Introduction to Central Indonesia Geographic Basins

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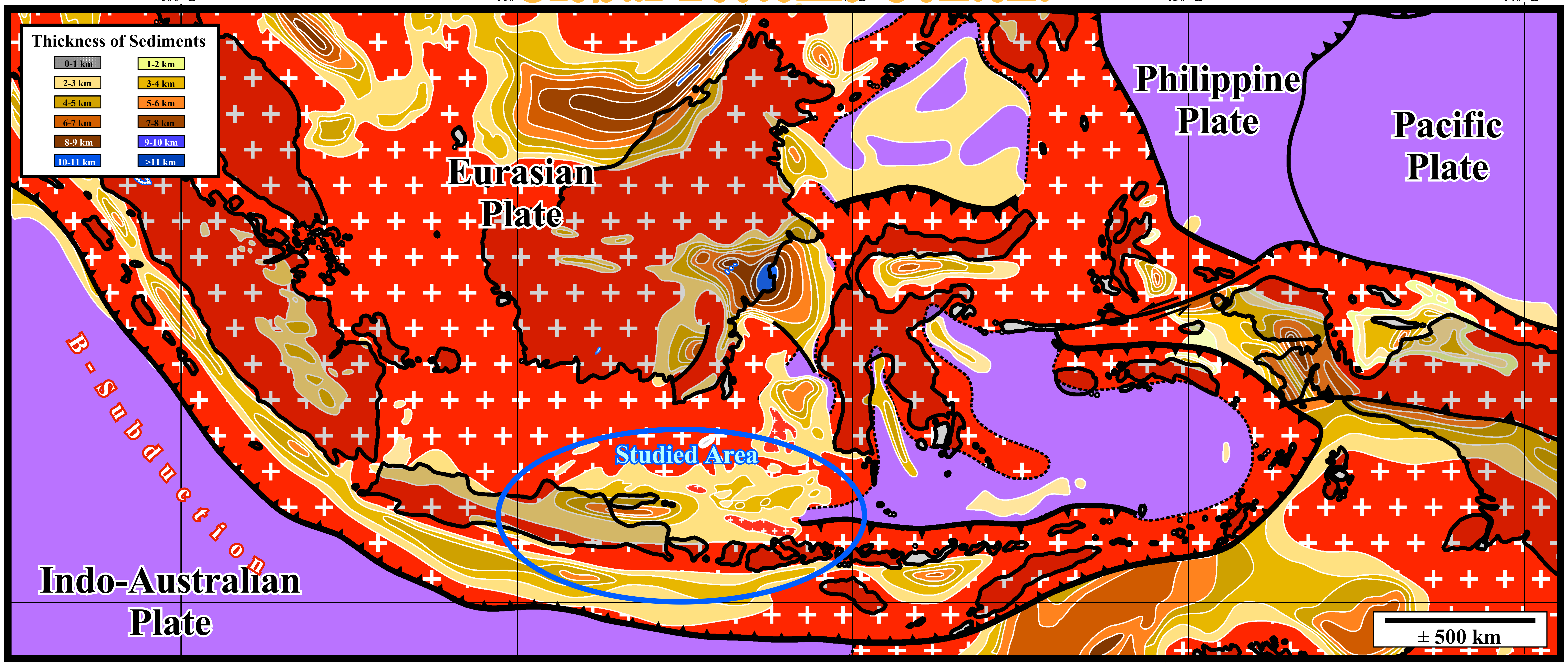
Indonesian Basins & Global Tectonic Context



In these notes we will review the more likely petroleum systems of the Central - East Java basins as well as the remaining hydrocarbon potential. We will take into account that these basins are fundamentally back-arc basins, which are formed by the vertical superposition of rift-type basins (rifting phase), in which the potential source-rocks were deposited, and the back-arc basins sensu stricto (sag phase) during which the subsidence mechanisms is mainly thermal. Near the end of the back-arc, a compressional tectonic regime took place. It shortened the sediments either by buckling and folding or by reactivation of the pre-existing normal faults creating during the rifting phase, creating

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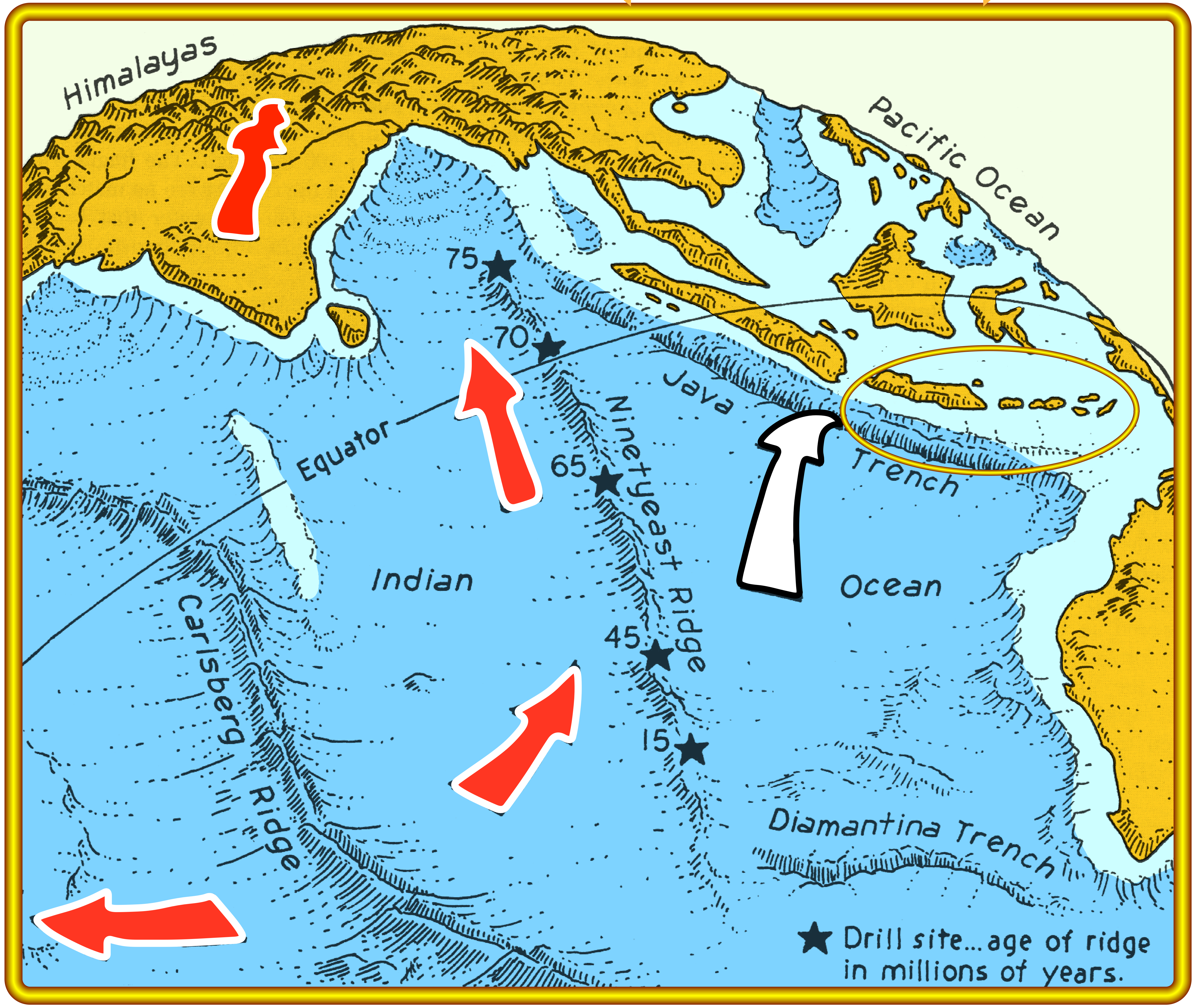
Java Trench (Benioff Zone)



All of the basins studied are directly or indirectly related to the Java Rift, which is geologically equivalent to a Benioff subduction zone (or "B" subduction), where an oceanic tectonic plate dives beneath a continental plate, creating a volcanic arc within the continent. Such a mechanism developed an extensional tectonic regime behind the volcanic arc, which was responsible for the development of back-arc basins, where organic-rich sediments generated hydrocarbons, which were mainly trapped in non-structural traps.

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Exploration Approach

In these mature petroleum basins, it is quite evident that additional reserves can just be discovery by an hypothetico-deductive exploration approach.

The naive inductive approach, in which serendipity is the key of exploration, cannot work any more, particularly when the large majority of the present structural highs have been drilled.

Contrariwise to the naive concept of induction, in petroleum exploration, observation is theory-laden, that is, the theoretical framework within which explorat

Top-Down Exploration

Exploration must be done from the general to the particular.

Explorationists must know what they are looking for. Theory precedes Observation.

Starting exploration picking reflectors on a seismic line, without knowing the geological setting and the controlling rules, is foolish.

Admittedly, seismic interpretation start with observations, but once some initial observations have

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Top-Down Exploration

Observations lead to hypotheses, which guide further observations, which influence the hypotheses.

There are serendipitous discoveries in exploration, in which observations truly instigate the development of hypotheses, but they inevitably occur to those who have the necessary framework to understand the importance of what they are observing (M. Ben-Ari, 2005).

So, let’s review the geological context and the main rules controlling the remnant HC potential

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Benioff-Waddati Zones

"B" Subduction

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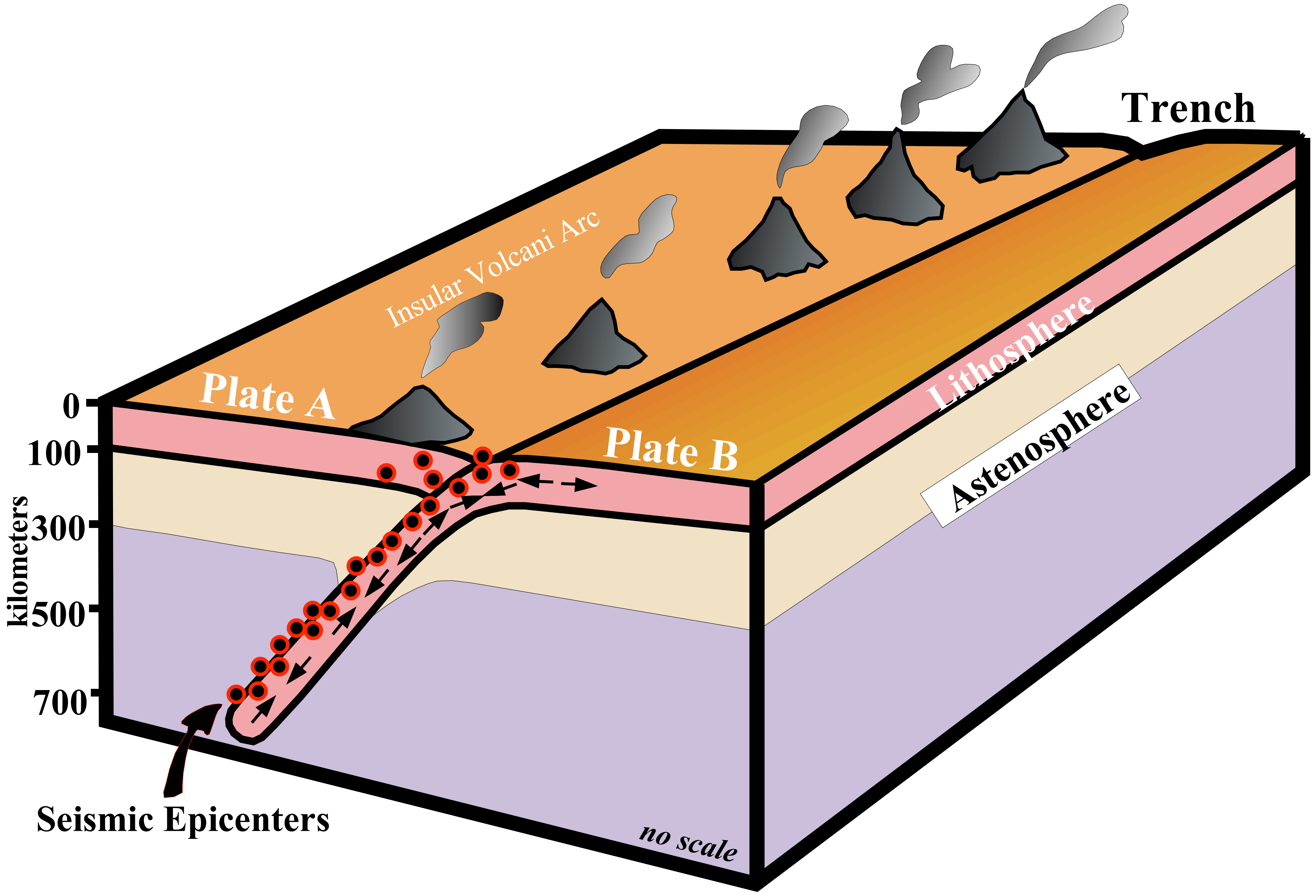
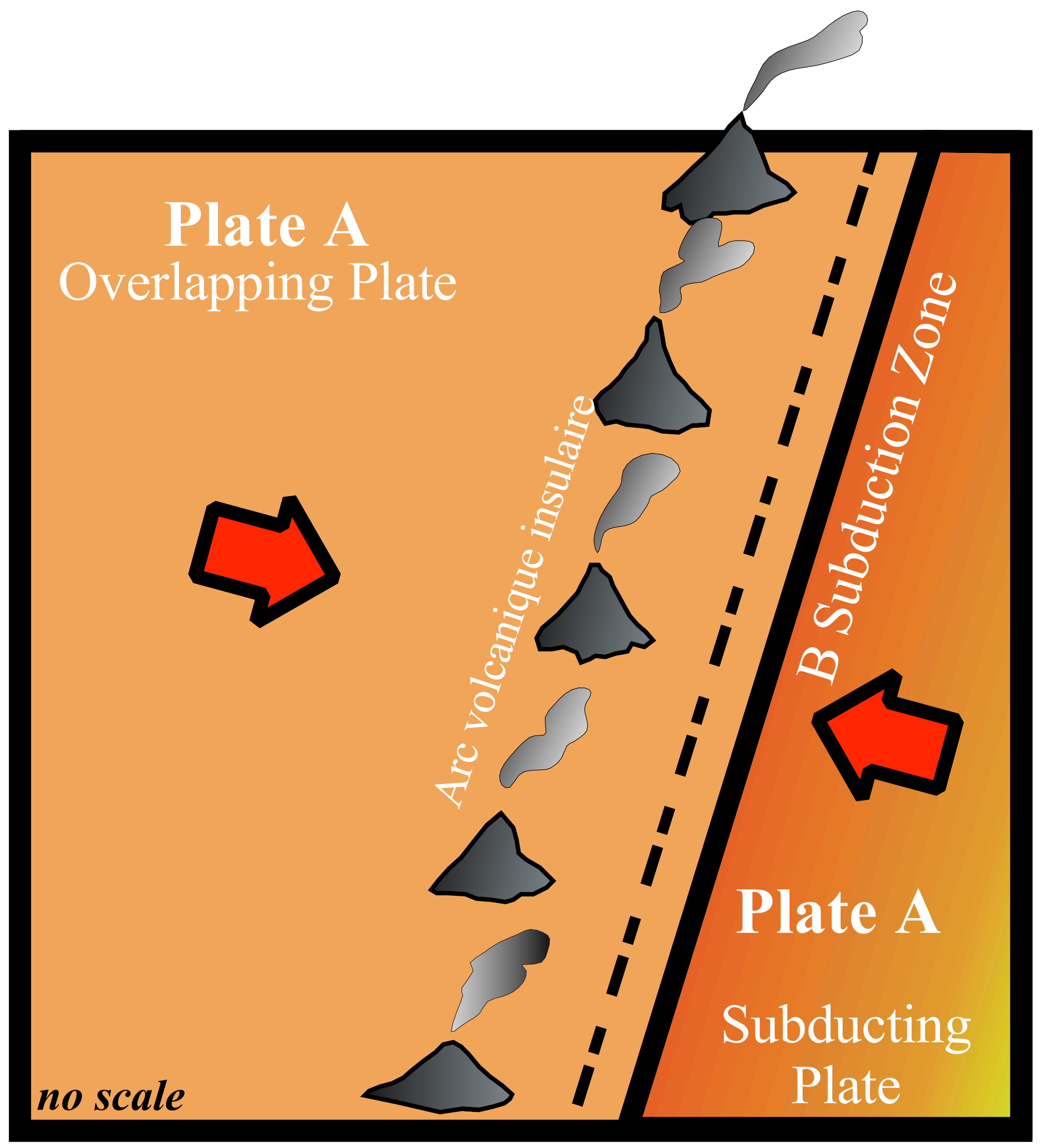
Benioff-Waddati Zone





As the subducting oceanic lithospheric plate plunges, due to gravity or other undiscovered factors, cold lithospheric material is brought into contact with the astenosphere, which is much hotter (> 1250°C). Depending on its thermal conductivity, the plunging slab is then heated and its rheology changes. Despite the fact that the plunging plate is generally in a state of compression, sectors in expansion, located near the break of its dip, have been highlighted by the study of seismic waves. The subduction of the oceanic plate (cold and brittle) gives rise to volcanos, in the overlapping plate (continental or oceanic), at a distance more or less important of the oceanic trench (function of its dip), forming a volcanic arc. On the other hand, as the isotherms of the astenosphere are modified, ascending convection currents develop in the upper mantle, creating an extensional zone behind the volcanic arc.

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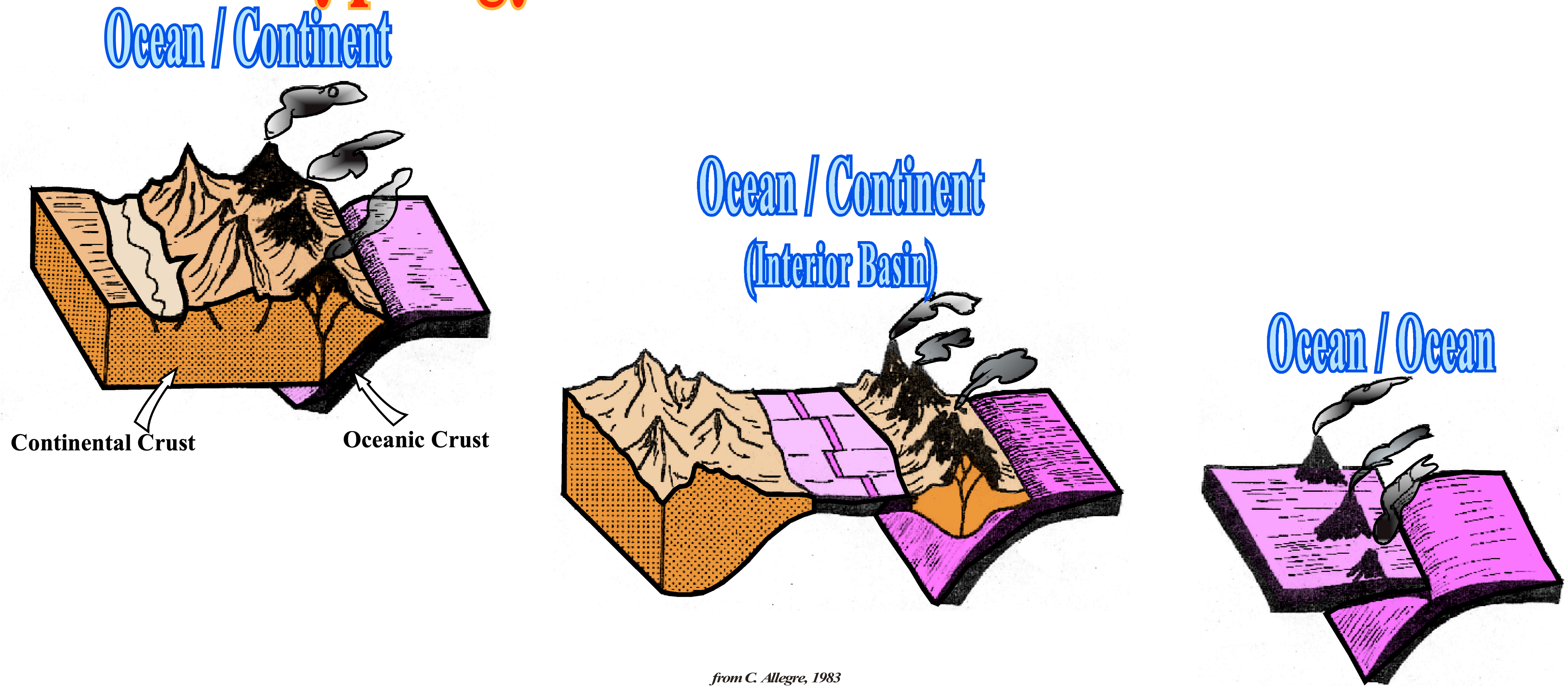
Typology of "B" Subduction Zones

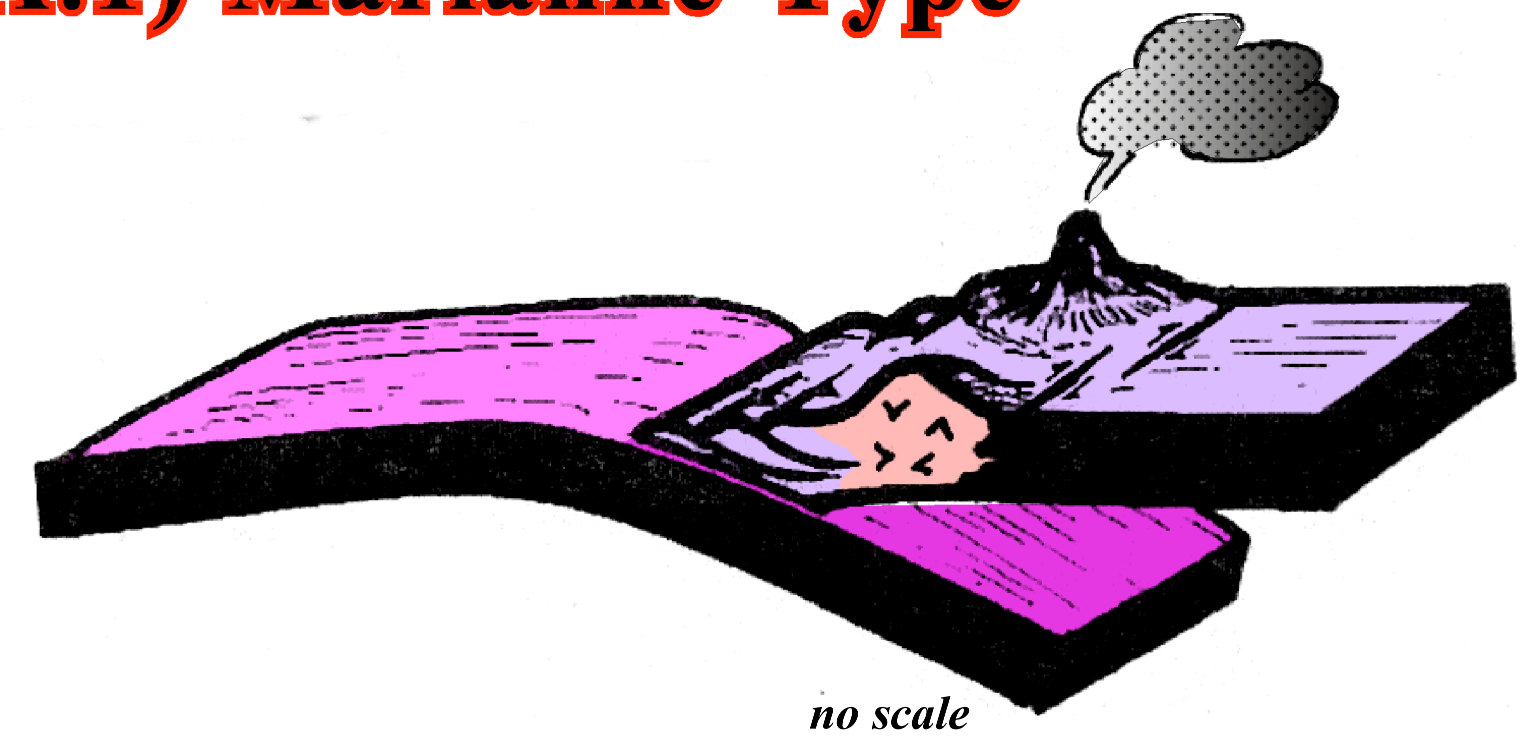


from C. Allegre, 1983

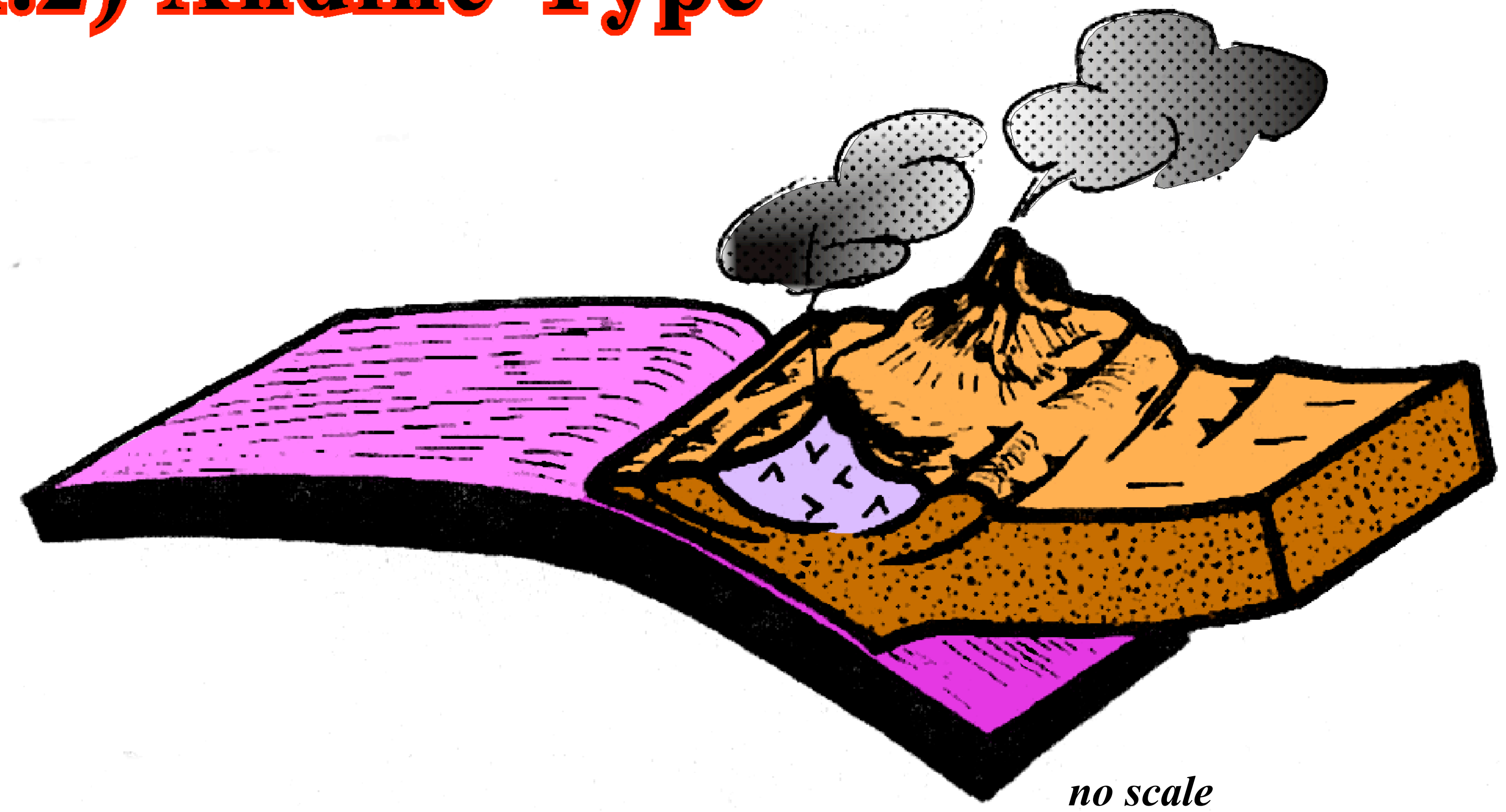
The morphology of the convergent margins suggests that the position and orientation of the "B" subduction zones (Benioff type) in relation to the main physiographic boundaries of the Earth are not uniform. Indeed, three typologies are often considered: (i) Ocean/Continent, when the subduction takes place at the boundary between the ocean and the continent, as in Mexico, Chilli, Peru, Sumatra, etc.; (ii) Ocean/Interior Basin/Continent, when the subduction zone borders the continent in a median position, since an oceanic basin, more or less developed, has developed between de subduction and the continent, as in Aleoutian, Kouriles, North Sumatra, etc.; (iii) Ocean/Ocean, when the subduction zone borders the continent in a median position, since an oceanic basin, more or less developed, has developed between de subduction and the continent, as in Aleoutian, Kouriles, North Sumatra, etc., (iii) Ocean / Ocean, when the subduction takes place in an oceanic real, as in Mariannes, Tonga, Kermadec, Lesser Antilles, etc. In Indonesia, the more common typology is Ocean/Continent, but Ocean/Interior Basin/Continent is also present, especially in East Indonesia.

Subduction Margins

A.1) Marianne-Type

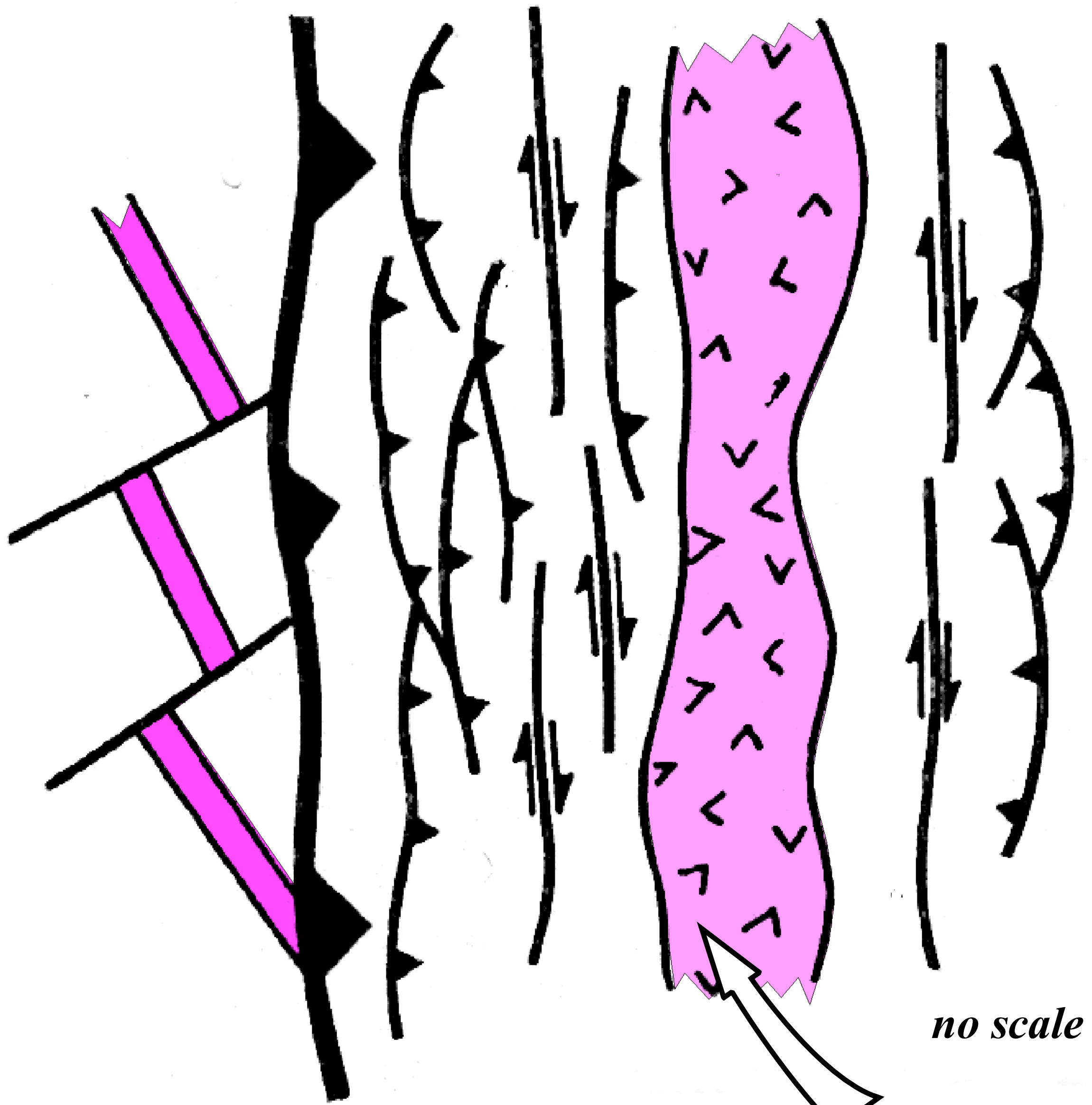


A.2) Andine-Type



from A. Bally, 1980

Tectonic Sketch



In the convergent margins, the plunging of a cold and brittle lithospheric plate in the upper mantle induces two phenomena causing failures in the plate: (i) A thermal phenomenon, which corresponds to heating of the plate, and (ii) a mechanical phenomenon, which is related to the resistance of the mantle to the penetration of the plunging plate. When one or both plates are formed by oceanic lithosphere and the plunging plate is oceanic, the margins are called subduction margins. Marianne-type is the one, in which the overlapping plate is oceanic, and Andine-type is the one, in which the overlapping plate is continental. Noticed that: (i) the plunging of cold lithosphere modifies the position of the isotherms of the upper mantle; (ii) The thermal flux is quite low in the oceanic trench and relatively high in the back arc area, which favor the maturation of the organic matter of the organic-rich sediments deposited, generally, during the rifting episodes of the back-arc basins and the absence of hydrocarbon generation in the oceanic trenches, even if organic sediments are deposited.

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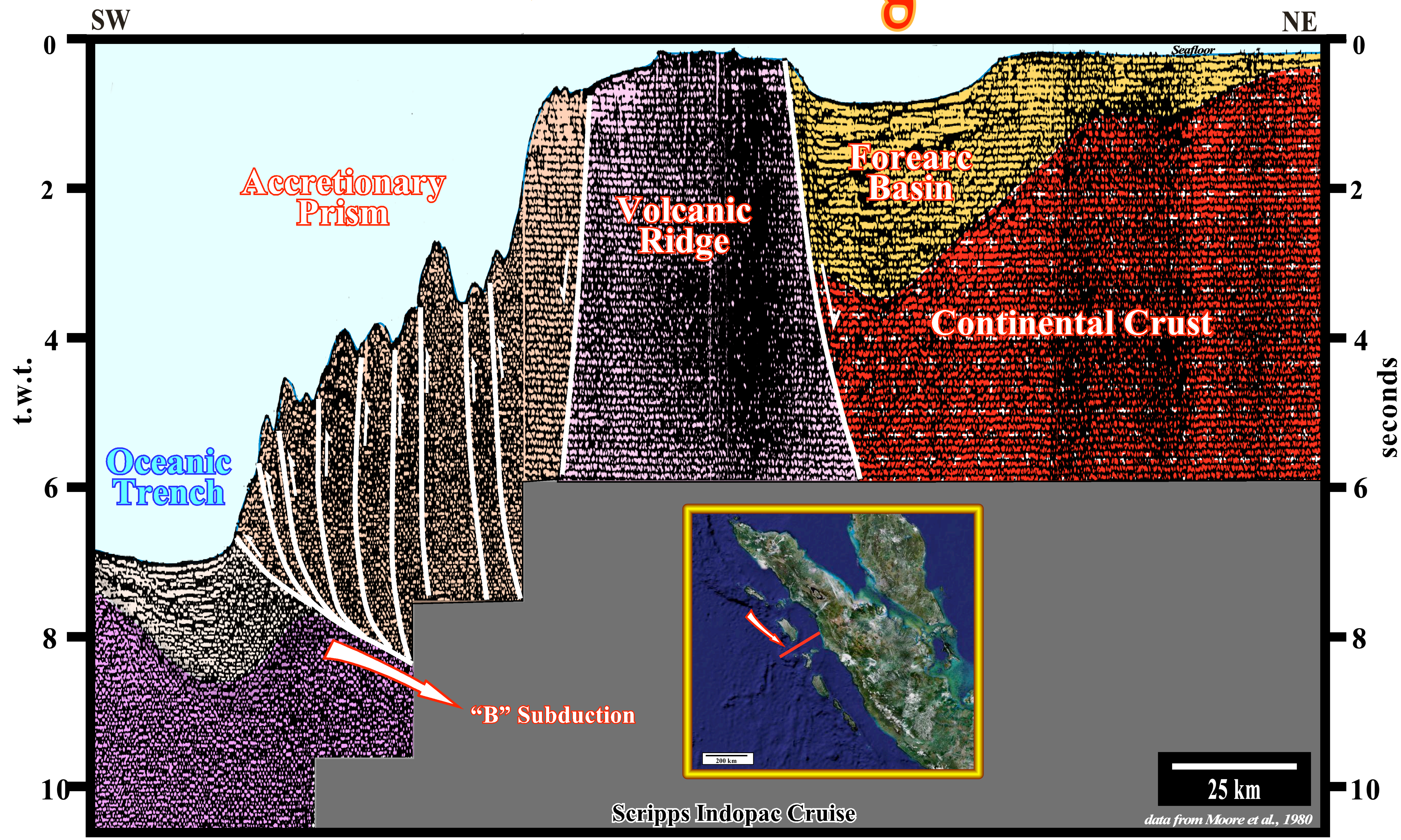
Subduction Margin



This tentative interpretation illustrates an Andine subduction margin. The subduction of the oceanic plate (lower plate) under the accretionary prism is quite visible. The strong shortening of the sediments of the accretionary prism suggests a high degree of decoupling between the two lithospheric plates (taking into account the pull-up anomaly induced by the lateral variation of the water depth of the continental slope). In the overlapping plate, behind the volcanic ridge, within the continental crust, a Mio-Pliocene forearc basin is also evident.

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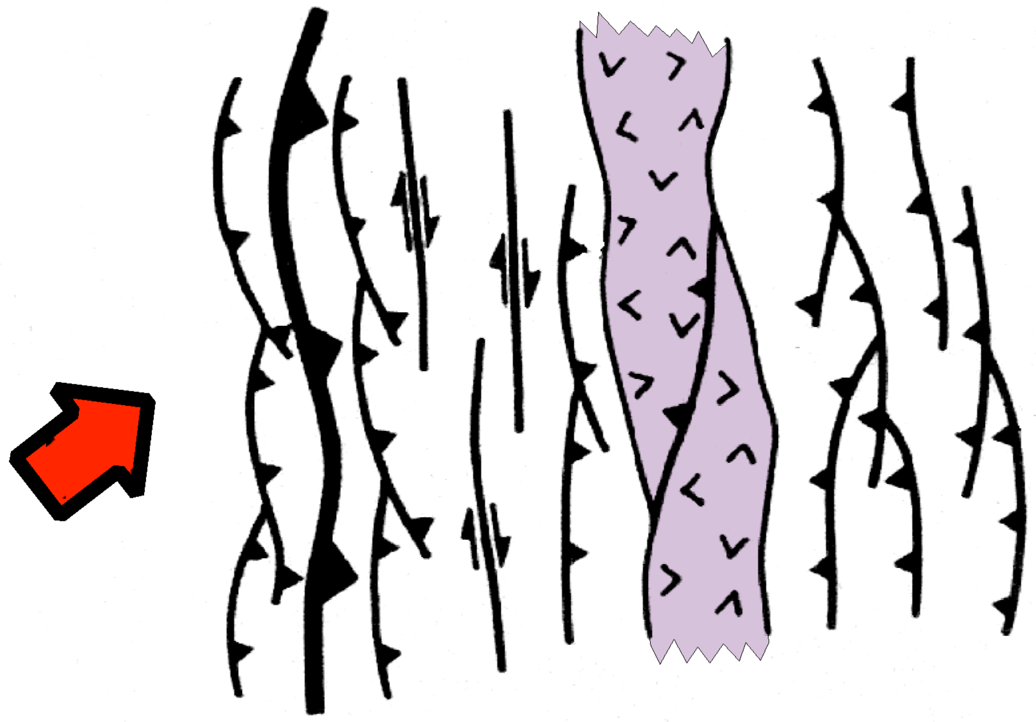
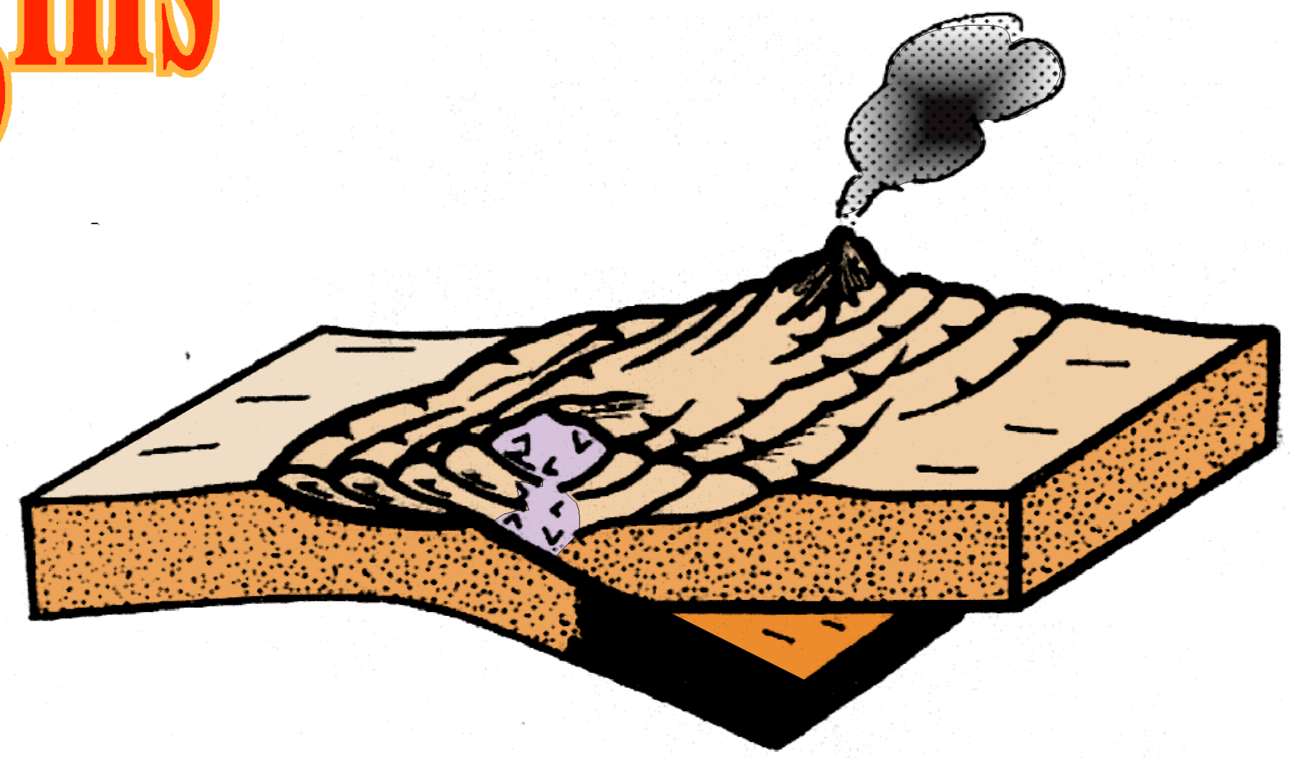
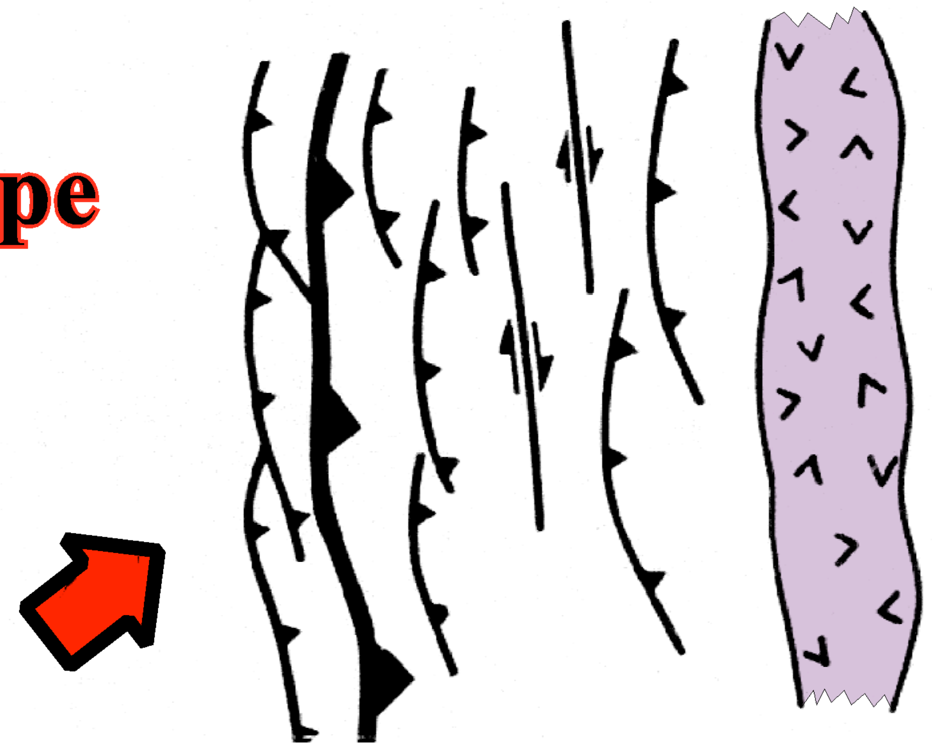
Collision Margins

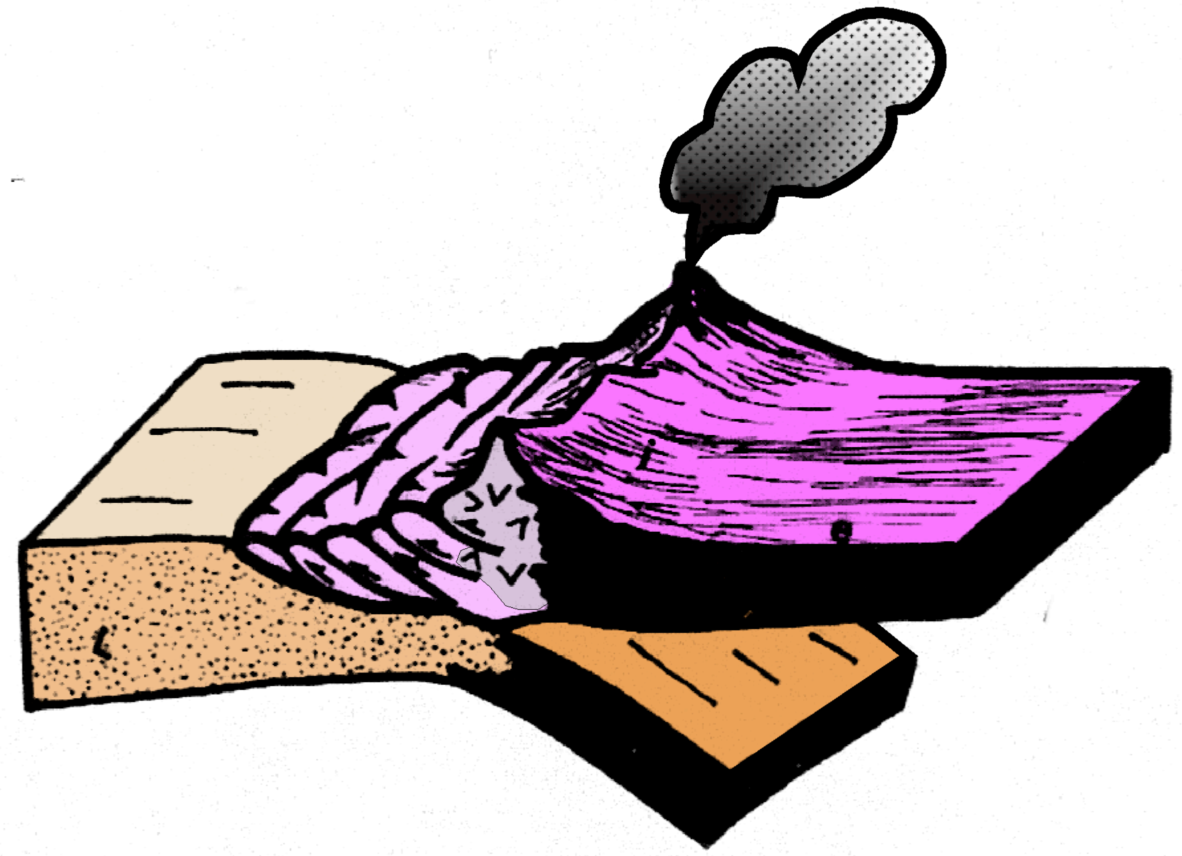
B.1) Alpine-Hymalayan Type





B.2) Taiwan Type

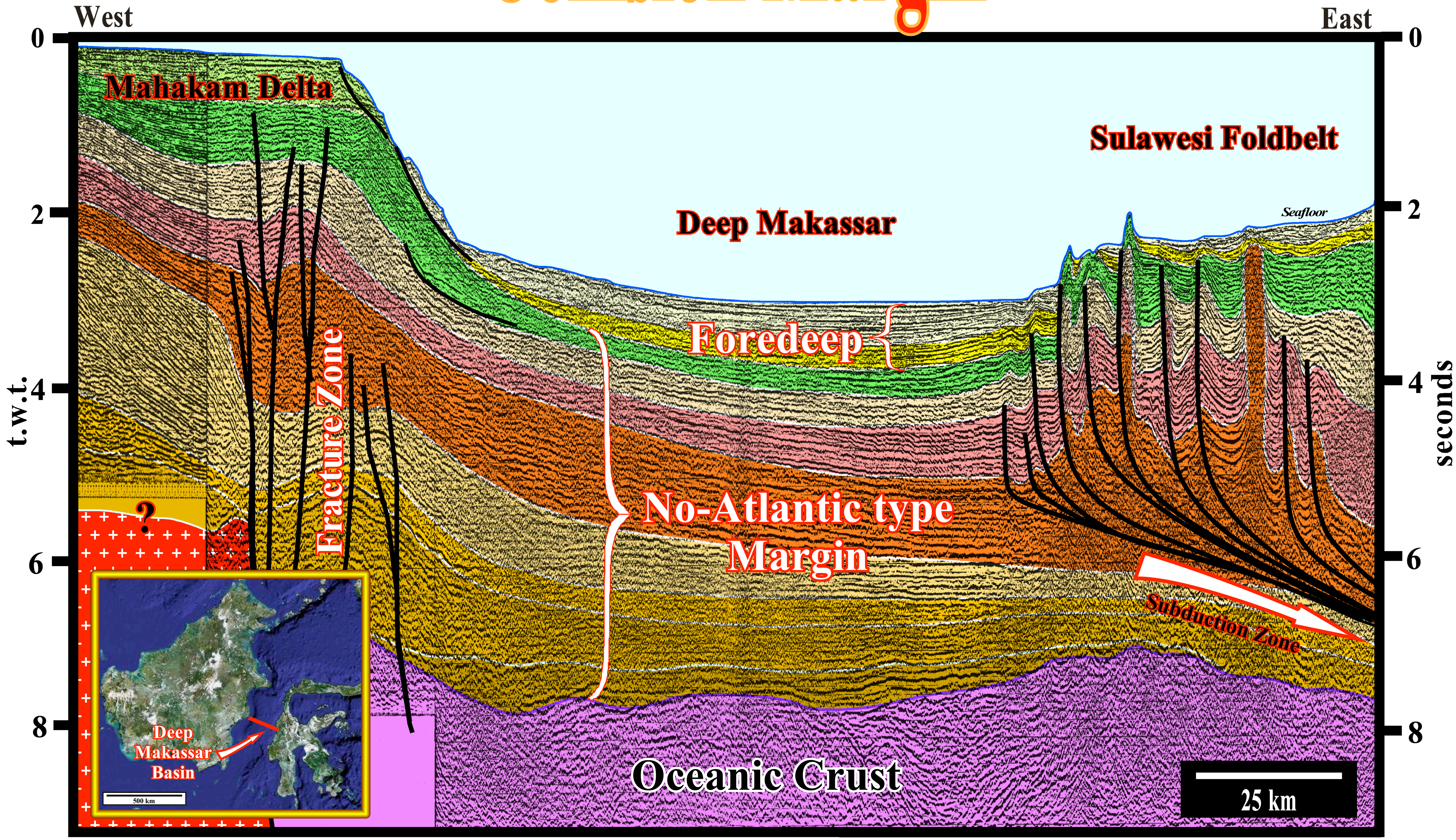




from A. Bally, 1980

The collision margins are those where one or both plates (subducting and overlapping) are composed of continental crust and where the subducting plate is continental. They are of Alpine-Hymalian type when the overlapping plate is continental and of Taiwan type when the overlapping plate is oceanic. In the first type, the sediments are shortened on both sides of the volcanic arc. In the second, the shortening is present only in the area adjacent to the trench. Examples of this type of margin are found in eastern Indonesia. The subduction associated with convergent margins, i.e. Ampferer or "A" subduction, has a different mechanism from "B" subduction. The term collision is misleading, particularly in relation to continental crustal blocks. It does not correspond to the current meaning of collision, i.e. it does not correspond to the conversion of kinetic energy into transformation energy. Kinetic energy plays no role in crustal deformation. Remember that plate tectonics recognises the rigidity of the oceanic crust and predicts the areas where the oceanic crust rises and where it disappears. In such a theory, it is inconsistent to speak of the collision of continental blocks, as Wegener thought.

Collision Margin



This tentative interpretation of a regional composite seismic line between Kalimantan and West Sulawesi strongly suggests: (i) formation of oceanic crust, in the back-arc area, with development of a margin sea and two small lithospheric plates; (ii) a non-Atlantic margin was formed on either side of the expansion centre, above the old back-arc basin; (iii) the non-Atlantic margin sediments overlie the new oceanic crust in the central area; (iv) a Benioff-Waddati zone was created by subduction of the newly formed oceanic crust beneath the eastern margin; (v) subduction of spreading and emergence of a collision margin, probably of Alpine-Hymalaian type.

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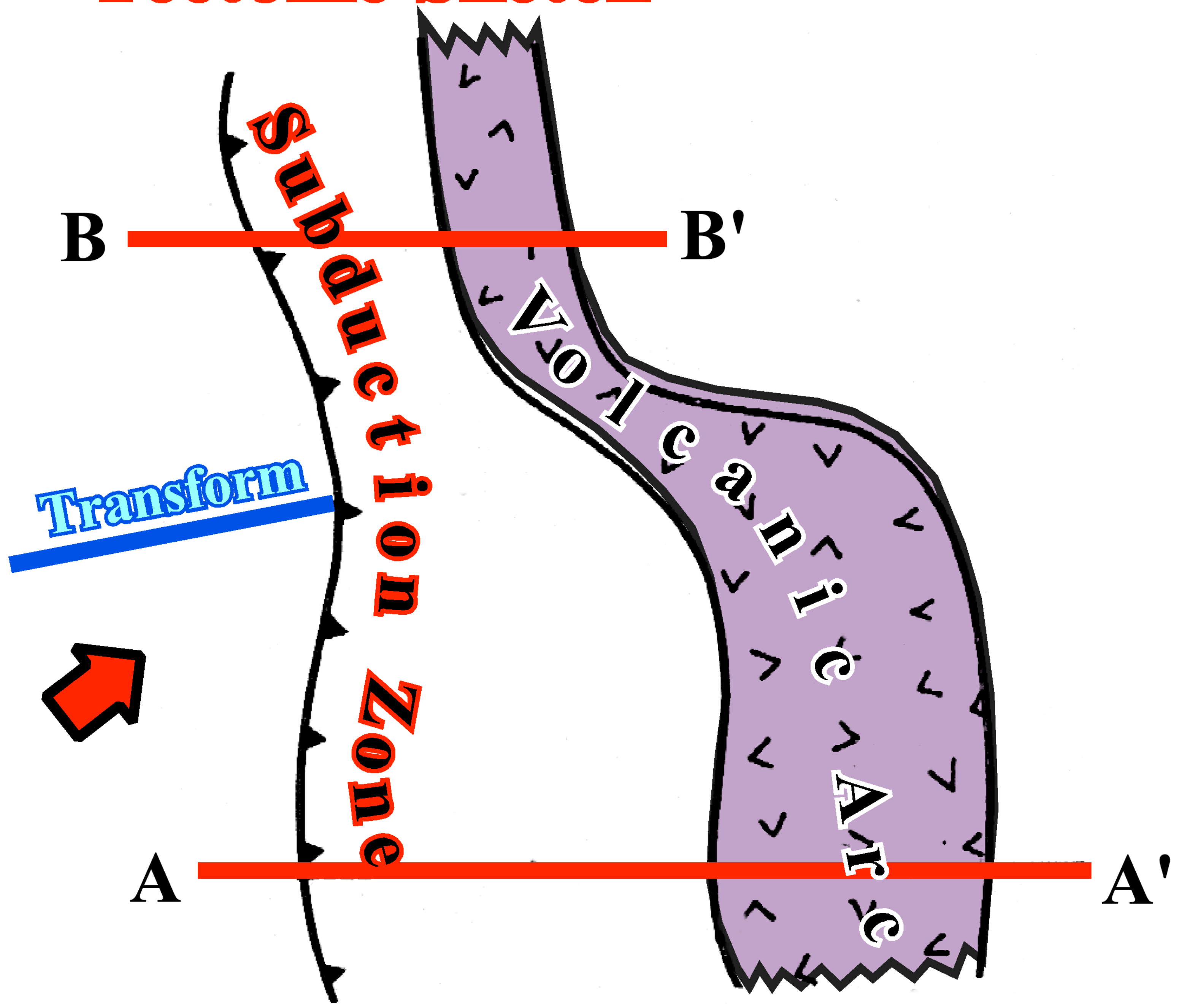
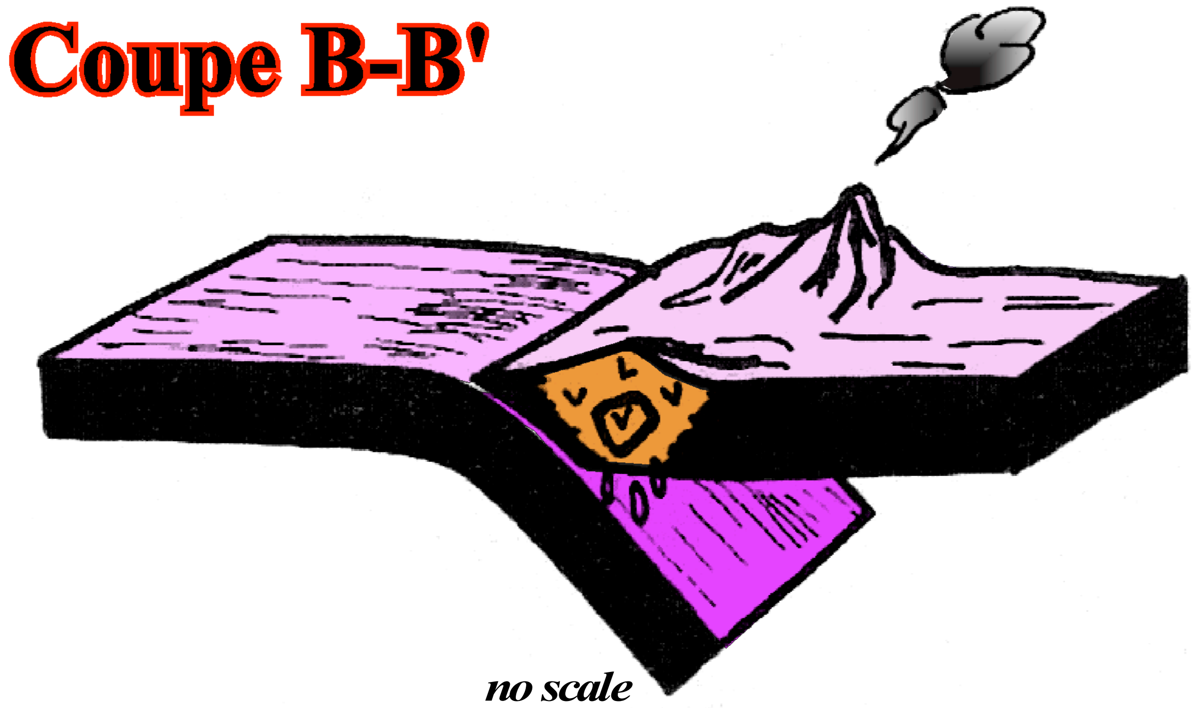
Angle of Subduction

Tectonic Sketch

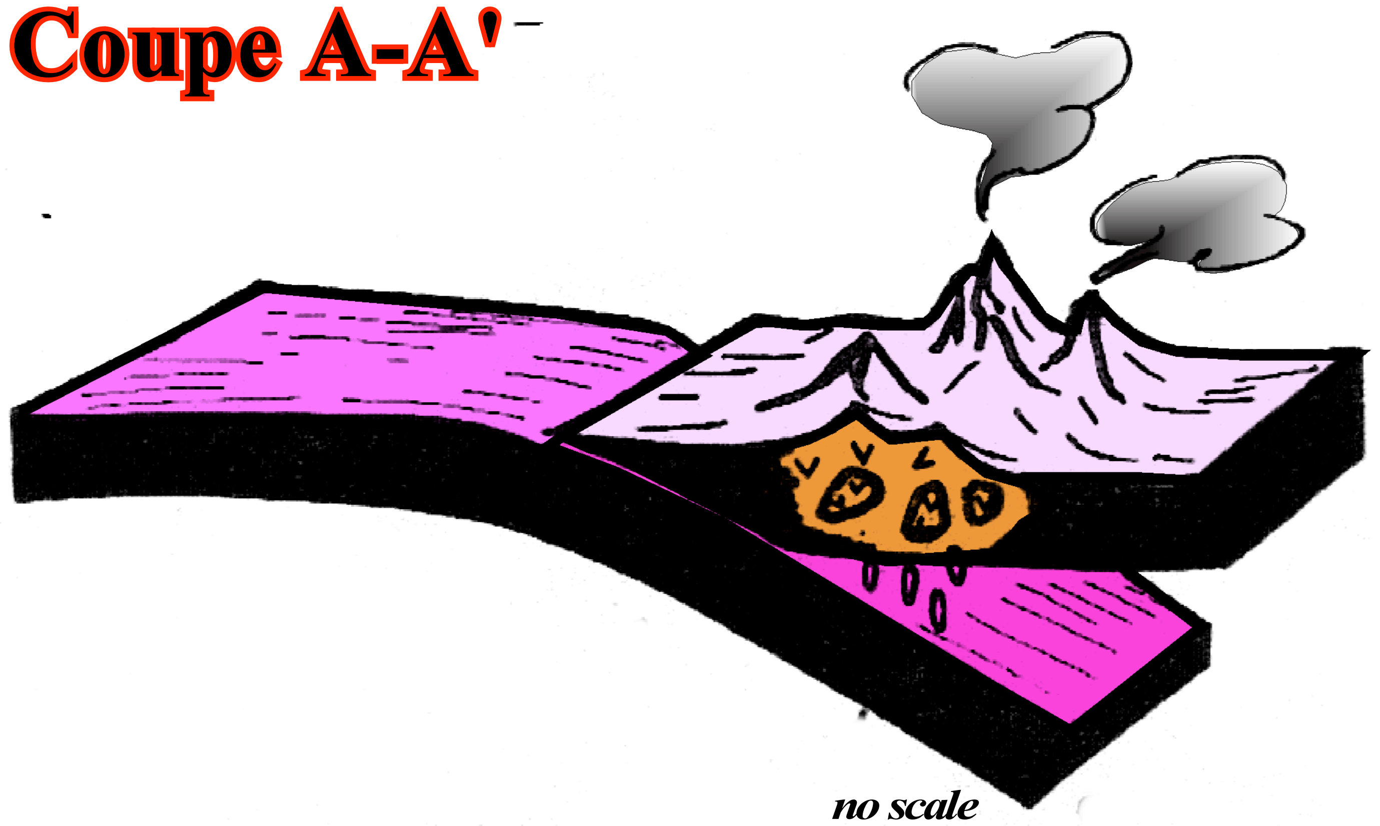


from C. Allegre, 1983

Coupe B-B'

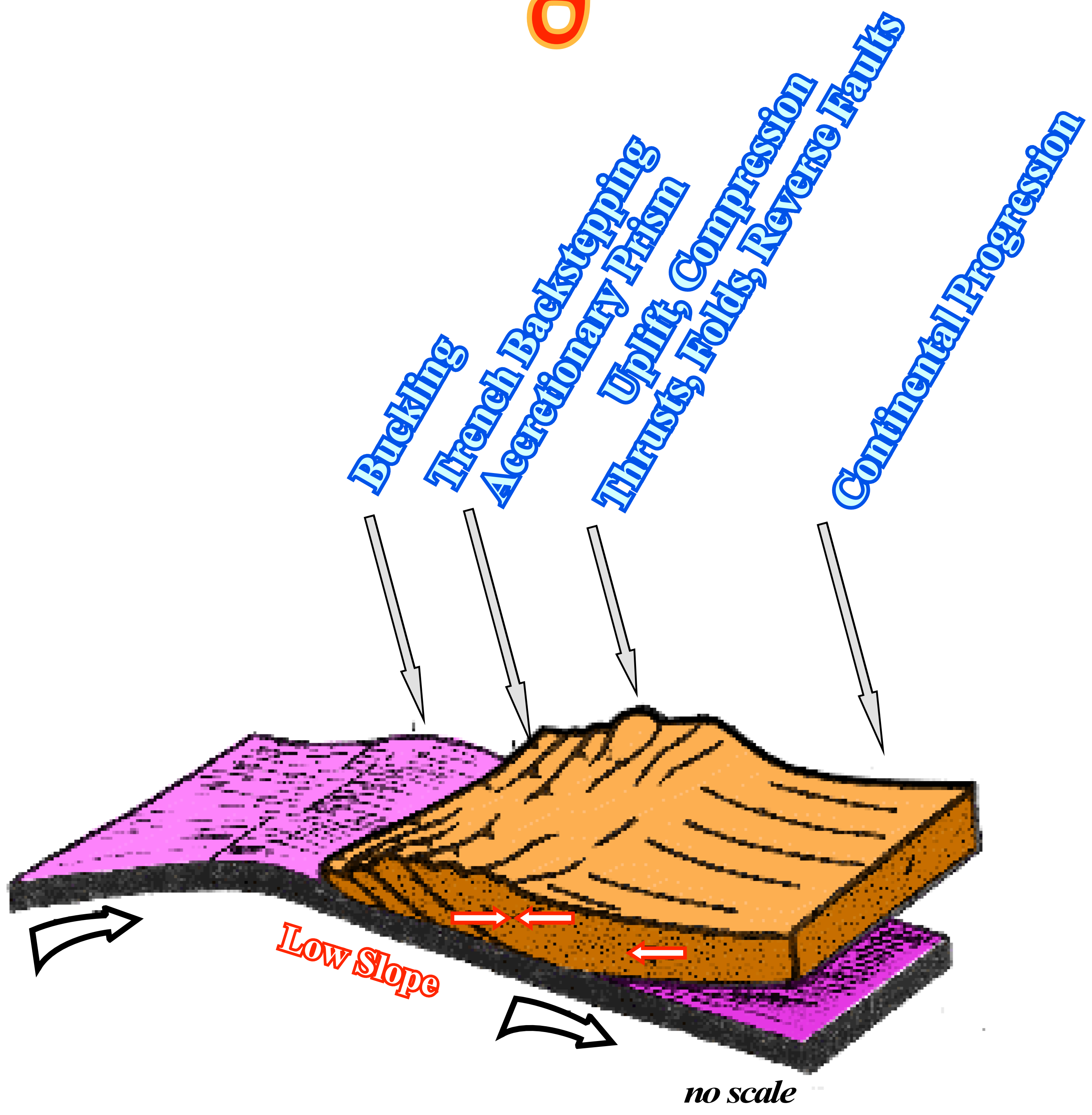


Coupe A-A'

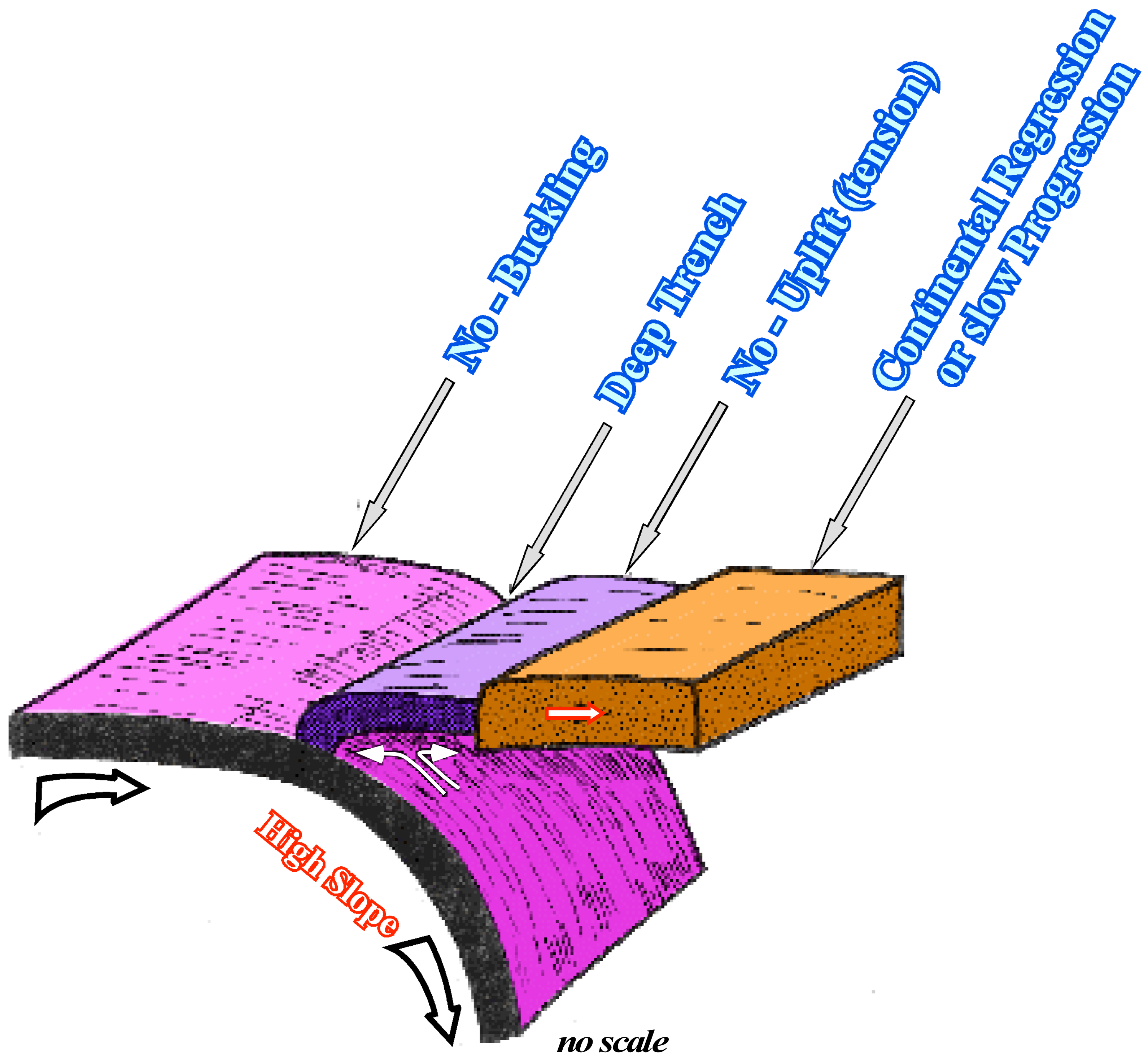


"B" subduction zones are characterised by subduction of the oceanic lithosphere. The basaltic interval and the sedimentary overburden penetrating the upper mantle are heated. Once the oceanic lithospheric material reaches the fusion temperature of the melange (basalt, water, sediments), it produces a volcanic magma which, being lighter than the surrounding material, rises to the surface and forms volcanoes. This explains one of the characteristics of "B" subduction zones, that is, the formation of volcanoes, in the overlapping plate, at a more or less significant distance from the oceanic trench. This distance is a function of the subduction angle, i.e. the angle between the subducting plate and the Earth's surface. The subduction angle is determined by several parameters: (i) the thermal state: the younger the plunging plate, the lighter it is, and so the smaller the subduction angle and the resistance to plunging; (ii) the rheology of the surrounding area: assuming that the surrounding oceanic lithosphere has a low density, it can induce extensional deformation at the moment of plunging, thus reducing the subduction angle; (iii) The relative velocity of the plates: whenever the relative velocity of the plates is low, the vertical component of the plunge has all the time to become dominant, thus increasing the subduction angle.

Angle of Subduction & Deformation



Chilian-Type

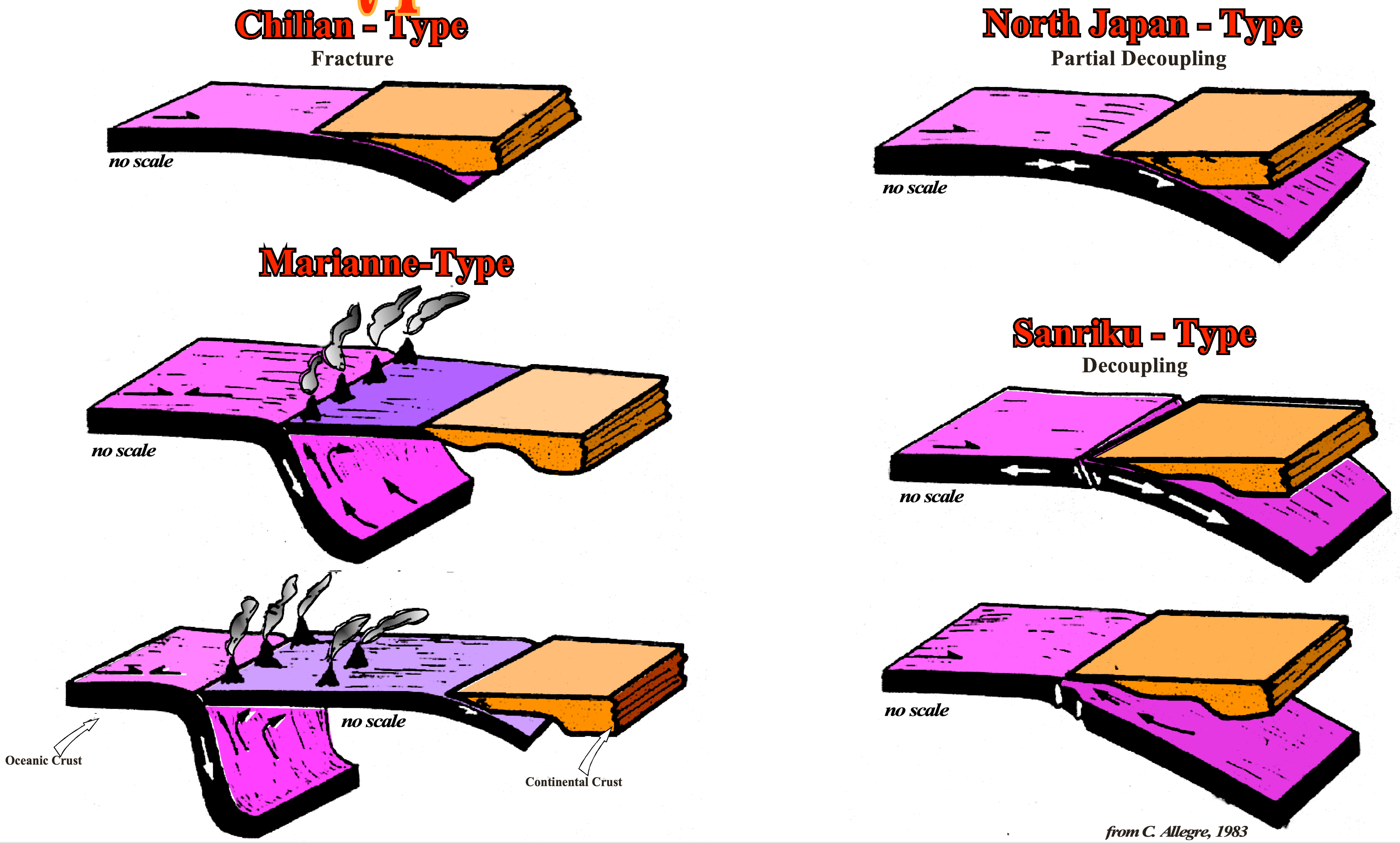


Marianne-Type

from C. Allegre, 1983

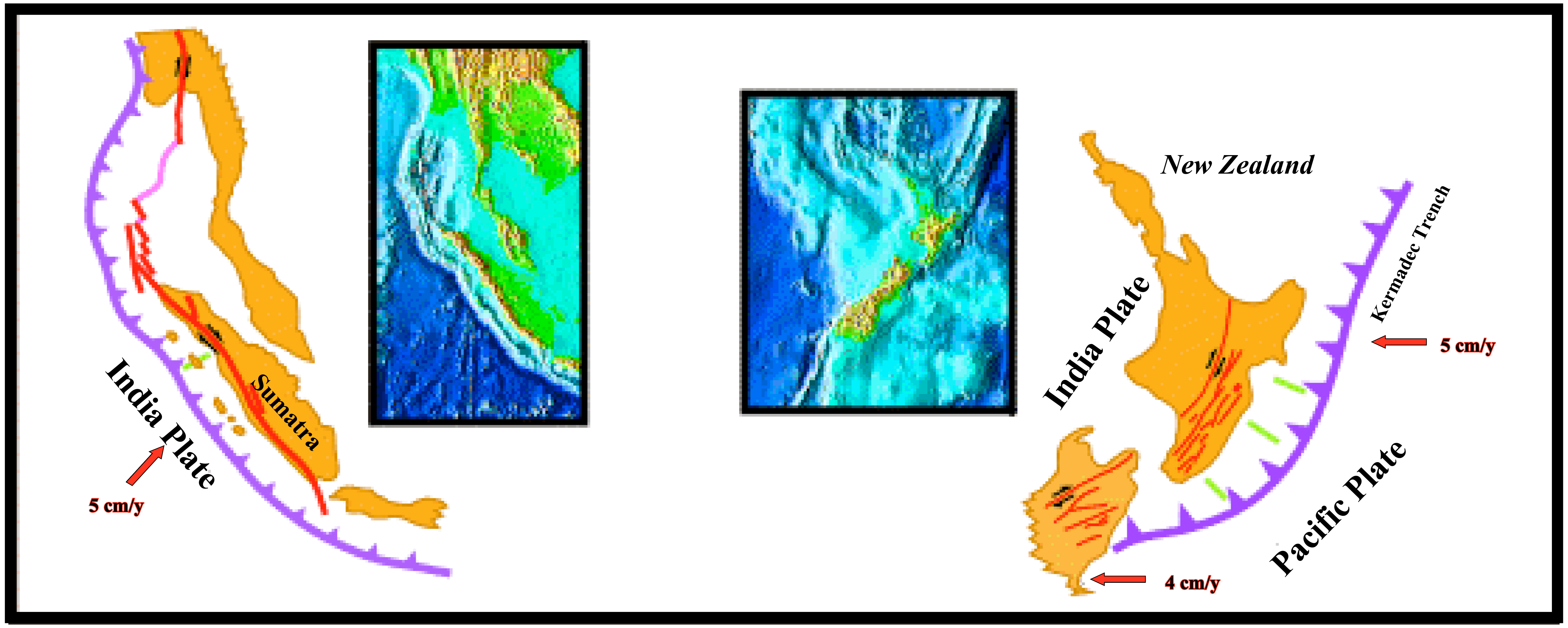
"B" subduction forces the abyssal sediments to penetrate the upper mantle. However, such intrusion is not possible if the subduction zone is not in extension. Such a feature raises the question: is the "B" subduction zone in extension or in compression? Takeuchi (1967) suggested that: (i) subduction begins by forced plunging (low subduction angle) with an oceanic trench bounded by folded sediments (Chilian type); (ii) as the plunging plate penetrates the upper mantle, it is folded and so has a tendency to push back; (iii) the oceanic trench becomes progressively an extensional zone; (iv) as the penetration of sediments and oceanic crust progresses, a subduction zone develops, which is well accentuated by the oceanic trench and has a tendency to run back, increasing the extensional characteristic of the zone (Marianne type). In other words, in the Chilian type of subduction, the overlapping continental plate is shortened at the level of the oceanic trench (compression), whereas in the Marianne type, the overlapping oceanic plate is lengthened (extension).

Types of “B” Subduction



C. Allégre (1983) proposed a probable evolution between the Chilian and Marianne types of subduction zones, which can be summarised as follows (i) Chilian type: buckling of the plunging plate, retreat of the oceanic trench, accretionary prism, uplift, compression and thrusting of the overlapping plate, low angle of subduction; (ii) Marianne type: no buckling of the plunging plate, deep oceanic trench, no compression on the overlapping surface, slow regressive progression of the overlapping plate, high angle of subduction. Compressive “B” subduction zones induce accretionary prisms. The absence of sediments in the oceanic trenches of extensional “B” subduction zones (Marianne-type) illustrates only one possible temporal and spatial evolution of the Chilian, Kouryles, Sanriku and Marianne-type Benioff zones.

Shortening in "B" Subduction Zones



In normal convergence, the relative motion of the plunging plate is perpendicular to the oceanic trench and the shortening of the plate margin is parallel to the relative motion vector. In oblique convergence, the shortening in the overlapping plate is not parallel to the relative motion vector. In a back-arc basin, shortening is perpendicular to the strike of the oceanic trench. The strike-slip component occurs in a specific shear zone. The presence of a strike-slip fault system in the magmatic arc may be the result of co-evolution of folding in the forearc. However, strike slip does not necessarily coincide with the relative movement of the plates. It can be a response to transpression along inter-arc strike-slip faults. When the rate of convergence between two lithospheric plates and the absolute motion of the overlapping plate towards the oceanic trench are significant, sediments are shortened by folds and reverse faults: (i) in the fore-arc region, such structures are parallel to the subduction plane; (ii) in the back-arc region, their vergence is generally antithetical. The accretionary complex develops within the oceanic trench and the forearc basin. In these areas the terrigenous influx is generally small and the thickness of the accretionary prism is not important. However, it is thick enough to allow for imbricated tectonic structures.

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Ampferer Zones

"A" Subduction

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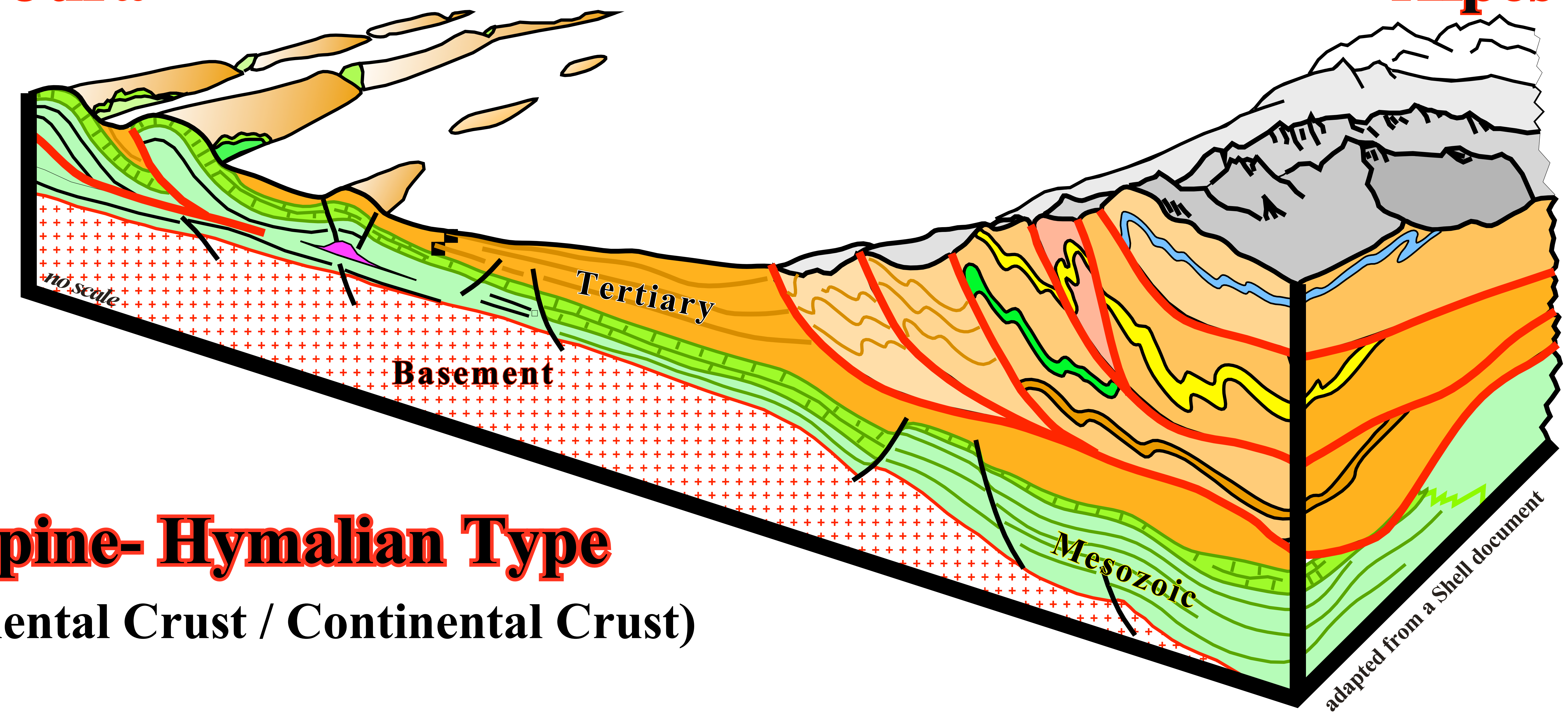
Collision Margins

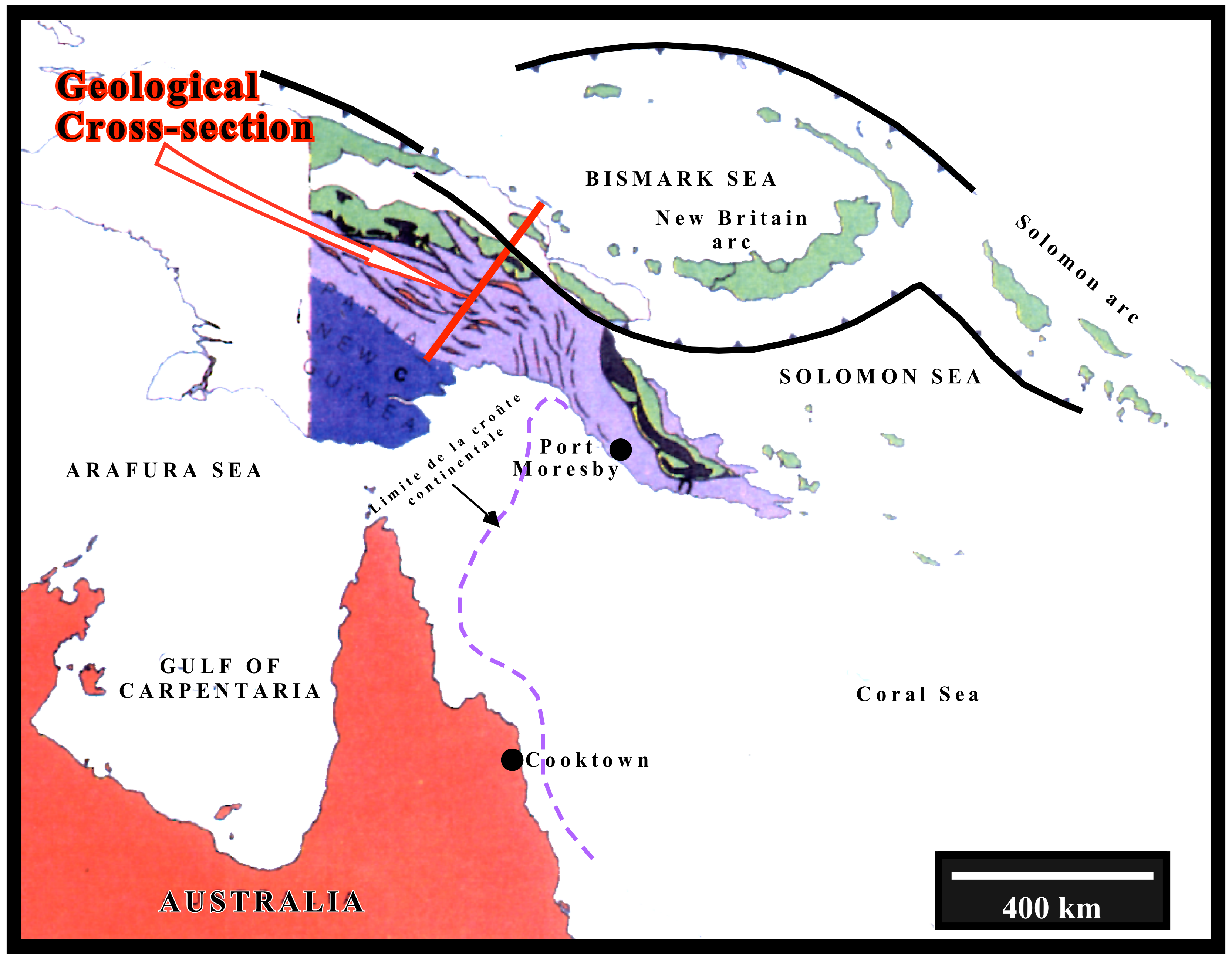


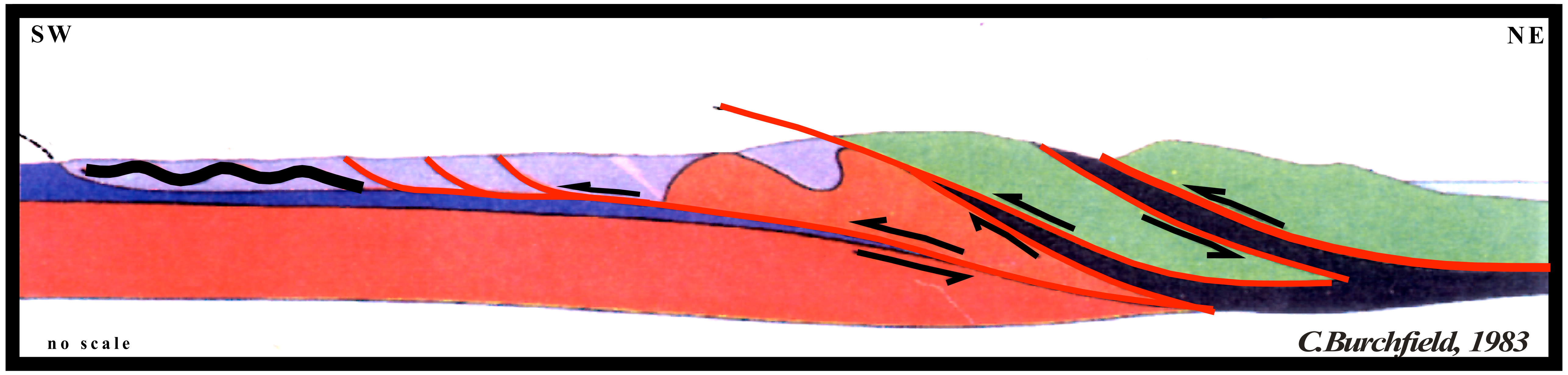
Alpine- Hymalian Type

(Continental Crust / Continental Crust)

In the Rocky Mountains, the Alps, the Appalachians, Irian Jaya (eastern Indonesia), etc., the geological reconstructions carried out by various geologists show that the sedimentary overburden is considerably higher than the underlying continental substrate. Such a feature forced them to propose a new subduction mechanism completely different from the Benioff zones (“B” subduction). This new subduction zone, called Ampferer or “A” subduction, occurs where part of the sialic continental crust is subducted at a relatively high depth under a megasuture. This geological situation implies the development of large décollements, folds and reverse faults in the sedimentary overburden. Initially, the vast majority of geologists were against the idea because of the low density of the continental crust, i.e. its tendency to float and penetrate into similar material. At present, all geologists accept the idea, especially after the studies of Molnar and Gray (1979), that even the lower continental crust subducts when it is individualised from the upper one. Bird et al (1975) point out that certain thermal and mechanical conditions can produce laminations in the lithosphere, which strongly favour the penetration into the astenosphere of the lower crust. However, the mechanism of lamination has nothing to do with the mechanism of détachment or décollement. Lamination corresponds to a tectonic disharmony within the basement. Some geologists correlate it with the Conrad discontinuity,

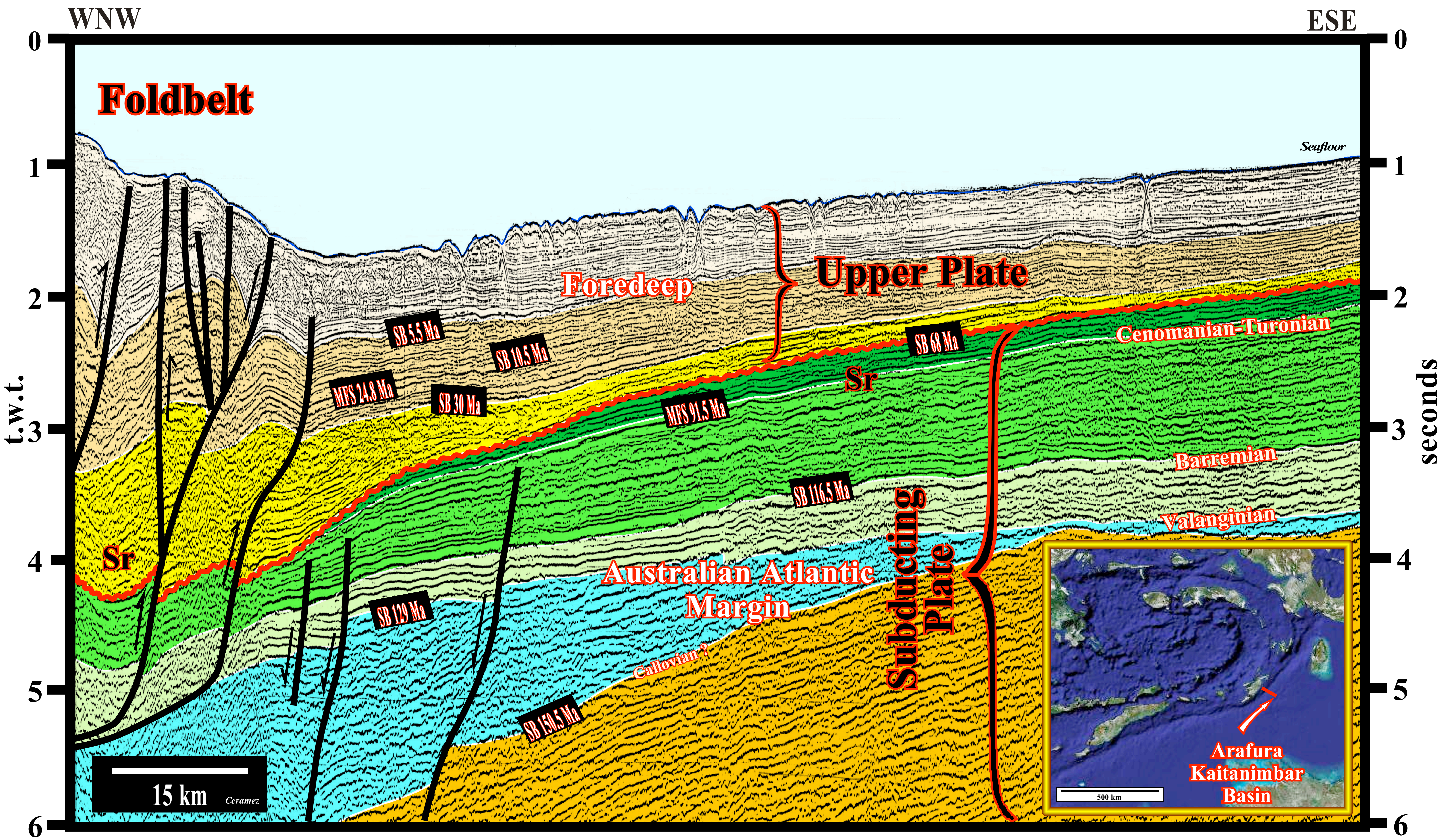
"A" Subduction





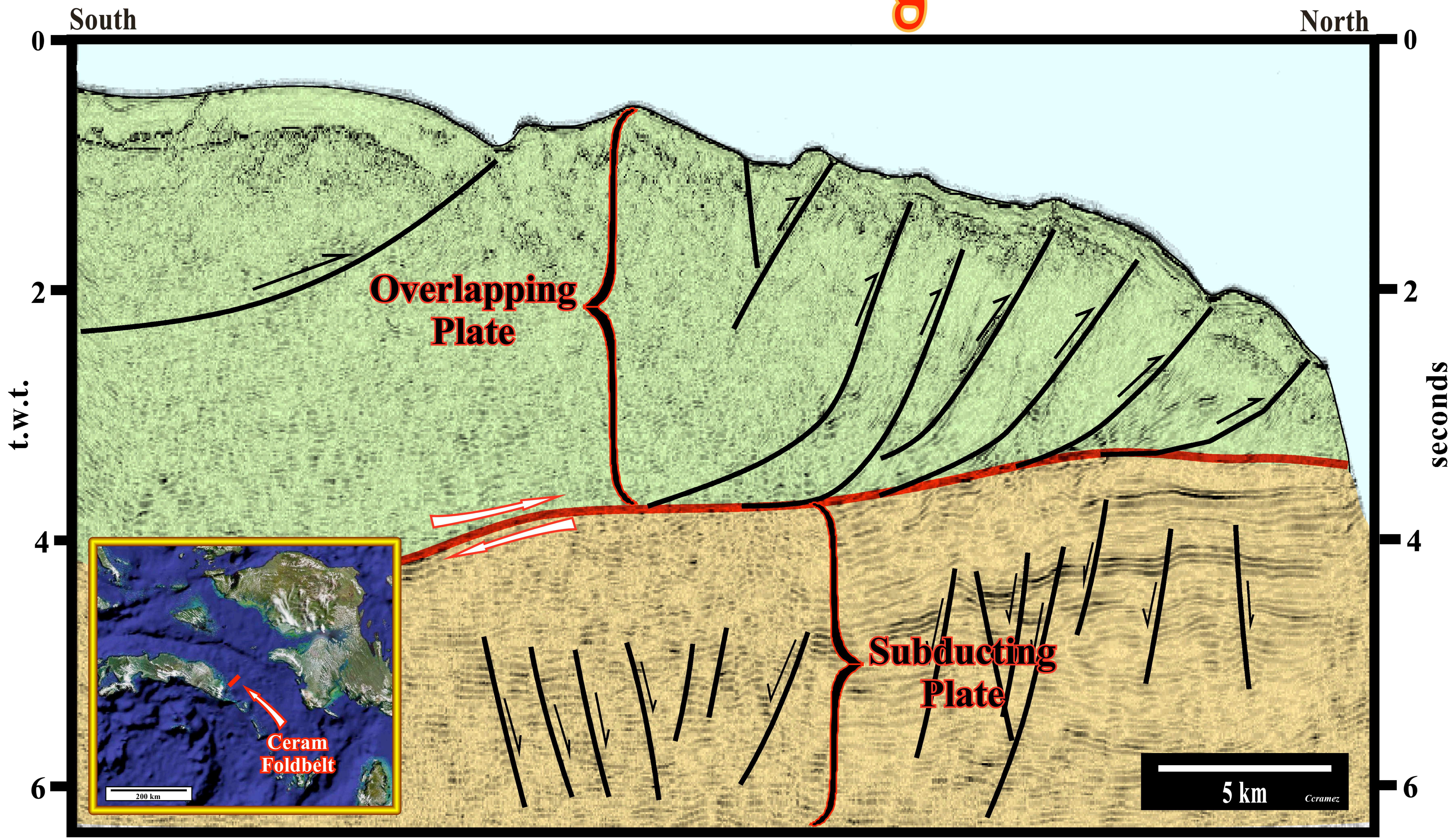
This example illustrates the collision of the northern margin of Australia with insular volcanic arcs, in which it is easy to identify: (i) the relics of volcanic arcs (green colour) and oceanic crust (grey colour) localised in Pappua New Guinea; (ii) the arcs formed by the subduction of the oceanic Pacific plate: (iii) the convergence between the two plates forces the Australian continent to plunge into the subduction zone, shortening the margin sediments (violet) and the old continental crust (red); (iv) the shortening was mainly due to thrusting and folding. Note that the relics of the arcs are the only remnants of the pre-phanerozoic sutures that now form geological terranes.

"A" Subduction



This tentative interpretation of a seismic line from offshore eastern Indonesia illustrates an Ampferer or "A" subduction. The lower or subducting plate corresponds to the North Atlantic-type Australian margin. The upper or overlapping plate is represented here by the foredeep and distal fold belt of Kaitanimbar. It is interesting to note the outward progression of the foldbelt, which progressively incorporates the foredeep and margin, as suggested by the frontal thrusts.

Collision Margin



The Ceram fold belt is associated with the collision of an island arc and the Australian Atlantic-type continental margin. Such a collision created an Ampferer or "A" subduction zone in the margin (old subducting plate), as the distal part of the margin overthrusts the proximal part with an eastward vergence. On this seismic line, it is easy to see the upper microplate, which is severely truncated, and the lower microplate, which retains the original extensional structures.

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"B" Subduction

Morphology of the Overlapping Plate

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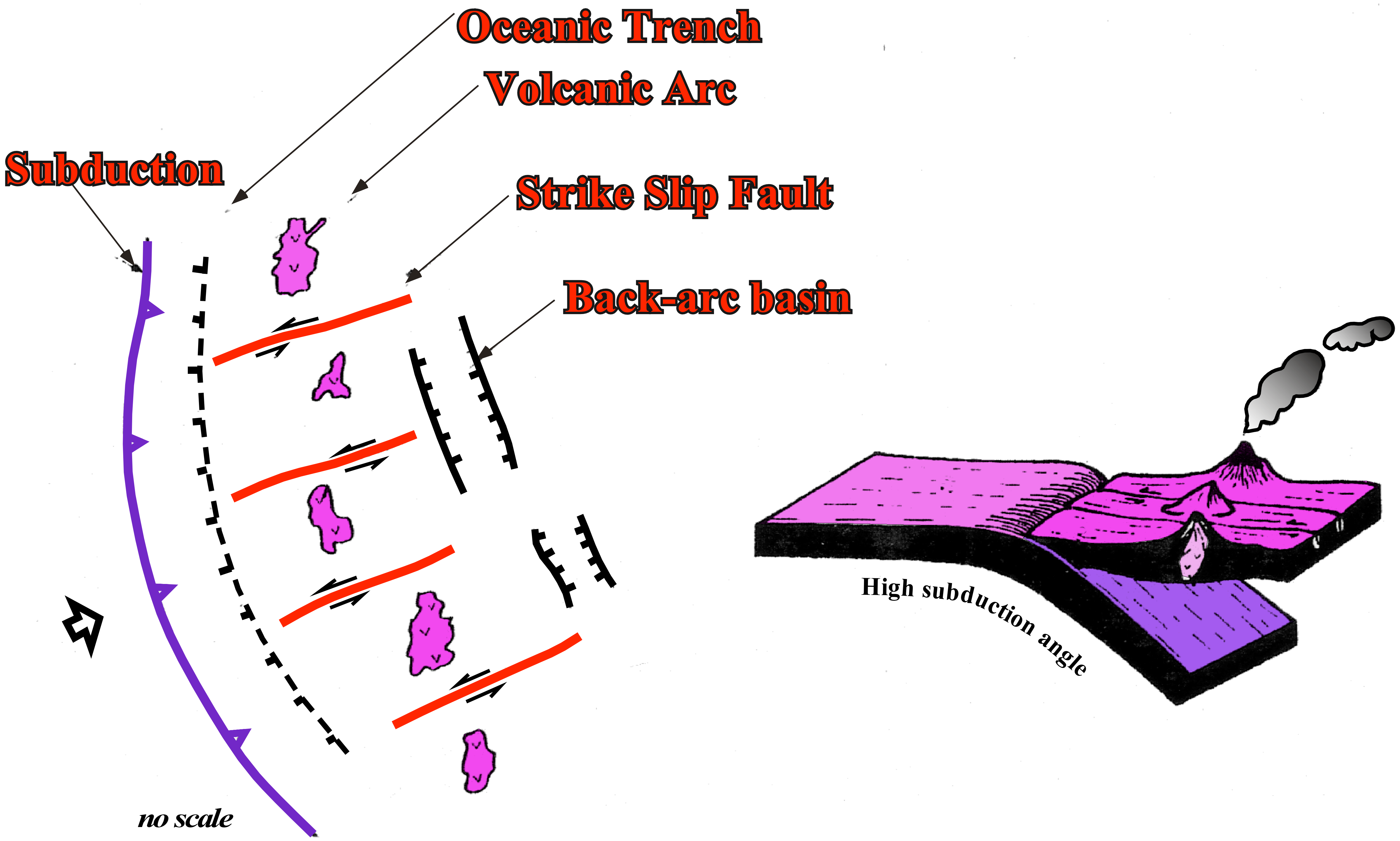
Morphology of the Overlapping Plate

Marianne-Type



from A. Bally, 1980

All along a Benioff zone, the morphology of the overlapping plate depends on the nature of the lithosphere, i.e. whether it is oceanic or continental. If the overlapping plate is continental (Marianne type), as shown: (i) the volcanic arc is insular and generally localised in an intra-oceanic plateau developed during the volcanic arc activity; (ii) the volcanism is more andesitic and localised mainly in the segment of the arc dominated by strong compressional stress; (iii) the volcanic arc is composed of a belt of islands displaced by strike-slip faults perpendicular to the plate margin; (iv) these strike-slip faults are common and distinctive in the fore- and back-arc areas; (v) the back-arc and marginal basins are extensional structures that developed during regional extensional tectonic regimes that developed in a global compressional context.

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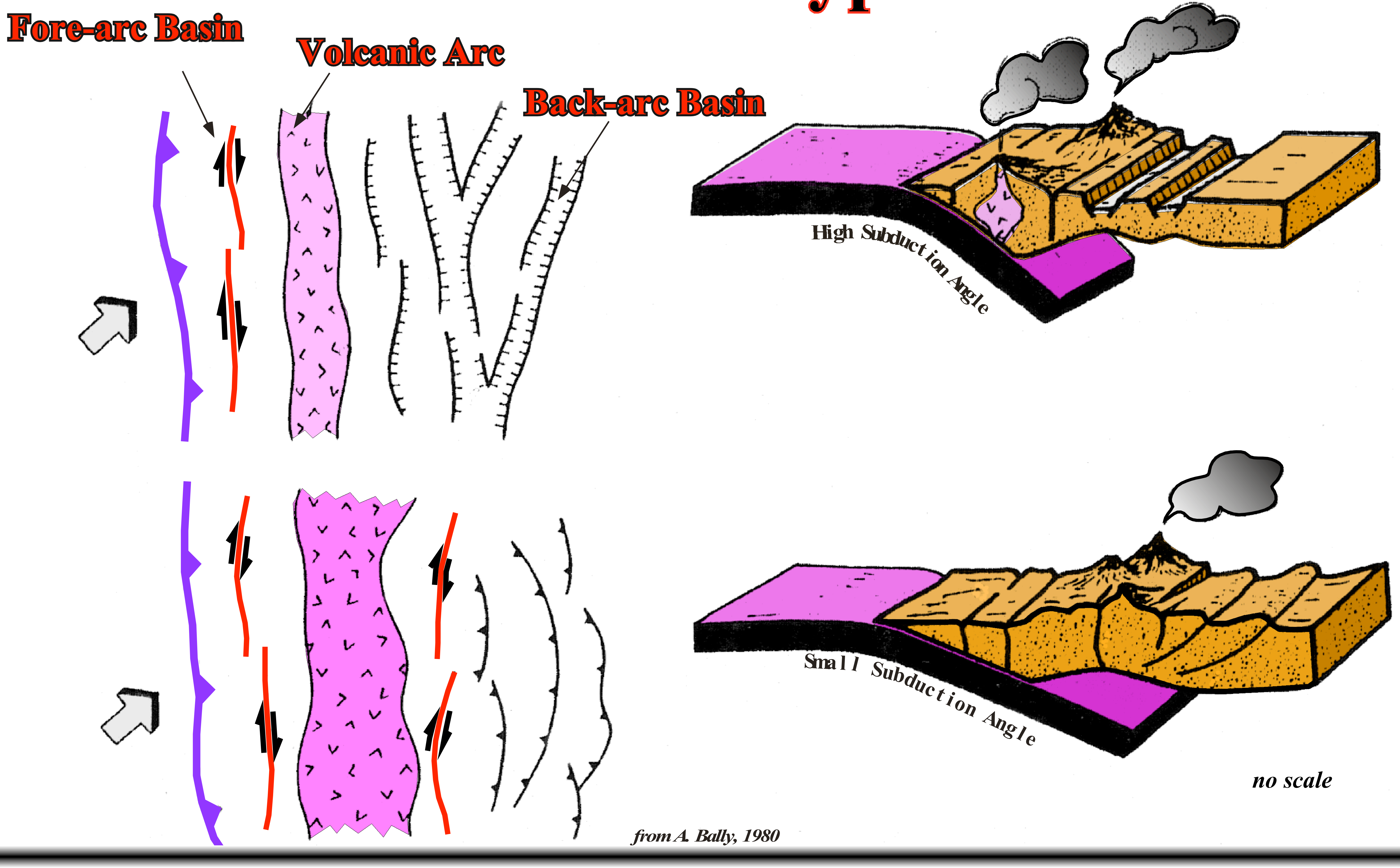
Morphology of the Overlapping Plate

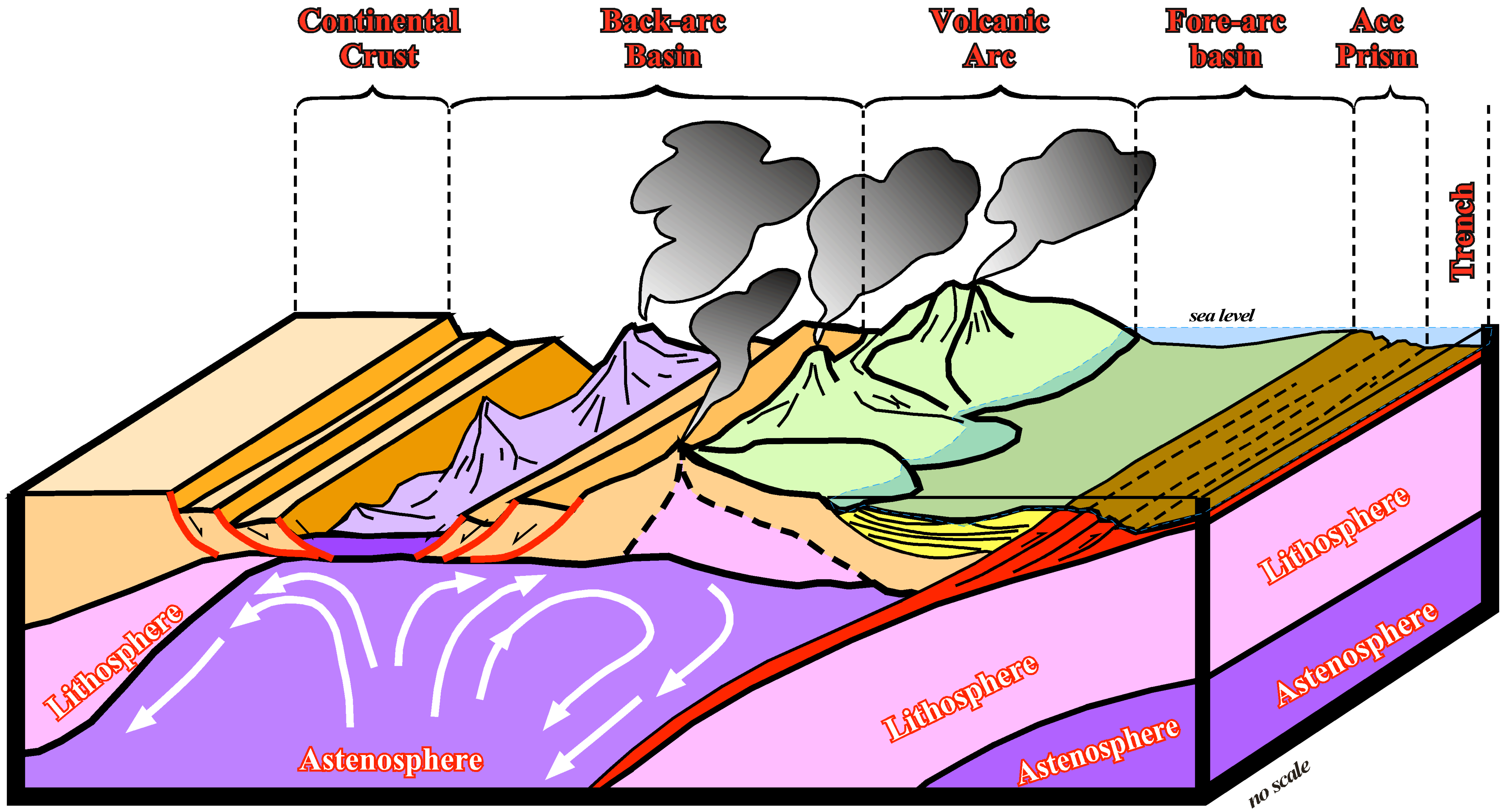
Andine-Type



If the overlapping plate is continental (Andine type): (i) the volcanic arc is characterised by a sub-aerial volcanic mountain with significant topography; (ii) the volcanism is quite variable with a basaltic predominance; (iii) calc-alkaline rocks, andesites and rhyolites are common; (iv) volcanism is mainly localised in the compressional sector of the arc or in the area where the continental crust is thick; (v) major accretionary complexes are often associated with this type of margin; (vi) frequent strike-slip faults parallel to the oceanic trench. The more likely structures in the overlapping plate of an Andine-type subduction margin are a function of the subduction angle: (1) when the angle is relatively large, the back-arc basin is well developed with grabens and semigrabens striking parallel to the oceanic trench with frequent strike-slip faults in the fore-arc basin; (2) when the subduction angle is small, there is partial decoupling between the plates and so the overlapping plate is shortened. Reverse and strike slip faults are common in the back-arc basin.

Morphology of the Overlapping Plate

Andine-Type



In an Andine-type subduction margin, from the tench towards the continent, one can distinguish: (i) the oceanic trench, (ii) the accretionary prism, (iii) the fore-arc basin, (iv) the volcanic arc, (v) the back-arc basin, and (vi) the continental crust strito sensu. If the extension in the back-arc area is large enough to break the substratum, oceanisation can occur with the development of a marginal sea and non-Atlantic-type divergent margins. In such a geological context, i.e. associated with a "B" subduction, by far the most interesting basins for petroleum exploration are the back-arc basins, where huge reserves have been found to date. These basins were formed by a rifting phase (associated with differential subsidence) and a sag phase (associated with regional thermal subsidence), during which the cratonic basins were filled. In the case of oceanisation, as mentioned above, twisted margins of non-Atlantic type developed on either side of the spreading centres.

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