# Seismic hazard of the Western Makran subduction zone: Effect of heat flow on frictional properties combining mechanical and thermo-mechanical modelling approaches

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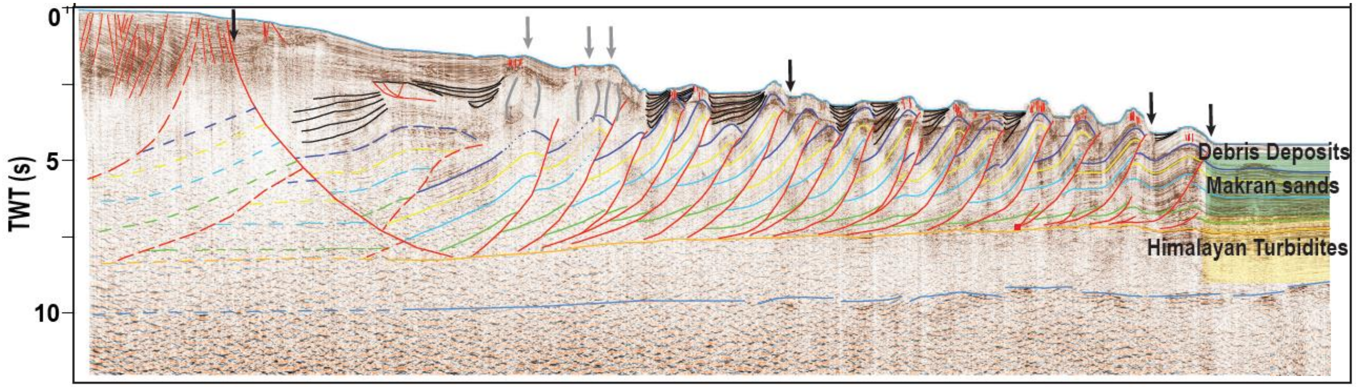


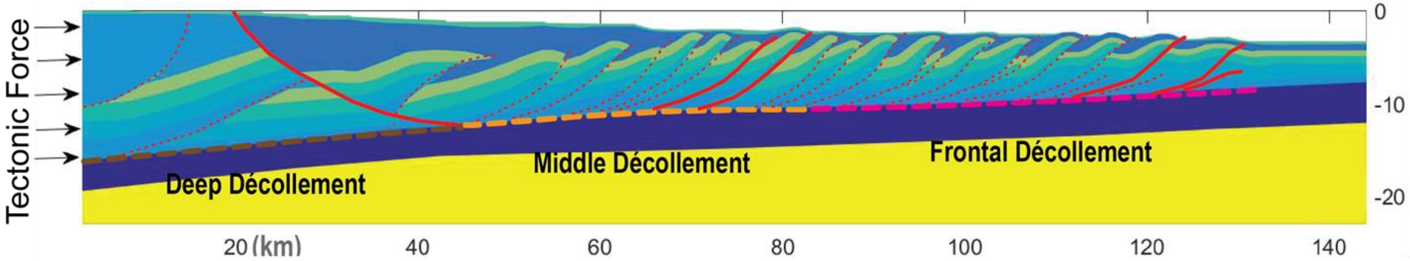


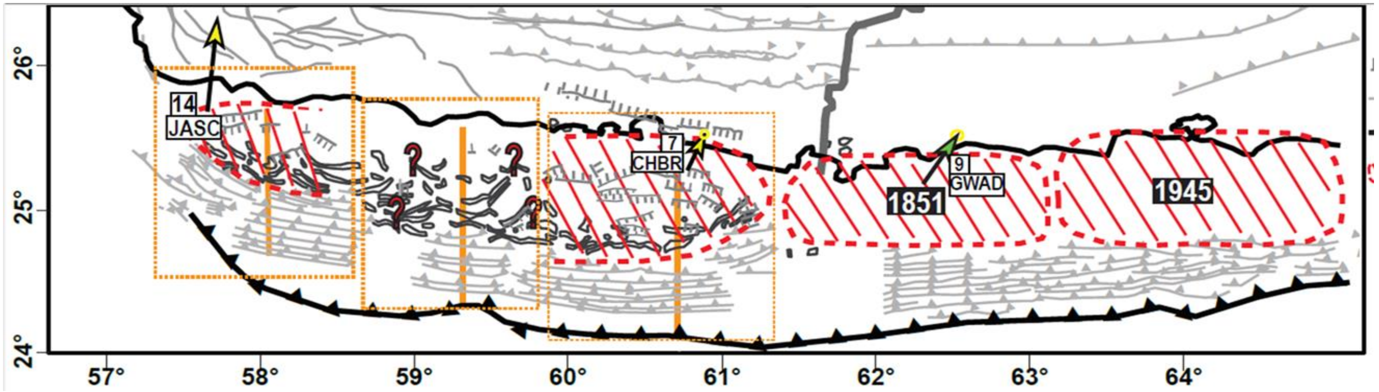


How to form such normal faults?

How to reduce friction?

**Thermo-mechanical modelling**

Normal faults and friction drop due to:

Hypothesis 1) Smectite-Illite transition

Hypothesis 2) Brittle-Viscous transition

Hypothesis 3) Seamount subduction/underplating

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* According to the sparse GPS stations, the subduction is accumulating some strain to be released during future earthquakes.

So,

* Mechanical modelling is used to retrieve the spatial variations of the frictional properties of the megathrust, and discuss its seismogenic potential along three N-S seismic profiles.

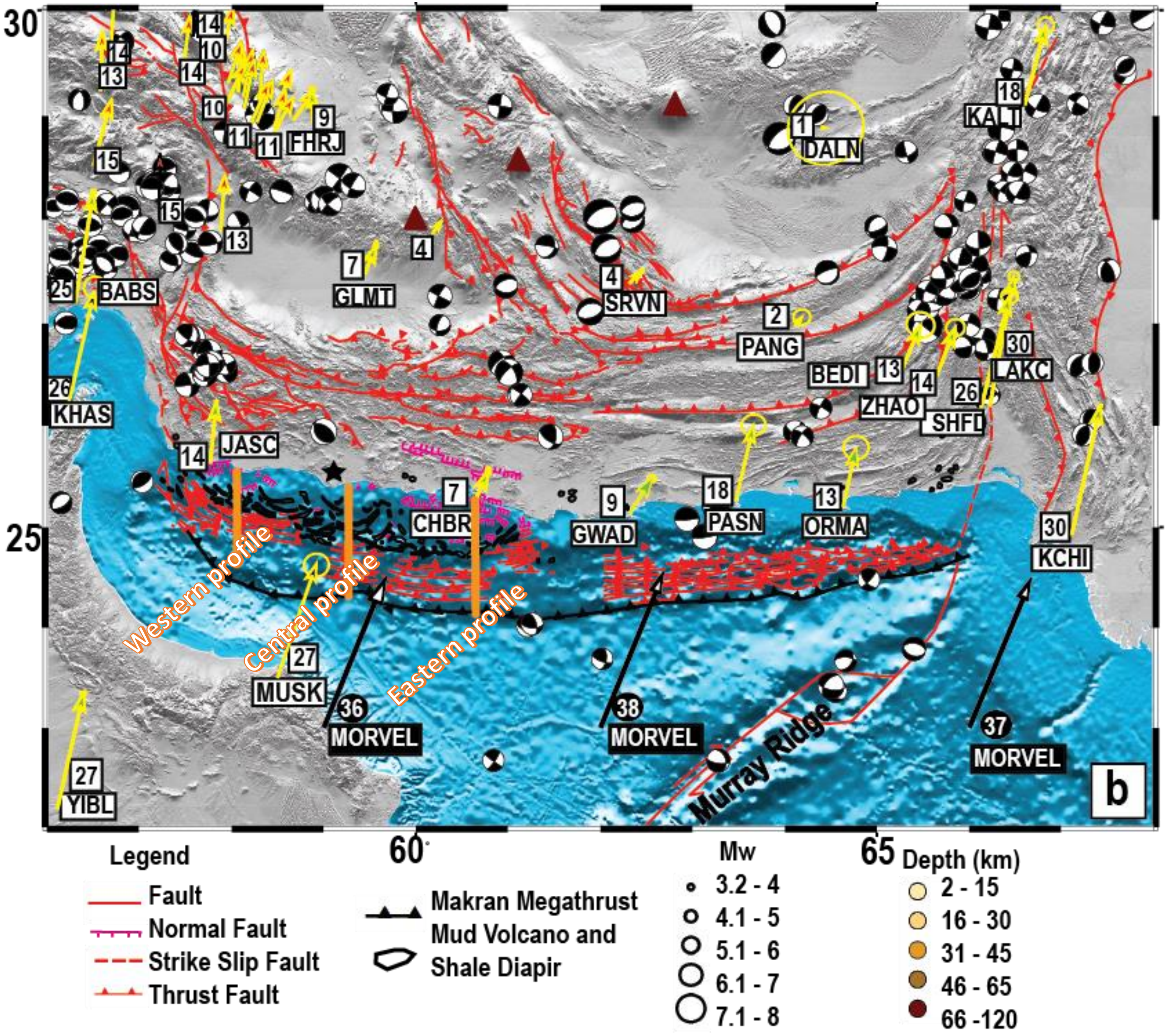
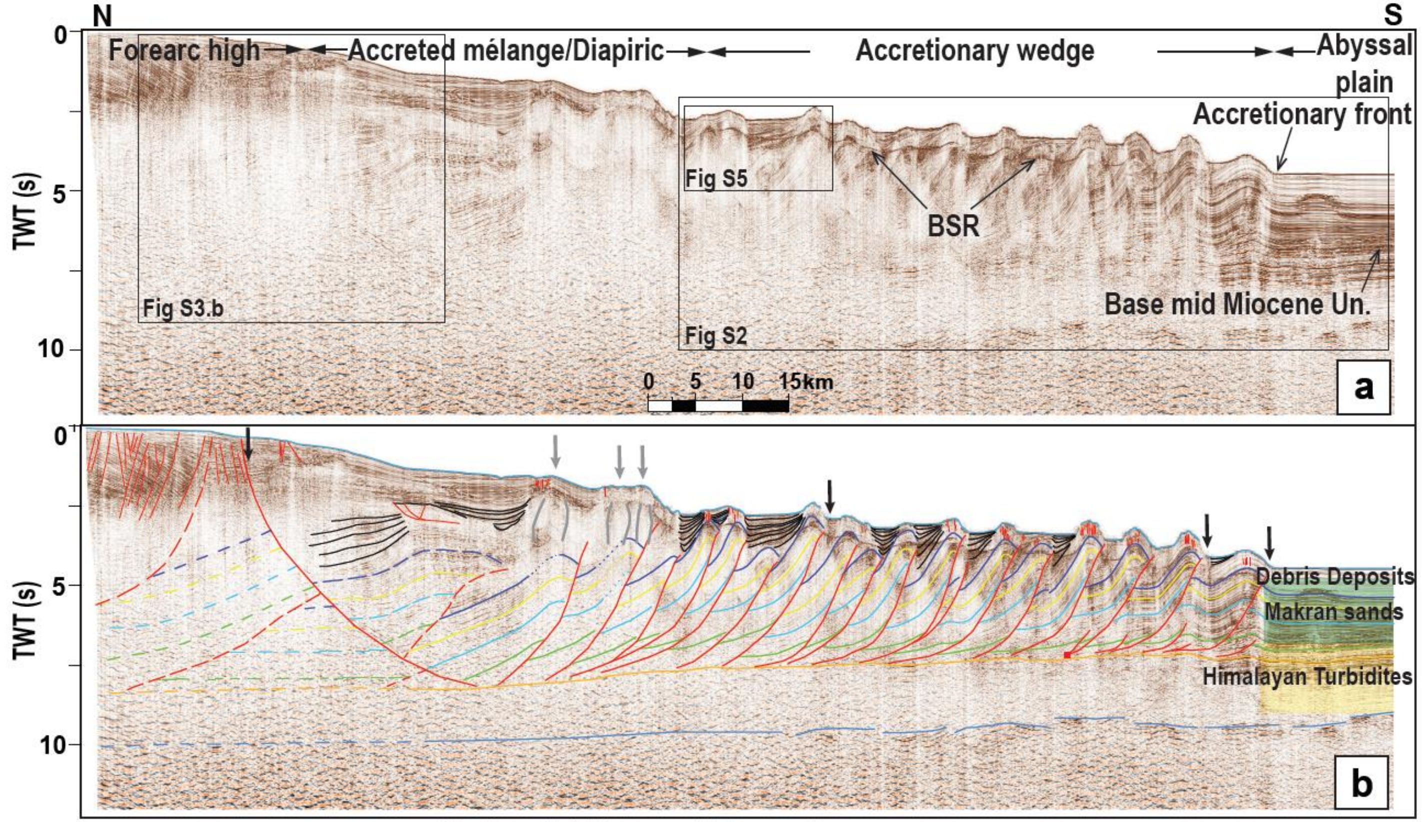



**Fig.** Structural map along the Makran subduction zone

- The profiles are characterized by a long imbricated thrust zone that takes place at the front of the wedge.
- A diapiric zone of shallow origin lies in between the imbricated zone and the shore.
- Along the eastern and western shores, active listric normal faults seem to root down to the megathrust.



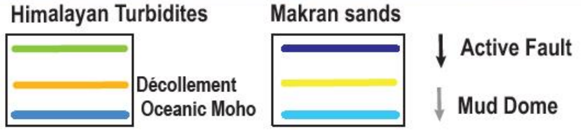




**Fig**. 2D offshore Eastern seismic profile

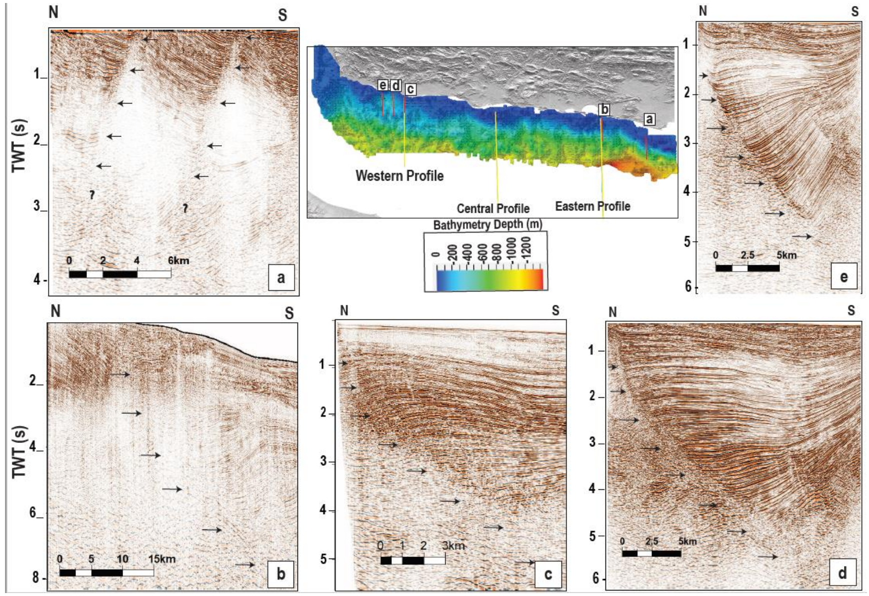



**Fig.** Duplexes are visible along the whole subduction zone, while seaward normal faults are limited to the eastern (a and b) and western (c and d) domains.

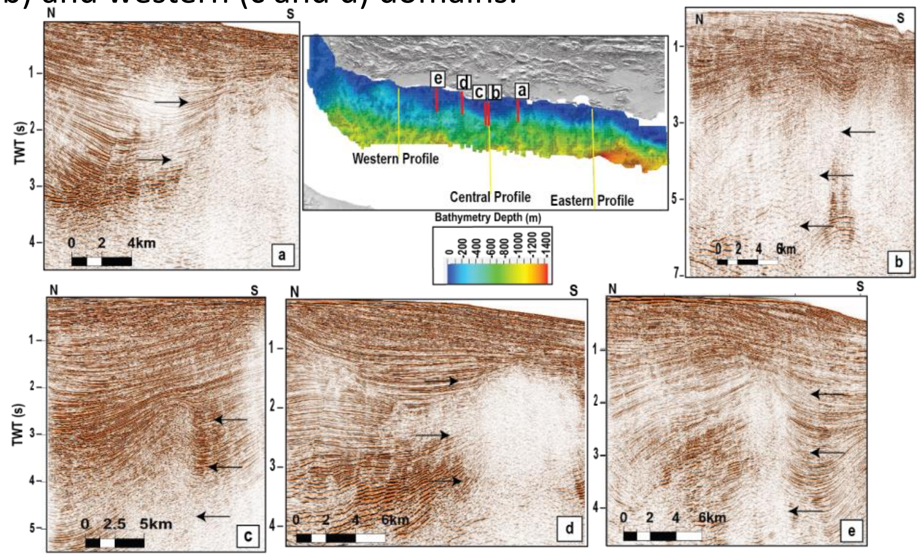



**Fig.** Duplexes and mud diapirs are visible in this Central domain, as shown by black arrows.

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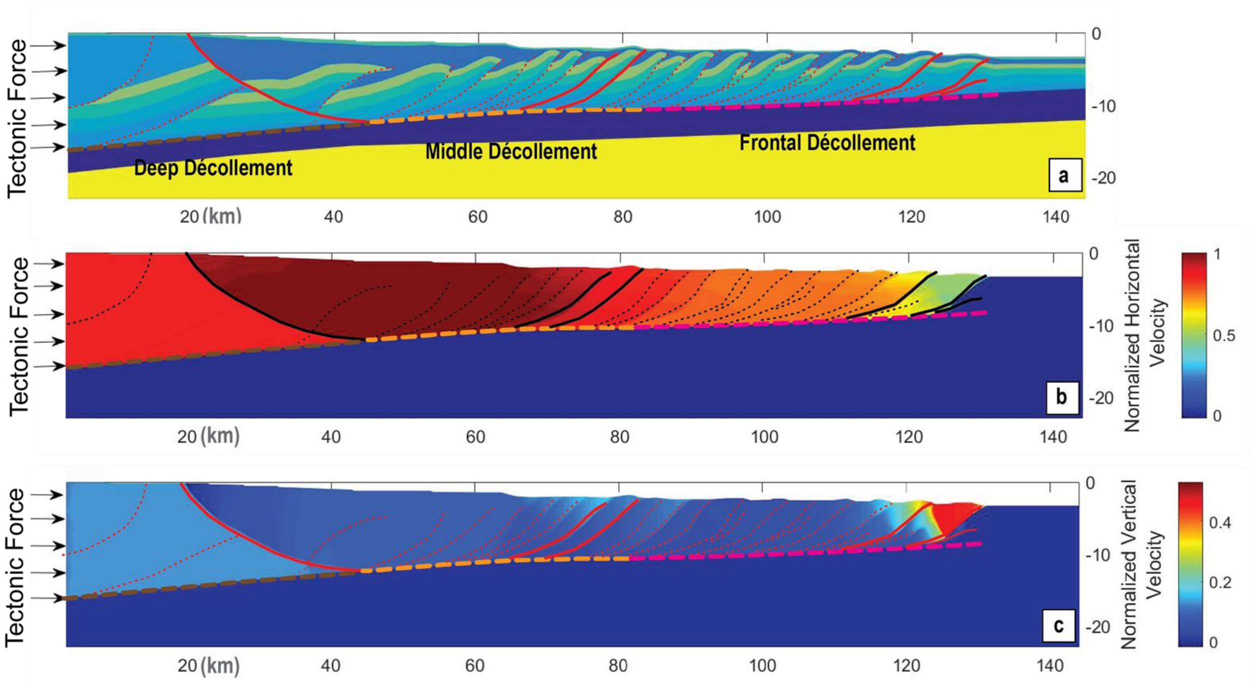
* The mechanical modelling is applied along eastern and central profiles.
* Since the Western profile does not reach the trench, the analysis could unfortunately not be carried out on this profile. Although, the deformation of western domain is very similar to the eastern one.



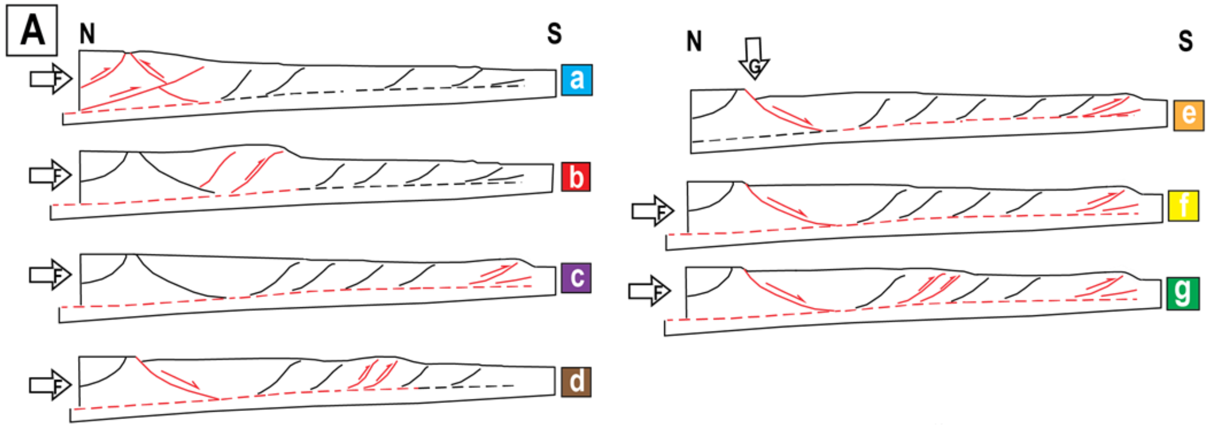




**Fig**. Seven kinematics obtained for the range of effective frictions along the décollement. Model g is consistent with the observed structure.

**Fig.** Model set-up with three distinct décollement segments along Eastern profile.

A transition from very low to extremely low friction is required to activate the large coastal normal fault

To propagate the deformation to the front, an increase of friction along the imbricated zone is necessary

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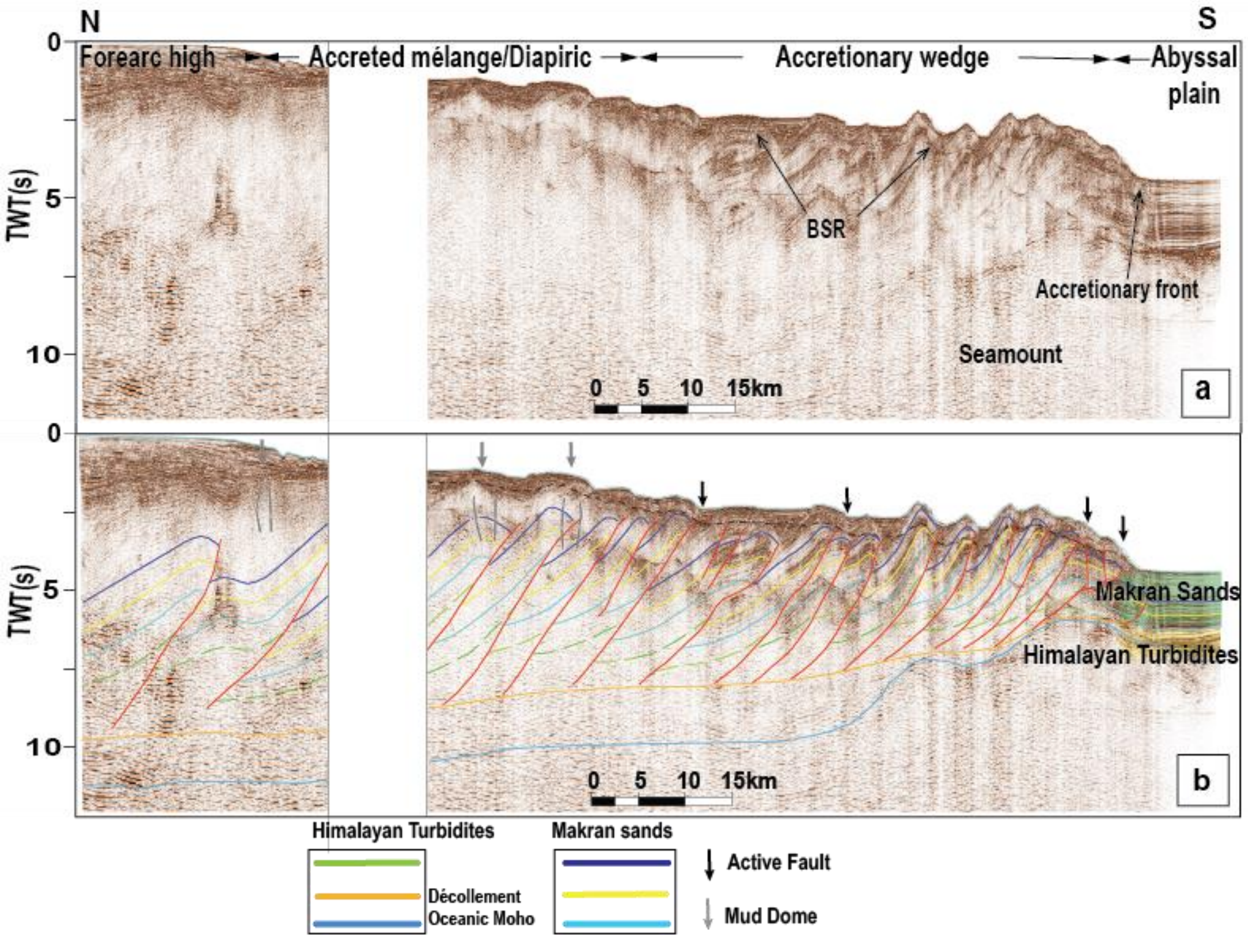


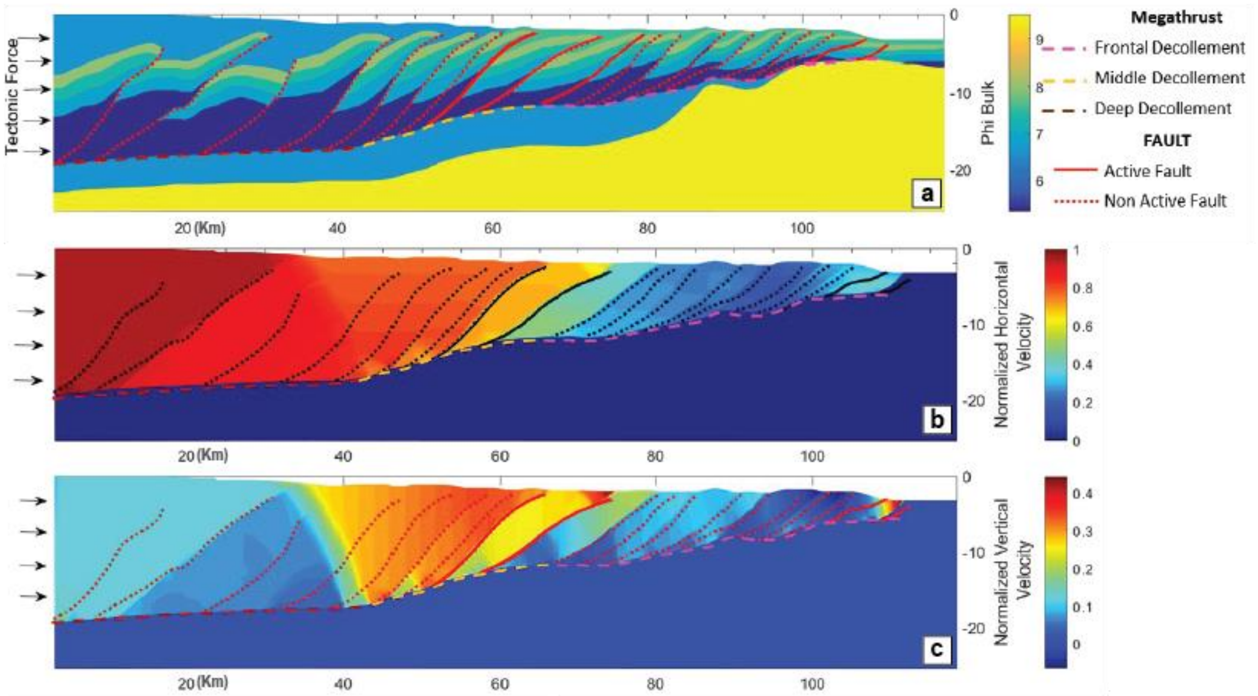
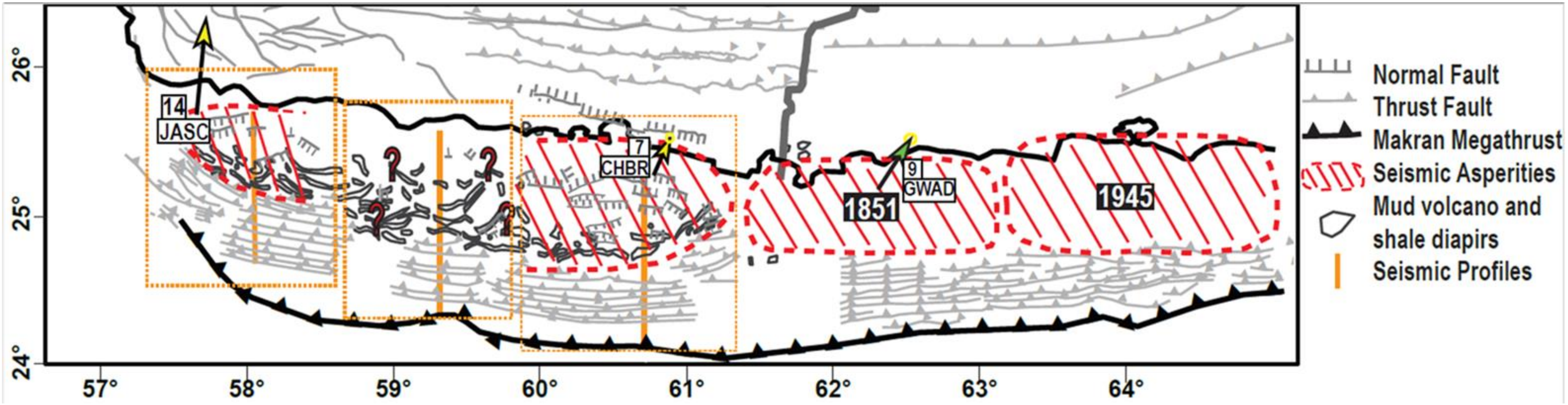




**Fig.** Mechanical modelling of the Central profile

Due to the presence of the seamount and the roughness of the frontal portion of the décollement, an extremely low effective friction is needed along the frontal décollement to propagate the deformation to the front

* Since dynamic effective friction coefficients are significantly lower than frictions at slow slip rate, the region of extremely low friction between the normal fault and the imbricated zone might reveal the location of a seismic asperity.




**Why do we have low friction?**
Is it due to smectite-illite transition?
Is it brittle-ductile transition?

**Why do we have normal faults?**
Are they related to presence of seamount or underplating?

Considering BSR reflector, we have added heat flow as an initial boundary condition which allowed us to apply Brittle-Viscous and smectite-illite transitions.

We use thermally dependant rheology in simulations of accretionary prism where a constant thermal gradient is applied at the base of the model and no horizontal gradient on the vertical walls.

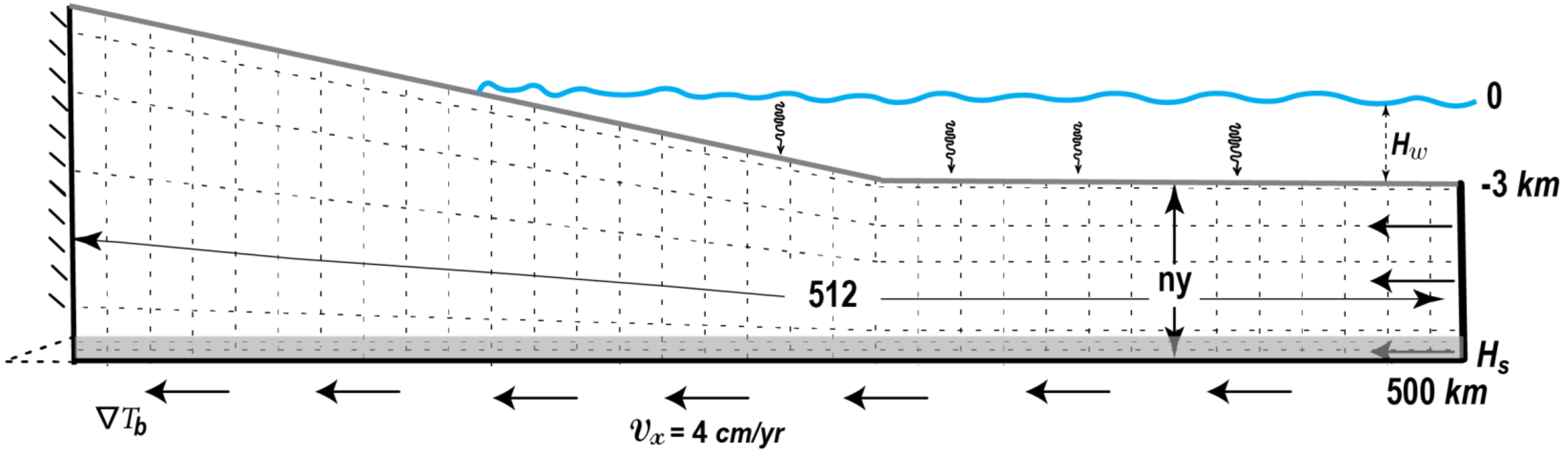



**Fig.** Model setup.

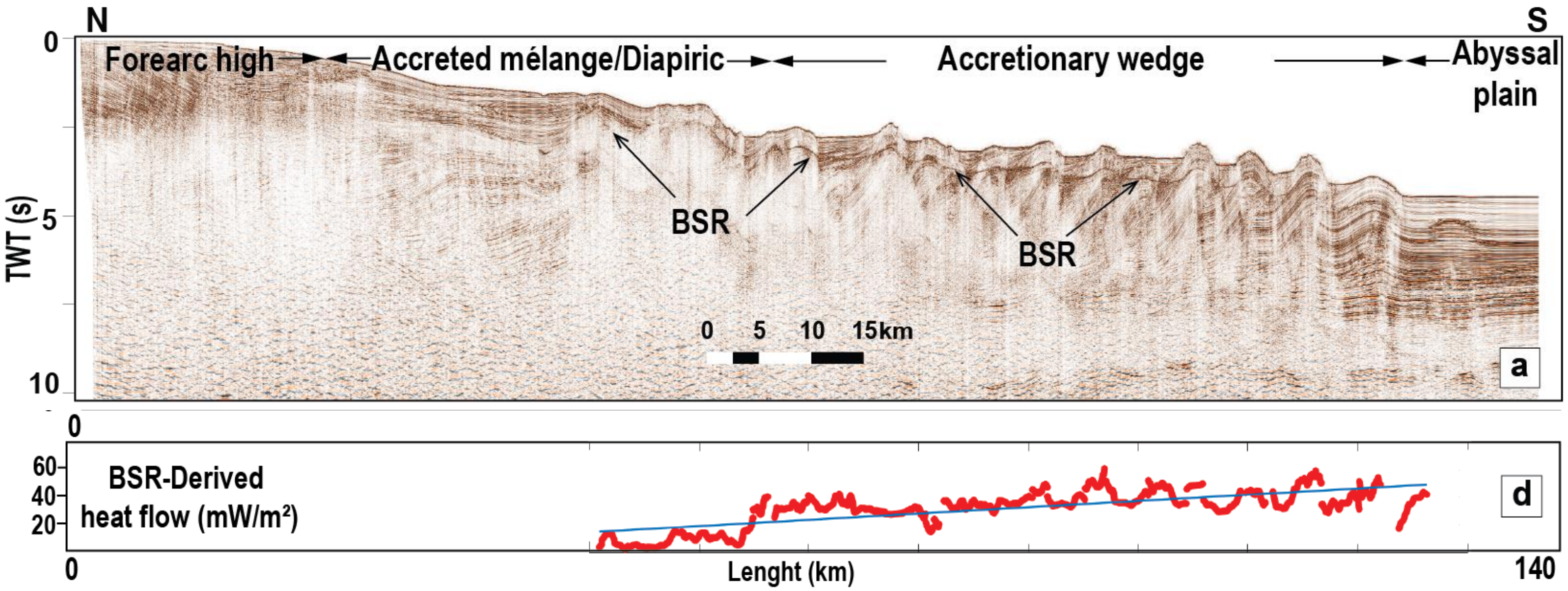
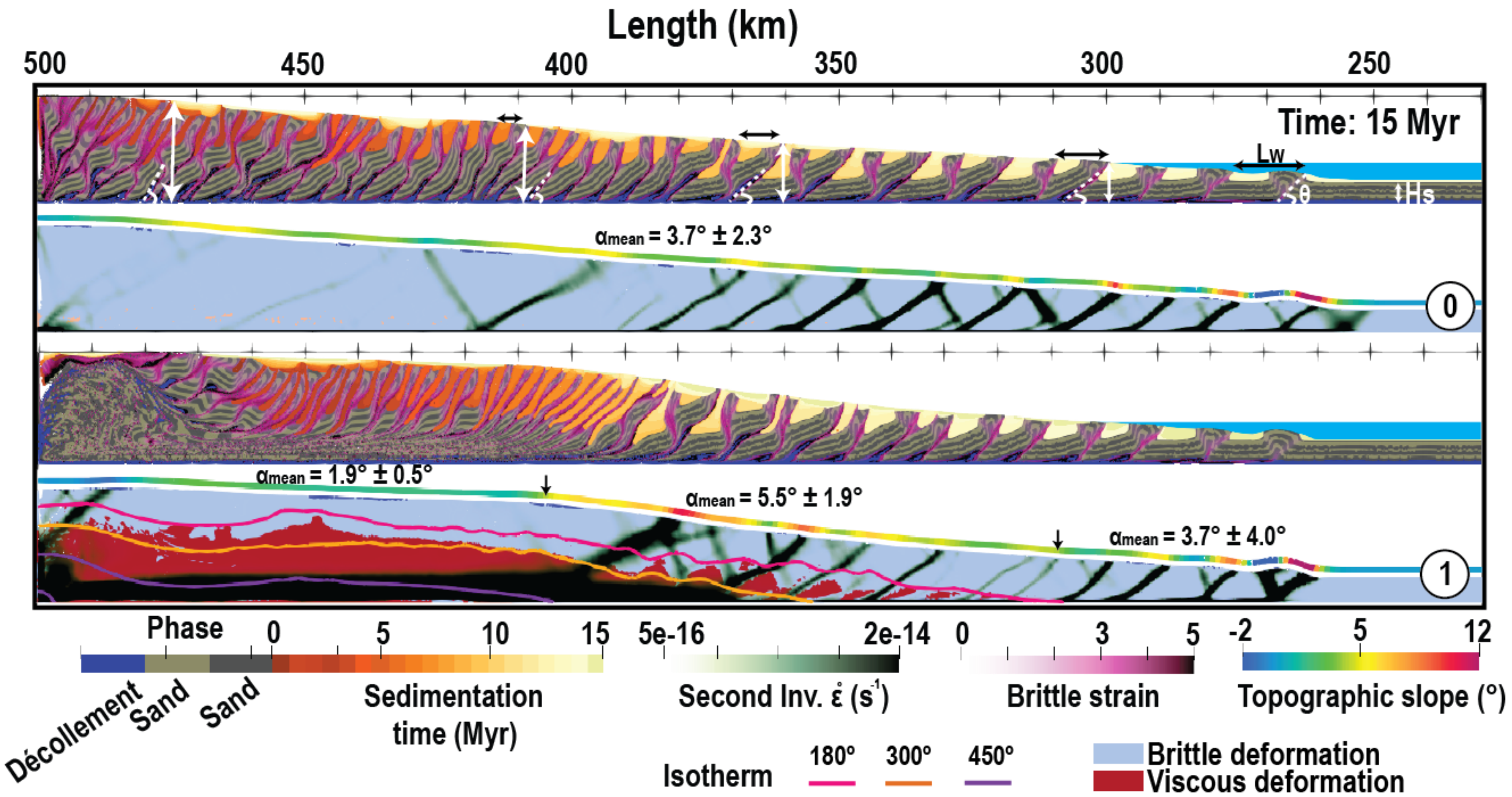



**Fig.** BSR derived heat flow along the eastern profile.

**Fig.** Model 0 : reference model without temperature evolution compared to model 1 with temperature dependant rheology after 15 Myr of shortening. While the frontal part of the two tapers are not significantly different, with similar thrust spacing, as soon as the thickness of the wedge doubles, active back-thrusts take place at the brittle/viscous transition.

In model 1, twinning of slices by back thrust occurs once the base of the model reaches the 300°C isotherm.



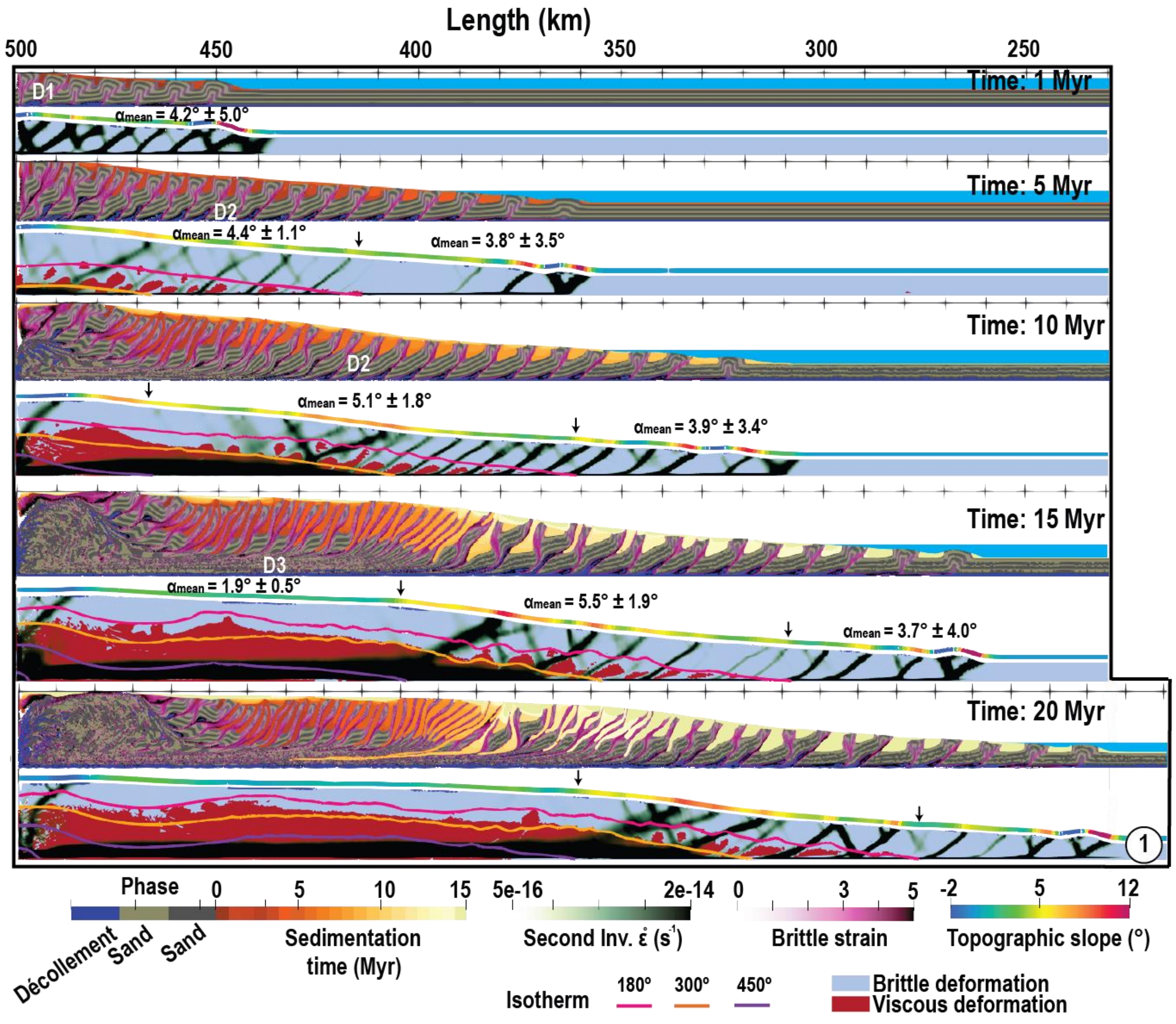
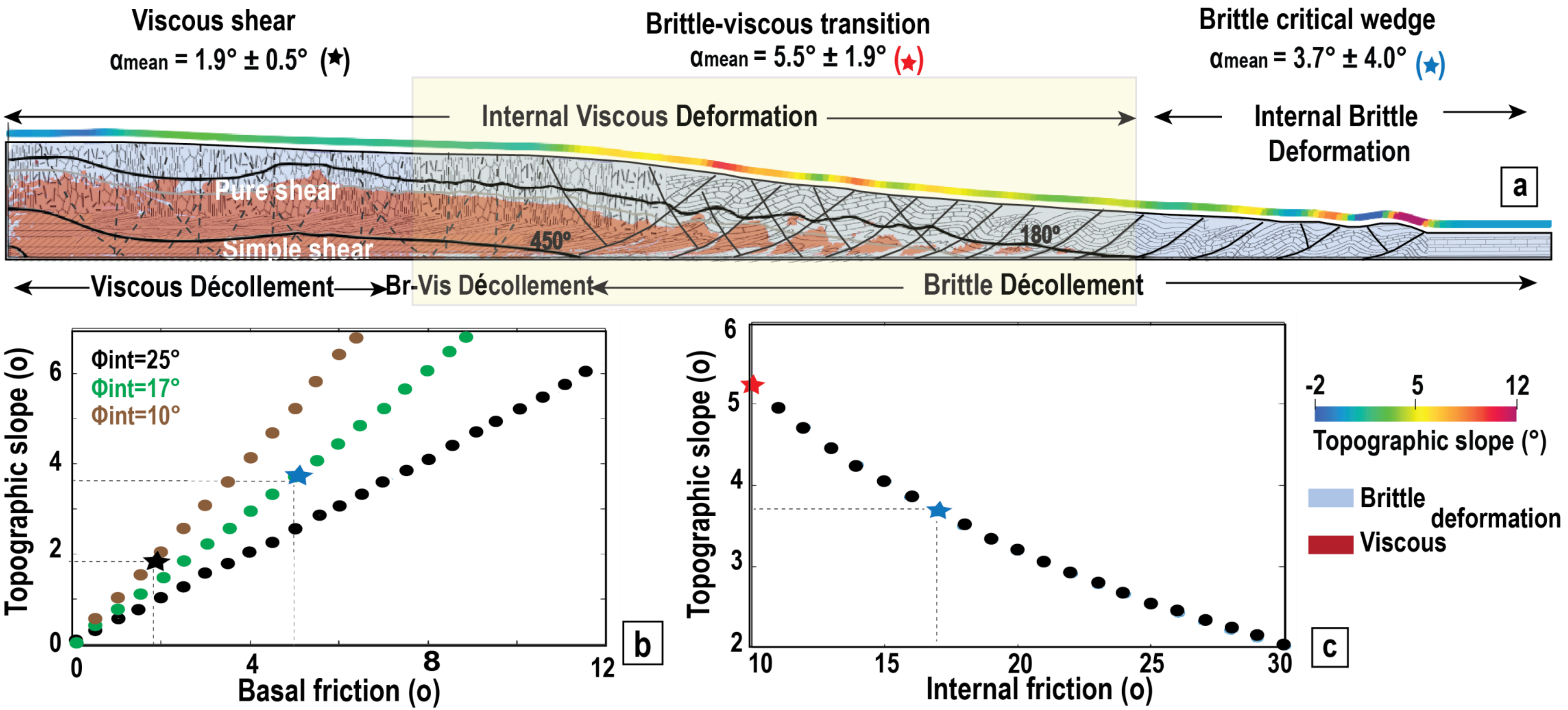



**Fig.** Temporal evolution of the model 1 from beginning to 20 Myr of shortening.




We find that in between the fully ductile prism, where the topographic slope is as expected to be close to zero, and the fully brittle accretionary prism, where the topographic slope follows the critical taper, there exists a segment where faults coexist with ductile penetrative deformation. This segment presents a significantly larger topographic slope which should correspond to a decrease of coupling.

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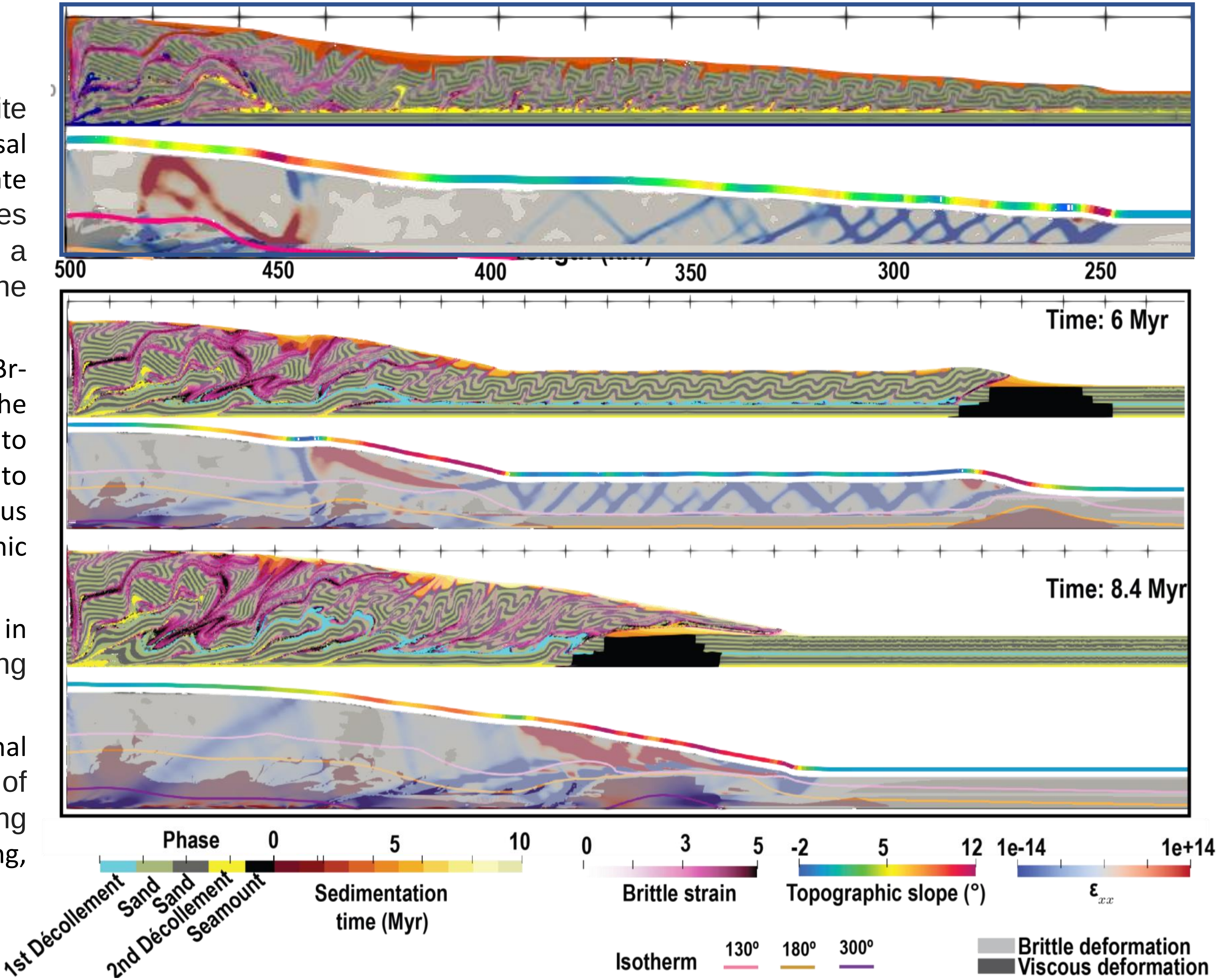
* Although the smectite-illite transition decreases the basal friction, is not capable to create normal faults. However it increases the wedge length, producing a wedge shape similar to the one observed in Makran.

* Underplating caused by the Br-Vis transition and the presence of the second decollement, leads to formation of normal faults rooted to the decollement. Brittle-viscous transition also affects the topographic slope.

* Passing a seamount results in formation of a normal faults rooting down to the decollement.

* The last possibility: the normal fault could result from the release of gravitational energy during earthquakes. We do static modeling, we could not test this hypothesis.



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For more information, you can follow our published paper in Earth and planetary science letter:
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and the paper which is ready to be submitted in Solid Earth in the following days.

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# Seismic hazard of the western Makran subduction zone: Insight from mechanical modelling and inferred frictional properties

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A B S T R A C T

Western Makran is one of the few subduction zones left with a largely unconstrained seismogenic potential. According to the sparse GPS stations, the subduction is accumulating some strain to be released during future earthquakes. To enhance the seismic hazard assessment, we here propose to study the finite deformation of the western Makran accretionary wedge. Mechanical modelling is used to retrieve the spatial variations of the frictional properties of the megathrust, and discuss its seismogenic potential. To do so, we first build a structural map along the Iranian part of the Oman Sea and investigate three N-S seismic profiles. The profiles are characterized by a long imbricated thrust zone that takes place at the front of the wedge. A diapiric zone of shallow origin lies in between the imbricated zone and the shore. Along the eastern and western shores, active listric normal faults seem to root down to the megathrust. Eastern and western domains have developed similar deformation, with three zones of active faulting: the normal faults on shore, thrusts ahead of the mud diapirs, and the frontal thrusts. On the contrary, no normal faults are identified along the central domain, where a seamount is entering into subduction. Two mechanical analyses are performed to retrieve the frictional properties of the megathrust. We first apply the critical taper theory to constrain the pore fluid pressure of the wedge. We then apply the limit analysis on two selected profiles. Along the eastern profile, a transition from very low to extremely low friction is required to activate the large coastal normal fault ($\mu^{eff}_{deep}$ = 0.01-0.06, $\mu^{eff}_{middle}$ = 0.003-0.012). To propagate the deformation to the front, an increase of friction along the imbricated zone is necessary ($\mu^{eff}_{front}$ = 0.017-0.031). The method could not be applied on the incomplete western profile. However, since the deformation is similar to the eastern profile, the same transitions of friction are expected. The Central domain is also characterized by very low effective friction; but, the absence of normal fault does not allow to evidence any frictional transition.
Since dynamic effective friction coefficients are significantly lower than frictions at slow slip rate, the region of extremely low friction between the normal fault and the imbricated zone might reveal the location of a seismic asperity. The difference in deformation along strike would thus reveal the existence of two different asperities, one along the eastern domain and a second along the western domain. Since no earthquake have occurred in the region for, at least, the last 1000 years, an event of large magnitude may strike the Iranian Makran, in particular the Eastern domain.