PS Late Jurassic-Early Cretaceous Tectonics and Exhumation Onshore Morocco: Implications for Terrigenous Sand Reservoirs in the Offshore of NW- Africa*

G. Bertotti[1,3], M. Gouiza[2,4], J. Foeken[2] and P. Andriessen[5]

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[1]Tectonics/Structural Geology, VU University Amsterdam, Amsterdam, Netherlands (giovanni.bertotti@falw.vu.nl)
[2]Tectonics/Structural Geology, VU University Amsterdam, Amsterdam, Netherlands
[3]Delft University of Technology
[4]Netherland Research Center for Integrated Solid Earth Science
[5]Dept. Isotope Geochemistry, VU University, Amsterdam, Netherlands

Abstract

Lower Cretaceous terrigenous sands are widespread in the NW Africa offshore. They form an exceptional sedimentary episode in the otherwise monotonous Mesozoic succession and are a potential reservoir. The tectonics driving continental exhumation and erosion are poorly known as they occurred following the appearance of oceanic crust in the Central Atlantic (passive margin stage) and prior to the onset of Atlas shortening. Using low-temperature geochronology we have recently documented 2-3km of exhumation and erosion in the Moroccan Meseta (Ghorbal et al., 2008) during the Late Jurassic to Early Cretaceous and have proposed that this event was responsible for the terrigenous sediments observed in the offshore. We present now (1) new low-T geochronology absolute ages, (2) a reconstruction of the strain regime controlling exhumation and, (3) the results of numerical modelling work we performed to constrain the evolution of the lithosphere of the Moroccan margin during and following rifting.

Our new data document that Middle Jurassic to Early Cretaceous exhumation and erosion affected also the High Atlas, the anti-Atlas and, further to the S, the Reguibate shield. The area experiencing exhumation was elongated in N-S direction and partly coincided with the “West Moroccan Arch”. The area was separated from the more distal parts of the passive margin by a domain of continuous subsidence presently in the coastal and continental shelf domains.

Structural studies document an overall contractional regime during exhumation in contrast with the general lack of tectonic activity

assumed for passive margins. In the coastal areas of Morocco, shortening triggered and interacted with the growth of salt diapirs. Most of these diapirs entered the diapiric phase long before the onset of Atlas orogeny. Rocks eroded from the exhuming area were routed by a fluvial system and shed into the subsiding margin forming of submarine deltas such as the Tan Tan delta.

Using kinematic and finite element numerical models we investigate the lithospheric evolution of the Moroccan lithosphere during and following rifting with the main goal of understanding the processes controlling the anomalous vertical movements observed. Modelling results suggest that the activation of secondary convection cells at asthenospheric/lithospheric is necessary to explain the observed vertical movements.

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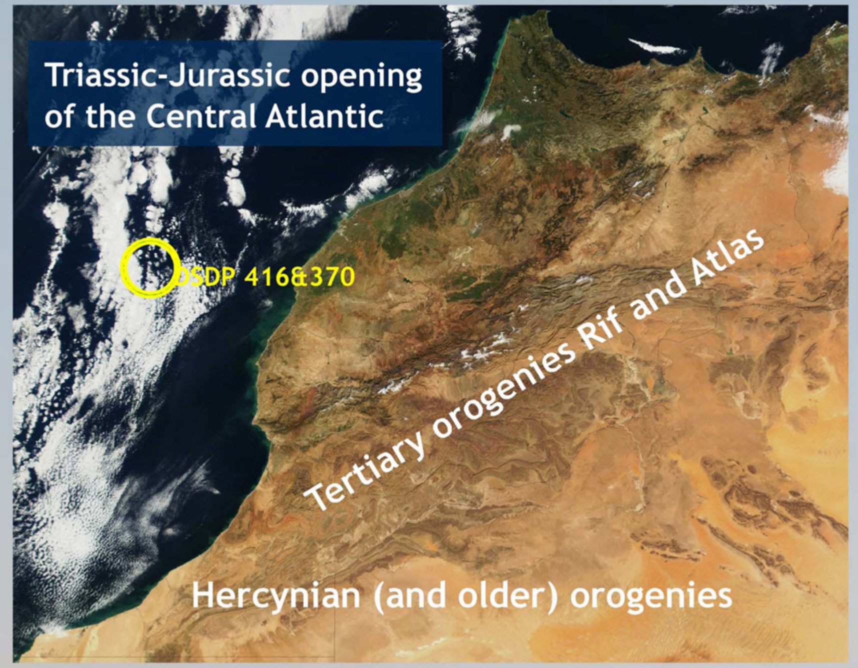
G Bertotti[1,2], M. Gouiza[1,3], J. Foeken[1], P. Andriessen[1]

[1]VU University Amsterdam, [2]Delft University of Technology, [3]Netherland Research Center for Integrated Solid Earth Science

1. General geology and exhumation data

Late Jurassic - Early Cretaceous: tectonically quiet but very sandy

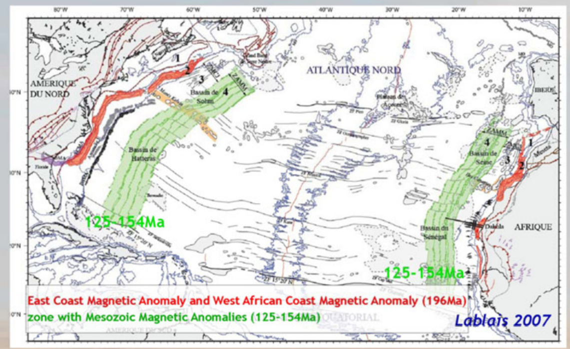


Late Jurassic-Early Cretaceous well in the post-rift: older than Tertiary mountain building and younger than Central Atlantic rifting

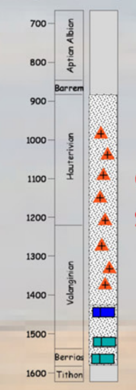
Central Atlantic tectonics

Central Atlantic rifting began in the (Late?) Triassic and ended probably at 175Ma (this is debated) with the appearance of oceanic crust (magnetic anomalies) and the following post-rift.

In Morocco, the tectonic quiescence typical for the post-rift evolution of passive margins is at odds with the thick terrigenous succession drilled at DSDP 370&416



Central Atlantic magnetic anomalies according to Lablais 2007



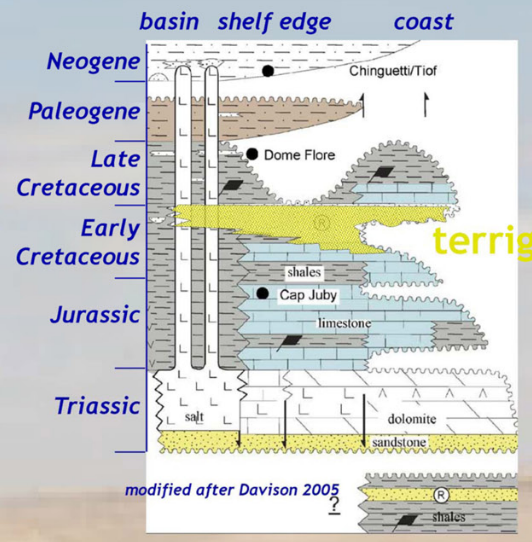
quartz, zircons, garnets, schists....

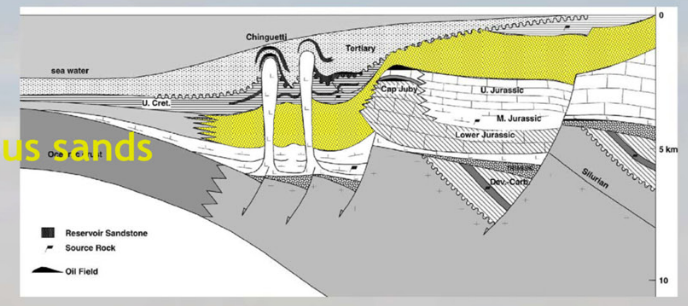
drowned carbonate platform

carbonate platform clasts

A regional reservoir

Similar sands are found over the entire NW passive margin and are a potential major reservoir





Where do these sands come from?

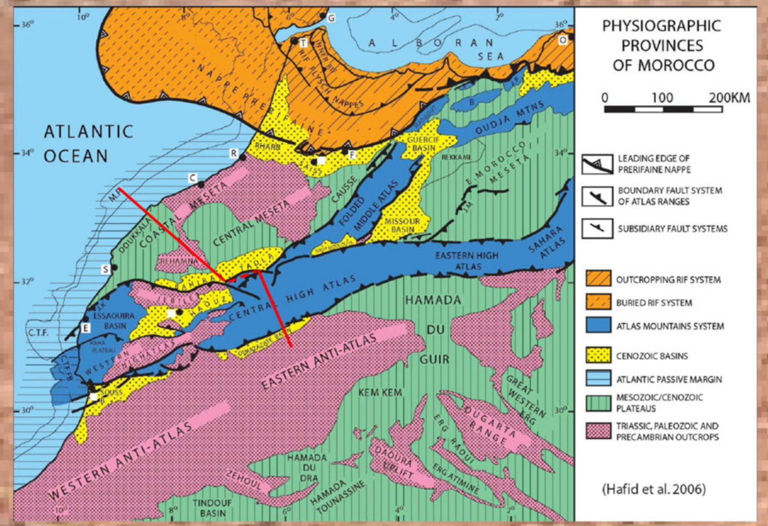
How were they produced?

What do they contain?

What is their distribution?

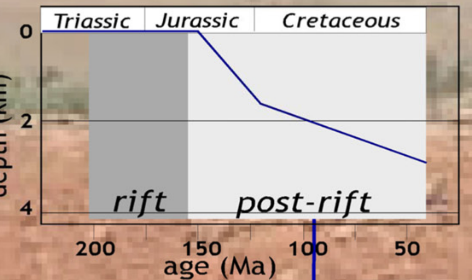
The Moroccan passive continental margin in Late Cretaceous times

The Doukkala section:
a transect across the passive continental margin of Morocco
It includes all structures from the oceanic crust to the stable Anti-Atlas

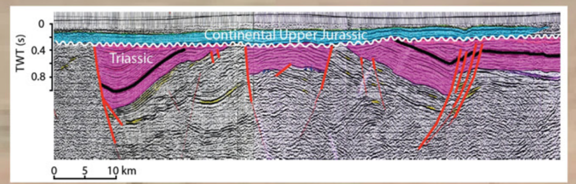


continental shelf

subsidence starts only in the Middle Jurassic!



Doukkala basin



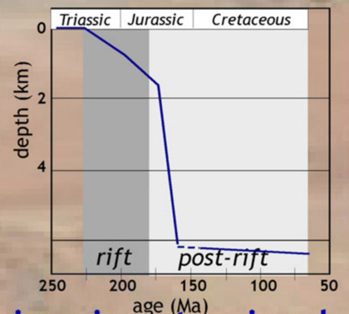
Triassic to Early Jurassic subsidence and pre-Late Jurassic inversion

Meseta

samples providing surprising vertical movements in Late Jurassic to Early Cretaceous

a major regional unconformity with marine Upper Cretaceous on peneplained Hercynian basement

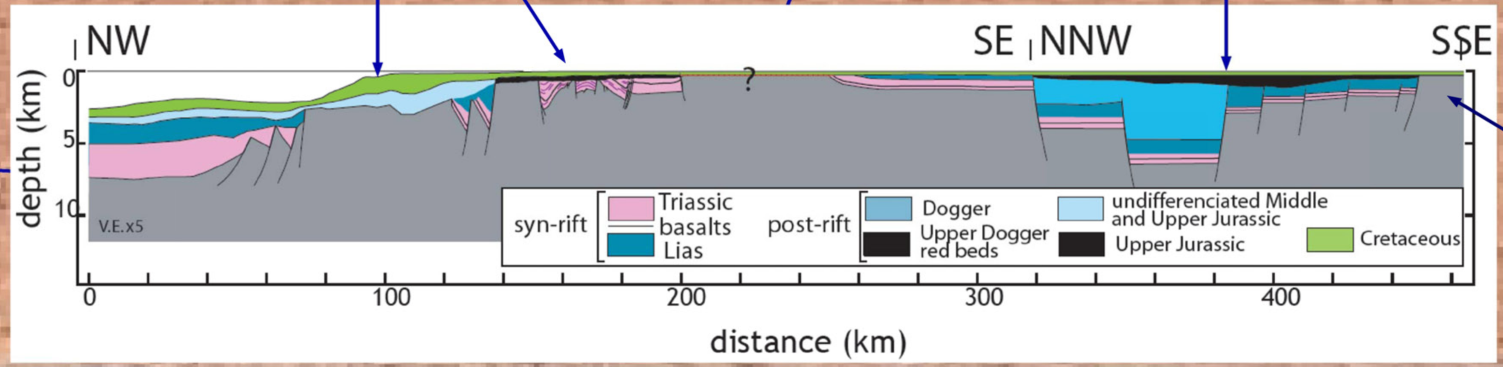
Atlas (inverted) rift



km-s thick sedimentary successions in extensional basins controlled by steep normal faults
subsidence continues following the supposed age of Central Atlantic break-up

distal margin

Triassic to Cretaceous subsidence



Anti-Atlas

stable Sahara platform

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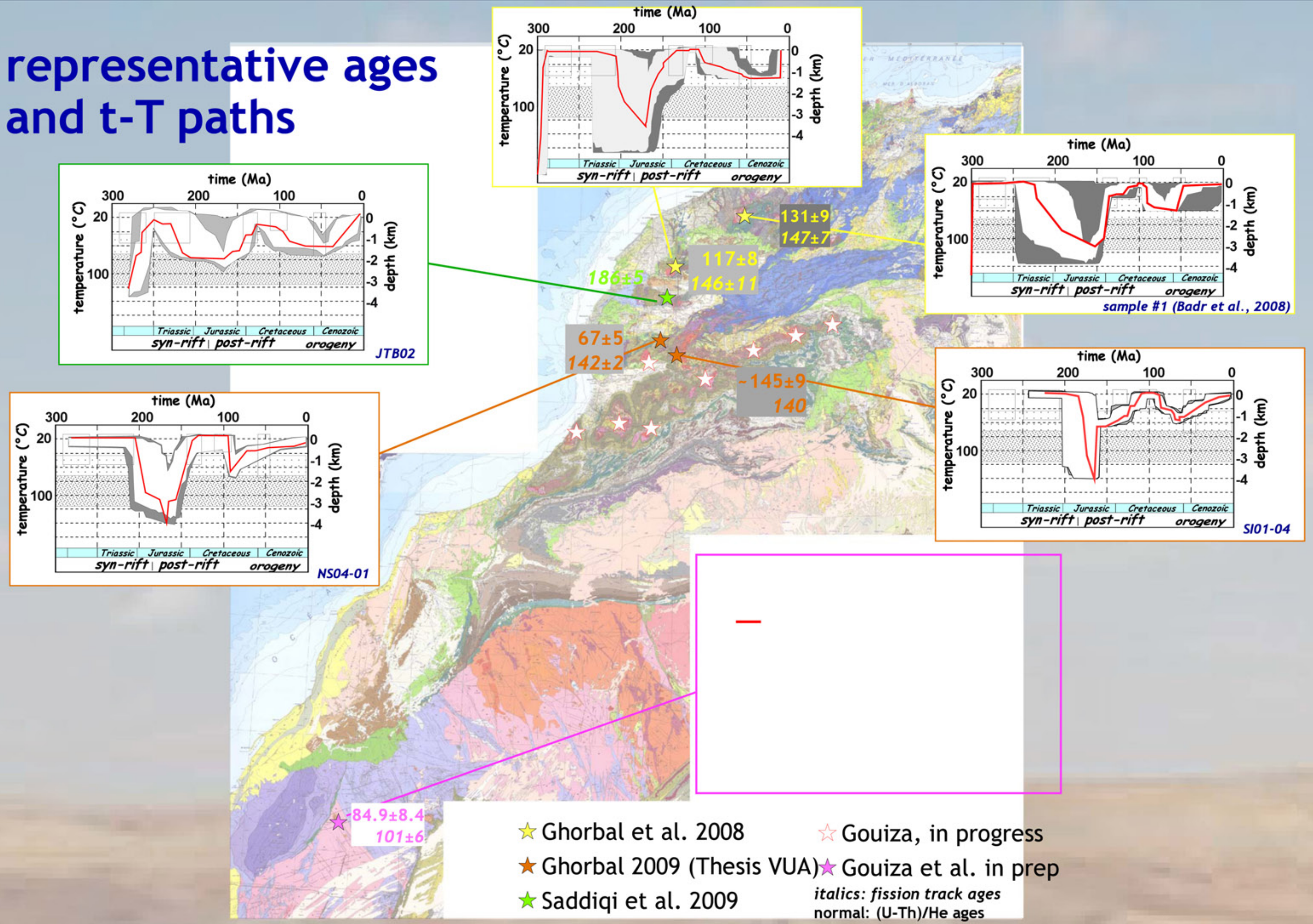
2. Vertical movements and their tectonics

low-temperature geochronology data - the exhuming area

low-T geochronology data

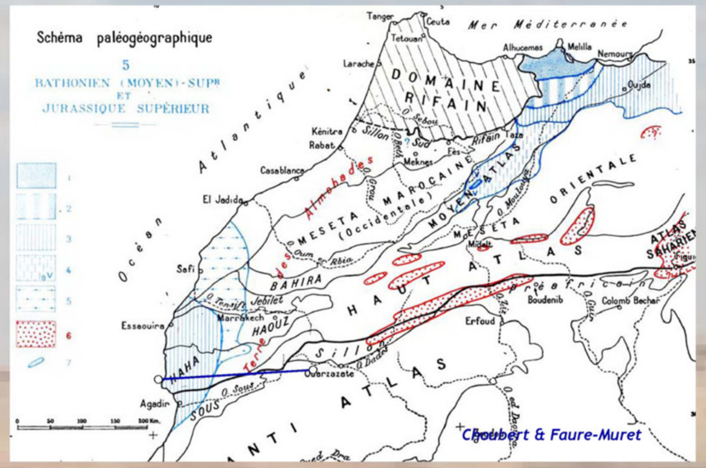
- *A powerful combination of apatite fission tack and (U-Th)/He analyses on apatites*
- *Sampling along long transects to capture the large scale signals*
- *sampling sediments or basement rocks close to sediments to use geological constraints*

representative ages and t-T paths



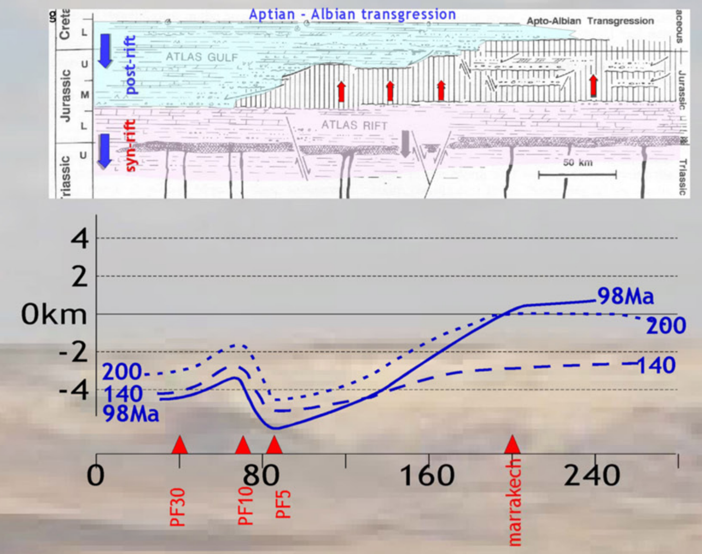
DISCOVERIES

- Mesozoic ages are widespread in Morocco, in areas previously considered as stable such as the Meseta but also the old Marrakech Massif, and parts of the Anti-Atlas and the Reguibate shield
- Ages document widespread Triassic to Early Jurassic subsidence followed by Late Jurassic - Cretaceous exhumation
- The exhuming area (no sedimentation in old literature) was flanked to the W by a subsiding domain. This is the Atlantic margin and, in particular the Essaouira basin an similar structures further to the S



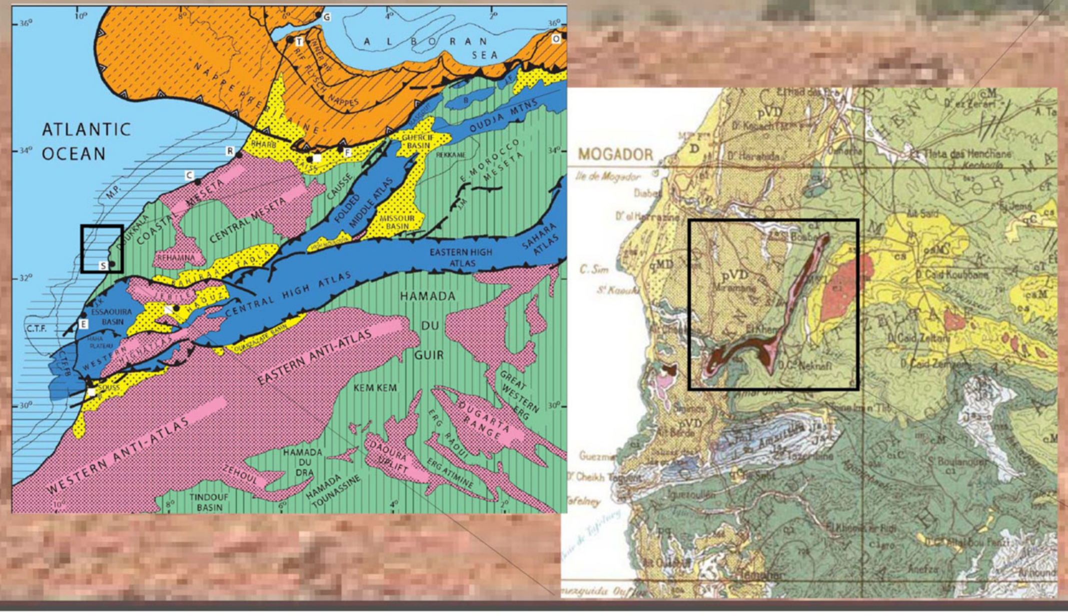
Late Jurassic paleogeography

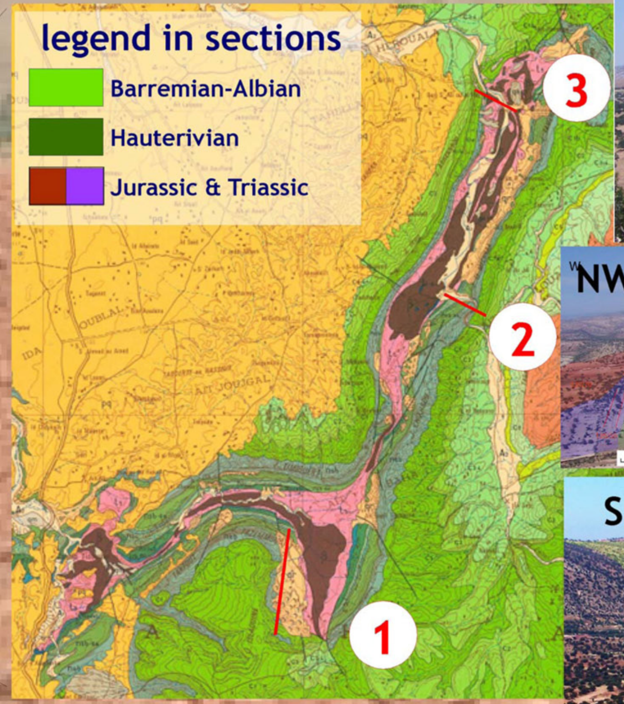
linking the exhuming and the subsiding domains

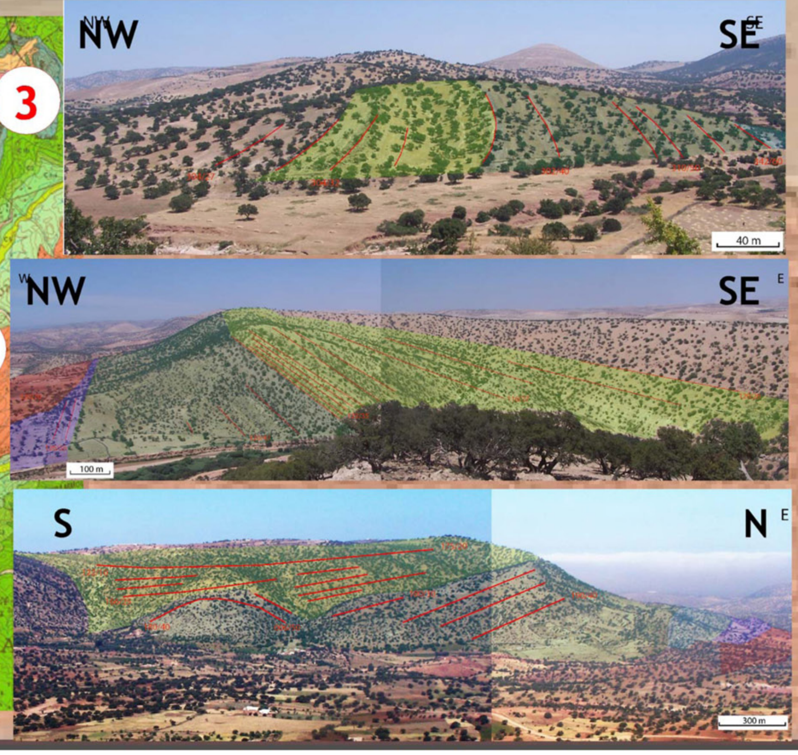


tectonics of Late Jurassic to Early Cretaceous vertical movements:

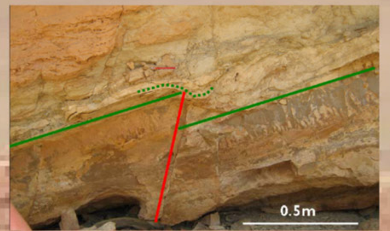
W of the region of exhumation, a continuously subsiding domain was present (Essaouira basin and similar basins). Here, Late Jurassic to Early Cretaceous growth structures are common







contraction structures are widespread: growth is driven by shortening and not diapirism



syn-sedimentary reverse faults are common with shortening direcions perpendicular to the fold axis

secondary syn-sedimentary thrusts develop on the flanks of the large anticlines

syn-sedimentary parasitic folds are common on the flanks of the large-scale structures

Low-T geochronology data provides a completely new picture of vertical movements during Jurassic-Early Cretaceous times.

Most of these movements are tectonic in nature and document a not-so-passive margin

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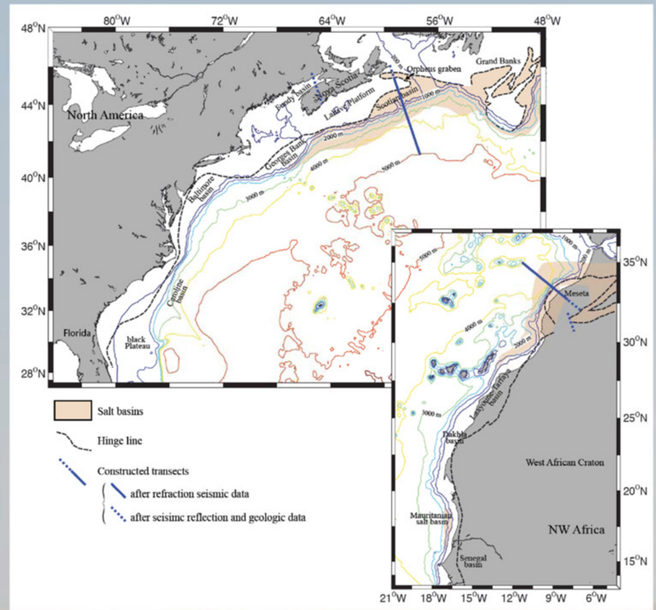
3. Source-to-sink perspective, quantitative models

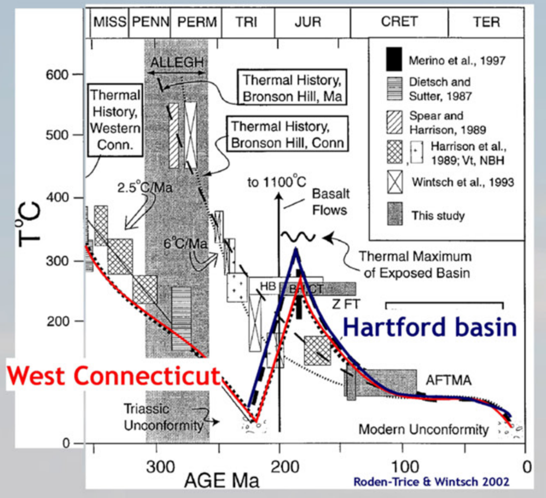
Exploring the passive margin perspective

The conjugate margin

The Atlantic margin of Canada is the conjugate to the Moroccan margin

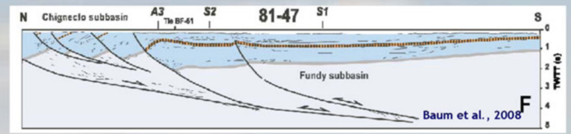


The two conjugate margins show apparent similarities in vertical movements and deformations during the Late Jurassic - Early Cretaceous. This is striking as the two margins are, at the time, separated by the (initial) Central Atlantic ocean.



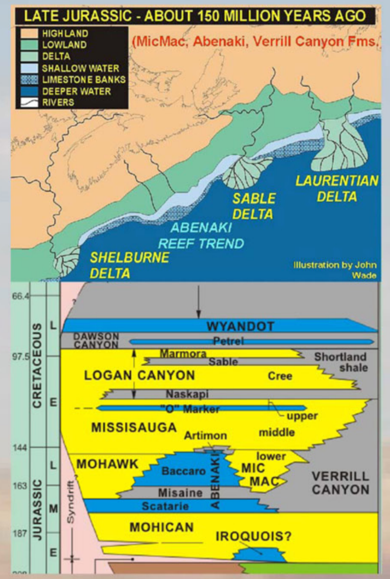
Late Jurassic to Early Cretaceous exhumation in eastern US

Exhumation coeval with shortening

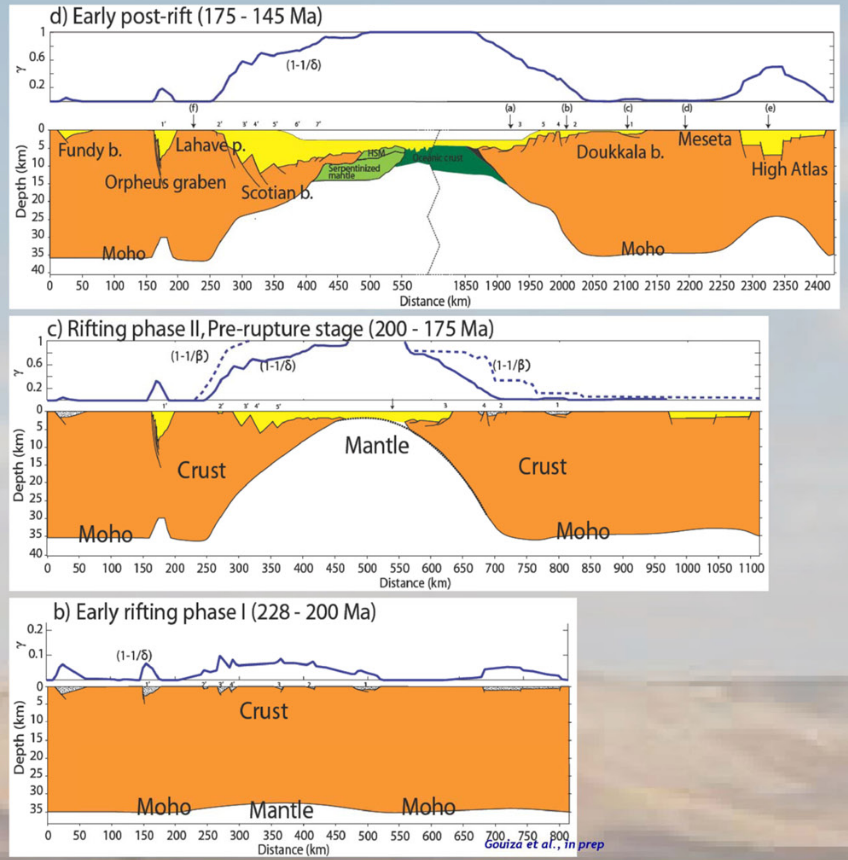


Late Jurassic-Early Cretaceous butress folds invert half-grabens in the Fundy Basin (and elsewhere). Shortening direction is NNE-SSW

Erosional products are transported to the Atlantic offshore



the kinematic evolution



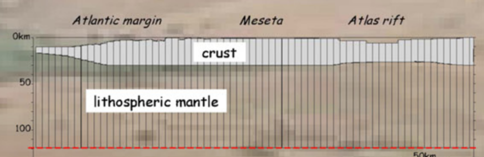
The kinematic evolution:

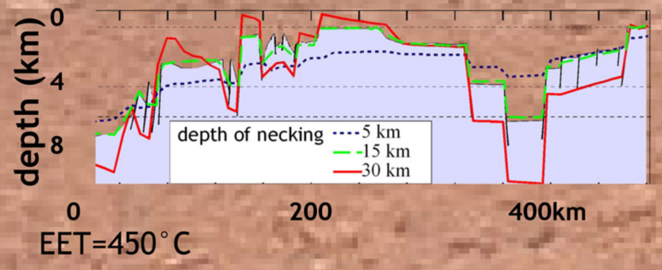
- rifting is slow (0.5 cm/year)
- extension was widely distributed leading to the formation of several syn-rift basins during the early rifting phase
- Extension in the late rifting phase is localized
- Mantle lithosphere exhumation took place shortly after crustal break-up.

Numerical models

simple kinematic models

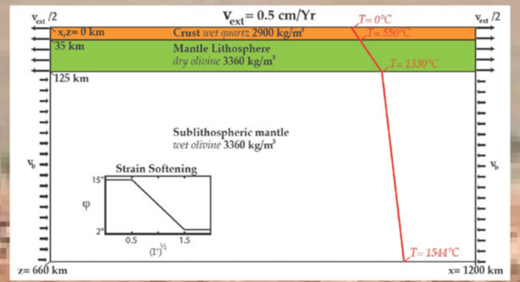
model investigates vertical movements associated with (sub)crustal thinning





The only upward movement predicted are related to deep depths of necking Magnitudes, however, are insufficient

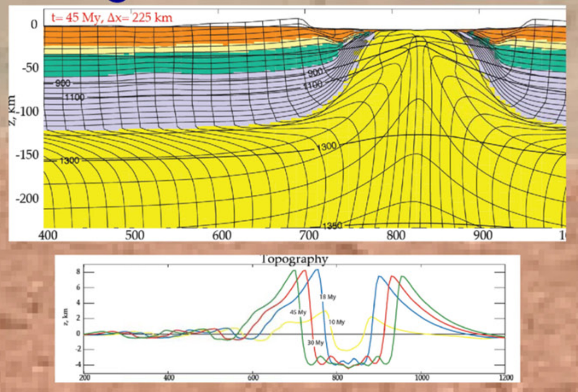
a numerical model to explore the importance of rift should and secondary convection cells for the observed exhumation



The model:
Extension of the lithosphere is modeled using an arbitrary Langrangian-Eulerian finite element calculation (Fullsack, 1995; Huismans and Beaumont, 2003).
Scaling factors are applied to wet Quartz viscosity in the crust and to dry Olivine in the mantle in order to modify their respective strengths.
Statistical noise in the initial strain field of the crust is used to localize deformation

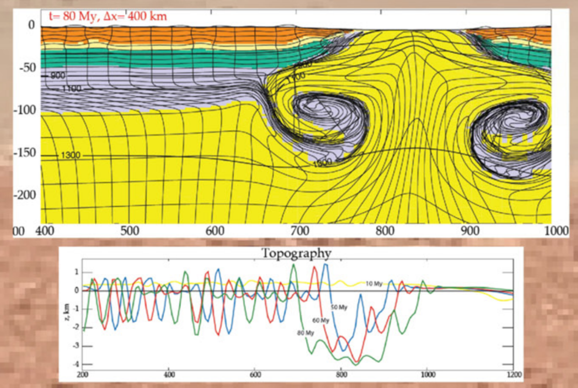
Gouiza and Huismans in prep

strong mantle and crust



- narrow rift
- lithospheric mantle is exhumed before break-up
- Vertical movements are mainly related to shoulder uplift

weak mantle and crust



- wide rift,
- sub-lithospheric mantle is exhumed
- rift shoulder uplift is attenuated,
- the convective thinning of the mantle lithosphere is very weakly expressed in surface uplift.

Conclusions

1. Areas of Morocco previously considered as stable have experienced more-than-predicted syn-rift subsidence and unexpected exhumation from the Late Jurassic to the Early Cretaceous.
2. the area experiencing exhumation was elongated in ~N-S direction and was flanked to the W by a domain of subsidence
3. Late Jurassic to Early Cretaceous vertical movements were essentially controlled by shortening. Its direction is poorly constrained
4. Strong similarities between phenomena taking place in Morocco and in the conjugate margin in Canada suggest that passive margins were .... not so passive