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Editorial: Subduction and collision dynamics of tectonic plates

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Editorial on the Research Topic
Subduction and collision dynamics of tectonic plates

Plate subduction and collision zones are some of the most active tectonic regions on the Earth, which control the mass and energy exchange between the Earth's surface and interior, produce volcanism and the majority of great earthquakes, and are strongly correlated with the generation of mineral resources. The subducting oceanic slab penetrates through the mantle, interacts with multiple phase transition layers and results in variable slab morphologies and complex mantle flow. On the other hand, the continental plate subduction and collision generally follow the closure of oceanic subduction and lead to formation of great mountain belts on the Earth. The subduction/collision zone is a key element of plate tectonics and geodynamics, involving multiple processes and multi-scale mechanisms; however, many problems in this research field remain unclear and widely debated. The set of 14 studies in this special Research Topic aimed to bring together multi-scale geodynamic modeling studies, with the general goal of understanding the processes, dynamics, and effects of plate subduction and collision, as well as providing a general framework for future research efforts.

Normal subduction

For a normal oceanic subduction zone, a narrow, linear trough (trench) is produced in front of the overriding plates. The trenches may have a wide variation in their topographic characteristics, such as width, depth, and bounding surface slopes. What are the controlling factors? Dasgupta and Mandal showed that the mechanical coupling between the subducting and overriding plates, expressed by the maximum depth of decoupling, is a leading factor controlling the topographic evolution of a trench.

Unusual subduction

In addition to the normal oceanic plate subduction, there are also unusual subduction geometries that challenge our understanding of subduction dynamics. A typical and important case is the mid-ocean ridge (MOR) subduction, including the trench-parallel and trench-perpendicular/oblique regimes. For the trench-parallel MOR subduction, Shen and Leng numerically investigated the dynamics and effects of three MOR types (fast spreading, slow spreading, and extinction modes), and find that the key factor controlling these subduction modes is the relative motion between the foregoing and the following oceanic plates, separated by the MOR. For the trench-perpendicular/oblique MOR subduction, Guo et al. numerically studied the effects of the unusual subduction around the Chile Triple Junction (CTJ), showing that the CTJ is not only a wedge subduction boundary but also an important factor controlling the lithospheric thermal structure and seismogenic zone of the overriding plate. The subduction of aseismic ridges or other positively buoyant features may lead to the development of flat and shallow dipping slabs, the formation of cusps in trench geometry, and the cessation of associated arc magmatism. Using a series of 3-D simulations of free subduction, Suchoy et al. examined the effects of downgoing plate age (affecting buoyancy and strength), ridge buoyancy, and ridge location along the trench, and found that the buoyant aseismic ridges can locally change slab sinking and trench retreat rates, in turn modifying the evolution of slab morphology at depth and trench shape at the surface.

Multiple-subduction system

On the natural Earth, several subduction zones may locate closely and interact with each other. For example, the New Guinea region is a widely accepted example of the parallel triple subduction system, including a northward dip at the New Britain Trench (NBT), a southward dip at the Trobriand Trough (TT), and North Solomon Trench (NST). Using systematic numerical models, Wang et al. deciphered the formation mechanisms of these three correlated subduction zones, as well as their interactions in the complex parallel subduction system. Numerical tests on model parameters suggest that the initiation and development of triple subduction are rather difficult, and the presence of pre-existing weakness and the length of the ocean-continental transition zone are the key parameters. The multiple subduction zones can also be oblique or perpendicular to each other, in which the trenches will be intersected to generate a corner, with the formation of a subduction cusp. Using 3-D numerical models with imposed two subduction zones that formed an initial subduction cusp, Zhao et al. showed that the subduction cusps have a tendency to become smooth and disappear during the subduction process. The asymmetric distribution of the overriding plate strength and initial slab-pull force determines the asymmetric evolutionary pathway of subduction cusps.

Deep subduction and mantle flow

The interaction of subducting slab and mantle transition zone results in contrasting slab morphologies. The mechanism of slab stagnation and the formation of a big mantle wedge are widely debated. Using 3-D global convection models, Wu et al. proposed that all subducted Izanagi slabs have completely fallen into the lower mantle until the late Cenozoic and the stagnant slabs currently observed at the mantle transition zone depth beneath Eastern Asia are entirely from the Pacific Plate. They also find that multiple slab stagnation events have occurred during the subduction of the Izanagi Plate in the Mesozoic, each lasting for tens of millions of years. The complex and long history of Western Pacific subduction has greatly modified and characterized the East Asian tectonics. Brown et al. proposed a solution to decipher the Cenozoic intraplate tectonism of this region, where hot Pacific asthenospheric material flows into East Asia through the slab window opened by the subduction of the Izanagi–Pacific ridge during the early Cenozoic. They find that this process significantly affects the topography and volcanic history of the backarc and hinterland regions.

Continental collision patterns

Continental collision generally occurs following the closure of oceanic subduction and leads to the formation of mountain belts. The collision pattern varies among different mountain ranges; even the same collision zone shows significant lateral tectonic variations along its strike. Using systematic numerical models, Liu et al. showed that slowdown of plate velocities after the closure of ocean basins strongly influences continental collision evolution. The decreasing convergent velocity promotes the extension inside the slab by decreasing the movement of the surface plate, which will contribute greatly to the subducting slab break-off. Li et al. further integrated the reconstruction-based, time-dependent convergence rate of the India–Asia collision into a large-scale thermomechanical numerical model, showing that the collision mode selection, deformation partition, and continental mass conservation are greatly controlled by the rheological strength of the overriding plate. The strain localization and shortening of the rheologically weak Tibetan plate hinder subduction transference to the Indian Ocean during the India–Asia collision but instead results in lithospheric shortening and delamination of the overriding plate.

Post-collision processes

When the collision slows down or terminates, it often leads to the detachment of earlier subducted oceanic lithosphere, which changes the subsequent dynamics of the orogenic system. Using visco-elasto-plastic models, Van Agtmaal et al. investigated the conditions for post-collisional slab steepening versus shallowing. The results show a two-stage elastic and viscous slab rebound process lasting tens of millions of years, which is associated with slab unbending and eduction that together generates orogenic widening and trench shift toward the foreland. On the other hand, the lithosphere delamination generally results during or after continental collision, which occurs not only along the Moho, but also along the mid-lithospheric discontinuity. Qi et al. numerically investigated the dynamics of intra-crustal continental delamination along the base of the upper crust, featured by decoupled crustal deformation, that is, the lower crust subducts attached to the mantle lithosphere while the upper crust shortens at shallow depth. The intra-crustal strength decoupling and continental delamination are controlled by the upper crustal thickness, lower crustal rheology and initial Moho temperature.

Himalayan–Tibetan system

As one of the most important continental collisional belts on the present Earth, the Himalayan–Tibetan system plays a key role in understanding the plate collision dynamics. Using 3D thermo-mechanical modeling, Zhang et al. investigated the effects of hinterland basins on the detailed topography evolution of the Tibetan Plateau and found that a strong hinterland basin develops into a lowland with respect to the surrounding plateau, but a weak hinterland basin forms a highland after ~20 Myr of convergence, which explains the Tibetan topography evolution. After the uplift of the Tibetan Plateau, the resulting great potential energy will lead to a strong push on the neighboring blocks. The rheologically strong Sichuan Basin is located to the east of the Tibetan Plateau, with a remarkable mountain range, that is, Longmen Shan, in between. Shen et al. revealed that the rigid Ruoergai block resists the formation of a weak layer in the northern Longmen Shan block, resulting in the observed difference in lithospheric properties between the northern and southern Longmen Shan blocks, and thus constraining the eastern Tibetan evolution.

The studies in this Research Topic collection cover a whole chain of plate convergent processes. We hope that the reader will find it a useful reference for future research on plate subduction and collision tectonics and dynamics.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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