Formation of Island Arc-Trench System due to Plate Subduction on the Basis of Elastic Dislocation Theory

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An earthquake is a process of releasing stress that has been accumulated in the crust. Stress accumulation is principally caused by plate motion; in subduction zones, subduction of an oceanic plate is the most fundamental cause of it.

The most conspicuous feature of subduction zones would be the formation of island arc-trench system. A pair of anomalies in topography and free-air gravity, high in the arc, low around the trench, and gentle high in the outer rise, is observed without exceptions all over the world. In this study, we clarified the fundamental mechanics in the formation of the island arc-trench system on the basis of elastic-viscoelastic dislocation theory.

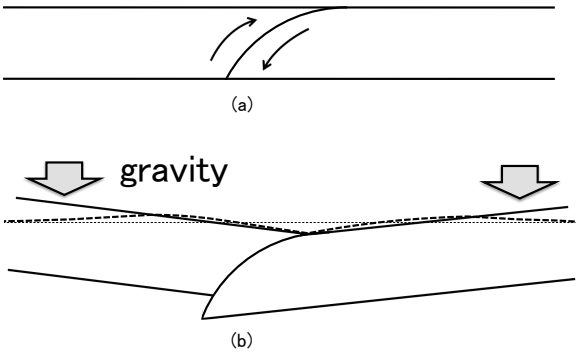

Figure 1. Schematic illustration to show the formation of island arc-trench system due to plate subduction. (a) Plate subduciton is caused by displacement discontinuity along the plate interface, as shown by the arrows. (b) Without gravity, the displacement discontinuity results in clockwise rotation of the overriding plate and counterclockwise rotation of the underlying plate without deformation (solid lines). The gravity, however, requires the lithosphere at a distance from the trench to remain in the original gravitational equilibrium state (thick broken line). The thin broken line represents the level of original Earth's surface.

By simply applying elastic-viscoelastic dislocation theory to plate subduction, Matsu'ura and Sato [1989, GJI] have shown that some crustal deformation remains after the completion of one earthquake cycle, which means that crustal deformation accumulates with time in a long term due to plate subduction. To understand the mechanism of this cumulative deformation, we've found that it is useful to consider plate subduction along a part of true circle (Fukahata and Matsu'ura, 2016, GJI). In this case, crustal deformation due to steady subduction is solely caused by the effect of gravity, because dislocation along a circle does not cause any intrinsic internal deformation. When an oceanic plate subducts from the right-hand side (Figure 1a), according to dislocation theory, the oceanic plate rotates anti-clockwise and the overriding plate rotates clockwise (Figure 2b). The gravity, however, requires both plates at a distance from the trench to remain in the original gravitational equilibrium, which results in upward bending of both plates. As subduction proceeds, the deformation of the upward bending accumulates with time.