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Observing and modelling the deformation of the Andean subduction zone

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The increasing accuracies of high resolution geodesy are providing new insights into the earthquake deformation and plate boundary dynamics. GPS-observed crustal movements in the Southern and Southern-Central Andes are governed by different phases of the earthquake deformation cycle. The transient elastic deformation related to subduction earthquakes present a short-term signal compared to geological timescales. The permanent plastic deformation that contribute to the formation of tectonic features can be characterized as a long-term signal. Most of the transient deformation can be explained by inter-seismic, co-seismic, and post-seismic phases of interplate thrust earthquakes.

Secular crustal movements are derived by subtracting model velocities from observations. Along the Andes, the most obvious long-term deformation signal is visible in the back-arc of the subduction where the Brazilian Shield underthrusts beneath the Subandean zone. Here, GPS observations suggest a slower back-arc convergence than geological rates that represent the average during the Andean evolution. The analysis of the residual velocity field and strain rates within the Chilean fore-arc indicates the presence of trench-perpendicular extension in accordance with geologic findings. The prominent signals in the residual velocity field are due to postseismic relaxation processes. The prominent signals in the residual velocity field (i.e. observed velocities minus modelled interseismic deformation) are obviously due to postseismic relaxation processes; they are visible in the area of the 1995 Mw 8.0 Antofagasta earthquake and in the area of the 1960 Mw 9.5 Valdivia earthquake. The latter area shows a pronounced post-seismic deformation 40 years after the event and a significant change in the displacement field with time.

Further insight into the plate boundary dynamics comes from 3D FE-Models that we used to explain the present-day deformation. The observed postseismic deformations put constraints on the viscosity of the upper mantle and lower crust. Postseismic displacements can be explained either by continuing slip along the deeper sections of the coseismic rupture surface (i.e. afterslip) and/or by viscoelastic relaxation processes occurring within the lower crust and the upper mantle. The former mechanism is believed to have a more short-term effect, while the latter is generally characterized by more long-term effects. Thus, the deformation in the area of the 1995 Antofagasta earthquake is most likely due to a continuing afterslip after the earthquake, while the viscoelastic relaxation effect is most likely responsible for the movements observed in the area of the great 1960 Valdivia earthquake. However, it is difficult to uniquely resolve the relative contribution of the two processes. Our data from southern Chile are best fitted with our three-dimensional finite element model when we incorporate a mantle viscosity of 4×10^{19} Pa s.

In addition to our conventional modeling efforts mentioned above, where the fault is treated in a pure kinematical manner, we set up an essentially more ambitiously model based on the commercial FE software package ANSYS. The advanced model is based exclusively on the geometry of the tectonic plates including the subduction zone and on gravitational forces, i.e. the model runs only based on ridge-push and slab-pull forces including frictional forces at the plates interface (Figure 1). No kinematical boundary conditions are given; the relative plate velocity is a result of the computation.

Further model descriptions are shown in Figure 2: the bottom of the mantle as well as the right and left model boundaries are fixed whereas the slab moves into fluid-like material simulating its behavior after melting. With this modeling approach we intend to be as close as possible to the reality. The model will contribute to a better understanding of the subduction earthquake cycle and will shed some light on long-term mountain building processes.

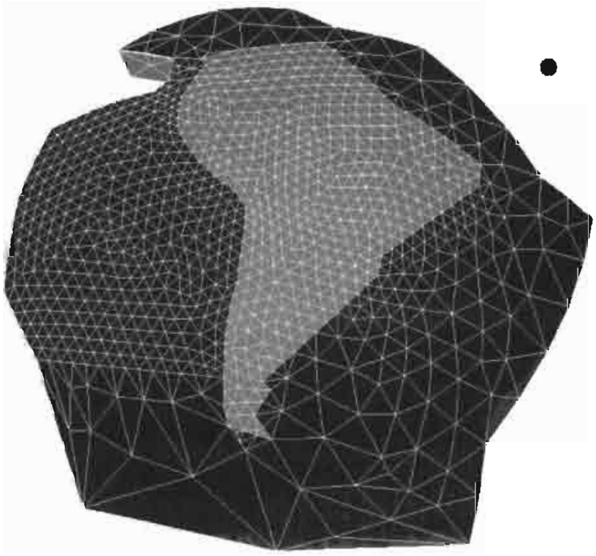

Figure 1: Finite element model of the tectonic plates in the South American region.

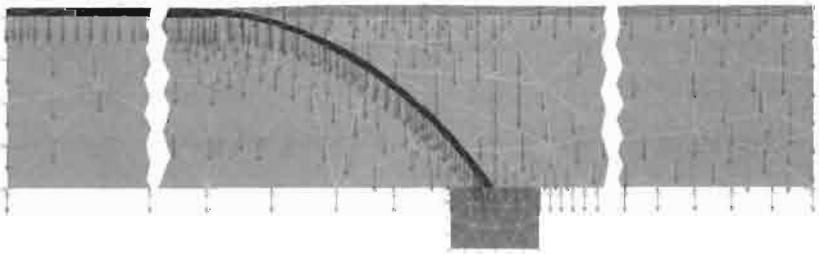

Figure 2: Cartesian cross section of the 3D FE-model with boundary conditions and gravitational forces.

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