CONTINENTAL MARGINS

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I- **Divergent (or Passive) Continental Margins**

Passive continental margins result from the dislocation of a continental mass subjected to extensional forces (rifting), through lithospheric thinning, followed by continental breakup (breakup) and oceanic accretion at the rift axis. Numerous thinning models have been proposed in the literature, and their complexity has often increased in recent years to account for the increasingly detailed knowledge of these margins.

What is a continental margin?

- It is the edge of a continent.
- It is a transition zone between a continent, consisting of continental crust, and an oceanic plate, consisting of oceanic crust.

Continental margins cover 11% of Earth's surface.

- Passive continental margins
- Transform continental margins
- Active continental margins

1- Passive Continental Margins (or Stable Margins)

1-1- Definitions and Generalities

- **Transition zone** between a continental mass and oceanic crust, created within the same lithospheric plate.
- **No seismic or volcanic activity** is present.
- Induced by **distant stretching forces** (~perpendicular to the rift axis).
- Resulting from a **rifting phase** that led to lithospheric rupture and oceanic accretion, forming two conjugate passive continental margins.
- **Location** where the continental crust thins (30 km → 0 km).
- **Location** where sediments transition from the continent to the abyssal plain.

1-2- Drivers of Extension

In the past, two categories of rifting were generally recognized: **active rifting** and **passive rifting**. In the case of "active rifting," the rift develops in response to the rise of a mantle plume, which causes thinning and doming of the lithosphere (Fig. 1a). In the case of "passive rifting," the rift develops in response to distant external forces (plate boundary forces) that cause passive upwelling of the asthenosphere to compensate for the thinning of the overlying lithosphere (Fig. 1b).

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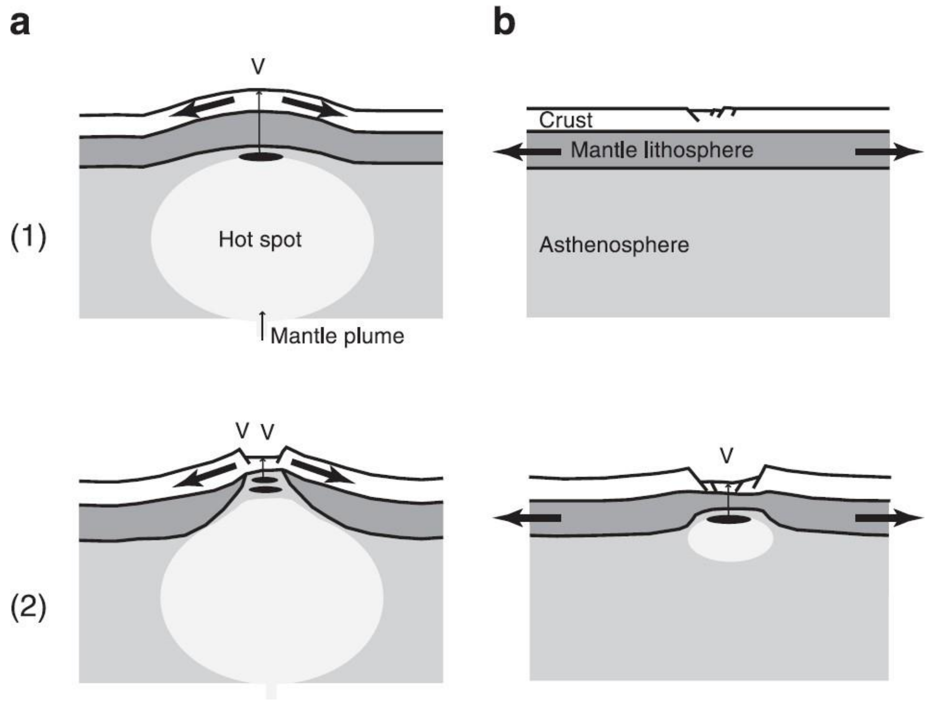


Figure 1 *– Schematic diagram showing the principles of (a) active rifting and (b) passive rifting [Corti et al., 2003]. (1) initial stage and (2) subsequent stage in rift evolution. (a) The upwelling of a mantle plume (hot and low-density) in the sub-lithospheric mantle causes topographic doming, uplift of the lithosphere base (thermal subsidence), and volcanism (indicated by a "V" on the figure). (b) Extension is controlled by the regional extensional stress field (plate boundary forces). The asthenosphere rises passively in response to lithospheric thinning. Magmatic activity occurs at a later stage of rifting.*

Logically, **passive rifting** would be responsible for **non-volcanic margins**, while **active rifting** would create **volcanic margins**. However, this view is overly simplistic to explain the variety of margins on Earth. Active and passive rifting should actually be part of a continuum, representing two extreme poles in the evolution of a rift.
The true driver of extension likely originates from the complex interaction between the forces governing plate tectonics: **plate boundary forces** (slab pull, ridge push forces, friction) and forces generated at the base of the lithosphere through **asthenospheric convection** (lithosphere-asthenosphere coupling). The action of a **mantle plume** (thermal perturbation) would therefore not be the primary driving force during rift initiation, but it does contribute to the mechanical weakening of the lithosphere, influencing the magnitude of magmatic activity during rifting.

1-3- From Lithospheric Thinning to Continental Rupture

The formation of passive margins is part of the "narrow rifting" mode [Buck, 1991; Brun, 1999]. In short, this rifting mode involves the thinning of an initially normal-thickness lithosphere, associated with the passive (or active) rise and partial melting of the lithospheric mantle and asthenosphere (Fig. 2b). Decompression-induced melting is controlled by the extension rate. Extension is accommodated by normal faults that delimit tilted blocks in the fragile lithosphere over hundreds of kilometers (Fig. 2b). When rifting reaches lithospheric rupture and oceanic accretion, two conjugate passive margins are created. These will evolve on either side of the oceanic domain, progressively moving apart with the expansion of the ocean floor (Fig. 2c).

The evolution shown in **Figure 2** is a simplified view of reality, or at least one possible example of what could be observed in nature. As with the driving forces behind extension (active and passive rifting), the mechanical response of the lithosphere to extension could vary between two extreme models: **pure shear** (Fig. 2 and Fig. I3, upper model) and **simple shear** (Fig. 3, middle model). Mixed extension models are also proposed, intermediate between simple shear and pure shear (Fig. 3, lower model). Models involving simple shear generally propose the existence of major detachments that cut the lithosphere entirely (simple shear model, Fig. 3) or partially (mixed shear model, Fig. 3). Simple or composite shear models were later invoked to explain the asymmetry of observed margins and the presence of exhumed mantle at the boundary between continental and oceanic crust.

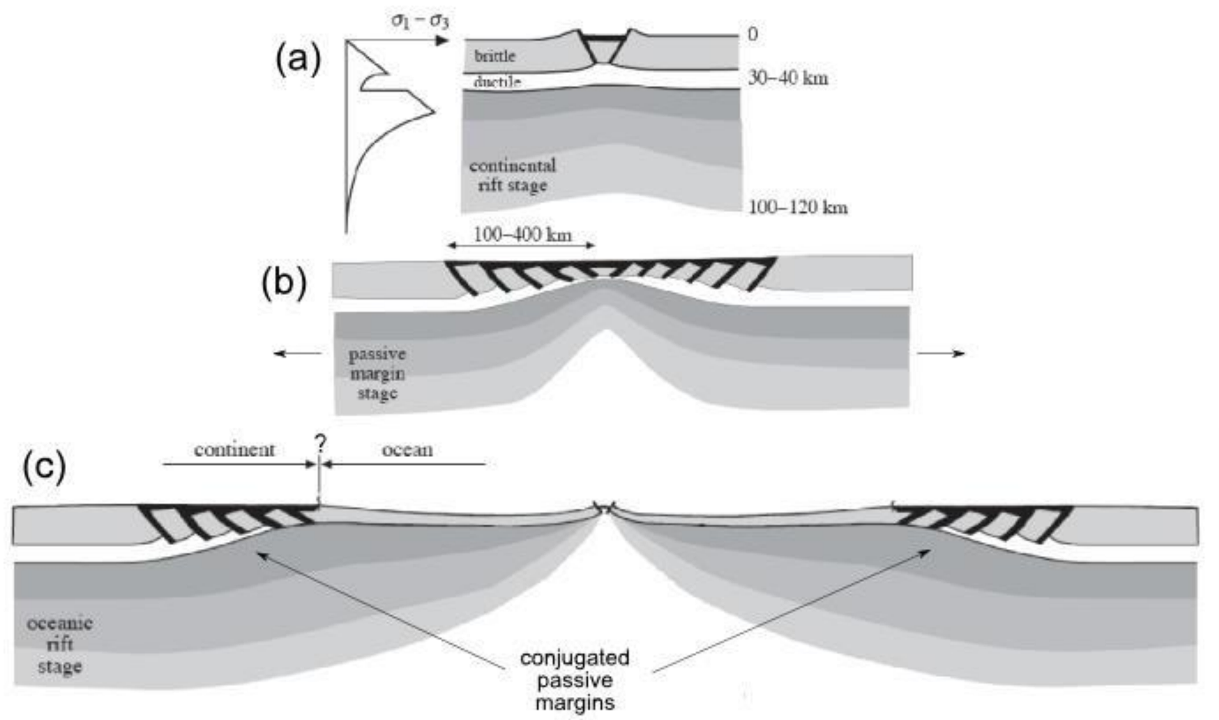


Figure 2 – Evolution model of a narrow rift leading to the formation of two conjugate passive margins and oceanization. [Brun, 1999]. (a) Lithospheric stratification into 4 layers representing the brittle and ductile levels of the crust and mantle. (b) Rifting stage: formation of tilted blocks bounded by normal faults. (c) Oceanization stage: formation of new oceanic crust at the ridge.

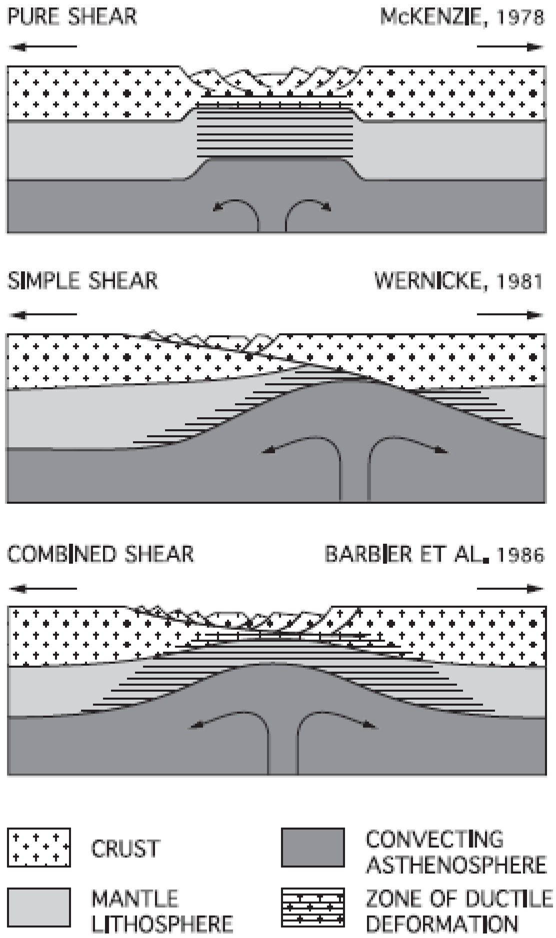


Figure 3 – Schematic representation of continental lithospheric extension models [Ziegler and Cloetingh, 2004, after McKenzie, 1978, Wernicke, 1981, and Barbier and Duverge, 1986]. Top: pure shear extension model. The rift is symmetric (symmetric conjugate margins). Middle: simple shear extension model. The rift is asymmetric (asymmetric conjugate margins). Bottom: mixed extension model, intermediate between pure shear and simple shear. The rift is asymmetric (conjugate margins are symmetric to asymmetric).

1-4- Morphology

- **Continental shelf**: 0 – 200 m

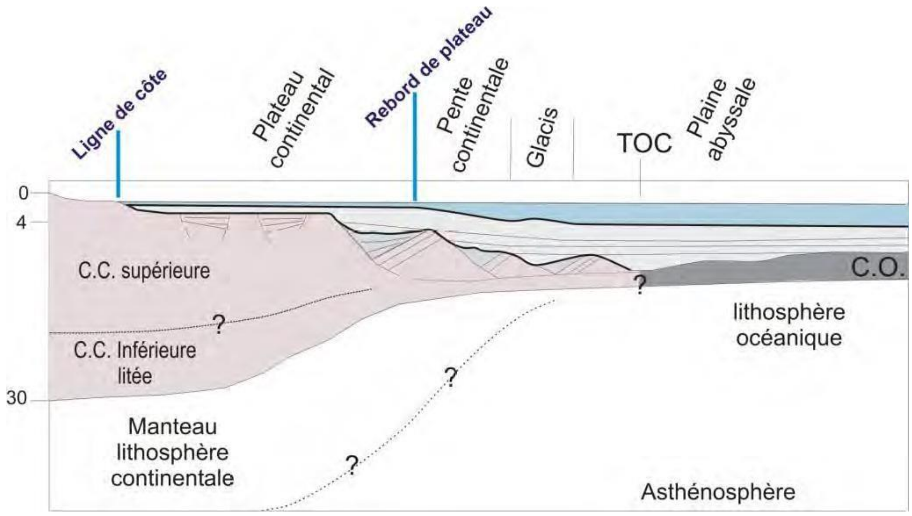
  Very gentle slope (~0.1°), Width (5 to 1500 km), Crustal thickness (~30-35 km)
- **Continental slope (escarpment)**: 200 – 4000 m

  Steep slope (1-5°) and narrow (10 – 100 km), Incised by submarine canyons, site of crustal thinning (30 to a few km).
- **Continental rise**: 2500–5000 m

  Accumulation of sediments at the foot of the slope
- **Abyssal plain**: 2500-5000 m

  Basement: oceanic crust

  Near the slope, site of the Ocean/Continent Transition (OCT).



2 Types of Continental Margins Based on Sediment Deposition

- **Lean margins** (e.g., Armorican Margin of the Gulf of Biscay)
- **Sediment-rich margins** (e.g., Gulf of Lion Margin, Gabon Margin)

2 Types of Continental Margins Based on Crustal Thinning Width

- **Narrow margin (< 50 km)**: Provence Margin, Armorican Margin (Gulf of Biscay)
- **Wide margin (> 100 km)**: Gulf of Lion

2- Volcanic & Non-volcanic Margins

During rifting and the early stages of oceanic accretion, the amount of magmatism produced will vary depending on thermal conditions (e.g., active rifting), deformation extent, and/or mantle composition. Based on the level of magmatism, margins are generally subdivided into two categories: volcanic margins and non-volcanic margins (Fig. 4).

2-1- Volcanic Margins

The formation of volcanic margins is characterized by a significant amount of magmatism at the ocean-continent transition zone. It is generally accepted that these margins reflect lithospheric rupture in the presence of an abnormally hot mantle [Geoffroy, 2005]. The intense magmatic activity leads to the formation of abnormally thick oceanic crust (>10 km) and the development of normal faults dipping toward the continent, accommodating magma emplacement during the extension phase (Fig. 4.a). In seismic imaging, these margins are recognizable by the presence of SDRs ("Seaward Dipping Reflectors") and high-velocity magmatic bodies underplated beneath the transitional crust, characterized by high seismic velocities [Vp > 7.2 km/s, Bauer et al., 2000; Gerlings et al., 2009; Keen et al., 2012] (Fig. 4.a).

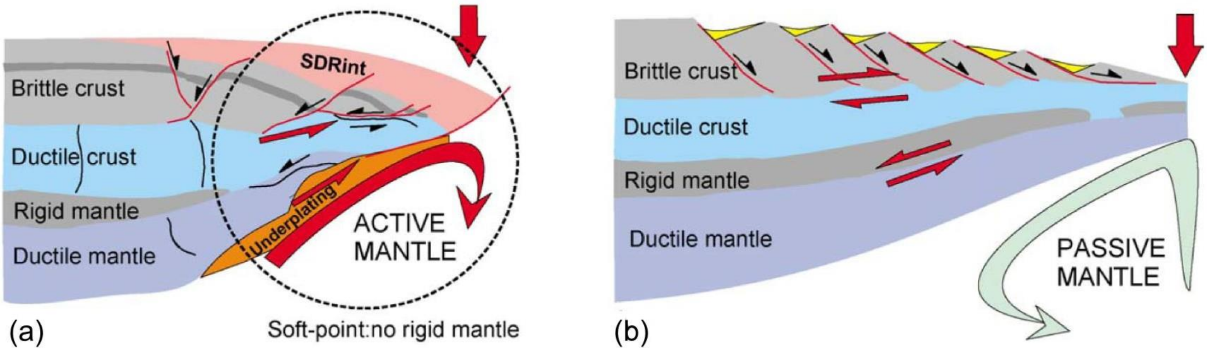


Figure 4 – Typical example of the structure (a) of a volcanic passive margin and (b) of a non-volcanic passive margin [Geoffroy, 2005].

2-2- Non-volcanic Margins

In contrast, the formation of so-called non-volcanic margins is accompanied by little to no magmatism. The term non-volcanic should thus be nuanced. In fact, an increasing number of studies on non-volcanic margins show some magmatic activity, even if weak. The term "magma-poor margin" (weakly volcanic margin) is more appropriate. These margins are generally characterized by:

1. A domain of tilted continental blocks toward the continent, bounded by extensional faults dipping toward the ocean, accommodating extension in the brittle upper crust (Fig. 2.c).
2. An exhumed and serpentinized mantle at the ocean-continent transition (OCT).
3. A thinner oceanic crust (7 km) (Fig. 4.b). These margins do not show SDRs and rarely have high-velocity bodies underplated.

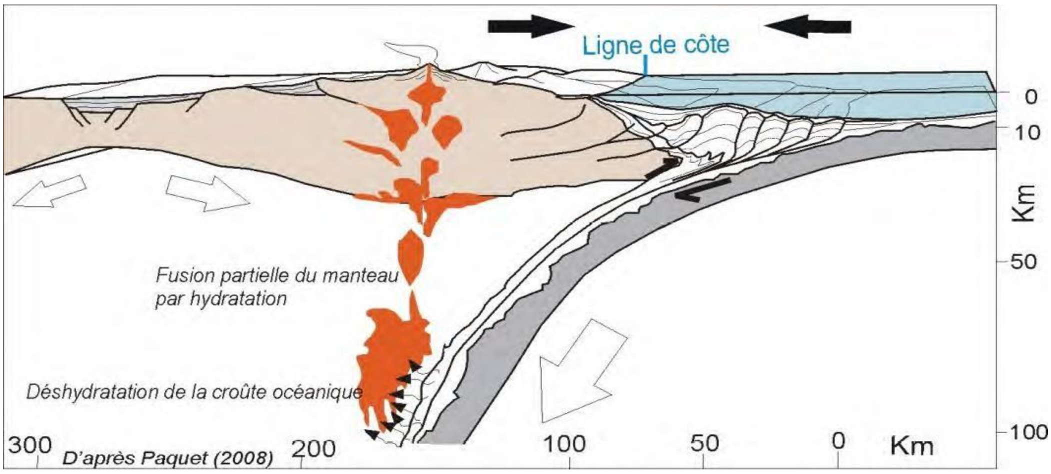
II - Convergent Continental Margins (or Active Margins)

These margins are located above a subduction zone and therefore exhibit chronic seismic and volcanic activity (active margins), the latter expressed by the existence of a volcanic (or magmatic) arc.

- **Convergent lithospheric plate boundary**
  Subduction Zone: One lithospheric plate sinks beneath another in the asthenosphere.
    - **Oceanic subduction**:
        - Ocean/Continent (67%): Andean subduction
        - Ocean/Ocean (15%): Mariana subduction, Antilles arc
    - **Continental subduction**:
        - Continent/Continent (17%) = Subduction continues after collision (Himalayas)
        - Continent/Ocean (1%)
- **Important seismic and volcanic activity**
- **Place of lithospheric thickening + creation of reliefs**

Morphology:

- **Continental shelf**: Narrow or absent
- **Continental slope**: Steep slope (10-20°) and narrow. One can encounter:
  Note*: The morphology of active margins depends on the type of subduction.*



III - Transform Margins: Example of the Ghana-Côte d'Ivoire Margin

Transform margins result from strike-slip movements between lithospheric plates during rifting and oceanic accretion. These margins, resulting from this particular evolution, inherit specific morphological and structural features that distinguish them from the geometry of divergent margins. In these cases, the contact between continental and oceanic lithospheres occurs through a vertical contact located along the transform fault.

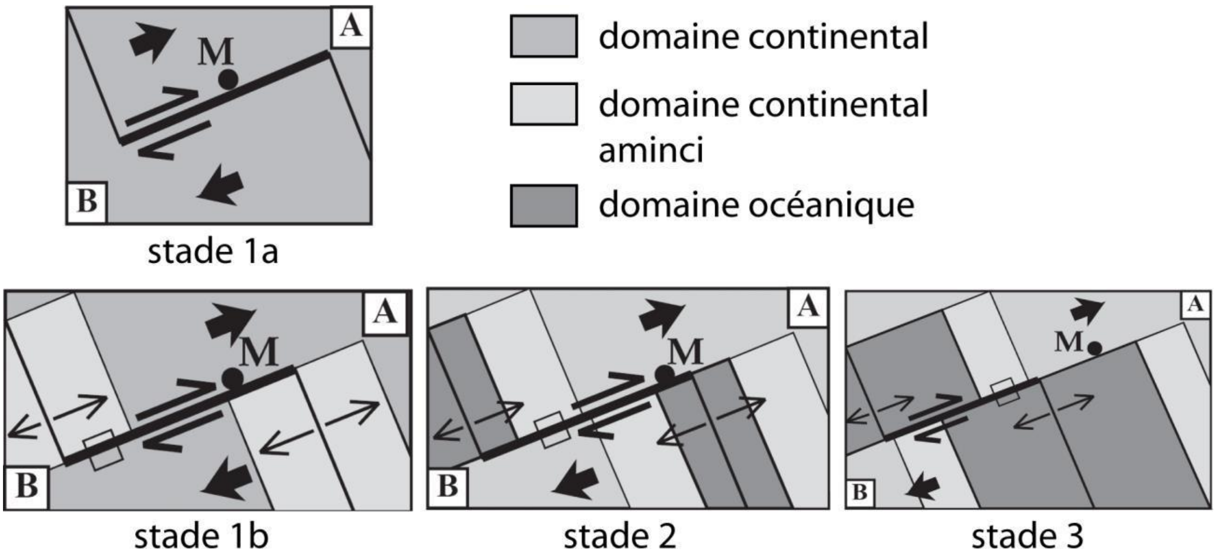


Figure 5 *– Evolution schematic of a transform margin [Sage et al., 2000; modified] (See explanations in the text).*