3D mantle flow induced by retreating and advancing slabs: insights from analogue subduction models analysed with tomographic PIV

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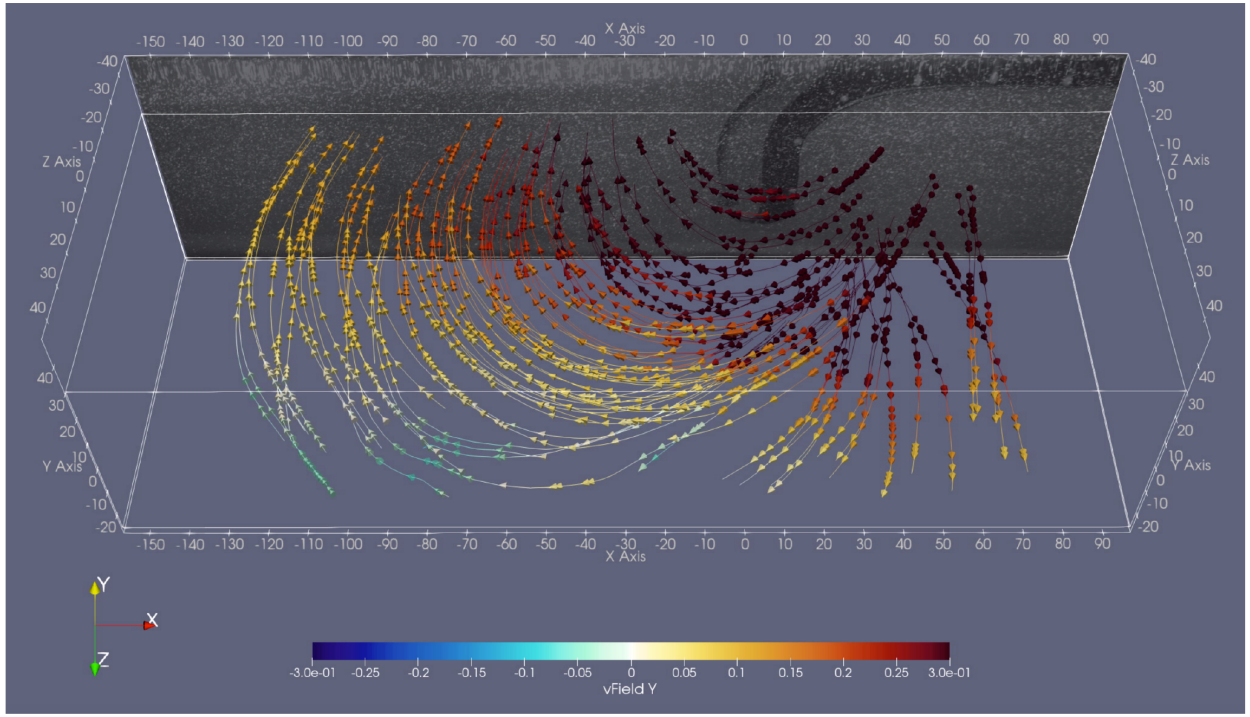
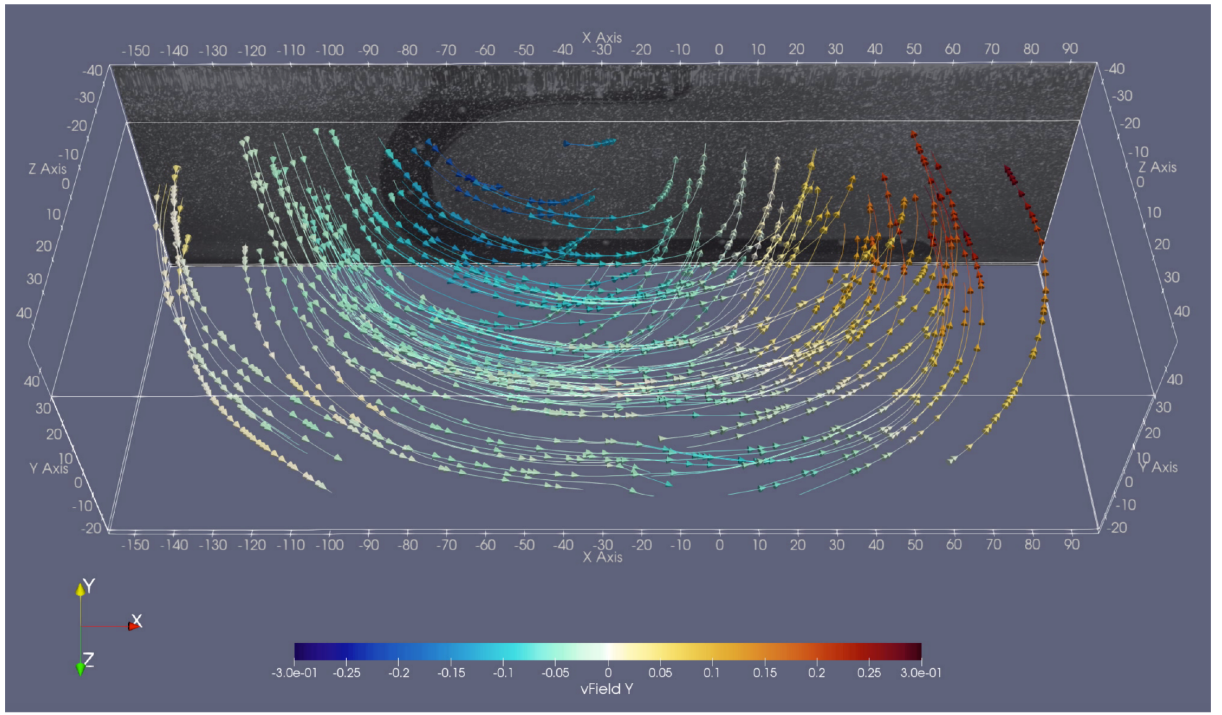
Retreating slab (rollback)



Advancing slab (rollover)



Purpose:

1) Quantify the location and magnitude of the upwellings produced by the subduction-induced mantle flow.
2) Such upwellings can be involved in the generation of intraplate volcanism, thus the model results will help identify where and when this causal relationship could have occurred.

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Introduction

Retreating slab (rollback)

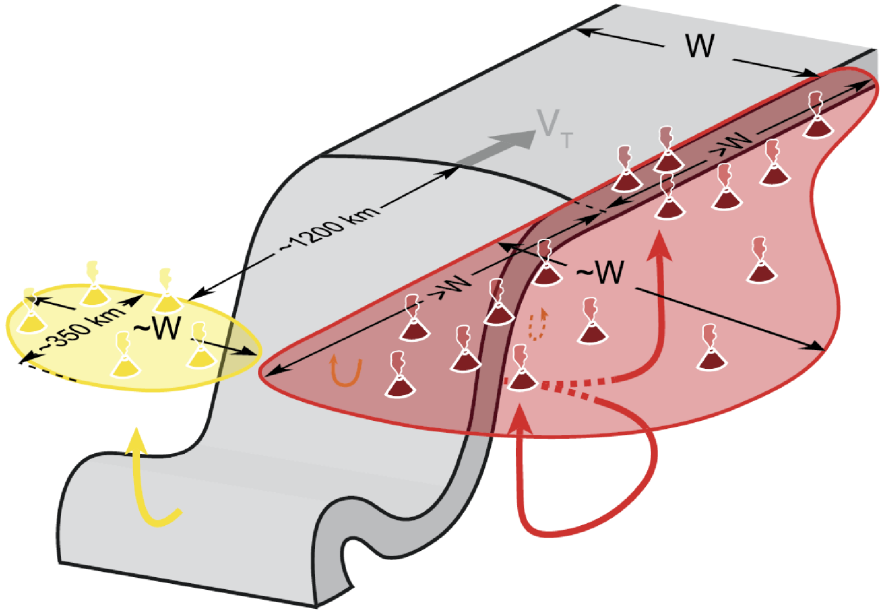

Fig. 1: Mantle upwellings produced by slab roll-back-induced mantle flow (e.g. Calabrian subduction zone; Strak and Schellart, 2014, EPSL)

Advancing slab (rollover)

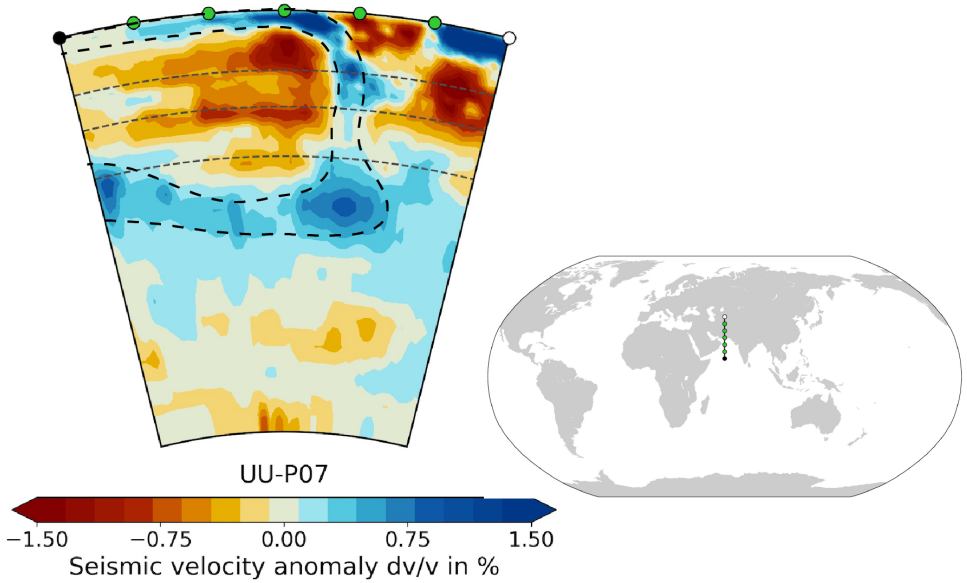

Fig. 2: Rollover geometry of the Makran subduction zone (UU-P07 tomography model; Amaru, 2007, PhD Utrecht University)

Slab rollback-induced mantle flow in retreating subduction zones is known to have a significant geodynamic impact on Earth. The resulting quasi-toroidal circulation can deflect mantle plumes, transport geochemical signatures and have an upwelling component that generates atypical intraplate volcanism near lateral slab edges (**Fig. 1**). Nevertheless, the mantle flow generated by advancing slabs (**Fig. 2**) remains unstudied and its geodynamic significance unclear. We therefore conducted analogue buoyancy-driven subduction models to investigate the mantle flow generated during the advancing (rollover) subduction mode.

Methods

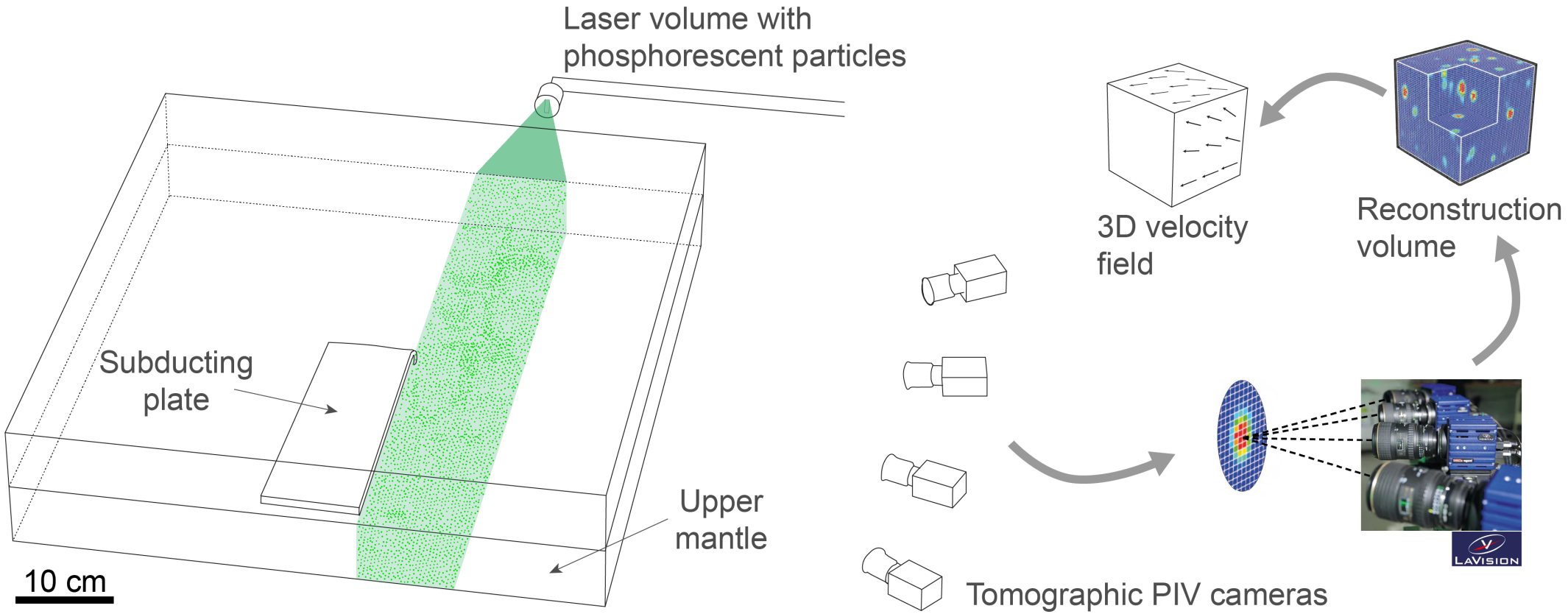

Fig. 3: Setup of the analogue subduction models and tomographic PIV system to compute the 4D mantle flow in a volume of the mantle next to the subduction zone (Strak et al., in prep)

We performed 4D analogue models of a 10 cm (800 km) wide subducting plate represented by a Newtonian mixture of silicone putty and iron powder diving freely into an upper mantle reservoir simulated using glucose syrup. We analysed our models using a novel tomographic Particle Image Velocimetry technique, allowing us to compute the 3D velocity field in a volume of the mantle (**Fig. 3**). The volume is 10 cm (800 km) wide and is located next to the subduction zone.

Results

Retreating slab (rollback)

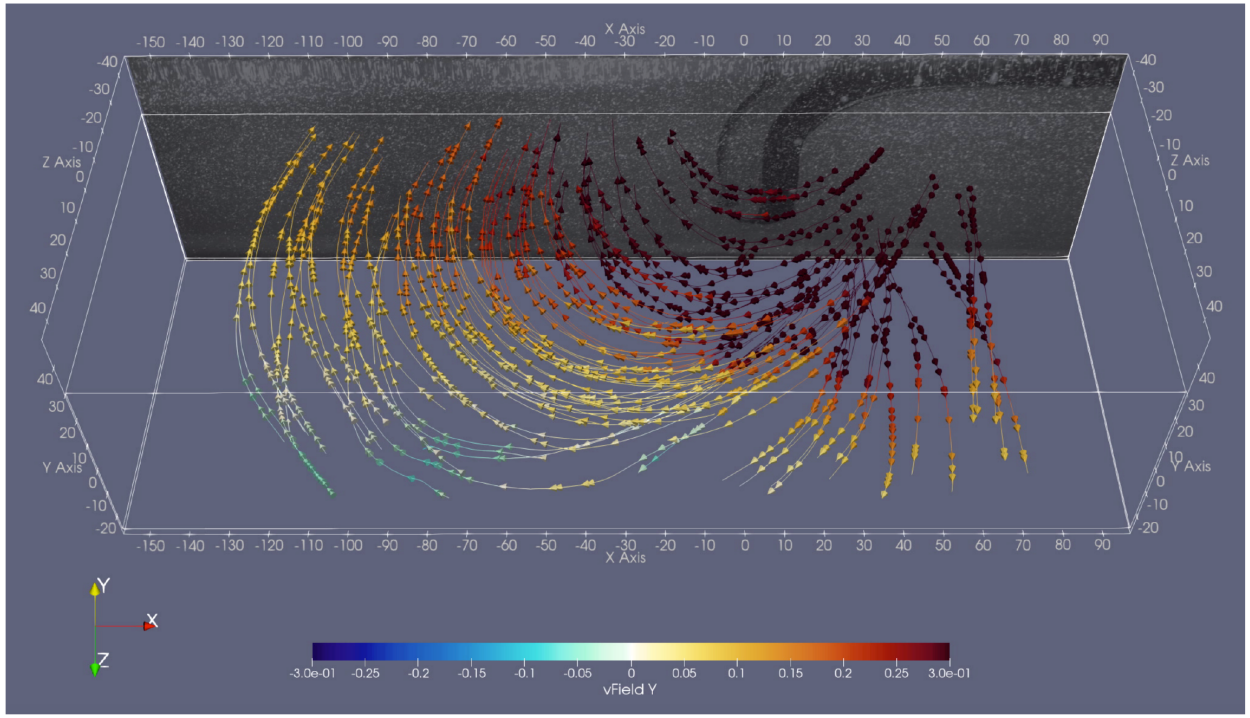

Fig. 4: 3D mantle flow around lateral slab edge during slab free sinking phase. The flow is represented by streamlines with the colour scale indicating the magnitude of the vertical component (in cm/h).

Advancing slab (rollover)

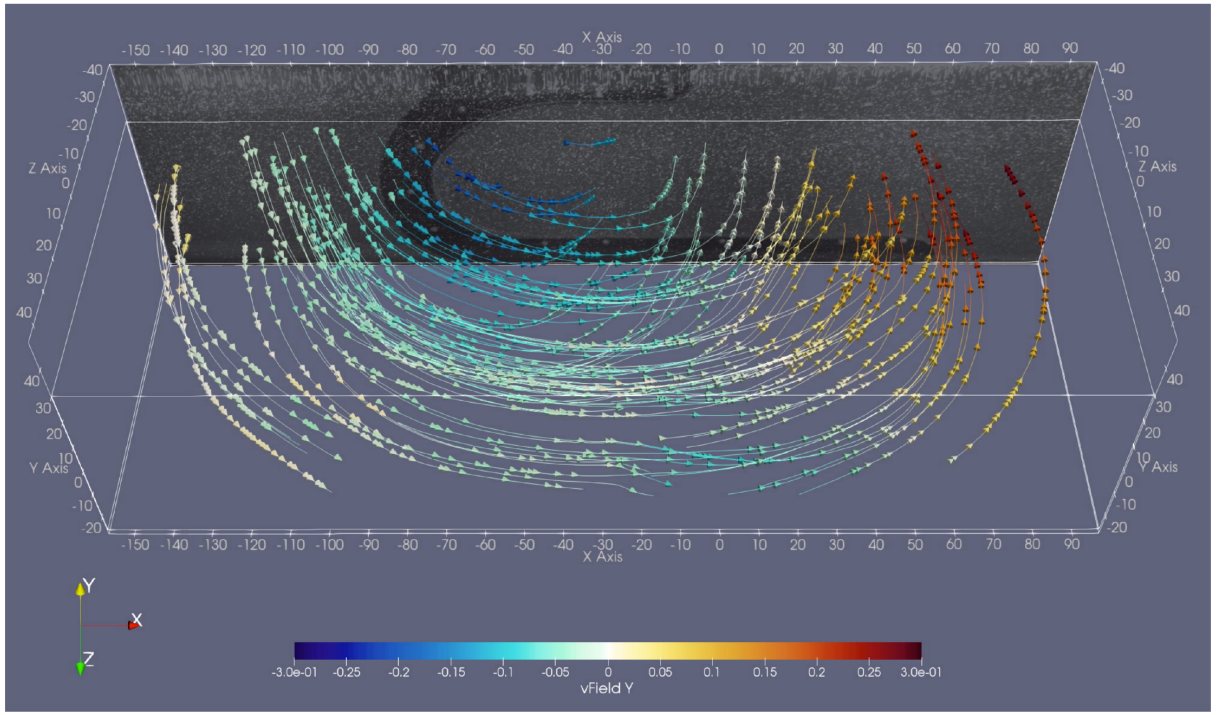

Fig. 5: 3D mantle flow around lateral slab edge during slab advancing phase.

Our results show that when the slab sinks freely into the mantle, mantle material escapes the sub-slab domain and flows around the lateral slab edge towards the mantle wedge in a quasi-toroidal fashion (**Fig. 4**). With this mantle flow, a significant upwelling component is produced next to the lateral slab edge, similar to the one produced during typical slab rollback. During the slab advancing phase due to rollover subduction, the quasi-toroidal mantle flow is inverted, so goes from the mantle wedge towards the sub-slab domain, and the most significant upwelling is located far away from the trench (~1000 km) to the side of the subducting plate (**Fig. 5**).

Discussion

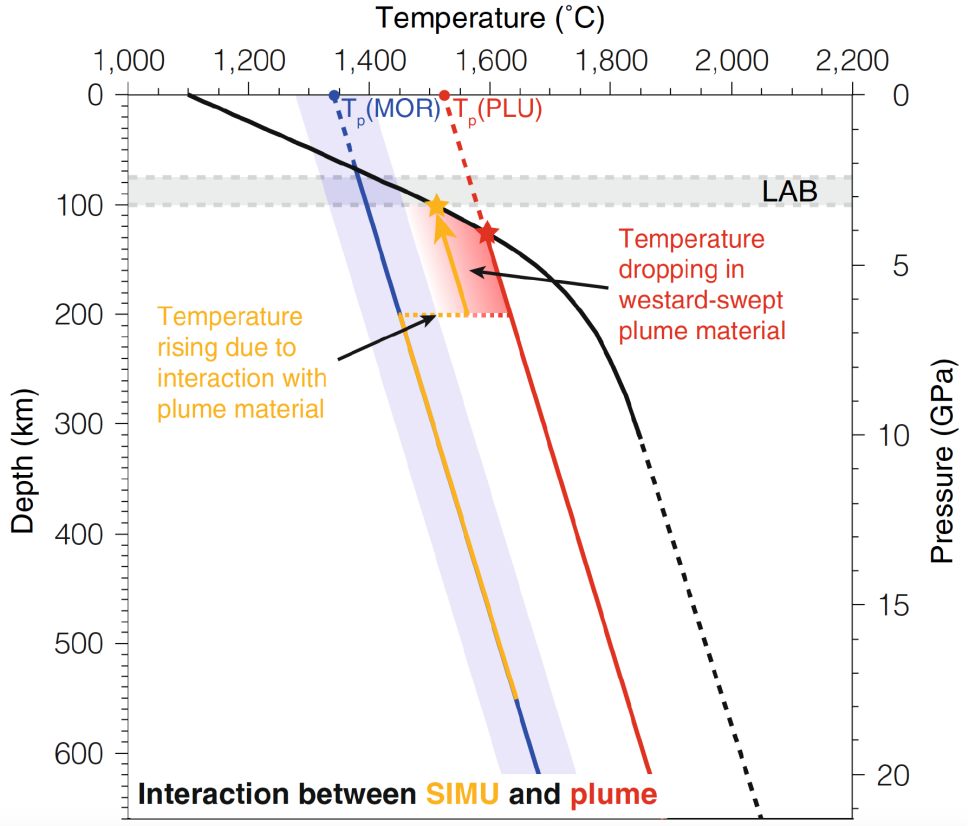

Fig. 6: Example of proposed interaction between SIMU and mantle plume to explain rejuvenation of volcanoes in the Samoa chain (Strak and Schellart, 2018, Scientific Reports).

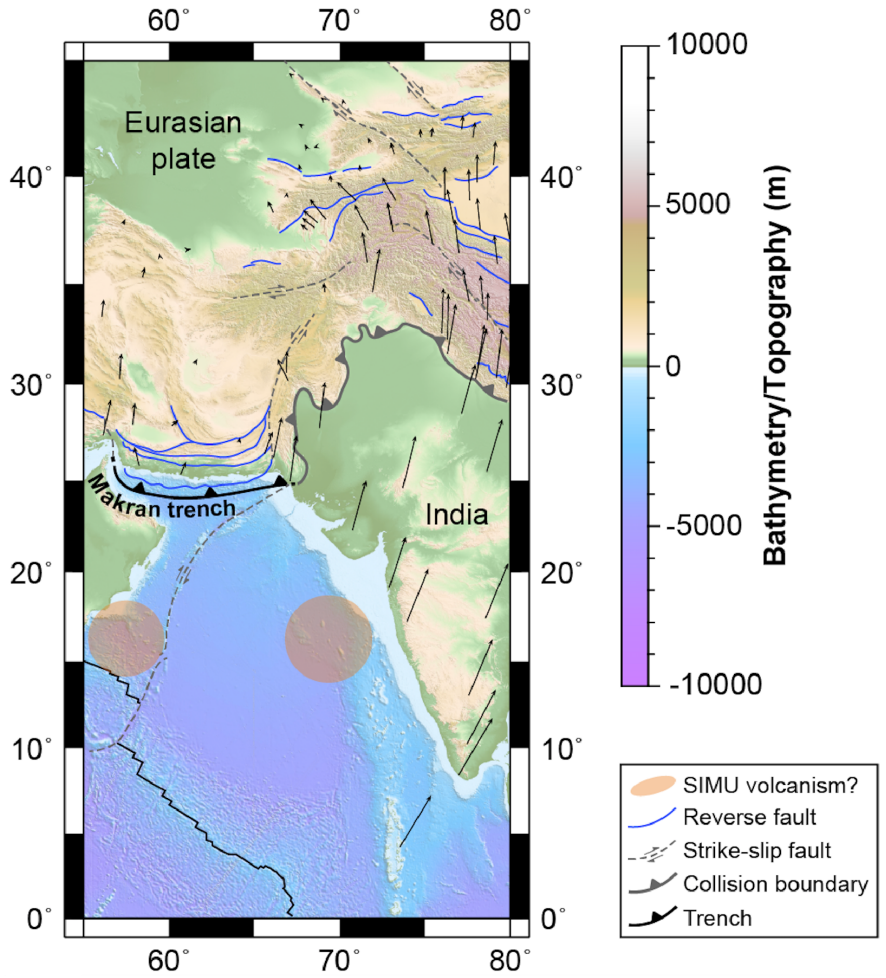

Fig. 7: Geodynamic setting of the Makran subduction zone and present-day location where intraplate volcanism caused by SIMU might be expected.

To invoke subduction-induced mantle upwellings (SIMU) as a cause of volcanism may require an interacting mechanism, for example with sources of anomalous mantle temperature, such as mantle plumes (**Fig. 6**), or with other sources of upwellings, such as small-scale or shear-driven convection due to the presence of lithospheric steps. Quantifying SIMU with subduction models can thus help to predict the location and time of those interactions in nature. For the Makran subduction zone we can expect intraplate volcanism to have occured some 1000 km south of the trench due to SIMU (**Fig. 7**).