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The Source of Tectonic Deformation in Plate Convergence Zones

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The solid Earth consists of the crust, mantle and core that are different, both physically and chemically, from each other. To short time-scale disturbances such as seismic waves, the Eath system behaves like an elastic body, except for the outer core. To intermediate time-scale changes such as interseismic loading or postglacial unloading, the Earth's surface layer (the lithosphere) still behaves like an elastic body, but the underlying uppermost mantle layer (the asthenosphere) behaves like a viscous fluid. To long time-scale tectonic loading, even the lithosphere behaves like a viscous fluid. Such difference in rheological properties between the lithosphere and the asthenosphere is essential for the seamless understanding of plate boundary processes. The lithosphere is divided into a number of elastic plates that are in relative motion with respect to one another. Diverse plate boundary processes such as earthquake occurrence, crustal deformation and mountain building can be ascribed to mechanical interaction at plate interfaces, which make a closed circuit on the Earth's surface with the mode of relative motion changing from divergence to convergence through lateral slip. Nowadays we can precisely determine the 3-D geometry of plate interfaces from seismological observations and the relative plate velocities from space-based geodetic measurements such as GPS, SLR and VLBI. Therefore, one of the rational ways to represent mechanical interaction at the various types of plate boundaries is to specify the increase rates of normal or tangential displacement discontinuity at plate interfaces. The point is that the spatial change of displacement discontinuity vectors both in magnitude and direction yields a force system that brings about crustal deformation. In the case of tangential displacement discontinuity (fault slip), for example, coseismic slip or interseismic slip deficits (spatial change in slip magnitude) at the plate interface brings about crustal deformation. For the same reason uniform steady slip along the curved plate interface (spatial change in slip direction) also brings about crustal deformation. This effect is essential to understand long-term crustal deformation in plate convergence zones. On such a basic idea we have developed a physics-based, realistic computer simulation model for plate boundary processes. As an example we show the results of 3-D computer simulation for earthquake generation cycles and long-term crustal deformation in and around Japan, where the four plates of Pacific, North American, Philippine Sea and Eurasian are interacting with each other in a complex way.