Dynamics of intra-oceanic subduction initiation: supra-subduction zone ophiolite formation and metamorphic sole exhumation in context of absolute plate motions

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Conclusions

Supra-subduction zone (SSZ) ophiolites are widely recognized to be the direct product of intraoceanic subduction initiation. Using structural, petrological, geochemical, and plate kinematic constraints on their kinematic evolution we show that SSZ crust forms at forearc spreading centers at the expense of a mantle wedge, thereby flattening the nascent slab. This leads to the typical inverted pressure gradients found in metamorphic soles that form at the subduction plate contact below and during SSZ crust crystallization. Former spreading centers are preserved in forearcs when subduction initiates along transform faults or offridge oceanic detachments. We show how these are reactivated when subduction initiates in the absolute plate motion direction of the inverting weakness zone. Upon inception of slab pull due to, e.g., eclogitization, the sole is separated from the slab, remains welded to the thinned overriding plate lithosphere, and can become intruded by mafic dikes upon asthenospheric influx into the mantle wedge. We propound that most ophiolites thus formed under special geodynamic circumstances and may not be representative of normal oceanic crust. Our study highlights how far-field geodynamic processes and absolute plate motions may force intraoceanic subduction initiation as key toward advancing our understanding of the entire plate tectonic cycle.

Problem Statement

Formation of SSZ ophiolites and associated metamorphic soles requires (i) upper plate extension in the initial phases of subduction initation, (ii) and subduction starting below or near a hot spreading ridge (Figure 1). How can these two conditions be satisfied? Are these processes synchronous? How is the metamorphic sole exhumed and welded below the ophiolite soon after subduction initiation?

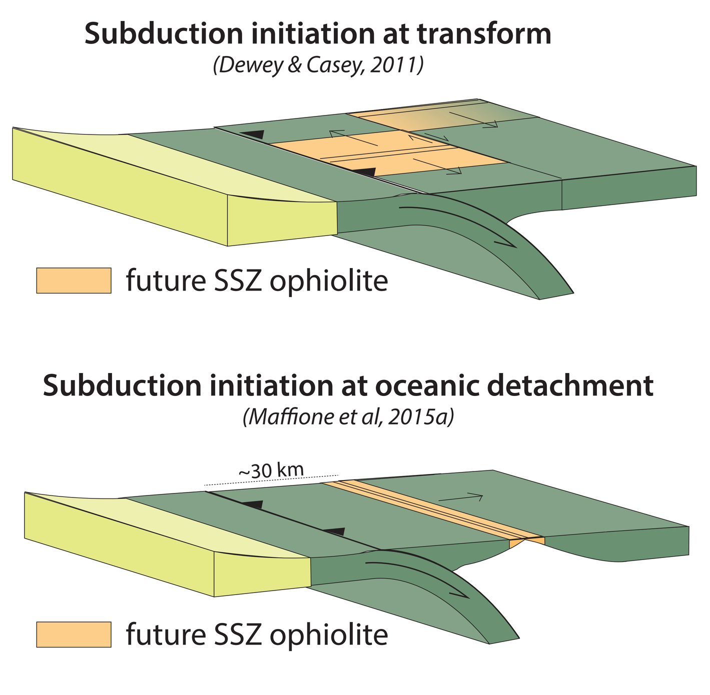


Figure 1. (Above) Two proposed modes of subduction initiation, along (a) a transform-fracture zone, and (b) an oceanic detachment fault, in which a former spreading ridge is preserved in a forearc position.

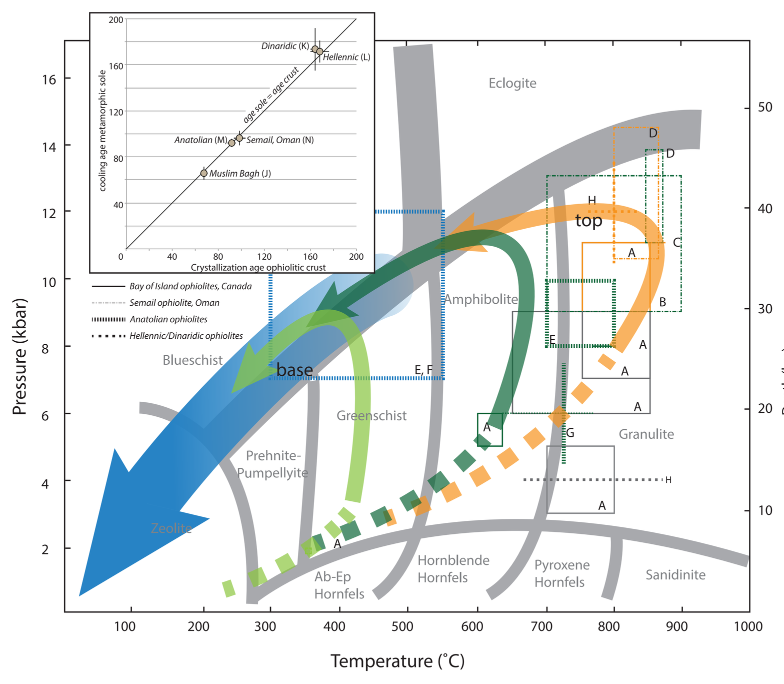


Figure 2. (Above) Conceptual pressure-temperature paths of different levels of metamorphic soles based on four well-studied sole systems. The structurally higher part of the sole underwent a longer, deeper, and hotter evolution than the structurally lower part, which was welded to the sole during decompression and cooling of the upper part. Top left inlet show how the ages of the SSZ crust and metamorphic sole are comparable.

Slab Flattening and Exhumation of the Metamorphic Sole

STAGE 1. Immediately before ridge inversion, slow spreading is accompanied by oceanic detachment fault formation. Both plate A and B are moving (to the right) relative to the mantle, as it is the spreading ridge.

STAGE 2. Detachment inversion aids subduction initiation upon forced convergence. Extension in the upper plate causes reactivation of the paleoridge, and the formation of SSZ oceanic crust at the expense of the underlying mantle wedge. Metamorphism of the uppermost level of the slab occurs.

STAGE 3. Mantle melt extraction and ultradepletion, possibly associated with forearc hyperextension (*Maffione et al., 2015b*) reduced the volume of the mantle wedge. This is accommodated by slab shallowing. At the plate contact, rocks from the top of the nascent slab are welded to the base of the hot mantle section to form a metamorphic sole.

STAGE 4. Upon eclogitization in the nascent slab creating negative buoyancy, slab pull starts and the slab decouples from the sole and steepens. This leads to asthenospheric inflow into the mantle wedge, reflected in the intrusion of mafic dykes into the sole and the overlying lithospheric mantle. Ophiolites are formed upon arrival of a buoyant collider, e.g., a passive margin, in the subduction zone, and the consequent uplift of the fore-arc.

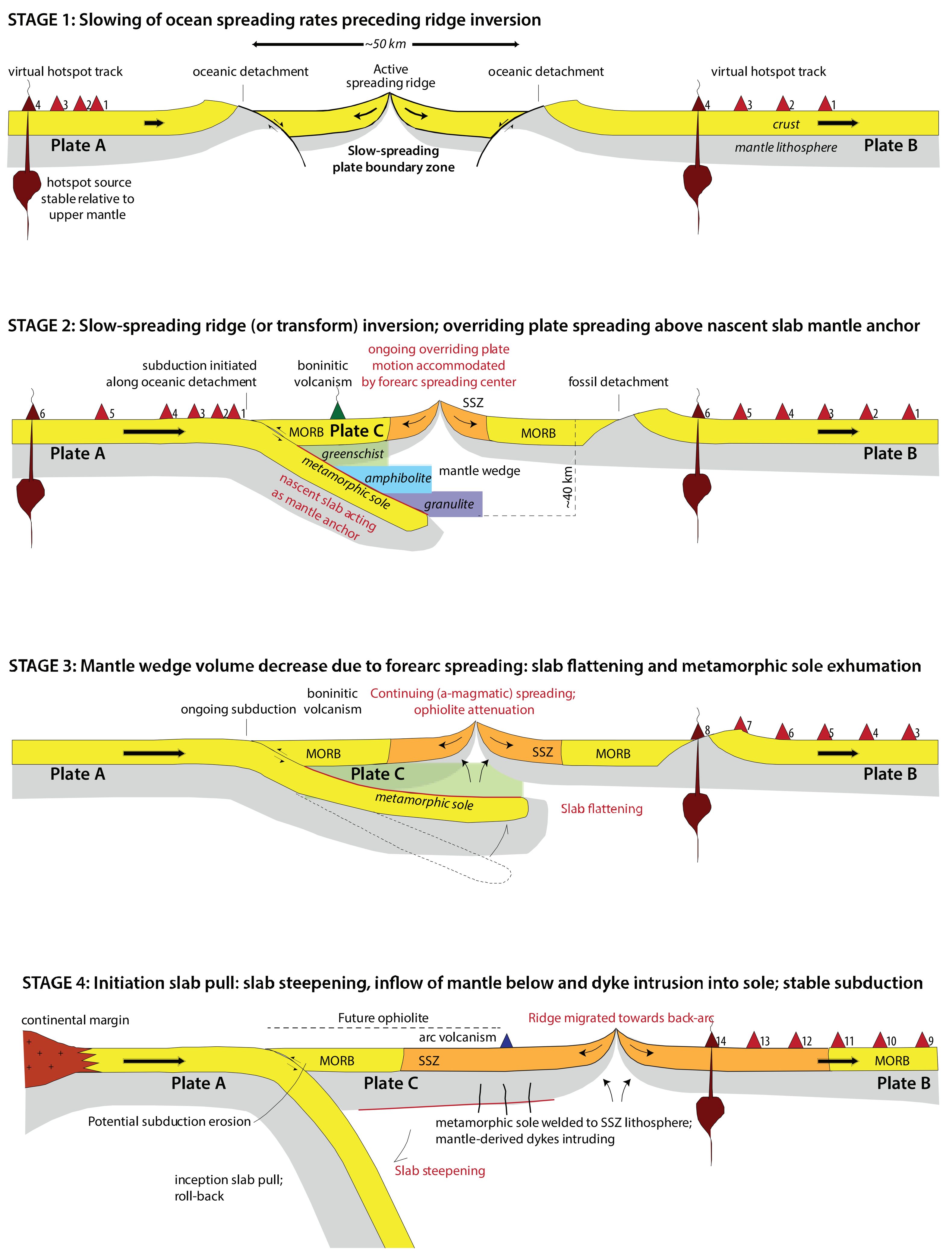
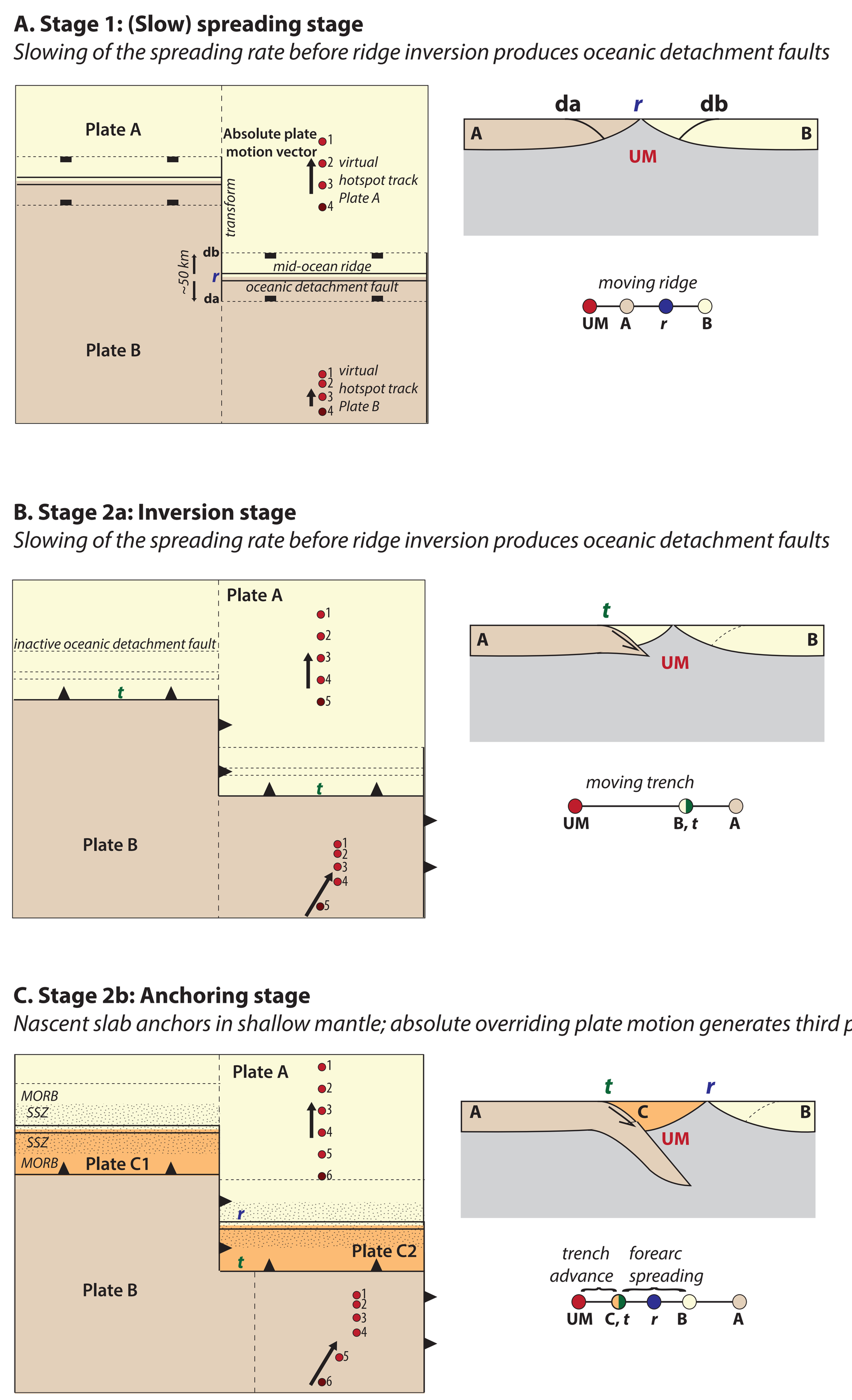


Figure 3. (Above) Proposed evolution of intraoceanic subduction initiation, SSZ ophiolite formation, and metmorphic sole formation and exhumation, in a mantle reference frame.

Absolute Plate Motion and Upper Plate Extension



Stage 1. The slow spreading phase prior to subduction initiation cause the formation of oceanic detachment faults at/near the ridge.

Stage 2a. Inversion of detachment faults and transforms upon forced, oblique convergence. Subduction will be favored in the direction of absolute plate motion.

Stage 2b. Inversion of a slow spreading ridge that moves relative to the mantle will generate an advancing trench if plate B becomes the overriding plate. An advancing trench will experience resistance of the mantle that will lead to anchoring of the slab and stagnation of the trench. If the velocity of plate B does not change, or changes less, a third plate will form by reactivation of ridge r, which then forms a fore-arc spreading center that can generate a SSZ ophiolite.

Figure 4. (Above) Schematic plate kinematic scenario of intra-oceanic subduction initiation in a mantle reference frame. (Left) Plates and plate boundaries, with absolute plate motions illustrated through virtual hot spot tracks. (Top right) Plates in cross-sectional view. (Bottom right) Plates and plate boundaries on a velocity line (see *Cox and Hart, 1986*), in which a position of plate B to the right of plate A on the velocity line shows that plate B is moving to the right relative to plate A at a rate proportional to the distance between the points.

References

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