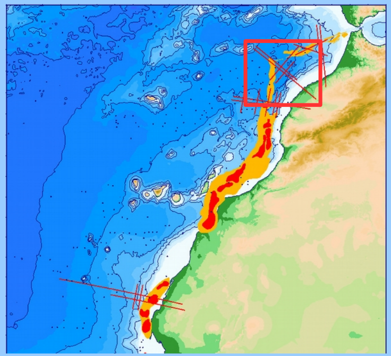
Salt Basin: existing data



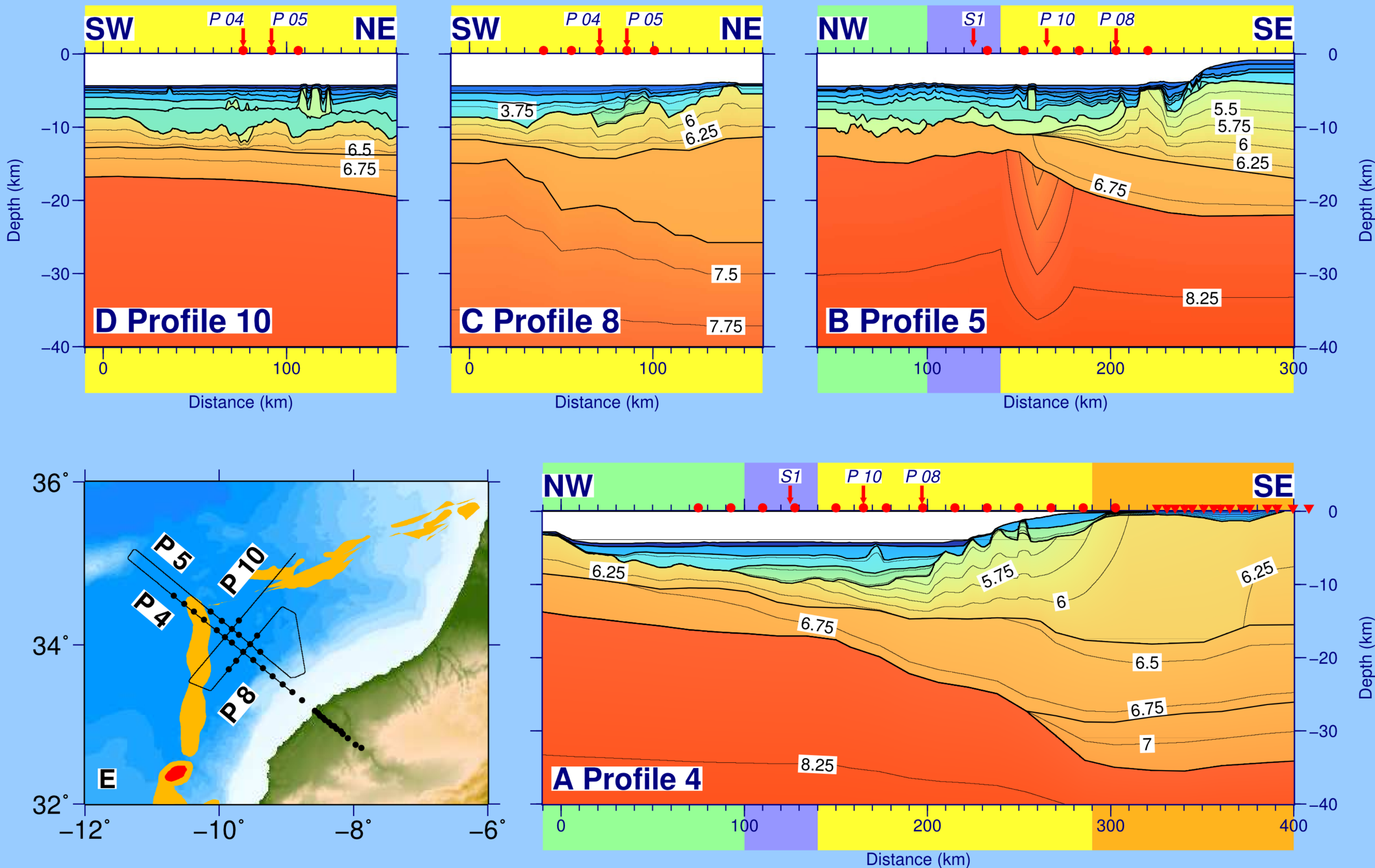
SISMAR: magnetic anomaly



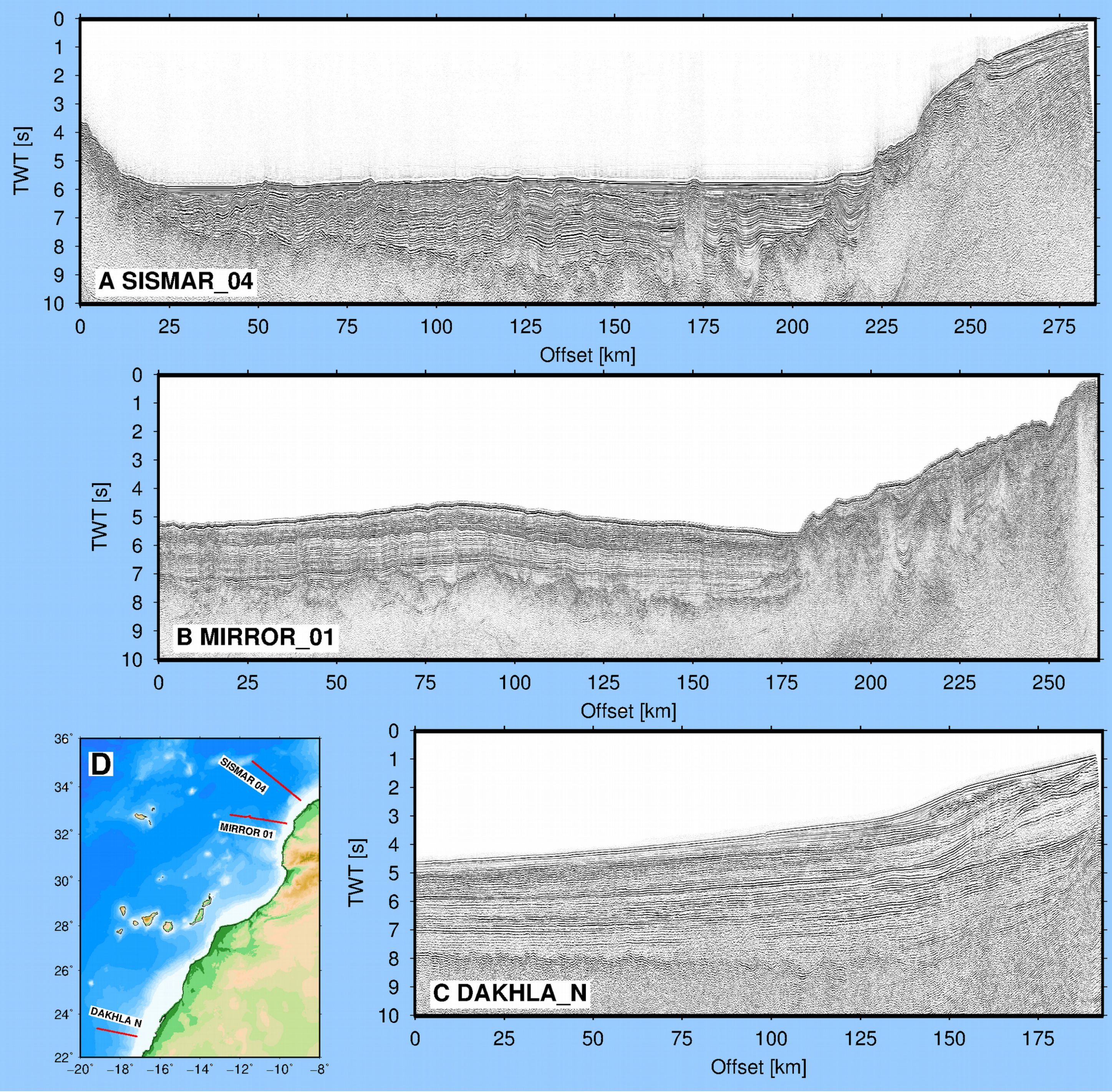
SISMAR Sud: Wide-angle seismic profiles



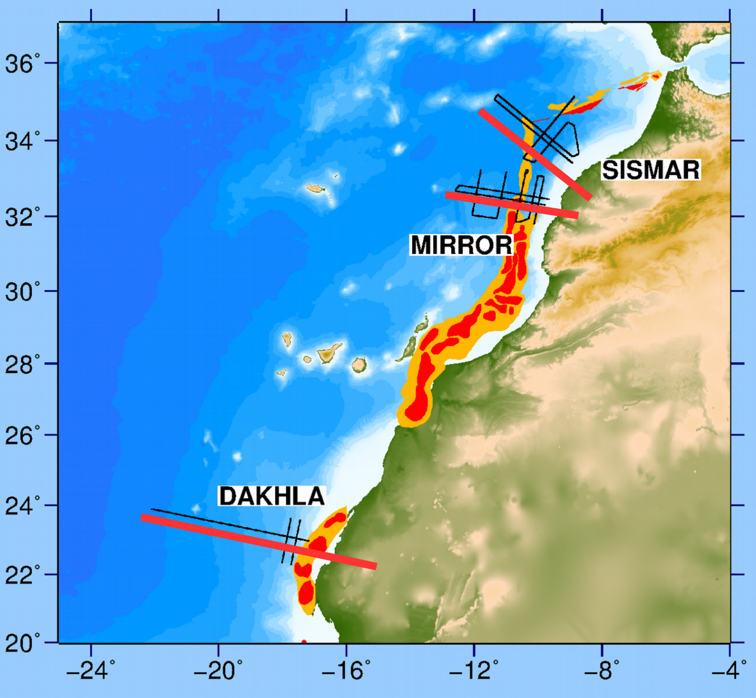
Oceanic | OCT | Thinned cont. | Continental



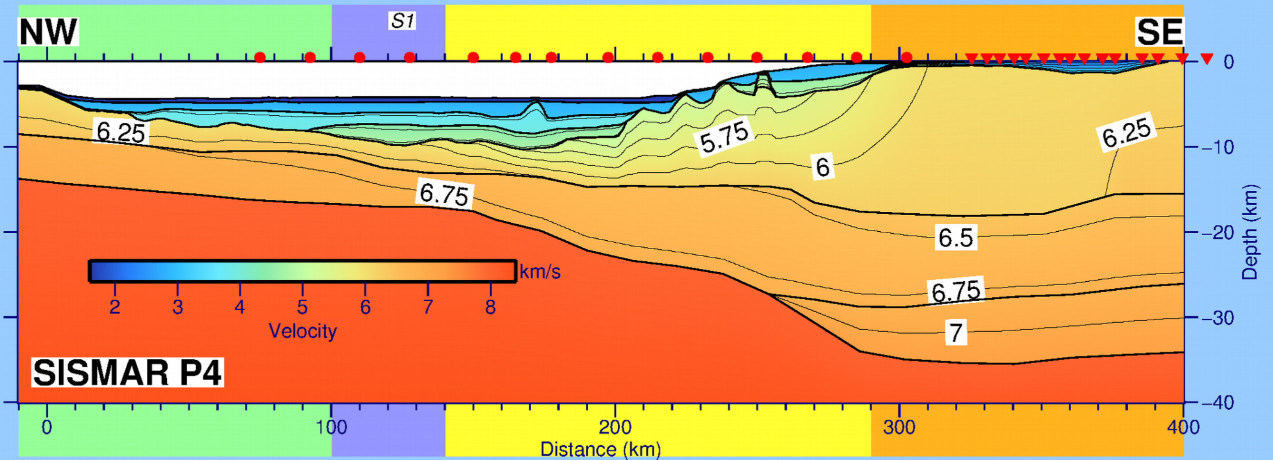
Dakhla, Mirror and Sismar MCS profiles



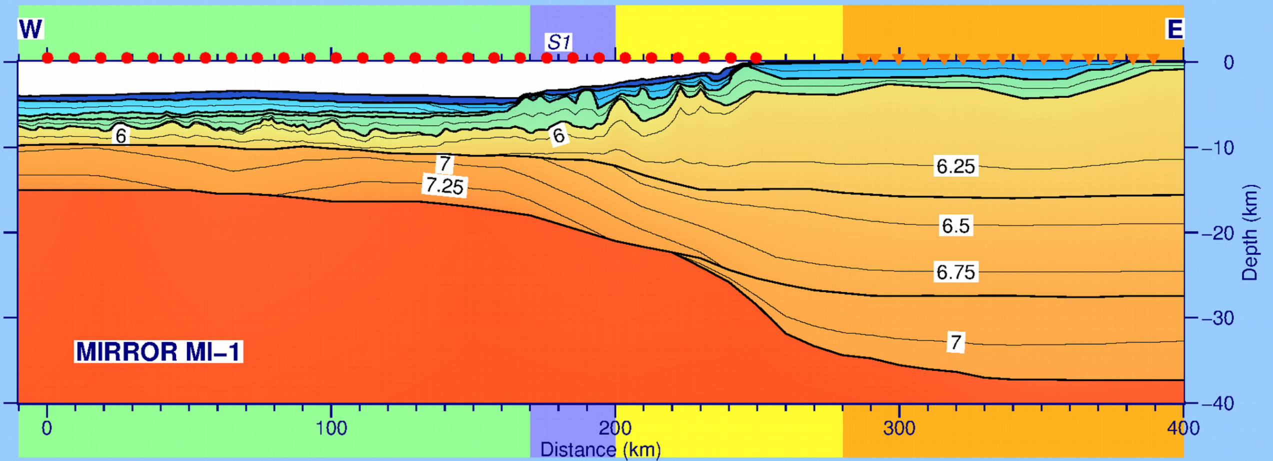
Comparison



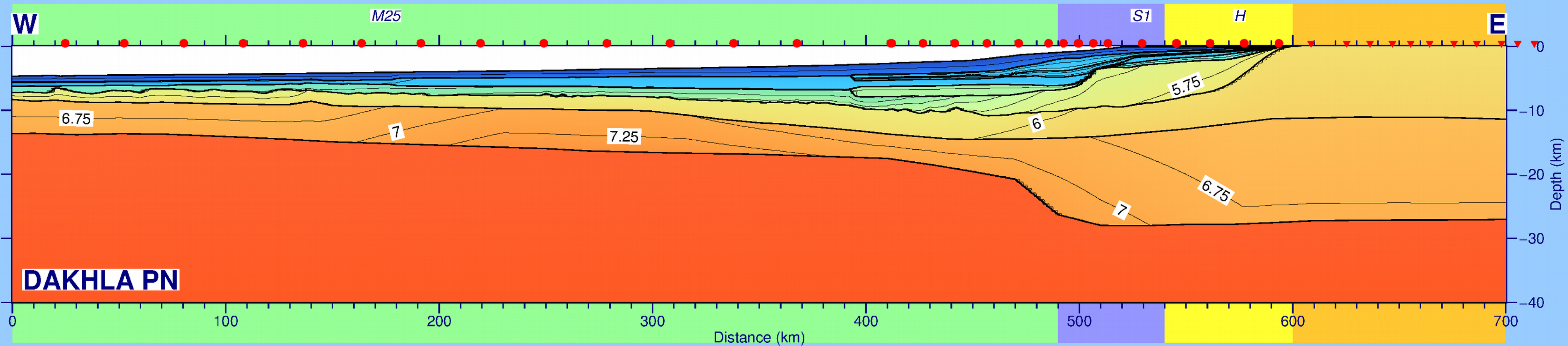
SISMAR
MIRROR
DAKHLA



NW
SE
S1
SISMAR P4
km/s
Velocity
Distance (km)
Depth (km)

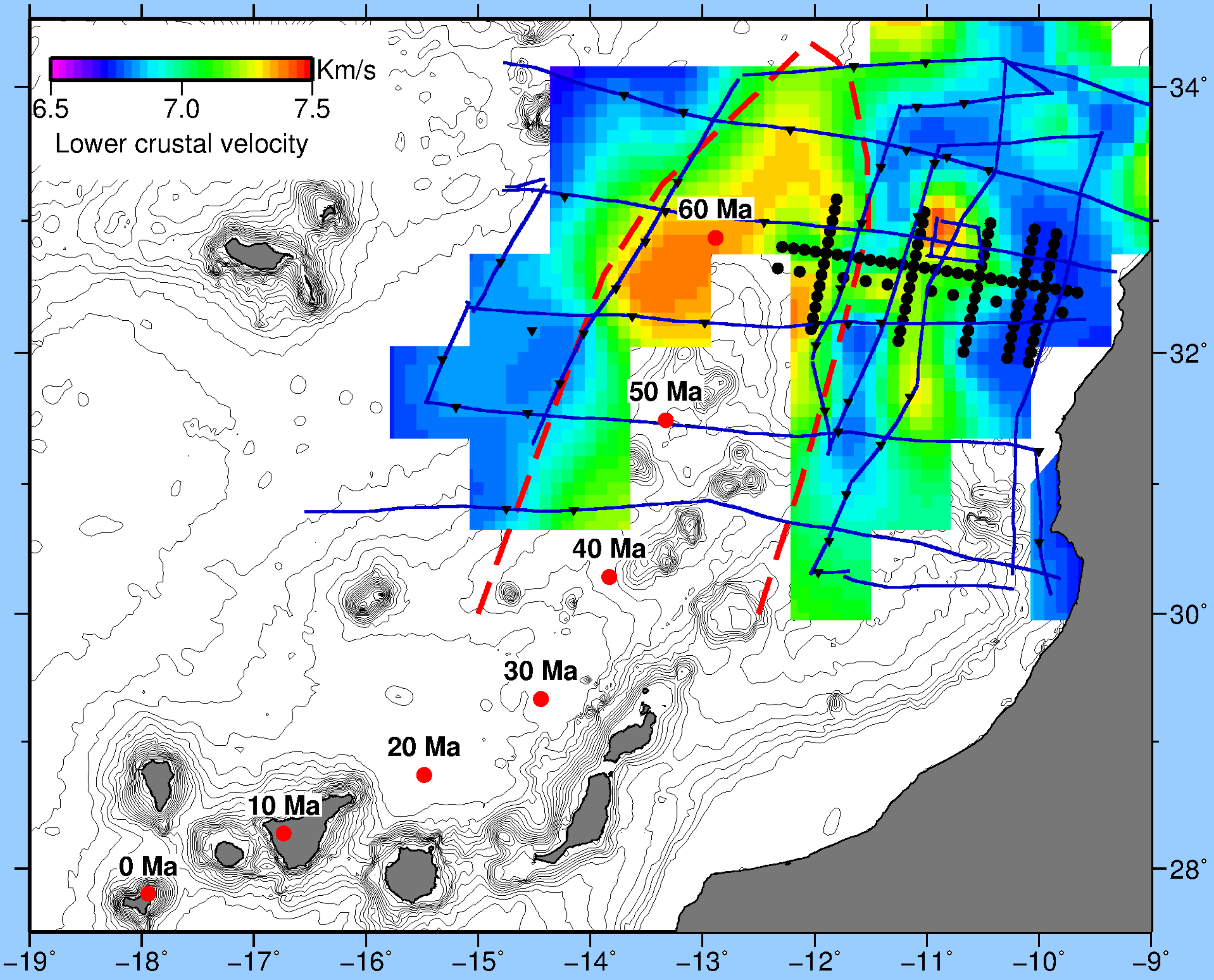


W
E
S1
MIRROR MI–1
Distance (km)
Depth (km)



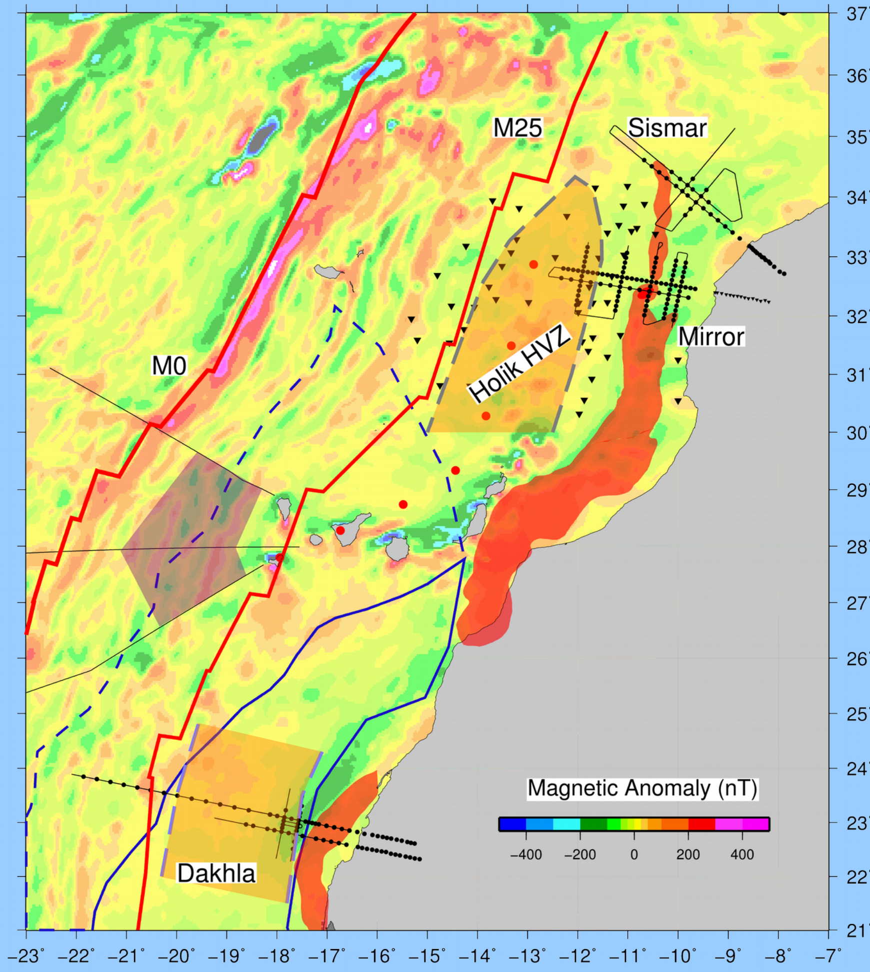
W
E
M25
S1
H
DAKHLA PN
Distance (km)
Depth (km)

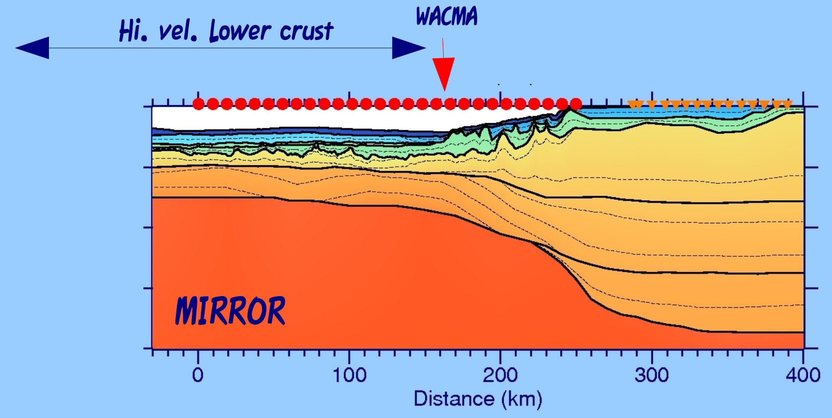
Lower crustal velocity

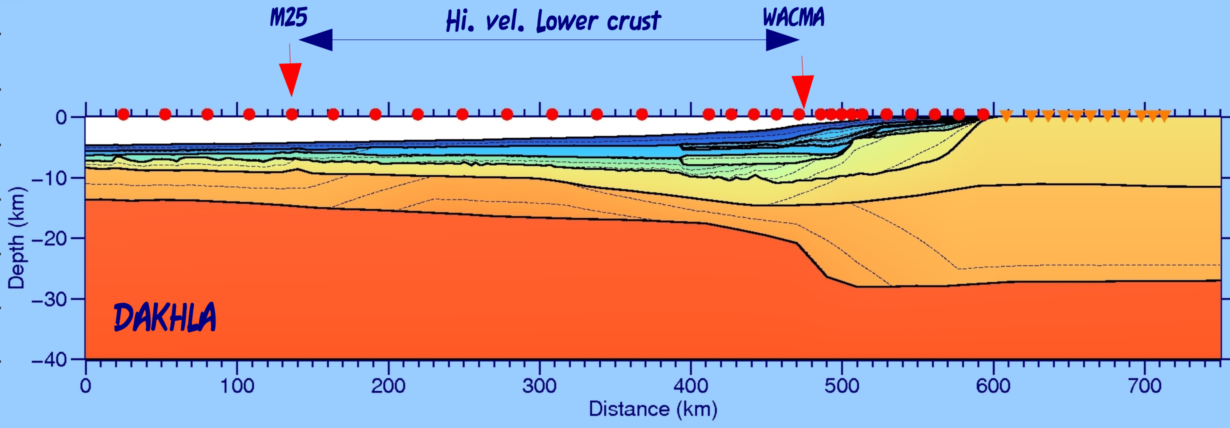


After Holik, 1991

Magnetic anomalies



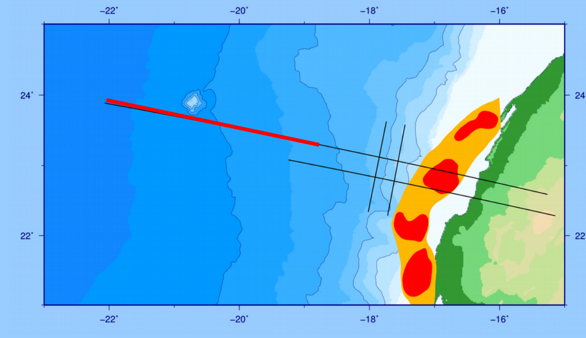


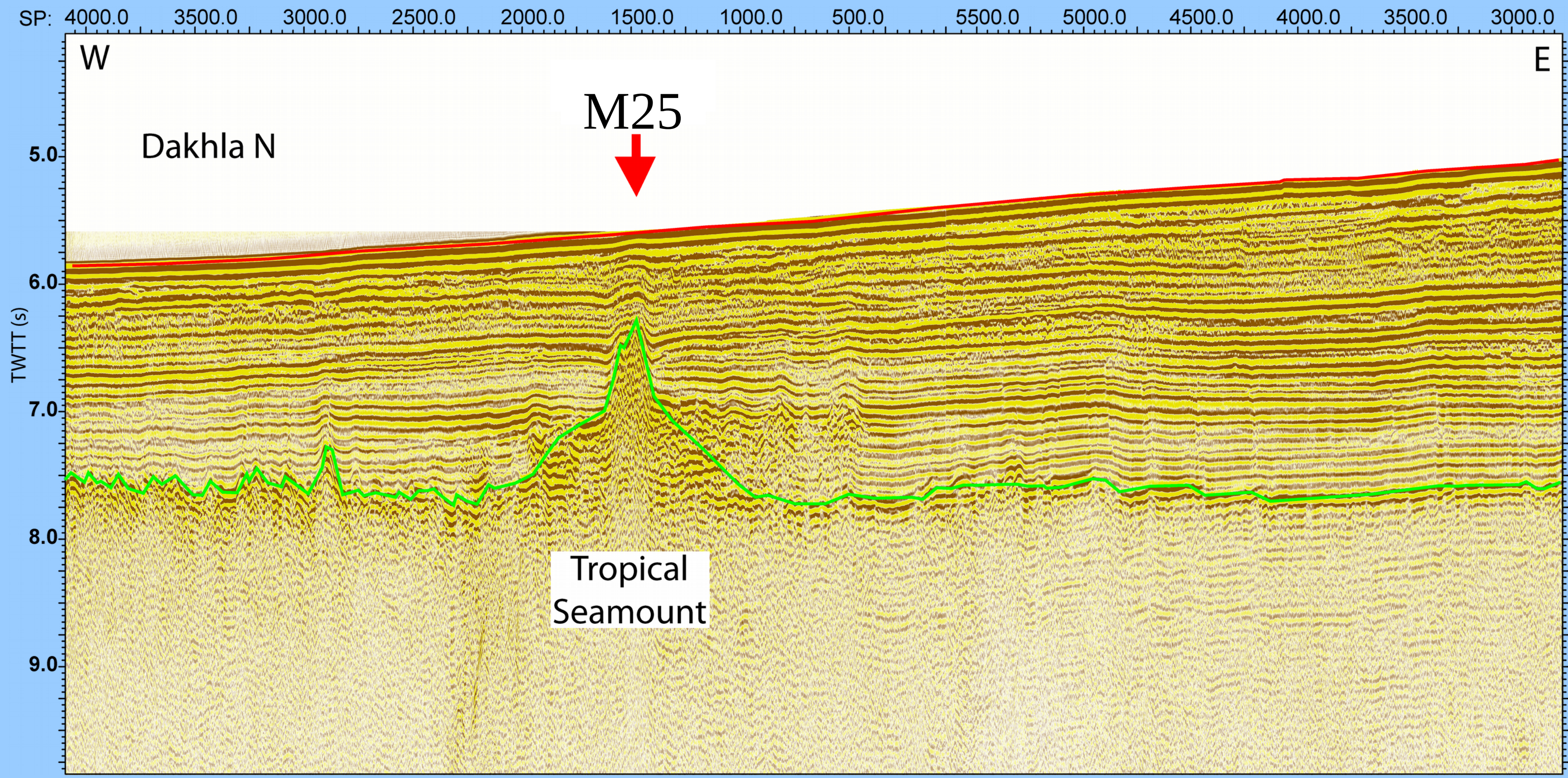


Verhoef et al., 1986

The southern Morrocan margin

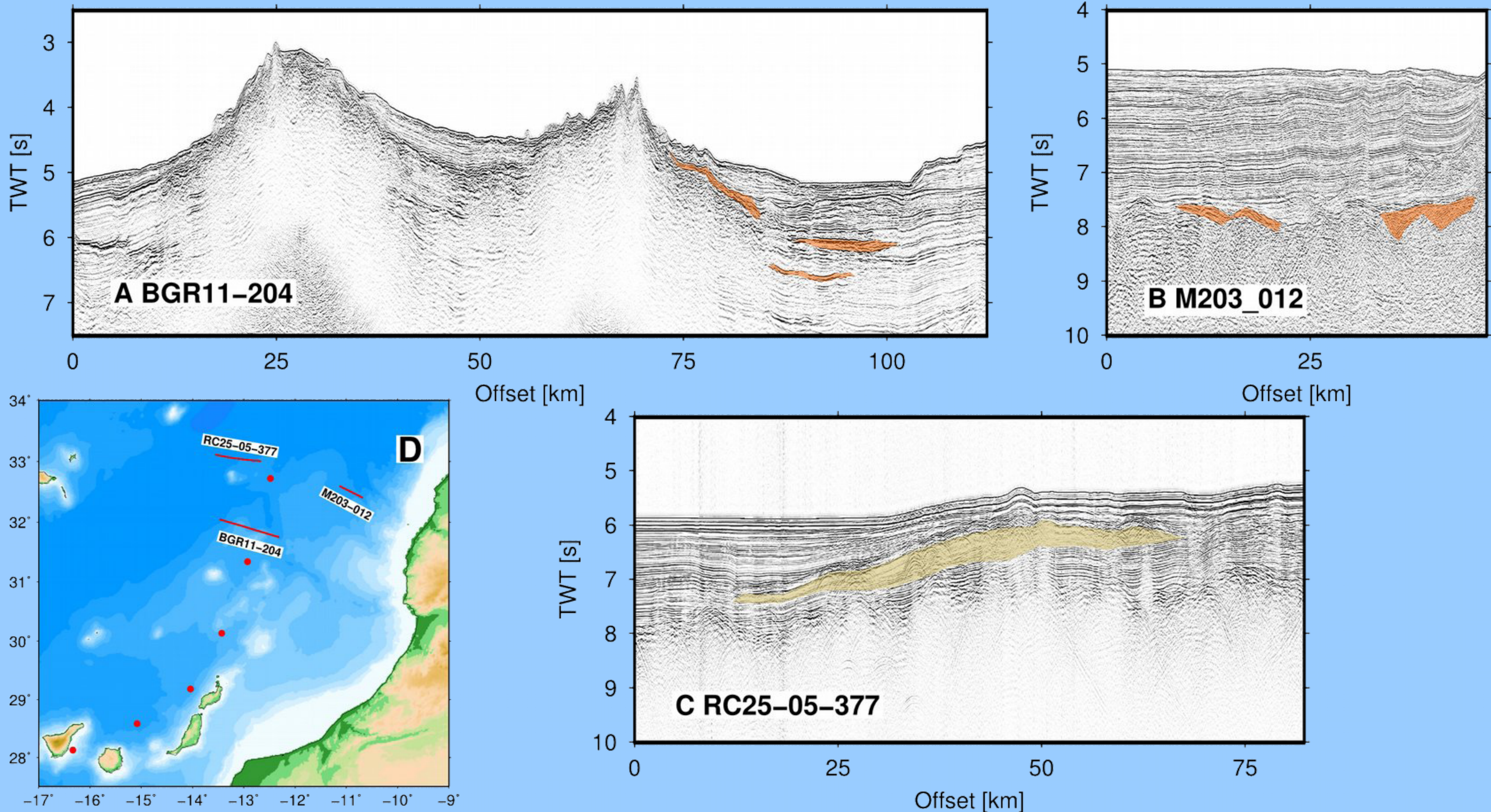
Seabed Morphology of the offshore Dakhla (off Western Sahara)



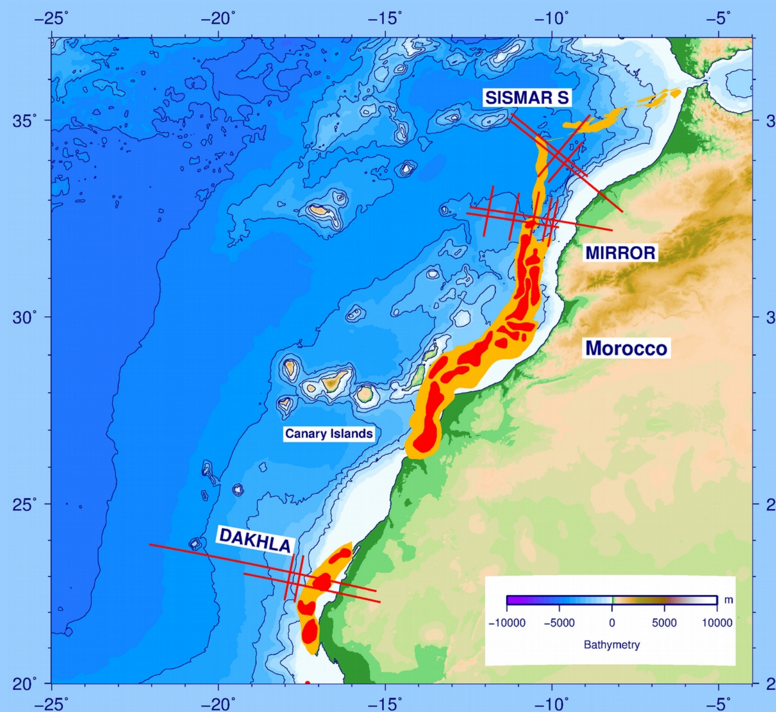


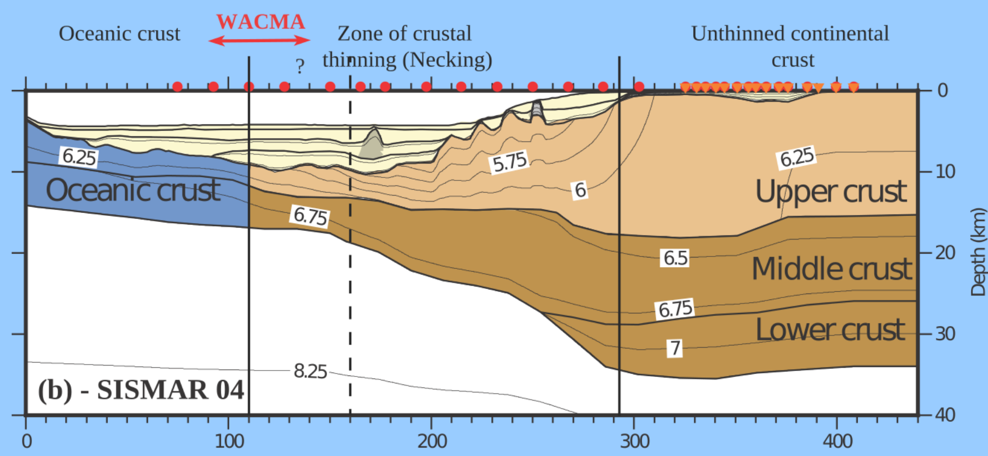
Volcanism along the margin

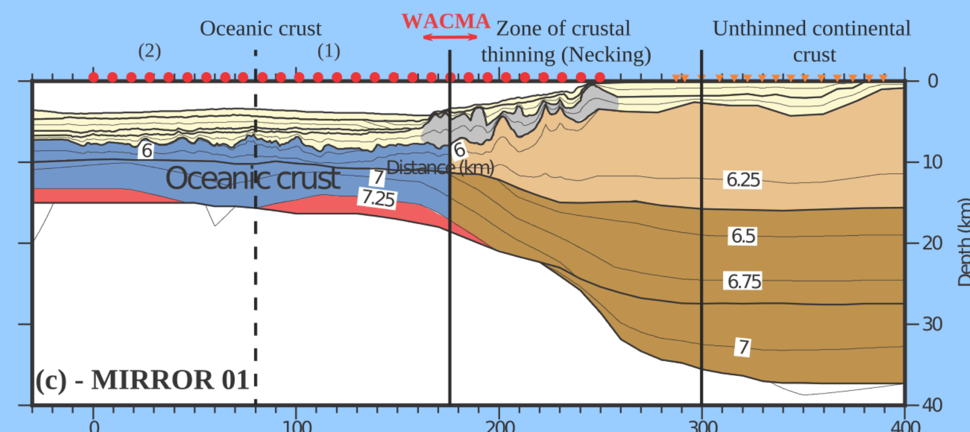
- Small seamounts and dykes in the southern part of the study region
- Mostly related to the Canary Hotspot



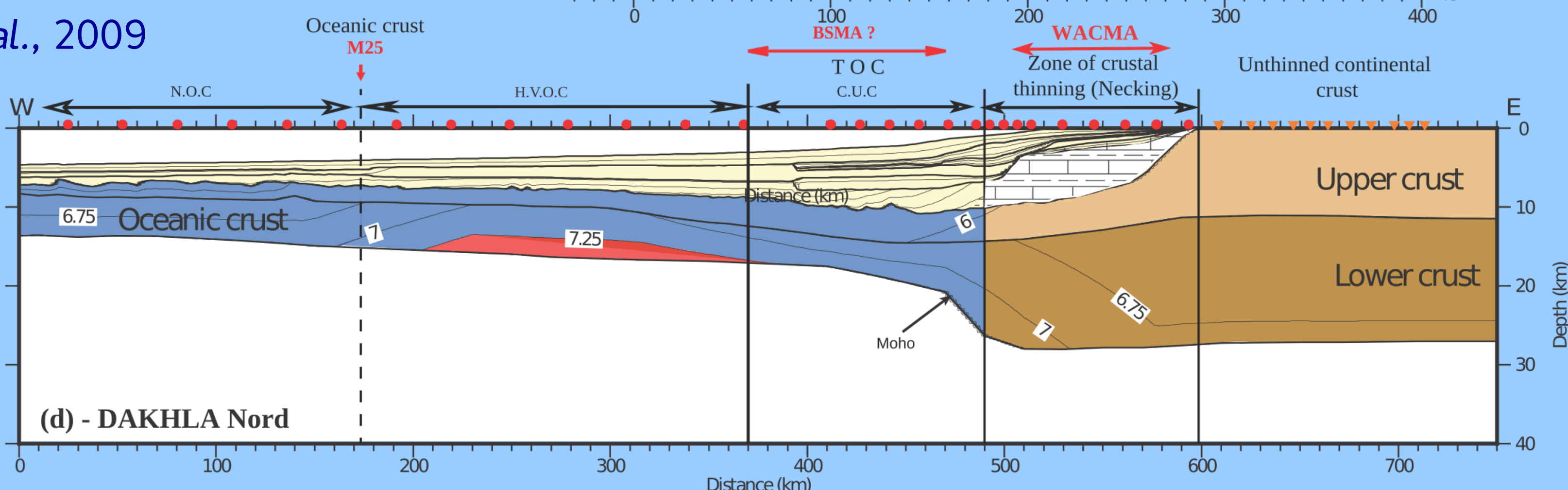
Morocco: SISMAR, MIRROR, DAKHLA



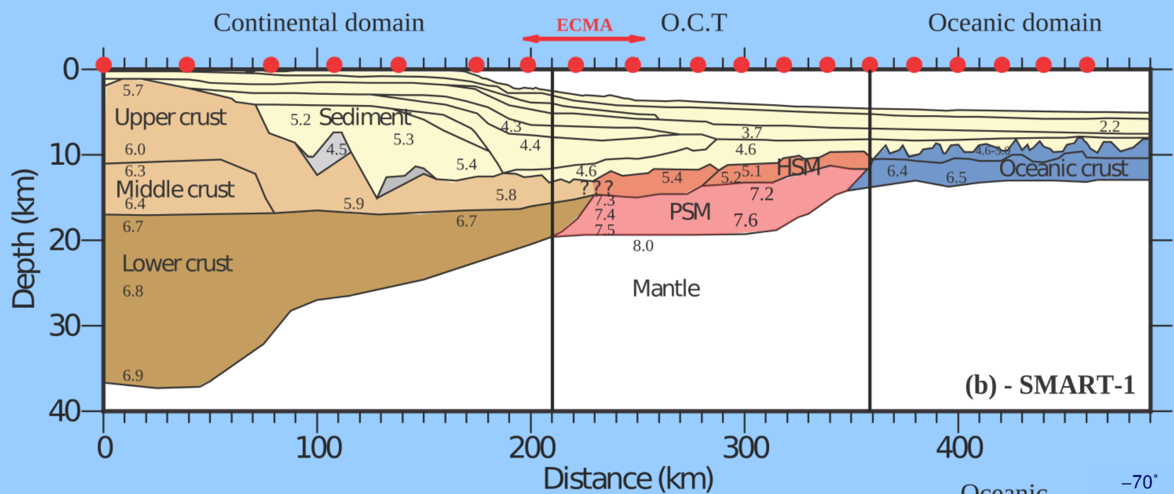


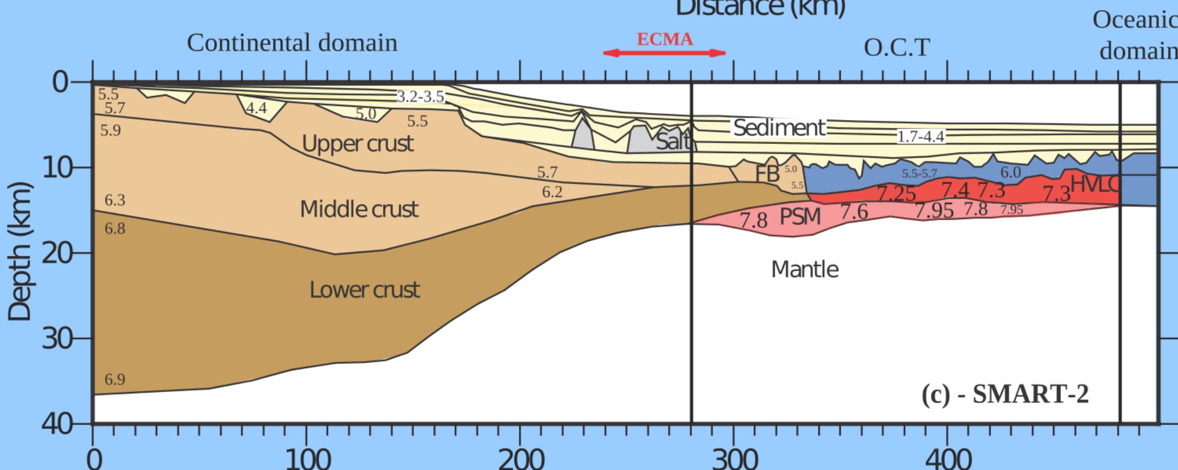


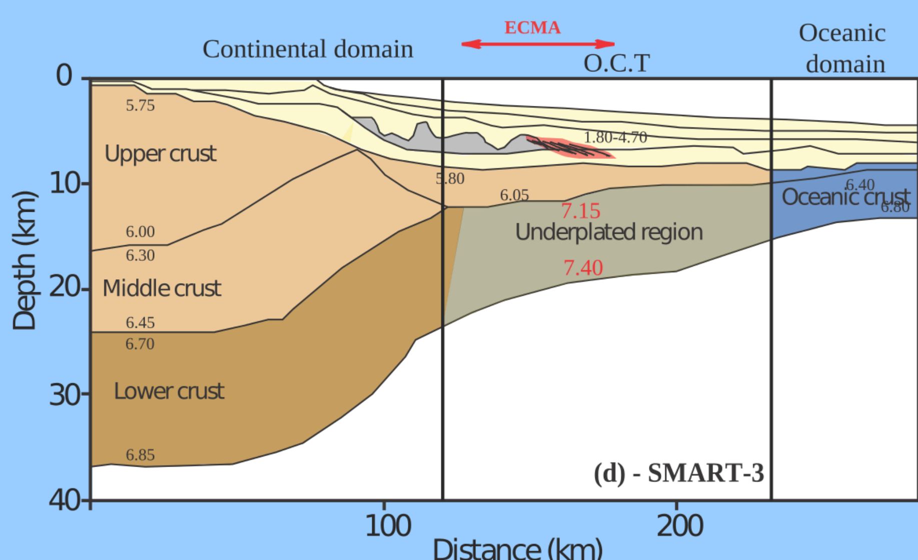
Contrucci *et al.*, 2004
Biari *et al.*, 2015
Klingelhoefer *et al.*, 2009

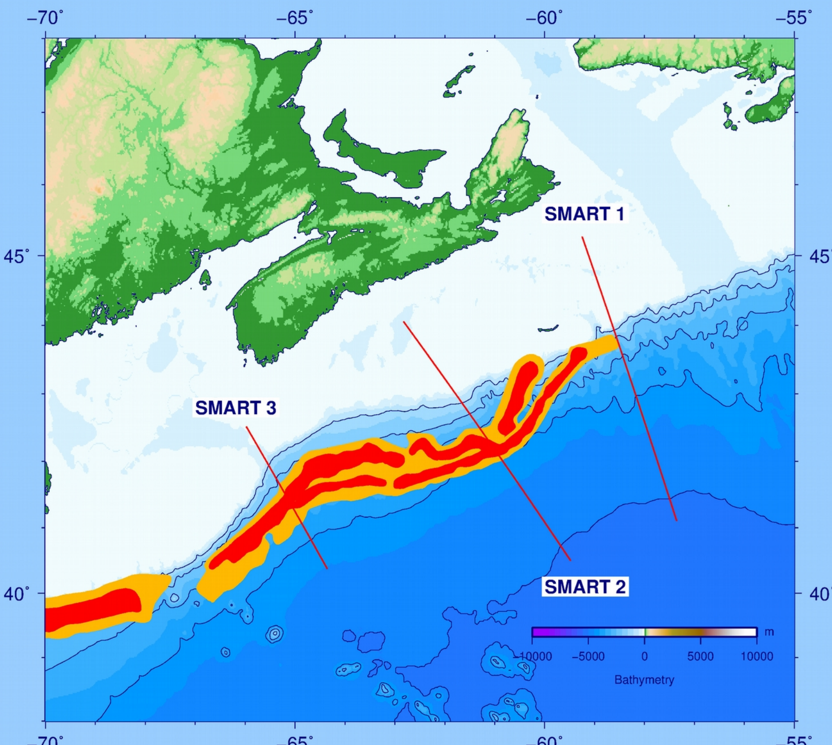


Canada: SMART 1-2-3



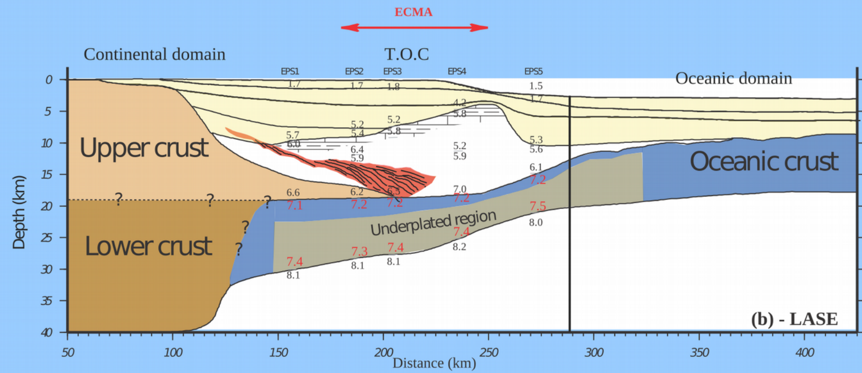


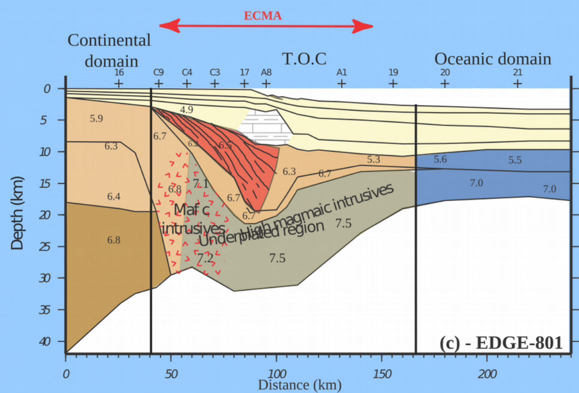


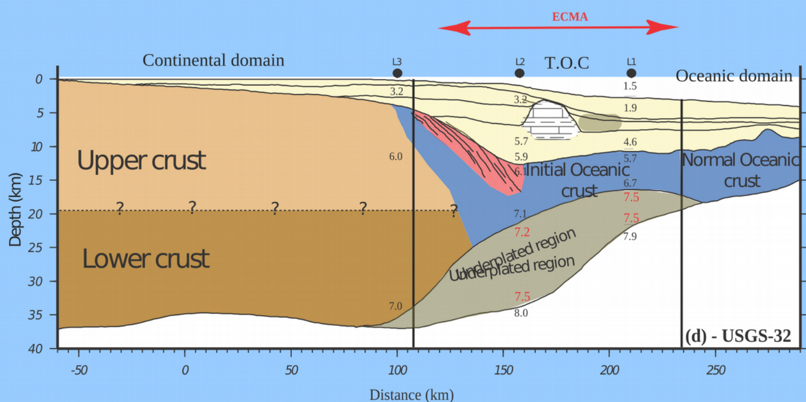


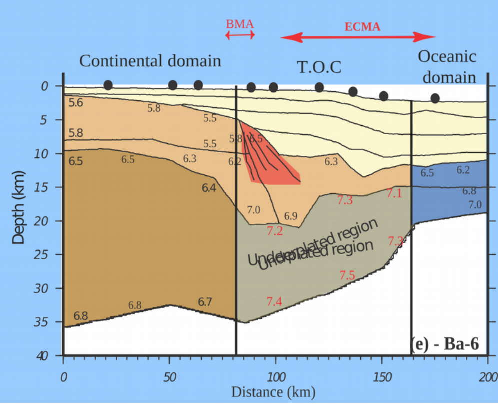
Funck *et al.*, 2004
Wu *et al.*, 2006
Dehler *et al.*, 2008

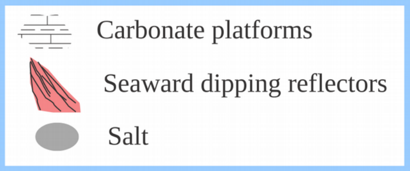
LASE, EDGE, USGS-32, BA-6

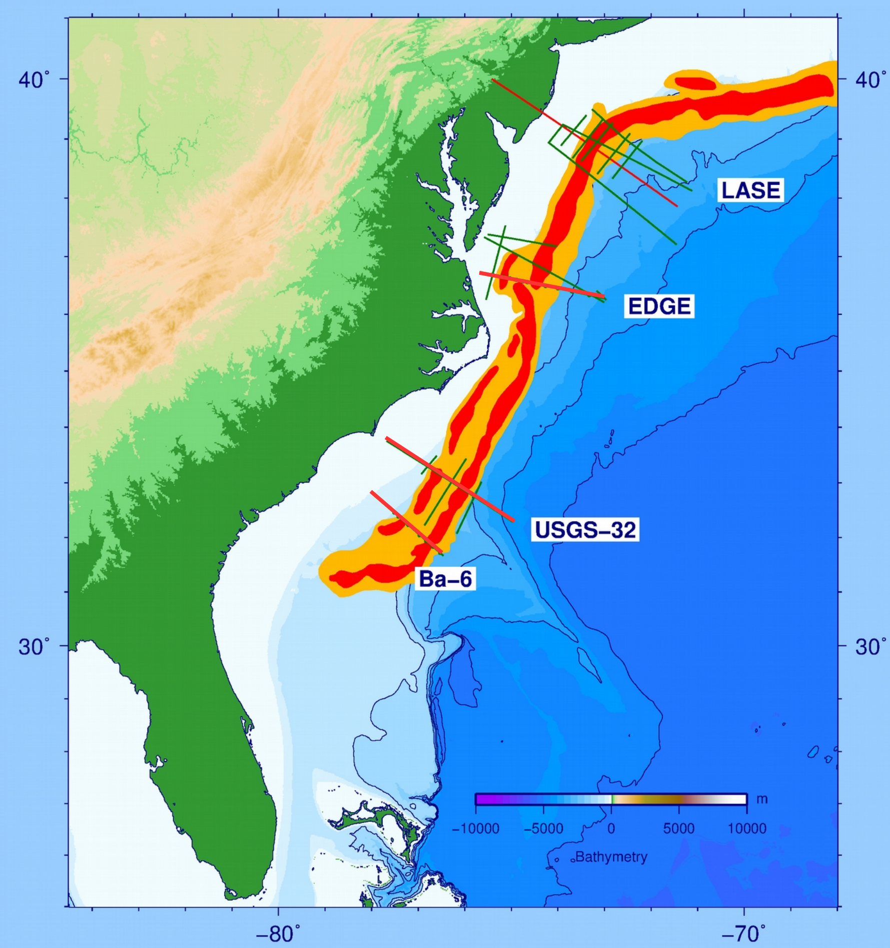






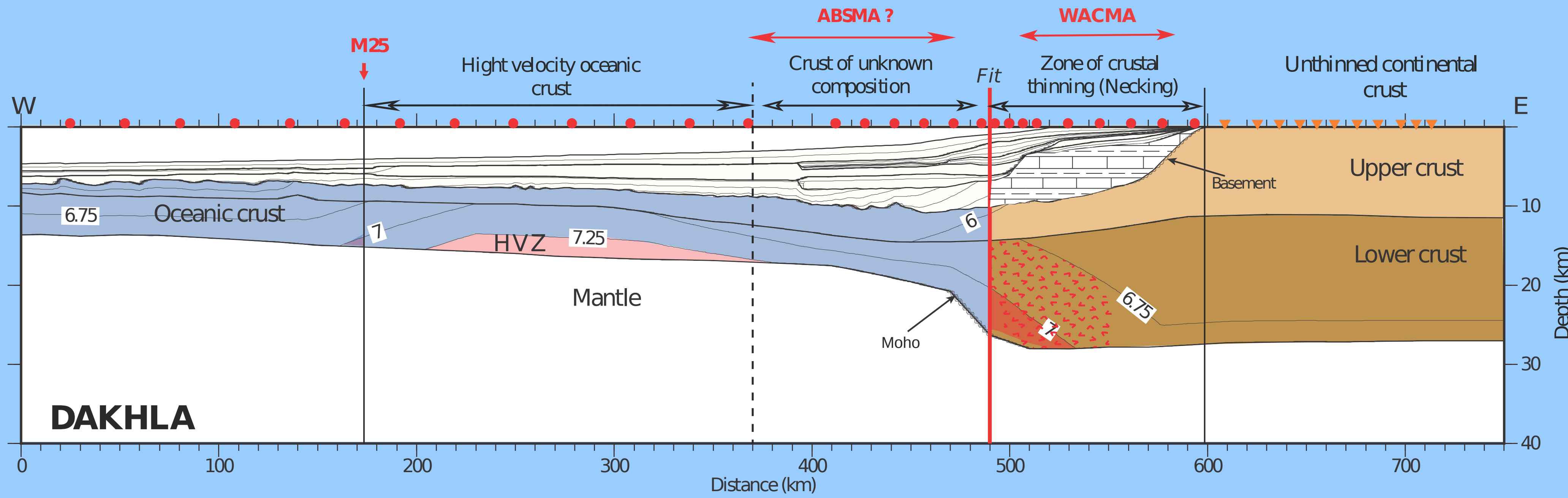






LASE Study Group, 1986
Holbrook *et al.*, 1994
Tréhu *et al.*, 1989
Austin *et al.*, 1990

Dakhla and Lase



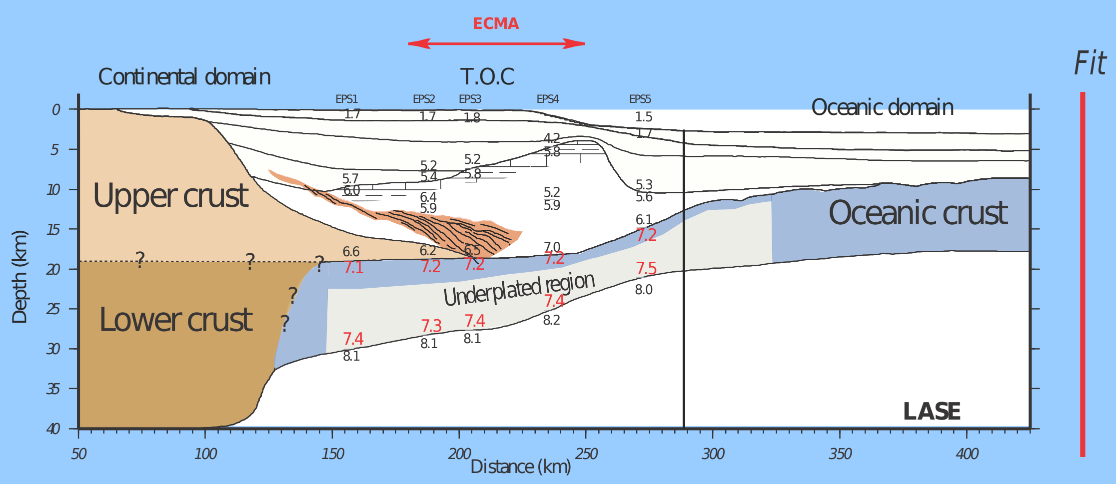
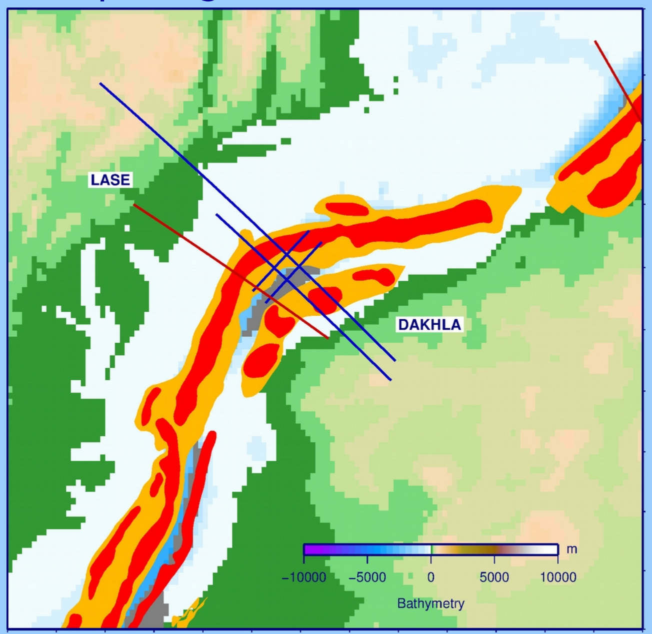


Plate kinematic reconstruction at opening



LASE Study Group, 1986
Klingelhoefer *et al.*, 2009

Dakhla and Lase

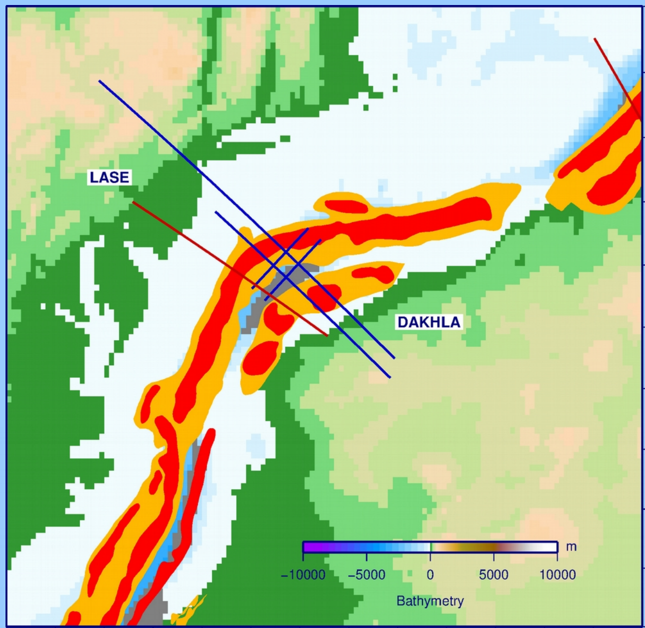
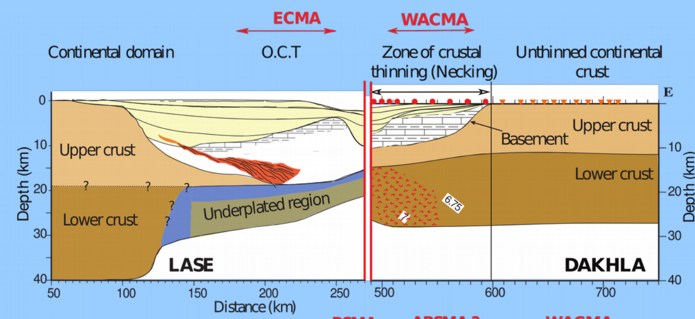
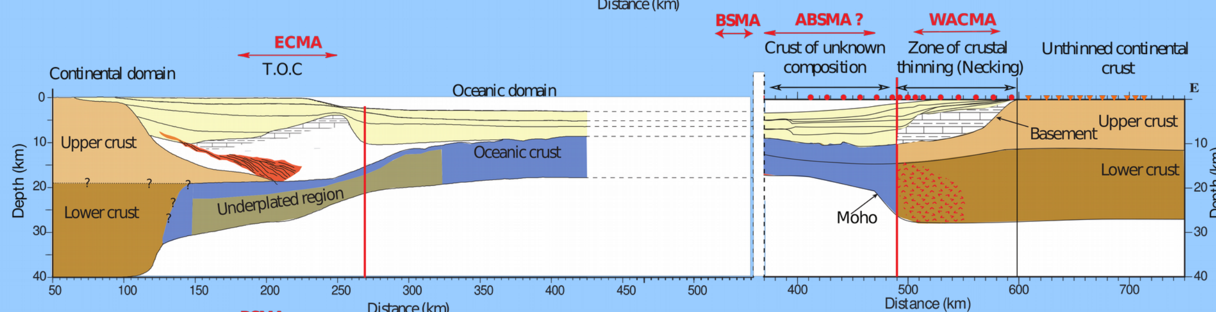
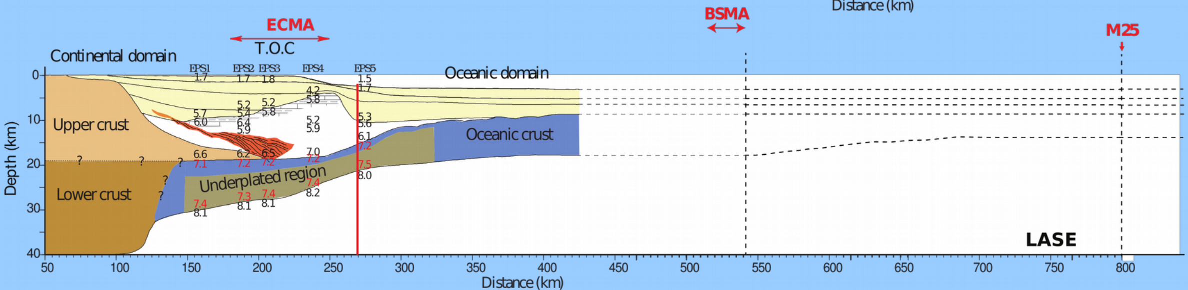
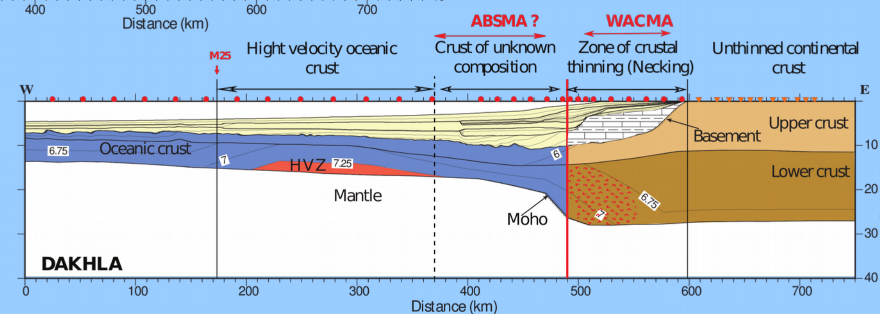


Plate kinematic reconstruction at opening





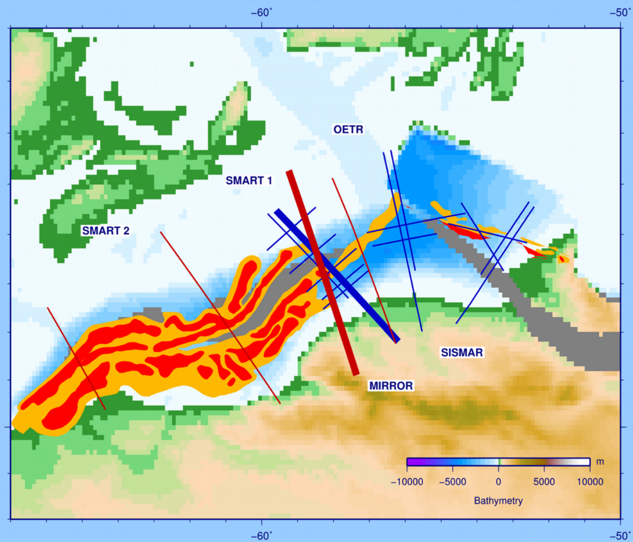


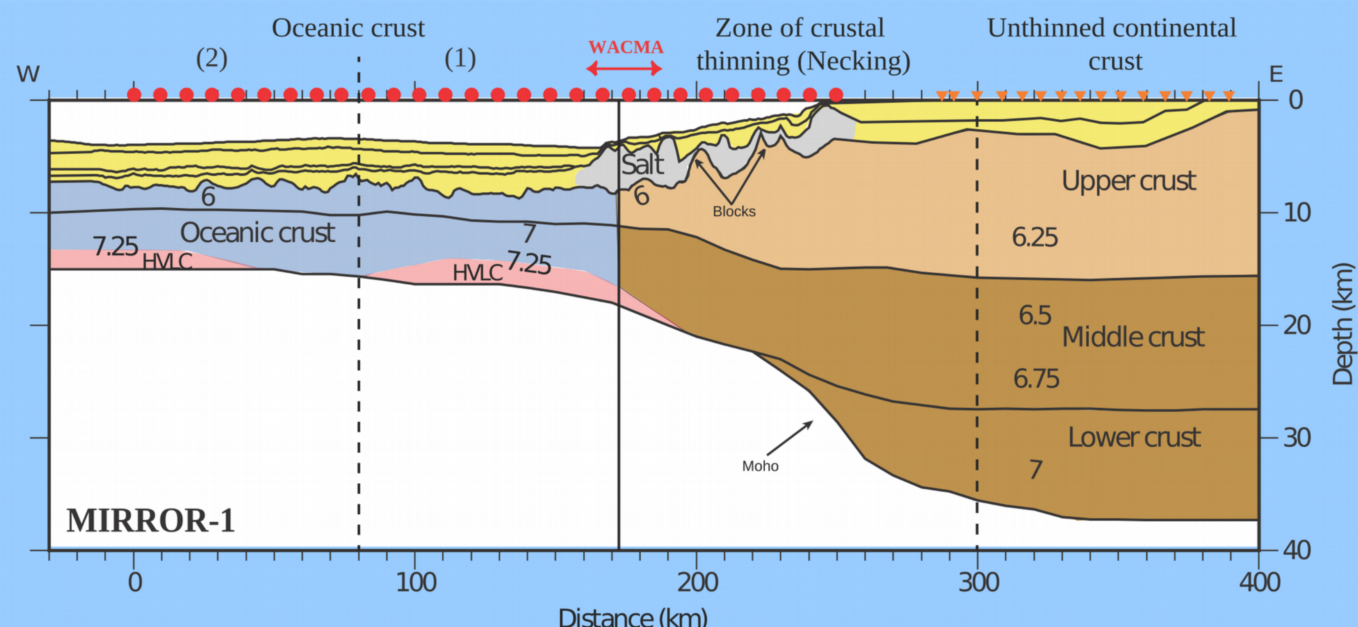


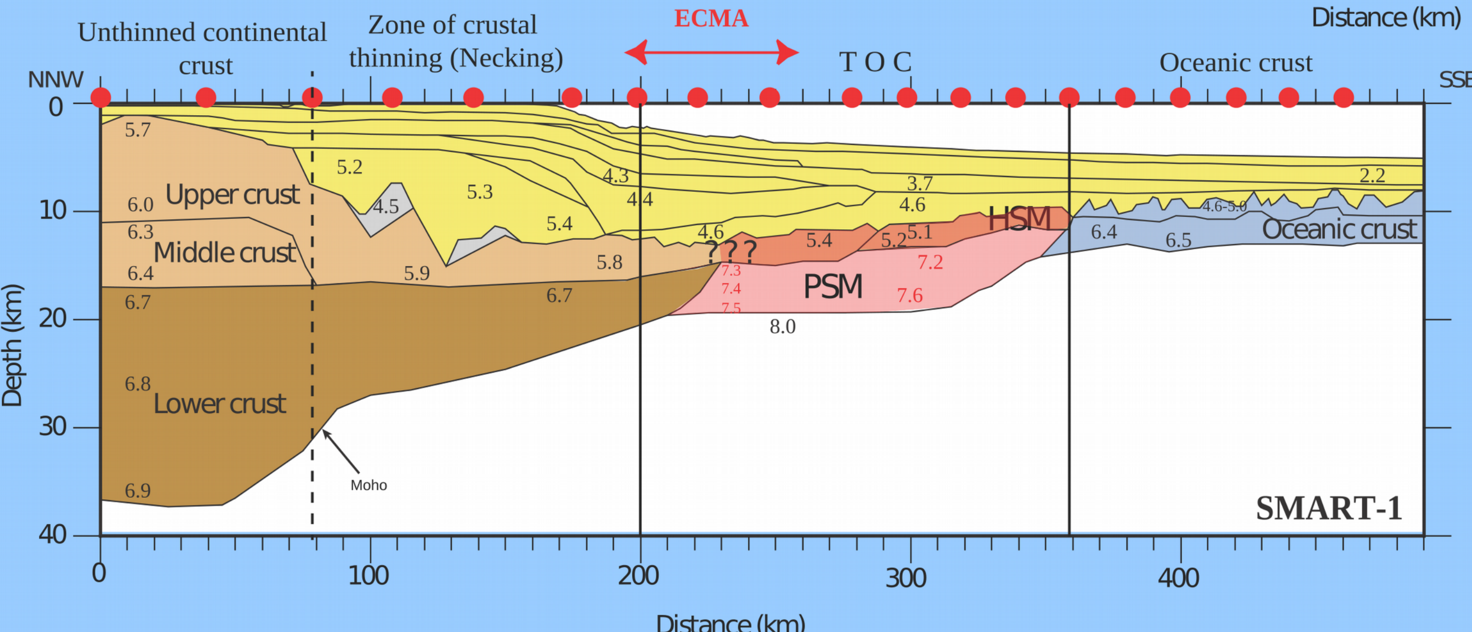
LASE Study Group, 1986
Klingelhoefer *et al.*, 2009

MIRROR-1 and SMART-1

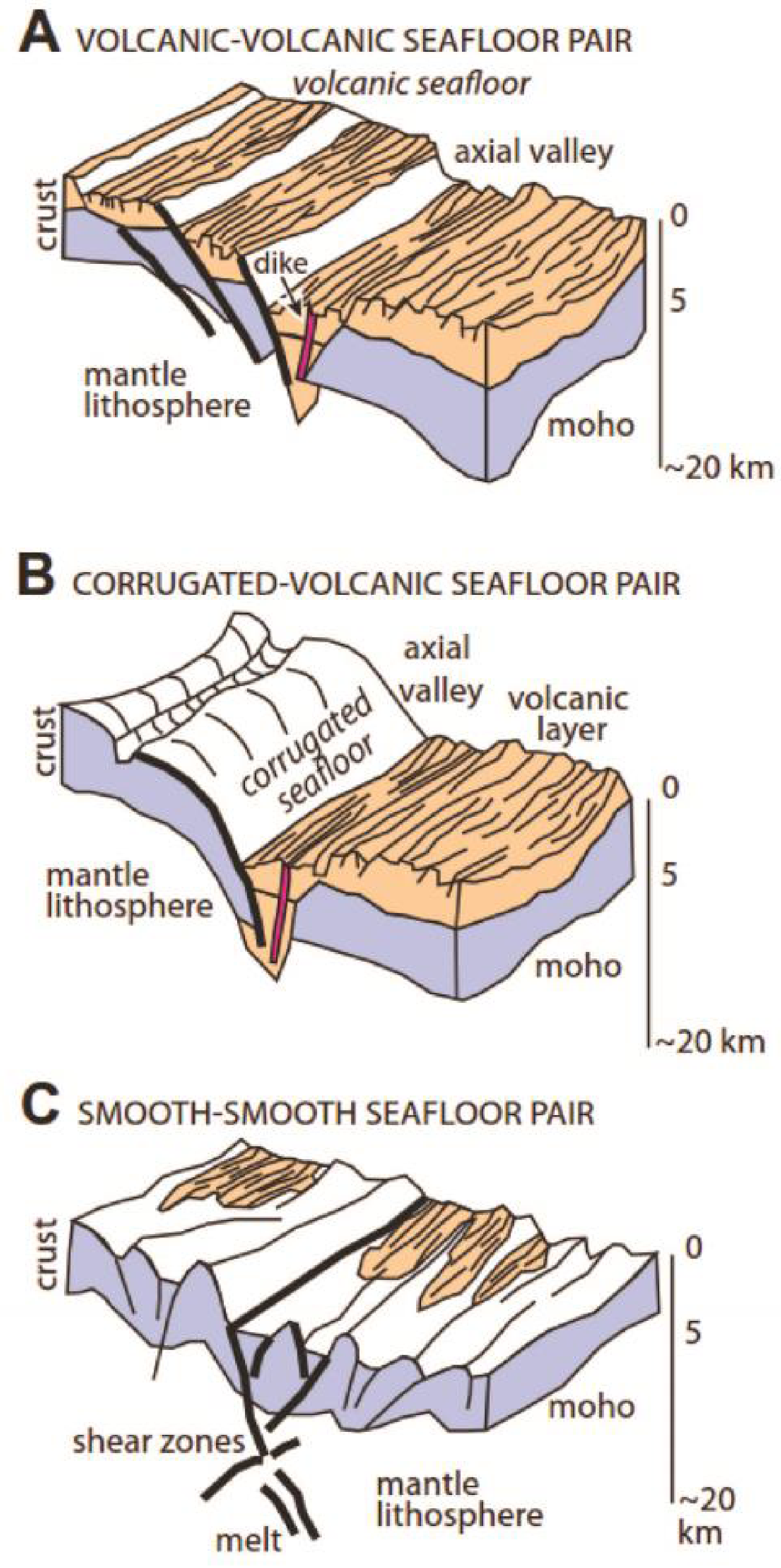
Plate kinematic reconstruction at opening (185 Ma)







Biari *et al.*, 2015
Funck *et al.*, 2004



Modes of seafloor generation at a melt-poor ultraslow-spreading ridge

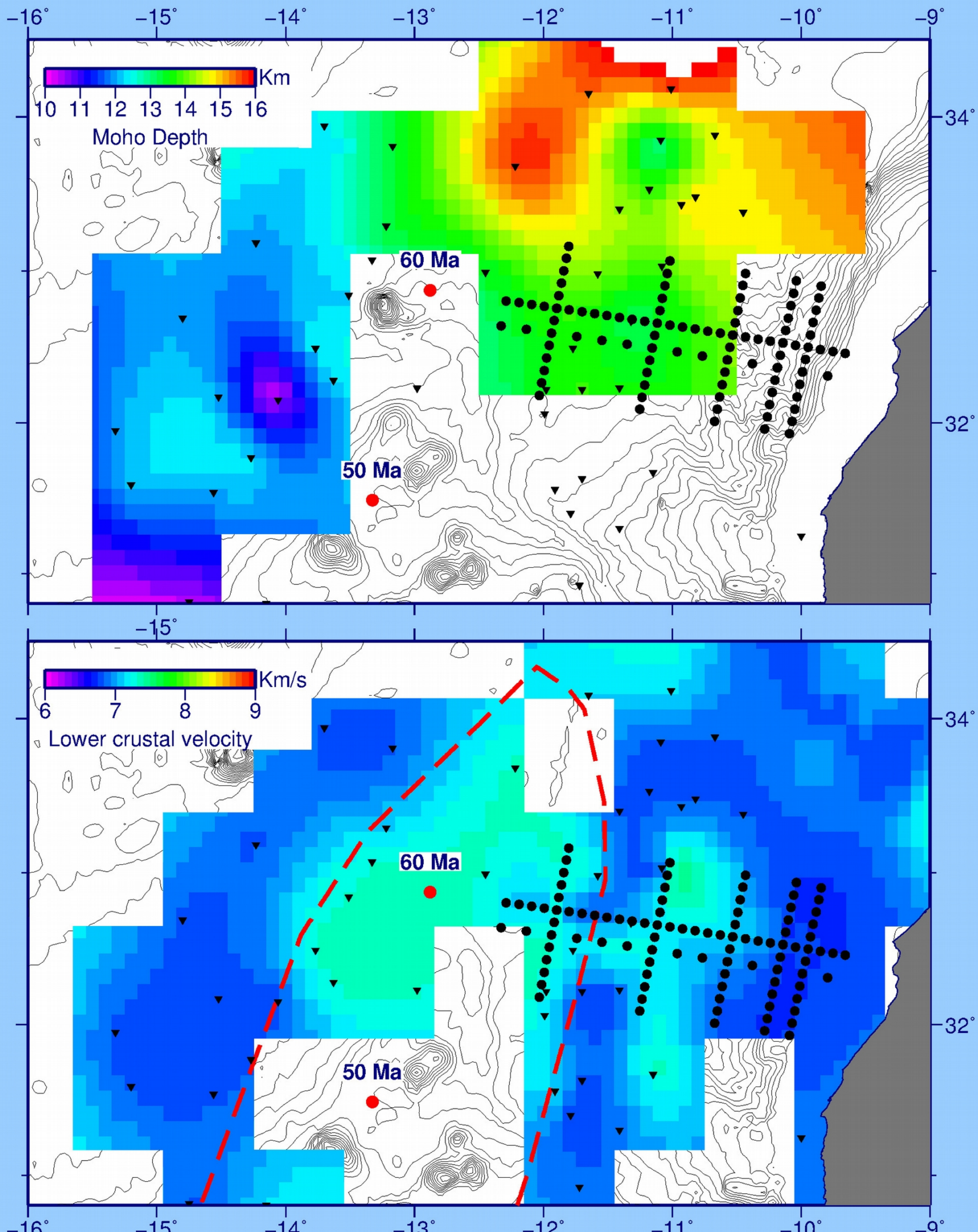
Mantle derived rocks can be continuously exhumed for at least 11 million years.

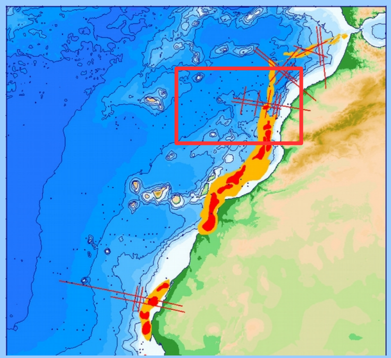
These mantle derived serpentinites form broad patches of smooth seafloor, several tens of kilometers across

The crust at Smart 1 and Mirror 1 profiles could have been generated by asymmetric spreading.

Cannat *et al.*, 2006

Moho depth and lower crustal velocity





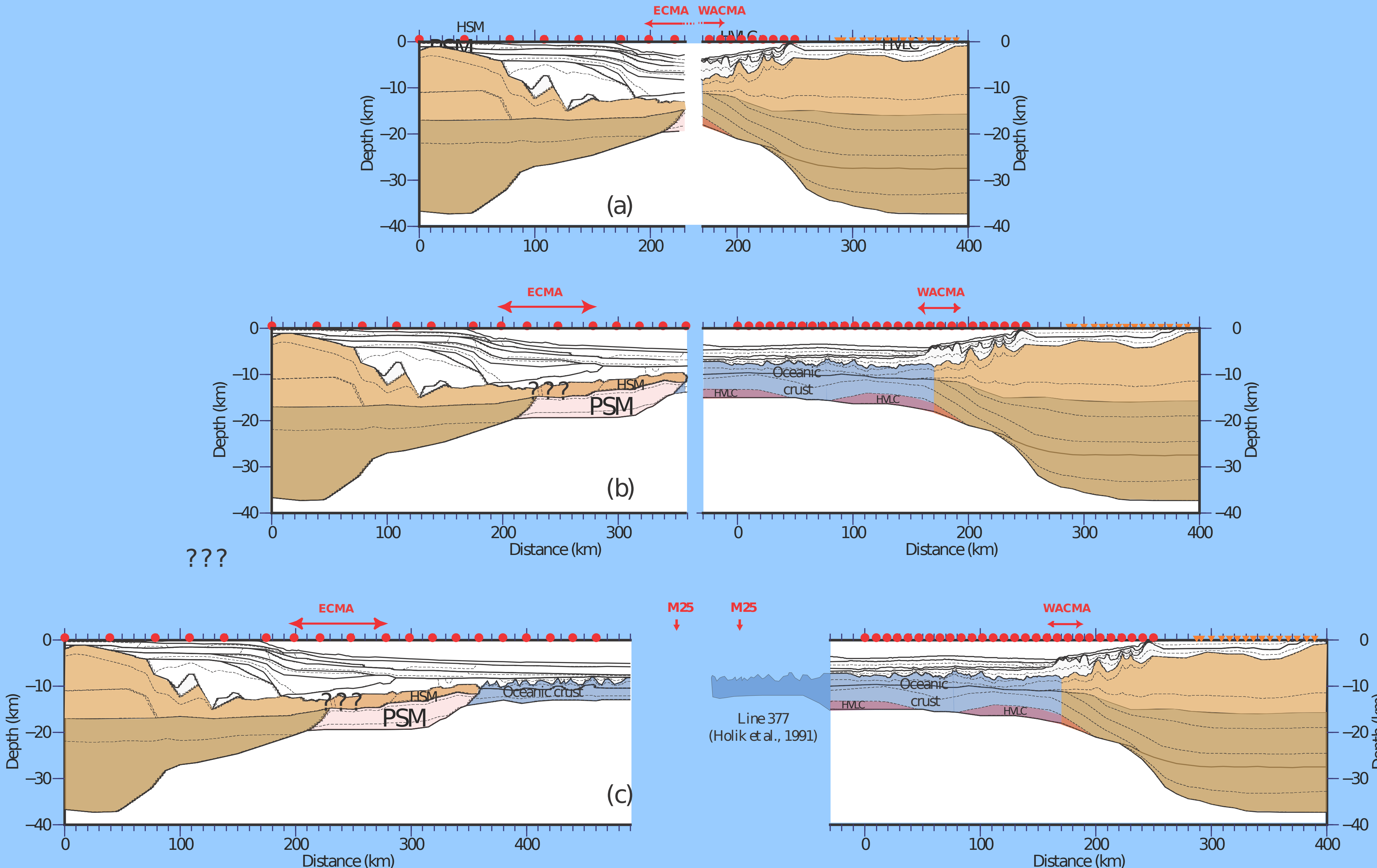
Crustal thickness is higher in the region of the passage of the Canary Hotspot

This region is located inside WACMA and the M25 magnetic anomalies

Seaward of M25 the crustal thickness decreases to 4-5 km.

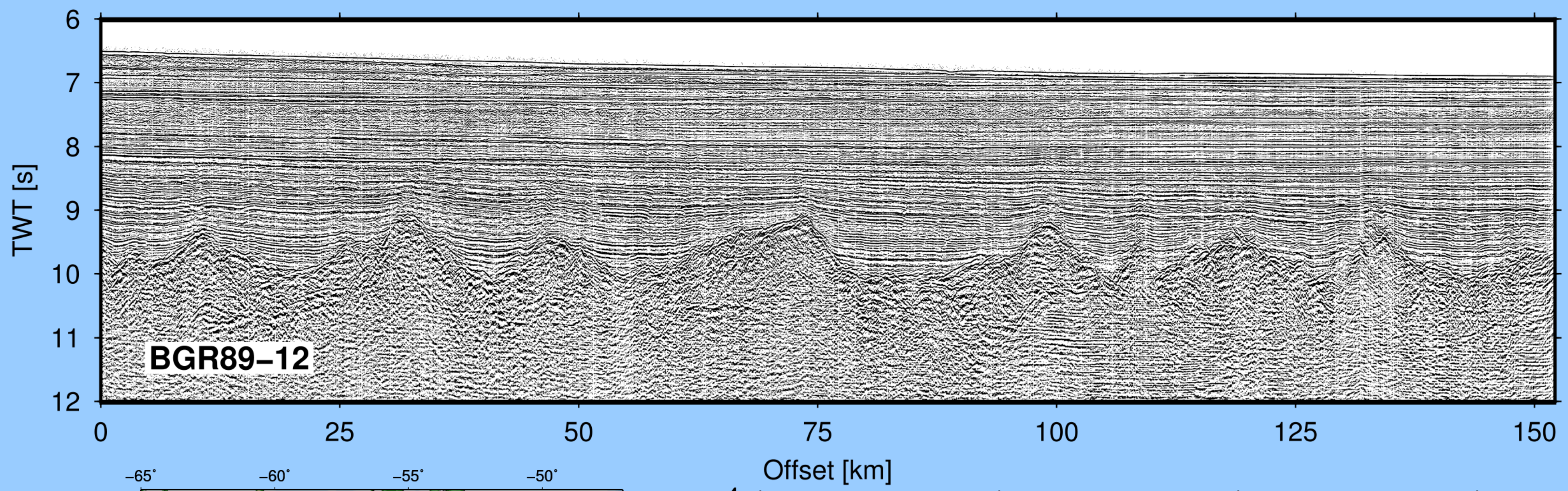
After Holik *et al.*, 1991

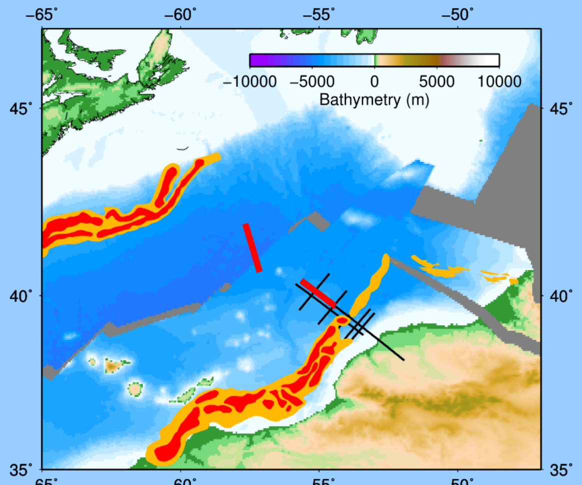
Opening of the Central Atlantic

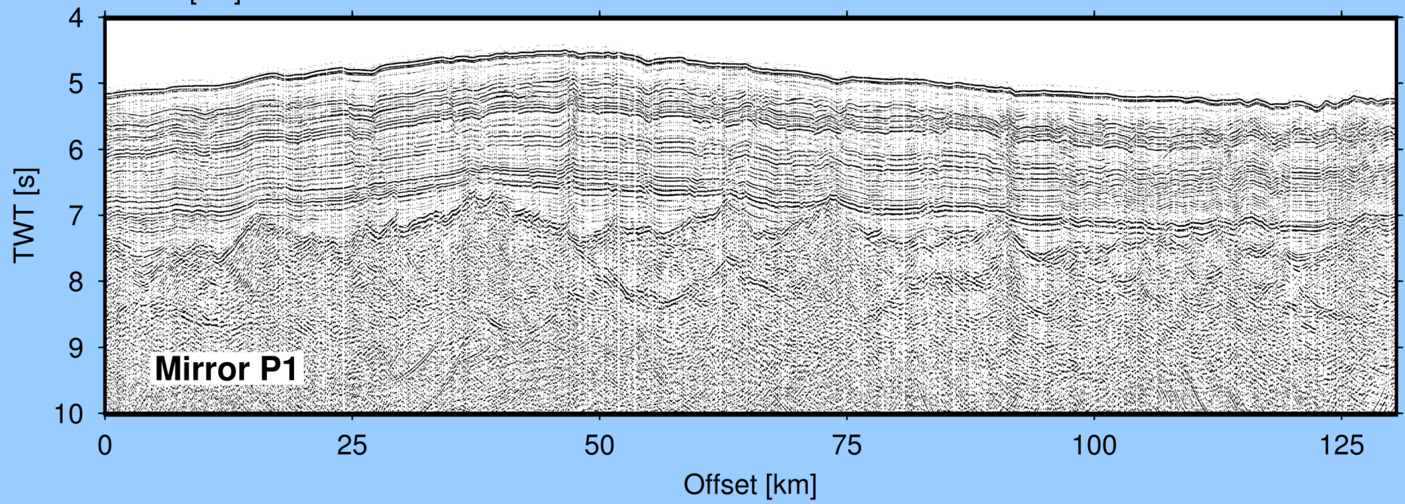


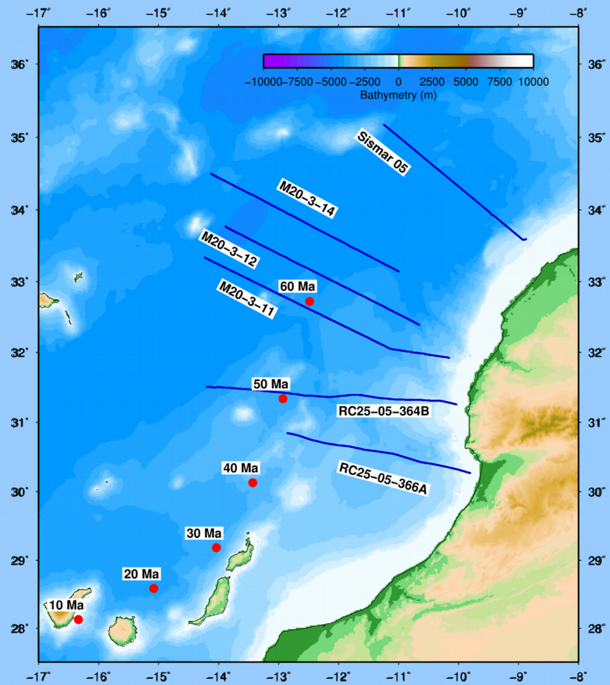
Biari *et al.*, submitted

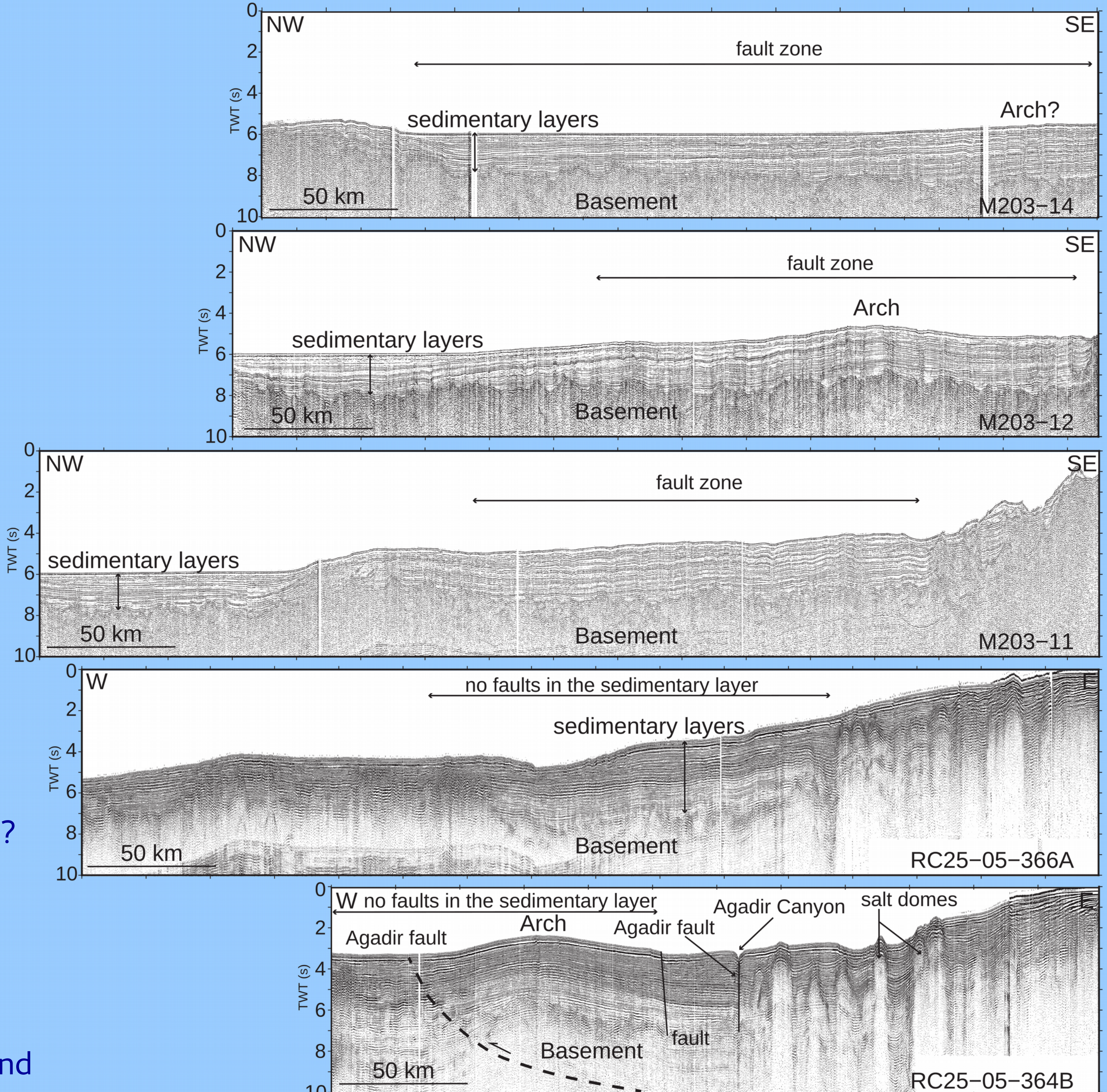
Sedimentary basins









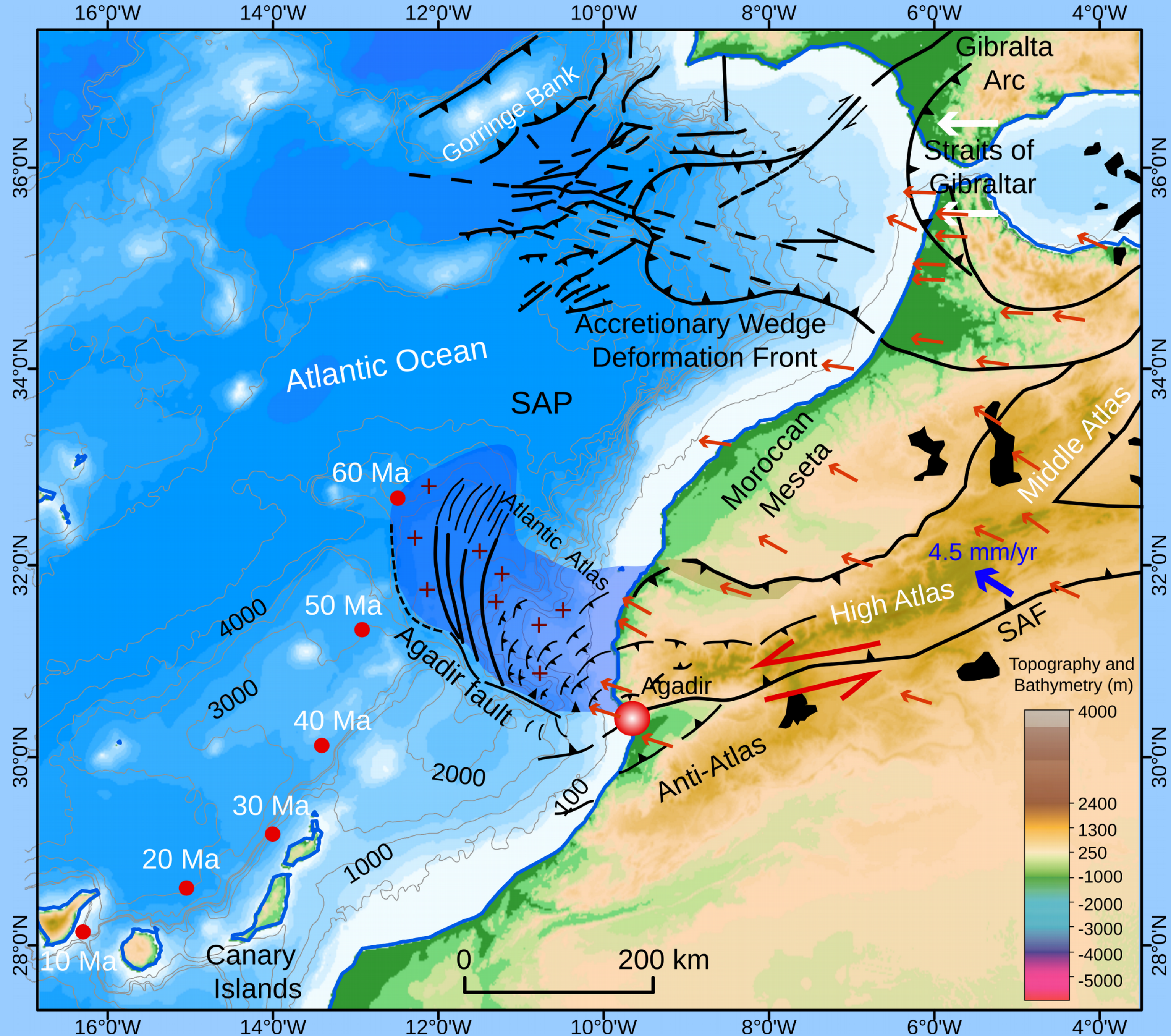


Passage of the Canary Hotspot ?
(Holik *et al.*, 1991)

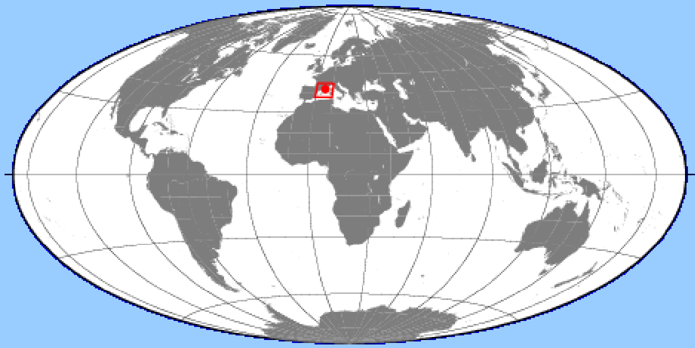
Sublithospheric flow ?
(Duggen *et al.*, 2009)

Compression between African and European plates ?

Atlantic Atlas



Benabdellouahed *et al.*, submitted



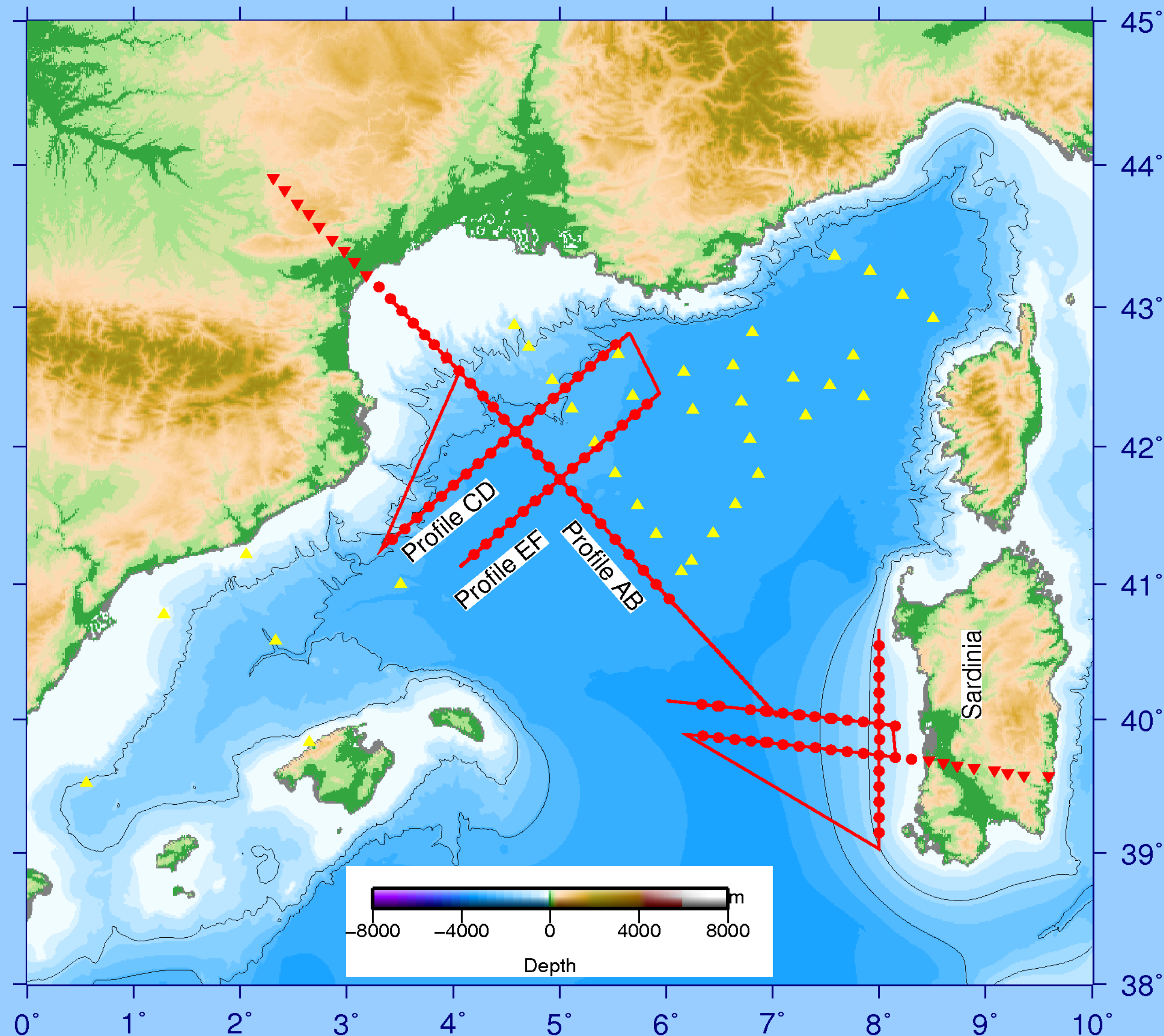
Sardinia: the Liguro-Provencal Basin

Young margin pair

Opening as back-arc basin in Oligocene

Second phase from rotation of the Corsica Sardinia Block.

-> good constraints on reconstruction



Reconstruction at opening

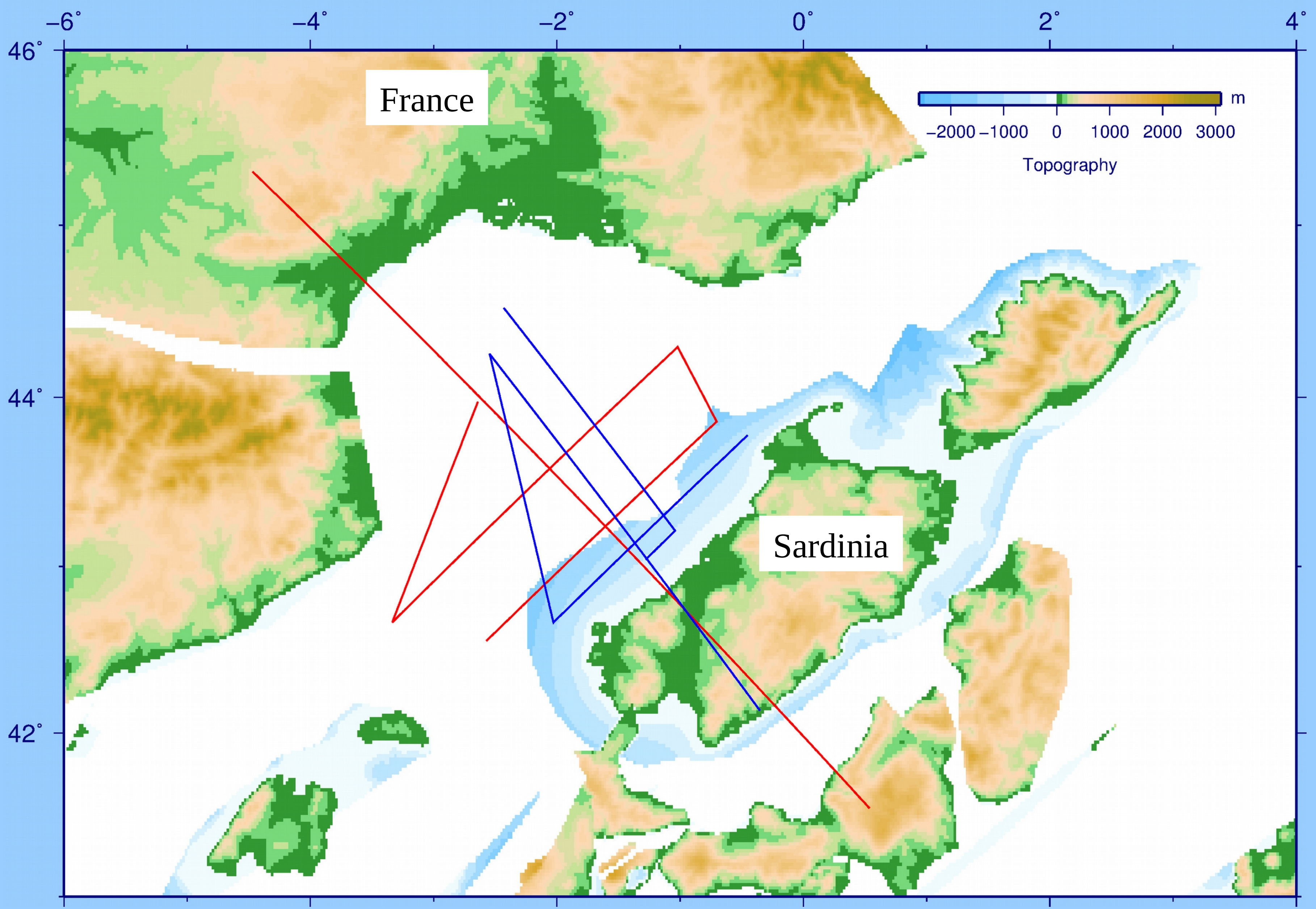
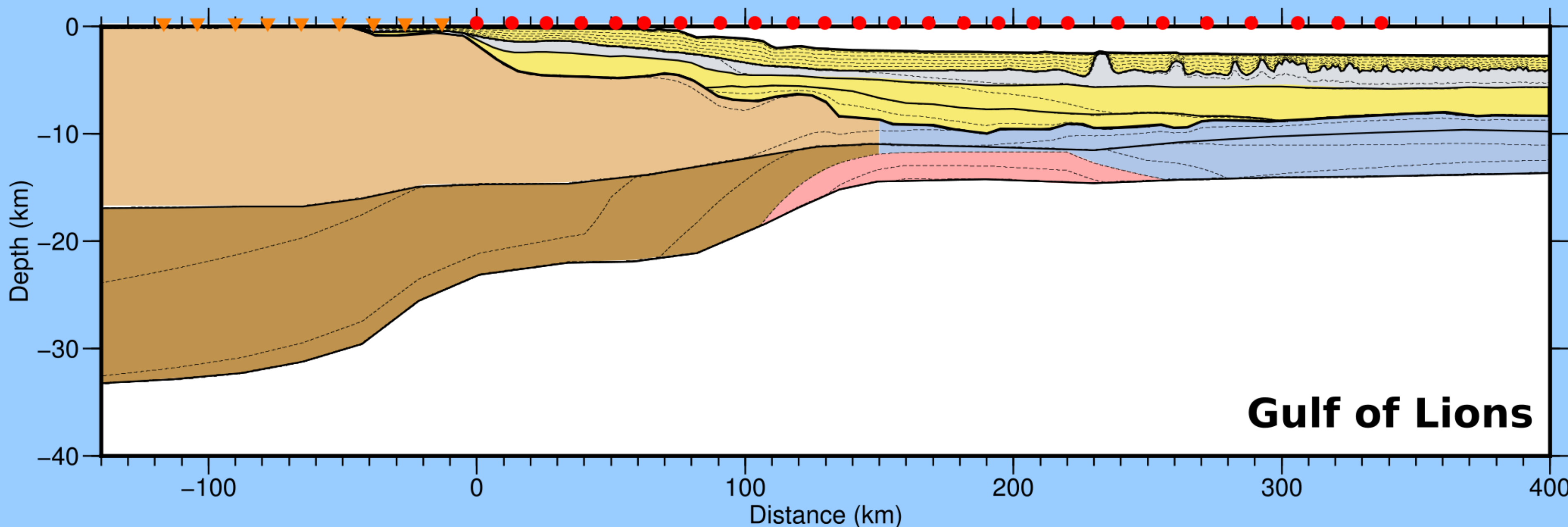
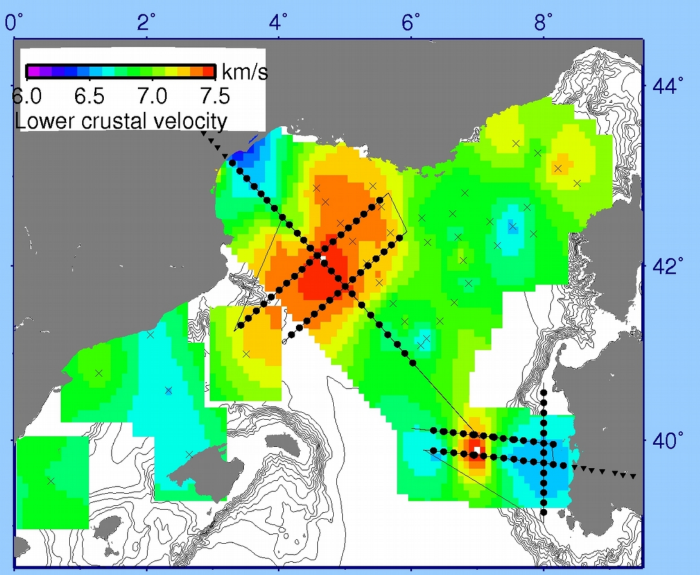


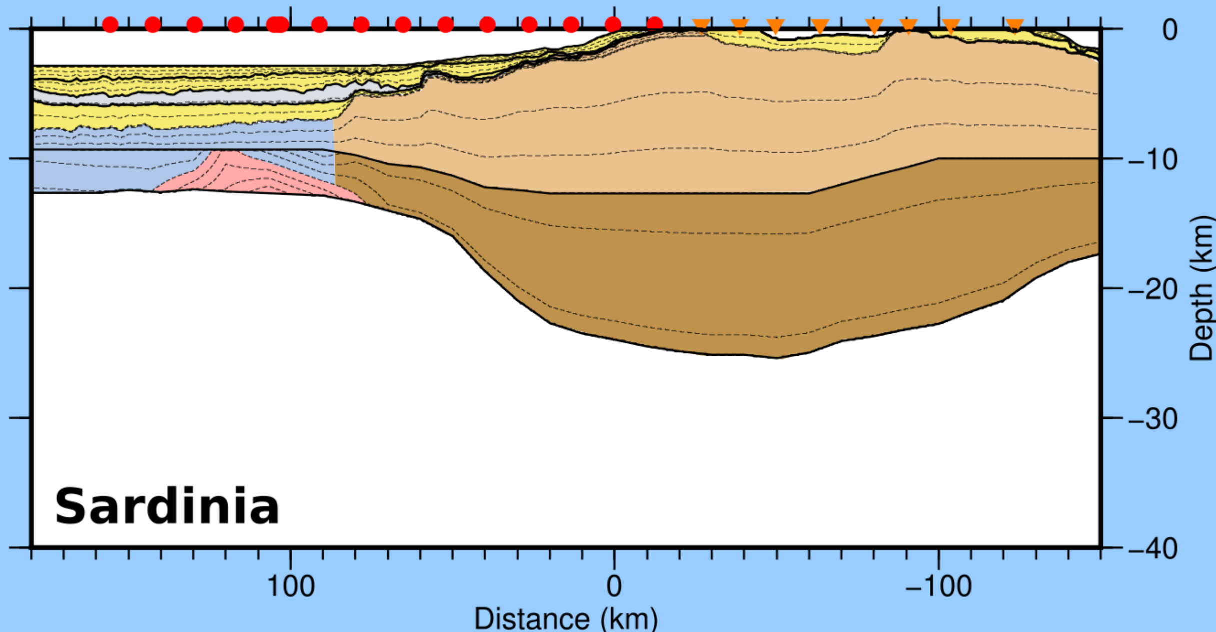
Plate cinematic reconstruction at 25 Ma, Poles from: Van Hinsbergen *et al.*, 2014

Sardinia margin pair

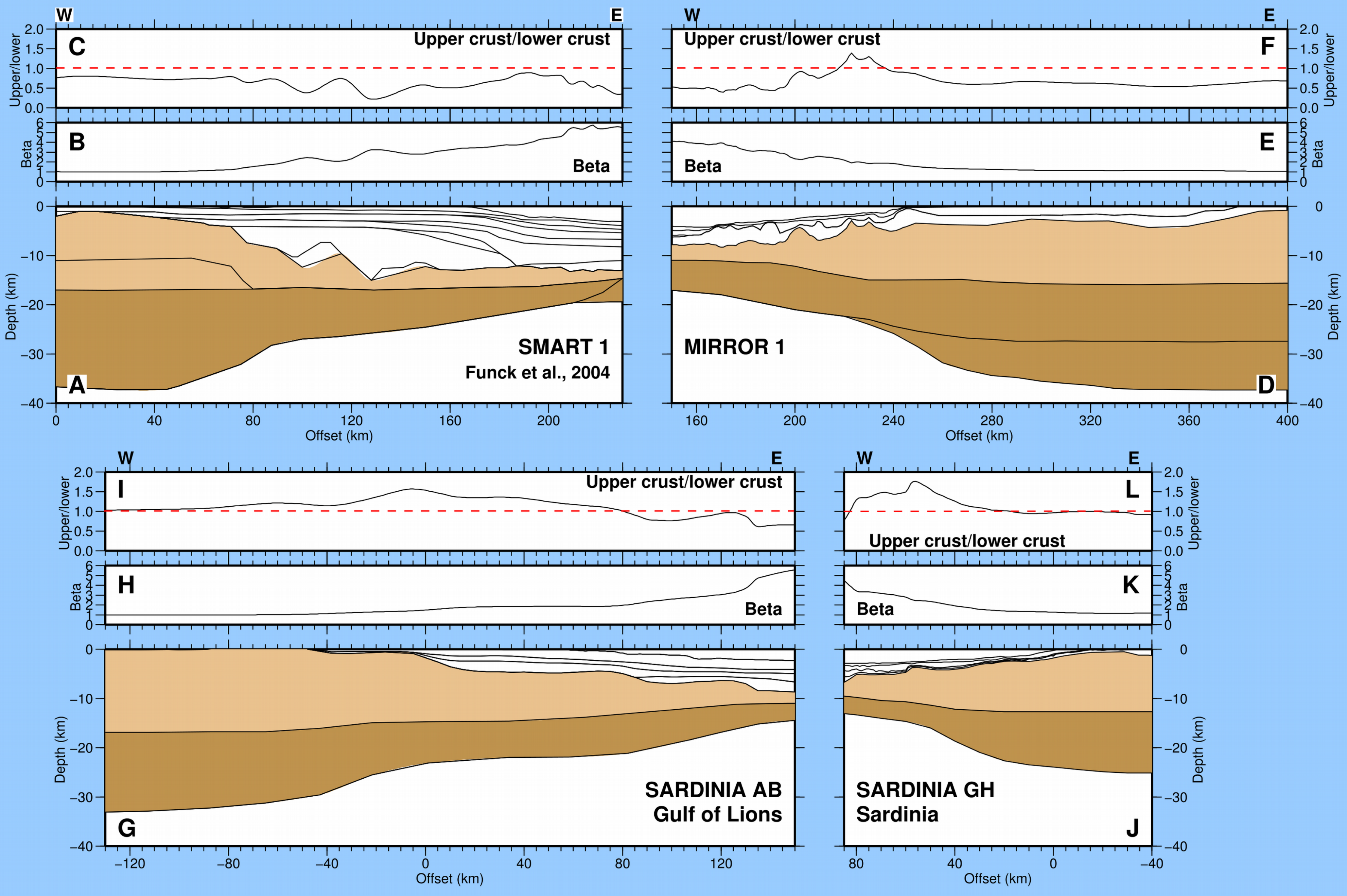




Lower crustal velocity



Upper/lower crust



Conclusions

- The central Atlantic opened symmetrically, but first seafloor spreading produced mainly serpentinised upper mantle material on the Canadian and untypical oceanic crust on the Moroccan side.

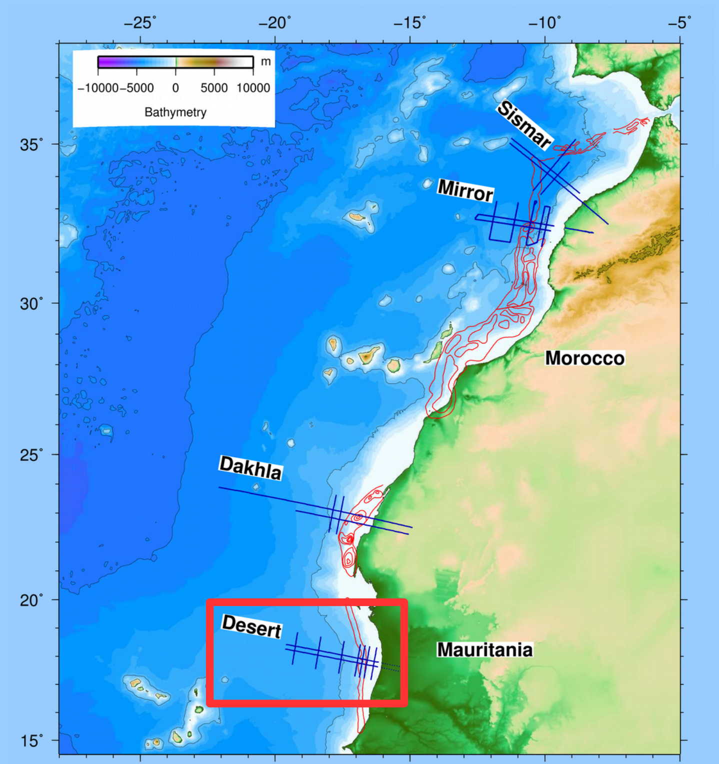
- More volcanic products can be imaged along the western than on the eastern part of the margin, which might explain the higher amplitude of ECMA as compared to WACMA

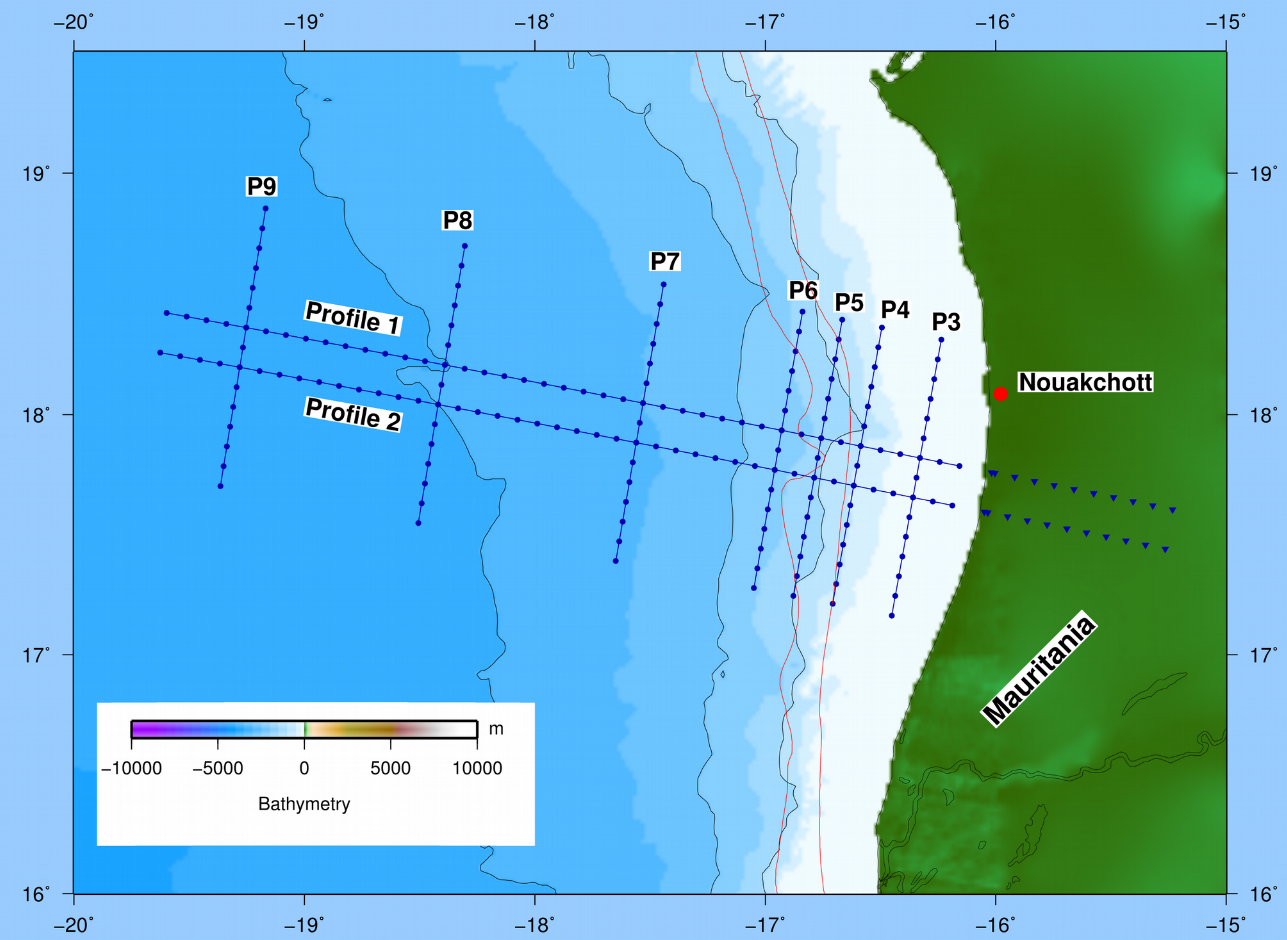
- Sedimentation on the Canadian side was mainly undisturbed, however the compression between the African and European plates and/or the passage of the Canary Island Hotspot created fault structures and updoming of the seafloor at the Moroccan margin.

- Comparison with the Sardinia-Gulf of Lions margin pair shows a more asymmetric distribution of zones of high lower crustal velocities, which might be linked to the presence of a cold downgoing slab at the Sardinian side.

Mauritania: DESERT

DEep SEismic Refraction Transect of Mauritania





The French Research Institute for Marine Studies

Exhibition: Hall B 2412

Geophysical & geodynamic studies

Geotechnical studies (oil-gas, geohazard)

Geochemistry, metallogeny

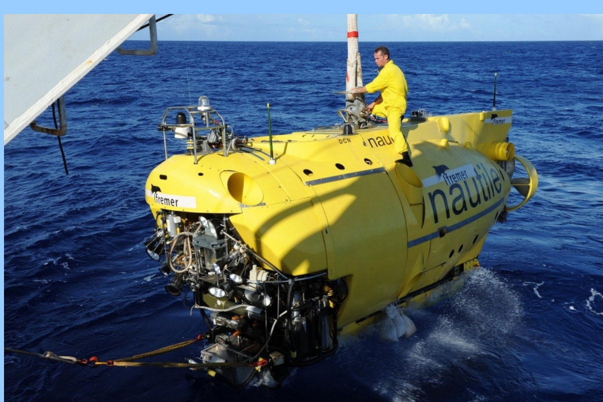
Biochemistry, biotechnology

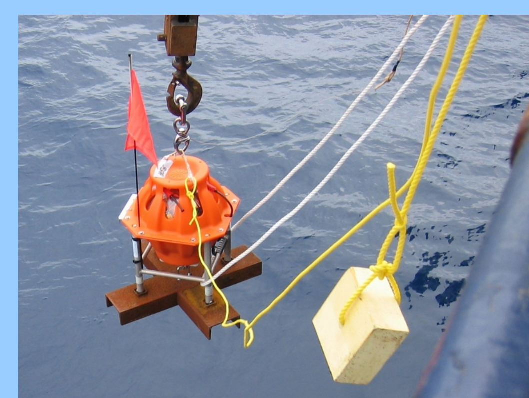
6 vessels

Underwater vehicles (Nautile, ROV, AUVs)

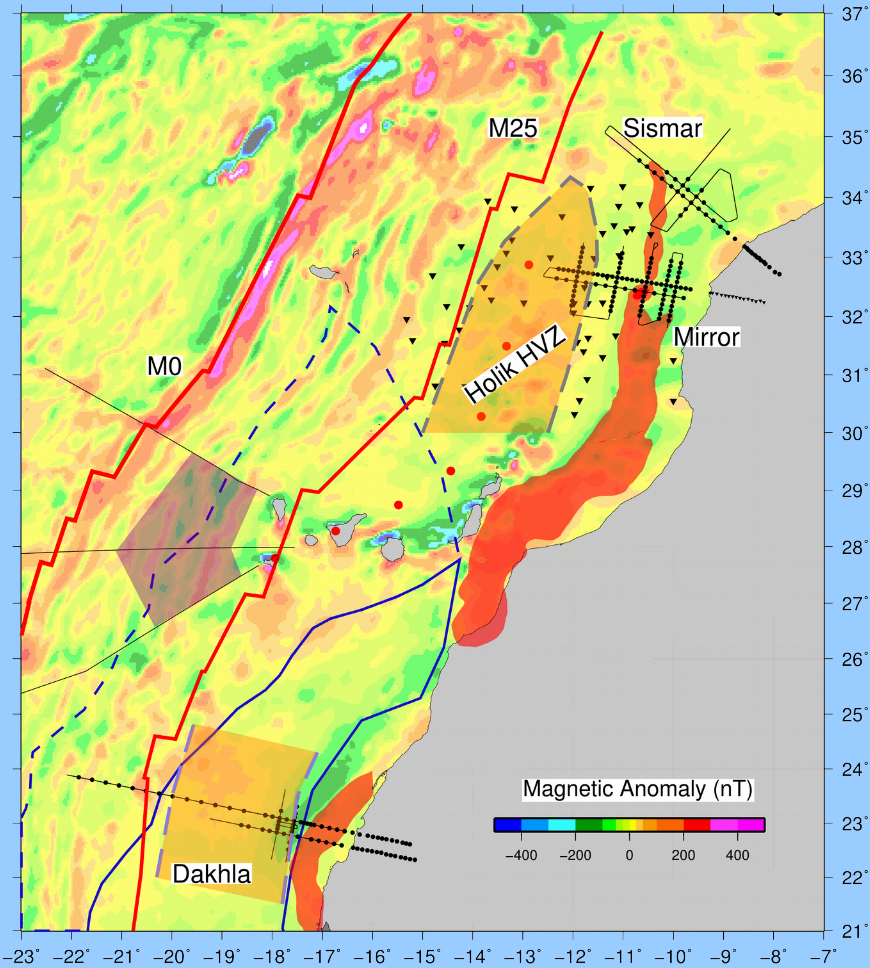
3 test basins

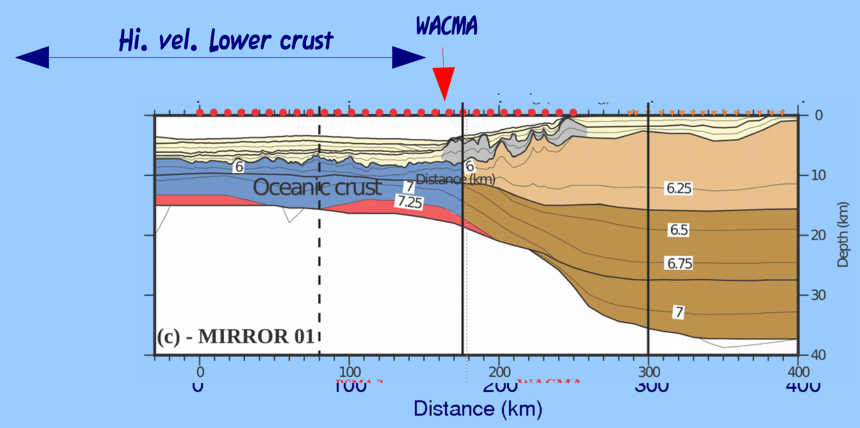
26 locations and 1500 employees

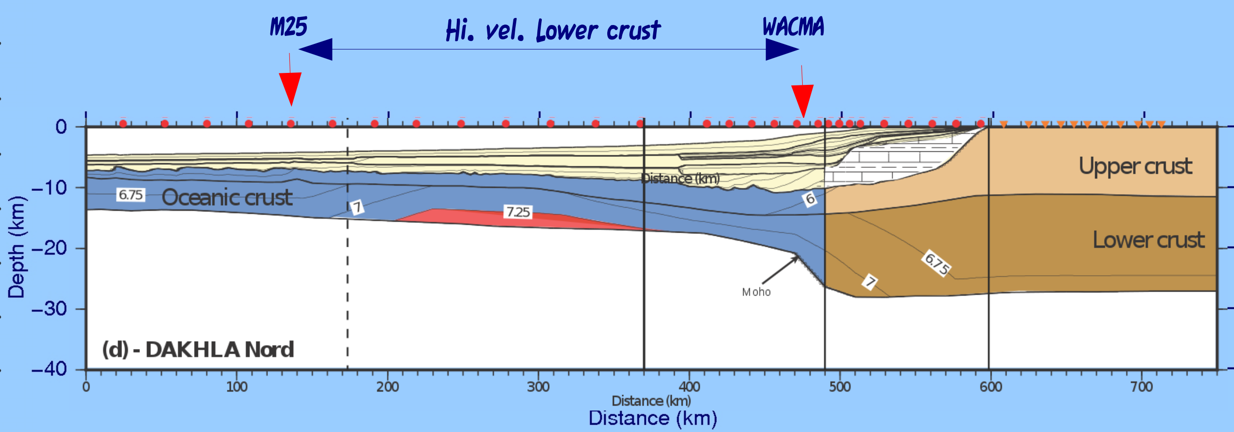




Magnetic anomalies

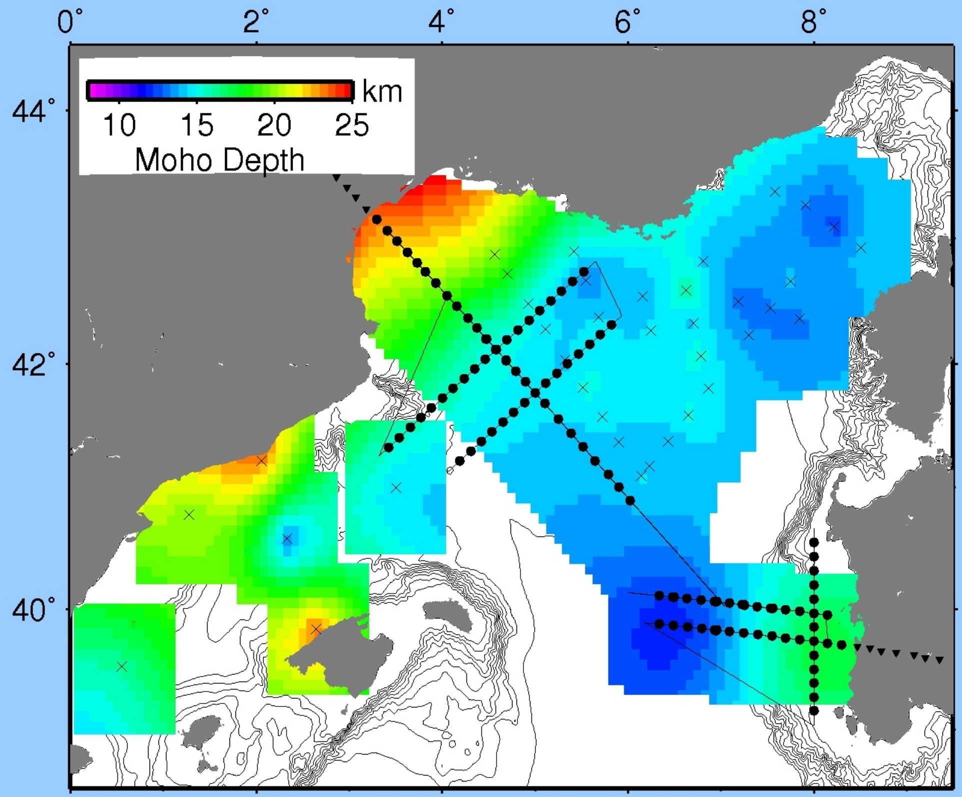




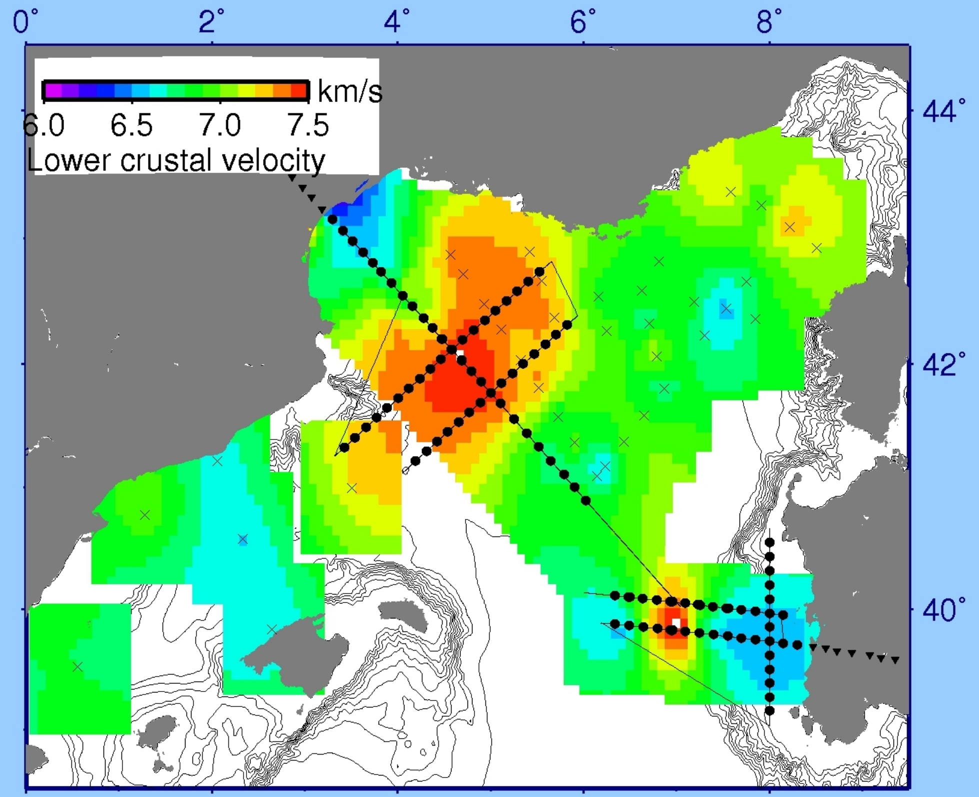


Verhoef *et al.*, 1986

Moho depth and lower crustal velocity



Moho depth



Lower crustal velocity