Subduction initiation at oceanic detachment faults and the origin of forearc ophiolites

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Conclusions

Subduction initiation is a critical link in the plate tectonic cycle, yet its causes and kinematics are still debated. Intra-oceanic subduction zones can form along transform faults and fracture zones, but how subduction nucleates parallel to mid-ocean ridges, as in e.g. the Neotethys Ocean during the Jurassic, remains controversial. In recent years, extensional detachment faults have been widely documented adjacent to slow- and ultraslow-spreading ridges where they cut across the oceanic lithosphere. These structures are extremely weak due to widespread occurrence of serpentine and talc resulting from hydrothermal alteration, and can therefore effectively localize deformation. Here, we show geological, geochemical, and paleomagnetic evidence from the Jurassic ophiolites of Albania for a subduction zone formed along an oceanic detachment fault parallel and adjacent to a pre-existing spreading ridge. With 2-D numerical modeling that explored the evolution of a detachment-ridge system under compression, we show that detachments are always weaker than spreading ridges and can accommodate most of the shortening. We conclude that, owing to their extreme weakness, oceanic detachment faults effectively localize deformation under far-field forcing, providing ideal conditions to nucleate new subduction zones parallel and close to (or at) spreading ridges. Direct implication of this, is that resumed magmatic activity in the forearc during subduction initiation can yield widespread supra-subduction-type (SSZ) magmatism parallel to the pre-existing paleo-ridge and extending laterally over hundreds of kilometers. We argue that this represent one possible mechanism for the formation of extensive ophiolite belts.

References

Maffione, Marco, Thieulot, C., van Hinsbergen, D.J.J., Morris, A., Plümper, O., Spakman, W. (2015), Dynamics of intra-oceanic subduction initiation: 1. Oceanic detachment fault inversion and the formation of forearc ophiolites. Geochemistry, Geophysics, Geosystems, 16, doi:10.1002/2015GC005746..

Background

Jurassic and Cretaceous SSZ ophiolites (red units, Figure 1) generated after subduction initiation in the Neotethys Ocean form a continuous, hundreds of kilometer long ophiolite belts. These ophiolites are parallel to continental margins of Eurasia, Africa-Arabia, and India, and most probably formed parallel to the spreading ridge of the Neotethyan Ocean that once separated these continents. How did this occurred? Which lithospheric weakness accommodated subduction initiation?

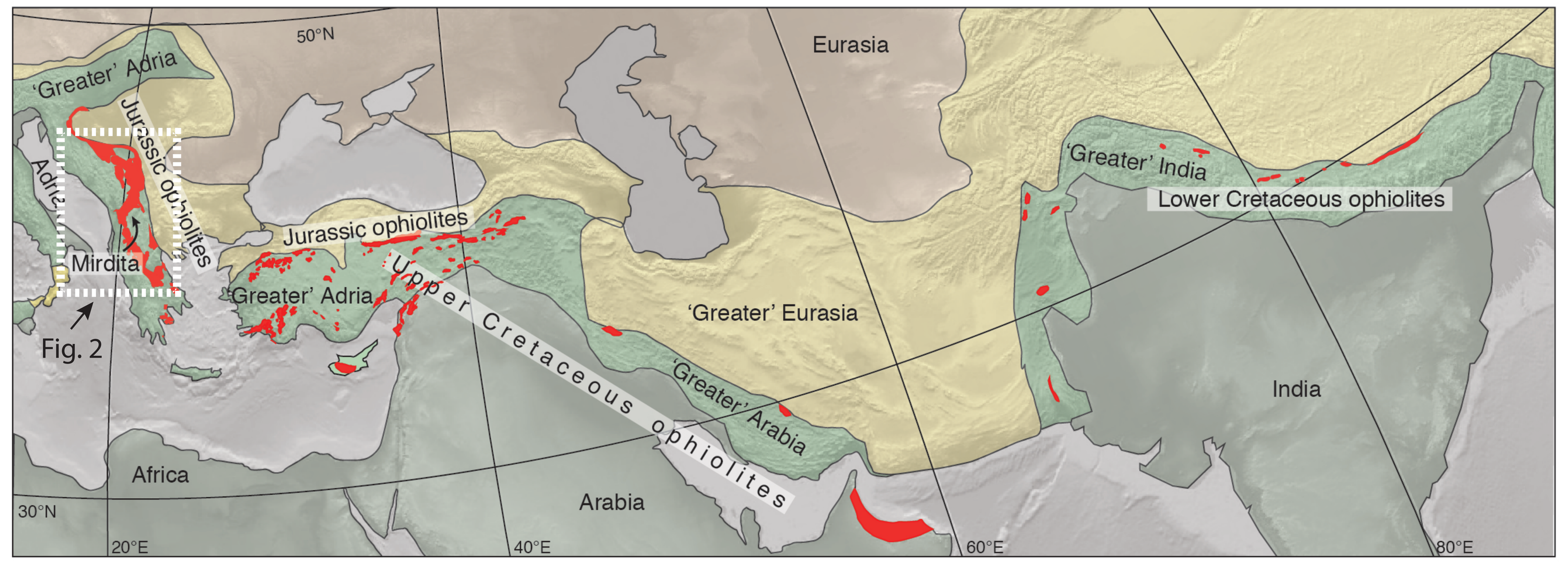


Figure 1. Distribution of the Jurassic and Cretaceous Tethyan ophiolite belts (red units) accreted above subduction zones that at least locally were parallel to spreading ridges.

Geological, Geochemical, Paleomagnetic, and Numerical Modelling Evidence

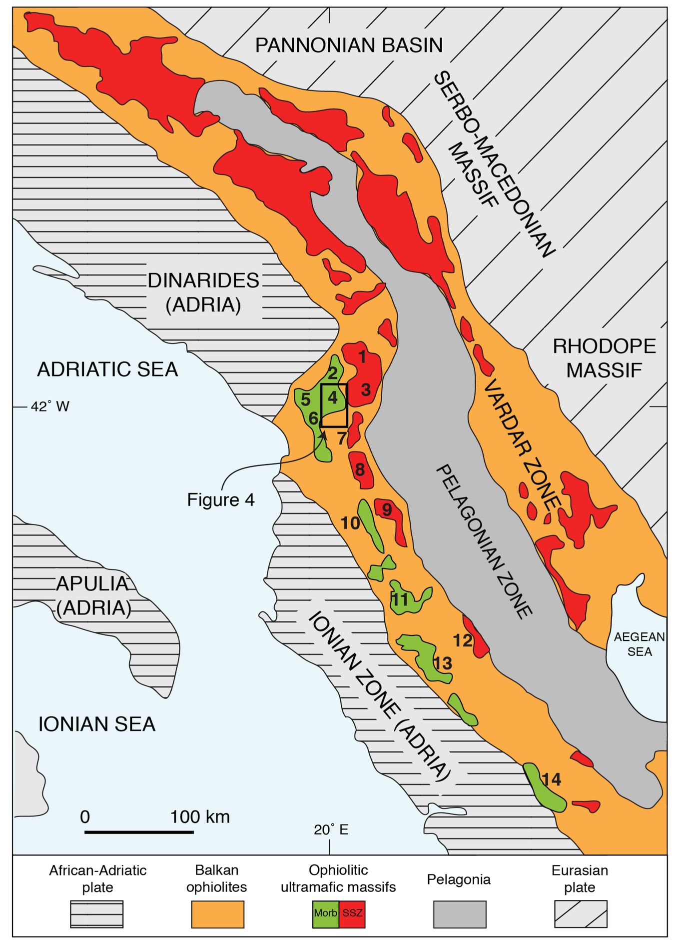


Figure 2. (Above) The ~500 km long segment of Jurassic ophiolites running form Albania to Greece are composed of two belts with different geochemical signature: a western belt (green) characterized by a mid-ocean ridge basalt - MORB - affinity crust, and an eastern belt (red) dominated by a suprasubduction zone (SSZ) affinity crust.

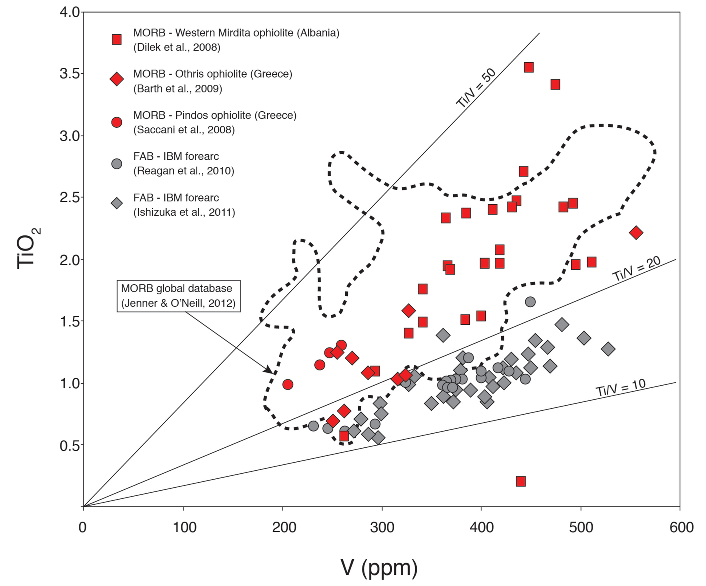


Figure 3. (Above) Geochemical constraints (Titanium/Vanadium ratio) indicates that the MORB western belt formed before and not during/after subduction initiation, like in the case of forearc basalts (FAB) from the Izu-Bonin-Mariana (IBM) system. These MORB segments of the Balkan ophiolites represent therefore a relic of the pre-existing (pre-subduction initiation) Neotethyan lithosphere.

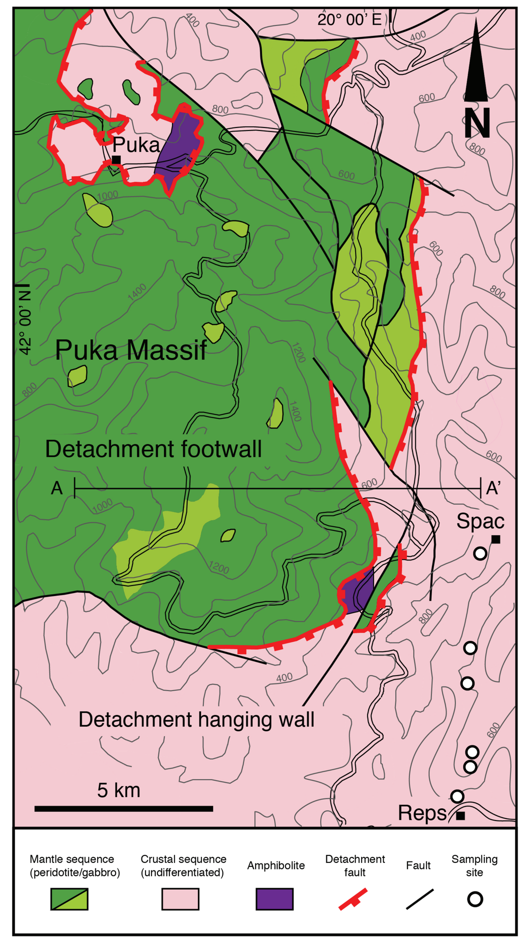


Figure 4. (Left and below) The Mirdita ophiolite of Albania (see Figure 2 for location), in the MORB-type western belt, preserves a fossil detachment fault and associated core complex (Puka Massif). Paleomagnetic analyses have revealed a westward tilt of the fault footwall (peridotites) consistent with an east-dipping fault plane. Since detachments dip towards the spreading ridge, the paleo-spreading ridge must have been located to the east. Since this area is a relic of pre-subduction initiation Tethyan lithosphere (see Fig. 3), subduction nucleated ~50 km west of the pre-existing spreading axis. An ideal locus for subduction initiation is therefore represented by a young detachment fault.

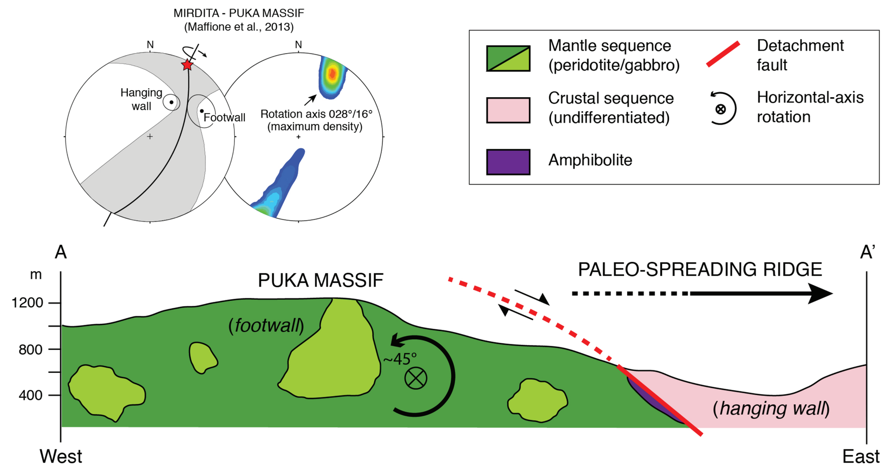
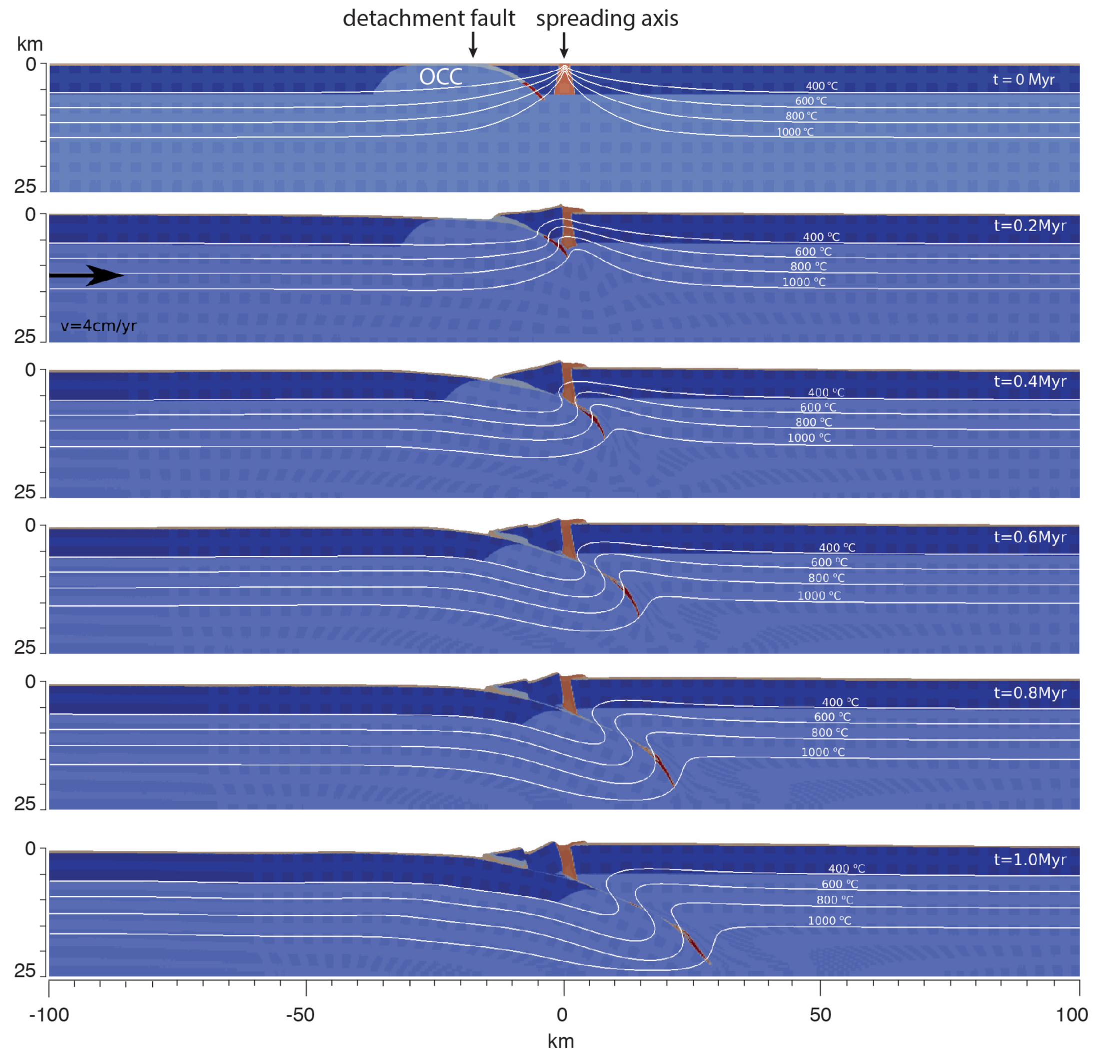


Figure 5. (Below) Results of the numerical modeling during a 40 km net convergence testing the possibility to invert a detachment fault in the presence of an ultra-weak spreading ridge. Sediments (light brown), crust (dark blue), mantle (light blue), a serpentinized (400 m thick) detachment (light green), and the ridge axis (orange) are shown. Serpentine is converted into wet olivine (red) at >500°C. OCC, oceanic core complex.



A new model of subduction initiation

Figure 6. (Below) Using paleomagnetic analyses we reconstructed a ~N-S striking spreading ridge in the Neotethys in the area where the Mirdita ophiolite formed at ~170 Ma. Continental margins of Adria and Eurasia (Moesia) were parallel to this spreading ridge. A forced subduction initiation in the western Tethys may have been caused by an ~E-ward compression during the opening of the Central Atlantic, resulting in detachment fault inversion (rather than transform fault inversion).

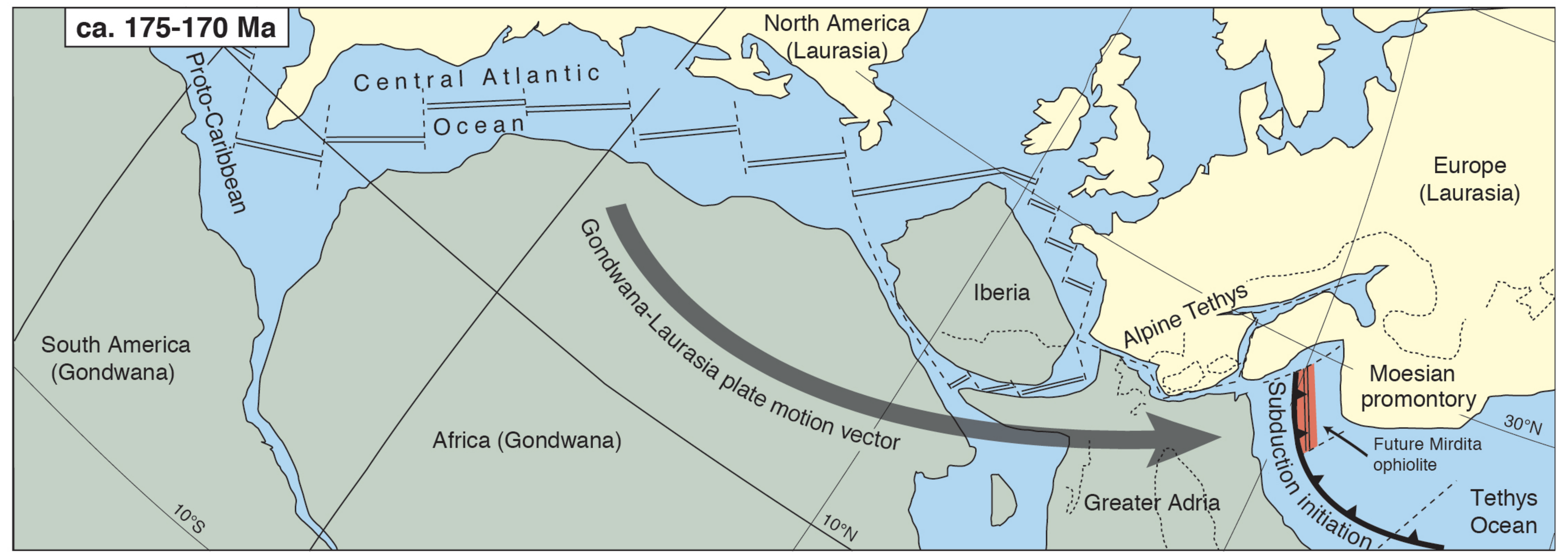


Figure 7. (Below) Proposed tectonic model for subduction initiation at detachment faults. (a, b) Detachment faults and associated oceanic core complexes (OCC), widespread in slow-spreading oceans, can localize deformation upon ridge-perpendicular far-field forcing, aiding the nucleation of subduction zones within discrete ridge segments. (c) Incipient subduction can then propagate laterally. (d) Magmatic activity at the paleo-ridge generates SSZ-type crust (future ophiolite).