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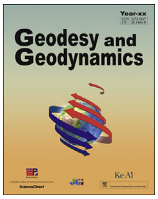

Finite element modelling of the geodynamic processes of the Central Andes subduction zone: A Reference Model

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ABSTRACT

This paper presents preliminary results of three-dimensional thermomechanical finite-element models of a parameter study to compute the current temperature and stress distribution in the subduction zone of the central Andes (16°S–26°S) up to a depth of 400 km, the bottom of the asthenosphere. For this purpose a simulation running over c. 50,000 years will be realized based on the geometry of a generic subduction zone and an elasto-viscoplastic Drucker–Prager rheology. The kinematic and thermal boundary conditions as well as the rheological parameters represent the current state of the study area. In future works the model will be refined using a systematic study of physical parameters in order to estimate the influence of the main parameters (e.g. viscosity, fault friction, velocity, shear heating) on the results of the reference model presented here. The reference model is kept as simple as possible to be able to estimate the influence of the parameters in future studies in the best possible way, whilst minimizing computational time.

1. Introduction

Subduction zone seismicity accounts for more than two thirds of the global seismic energy release (e.g. [1]) and is hence an integral process accompanying the recycling of lithospheric plates along convergent plate boundaries. Most subduction earthquakes, including 'giant' ones with moment magnitudes $Mw \geq 8$, are generated at intermediate depths between c. 50 and 300 km (e.g. [2]) and many factors have been invoked to explain their occurrence. The classical concept is that 'embrittlement' induced by metamorphic dehydration reactions in the downgoing slab is responsible for triggering intermediate depth seismic dislocations (e.g. [3,4]). 'Embrittlement' essentially means overcoming the brittle shear strength along the plate interface in the presence of a free fluid phase that counteracts normal stresses on faults. As an alternative mechanism for intermediate depth earthquakes, John et al. [5] and Prieto et al. [6] suggested that, in the absence of free fluids, so-called 'thermal runaway melting', induced by self-localising shear heating, might control seismogenic material failure at differential stresses lower than those needed for inducing brittle failure along a plate interface. Recent ideas on the occurrence of $Mw \geq 8$ earthquakes also suggested that they occur preferably along accretionary, i.e. addition of material to the overriding plate, rather than erosive margins, i.e. removal of material from the upper plate basement ([7] and references therein), implying that the presence vs. absence of large volumes of low-friction pelitic material constituting a trench-fill effectively controls fault friction and, in turn, when dynamically weakened during seismic slip ('velocity weakening' [8,9]), the size of the ruptured area and hence the seismic moment released along a subduction plate interface. However, the Tohoku $Mw = 9.1$ earthquake of 2011 [10] occurred along a clearly erosive subduction segment, rendering the notion of [7] at best contradictory and suggesting that possibly still other factors exert a control on where seismicity localises. The above examples highlight how strongly interdependent the rheological, geometrical and physical parameters (such as pressure, temperature as well as the presence vs. absence of volatile phases) are in triggering subduction zone seismicity; and controversies still prevail.

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This study addresses the temperature-dependent rheology of subducting lithosphere by means of three-dimensional numerical finite-element modelling using an elasto–viscoplastic rheological model, to obtain a better understanding of the stress distribution in subduction zones. For this the subduction zone of the central Andes (16°S–26°S) serves for scaling and calibration of the models (Fig. 1).

2. The reference model

The FEM (finite-element method) is a widely used technique among geophysicists for simulating plate movements along subduction zones. Using three-dimensional geometries enables us to do most realistic numerical simulations. However, these computations require very robust and time efficient numerical algorithms. This work therefore makes use of the FEM package Abaqus 6.14–2 [12], which is a widely accepted tool for a large range of applications in geosciences (e.g. www.ruhr-uni-bochum.de/geoqus). For testing purposes the geometry of the current reference model describes a generic subduction zone using a two-dimensional cross section extended to the third dimension (Fig. 2).

The size of the reference model is 650 km from west to east (*x*-direction), 400 km from south to north (*z*-direction) and 400 km from bottom to top (*y*-direction), resulting in approx. 27,000 three-dimensional finite elements. The boundary conditions (Fig. 3) applied include a constant gravitational acceleration acting on the overall model, the horizontal motion of the oceanic and continental plate, slab pull on the subducting slab into the lower earth's mantle, as well as friction including shear heating between the oceanic and continental crust along the plate interface (Fig. 3). During the simulation the eastern and western boundary elements of the asthenosphere are only allowed to move in vertical direction (*y*) while fixing the horizontal directions (*x* and *z*) to account for surrounding materials. The bottom of the oceanic as well as continental asthenosphere is completely fixed. The applied plate velocities are typical mean values according to Refs. [13–15]. The coefficient of friction along the plate interface was set to $\mu = 0.3$ down to the base of the upper plate Moho and $\mu = 0$ between the Moho and the lithosphere-asthenosphere boundary (LAB). This strict simplification was necessary for obtaining a numerically stable solution. In developing the models further, the author intends to modify the downdip variation in a more realistic way. The simulations intend to reflect the current subduction state before the occurrence of large earthquakes. To achieve this a dynamically stable equilibrium must be realized, which is considered to appear after c. 100,000 years of simulation duration. Due to this long-term effects such as erosion, convection and serpentinization in the forearc mantle are to be neglected.

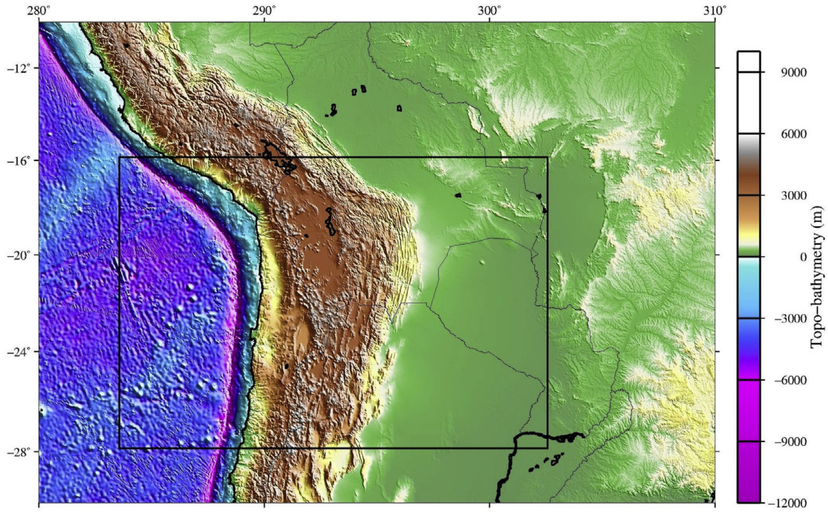

Fig. 1. Topographic map of the central Andes (conceived with Submap 4.0 [11]). The rectangle denotes the study area.

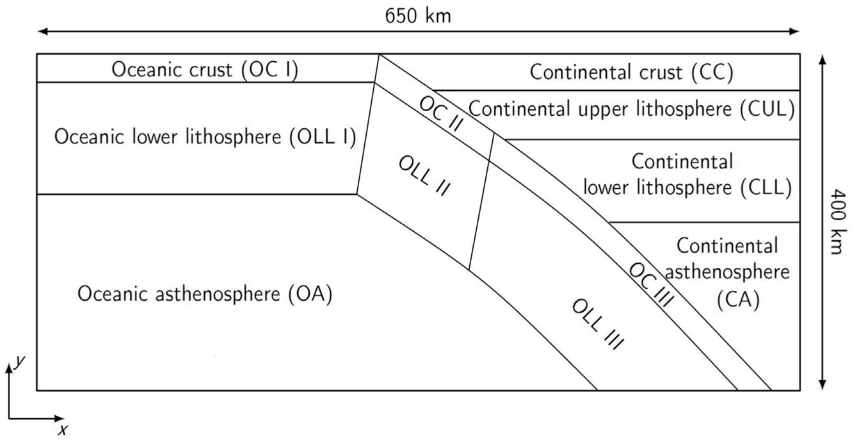

Fig. 2. Different parts of the model and their abbreviations.

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