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Geometric evolution of a plate interface-branch fault system: Its effect on tectonics in Himalaya

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The Himalayas is a tectonically very active region where rapid crustal uplift due to the collision of India and Eurasia is still going on. The present-day convergence rate between the Indian and Eurasian plates has been estimated as 50 mm/yr. About 40 % of the total convergence rate is consumed at the collision boundary along the Himalayas by subduction of the Indian plate beneath the Eurasian plate. The rest of 60% is consumed by internal deformation of the Eurasian plate.

In such a tectonic framework, we first construct a kinematic model for steady subduction of the Indian plate beneath the Eurasian plate on the basis of elastic dislocation theory. The crust and mantle structure is modeled by an elastic surface layer overlying a Maxwellian viscoelastic half-space, and the kinematic interaction between the adjacent plates is represented by the increase of tangential displacement discontinuity (dislocation) across the plate interface. With this plate subduction model Takada and Matsu'ura (2004) computed the present uplift rates of the Himalayas due to steady slip along the India–Eurasia plate interface (detachment) with a large-scale ramp beneath the high Himalayas. The computed results are in accord with observed free-air gravity anomalies, river terrace uplifts, and geodetic data for level changes. The computational analysis of internal deformation fields by Takada (2002) showed that the steady slip along the ramp of the plate interface is the essential cause of the present-day rapid uplift of the high Himalayas. This means that the crustal deformation process strongly depends on the geometrical structure of the plate interface.

In the India-Eurasia collision zone the plate interface is associated with a series of under-thrusting branch faults, called the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) (e.g., Schelling and Arita 1991). The slip motion along these under-thrusting branch faults has also caused the long-term crustal deformation in the Himalaya. An important point is that the geometry of the fault system will be changed because of the internal deformation caused by slip on the fault system itself. Thus, it is necessary to reveal this feedback mechanism to understand the topographic evolution process of the Himalaya.

In this study, considering the changes in fault geometry with time caused by internal deformation, we developed a simulation algorithm for the geometric evolution of the fault system. Through numerical simulations we revealed the fundamental properties of geometric evolution of faults. When the plate interface is sufficiently smooth everywhere, there is no significant change in fault geometry. When the plate interface has a ramp, remarkable changes in fault geometry occur. The ramp moves horizontally toward the hanging wall side at a half of the plate convergence rate. The offset of the ramp decreases with time. These characteristics are strongly reflected on the surface uplift pattern. When the plate interface has an under-thrusting branch fault, we can find the accelerative increase in dip-angle of the branch fault and also the development of a ramp-and-flat structure on the plate interface around the branching point. Since the branch fault with a steeper dip-angle is harder to consume the horizontal convergence, we may conclude that the increase in dip-angle results in the cessation of slip along the branch fault at last. The shallower the depth of the branching point is, the faster the rate of increase in dip-angle of the branch fault is. It means that the branch fault with a shallow branching point can not produce the large-scale mountain range, because large amount of slip can not be accommodated by the branch fault.

Incorporating the mechanism of geometric fault evolution into geological knowledge, we propose a scenario on the tectonic evolution of the Himalayas in the last 30 Myr. The tectonic evolution may be divided into three stages. From 30 Ma to 15 Ma, the Main Central Thrust (MCT) with a deep branching point has been active, and produced very high mountain ranges. After the stop of the MCT activity, the produced high mountain ranges has been gradually eroded with time. From about 10 Ma the Main Boundary Thrust (MBT) with a shallow branching point became active instead of the MCT, and produced middle-class mountain ranges. At present, the thrust motion along the MBT has not continued at many locations (Nakata et al. 1990; Mugnier et al. 1994). During the last several million years, the steady slip along the ramp of the plate interface raised the high Himalayas at the place where once the MCT had raised the high mountain ranges.

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