EXTENSION

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Failles normales au niveau du rift est-africain

Les zones en extension

Baïkal, Est-Africain, Tibet, Basin & Range, Egée, Mexique…

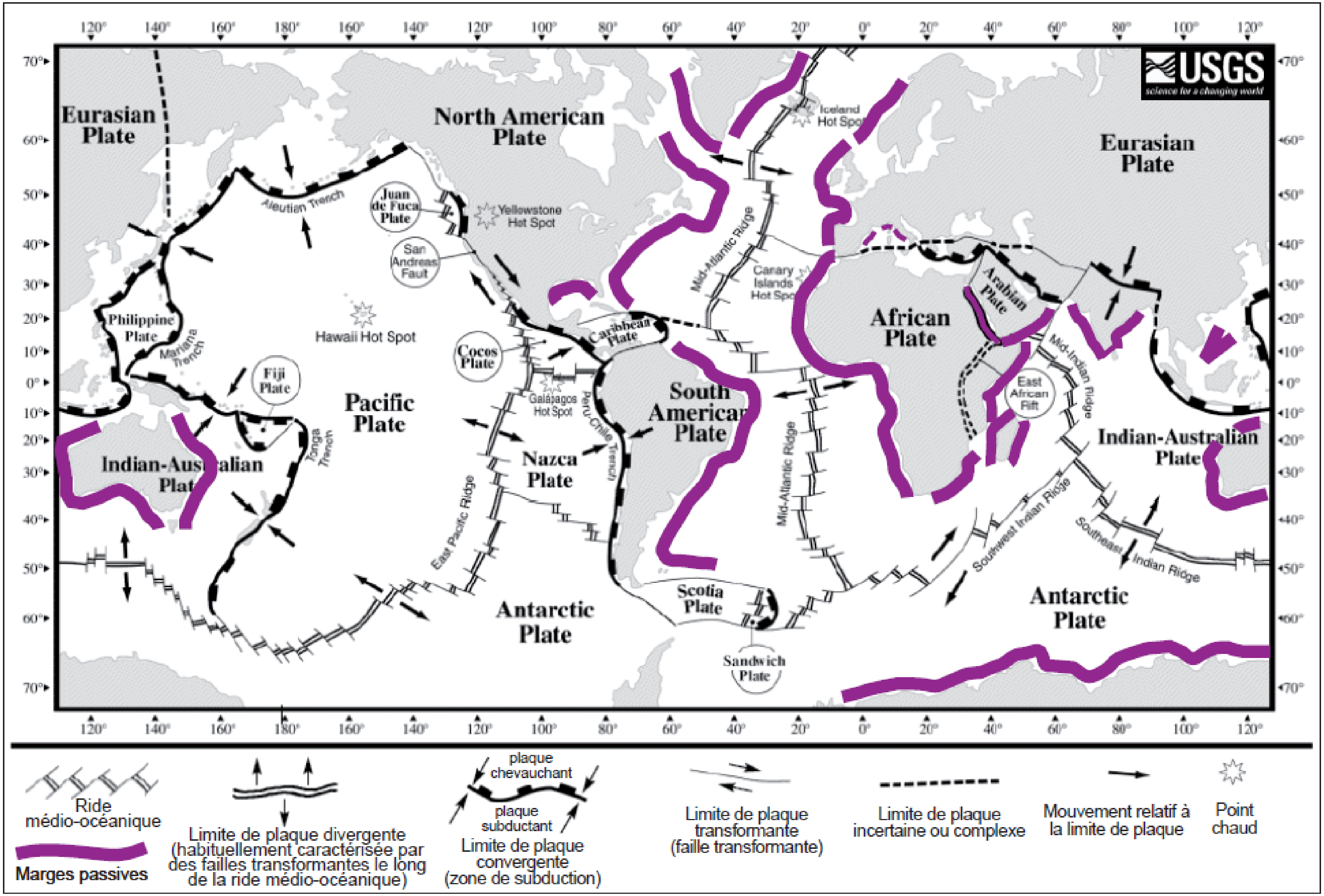


Figure 1. Carte tectonique des limites de plaques montrant la localisation des marges passives à travers le monde au sein des zones géodynamiquement stables. *Image modifiée de USGS.*

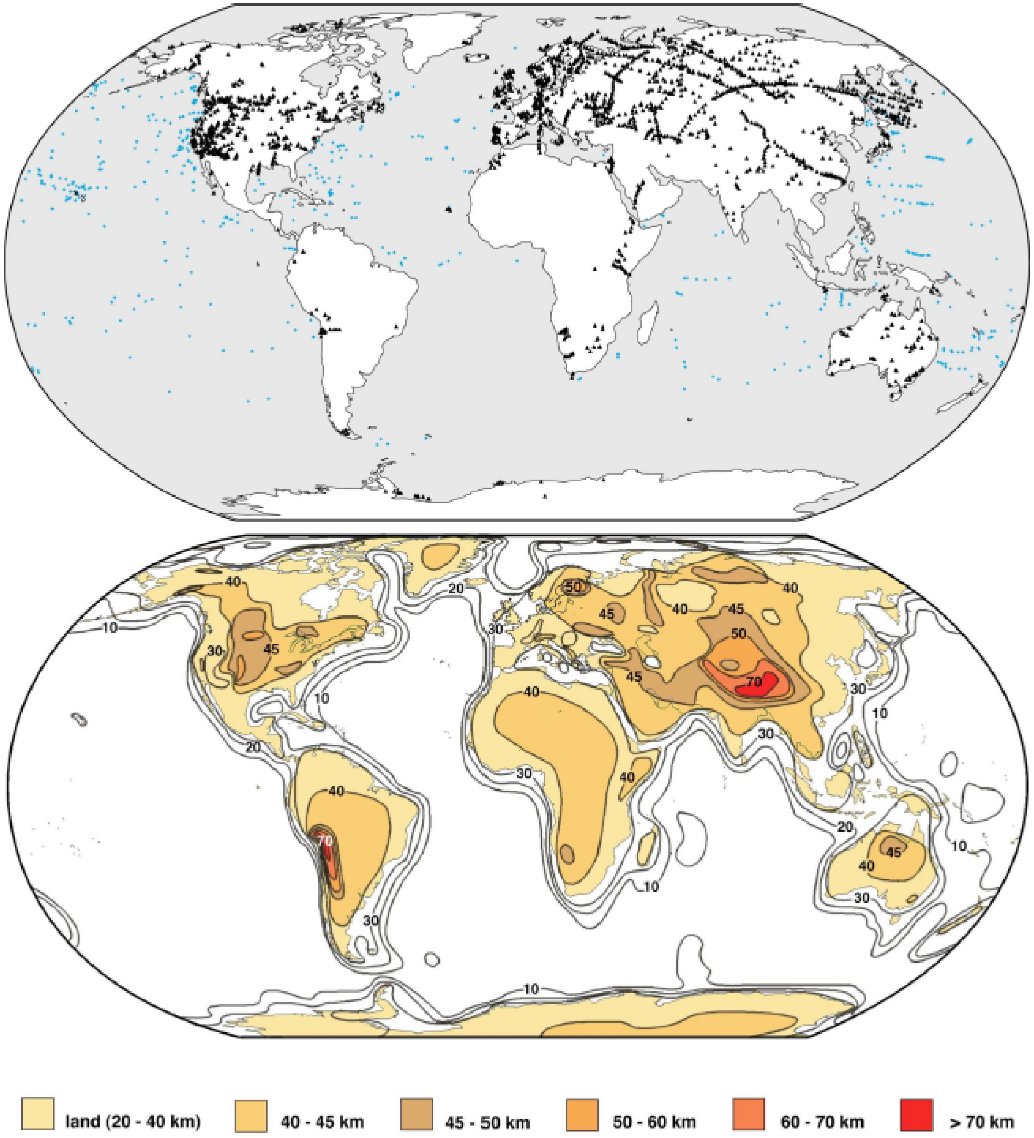
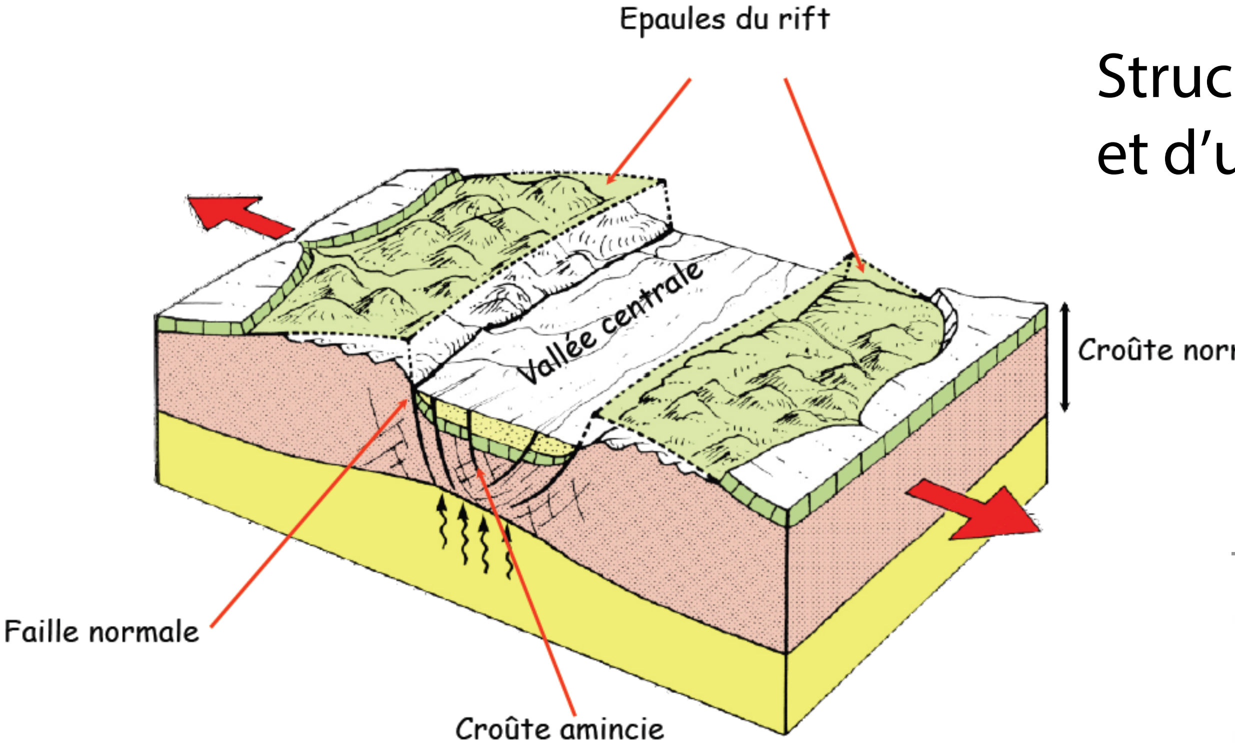


Fig. 1.16: *Carte mondiale des épaisseurs de croûte continentale (Mooney* et al.*, 2002), déduite des points de mesures de sismique réfraction à terre (triangles noirs) et en mer (points bleus).*

- Il existe des rifts dans des zones où la croûte est soit épaisse, soit amincie

Structure générale d'un rift et d'une marge passive



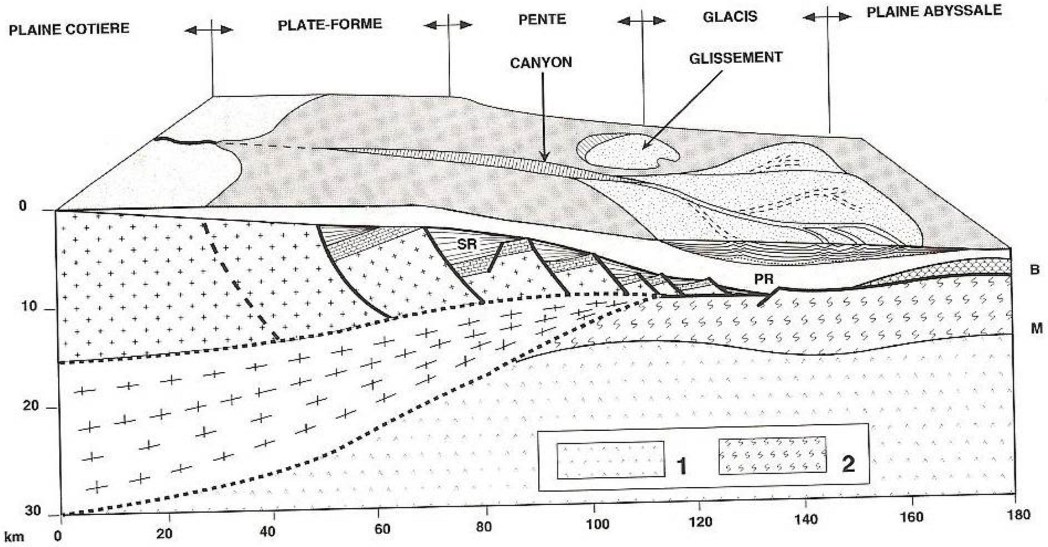
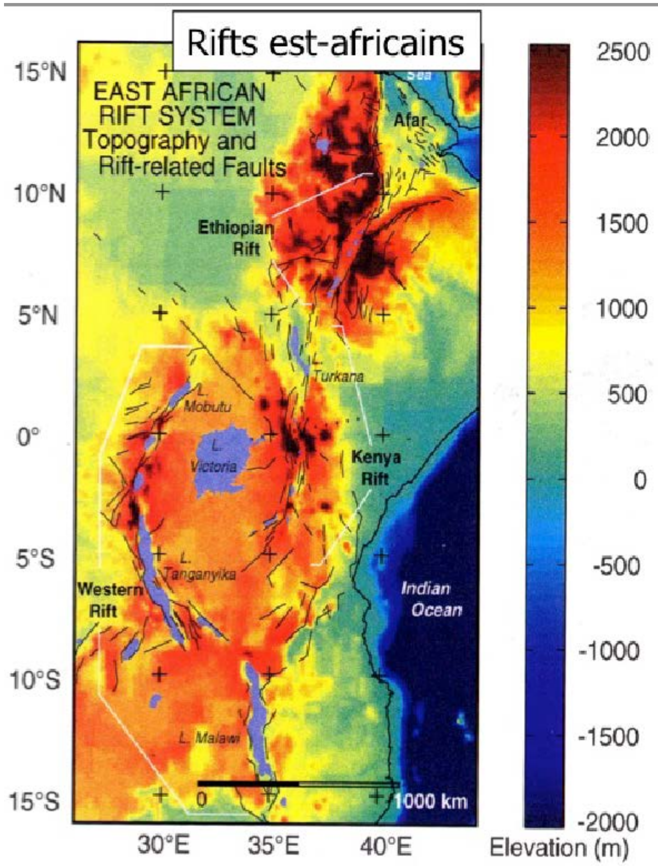


Fig. 1.14 Morphologie et structure superficielle d'une marge passive de divergence non volcanique. 1 : péridotite fraîche du manteau; 2 : péridotite partiellement serpentinisée. B : basalte océanique; M : Moho. La structure crustale est expliquée dans les chapitres II et III.

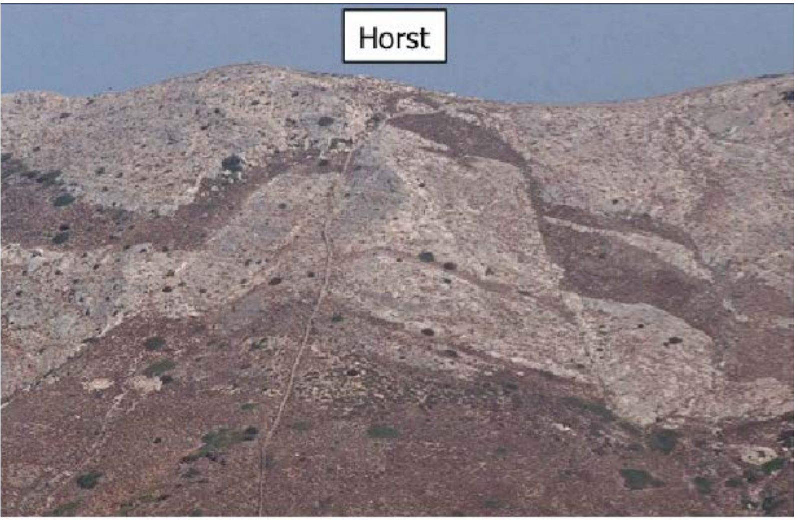
Topographie



Structures extensives : diversité

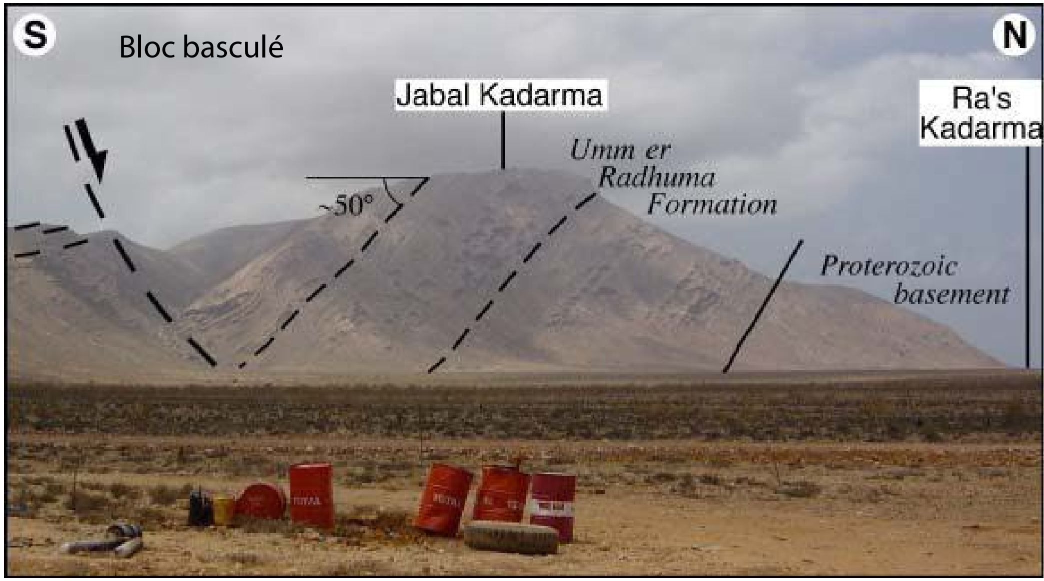
- *Mode de mise en place?*

Failles normales, rift est-africain



Horst

Graben



Bloc basculé

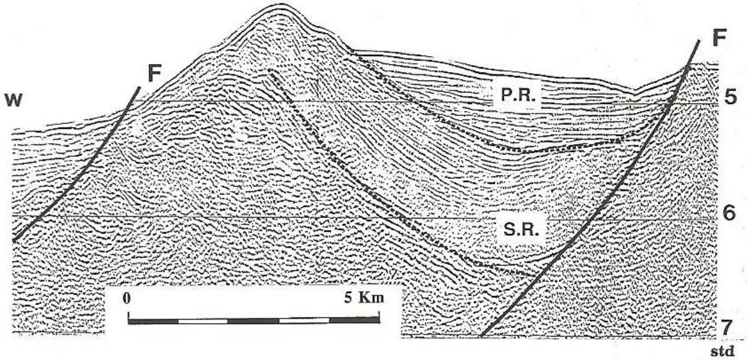
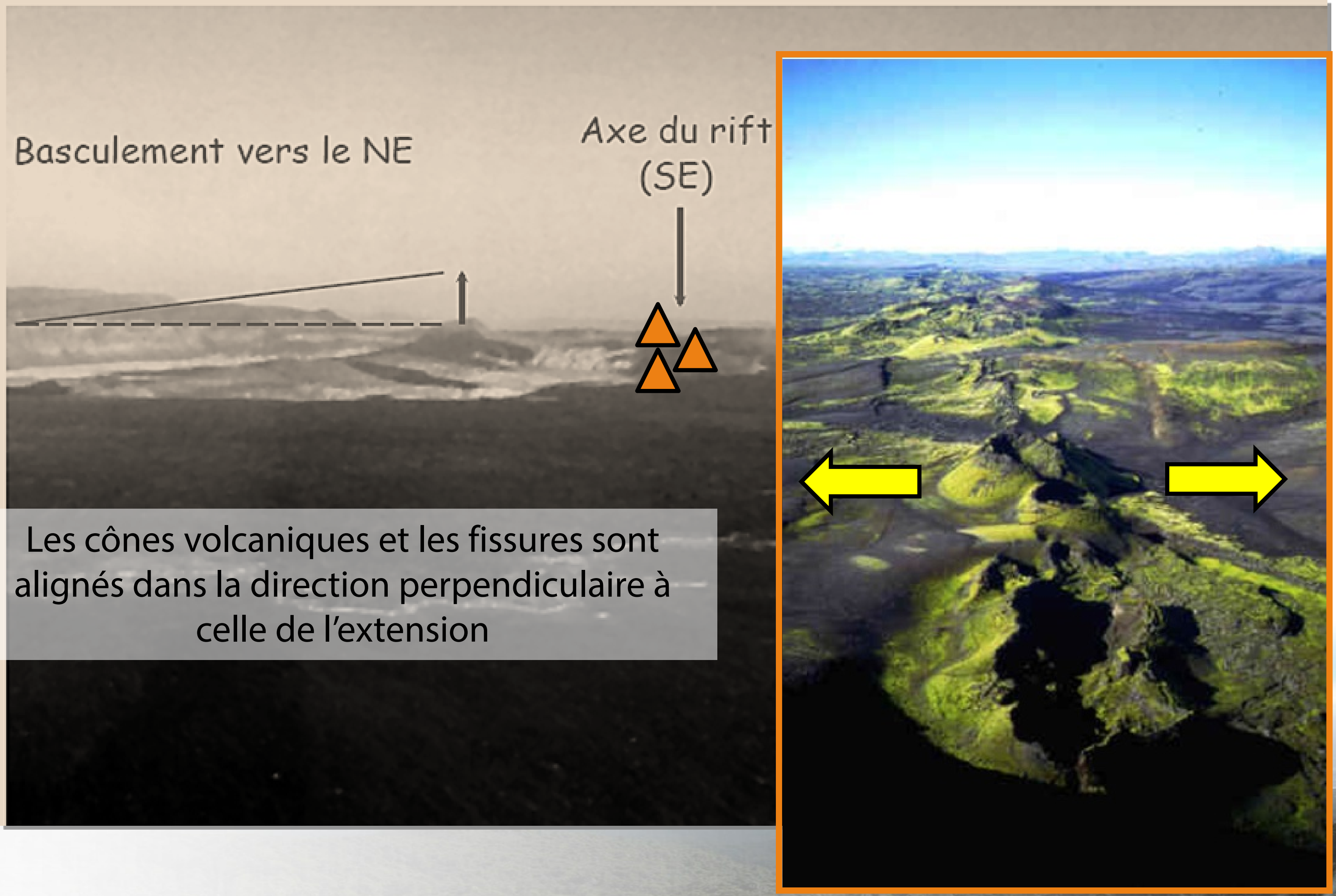


Fig. 2.4 Image sismique du bloc et du bassin situés en haut de la coupe de la fig. 2.1, entre les points de tirs 3300 et 3700 (échelle verticale en secondes, temps double). P.R. : sédiments post-rift; S.R. : sédiments syn-rift; F : failles normales entre les blocs crustaux basculés. std : secondes, temps double.

Volcanisme
rift est-africain

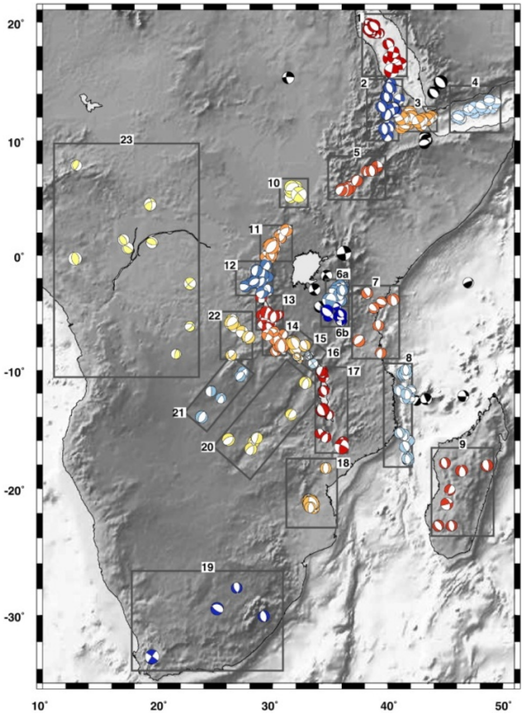


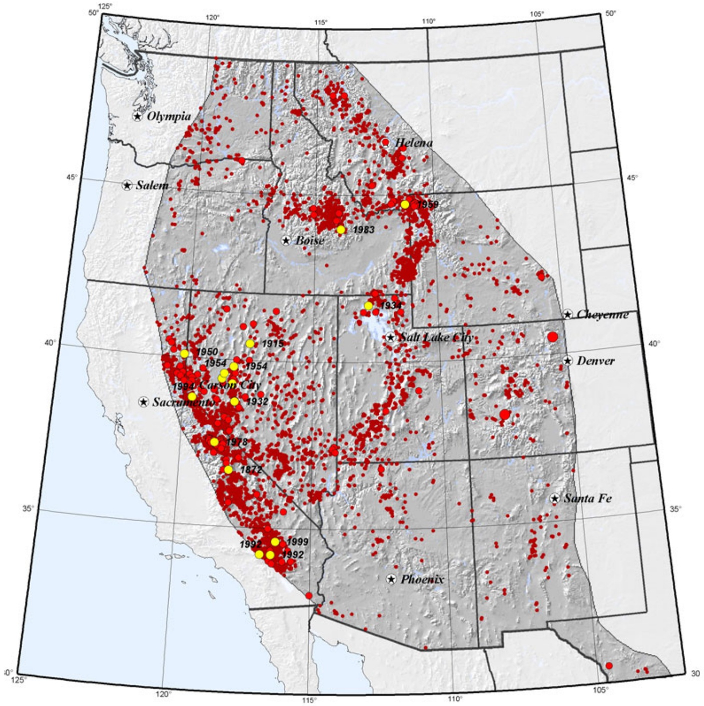
Les cônes volcaniques et les fissures sont alignés dans la direction perpendiculaire à celle de l'extension

Rift étroits et rifts étendus


Rift Est-africain

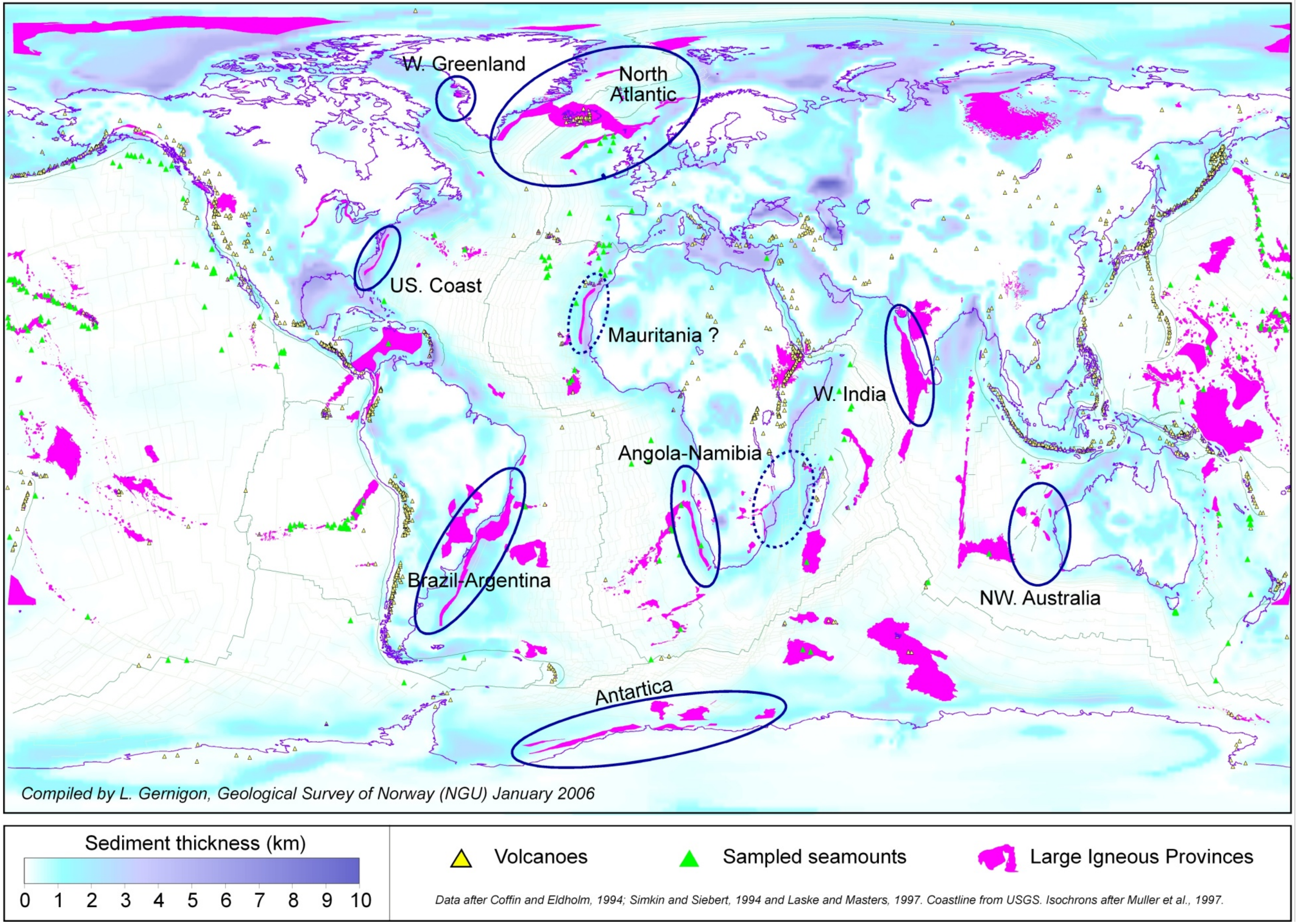

Basin & Range, USA





- ➢Diversité des modes de rifting : origine?

Marges volcaniques et non volcaniques

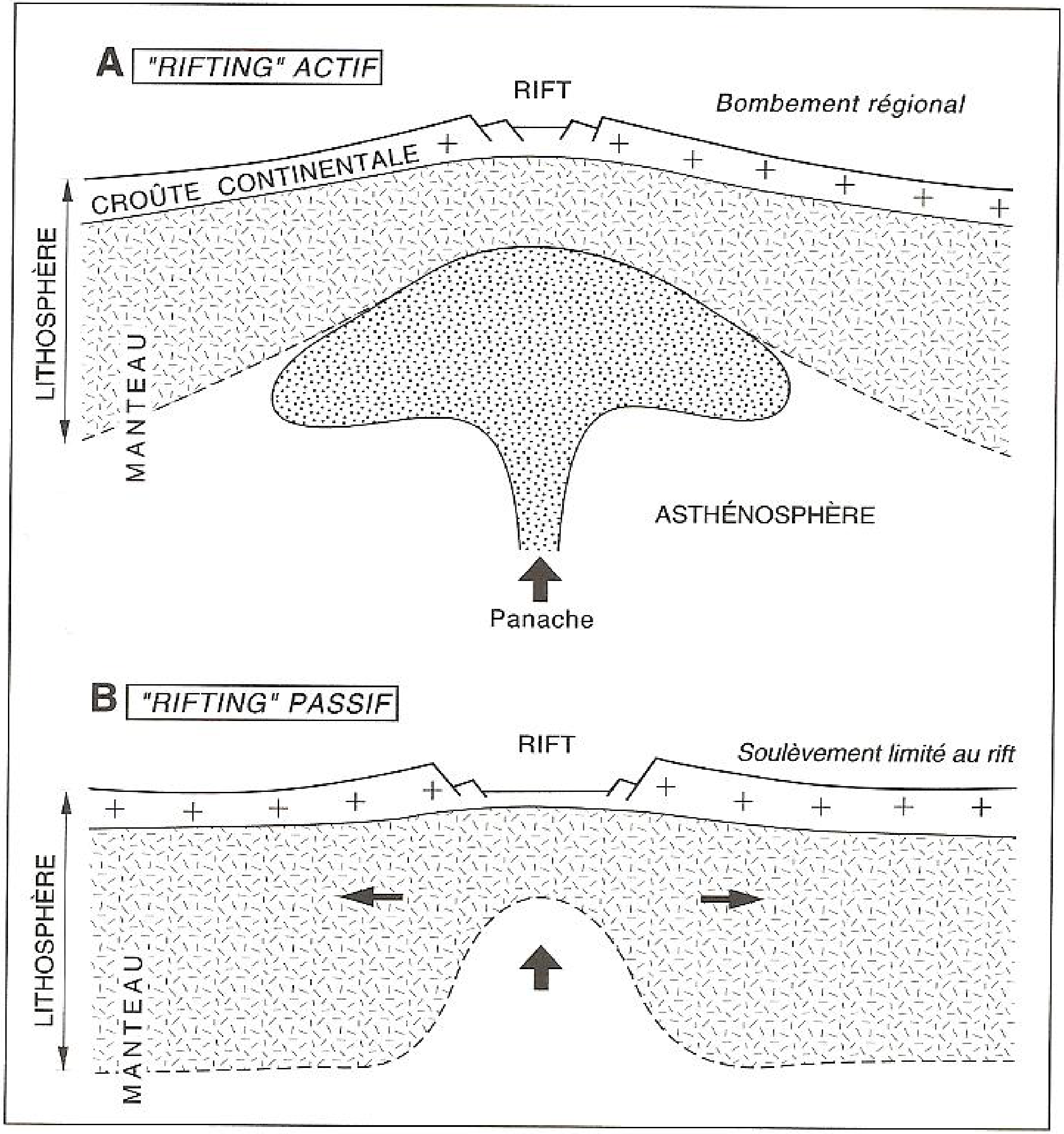


World sedimentary basins, Large Igneous Provinces and distribution of volcanic rifted margins

Compiled by L. Gernigon, Geological Survey of Norway (NGU) January 2006

Data after Coffin and Eldholm, 1994; Simkin and Siebert, 1994 and Laske and Masters, 1997. Coastline from USGS. Isochrons after Muller et al., 1997.

- ➢Rôle des panaches mantelliques et du volcanisme dans le rifting et la déchirure continentale?



g. 8.2 Les deux modèles de rifting (d'après Keen, 1985 ; Wilson, 1989).

EXTENSION

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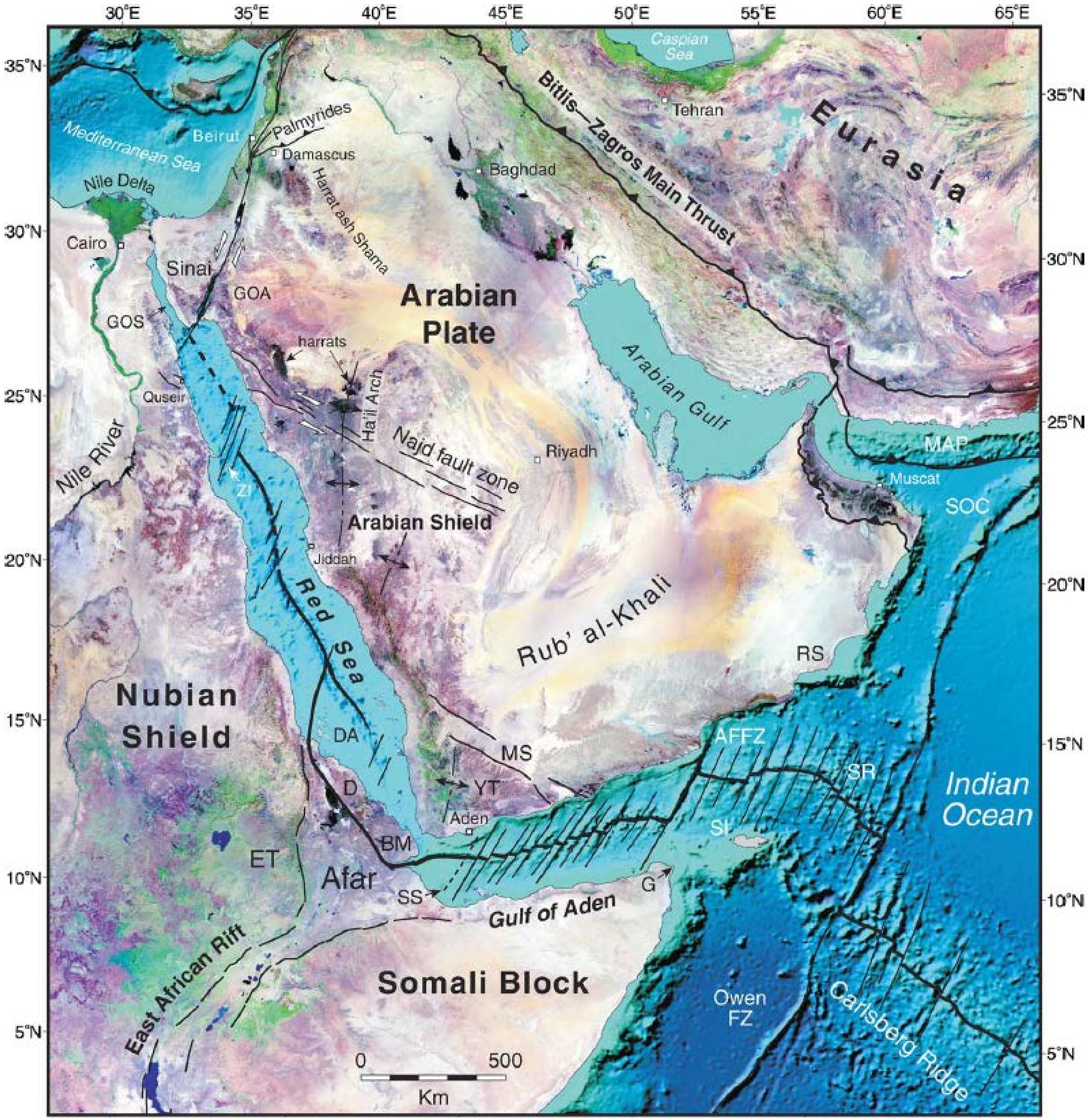
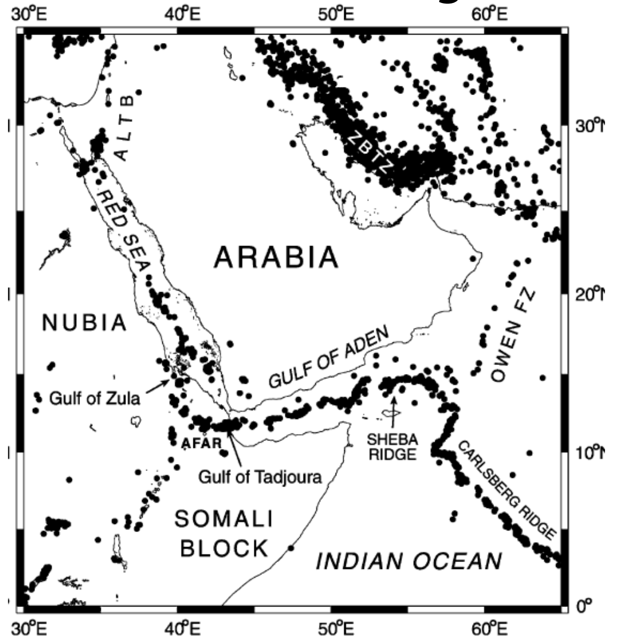
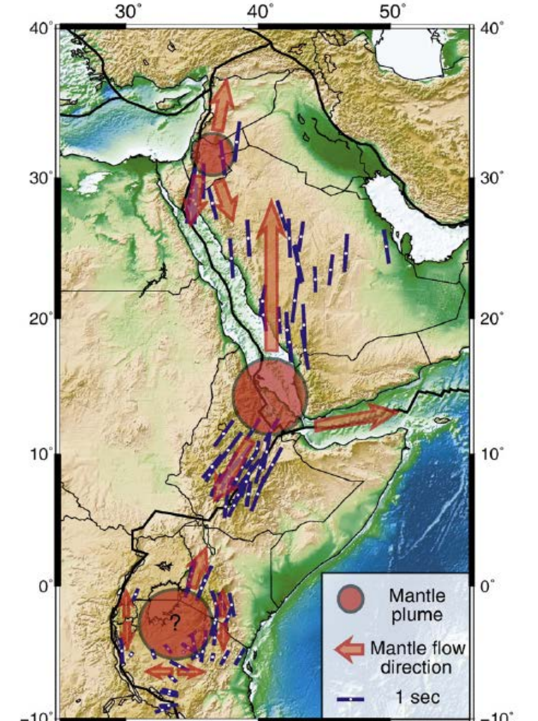
Failles normales au niveau du rift est-africain

Du rifting continental à l'ouverture océanique : le système rift africain, mer Rouge, & golfe d'Aden

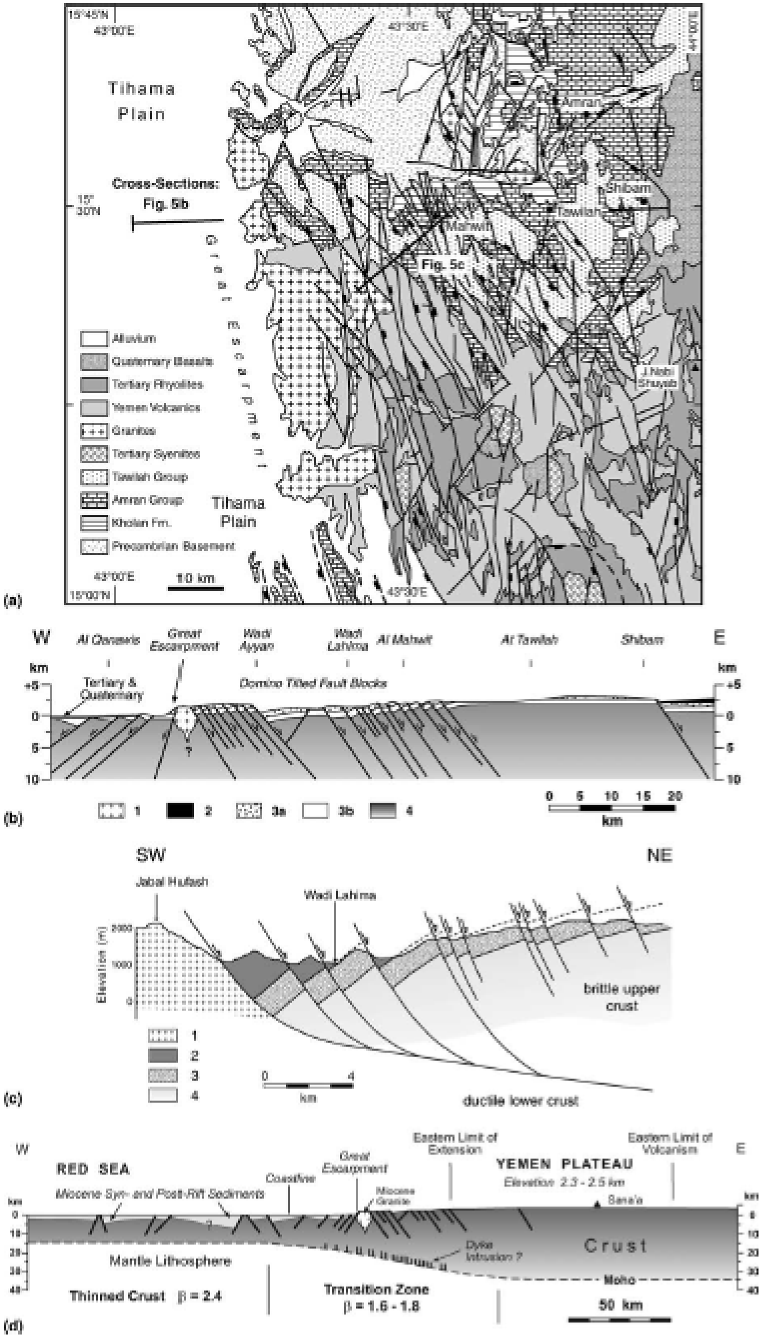






Bosworth et al., J. Arab. Geosci., 2005
Chan and VanderLee, EPSL, 2011

Mer Rouge : marge du Yemen



Mer Rouge : marge du golfe de Suez

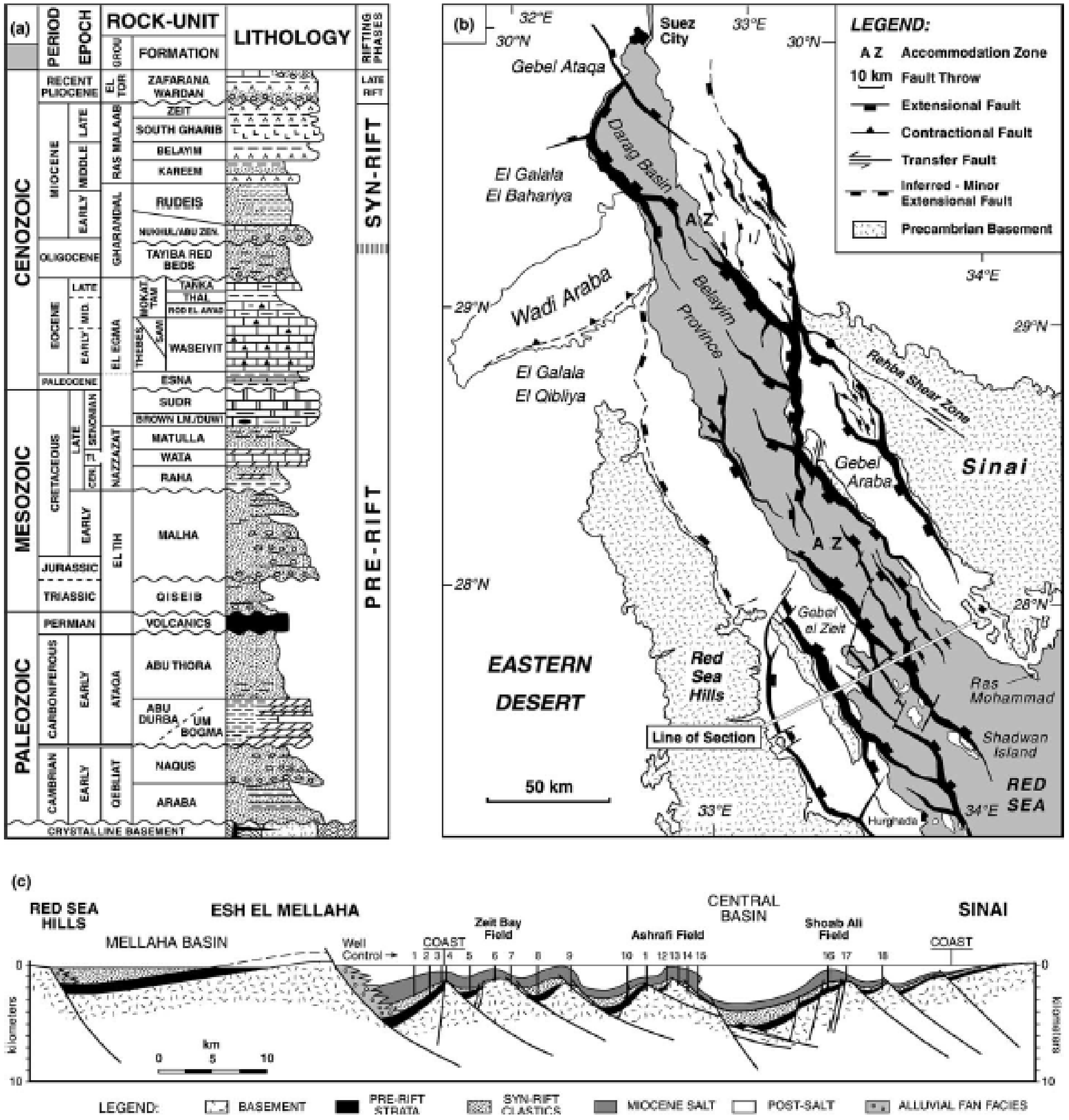
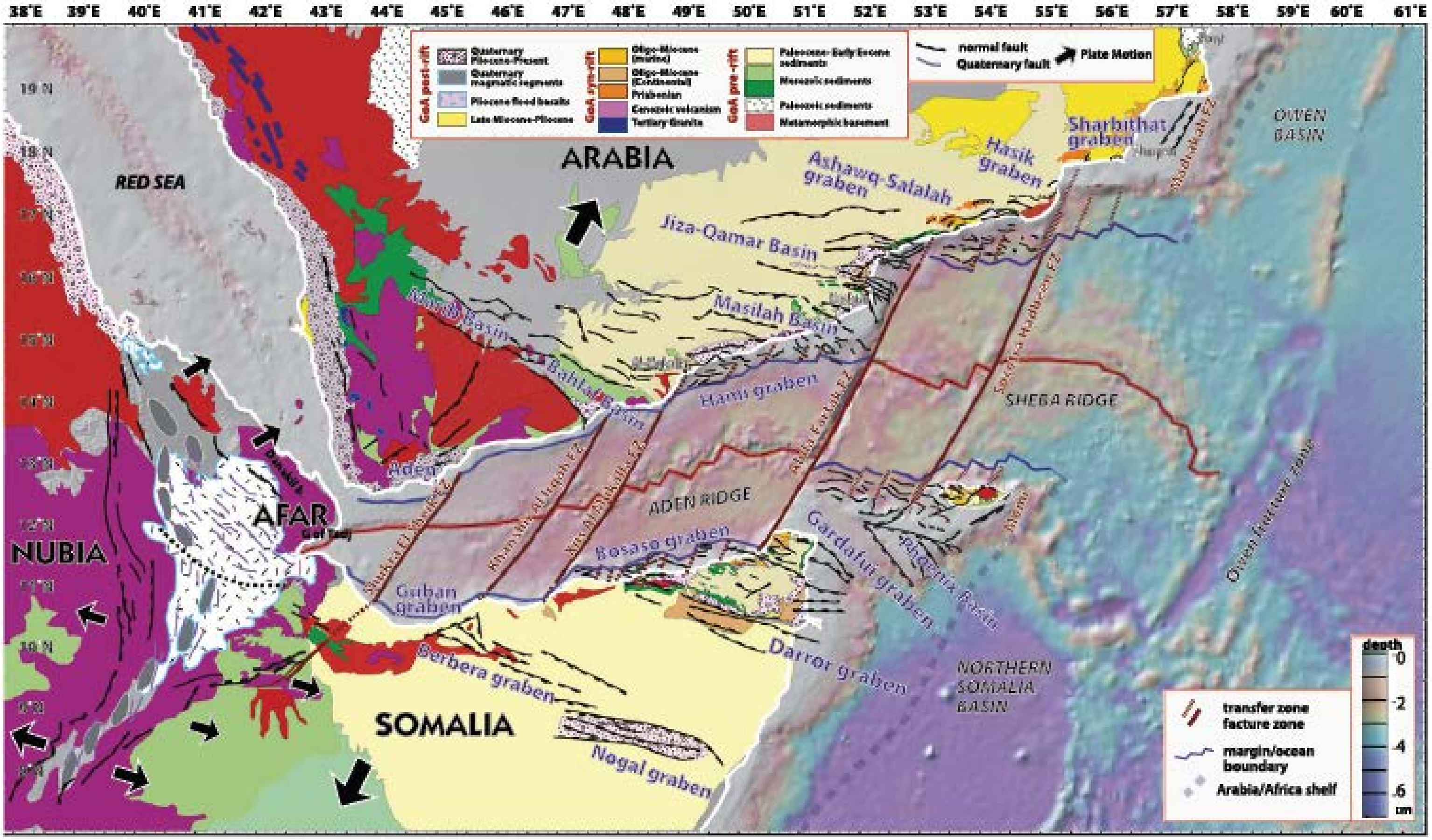


Fig. 8. Stratigraphy and structure of the Gulf of Suez: (a) detailed stratigraphic nomenclature and lithologies (after Darwish and El Araby, 1993; Bosworth and McClay, 2001); (b) principal basement faults, with width proportional to throw (after Khalil, 1998; Bosworth and McClay, 2001). Wadi Araba is a pre-rift, Late Cretaceous age anticline; (c) cross-section across the southern Gulf, illustrating rotated fault block geometry that is thought to be representative of the early phases of Red Sea rifting (after Bosworth, 1994).

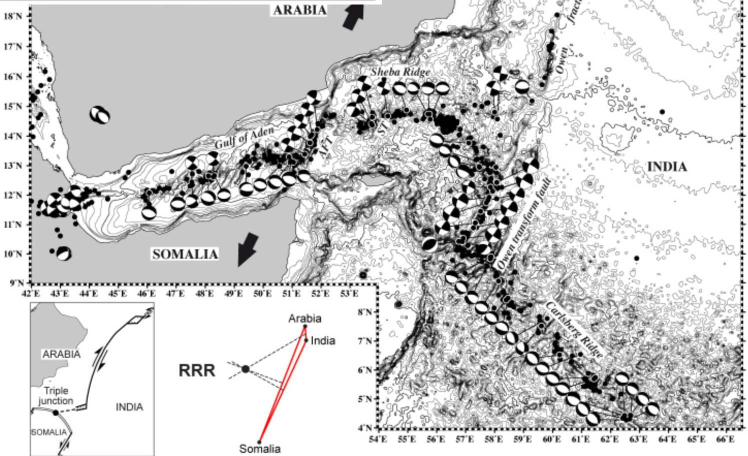
Bosworth et al., J. Arab. Geosci., 2005

Golfe d'Aden

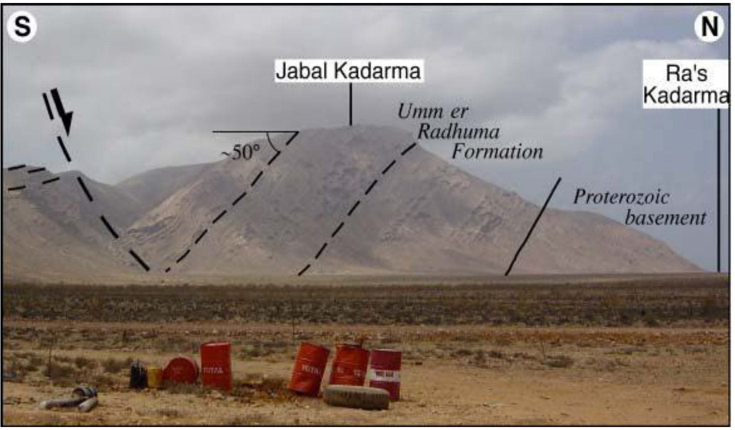


Leroy et al., J. Arab. Geosci., 2010

Fournier et al. EPSL, 2001



Blocs basculés à terre…et en mer



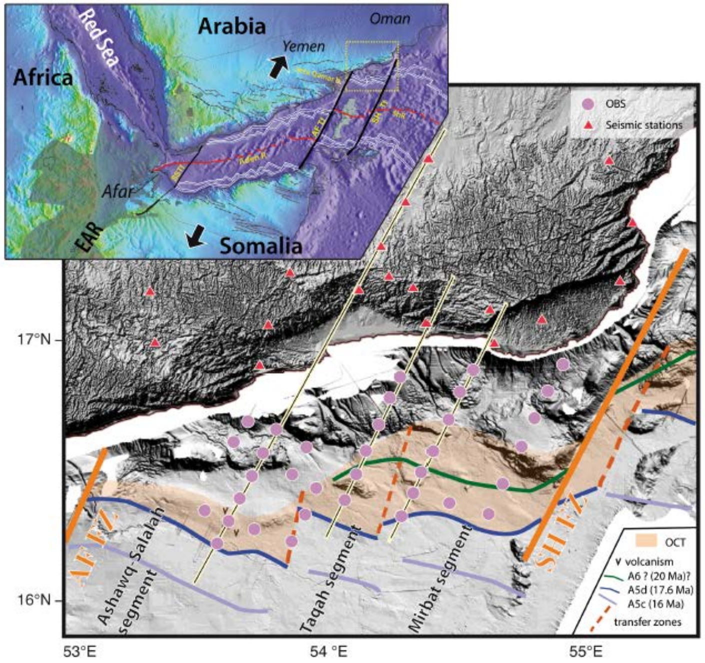
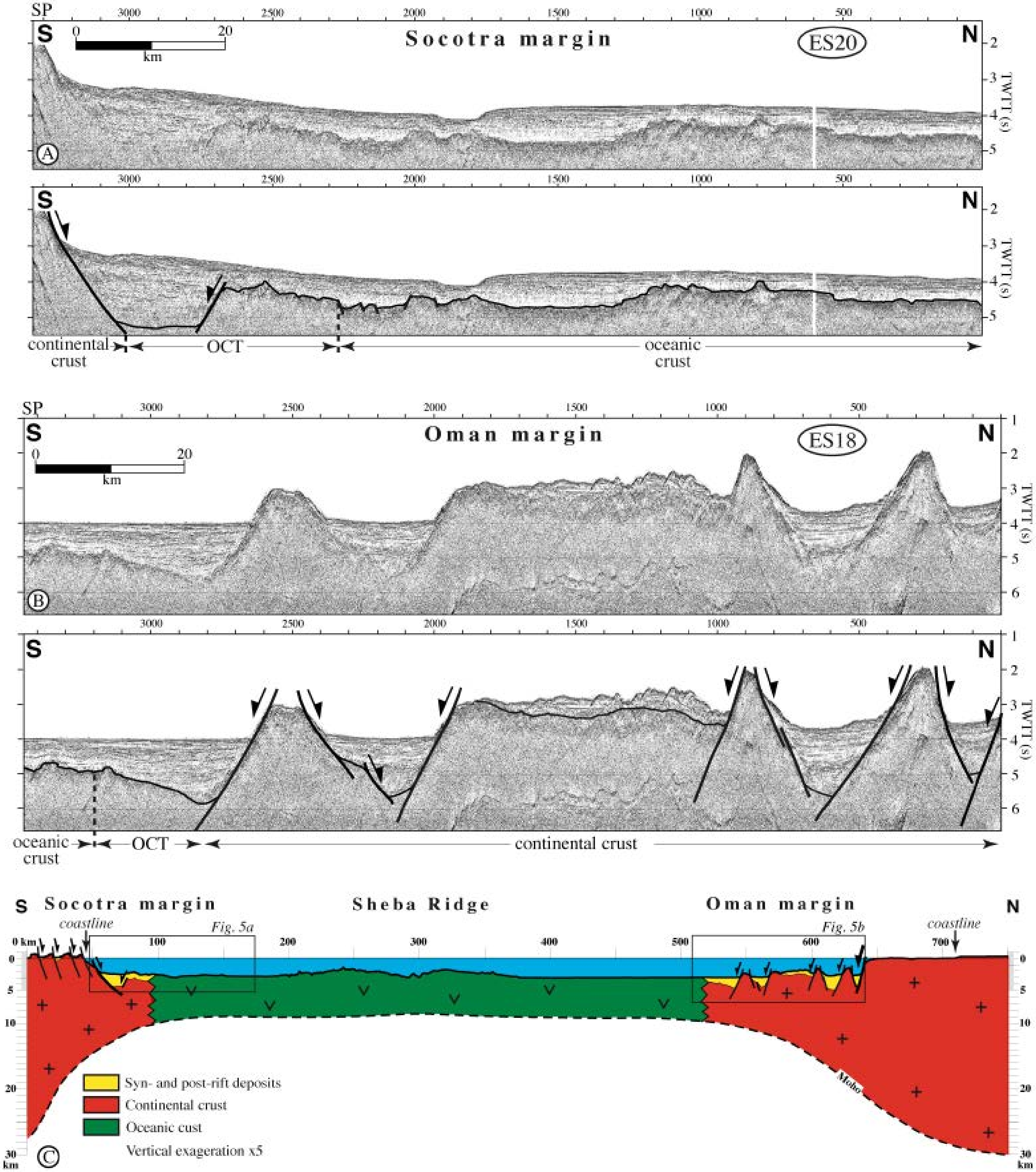
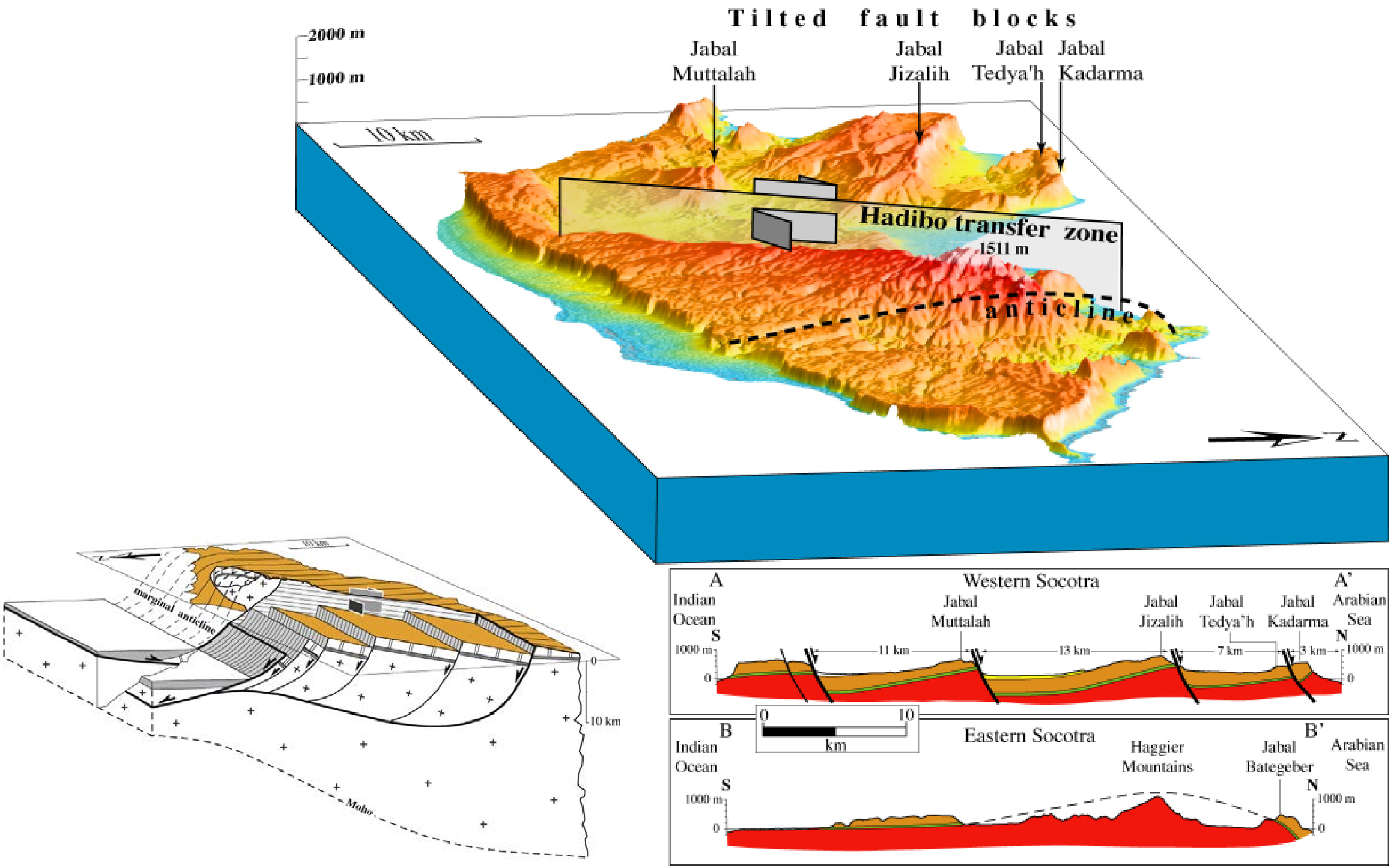


FIG. 2.10: *Carte de la marge nord-est du golfe d'Aden (Leroy et al., 2010b). Les*



Fournier, Hdr, 2009

Diversité structurale des marges du golfe d'Aden



Fournier, Hdr, 2009

Diversité structurale des marges du golfe d'Aden

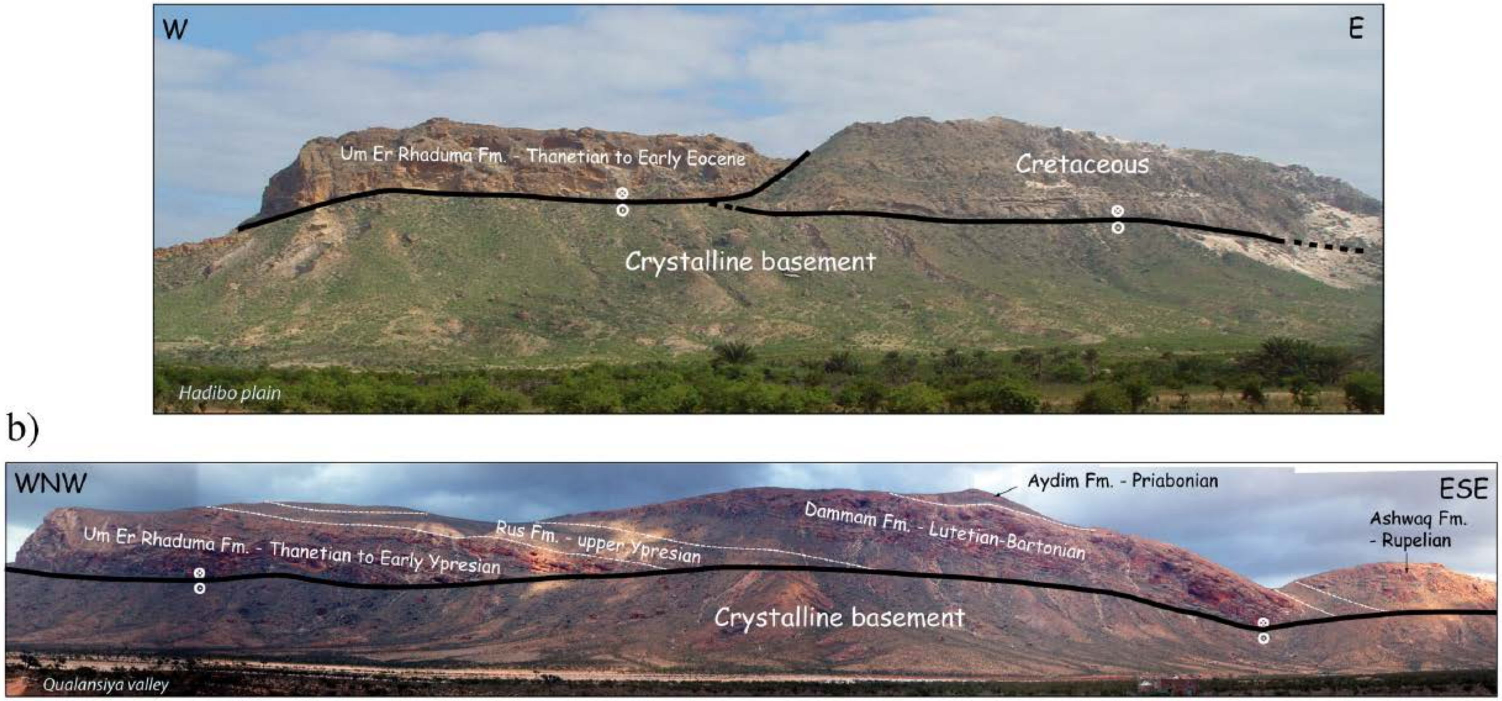
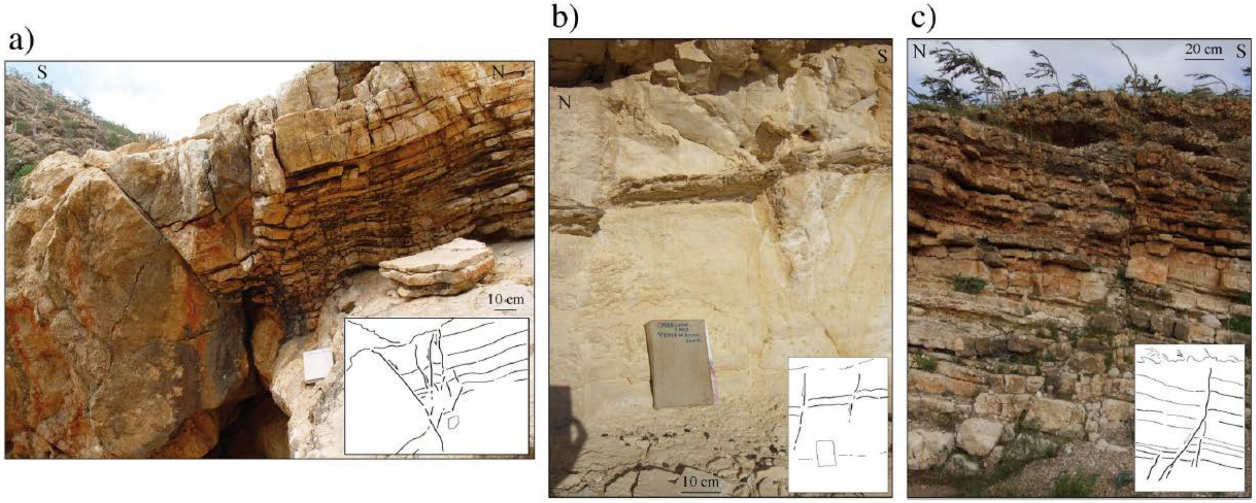


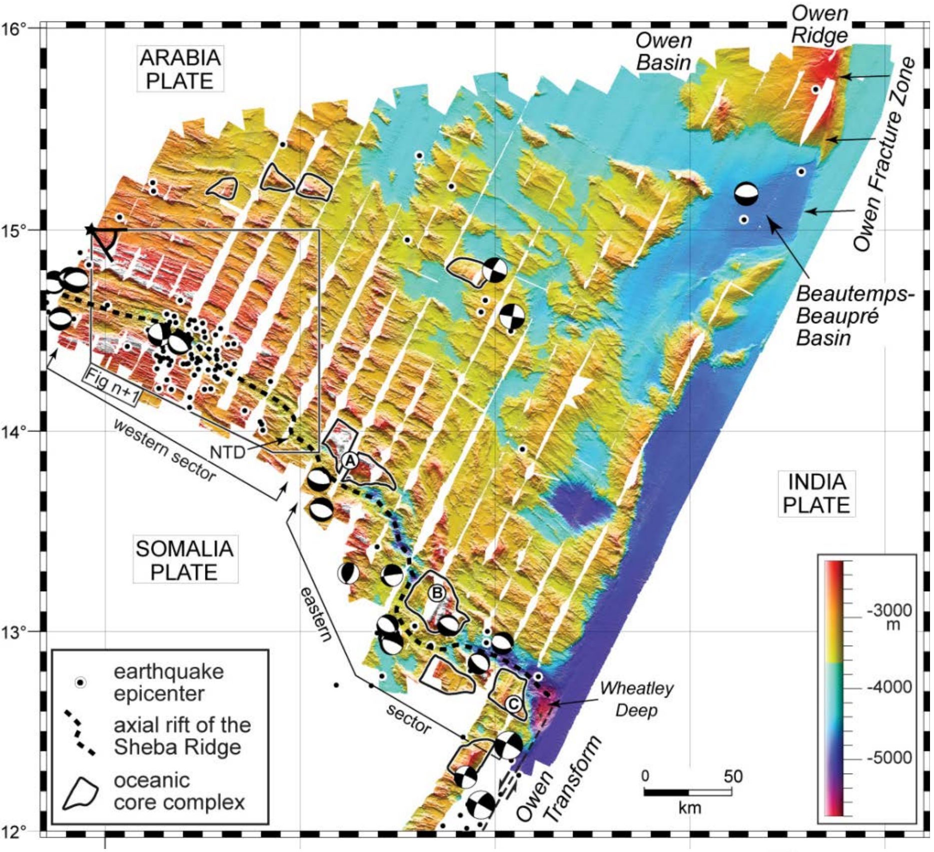
Fig. 6. Field photos of low-angle normal fault segments. a) East of Hadibo (Figs. 3 and 9). Eocene Umm Er Radhuma and Cretaceous limestone over low-angle normal faults, with basement rocks in the footwall. b) East of Qalansya (Figs. 3 and 5). Tertiary sedimentary rocks above low-angle normal fault with basement rocks in the footwall. The cliff is about 500 m high.

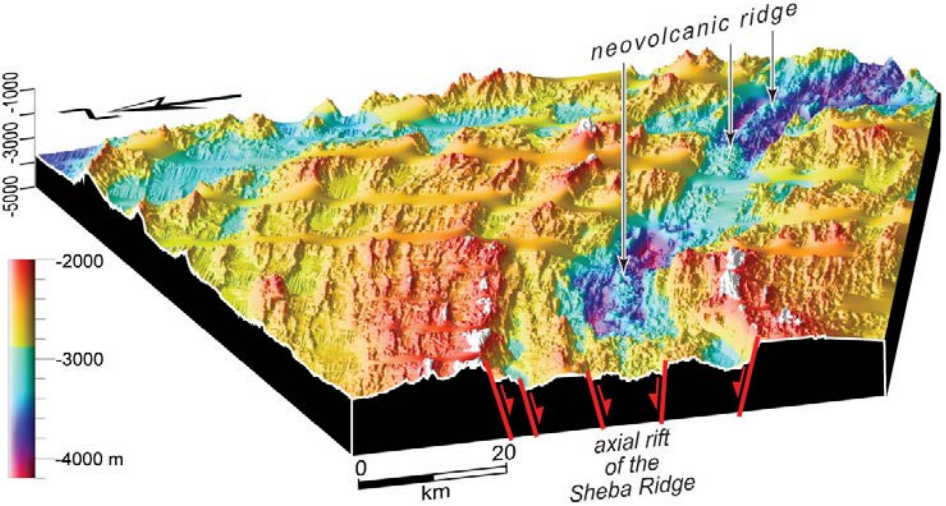


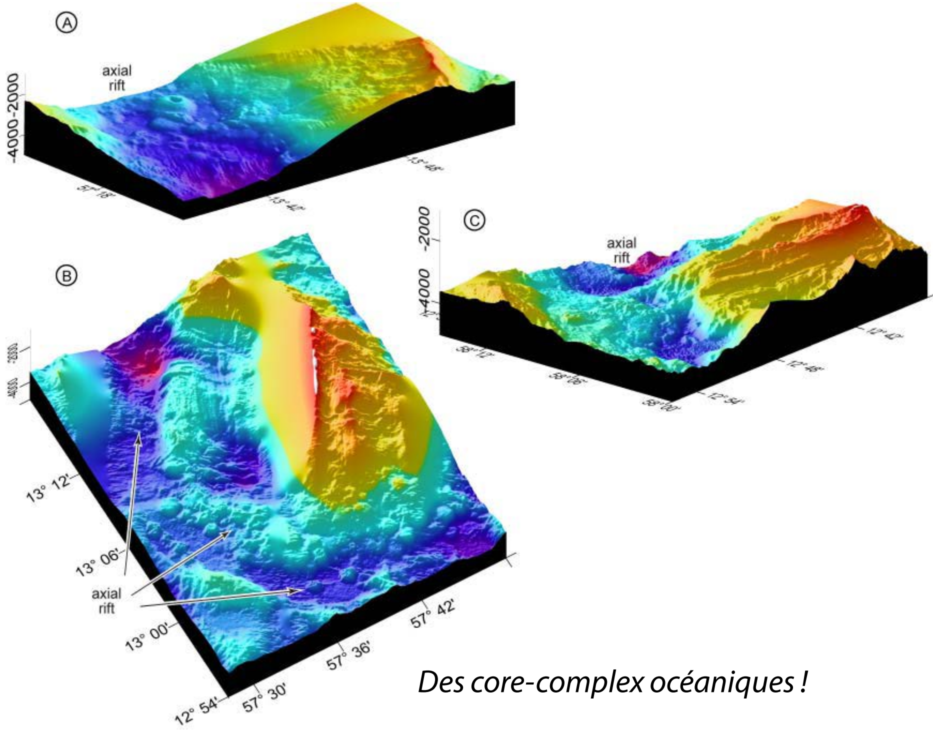
Bellahsen et al.,
Tectonophysics, 2013

Fig. 7. Field photos of small normal faults. a) ESE–WNW normal fault at site 141 in Eocene Umm Er Radhuma Fm. (Fig. 5). b) ENE–WSW normal faults in Jebel Allan in Oligo–Miocene Mughsayl Fm. (Fig. 5). c) ESE–WNW normal fault at site 275 in Oligocene Ashawq Fm. (Fig. 5).

La dorsale de Sheba



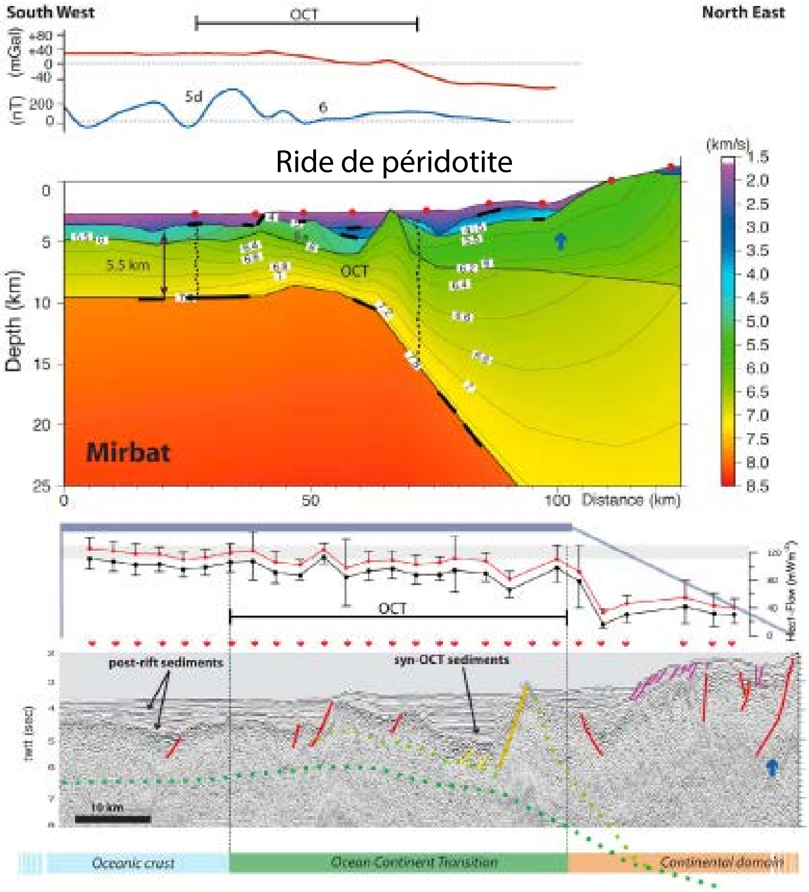


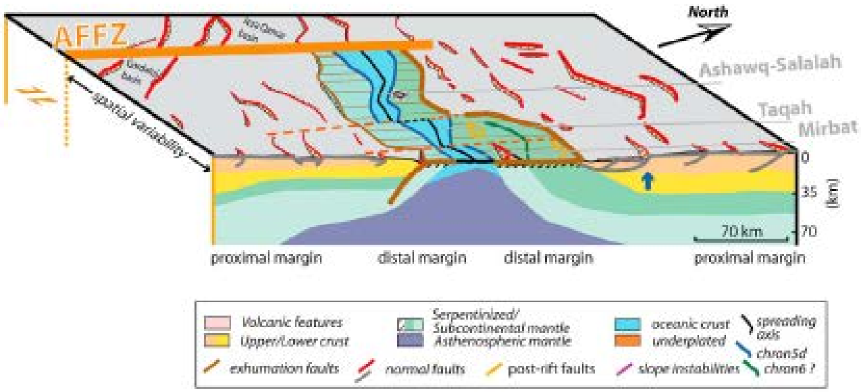


Des core-complex océaniques !

Fournier, Hdr, 2009
Chamot-Rooke et al., in prep.

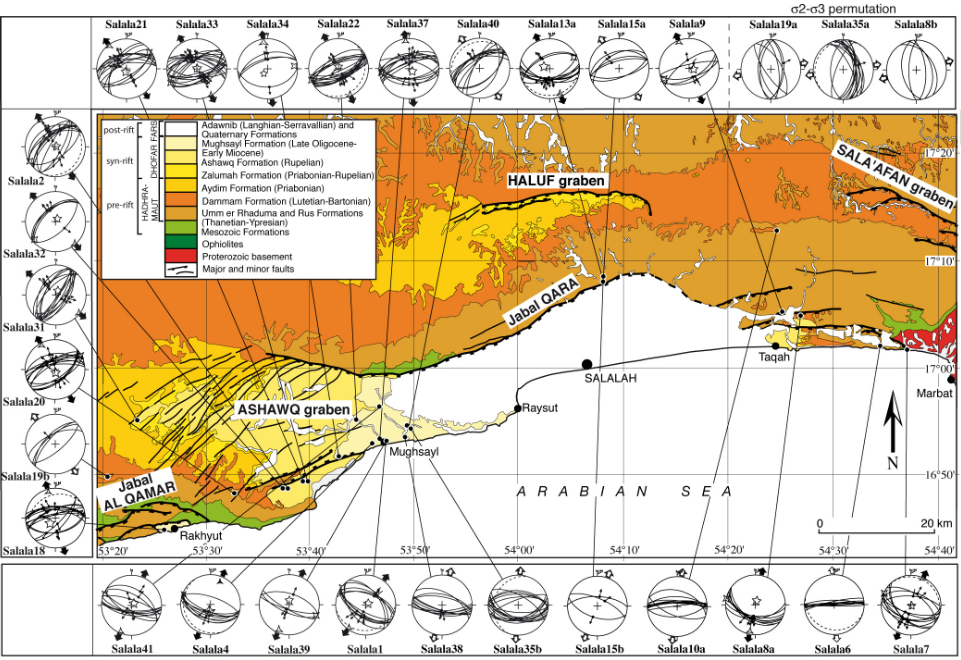
La transition continent-océan





Watremez et al., GJI, 2010

Rifting oblique : mode d'ouverture



Fournier et al., G3, 2004

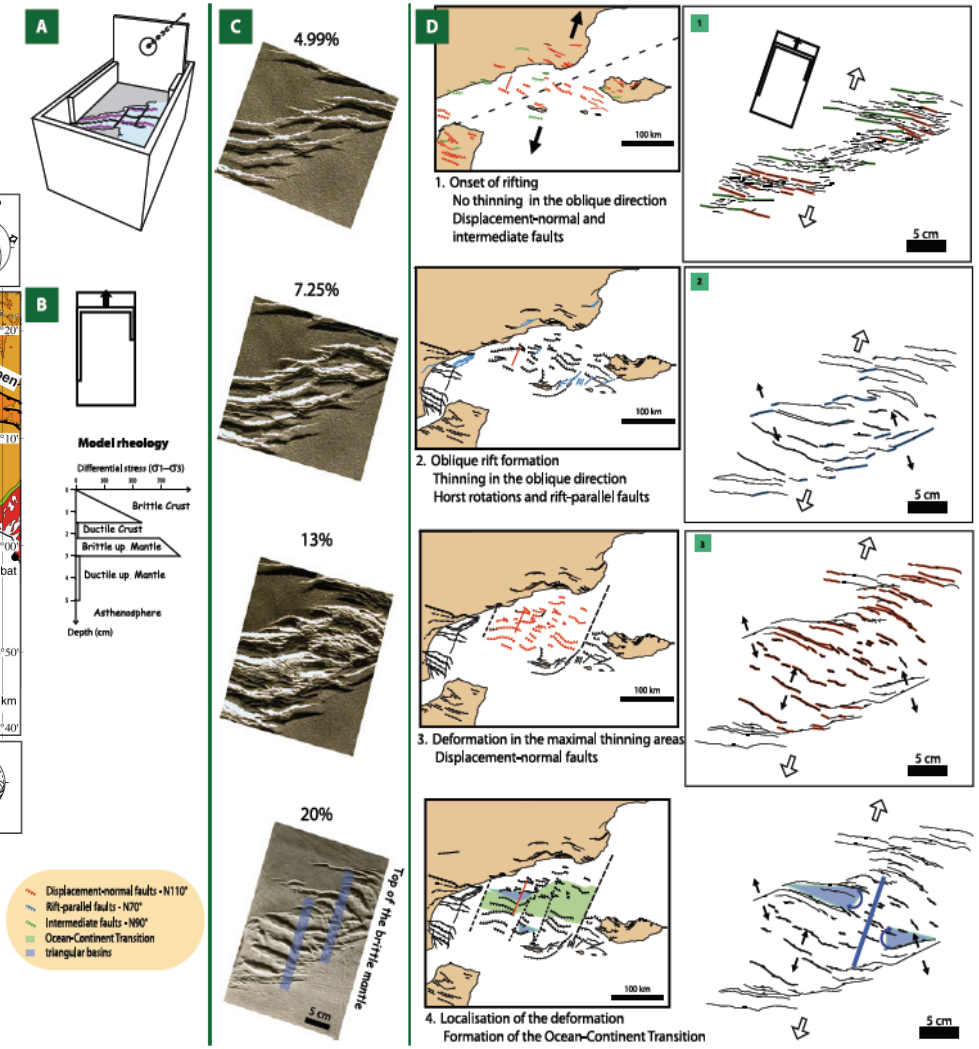


Fig. 10 a Box used for analogue modelling. The arms of the sliding box vary in length, thus creating two lateral discontinuities in velocity that impose an oblique orientation to the deformation, similar to that found in the Gulf of Aden. b Rheological profile of the model. c Main stage of evolution of the model. The model is rotated to match the Gulf of Aden. d Analogies between the model and the eastern Gulf of Aden. Reconstruction of the opening of the eastern Gulf of Aden, based on the onland and offshore structural pattern. Line-drawing of the model, tilted so as to match the direction of the gulf extension (see Autin et al. 2010a)

Leroy et al., J. Arab. Geosci., 2010

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Failles normales au niveau du rift est-africain

Extension au cœur de la chaîne Himalayenne

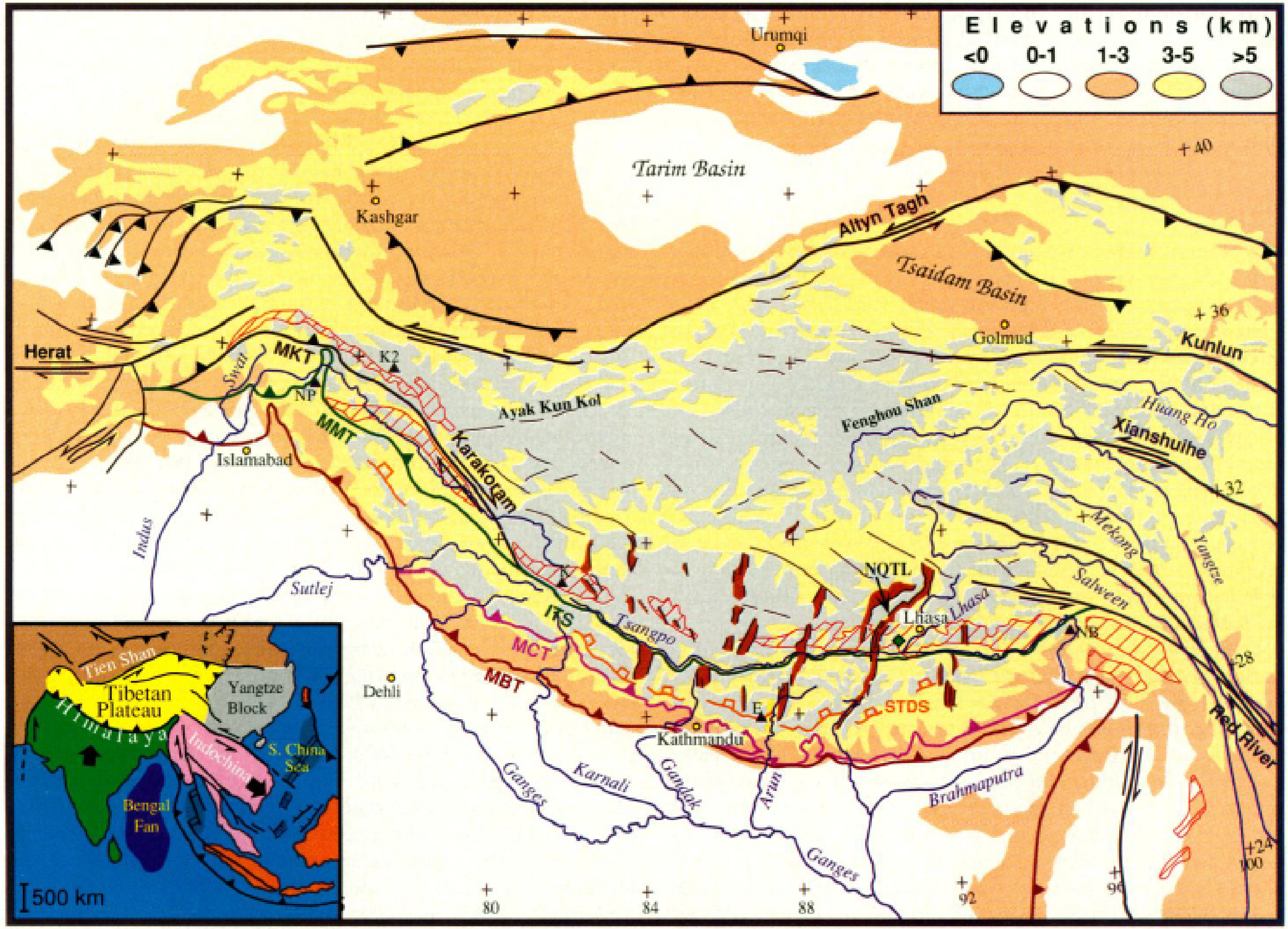
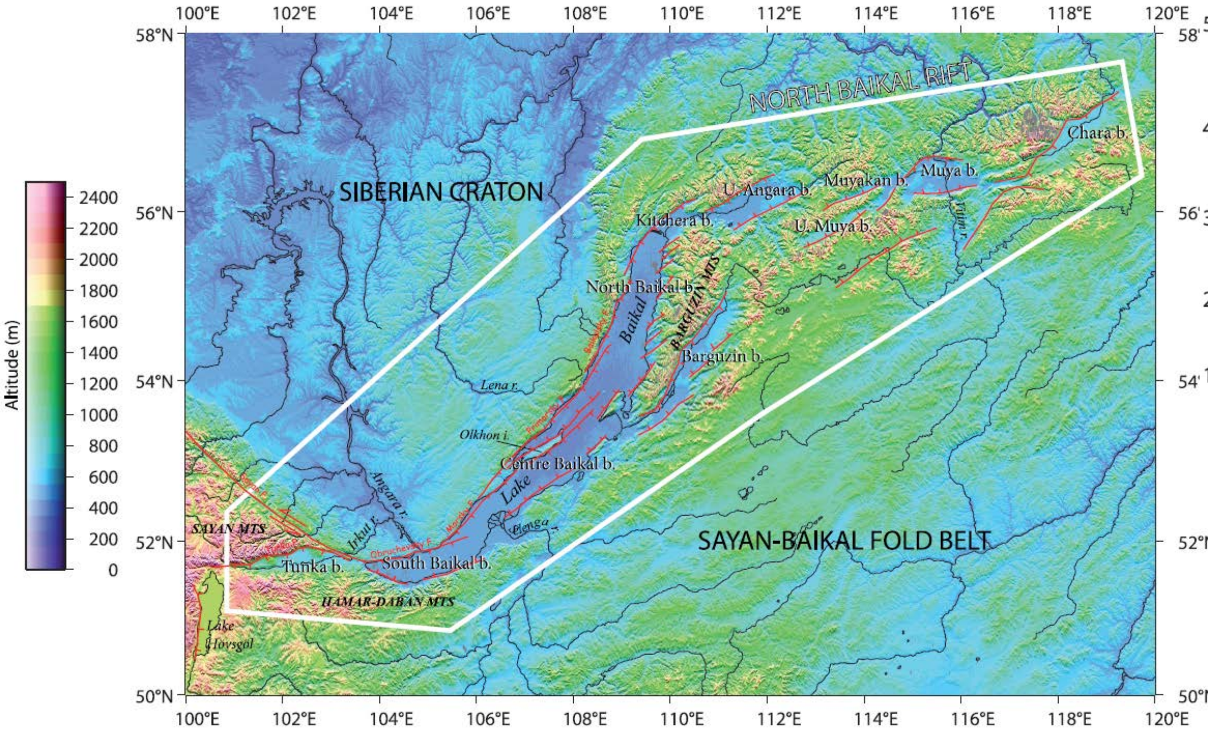


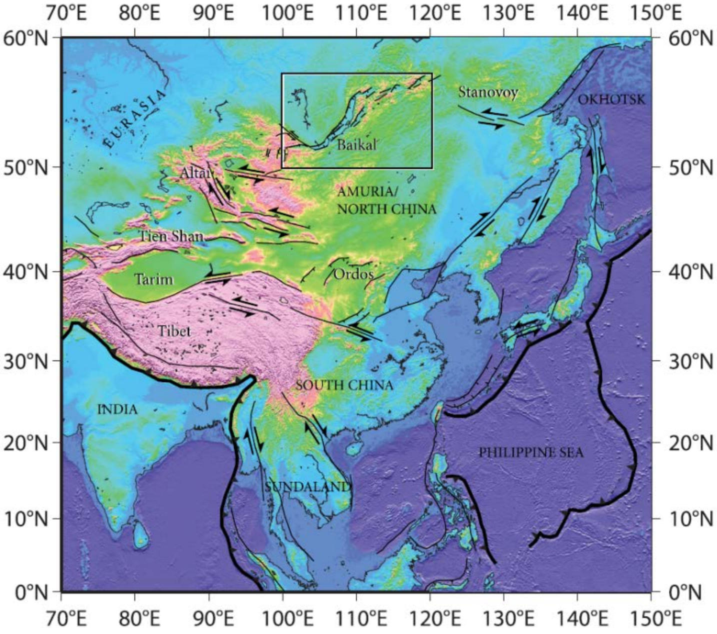
Fig. 1. Geological sketch map of the Tibetan plateau and the Himalaya. Heavy lines with triangles are thrust faults that point in dip direction, MBT is the Main Boundary thrust (brown), MCT is the Main Central thrust (purple), MKT is the Main Karakoram thrust (black), and MMT is the Main Mantle thrust (green); STDS is the Southern Tibetan detachment system (orange), horizontally striped patterns are late Neogene grabens, and heavy black lines are strike-slip faults with relative motions shown (Red River, Xianshuihe, Altyn Tagh, Kunlun, Herat, and Karakorum); ITS is the Indus-Tsangbo suture (green); Gangdese belt is shown by red oblique striped pattern; major rivers are identified in navy italics. Selected peaks shown: E, Mt. Everest (8848 m); K, Mt. Kailas (6714 m); K2, Mt. Godwin-Austin (8611 m); NP, Nanga Parbat (8126 m); and NB, Namche Barwa (7756 m). The Nyainqentanghla Shan (NQTL) is a northeast-southwest–trending range to the northwest of Lhasa. The green diamond near Lhasa shows the location of the Quxu pluton thermochronologic studies (*23*). Inset shows the location of other features described in the text (Bengal fan, South China Sea, Tien Shan).

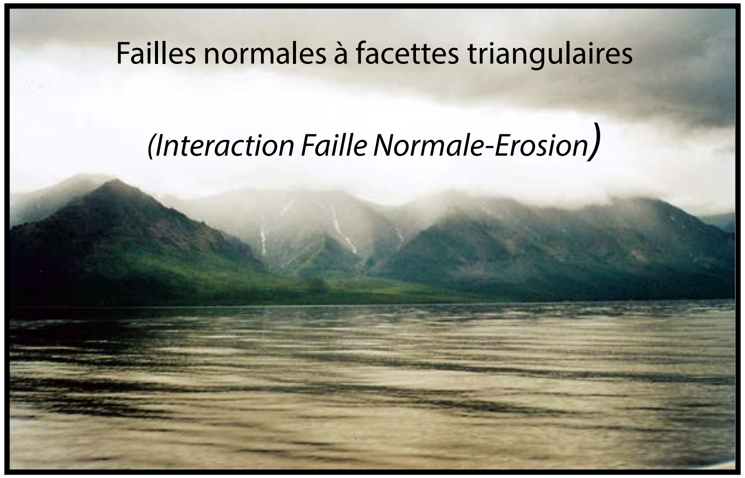
Harrison et al., Science, 1992

Lac Baïkal

(630x80 km)

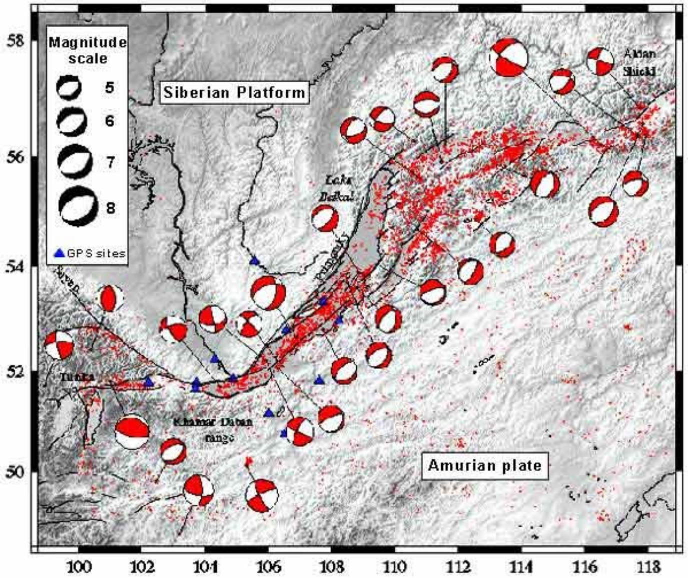






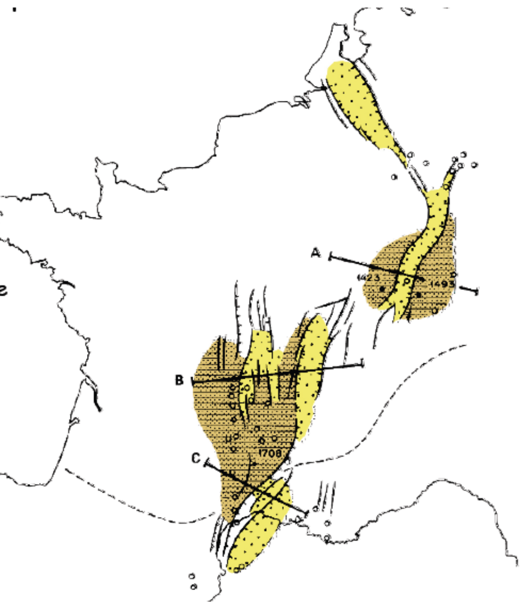
Failles normales à facettes triangulaires

(Interaction Faille Normale-Erosion)

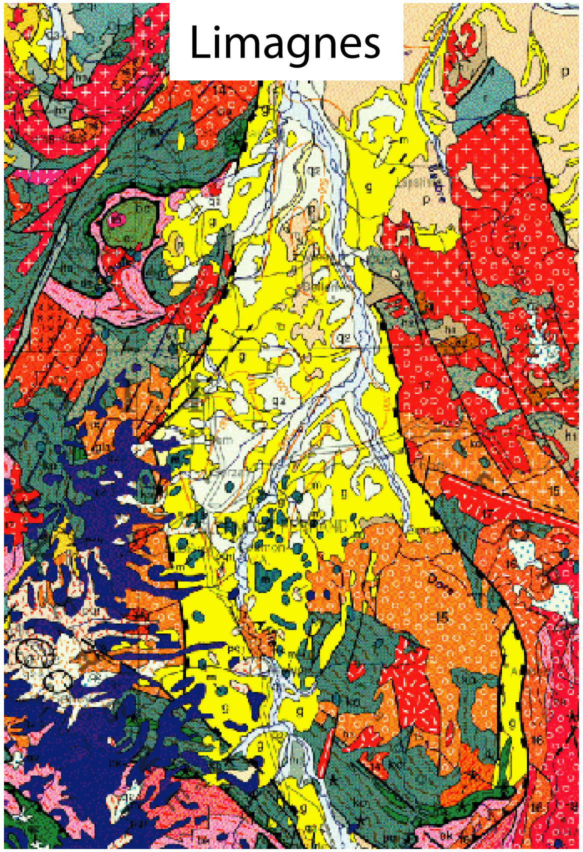


Petit and Deverchère, G3, 2006

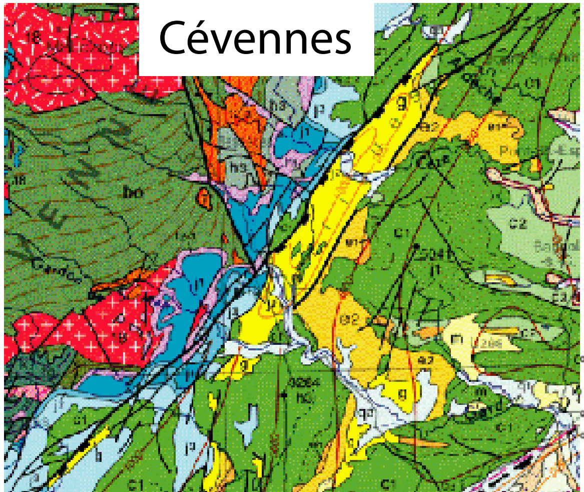
Les fossés d'effondrement cénozoïque en France



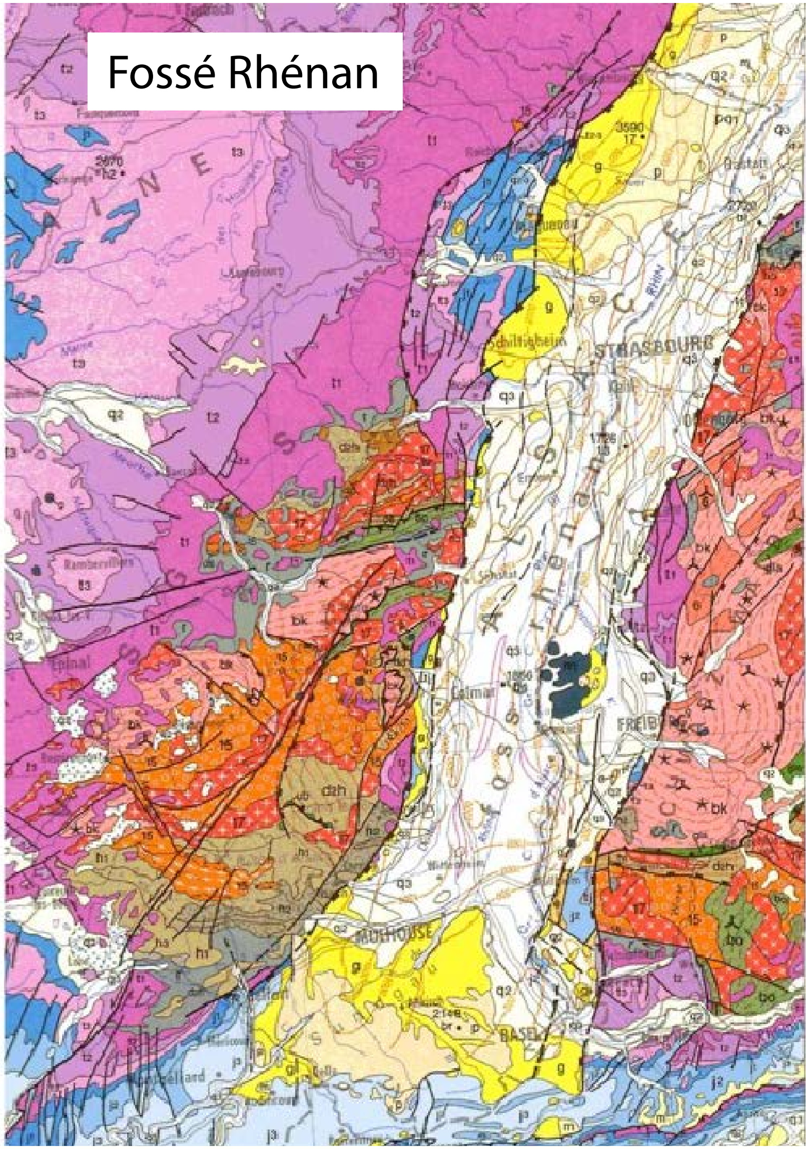
Limagnes

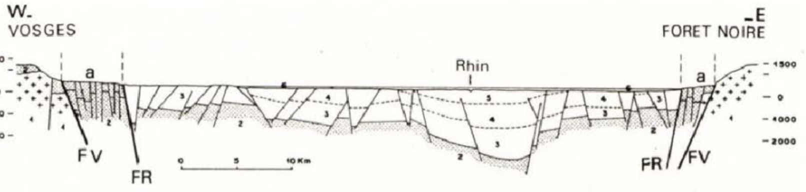


Cévennes

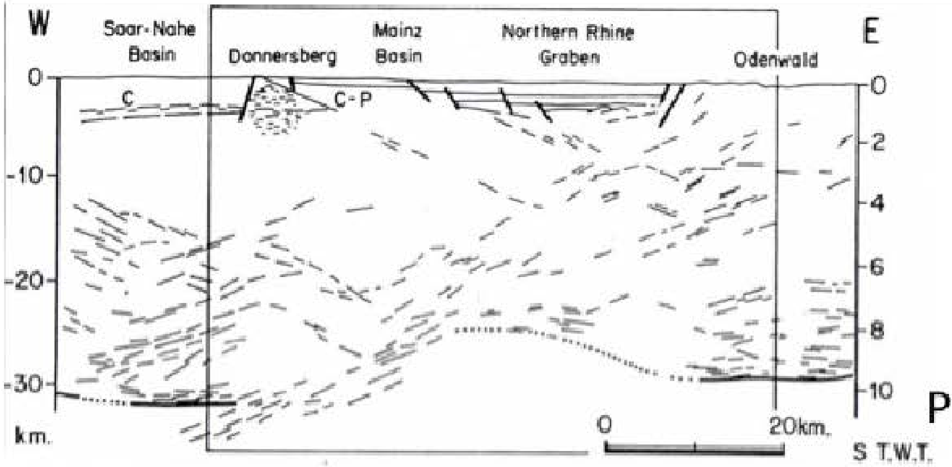


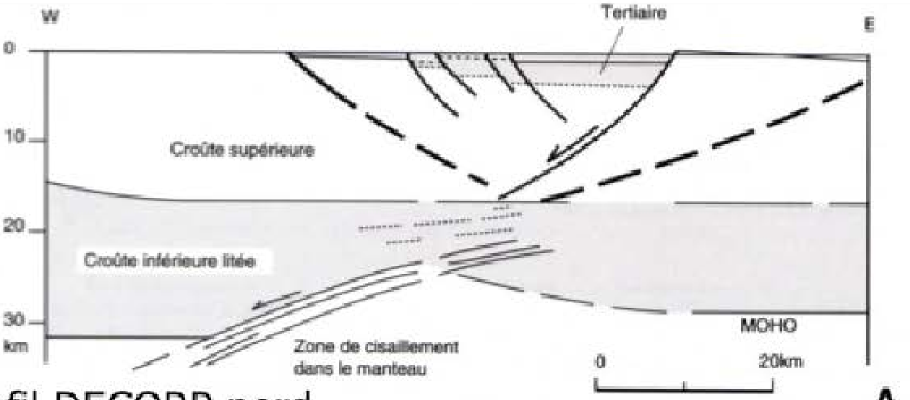
Fossé Rhénan





Le rift rhénan

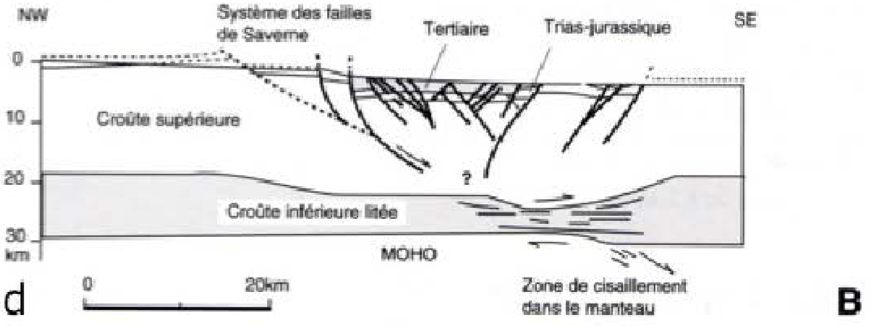




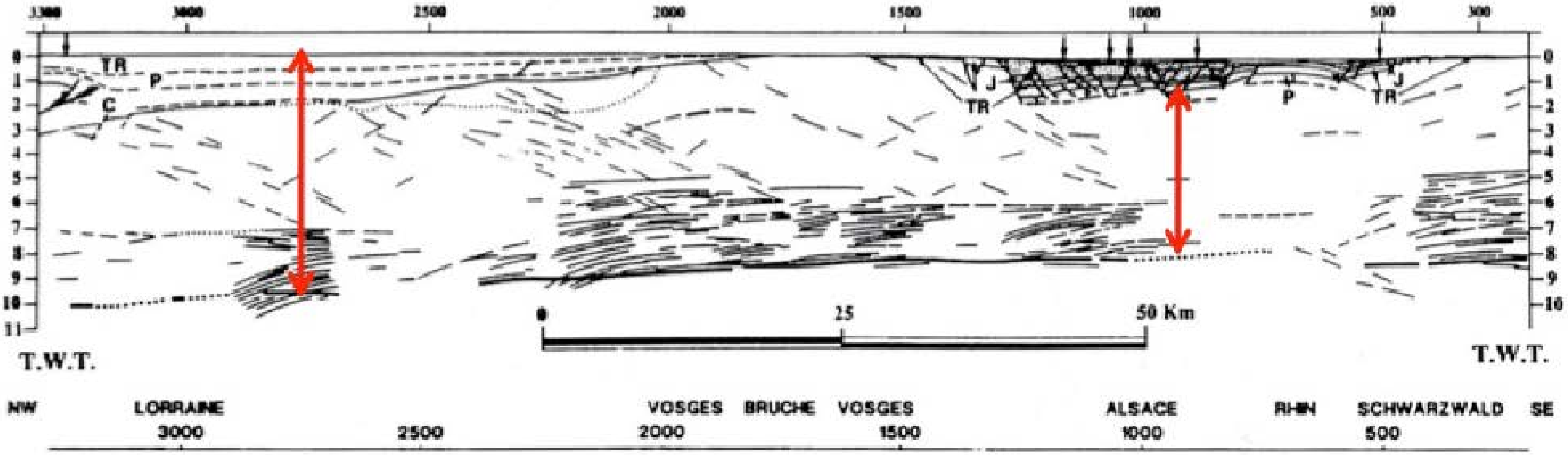
Profil DECORP nord

Amincissement crustal

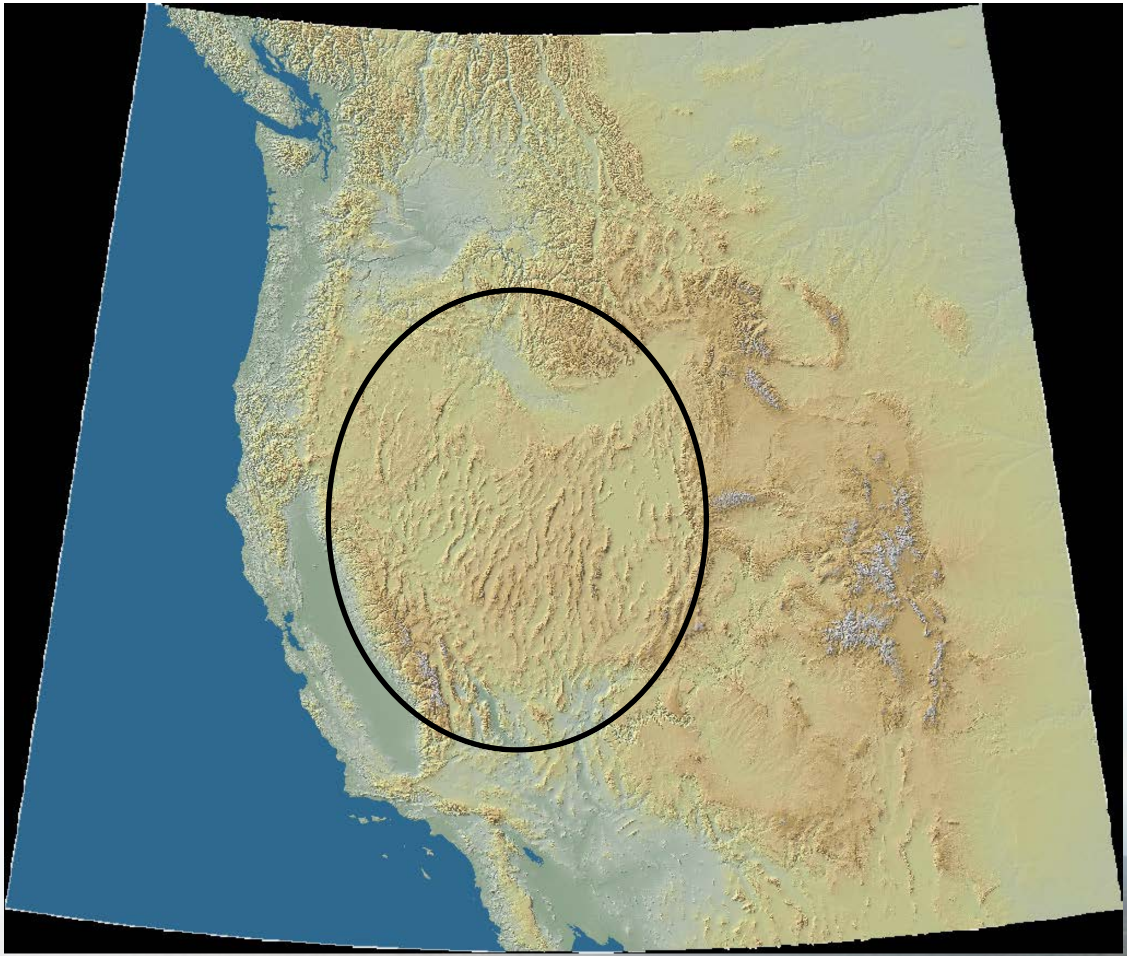
Boillot & Coulon, p. 13
Larroque & Virieux, p. 258



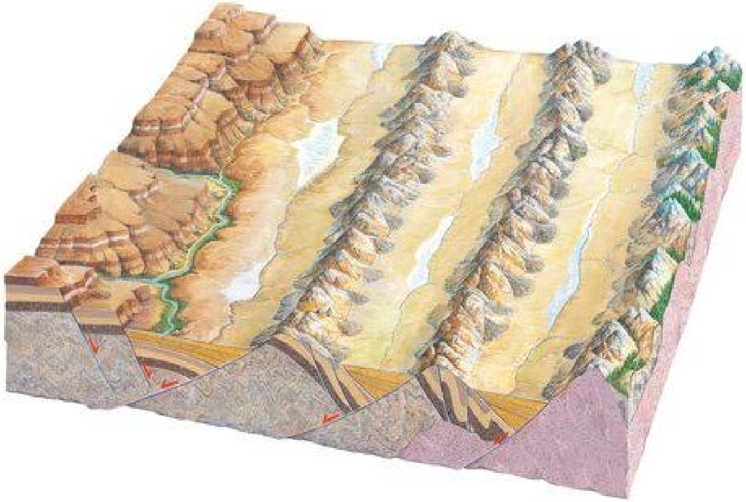
Profil ECORS sud



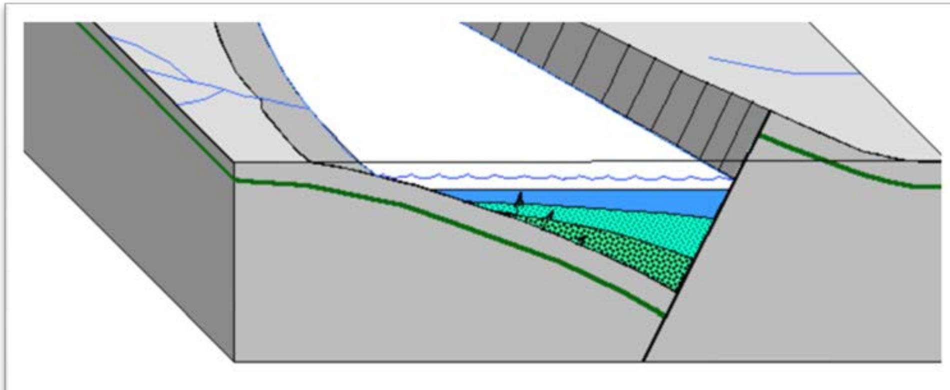
Basin and Range



Basin and Range :
les metamorphic core complex continentaux



Piano keys fault system



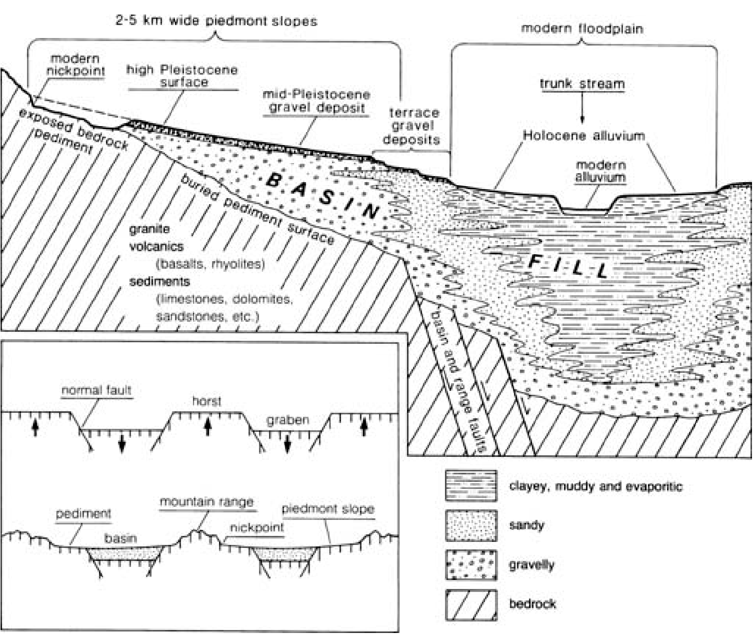
Basin and Range

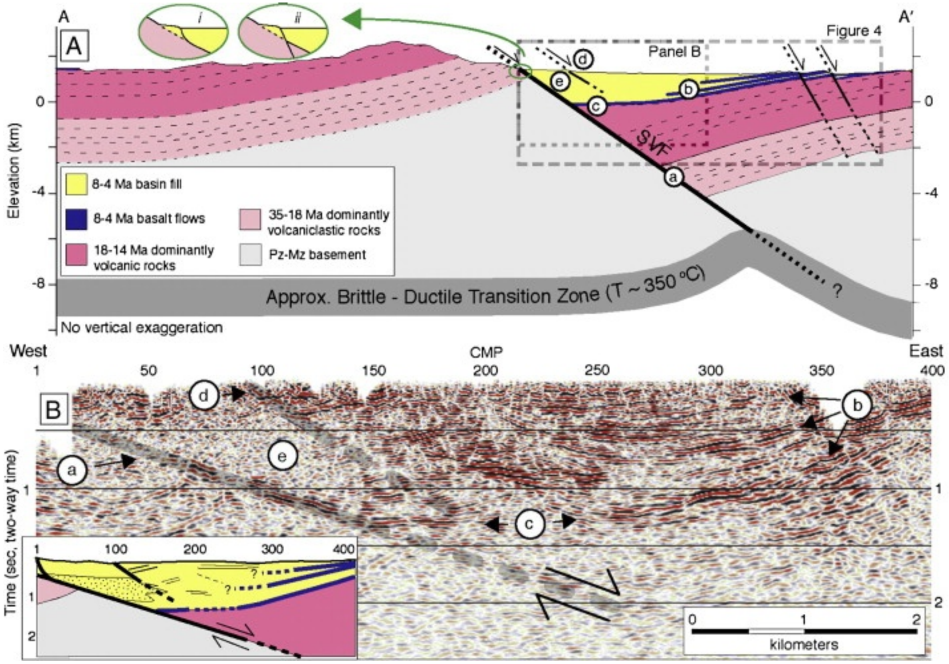
E **W**

Versant abrupt contrôlé par une faille normale active

W **Versant à pente faible contrôlé par l'érosion et la sédimentation** **E**

Basin and Range





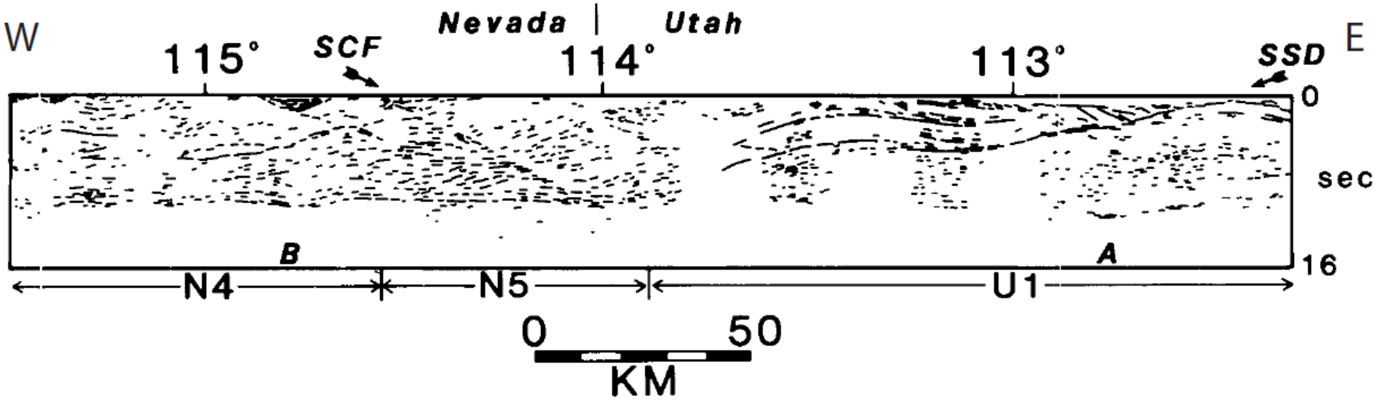
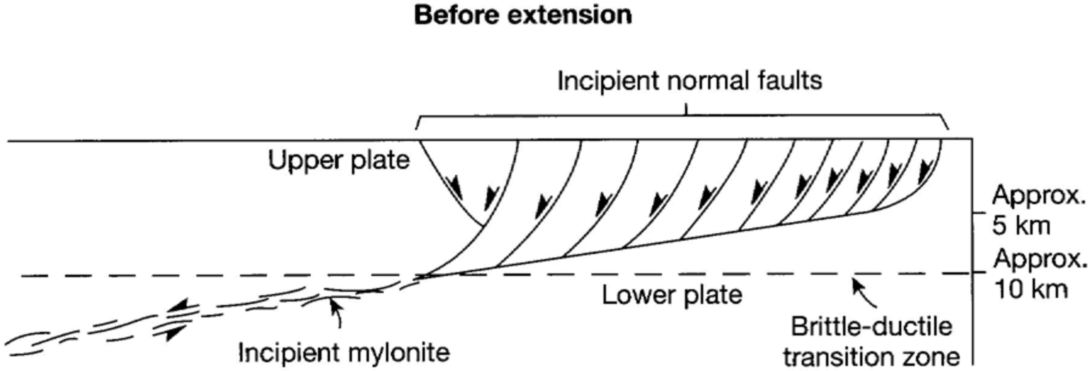
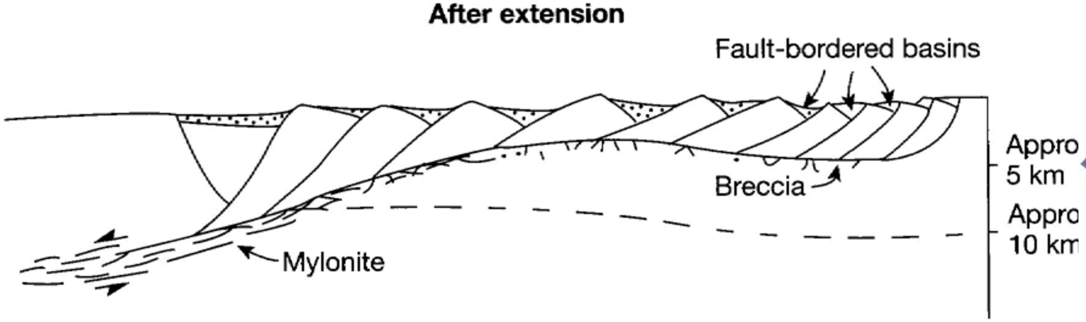
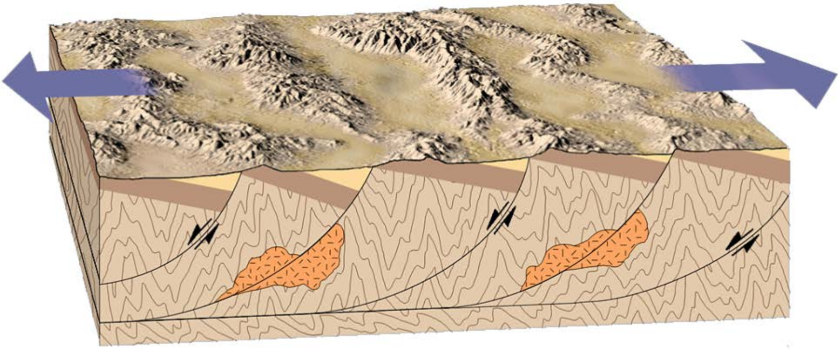


Fig. 2.25: Géométrie crustale des Basin and Range. Profil de sismique réflexion W-E à travers les MCCs du Snake Range (à l'est de la faille de Schell Creek, SCF) et du Sevier Desert. Le réflecteur qui prolonge le détachement du Sevier Desert est indiqué par une flèche (SSD). D'après Allmendinger, et al. [1983].

Basin and Range

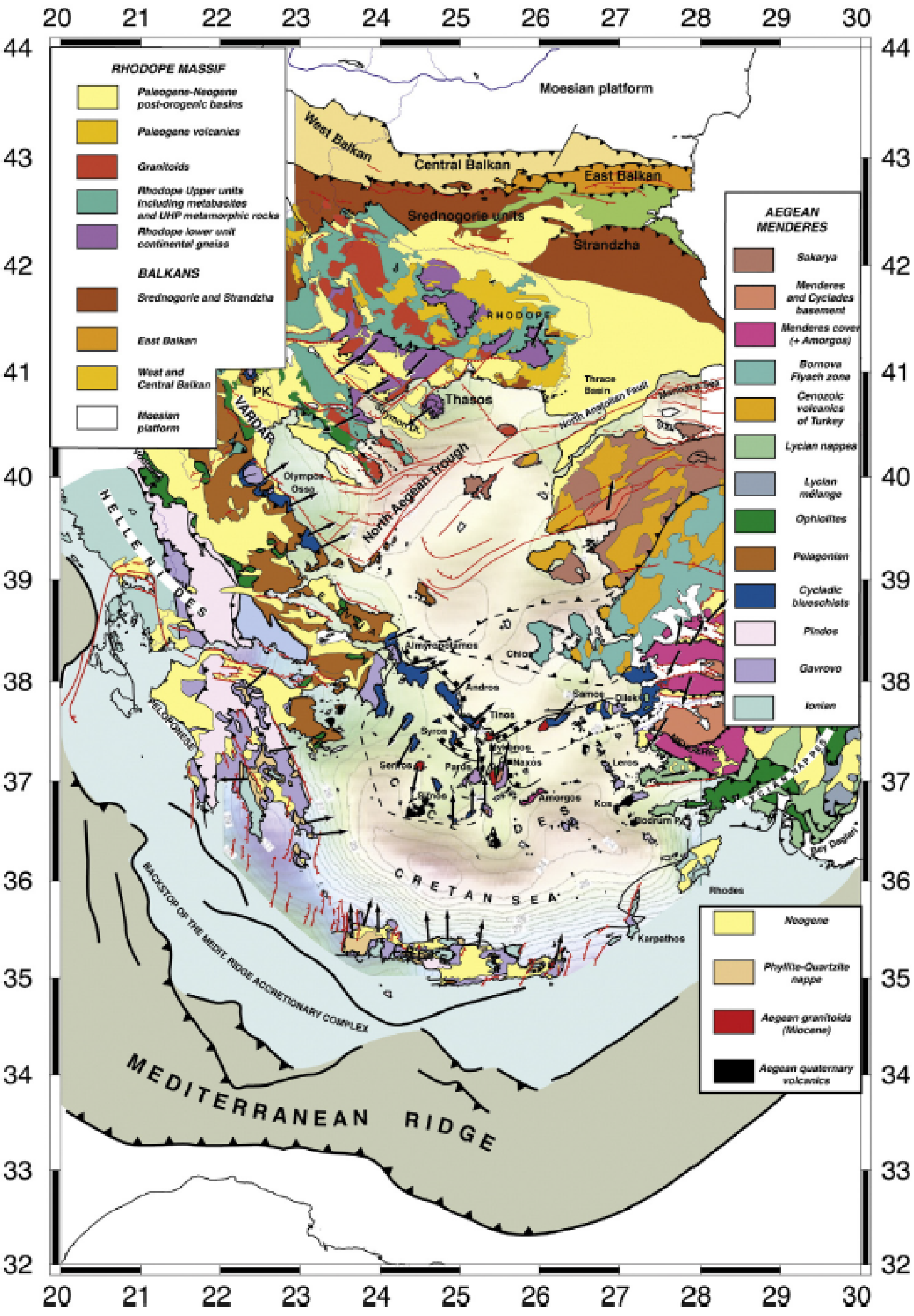






BASIN AND RANGE: une extension distribuée

Core complexes continentaux en mer Egée : les Cyclades



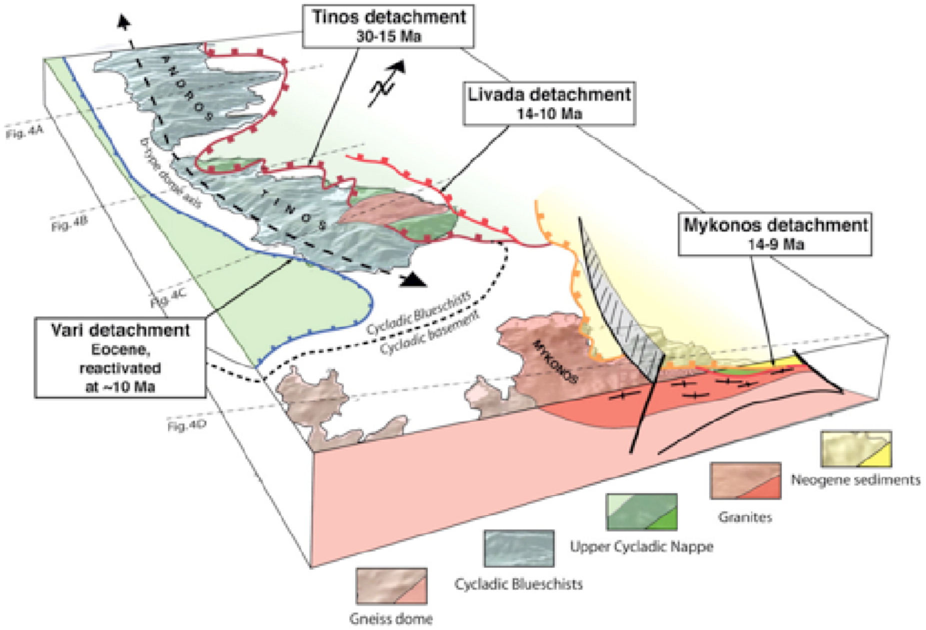


Fig. 1.15: Les différentes structures composant le NCDS. D'après Jolivet, et al. [2010].

Jolivet et al., tectonophysics, 2012

Core complexes continentaux en mer Egée : les Cyclades

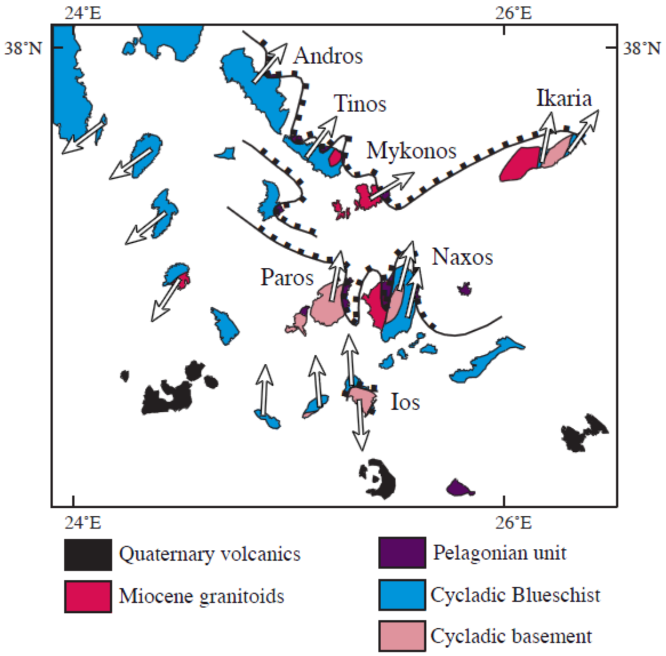


Fig. 3.1: Carte géologique des Cyclades avec les sens de cisaillement post-orogéniques (flèches blanches). À Ios, deux sens de cisaillement opposés sont décrits dans la littérature. Le sens de cisaillement vers le sud est associé au contact entre l'unité des Schistes Bleus Cycladiques et du Socle Continental Cycladique. D'après Huet, et al. [2009].

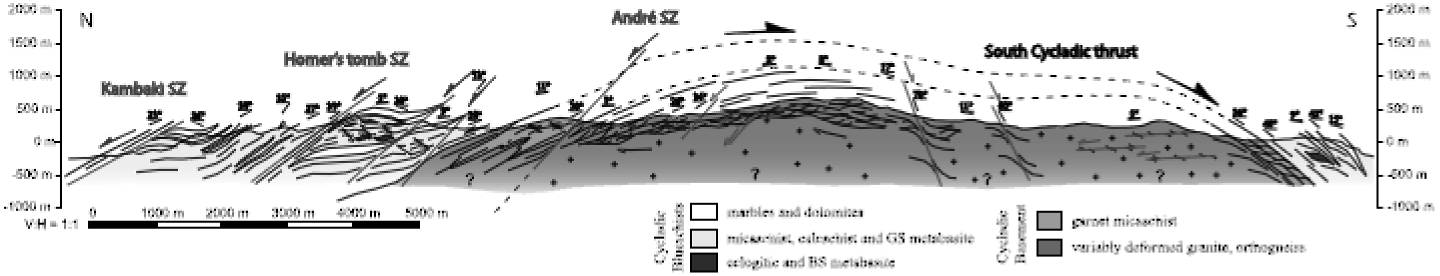


Figure 14. N–S cross section of Ios island. The contact between the Cycladic Blueschists and the Cycladic Basement is a thrust (the south Cycladic thrust) associated to top-to-the-south deformation. In the Cycladic Blueschists, top-to-the-south structures and blueschist facies rocks are preserved in the southern part of the unit and between the extensional shear zones, where the top-to-the-north deformation is less intense. In the Cycladic Basement, the top-to-the-south movements induced a vertical strain gradient. The stretching rises from the core, where the granite is preserved, to the rim, where it is fully mylonitized. In both units, the top-to-the-north extensional deformation is located in large shear zones that deform the previous structures.

Huet et al., Tectonics, 2009

Core complexes continentaux en mer Egée : les Cyclades
Exemples de déformation ductile (mylonite) au niveau d'un détachement

Huet et al., Tectonics, 2009

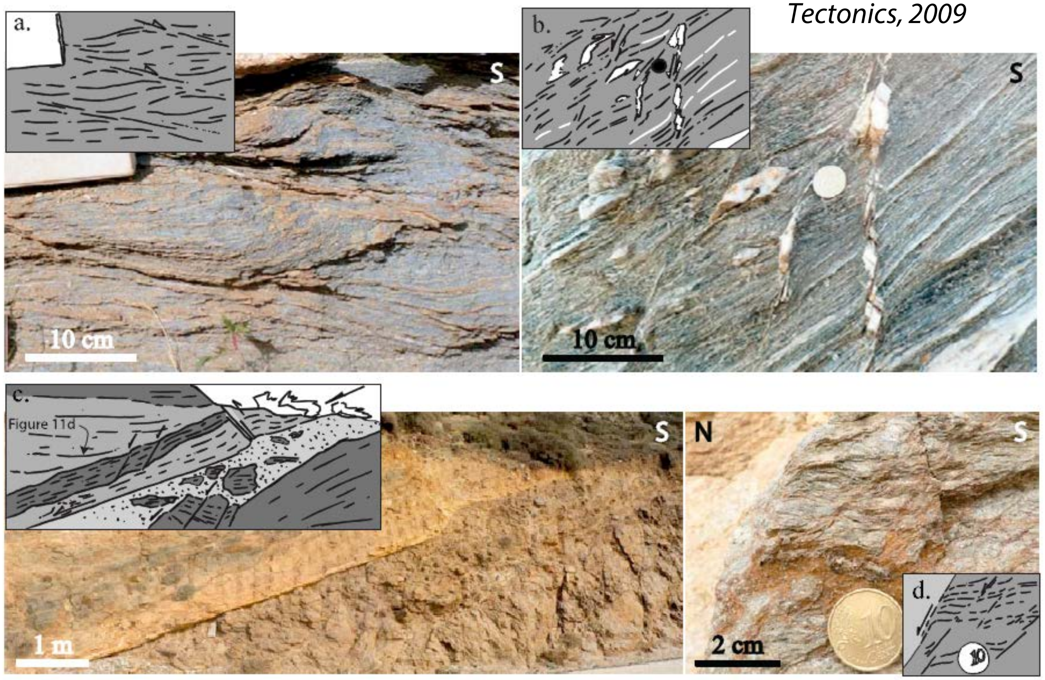


Figure 11. (a) Top-to-the-south shear bands in epidote-blueschist metabasites. Glaucophane and epidote grow in the shear bands. (b) C′-type cleavage with top-to-the-north movements. Quartz veins crystallized in the shear bands. They have pull-apart shape. (c) Top-to-the-north shear bands parallel to the schistosity. They induced brecciation in the schists. (d) Top-to-the-north C′-type cleavage in chlorite schist. Detail of the outcrop shown on Figure 11c.

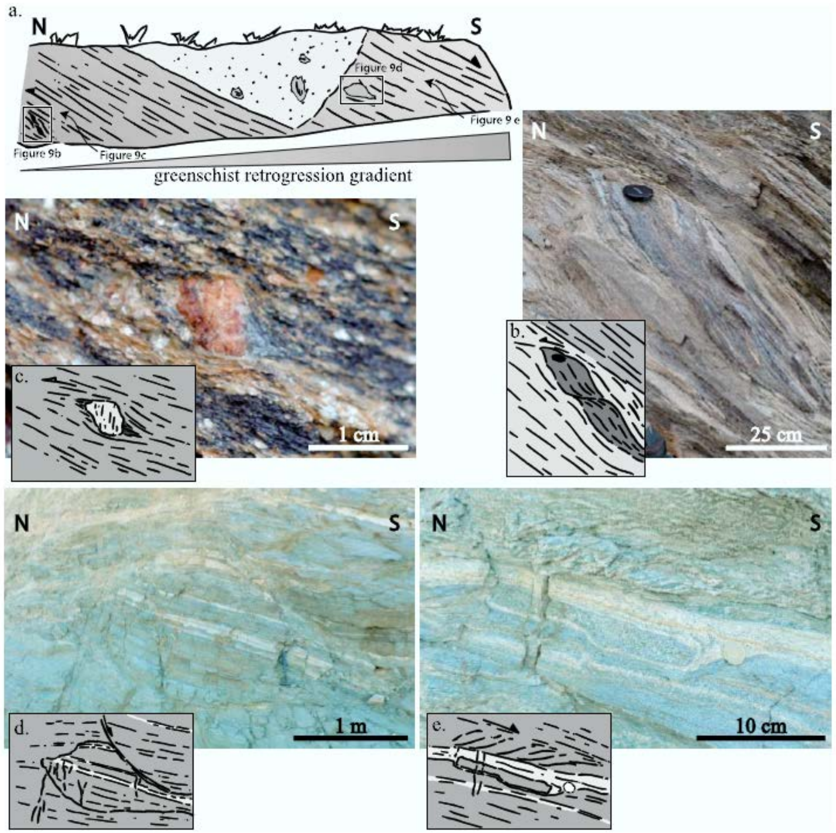


Figure 9. Deformation and metamorphic facies in the Cycladic Blueschists. (a) Diagram of an outcrop showing blueschist facies top-to-the-south structures (Figures 9b and 9c) in the south and greenschist facies top-to-the-north structures (Figures 9d and 9e) in the north. (b) Top-to-the-south asymmetric boudinage affecting a blueschist facies metabasic lens. (c) Top-to-the-south glaucophane pressure-shadow around a garnet. (d) Boudinage of greenschist with a top-to-the-north normal shear band rooting in the schistosity. (e) Top-to-the-north shear band in greenschist facies rocks.

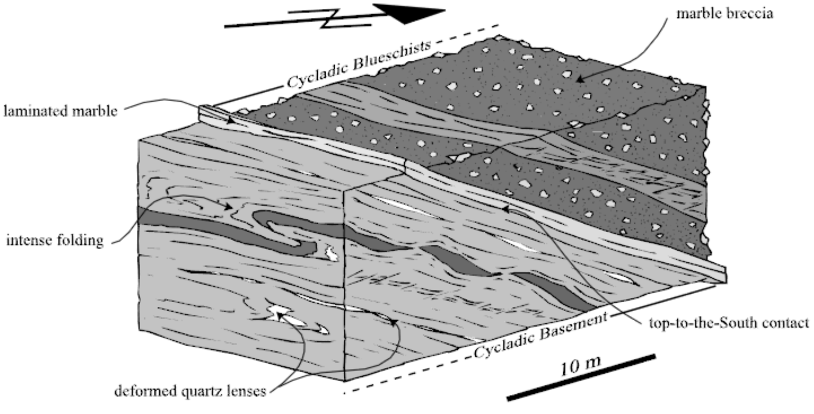


Figure 7. Synthetic 3-D diagram of the deformation associated to the Cycladic Blueschists–Cycladic Basement contact in Ios harbor area. The shear criteria indicate top-to-the-south sense of shear.

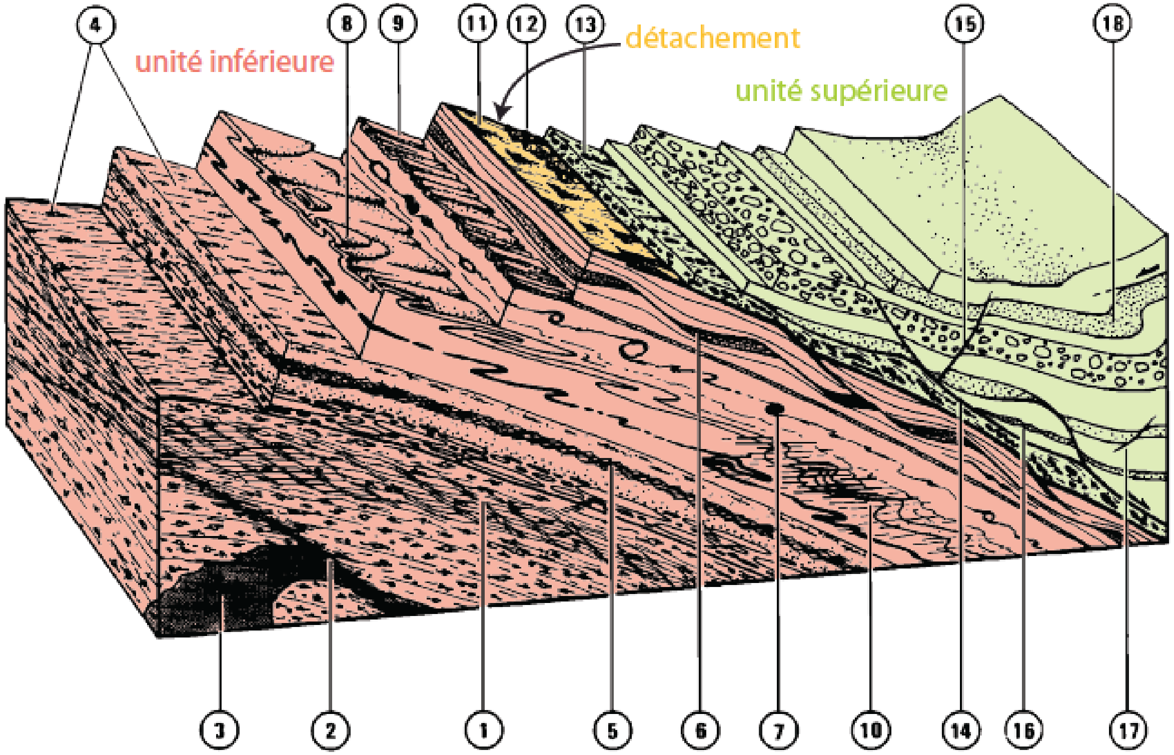


Fig. 6. Synthetic block diagram showing the different structures associated with extensional shear zones: 1, foliated rocks with extensional shear bands (C' planes); 2, small-scale normal shear zones; 3, synkinematic granite bodies or sills, mylonitized and boudinaged; 4, stretching and mineral lineations; 5, extensional crenulation clivage; 6, boudinage at different scales; 7, shear criteria (rolling structures); 8, sheath folds in zones of high shear strain; 9, folds with axes parallel to stretching lineations which may develop at a large scale; 10, tight folds with subhorizontal axial planes, which develop in rock with strong anisotropy, during the late ductile stages of deformation, refolding mylonitic foliation; 11, slickensides on brittle detachment surfaces; 12, cataclastic breccia. - Structures in sediments associated with basin formation; 13, fractured pebbles, stretched and striated ; 14, low-angle decollements in weak layer ; 15, high-angle brittle faults; 16, stretched layers; 17, synsedimentary hydroplastic faults; 18, gravity folding.

Fig. 2.22: Schéma synthétique de la déformation dans l'unité inférieure, le détachement et le bassin sédimentaire d'un MCC. La déformation évolue progressivement depuis des structures ductiles au cœur de l'unité inférieure vers des structures cassantes au niveau du détachement. Cette évolution s'accompagne d'un gradient de cisaillement simple. L'unité supérieure, ici représentée par un bassin sédimentaire, ne subit qu'une déformation cassante. D'après Malavieille [1993].

Core complexes océaniques

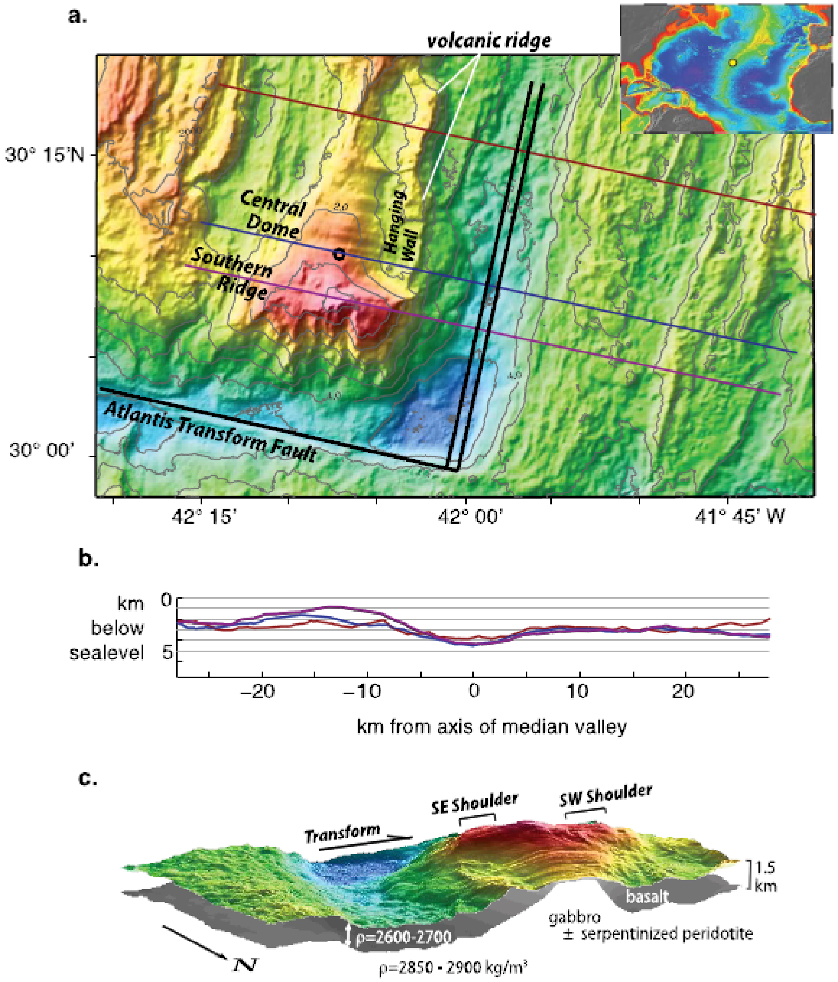
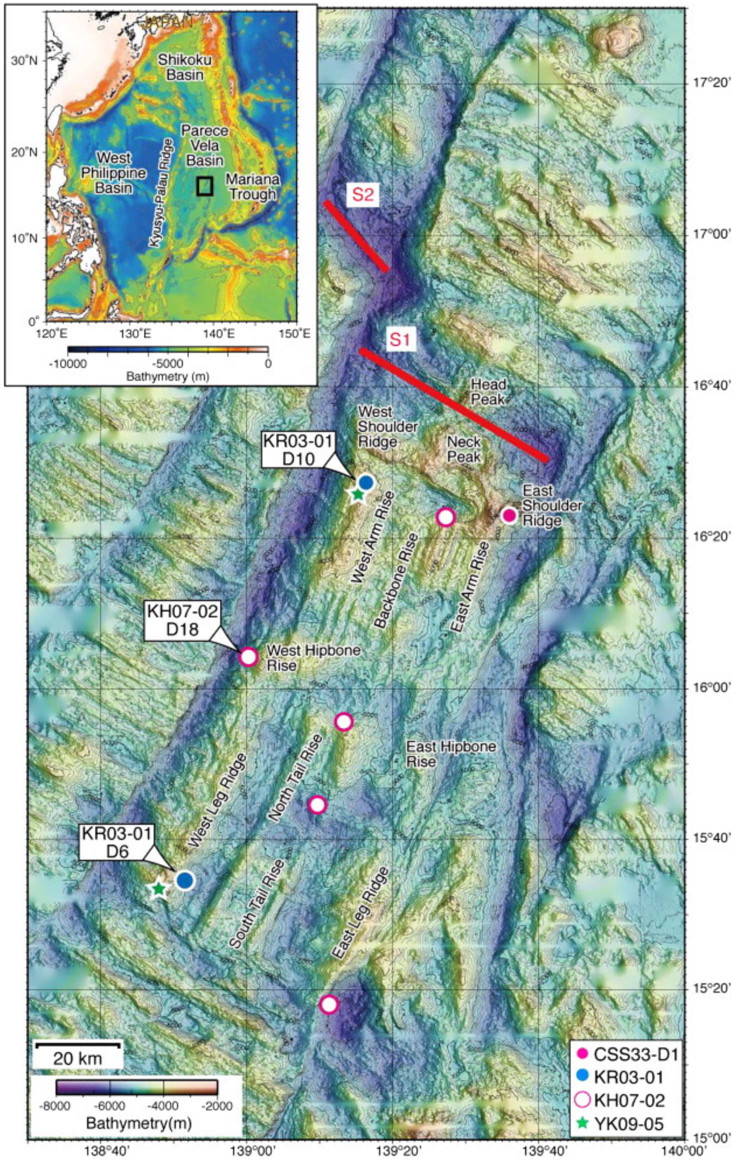


Figure 1. Seafloor topography in the vicinity of the intersection of the Mid-Atlantic Ridge and Atlantis transform fault and basic structure of Atlantis Massif oceanic core complex. (a) Contour interval 0.5 km. Corrugated surface is inferred to be exposed detachment capping the domal high. Axis of the Mid-Atlantic Ridge and Atlantis Transform Fault are shown by black lines; circle marks IODP Site U1309. Location of profiles across the middle of the segment (brown), the Central Dome (blue) and the Southern Ridge (purple) are shown. (b) Seafloor depth along these three profiles. (c) Perspective view of Atlantis Massif looking SSW. Gray interface shows 3-D model of upper/lower crustal boundary that can explain most of the Bouguer gravity anomaly in this area.

Blackman et al., JGR, 2011

Harigane et al., Lithos, 2011



Godzilla mégamullion

En général, localisés au niveau des dorsales lentes/ultralentes…vitesse d'accrétion de quelques cm au max pour Godzilla

Exemples de mylonites forées sur un détachement océanique (Godzilla megamullion)

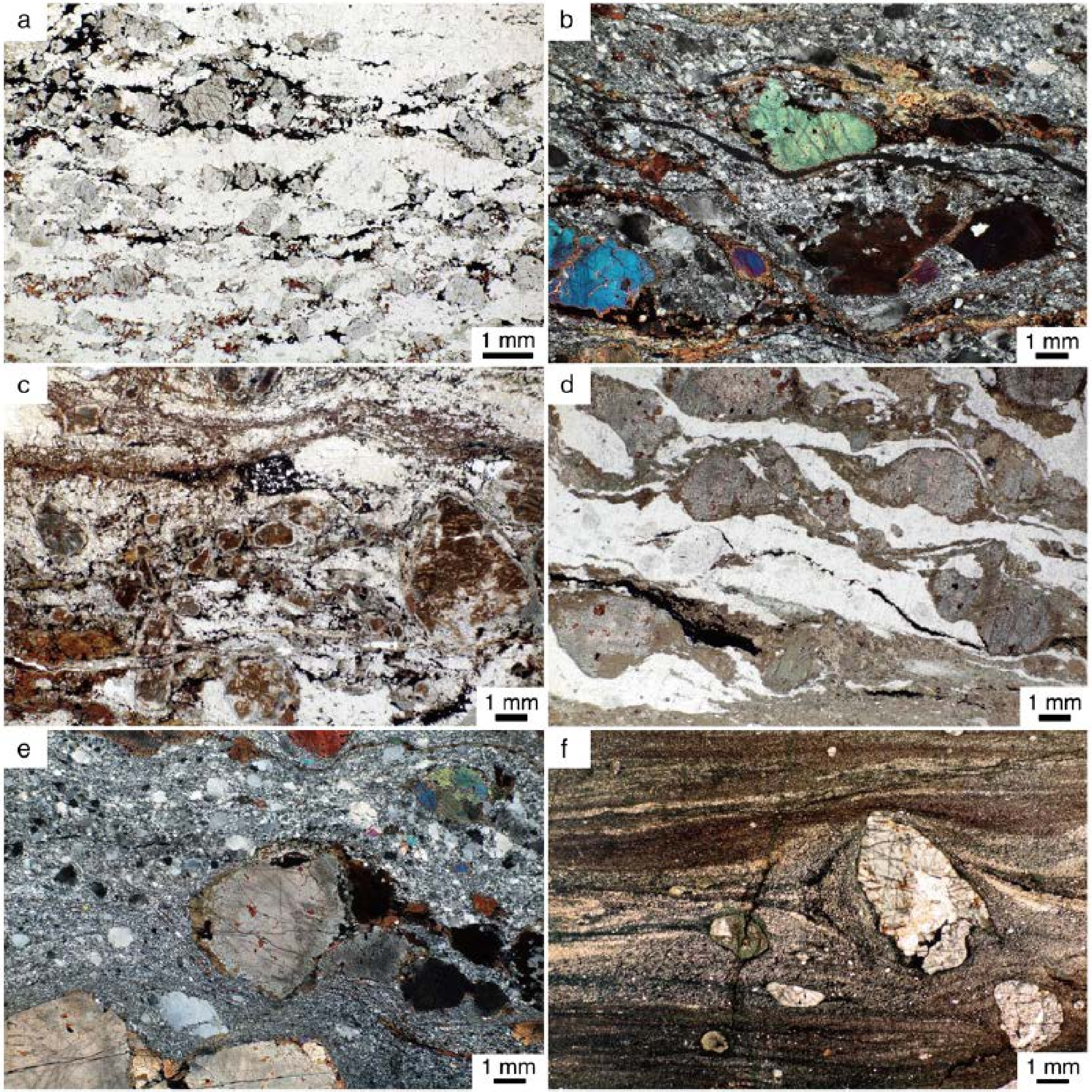


Fig. 2. Photomicrographs of microstructures within mylonites and ultramylonite collected from site KH07-02-D18 of the Godzilla Megamullion. (a) Sample KH07-02-D18-6. Plane-polarized light. (b) KH07-02-D18-10. Crossed polar. (c) KH07-02-D18-11. Plane-polarized light. (d) KH07-02-D18-1. Plane-polarized light. (e) KH07-02-D18-29. Crossed polar. These gabbro mylonites indicate a foliation defined by alternating layers of plagioclase and clinopyroxene/amphibole with ilmenite. Amphiboles commonly occur at the rims of clinopyroxene grains. Several gabbroic mylonites (KH07-02-D18-1 and -29) show blebs within clinopyroxene porphyroclasts. (f) KH07-02-D18-35. Microstructure of ultramylonite shows a well-developed foliation defined by monomineralic layers of fine-grained plagioclase and mixed layers of fine-grained plagioclase and amphibole. This sample contains fewer plagioclase and clinopyroxene/amphibole porphyroclasts than the mylonite. Plane-polarized light.

Harigane et al., Lithos, 2011

Bilan : Les modes d’extension lithosphérique

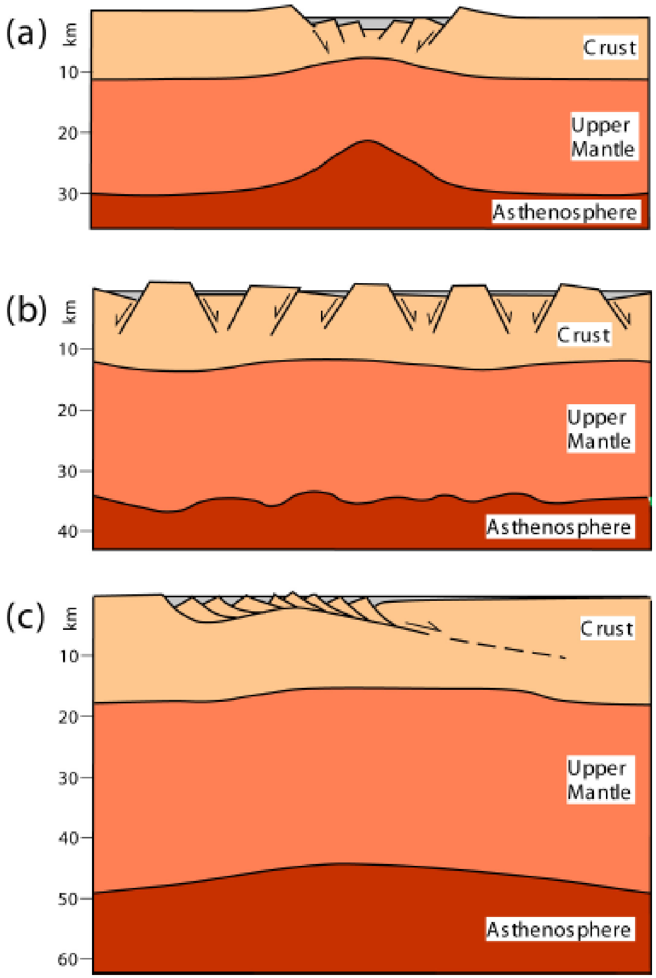


Fig. 1.1: *Schémas illustrant les trois principaux modes d’extension lithosphérique (Rosenbaum* et al.*, 2008, d’après Buck, 1991). (a) Rift étroit, (b) Rift large, et (c) Extension en mode* core-complex *(d’après Lister & Davis, 1989).*

EXTENSION

- ➢Définition des rifts et marges passives
- ➢Du rifting continental à l'ouverture océanique : le système rift africain, mer Rouge, & golfe d'Aden
- ➢Distribution des zones de rift et diversité
- ➢**Marges passives volcaniques et non-volcaniques**
- ➢Modes de formation des rifts : rhéologie, mécanique
- ➢Les contextes géodynamiques favorables au rifting continental : quel moteur pour la déchirure continentale?

Failles normales au niveau du rift est-africain

La marge de Galice : un exemple de marge appauvrie en magma

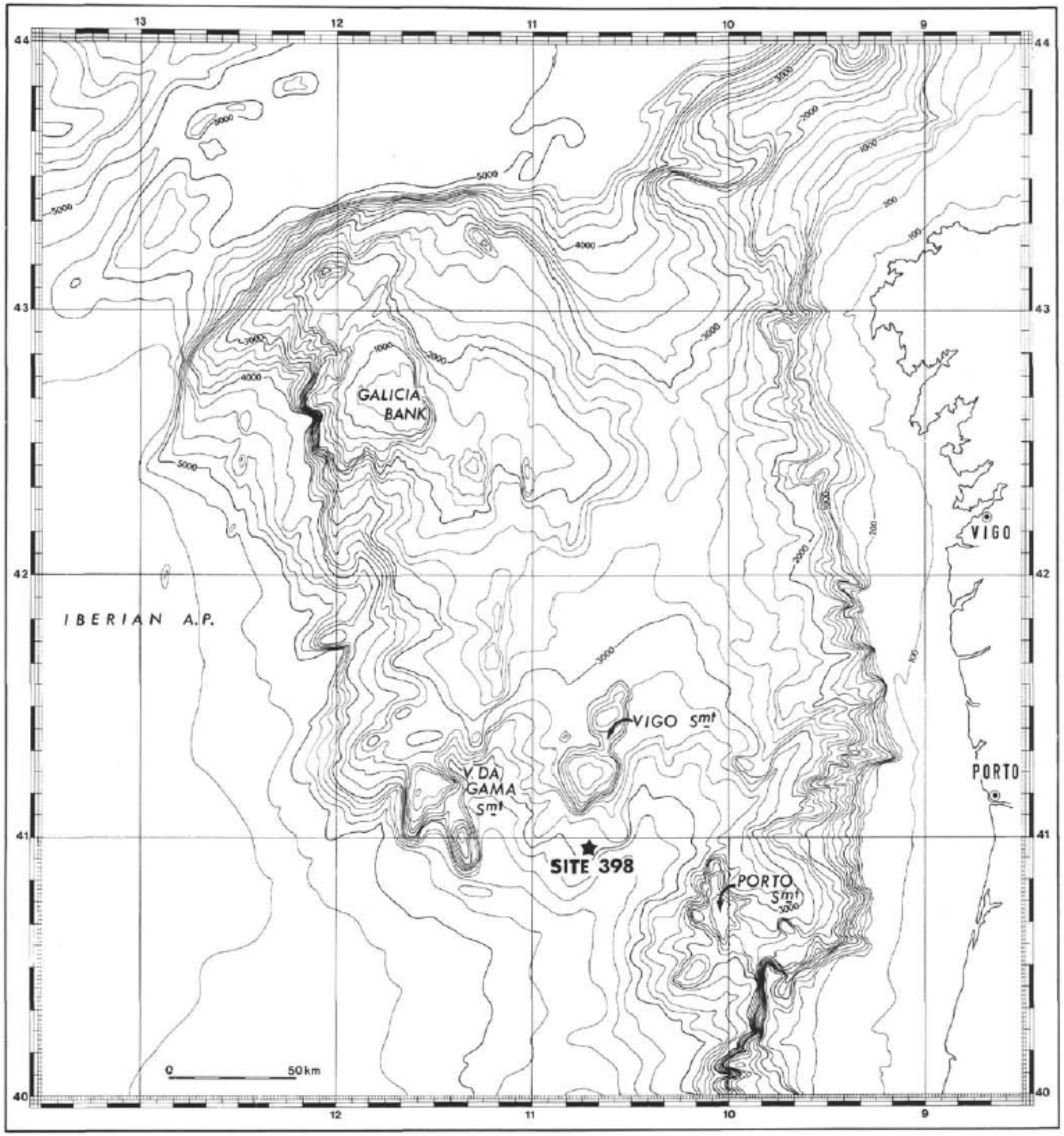


Figure 2. *Bathymetric map of the western Iberian margin. Contours in corrected meters (intervals of 200 meters in the margin and 100 meters in the Abyssal Plain). Map contoured by J. L. Auxietre, J. P. Dunand, and J. R. Vanney, after data from Laughton et al. (1975) and French cruises.*

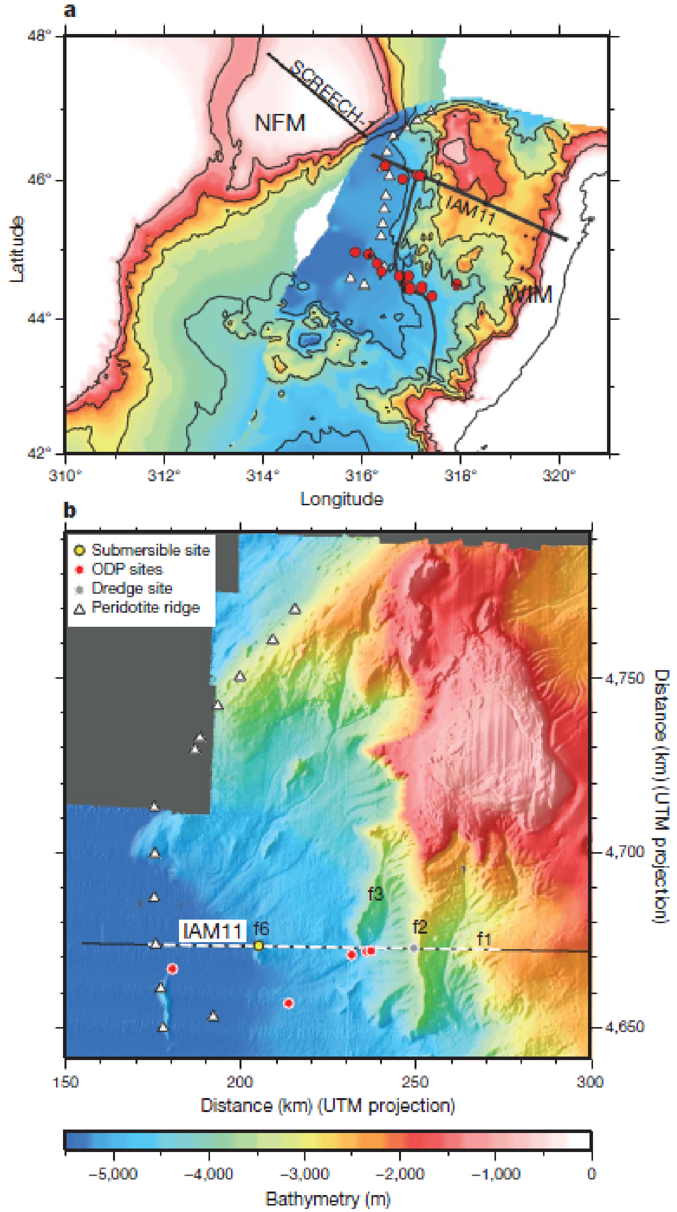


Figure 1 | WIM and NFM. a, Reconstruction at chron M0[29]. Black lines are seismic profiles. IAM11 has been processed and pre-stack depth-migrated, and SCREECH-1 (originally published by ref. 5) has been reprocessed and pre-stack depth-migrated with refined velocities. The black curved line marks oceanward extent of continental crust at the WIM. **b**, Multibeam bathymetry of the deep Galicia margin[11]. The IAM11 segment in Fig. 2 is marked by white dashes. Scarps f1, f2, f3 and f6 correspond to faults on IAM11 (Fig. 2a). ODP, Ocean Drilling Program. UTM, universal transverse Mercator.

Ranero & Perez-Gussynié, Nature, 2007

La marge de Galice

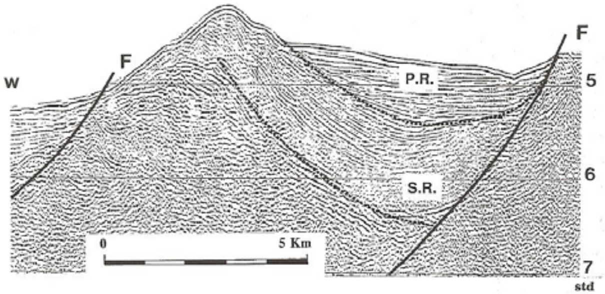


Fig. 2.4 Image sismique du bloc et du bassin situés en haut de la coupe de la fig. 2.1, entre les points de tirs 3300 et 3700 (échelle verticale en secondes, temps double). P.R. : sédiments post-rift ; S.R. : sédiments syn-rift ; F : failles normales entre les blocs crustaux basculés. std : secondes, temps double.

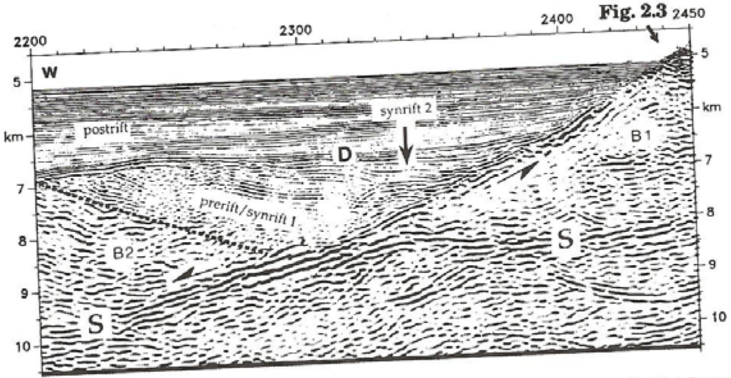
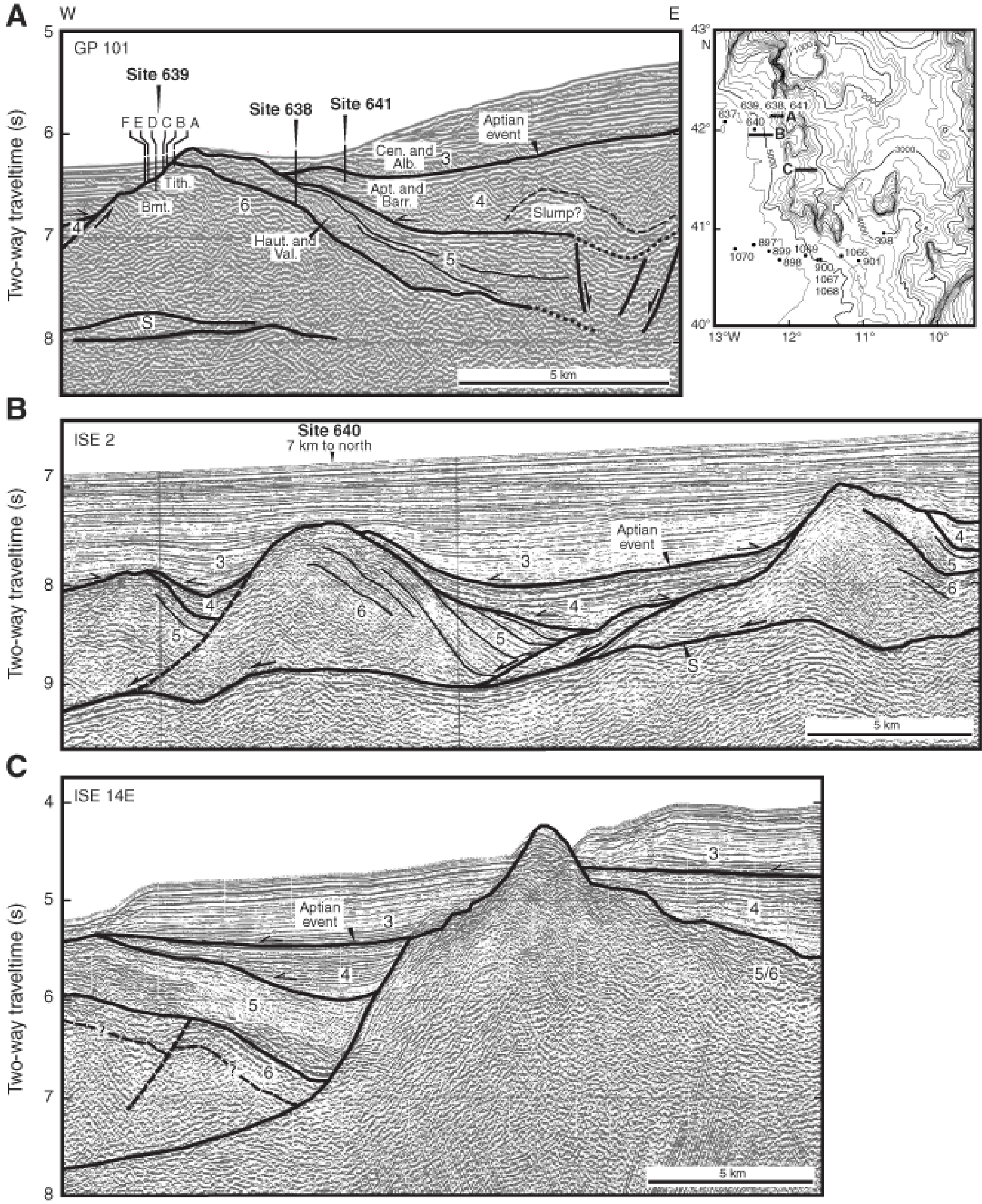


Fig. 2.9 Coupe sismique G-P 101, enregistrée sur la marge continentale de Galice par l'Institut Français du Pétrole, et traitée au centre GEOMAR de Kiel (Allemagne). B1 et B2 : socle continental identifié (B1) ou supposé (B2). D : discordance post-rift. S = réflecteur S. Échelle horizontale : points de tirs également reportés sur la fig. 2.1. Pas d'exagération verticale. D'après Krawczyk and Reston, 1995.



La marge de Galice

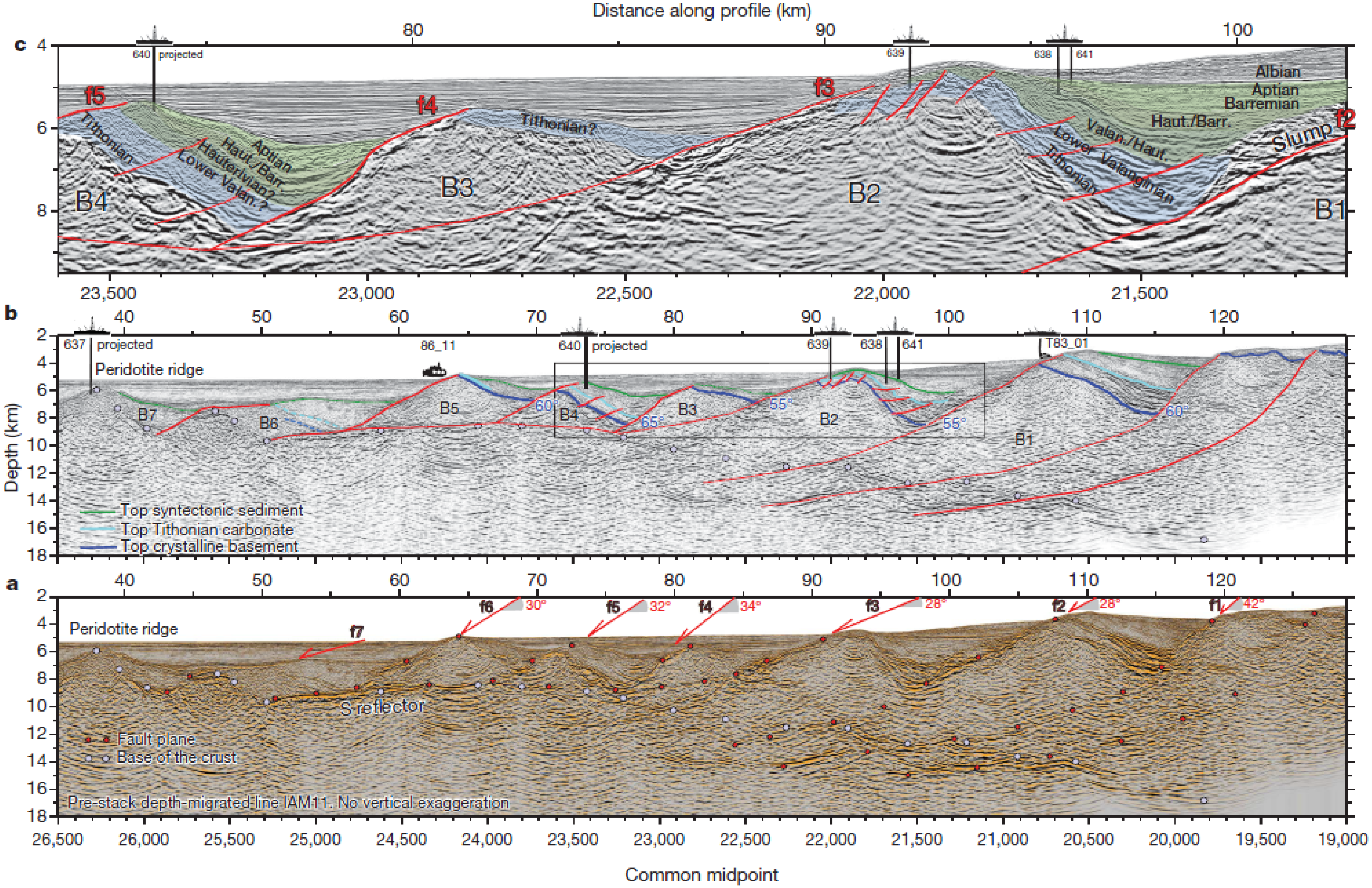
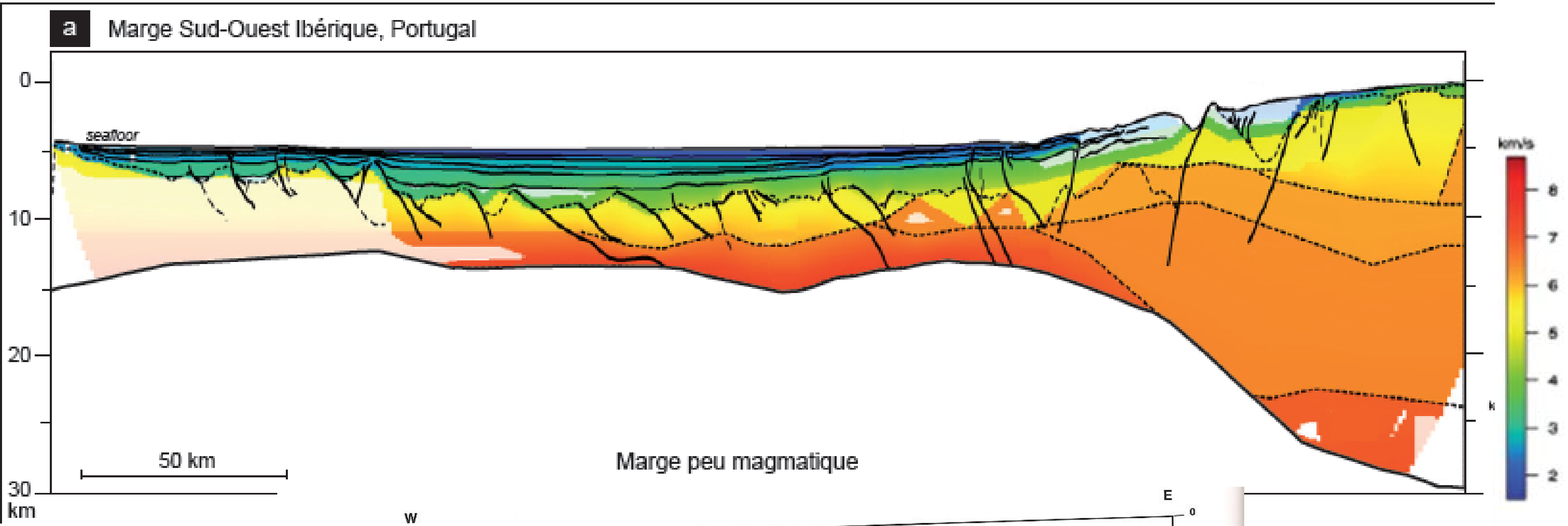


Figure 2 | Pre-stack depth-migrated line IAM11. **a**, Arrows and numbers indicate the average dips of the block-bounding fault segments exhumed during rifting. Red circles delineate reflections in crust and mantle interpreted as faults, which project up-dip to the exhumed block-bounding fault segments. Grey circles mark the crust base, constrained with wide-angle seismic data[30]. **b**, Tectonic and stratigraphic interpretation calibrated with ODP sites 637–641, dive 86_11 and dredge T83_01 (ref. 17). Faults bounding blocks B1–B5 possibly formed at 55°–65° (in blue), as inferred from their angular relationship to Jurassic strata originally deposited subhorizontally. **c**, Magnified view of box in **b**, showing geometry and calibrated ages of sediment units. At block B2, four units overlie pre-rift carbonates. A Valanginian/Hauterivian unit, drilled at sites 638 and 639, was deposited during the main activity of fault f2. Younger Hauterivian/Barremian, Barremian/Aptian and Albian/recent units drilled at sites 638 and 641 are post-tectonic. Block B3 is imaged at its edge and sediment units are too thin to be resolved. At site 640, in block B4, Barremian/Aptian sediment was found as part of the section of syn-rift strata. Thus, the activity of fault f2 stopped during Hauterivian time, possibly before the activity of fault f4 began, during Barremian time, and several million years before the end of f4 activity, during late Aptian or early Albian time.

Ranero & Perez-Gussynié, Nature, 2007

La marge de Galice



Marge peu magmatique

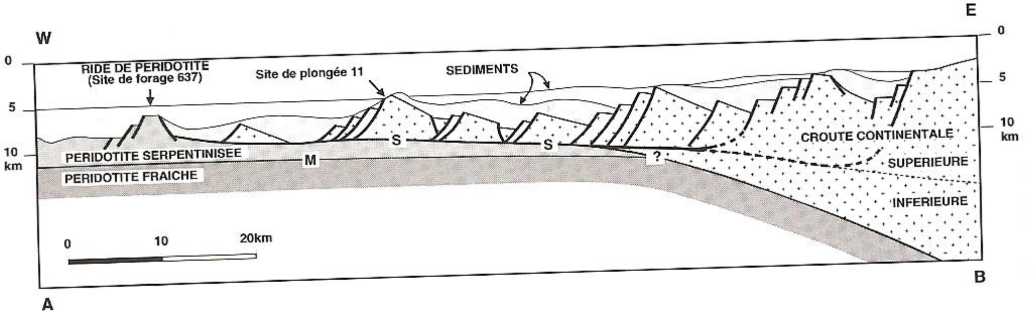


Fig. 3.6 Coupe synthétique de la marge de Galice.

1 – La structure sismique de la ride de péridotite située à l'ouest de la coupe est détaillée sur la fig 3.2. Sous la ride, le Moho est la limite entre les péridotites « fraîches » et les péridotites partiellement serpentinisées, c'est-à-dire une limite de changement de phase minéralogique correspondant au paléo-front de serpentinisation.

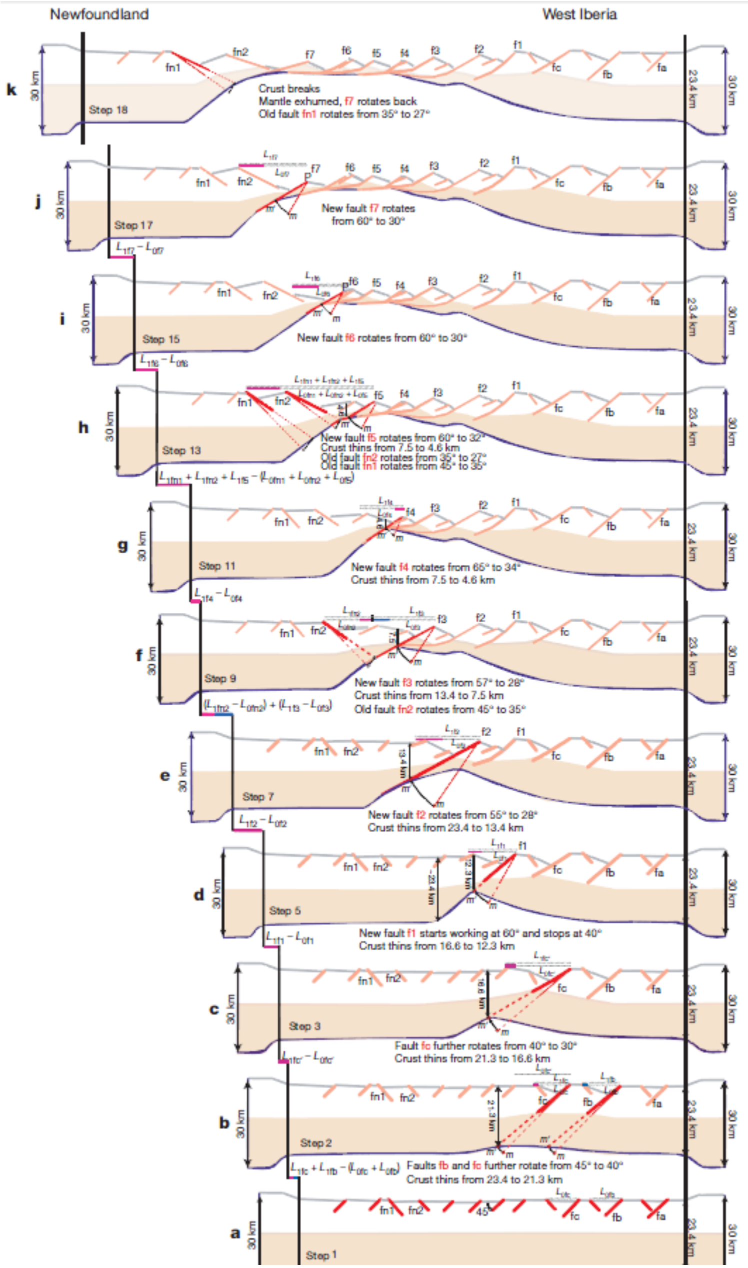
2 – Du côté océanique de la coupe, à l'ouest de la ride, les fonds sous-marins sont également constitués de péridotites serpentinisées, localement recouvertes d'une mince couche de basalte mise en place après la rupture continentale (fig. 3.4 et § 3.5).

3 – Du côté oriental de la ride, les blocs de croûte continentale supérieure reposent directement sur les péridotites serpentinisées par l'intermédiaire d'un contact anormal (un détachement; fig. 3.4), dont l'image sismique est le réflecteur S (fig. 2.9).

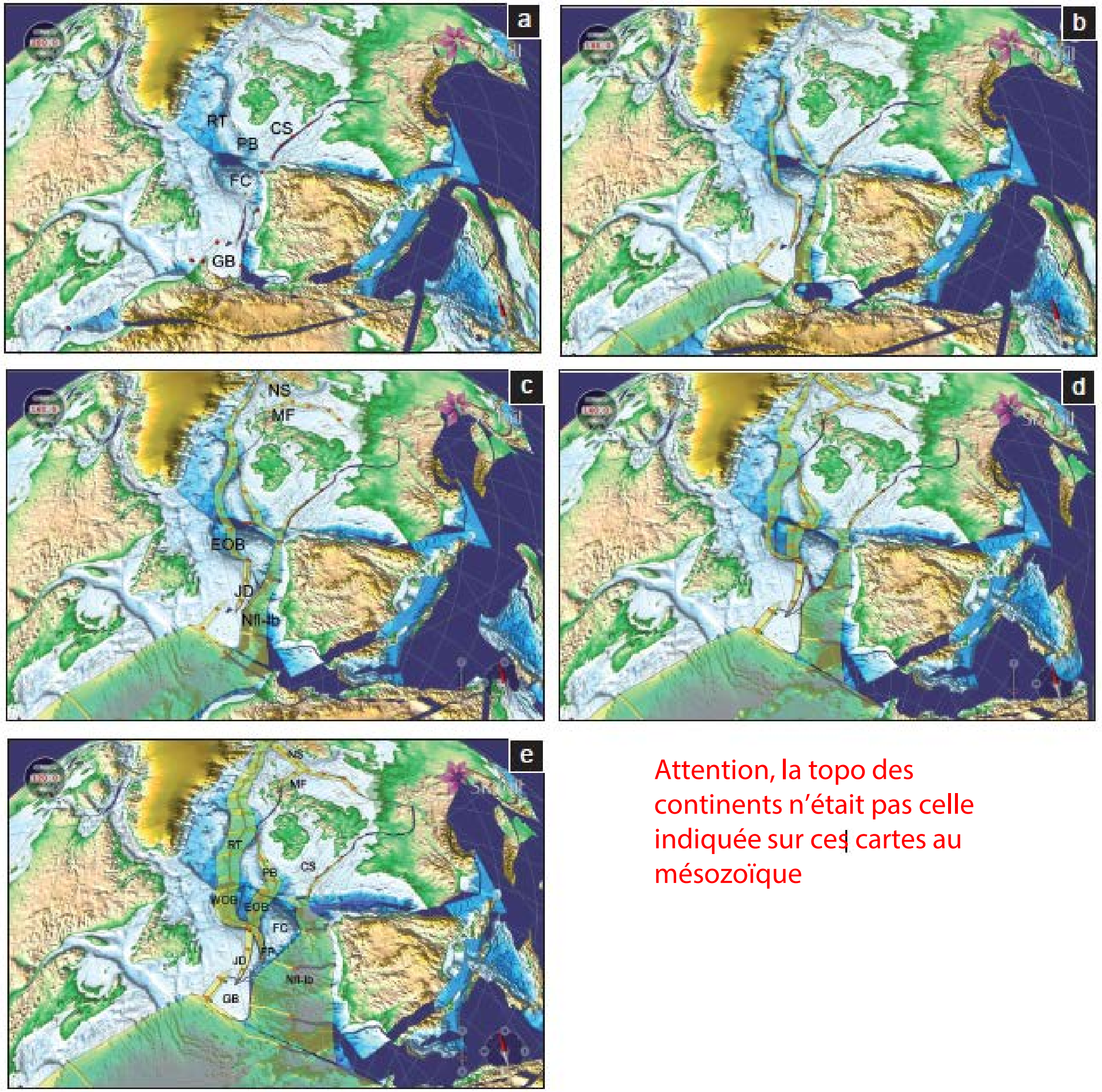
4 – Les failles normales limitant les blocs crustaux sont à fort pendage en surface (60 - 70°), et s'enracinent en profondeur dans la faille de détachement sub-horizontale située à la base de ces blocs (chapitre II, § 2.2).

5 – Les données sismiques et gravimétriques montrent que des péridotites serpentinisées contribuent à la constitution de la croûte inférieure (définie par ses propriétés physiques) dans la partie la plus profonde de la marge, à proximité de la frontière continent-océan (fig. 3.5). Mais l'étendue des terrains mantelliques serpentinisés sous la marge vers le continent n'est pas connue pour le moment, ni les modalités de leur transition avec la croûte continentale inférieure pré-rift (§ 3.3). D'après Boillot et al., 1995c.

La marge de Galice, histoire de l’ouverture



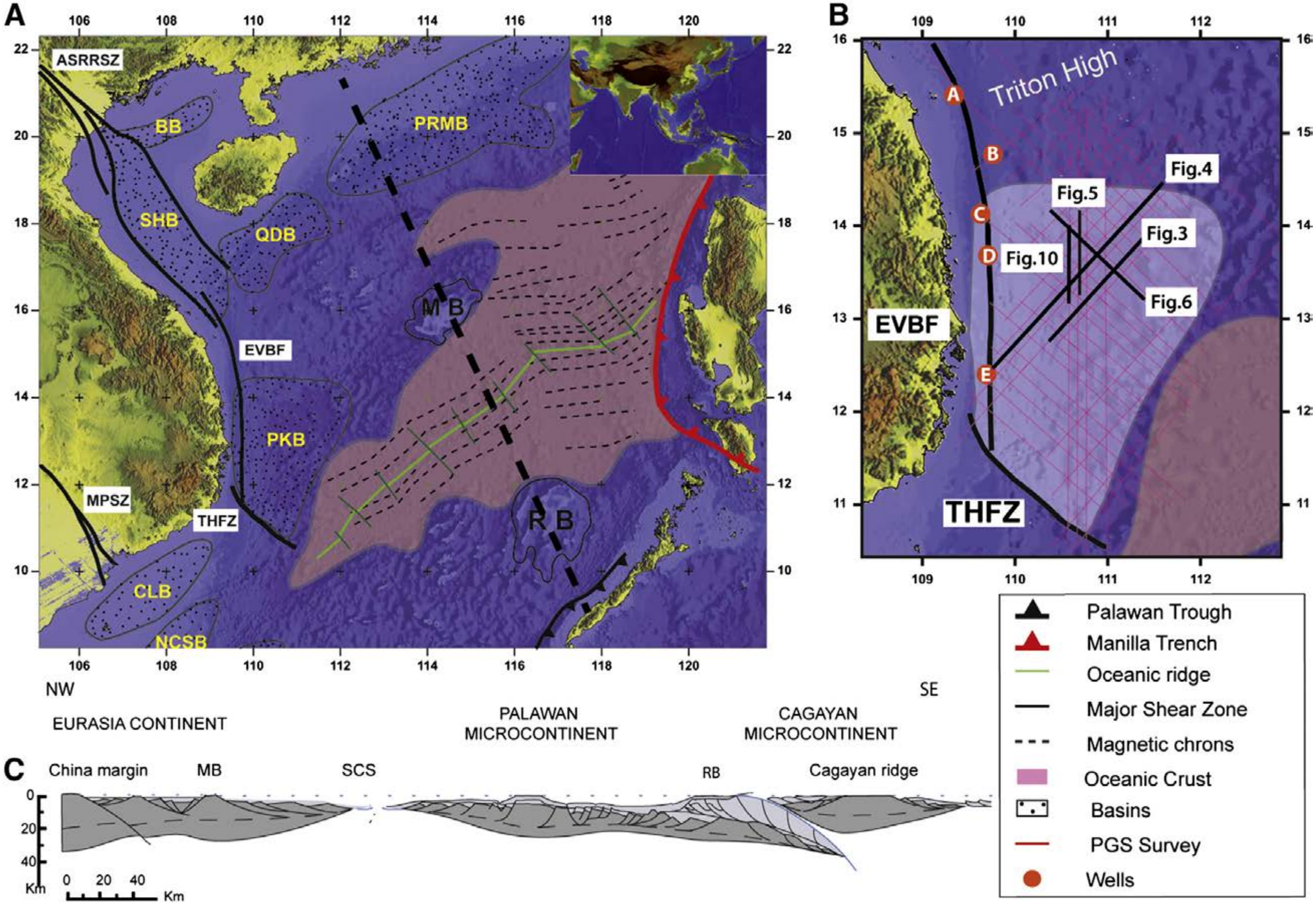
Ranero & Perez-Gussynié, Nature, 2007



gure 11. Modèle de reconstruction cinématique du mouvement des plaques au cours du rifting mésozoïque de l’Atlantique Nord à 200 Ma (a), 180 Ma (b), 160 Ma (c), 140 Ma (d) et 120 Ma (e). GB: Grand Banks; CS: Celtic Sea; EOB: East Orphan Basin; FC: Flemish Cap; JD: Jeanne d"Arc Basin; MF: Moray Firth Basin; Nfl-Ib: Newfoundland-Iberia rift zone; NS: North Sea Basin; RT: Rockall Trough; PB: Porcupine Basin (Skogseid 2010).

Attention, la topo des continents n’était pas celle indiquée sur ces cartes au mésozoïque

exhumation du manteau en Mer de Chine



- ➢ *Rift avorté au stade exhumation du manteau-formation de la toc*

Savva et al., Tectonophysics, 2013

exhumation du manteau en Mer de Chine

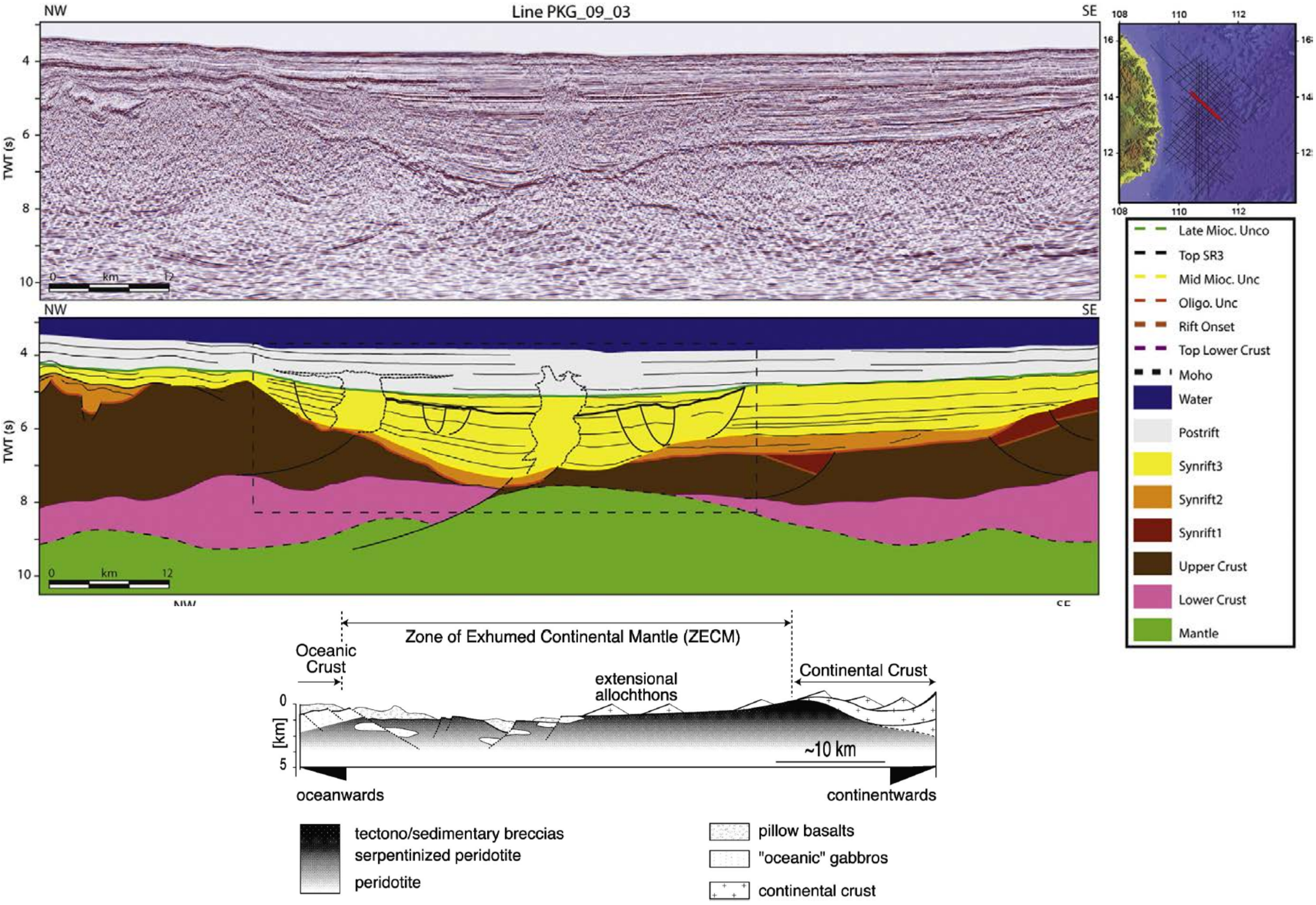


FIG. 1.19: *Architecture de la* Zone of Exhumed Continental Mantle *au niveau des marges passives non-volcaniques (Manatschal, 2004).*

Savva et al., Tectonophysics, 2013

Marge avolcaniques ou peu volcaniques : bilan

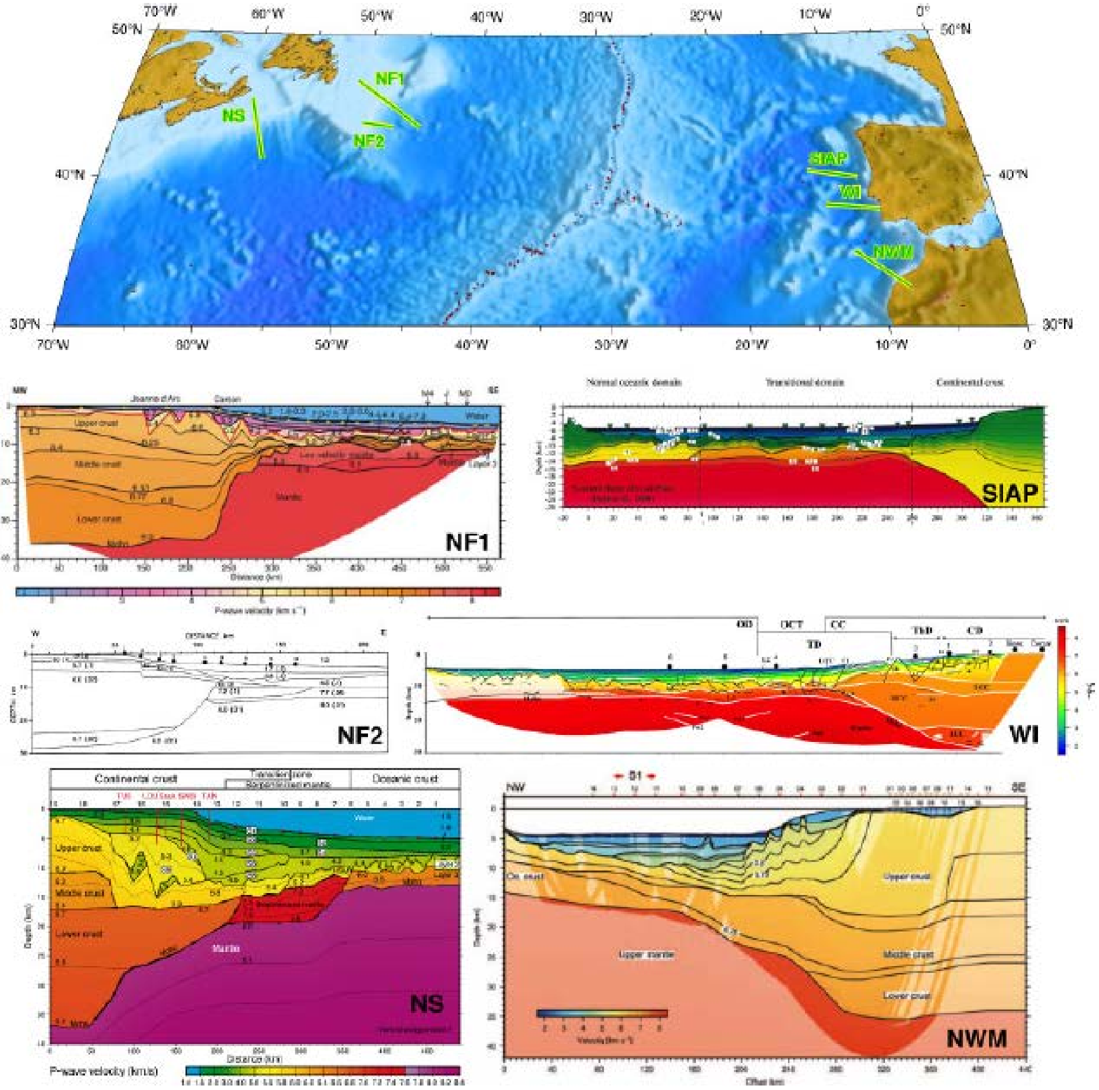
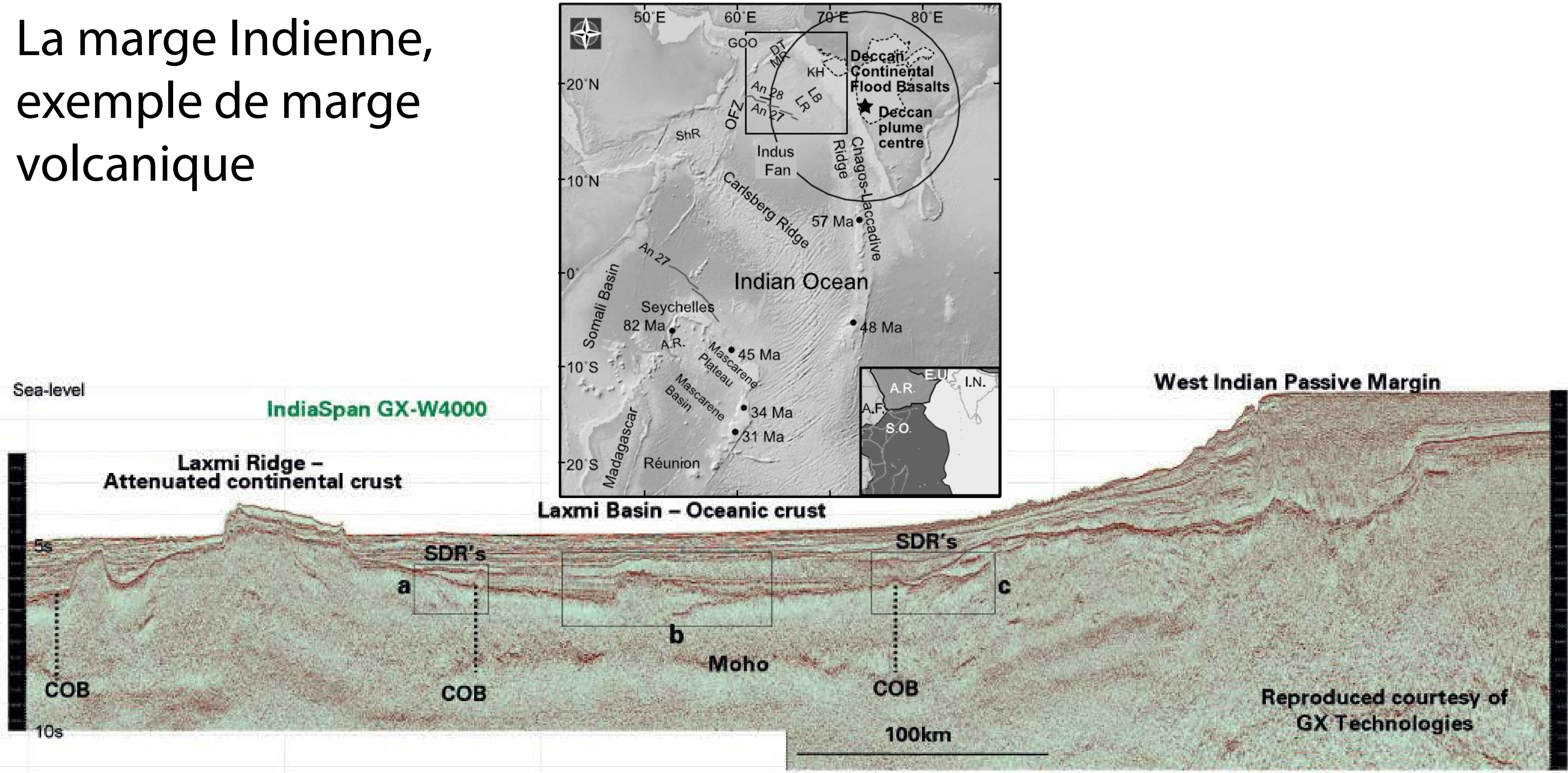
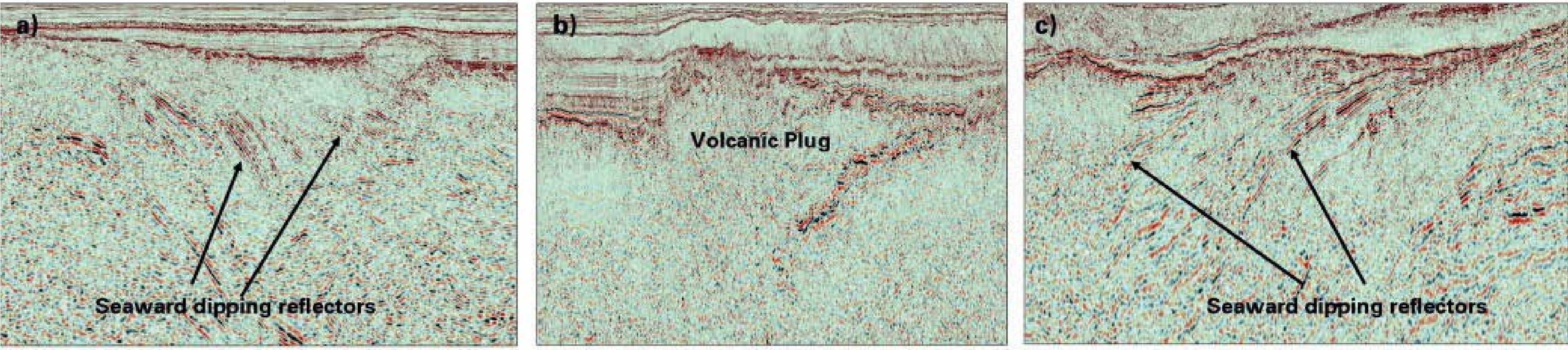


Fig. 1.25: *Modèles de vitesse des ondes P de 6 marges peu-volcaniques du nord de l'Atlantique. Les abréviations signifient :* NF *pour Newfoundland (Terre-Neuve),* SIAP *pour South-Iberia Abyssal Plain,* WI *pour West-Iberia, NS pour Nova-Scotia (Nouvelle-Ecosse), et NWM pour North-West Morocco. Les marges sont représentées par paires de marges conjuguées, les figures sont issues de Lau* et al. *(2006) pour* NF1, *Contrucci* et al. *(2004b, à partir de Dean* et al. *(2000)) pour* SIAP, *Reid (1994) pour* NF2, *Afilhado* et al. *(2008) pour* WI, *Funck* et al. *(2004) pour* NS *et Contrucci* et al. *(2004a) pour* NWM.

Watremez, phd, 2010

La marge Indienne, exemple de marge volcanique





Formation des « Seaward Dipping Reflectors »

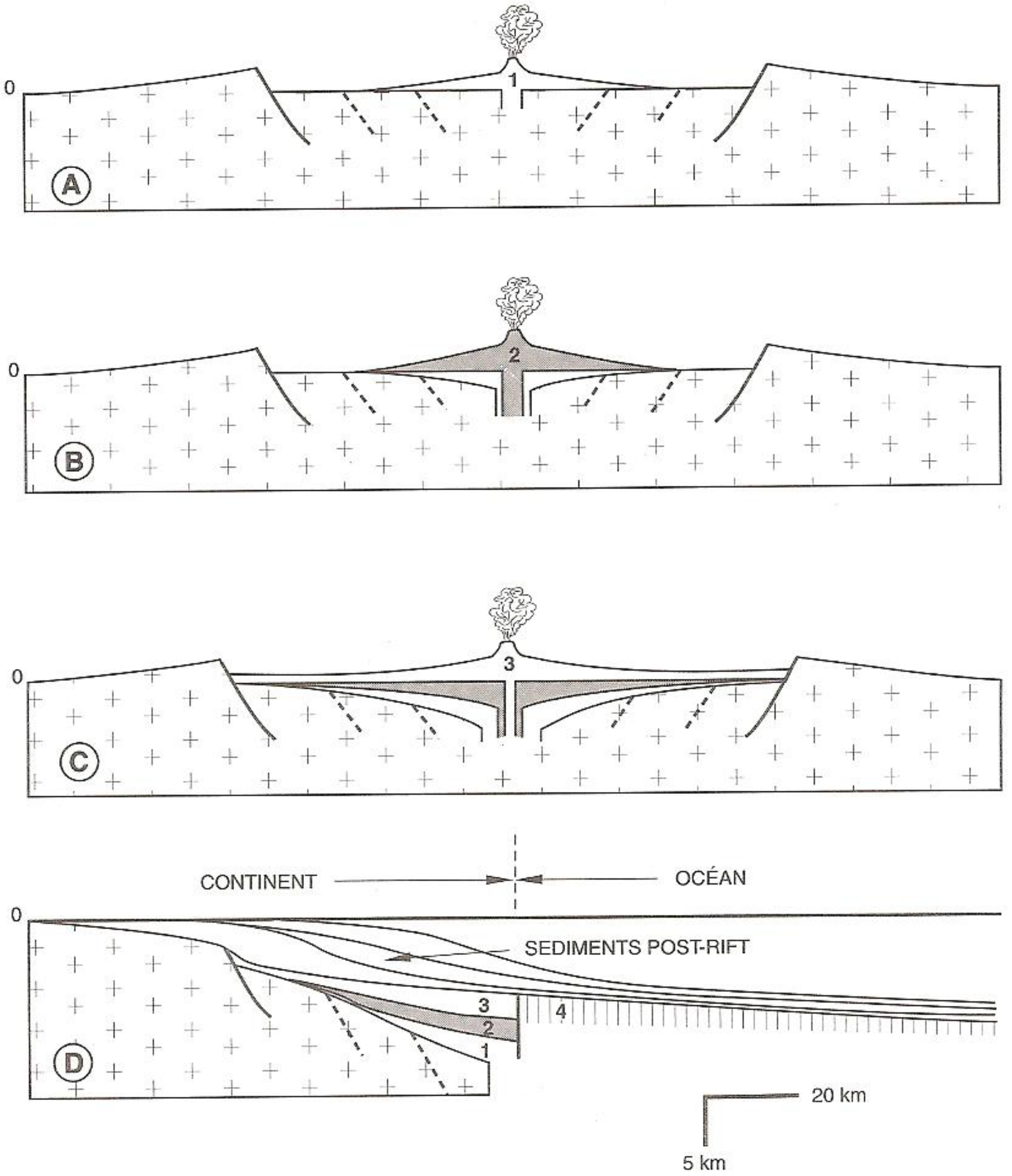
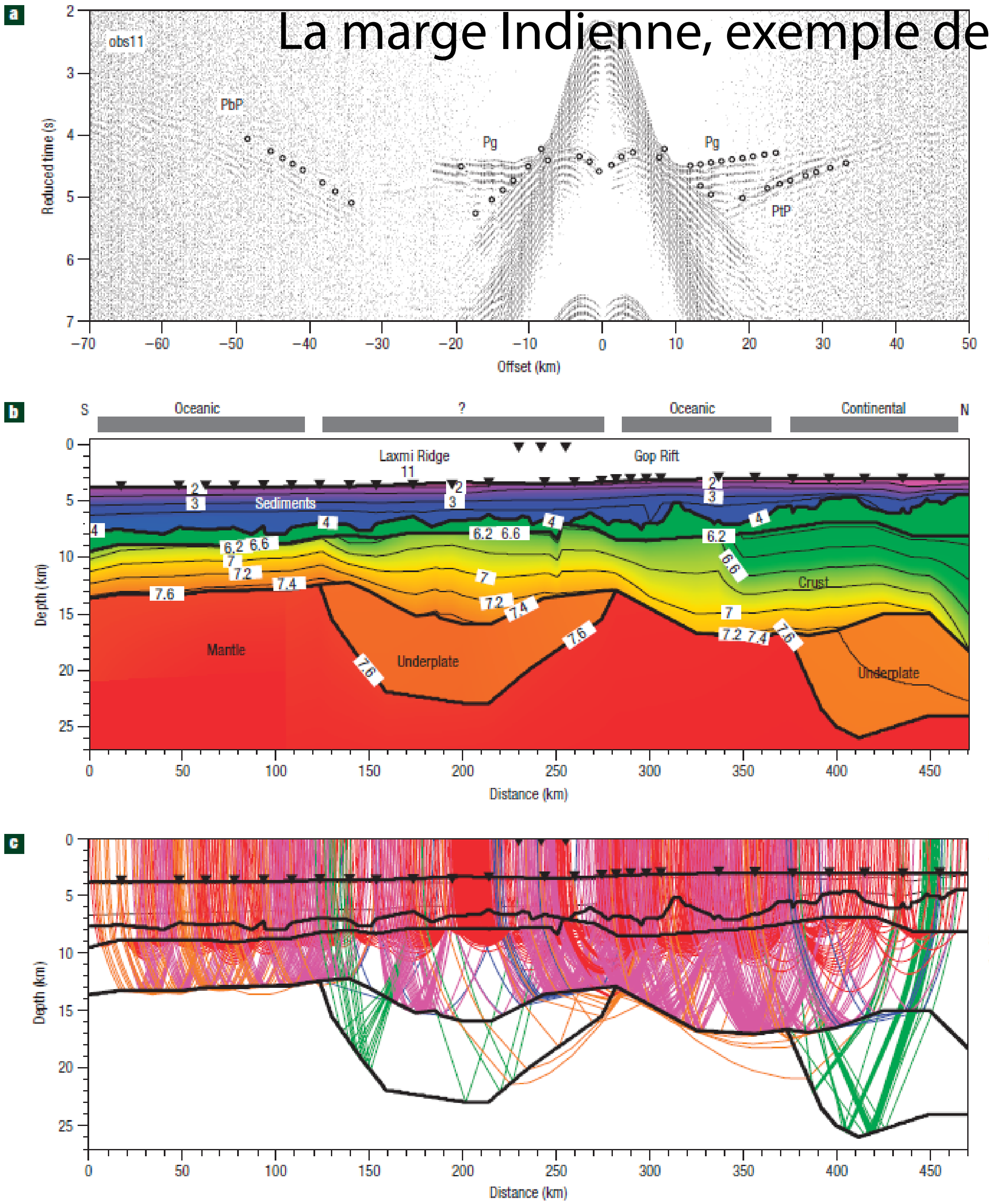


Fig. 8.1 Évolution d'un rift continental volcanique (stade A) à une marge continentale passive (stade D). 0 : niveau de la mer; 1, 2, 3 : formations volcaniques successives épanchées au cours des stades A, B, C; 4 : croûte océanique (d'après Boillot, 1996).

La marge Indienne, exemple de marge volcanique



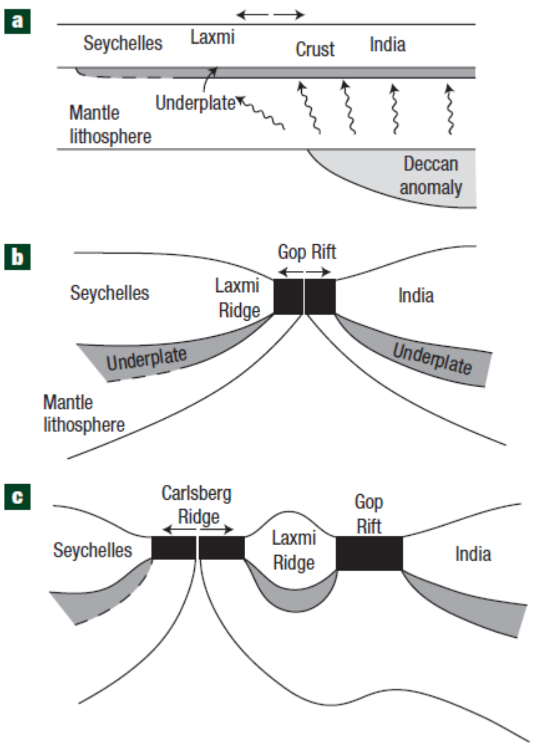
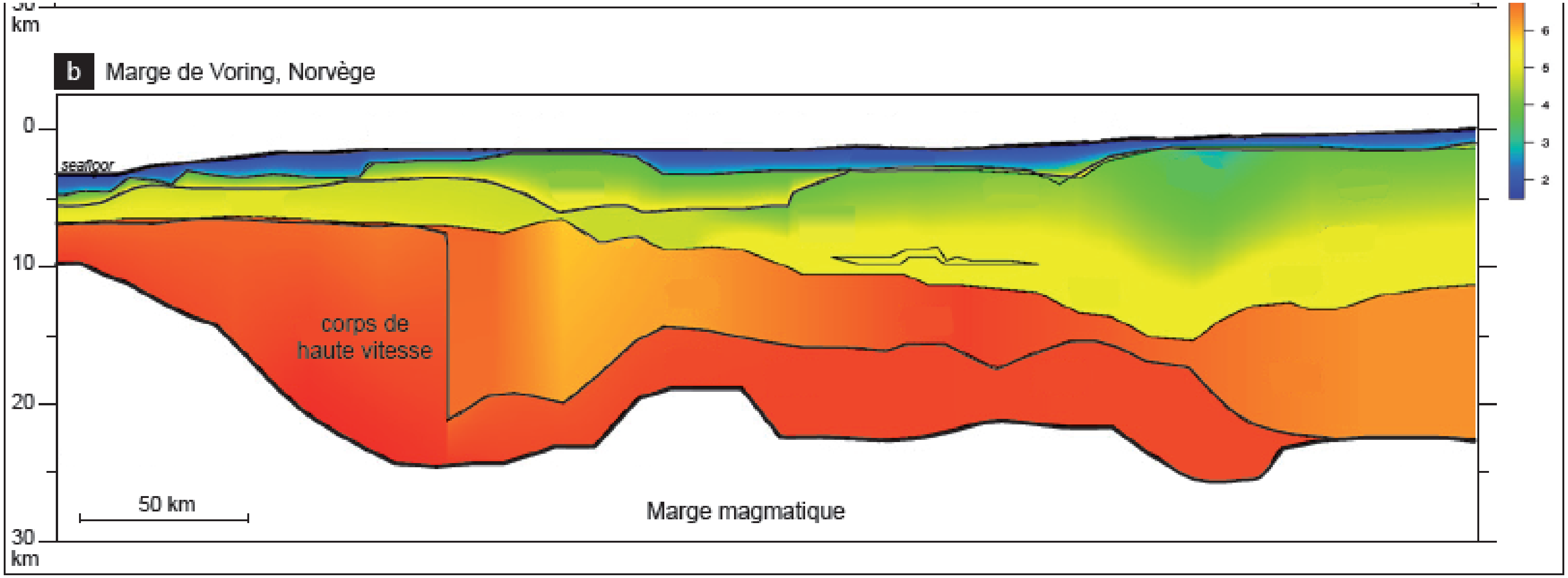


Figure 4 Cartoon illustrating a model of events through time that is consistent with data. a, Deccan (or pre-Deccan) magmatism and lateral melt transport lead to initiation of underplating across a broad extending region. **b**, The underplate is split by the formation of oceanic crust in Gop Rift. **c**, Extension has ceased in Gop Rift and seafloor spreading has commenced at the proto-Carlsberg Ridge. The horizontal and vertical scales are smaller in **a** than in **b** and **c**.

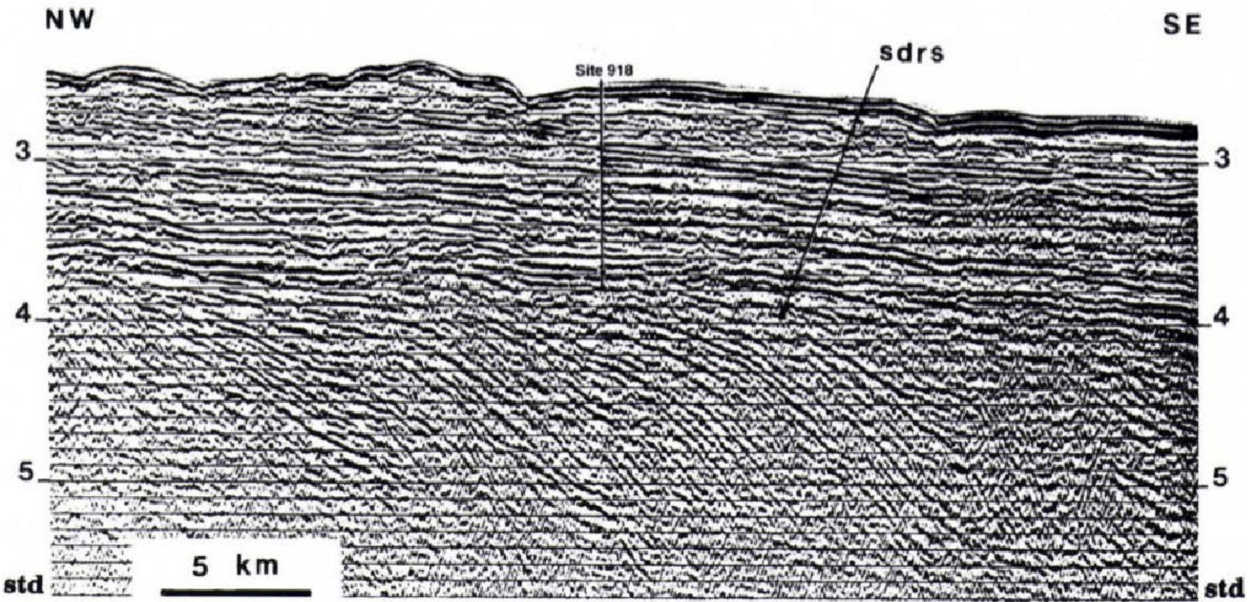
Le point chaud créé du sous-placage magmatique au niveau du moho

Minshull et al., Nat. Geosci., 2008

Autres exemples de marges volcaniques



SDR de la marge volcanique du Groenland



Bilan : diversité des marges passives

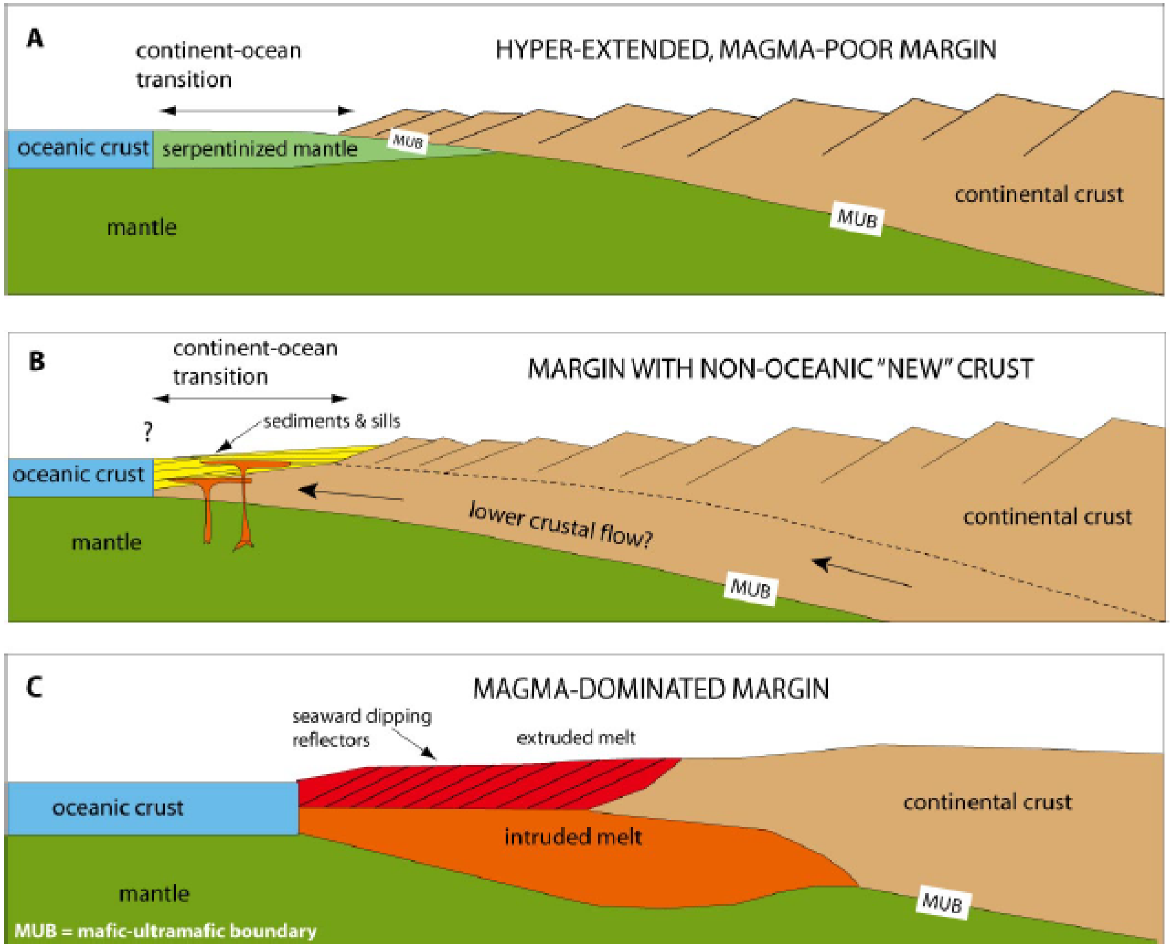


FIG. 1.22: *Coupes schématiques de structures profondes de marges continentales étirées (Sawyer* et al.*, 2007).* **A** *: Marge fortement étirée, la TOC est constituée de manteau exhumé serpentinisé (e.g. les marges d'Ibérie et de Terre-Neuve).* **B** *: Marge étirée avec une croûte néoformée non-océanique, la TOC est constituée de sédiments et de magmatisme (e.g. le Nord de la Golfe de Californie).* **C** *: Marge volcanique où l'on observe de grandes quantités de magmatisme en surface (coulées) ainsi qu'en profondeur (croûte inférieure intrudée ou sous-plaquage magmatique, e.g. les marges du Nord-Ouest de l'Europe et l'Est du Groënland).*

Watremez, phd, 2010

EXTENSION

- Définition des rifts et marges passives
- Du rifting continental à l'ouverture océanique : le système rift africain, mer Rouge, & golfe d'Aden
- Distribution des zones de rift et diversité
- Marges passives volcaniques et non-volcaniques
- **Modes de formation des rifts : rhéologie, mécanique**
- Les contextes géodynamiques favorables au rifting continental : quel moteur pour la déchirure continentale?

Failles normales au niveau du rift est-africain

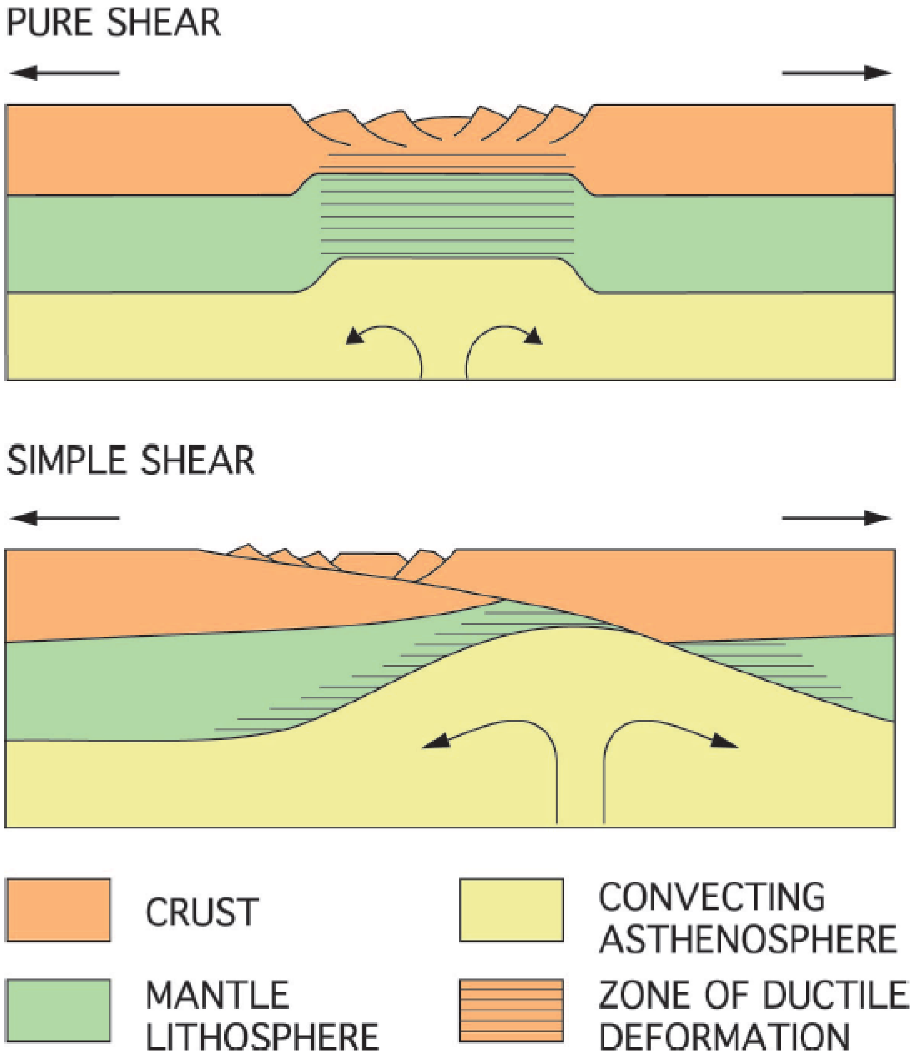
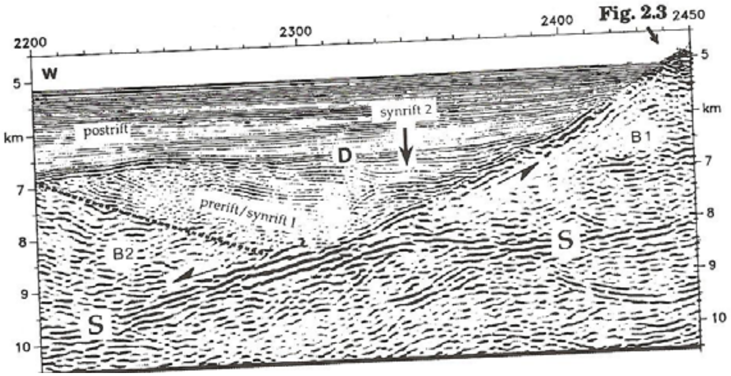
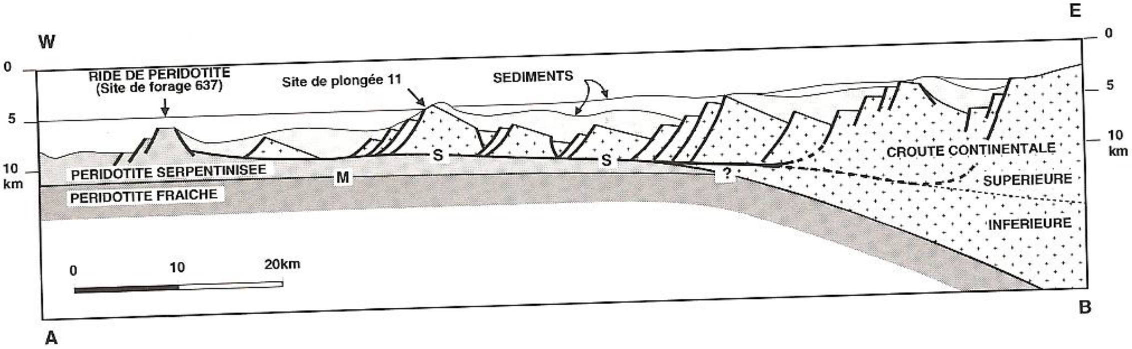
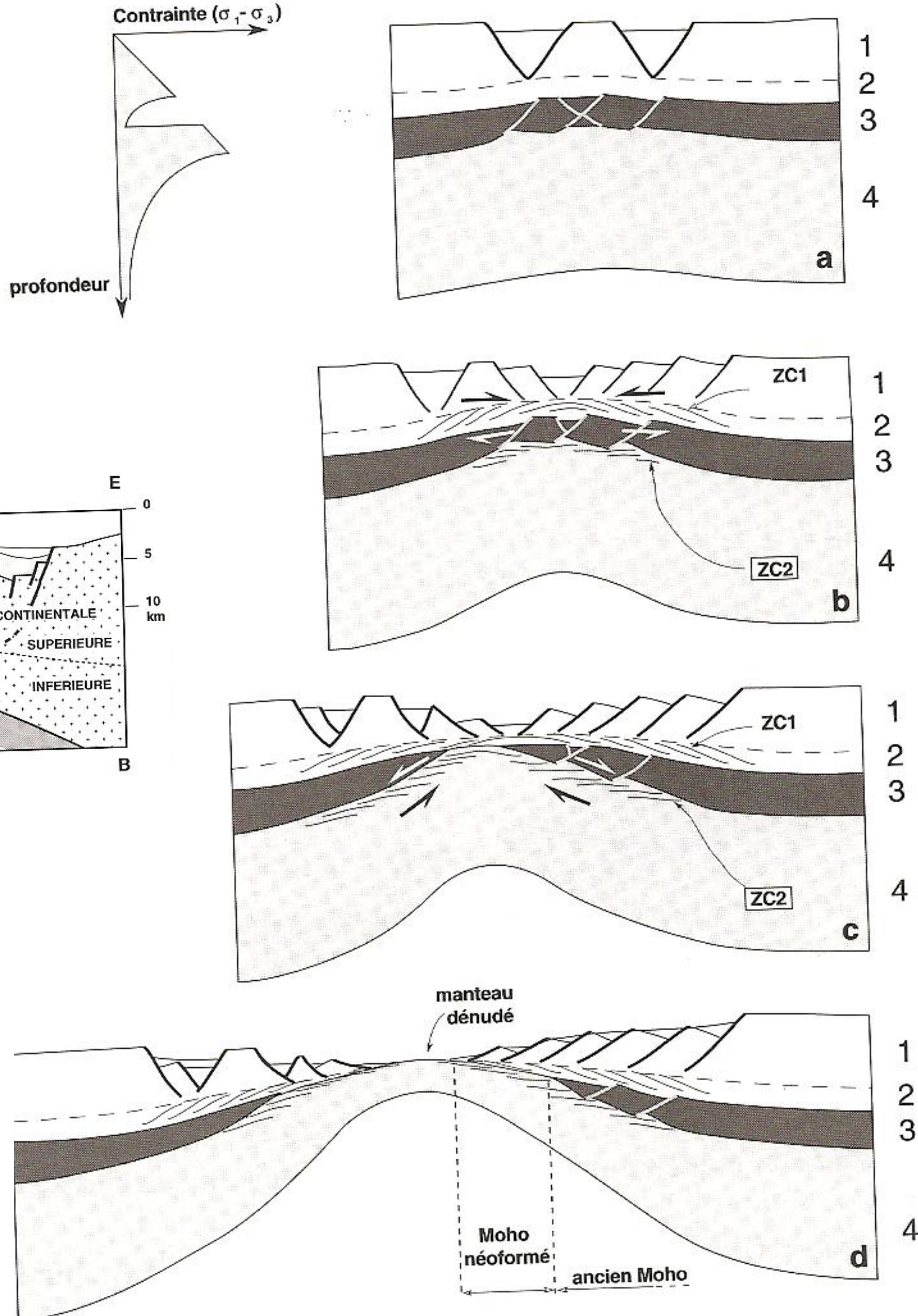


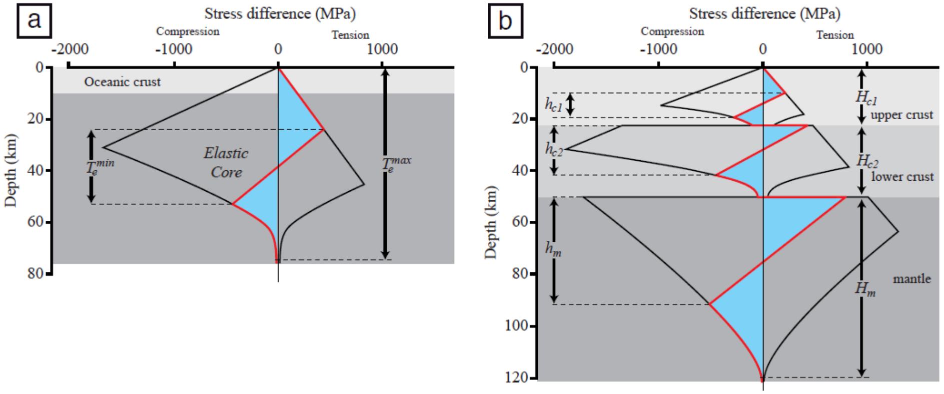
Fig. 1.3: *Modèles conceptuels de l'extension lithosphérique symétrique et asymétrique. En haut, le modèle de cisaillement pur, symétrique (McKenzie, 1978), et en bas, le modèle de cisaillement simple, asymétrique (Wernicke, 1985). Figure modifiée à partir de Ziegler & Cloetingh (2004).*

Formation des rifts et des marges passives (cas non-volcanique)



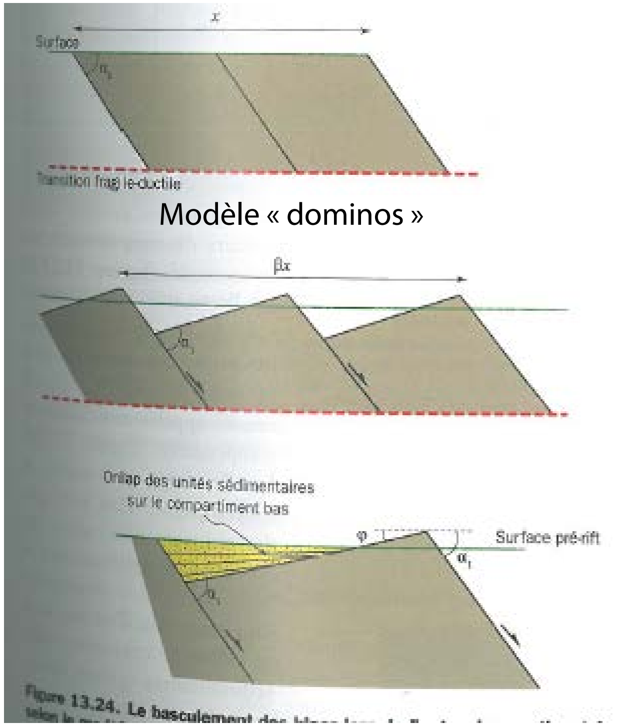






- *Evolution de la subsidence d'une marge passive? … cours de Matthias Delescluse*

Failles normales : modèles simplifiés de formation



Modèle « dominos »

Figure 13.24. Le basculement

Attention :
faille listrique = niveau de décollement, avec failles normales à fort pendage qui viennent se brancher dessus

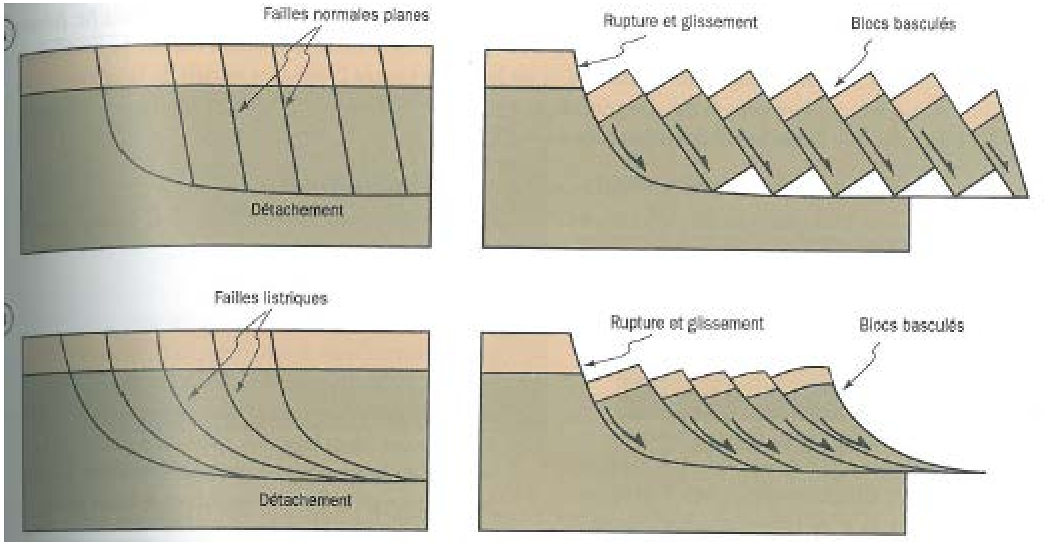


Figure 13.23. La géométrie des systèmes de failles normales dans l'extension continentale
(D'après Wernicke et Burchfiel, 1982)
A. Failles parallèles rotationnelles. Le basculement des blocs s'effectue selon le modèle des dominos. **B.** Failles listriques. Maintenant le contact avec le compartiment inférieur, le bloc distal prend une forme convexe, formant un anticlinal en rollover (cf. figure 13.25).

Pour les core-complex continentaux

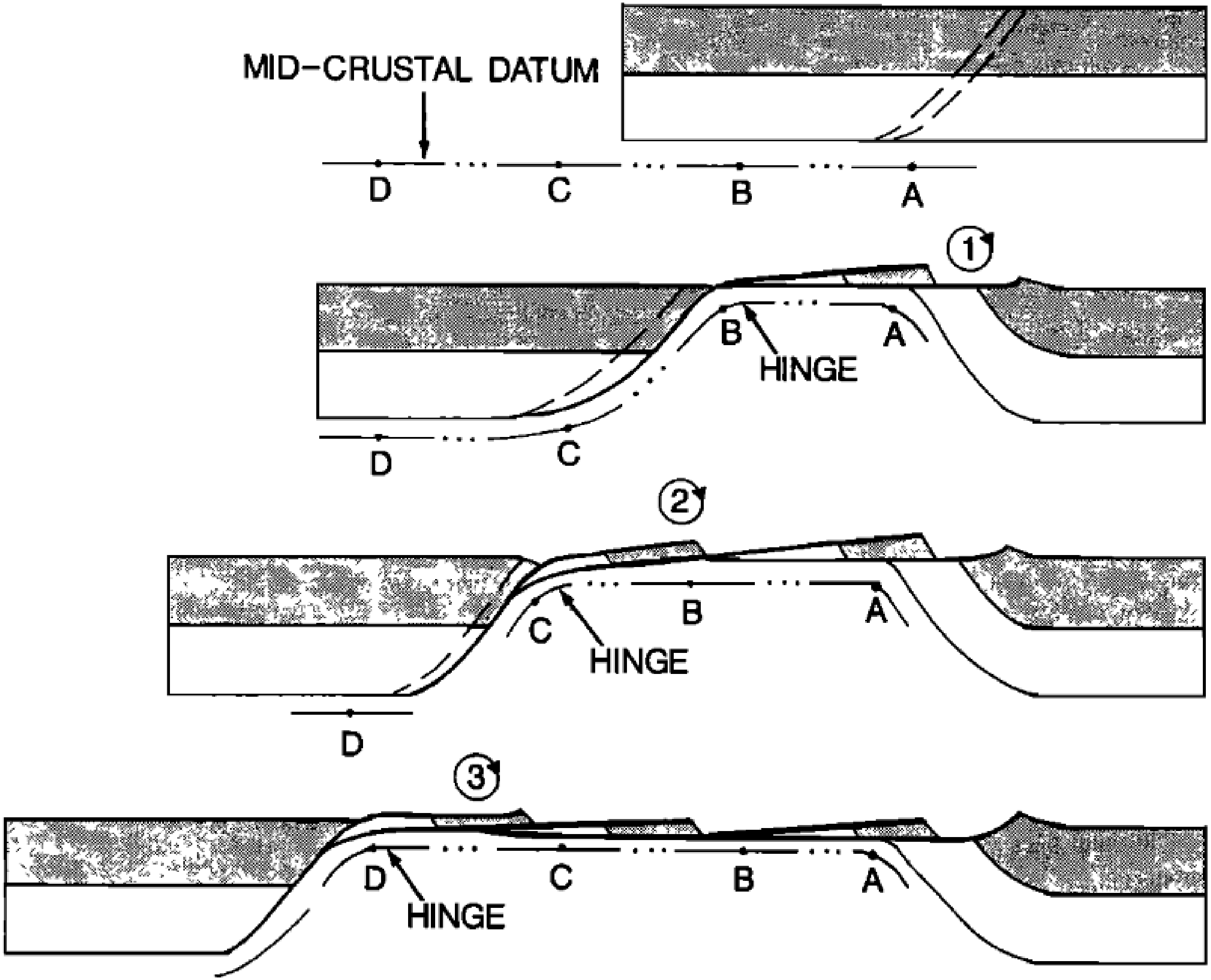


Figure 9. Rolling hinge model of detachment faulting [from *Wernicke*, 1992]. See text for discussion.

Un modèle parmi d'autres…

Pour les core-complex océaniques

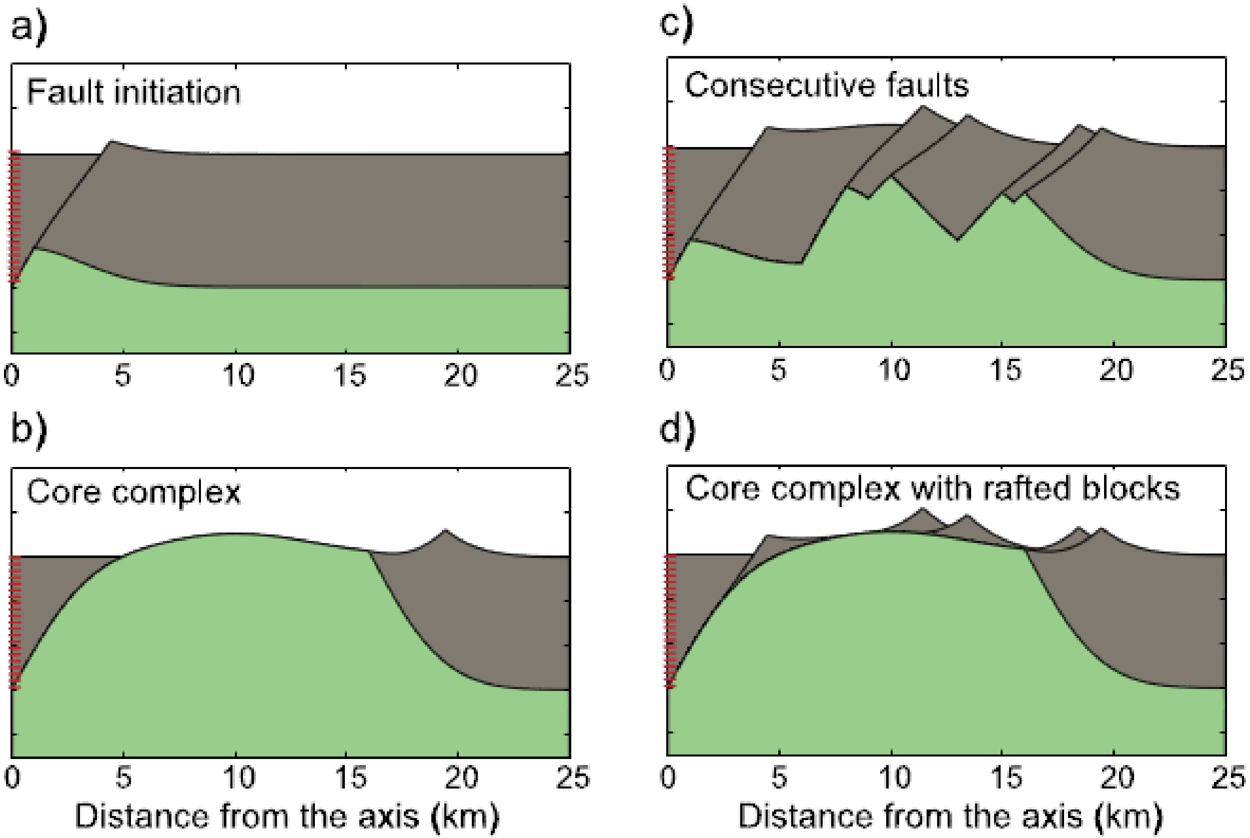


Figure 13. Four cartoons for the evolution of detachment faulting. (a) A normal fault at the axis. Flexural rotation of the fault results in the formation of a linear ridge and backing basin. Fault offset = 1 km; fault rotation = 18°. (b) Continued extension on the detachment fault increases the rotation of the fault and exposes lower crustal rocks and a corrugated footwall. Fault offset = 16 km; fault rotation = 36°. (c) Consecutive faults. In this case most of the lithosphere is accreted through typical magmatic processes at slow-spreading ridges. (d) Continuous detachment fault. New faults formed at the axis root into the main detachment. Triangular sections of median valley floor are transferred from the hanging wall to the footwall of the fault and rafted off axis. Gaps between rafted blocks may expose the primary detachment surface, which may show corrugations. The cartoons simulate regional isostatic compensation and use the flexural rotation of 60° normal faults for an effective elastic thickness of lithosphere Te = 0.4 km [e.g., *Buck*, 1988]. Gray on the figure is crust predating the onset of faulting and green is material from below drawn up during the slip on the fault and its rotation.

Un modèle parmi d'autres…

Pour les rift peu volcaniques/ dorsales lentes à ultra-lentes…

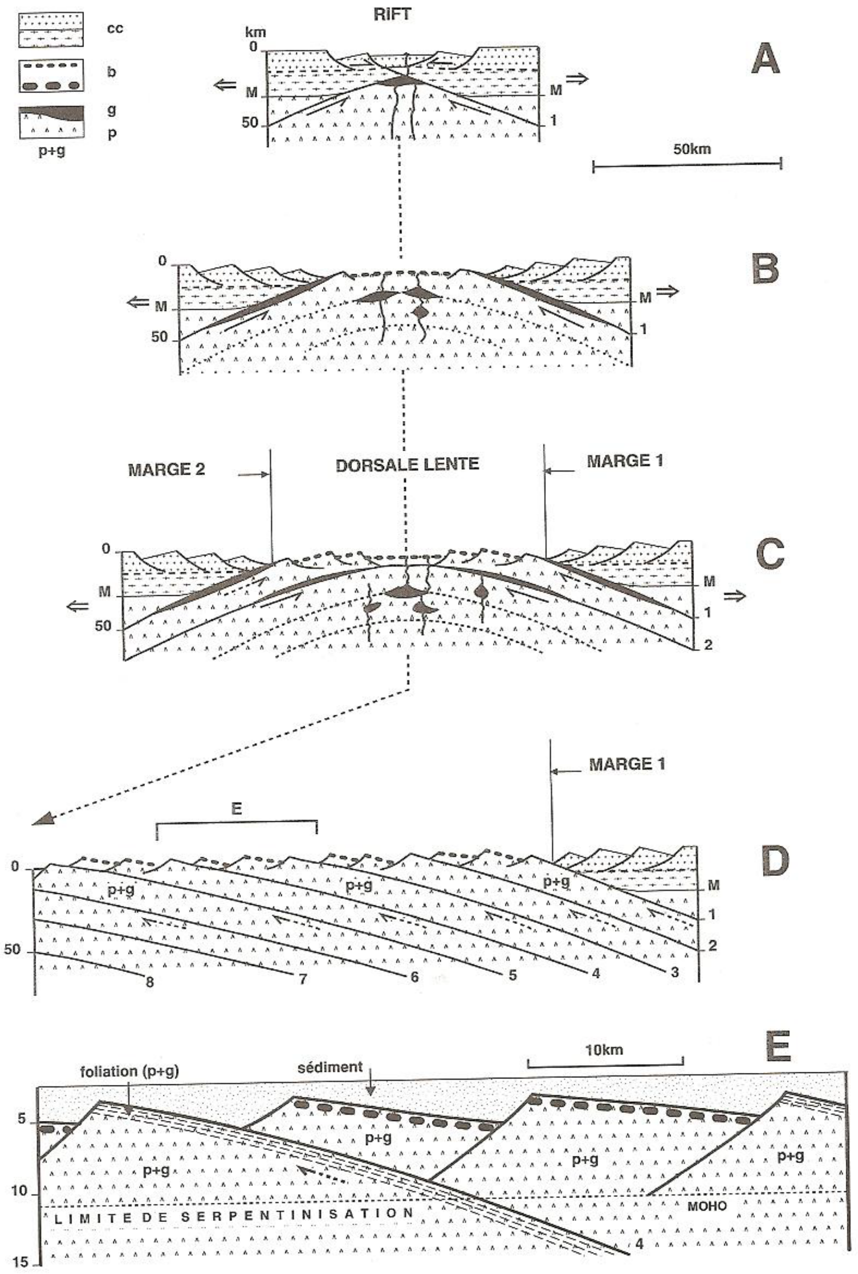


Fig. 3.18 Modèle de l'accrétion ultra-lente cc : croûte continentale; b : basalte; g : gabbro; p : péridotite (serpentinisée à proximité de la surface). La limite lithosphère-asthénosphère n'est pas figurée.

EXTENSION

- ➢Définition des rifts et marges passives
- ➢Du rifting continental à l'ouverture océanique : le système rift africain, mer Rouge, & golfe d'Aden
- ➢Distribution des zones de rift et diversité
- ➢Marges passives volcaniques et non-volcaniques
- ➢Modes de formation des rifts : rhéologie, mécanique
- ➢**Les contextes géodynamiques favorables au rifting continental : quel moteur pour la déchirure continentale?**

Failles normales au niveau du rift est-africain

Quels contextes géodynamiques favorisent les différents types de rifts?

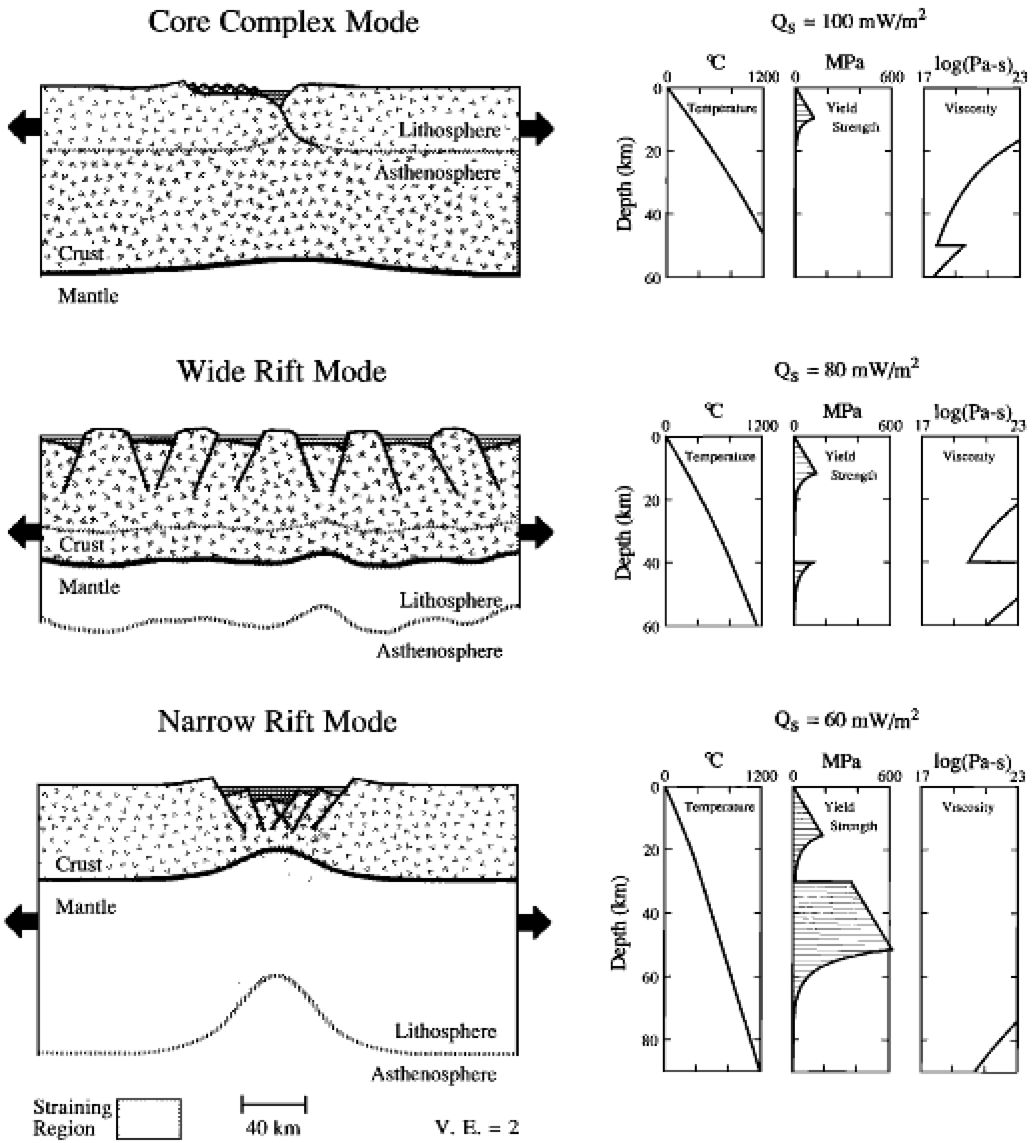
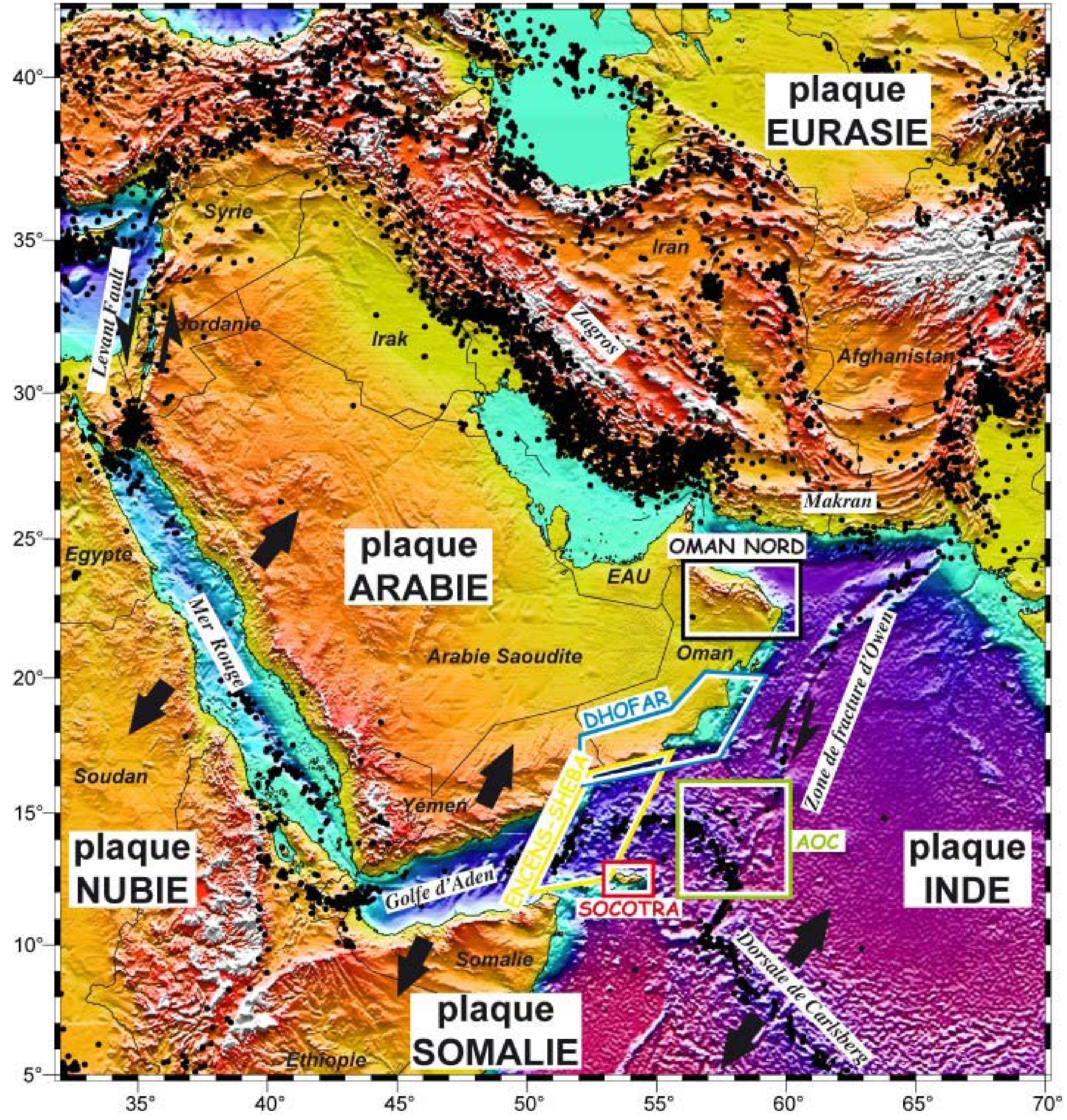
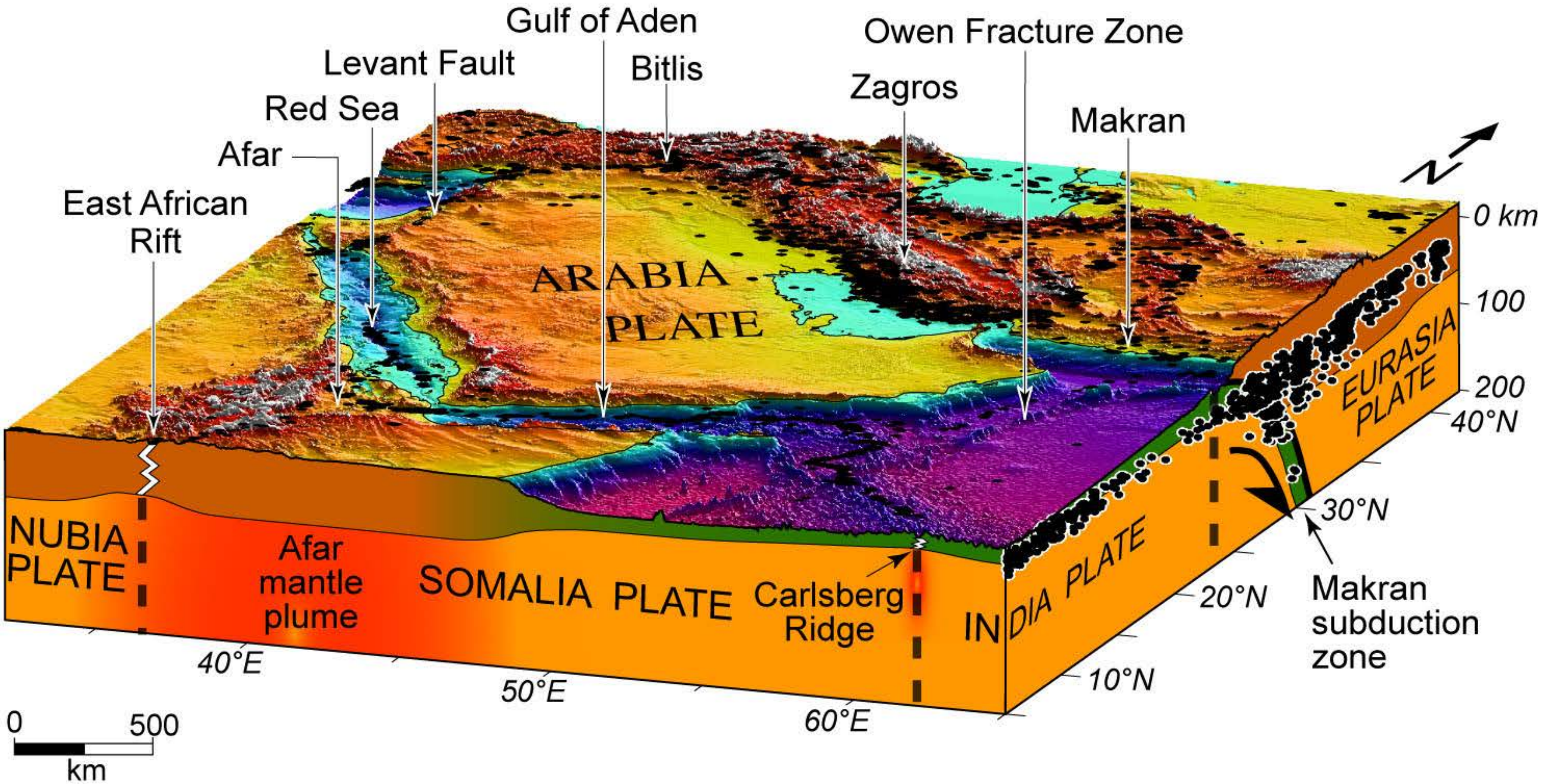


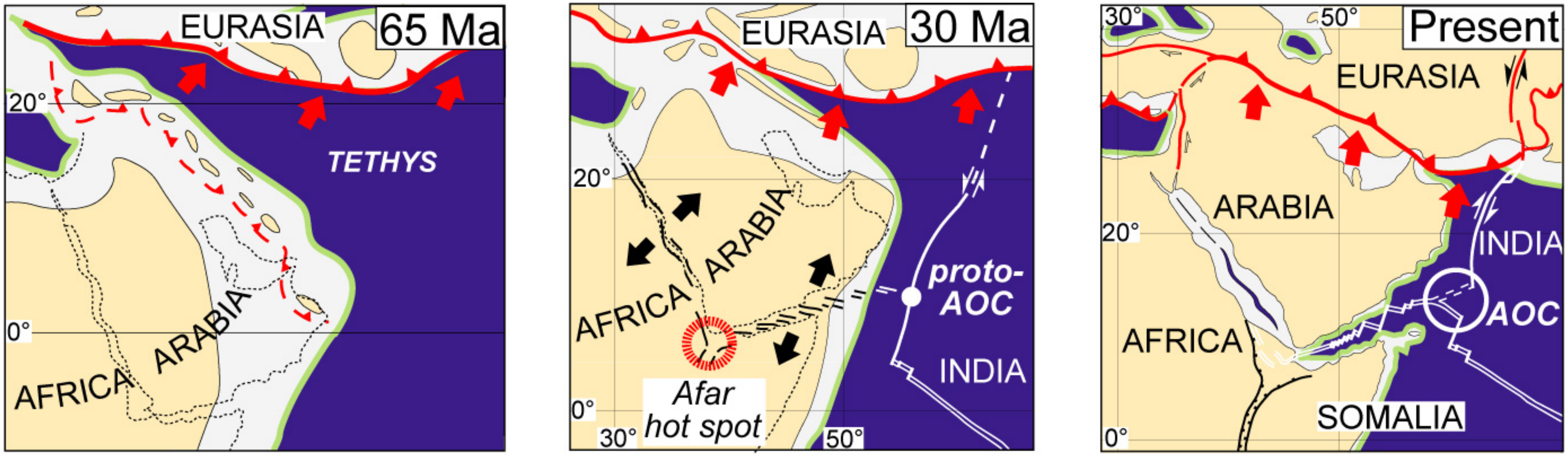
Fig. 1. Sketches of the lithosphere in the three modes of continental extension, emphasizing the regions undergoing the greatest amount of extensional strain. Lithosphere connotes areas with effective viscosities of $>10^{21}$ Pa s. Hatchured lines show the base of the lithosphere. The plots to the right show particular initial model geotherms, yield strengths (for a strain rate of 8×10^{-15} s^{-1}) and effective viscosities (as defined in the text for dry quartz crust overlying a dry olivine mantle) corresponding to each mode. From top to bottom the crustal thicknesses are 50 km, 40 km and 30 km. Q_s is the initial surface heat flow.

Interaction point chaud-subduction : le Golfe d'ADEN

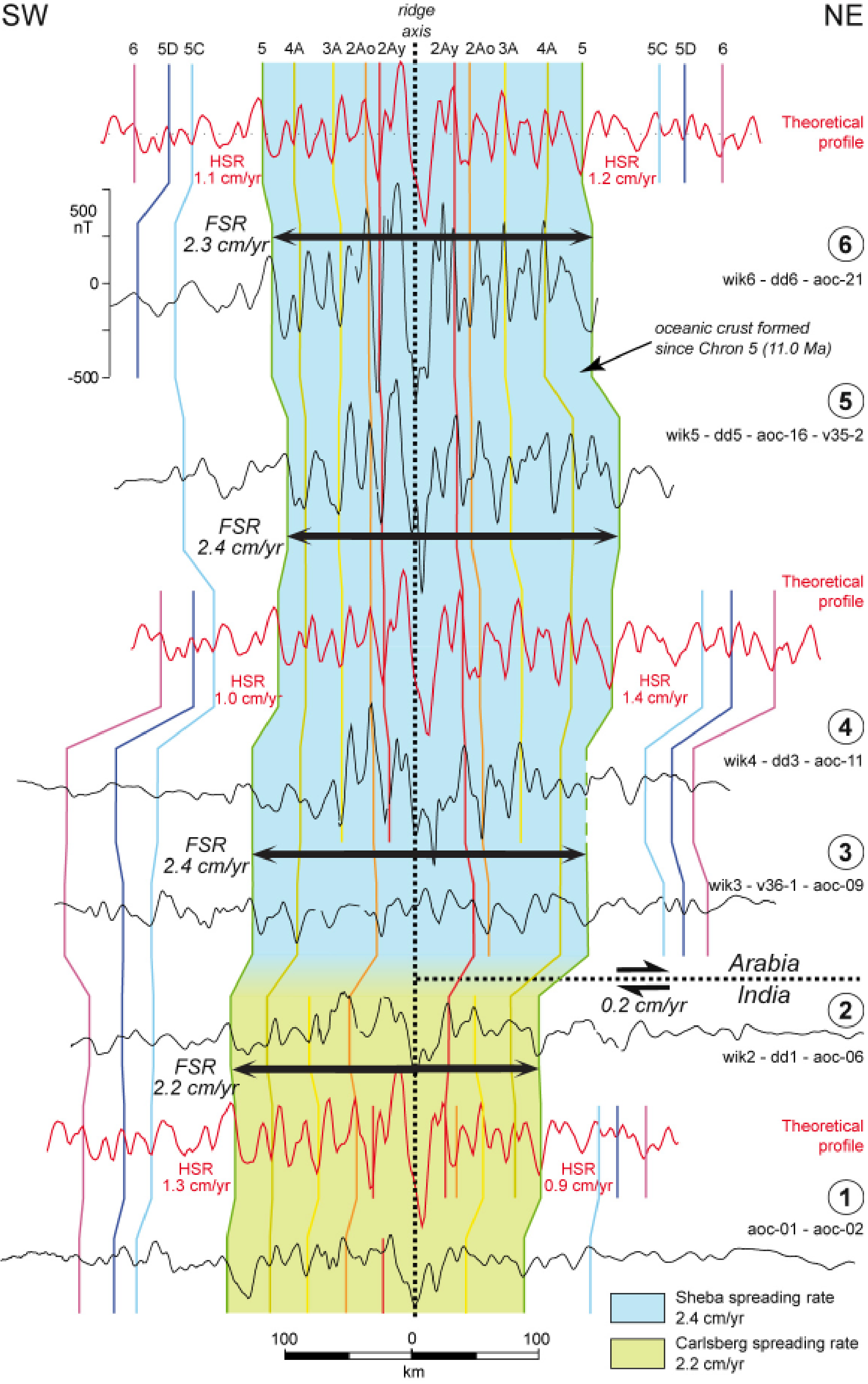


Fournier et al., JGR, 2010

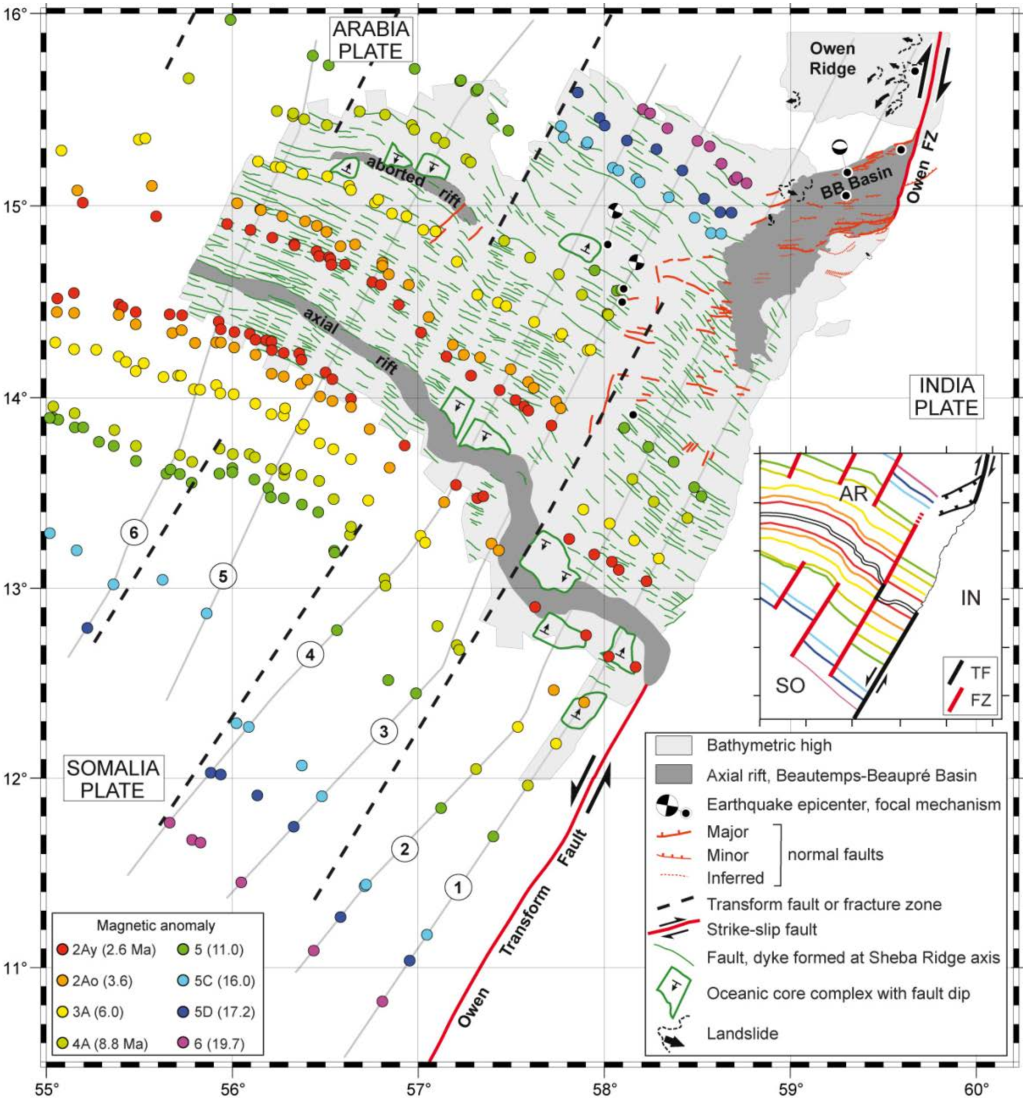

Gulf of Aden
Owen Fracture Zone
Levant Fault
Bitlis
Zagros
Red Sea
Makran
Afar
East African Rift
ARABIA PLATE
0 km
100
200
40°N
30°N
20°N
10°N
EURASIA PLATE
NUBIA PLATE
Afar mantle plume
SOMALIA PLATE
Carlsberg Ridge
INDIA PLATE
Makran subduction zone
40°E
50°E
60°E
N
0
500
km

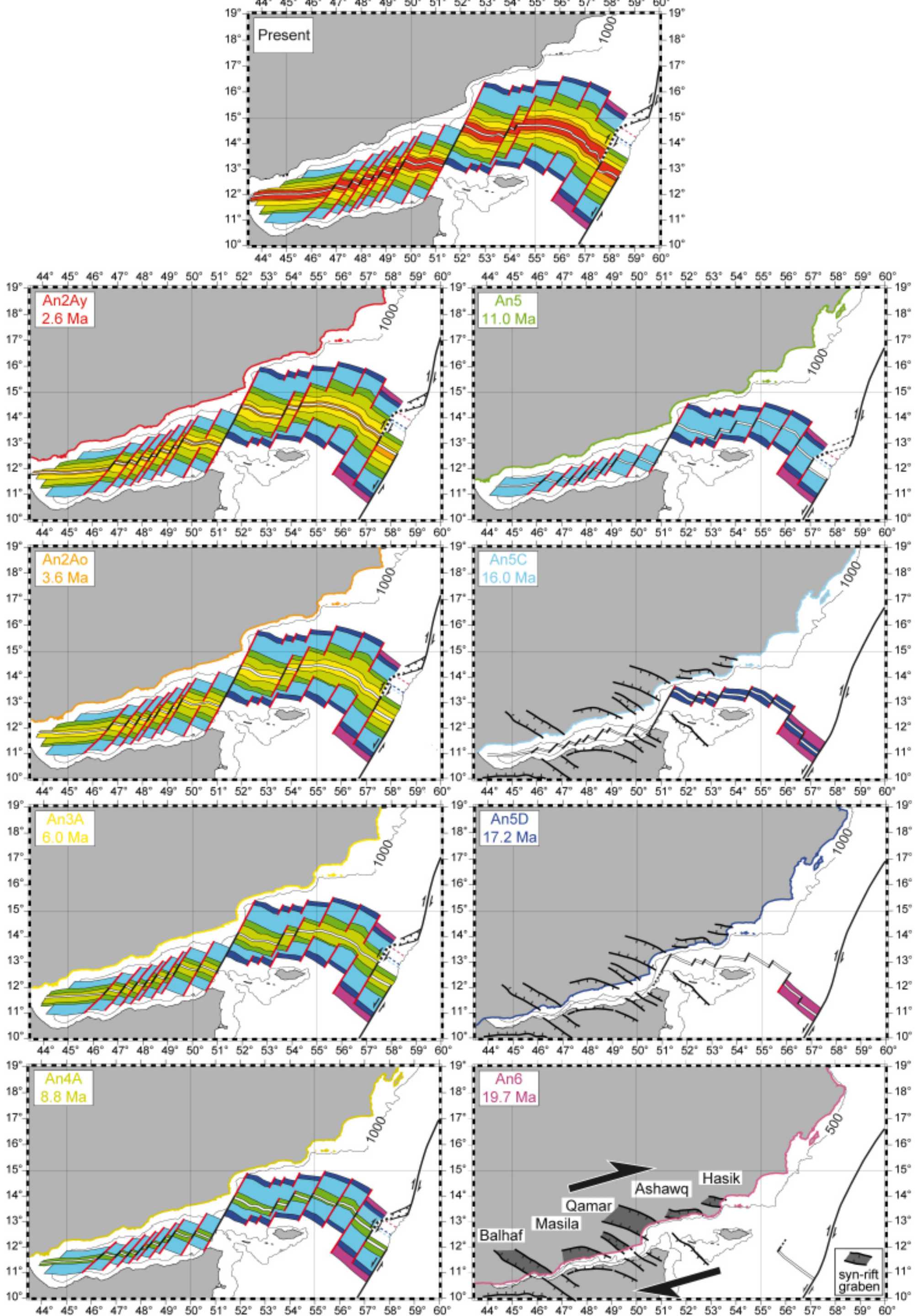

EURASIA
65 Ma
20°
TETHYS
0°
ARABIA
AFRICA
EURASIA
30 Ma
20°
ARABIA
AFRICA
proto-AOC
INDIA
Afar hot spot
0°
30°
50°
30°
50°
Present
EURASIA
ARABIA
20°
INDIA
AOC
AFRICA
SOMALIA
0°

Les anomalies magnétiques du Golfe d’Aden



Fournier et al., JGR, 2010





La subduction est la force motrice mais le point chaud guide et localise le rifting

Fournier et al., JGR, 2010

Rifts Asiatiques : extension post-orogénique

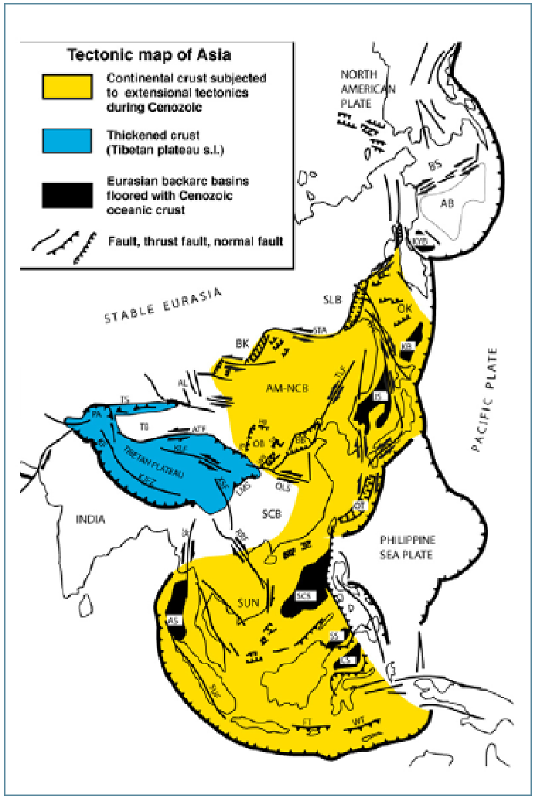


Figure 68. Carte tectonique de l'Asie. AB, bassin des Aléoutiennes ; AL, Altai ; AM plaque Amour ; AS, mer d'Andaman ; ATF faille de l'Altyn Tagh ; BB, bassin de Bohai ; BK, rift Baïkal ; BS, mer de Bering ; CS, mer des Célebes ; FT, chevauchement de Flores ; HB, bassins d'Hetao ; JS, mer du Japon ; KB, bassin des Kouriles ; KF, faille de Karakorum ; KJFZ, zone de faille de Karakorum-Jiali ; KLF faille des Kunlun ; KYB, bassin de Komandorsky ; LMS, Longmen Shan ; OB, bloc Ordos ; OK, mer d'Okhotsk Sea ; OT, fossé d'Okinawa ; PA, Pamir ; QLS, Qinling Shan ; RRF, faille de la Rivière Rouge ; SB, bassins du Shanxi ; SCB, bloc Chine du Sud ; SCS, mer de Chine du Sud ; SF, faille de Sagaing ; SLB, bassin de Shantar-Liziansky Basin, SS, mer de Sulu ; STA, chaîne des Stanovoy ; SUF, faille de Sumatra ; SUN, Sundaland ; TB, bloc Tarim ; TLF, faille de Tan-Lu ; TPF, faille de Tym-Poronaysk ; WB, bassin de Weihe ; WT, chevauchement de Wetar ; XSF, faille de Xanshuihe ; YB, bassins du Yinshuan.

Fournier, Hdr, 2009

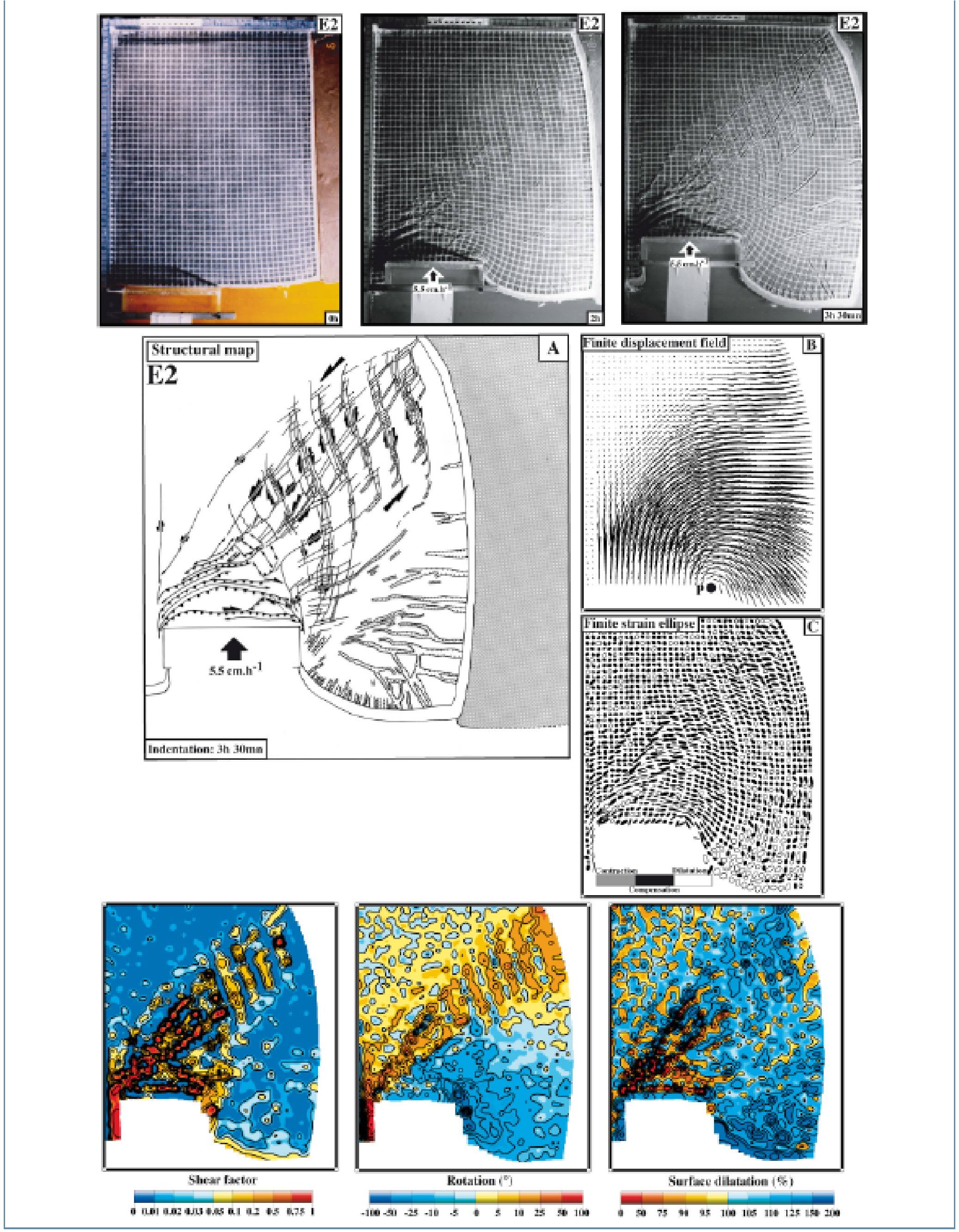
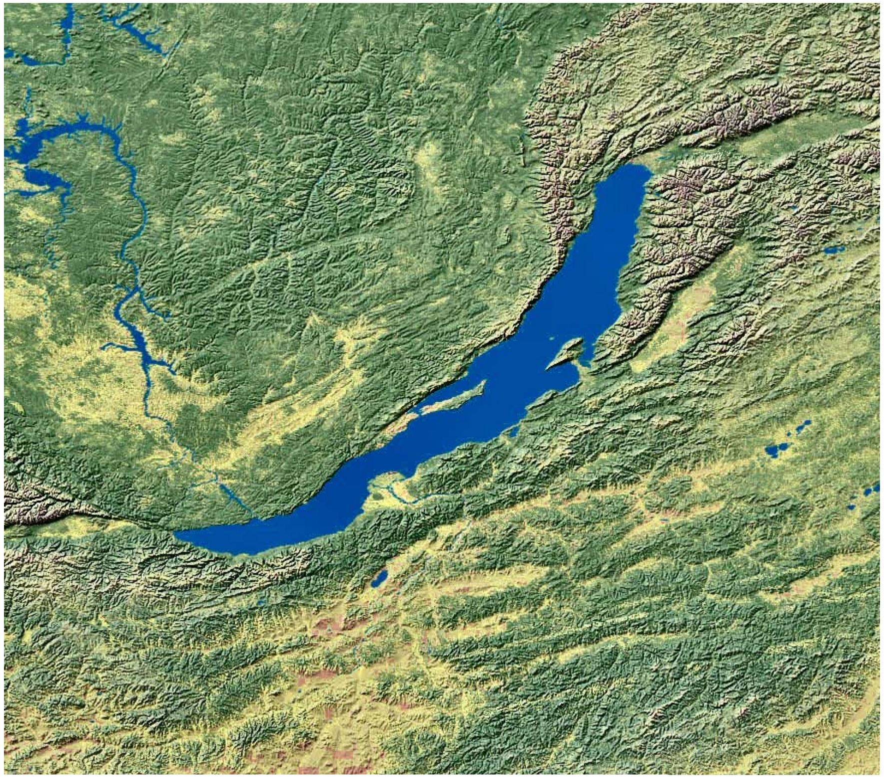
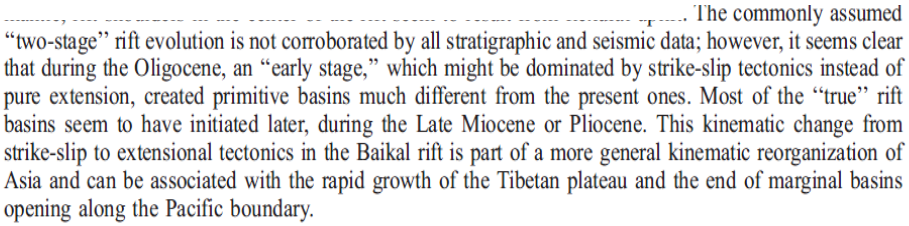


Figure 69. Exemple d'expérience avec confinement latéral pour limiter l'étalement gravitaire. En haut, trois stades de déformation de l'expérience E2. (a) Carte structurale. (b) Champ de déplacement fini par rapport à la boîte expérimentale. (c) Ellipse de déformation finie. En bas, intensité du cisaillement, rotation des axes principaux de la déformation, rapport de la surface finale sur la surface initiale.

Rifts Asiatiques : extension post-orogénique

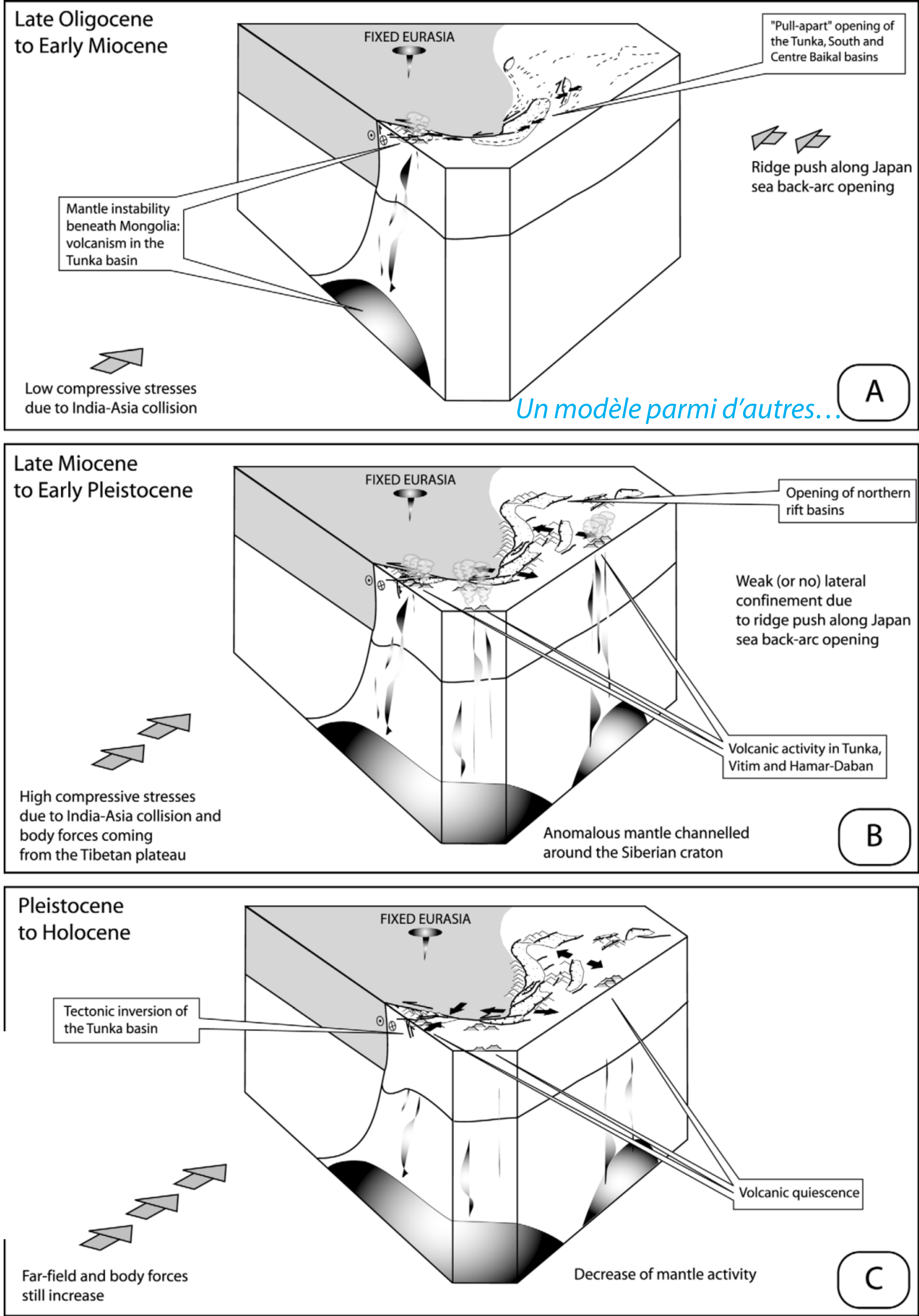
Cas particulier du lac Baïkal





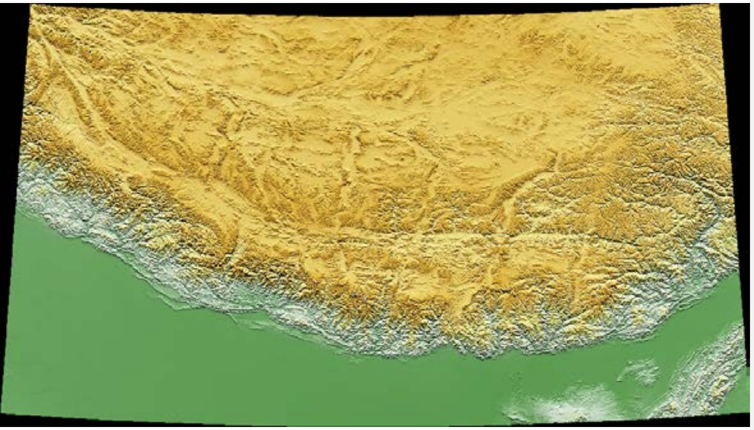
The commonly assumed "two-stage" rift evolution is not corroborated by all stratigraphic and seismic data; however, it seems clear that during the Oligocene, an "early stage," which might be dominated by strike-slip tectonics instead of pure extension, created primitive basins much different from the present ones. Most of the "true" rift basins seem to have initiated later, during the Late Miocene or Pliocene. This kinematic change from strike-slip to extensional tectonics in the Baikal rift is part of a more general kinematic reorganization of Asia and can be associated with the rapid growth of the Tibetan plateau and the end of marginal basins opening along the Pacific boundary.

Petit and Deverchère, G3, 2006

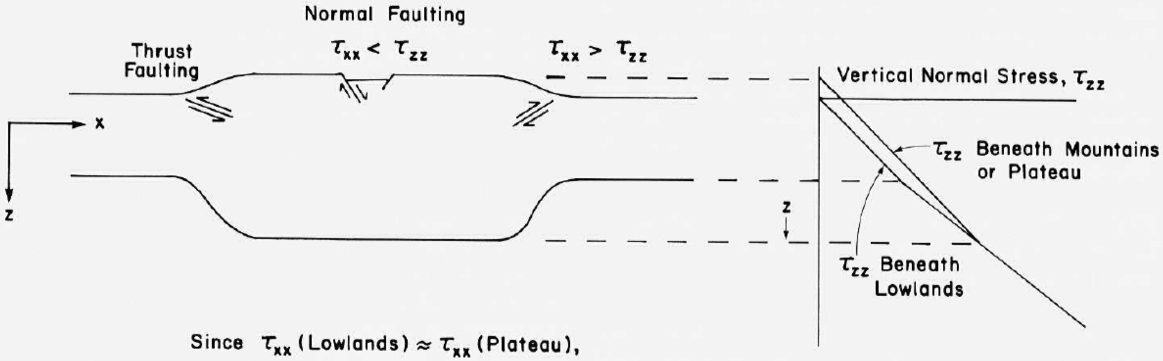


Un modèle parmi d'autres…

Rifts Asiatiques : extension post-orogénique



Sud Tibet



Since τ_{xx} (Lowlands) $\approx \tau_{xx}$ (Plateau),

if $\tau_{xx} \approx \tau_{zz}$ (Plateau) $> \tau_{zz}$ (Lowlands), then Thrust Faulting occurs in the Lowlands,

if $\tau_{xx} \approx \tau_{zz}$ (Lowlands) $< \tau_{zz}$ (Plateau), then Normal Faulting occurs in the Plateau, and

if τ_{zz}(Lowlands) $< \tau_{xx} < \tau_{zz}$ (Plateau), then both types of faulting occur simultaneously.

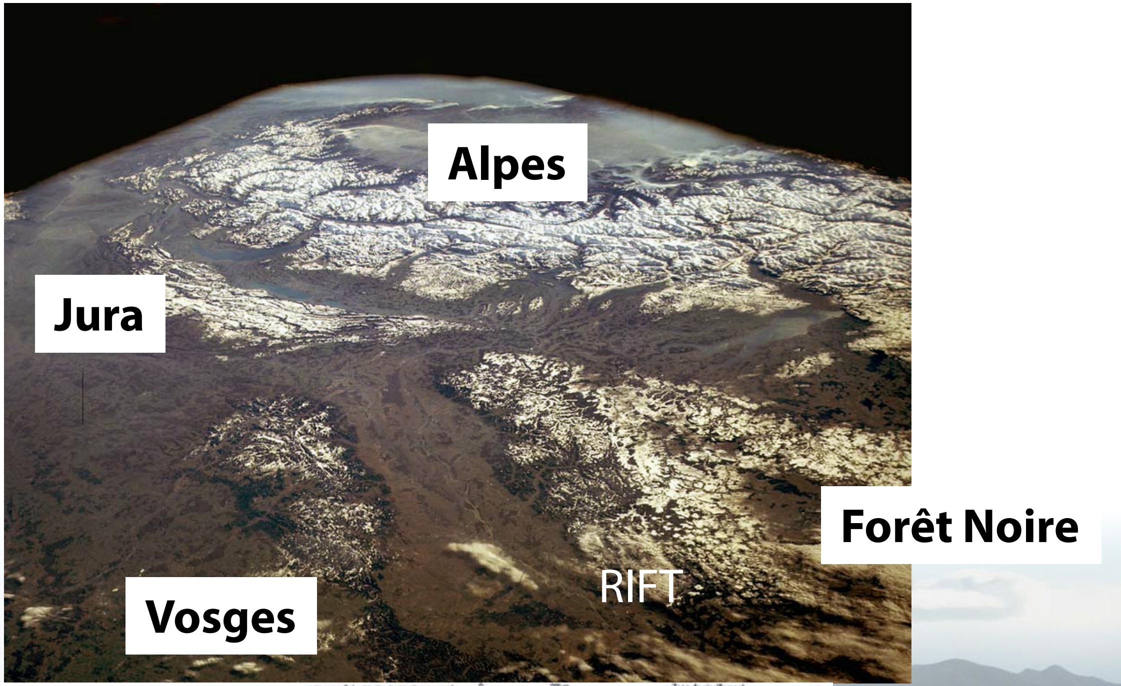
Figure 15. Simple explanation for juxtaposition of thrust and normal faulting on flanks of mountain ranges and beneath their high plateaus. If stresses applied to the base of the lithosphere are negligible, then average horizontal stress, τ_{xx} is constant, independent of horizontal position x. Vertical stress, however, depends markedly on elevation. The drawing on the right shows schematically τ_{zz} as a function of depth beneath mountains or plateaus and beneath lowlands. At all depths, τ_{zz} (plateau) $\geqslant \tau_{zz}$ (lowlands). Since average horizontal stress τ_{xx} does not depend on x, we might expect τ_{xx} to be less than τ_{zz} in the plateau but greater than τ_{zz} in the lowlands and on the flanks of the ranges. In such a case, normal faulting would prevail at high altitudes while thrust faulting occurred on the flanks of the range. Increases or decreases in τ_{xx} might suppress (or prevent) completely either the normal faulting at high altitudes or the thrust faulting on the flanks.

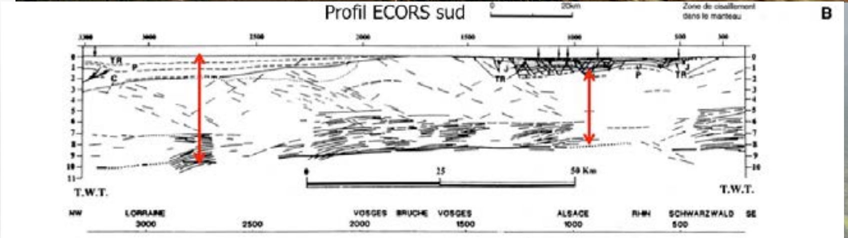
Molnar and Lyon-Caen, GSA Bull.,1988

Rifting Cénozoïque en France :
Pas de modèle convaincant disponible

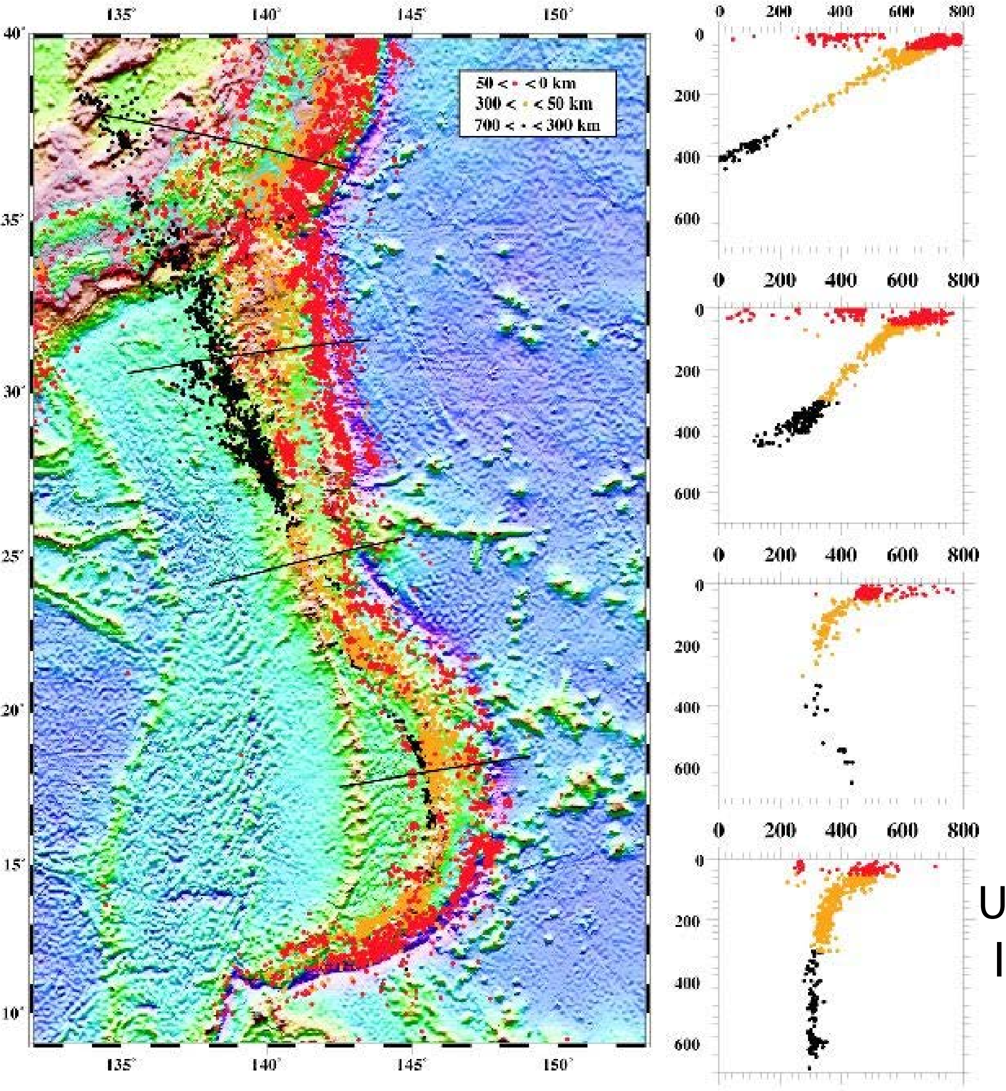
!Mon idée personnelle, non validée! :

- Flambage de la lithosphère suite à la collision alpine
- Flexure de la lithosphère, longueur d'onde variable (courte au front de la chaîne)
- Réactivation de l'héritage structural Hercynien (anciens décrochements post-orogéniques, zones « faibles » au sens rhéologique)?
- Extension sur l'extrados d'un pli à l'échelle lithosphérique?
- Lien avec l'origine du volcanisme Cénozoïque en France?

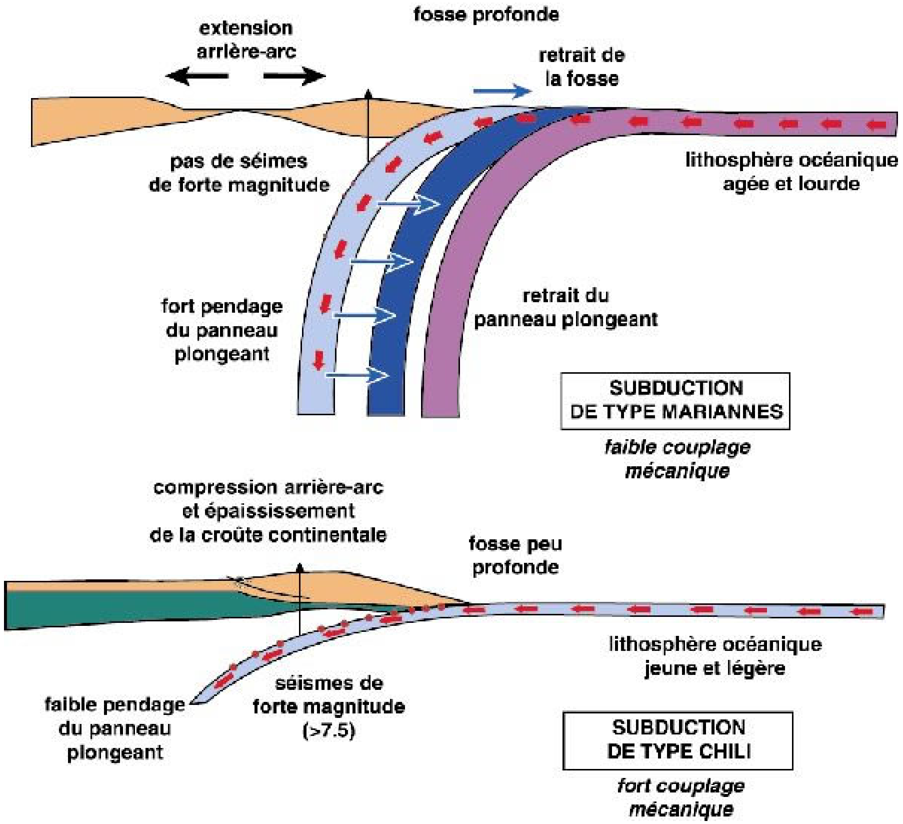




Ouverture des bassins arrière-arc

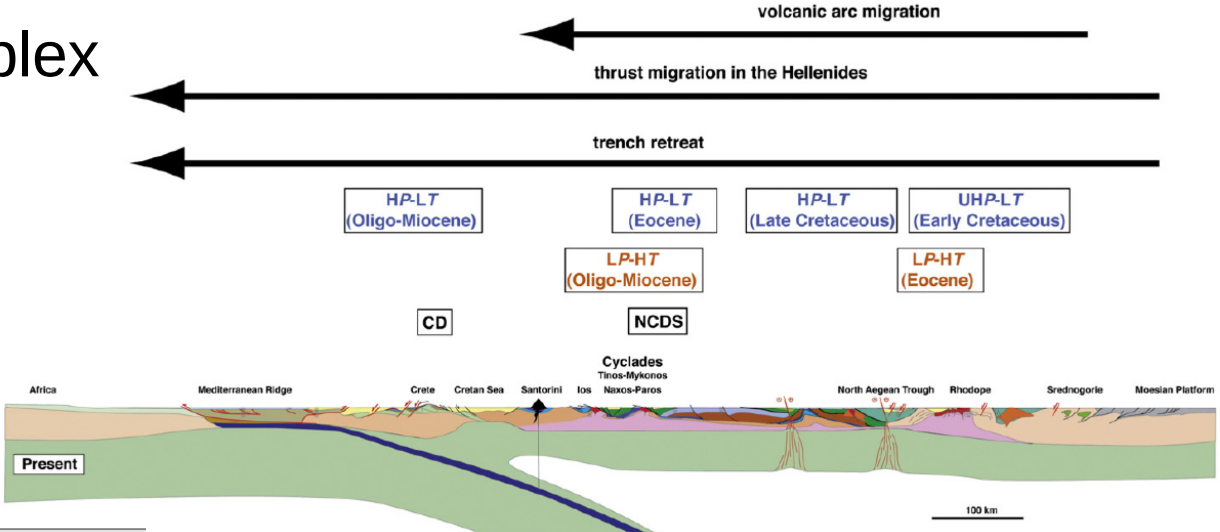


Coupes de sismicité dans les zones de subduction du Japon, des Bonins et des Mariannes



Une grande diversité de subductions, dont les types « Marianne » et « Chili » sont les extrêmes

Origine des core-complex de la mer Egée



- ➢*Retrait du slab : changement du couplage plaque subduite-plaque supérieure*
- ➢*Croûte épaissie en mer Egée*
- ➢*Etalement post-orogénique*

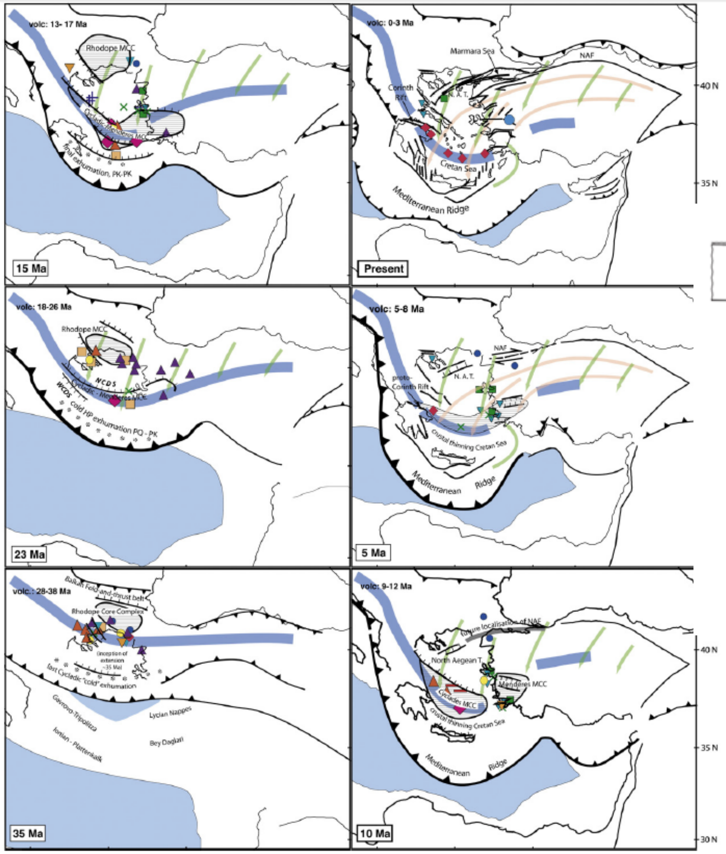


Fig. 11. Reconstructions of the Aegean region from the Late Eocene (35 Ma) to the Present. The thick blue line shows the position of the slab at a depth of 150 km. The blue do the oceanic lithosphere of the eastern Mediterranean. Green arrows represent the asthenospheric flow and orange arrows the upper crustal flow. Volcanism from Pe-Piper and Piper (2006, 2007).

ction of the Aegean region from the northern passive margin of Africa to the Moesian platform across Crete, the Cyclades and the Rhodope massif after Jolivet the southward migration of metamorphic, tectonic and magmatic processes.

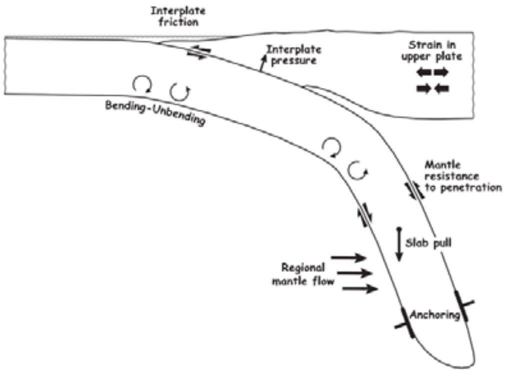
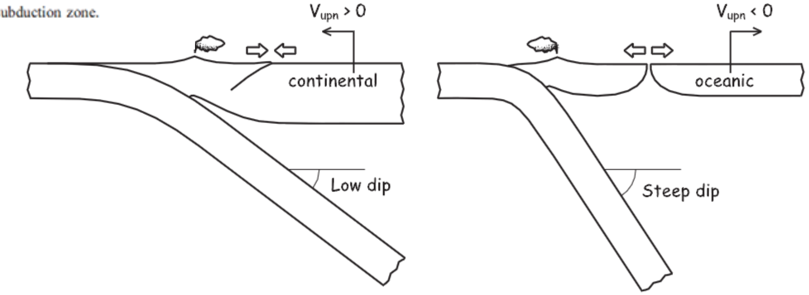


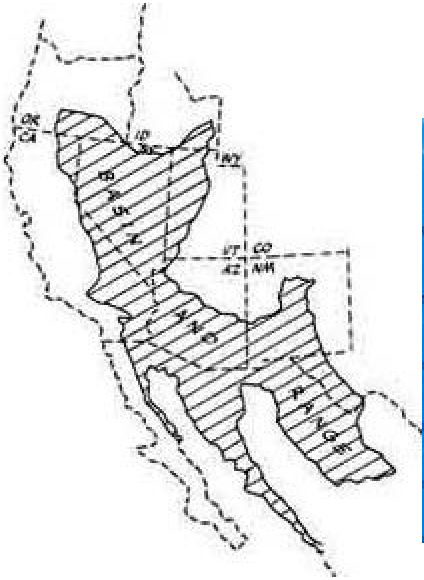
Figure 2. Major forces acting in a subduction zone.

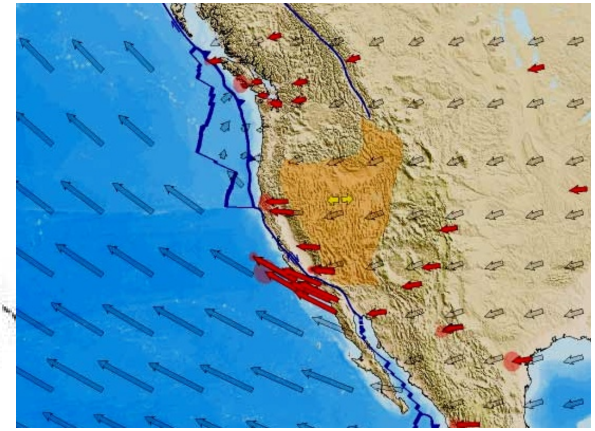
Couplage plaque plongeante-plaque supérieure & extension

(Lallemant et al., G3, 2005)



Basin and Range





T. Atwater

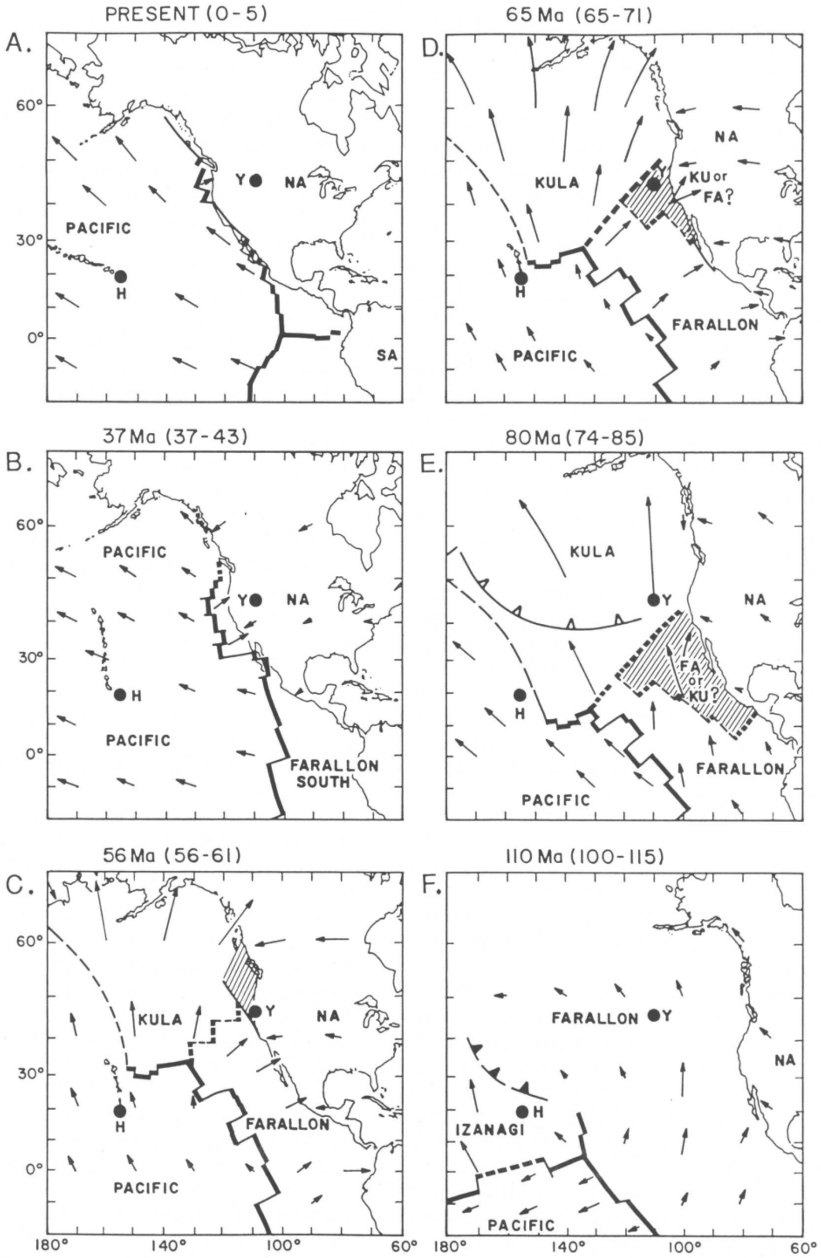
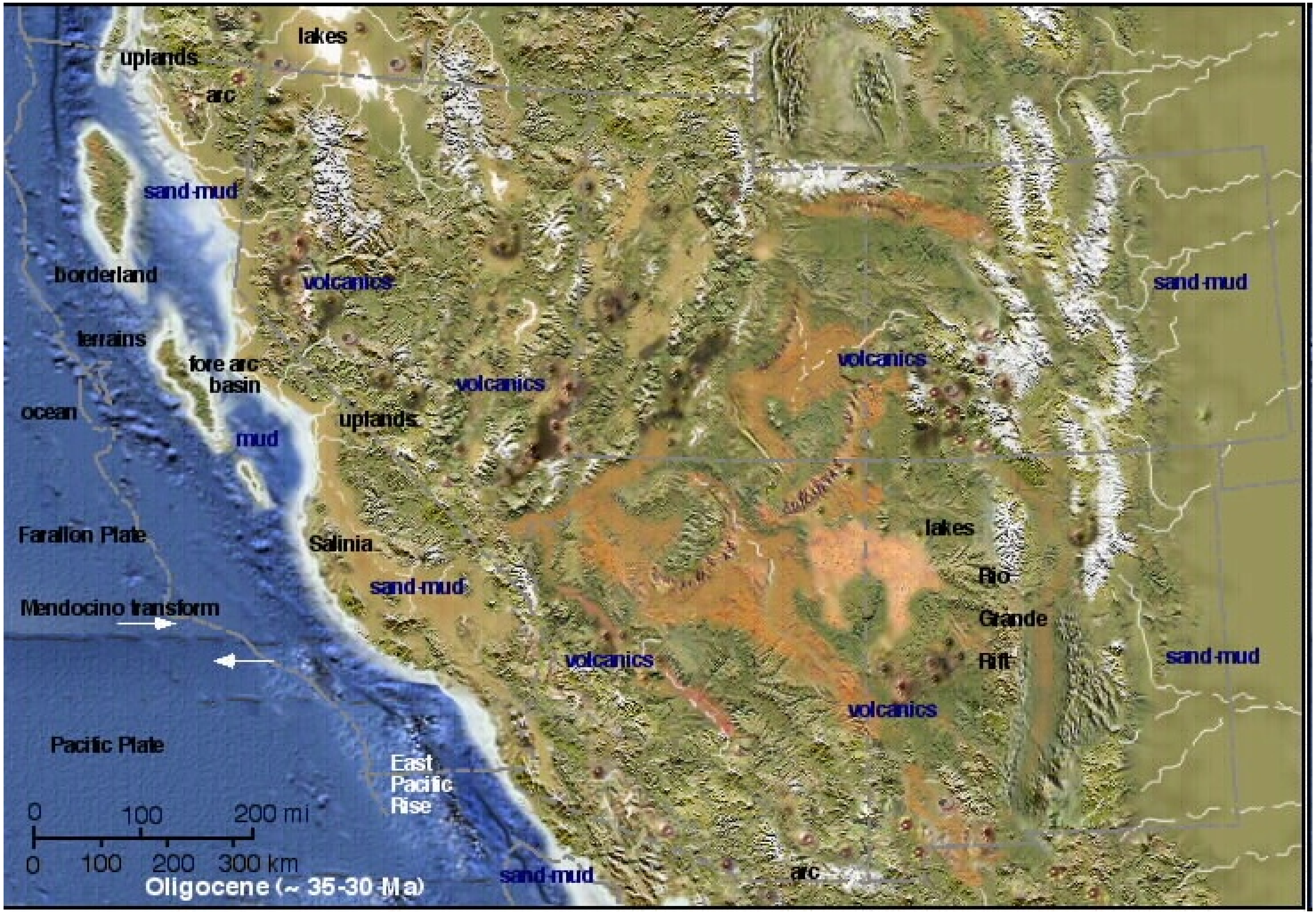


Figure 14. Late Mesozoic and Cenozoic paleogeographic maps and plate motions constructed with respect to the hot spots, after Engebretson and others (1985). Shaded areas in C, D, and E indicate range of possible locations for the Kula-Farallon spreading center. Y = Yellowstone hot spot, H = Hawaiian hot spot.

De l’orogène des Laramides à la transtension : des relations Farallon-Am Nord aux relations Pacifique-Am Nord.

Basin and Range



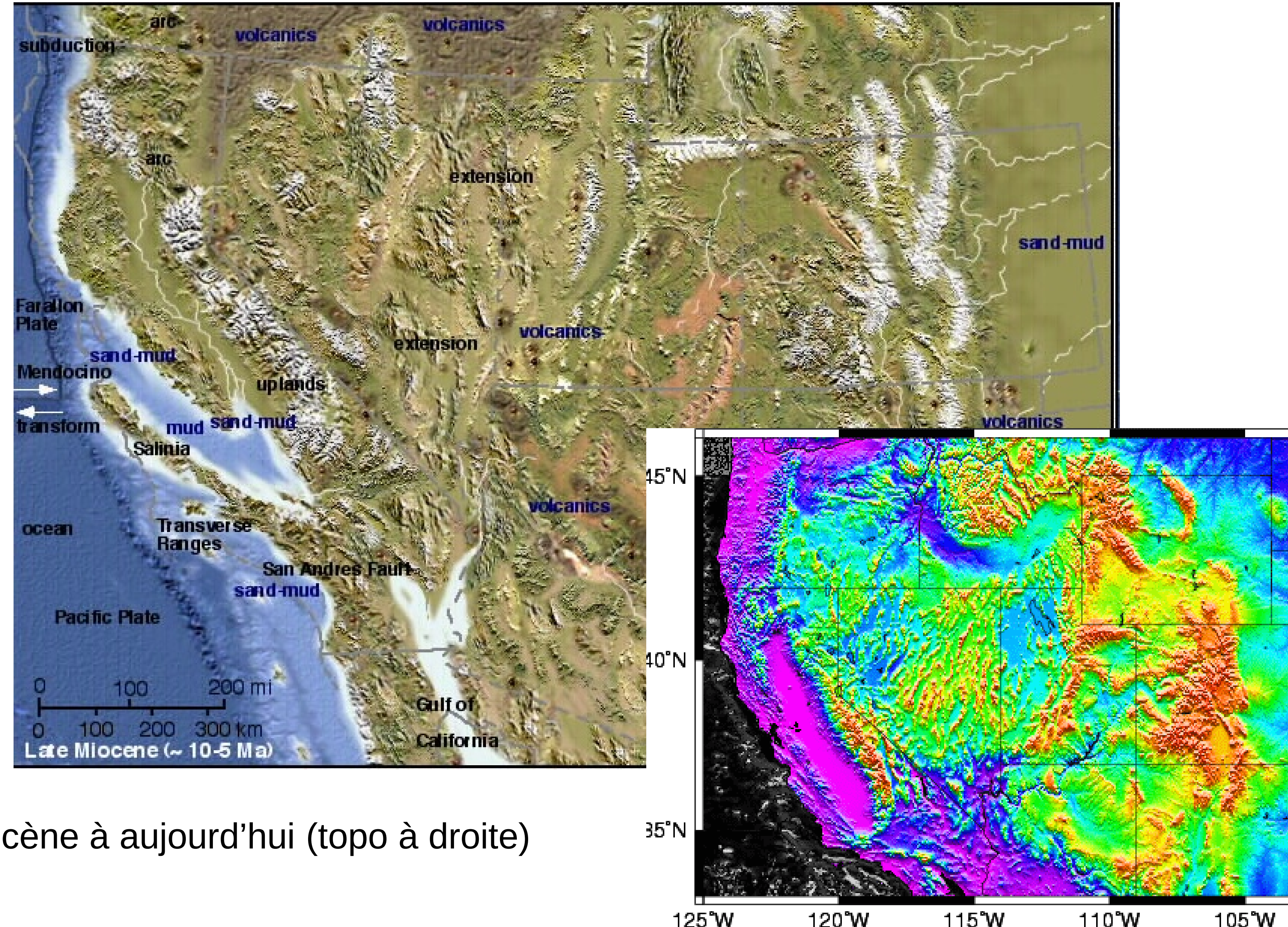
35 Ma: volcanisme d’arrière arc et dorsale pacifique Farallon se rapproche des côtes.

Basin and Range

15Ma: contact Pacifique – Amérique du nord / 15-12Ma: naissance SAF

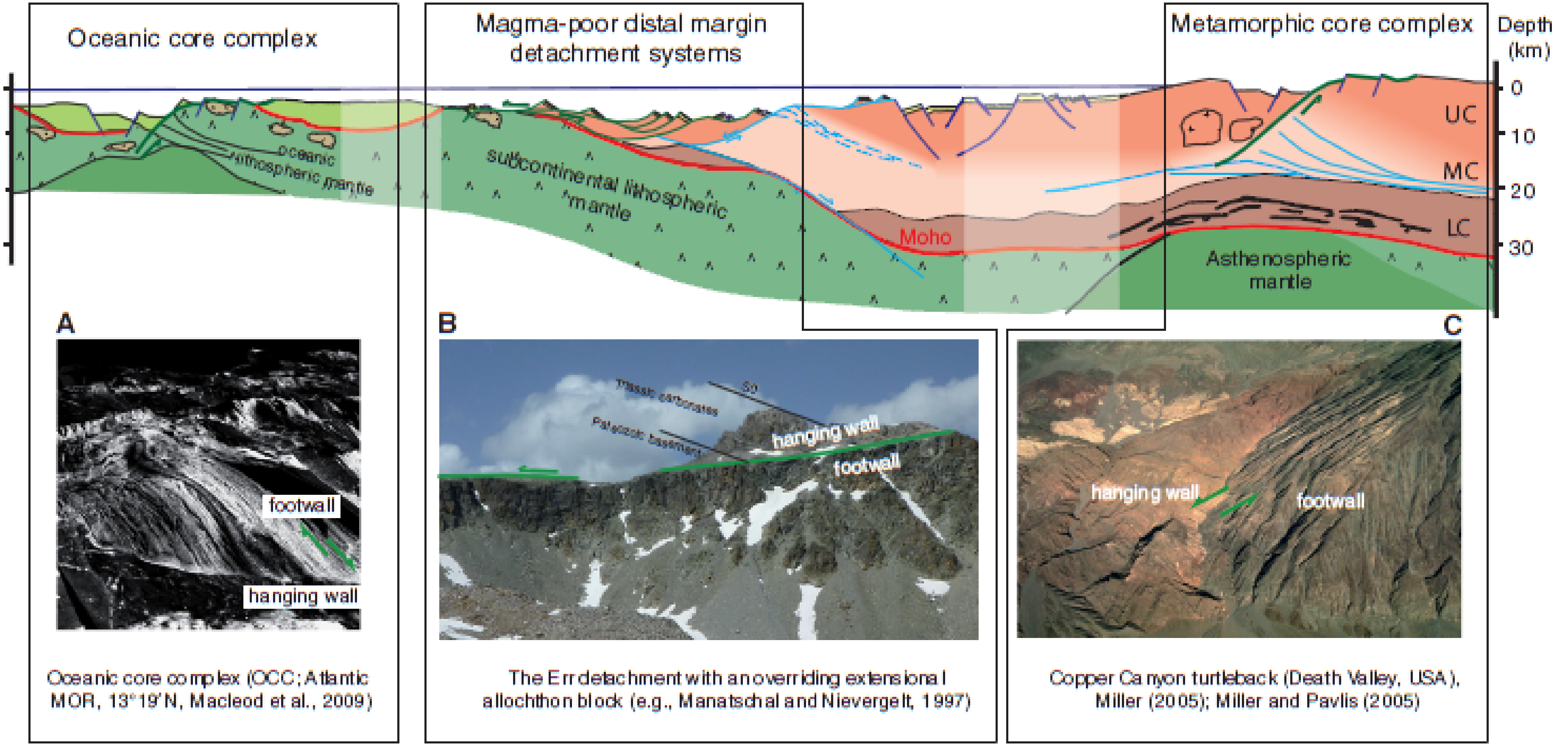
Début de l’extension dans le basin and range.

Basin and Range



Miocène à aujourd’hui (topo à droite)

Ouverture : intérêts de l'étude des marges passives fossiles



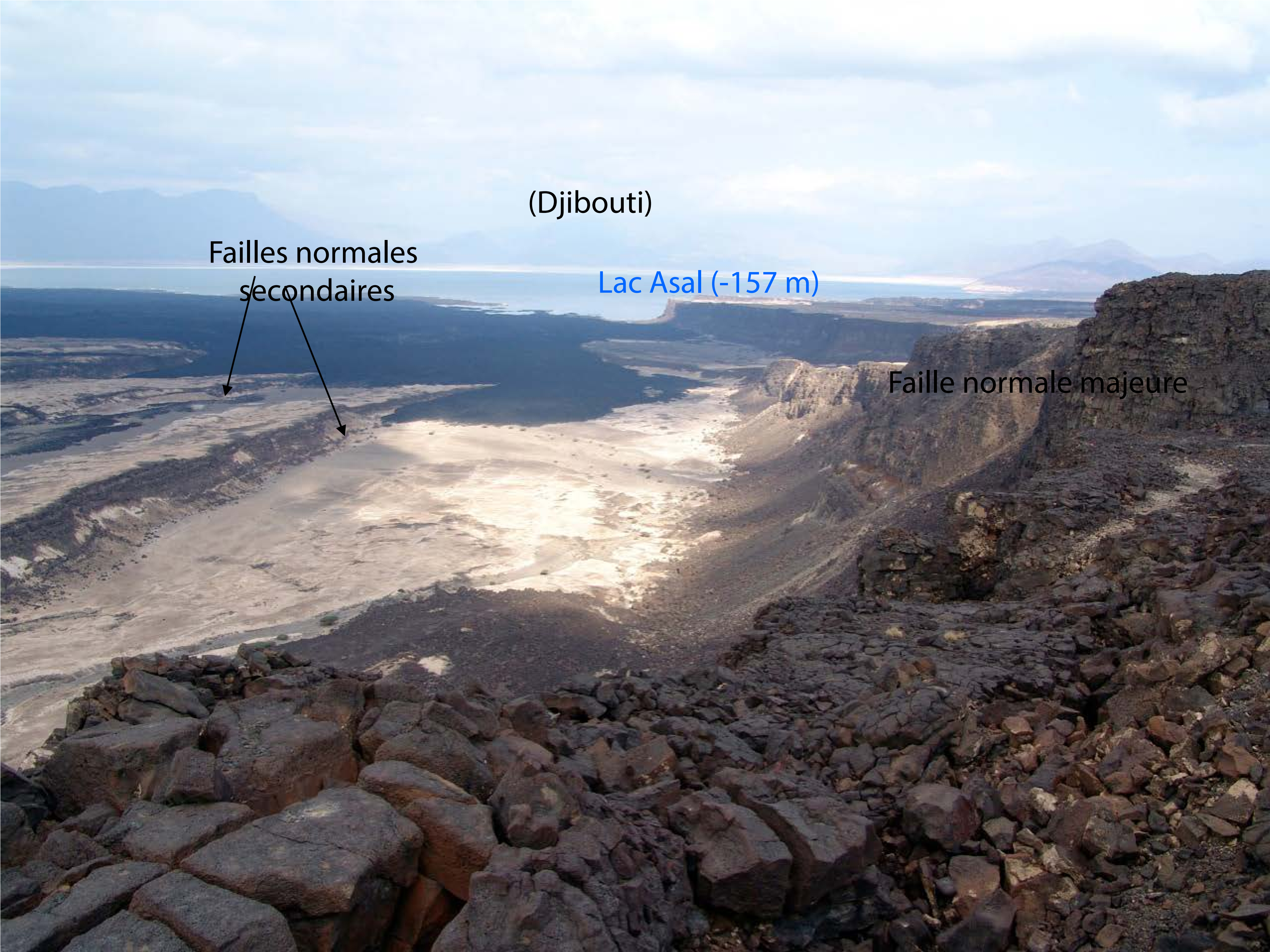
Oceanic core complex (OCC; Atlantic MOR, 13°19′N, Macleod et al., 2009)

The Err detachment with an overriding extensional allochthon block (e.g., Manatschal and Nievergelt, 1997)

Copper Canyon turtleback (Death Valley, USA), Miller (2005); Miller and Pavlis (2005)

Figure 1. Detachment systems in different tectonic settings: (A) Oceanic core complex (OCC) (e.g., Atlantic Mid-Ocean Ridge at 13°19′N). (B) Rift-related detachment fault in a hyperextended magma-poor rifted margin (e.g., Err detachment overlain by an extensional allochthon; this study). (C) Metamorphic core complex (MCC) in an intracontinental, postorogenic extensional domain (e.g., Copper Canyon turtleback; Death Valley, USA). UC—upper crust; MC—middle crust; LC—lower crust.

Masini et al., GSA bull., 2012


(Djibouti)
Failles normales secondaires
Lac Asal (-157 m)
Faille normale majeure