Abstract

This thesis aims to demonstrate that integration of detailed observations of deformation at short to long length scales with carefully formulated numerical modeling is an effective method for simulating the complex multiscale nature of mantle-lithosphere dynamics. In Part I, marine geophysical observations are used to determine the origin of the Osbourn Trough, a long linear depression within the Pacific Plate seaward of the Tonga-Kermadec Trench, and to determine the elastic strength of the subducting plate within the Kermadec Trench. Based on the morphology of the seafloor from swath bathymetry mapping and modeling of magnetic data, we conclude that the Osbourn Trough is an extinct spreading center which stopped spreading about 72 million years ago. Swath bathymetry mapping within the Kermadec Trench reveals extensive faulting within the trench on the subducting plate, with oblique grabens aligned perpendicular to the absolute plate motion direction. Using isostatic flexural response methods, we find that the flexural rigidity (10^{19}–10^{20} N m) is smaller than normally found for old oceanic lithosphere reflecting a local reduction in the strength of the plate.

In Part II, regional 3-D dynamic models of the Tonga-Kermadec and Aleutian subduction zones are used to constrain lateral variations in viscosity in the upper mantle. Modeling of the dynamic topography of the overriding plate for the Tonga-Kermadec subduction zone requires a low viscosity and low density ($\delta\rho = -20\ kg/m^3$) region within the wedge above the slab to decouple the slab-induced flow from. These efforts lead to a good fit to the observed shallow bathymetry on the overriding plate for a model with a slab density anomaly due to temperature of $\sim 80\ kg/m^3$. However, the geoid anomaly above the subduction zone is too large by 20–40 m at length scales of 100-1000 km. A reduction of the slab density by a factor of 1.5 is needed to match both the geoid and topography, suggesting the density anomaly of the slab due to temperature is compensated within the upper mantle (∼100–300 km). Similar modeling for the Aleutians including a narrower low viscosity region and

smaller density anomaly ($\delta\rho = -10\ kg/m^3$) in the wedge is able to fit the geoid and topography without reducing the slab density.