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Recent Development of Earthquake Generation Physics toward Earthquake Prediction

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From the standpoint of earthquake prediction, our target is limited to large earthquakes. The essential difference between large and smaller events is in their stress accumulation-release processes. The large events that completely break down the seismogenic zone may be regarded as the process of tectonic stress release, while the smaller events that break down only a part of the seismogenic zone should be regarded as the redistribution process of local stress. Thus, only to large events, we can apply the concept of the earthquake cycle that consists of tectonic loading due to relative plate motion, quasi-static rupture nucleation, dynamic rupture propagation and stop, and fault strength restoration. In the last decade there has been great progress in the physics of earthquake generation; that is, the introduction of laboratory-based fault constitutive laws as a basic equation governing earthquake rupture and the quantitative description of tectonic loading driven by plate motion. We can now quantitatively describe the entire process of earthquake generation cycle by a coupled nonlinear system, which consists of a slip-response function and a fault constitutive law. The driving force of this system is relative plate motion. The system to describe the earthquake generation cycle is conceptually quite simple. The complexity in practical modeling mainly comes from complex structure of the real Earth. Recently we completed a physics-based, predictive simulation system for the entire process of earthquake generation cycles in and around Japan, where the four plates of Pacific, North American, Philippine Sea, and Eurasian are interacting with each other. The total simulation system consists of a crust-mantle structure model, a tectonic loading model, and a dynamic rupture model. First, we constructed a realistic 3D model of plate interface geometry in and around Japan by applying an inversion technique to ISC hypocenter data. Second, by integrating microscopic effects of abrasion and adhesion at contacting rock surfaces, we theoretically derived a slip- and time-dependent fault constitutive law. Third, with this constitutive law and viscoelastic slip-response functions, we developed a quasi-static model of stress accumulation driven by relative plate motion. By applying the boundary integral equation method, we developed also a simulation model for dynamic rupture propagation on a 3D curved plate interface. Finally, combining the quasi-static stress accumulation model and the dynamic rupture propagation model on the same structure model, we constructed a unified simulation system for the entire earthquake generation process. Outputs of this system are the crustal deformation and internal stress change associated with seismic and/or aseismic slip at plate interfaces. From comparison of these outputs with observations, we can extract useful information to estimate past slip history and the present stress state by using an inversion technique. Given the past slip history and the present stress state, we can predict the next step fault-slip motion and stress change through computer simulation.