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Sandbox analogue experiments for subduction of trench-fill sediments beneath accretionary wedge and backstop

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Abstract

Ancient exhumed accretionary complexes are sometimes associated with high-pressure–low-temperature (HP–LT) metamorphic rocks, such as psammitic schists, which are derived from sandy trench-fill sediment. At accretionary margins, sandy trench-fill sediments are rarely subducted to the depth of HP metamorphism because they are commonly scraped off at the frontal wedge. **This study uses sandbox analogue experiments to investigate the role of seafloor topography in the transport of trench-fill sediment to depth during subduction.** The experiments were conducted with a detached, rigid backstop to allow a topographic high (representing a seamount) to be subducted through a subduction channel. In experiments without topographic relief, progressive thickening of the accretionary wedge pushed the backstop down, leading to a stepping down of the décollement, narrowing the subduction channel, and underplating the wedge with subducting sediment. In contrast, in experiments with a topographic high, the subduction of the topographic high raised the backstop, leading to a stepping up of the décollement and widening of the subduction channel. **These results suggest that the subduction of topographic relief is a possible mechanism for the transport of trench-fill sediment from the trench to high-pressure environments through a subduction channel.** A sufficient supply of sediment to the trench and topographic relief on the subducting oceanic plate might enable trench-fill sediment to be accreted at various depths and deeply subducted to become the protoliths of HP–LT metamorphic rocks.

Introduction

- High-pressure–low-temperature (HP–LT) metamorphic rocks derived from terrigenous sedimentary rocks are sometimes exposed alongside low-grade accretionary rocks and fore-arc basin strata that show the same depositional ages with the metamorphic rocks.
- Occurrences of HP–LT metasandstone demonstrate that terrigenous sediment can be subducted beneath the wedge.
- Subducting seamounts followed by layered trench-fill sediments can be observed along modern accretionary margins in southwestern Japan, Alaska, Barbados, and Hikurangi margins.
- Our hypothesis is that **growth of the accretionary wedge inhibit the subduction of terrigenous sediment beyond the wedge through the subduction channel** and **a topographic high enables trench-fill sediment to be subducted under the wedge.**

Methods

- A scaled 2-D analogue modeling technique was used for so that the results could be compared with naturally occurring geological structures.
- Two types of granular material were used for the experiments: Toyoura sand (μ = 0.59–0.68) and glass micro-beads (μ = 0.47).
- A rigid wedge (backstop) was placed next to the steel plate but was not fixed to it.
- A plastic sheet was placed over the rig's base plate and fixed to a roll that pulled the sheet using a stepper motor (0.5 cm/min).
- Two types of experiments were conducted. **Exp. A** investigated the subduction of a smooth oceanic plate beneath a static backstop. **Exp. B** investigated the subduction of topographic relief (e.g., a seamount), using a block that was attached to the plastic sheet.
- Scaling is that a 1 cm model layer in an experiment corresponds to 300 m to 1 km in nature.

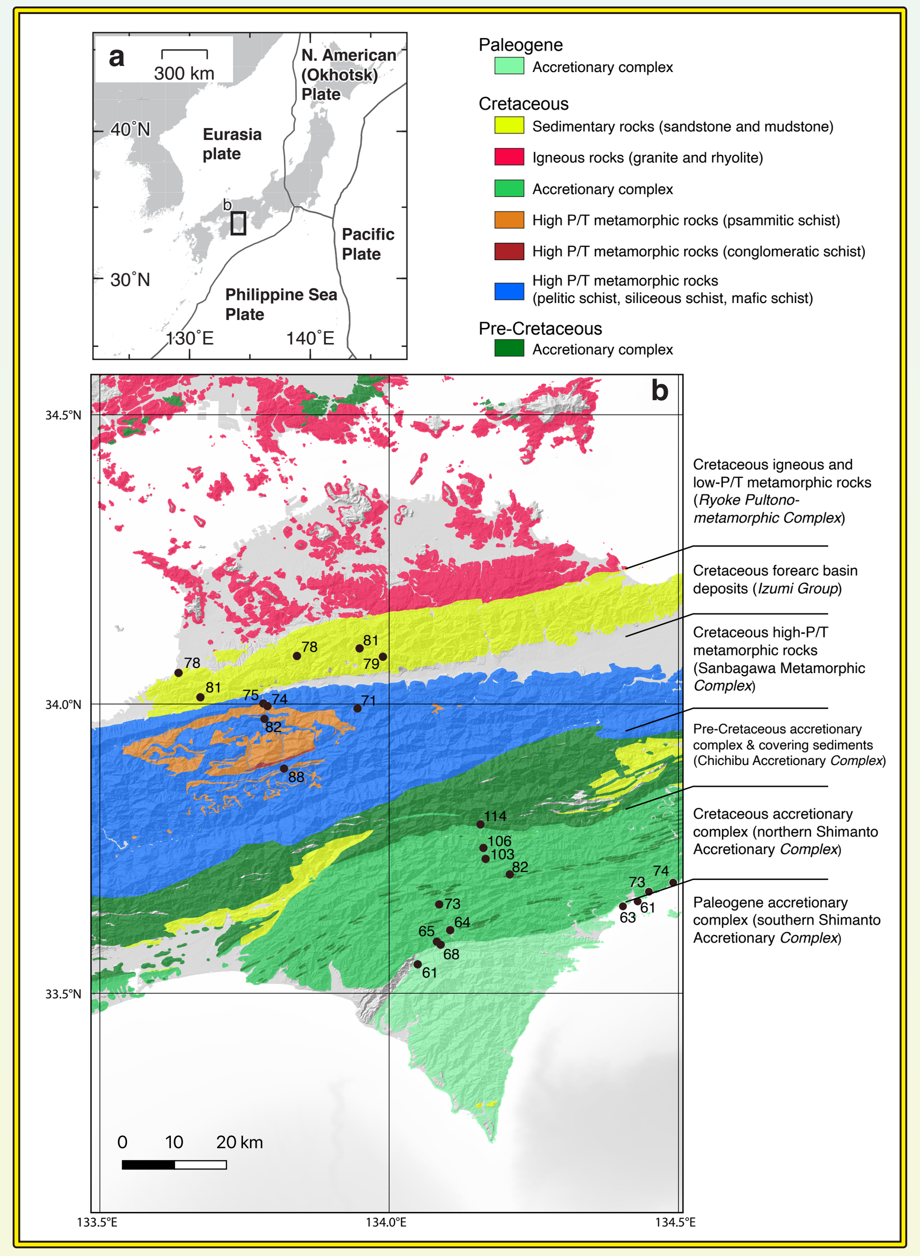

Figure 1: An example of HP-LT psammitic schist associated with shallowly accreted sedimentary rocks and forearc basin deposits showing the similar depositional ages (Ma). Southwestern Japan.

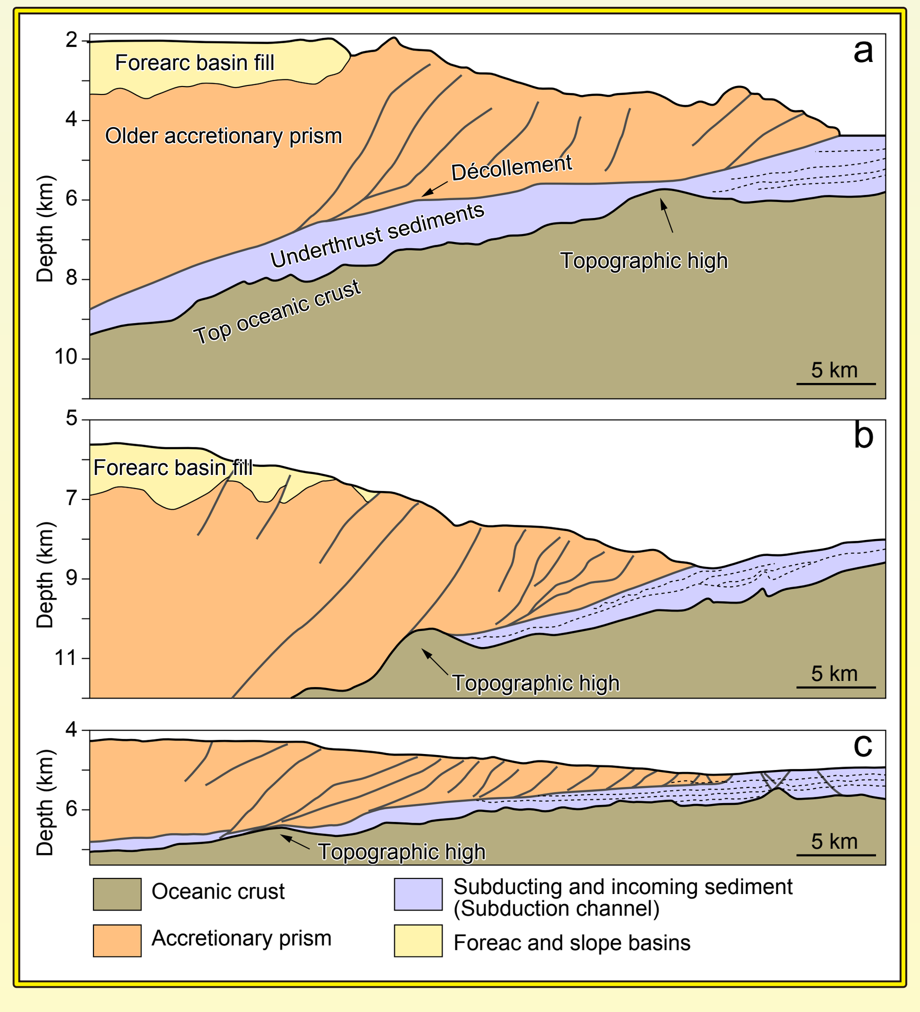

Figure 2: Representative cross-sections of accretionary margins with topographic highs which are followed by subducting layered trench-fill sediments beneath the accretionary wedges. (a) Nankai Trough (Moore et al., 2014). (b) Southwestern Alaskan margin (Li et al., 2018). (c) Northern Barbados margin (Moore et al., 1995).

Results

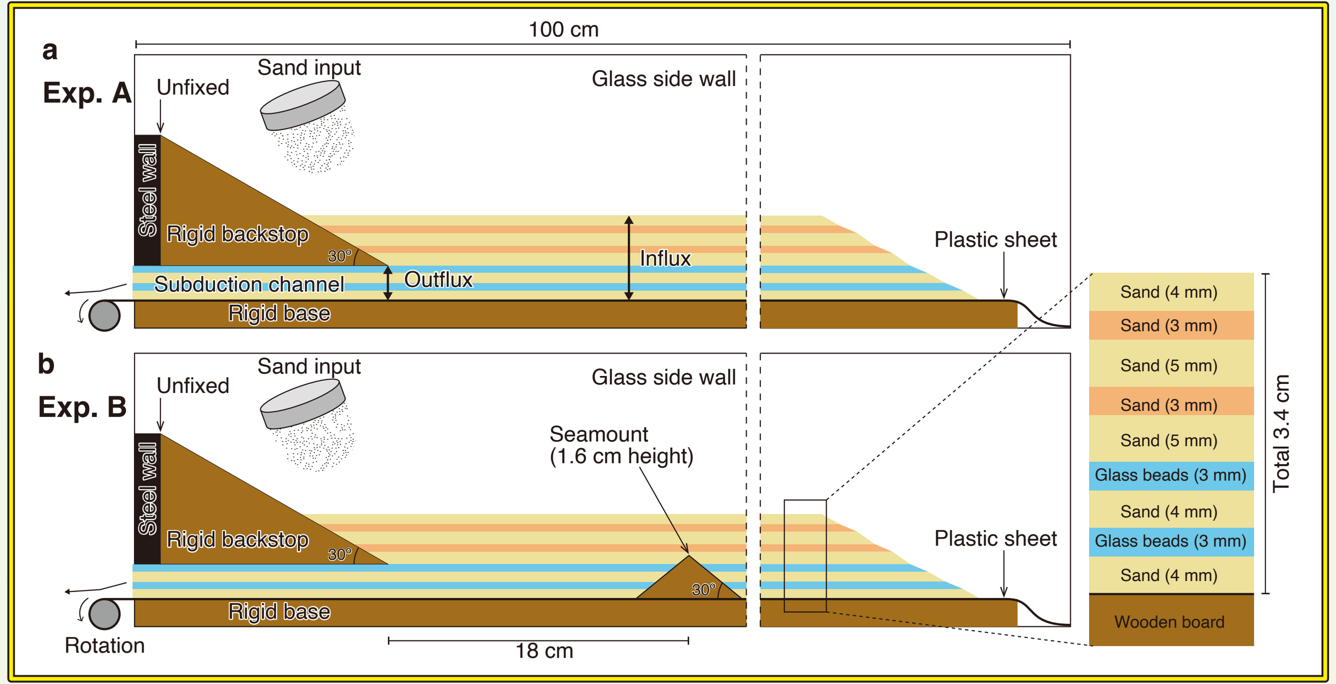

Figure 3: Experimental apparatus. (a) Experiment without topographic high (Exp. A). (b) Experiment with topographic high (Exp. B).

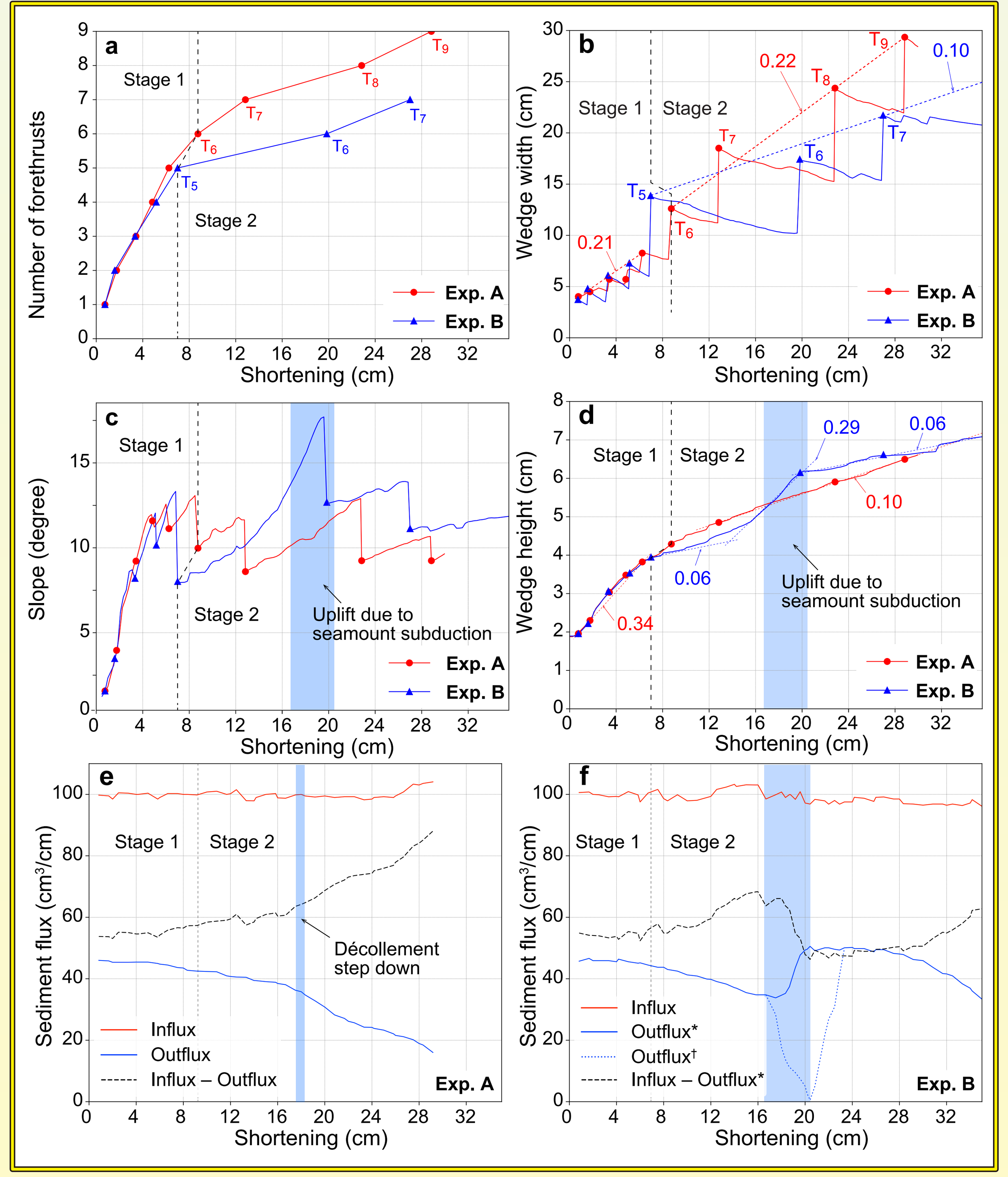

Figure 4: (a) Number of forethrusts. (b) Wedge width. Dashed lines are labeled with wedge progradation rates calculated from the amount of progradation (cm) divided by the amount of shortening (cm). (c) Wedge slope angle. (d) Wedge height. Dashed lines are labeled with uplift rates calculated from the amount of uplift (cm) divided by the amount of shortening (cm). (e) Sediment influx and outflux for Exp. A. (f) Sediment influx and outflux for Exp. B. Asterisk (*) and dagger (†) indicate outfluxes including and excluding the volume of the seamount, respectively.

Exp. A

- Deformation stage could be divided into stages 1 and 2, both were dominated by **frontal accretion.**
- Upper glass-beads layer was used as the décollement until 18 cm of shortening.
- An increase in overburden stress due to progressive thickening of the accretionary wedge led to a gradual subsidence of the backstop.
- As the backstop subsided, décollement stepped down, leading to **rapid decrease of outflux** and **underplating** beneath the inner wedge.

Exp. B

- A topographic high (seamount) subduction **prolonged underthrusting phase** (T_5) and **steepened the slope** that differentiated the deformation style from Exp. A.
- **Seamount subduction stepped up the décollement** from the lower glass-beads layer to the forethrust along the landward flank of the seamount.
- Seamount subduction also **raised the backstop** to and **opened the subduction channel** for sediments.
- This led to **increase of outflux** and **shifted the deformation style from underplating to frontal accretion.**
- Backstop subsided again after the seamount passed over.

Summary

- Growth of the wedge leads the décollement to step down, causing acceleration of the wedge growth through underplating and frontal accretion.
- If a subducting topographic high is rigid enough to raise the backstop, it can widen the subduction channel to transport terrigenous sediment that follows toward deeper environments.
- A sufficient sediment supply to the trench and a rough oceanic crust surface are necessary for simultaneous shallow accretion, underplating of the wedge, and transportation of sediment to deeper settings as protolith of HP–LT metamorphic rocks.

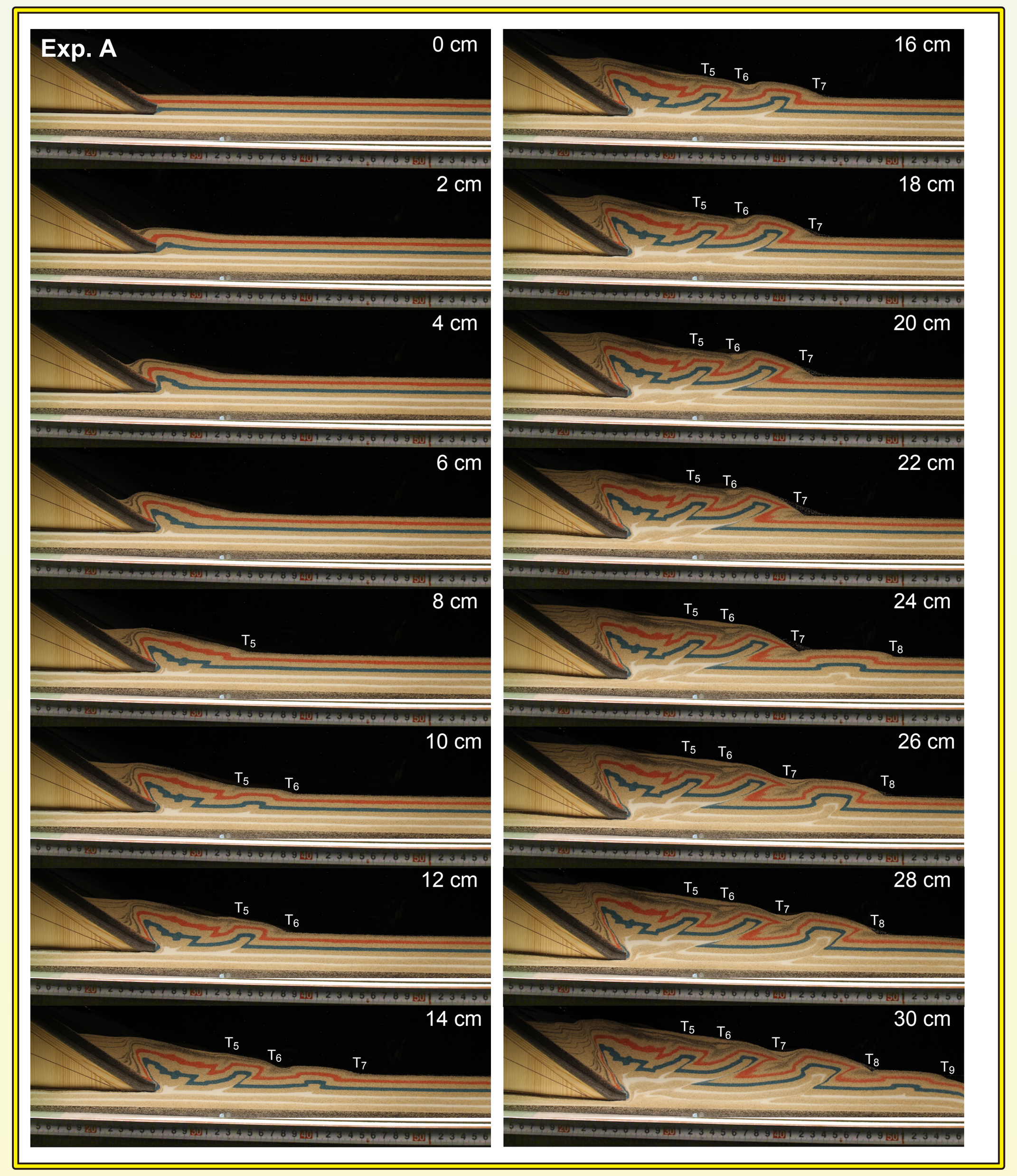

Figure 5: Representative images of Exp. A.

Figure 6: Representative images of Exp.

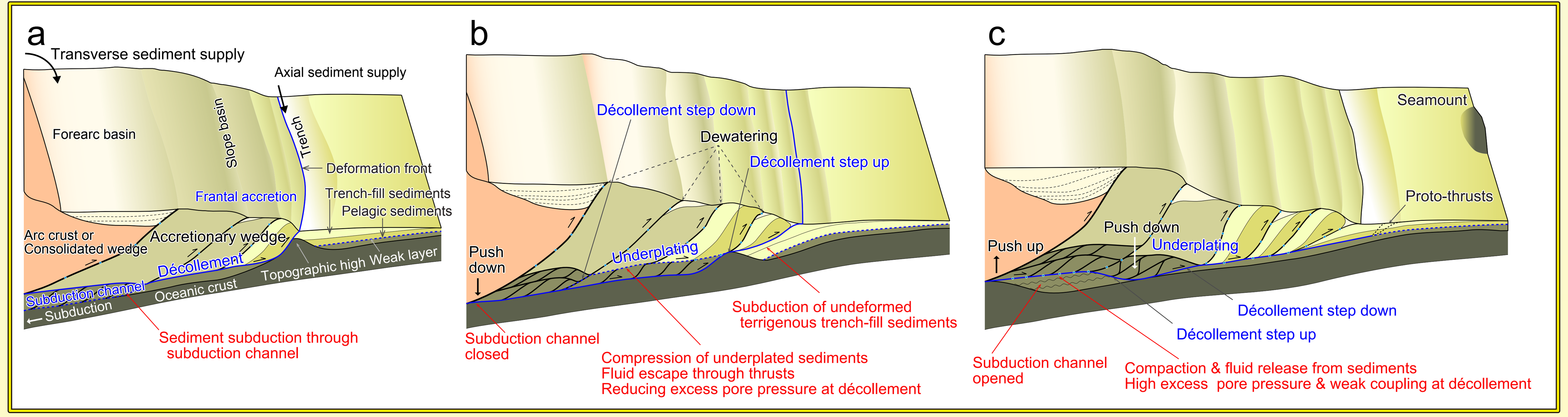

Figure 7a: Subduction of a topographic high raises the décollement to accommodate the topographic high and the following trench-fill sediment.

Figure 7b: An increase in overburden gravitational force under the inner wedge shifts the décollement downward and facilitates underplating. In the wake of the subducting seamount, terrigenous sediment is underthrust beneath the accretionary wedge.

Figure 7c: The seamount raises the backstop, enabling the subduction of terrigenous sediment. After the passage of the seamount, the décollement returns to the original, lower position, and the subduction channel closes, resulting in underplating beneath the wedge.