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New 3D Finite Element model of the Central Andes using realistic geometry

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Introduction

The South American subduction zone along the Andes characterised by geo-hazards is one of the most interesting regions to study dynamic processes related to subduction. For a better understanding of these processes numerical modelling is crucial. We developed various 3D models using the Finite Element Method (FEM) to investigate the effect of different parameters on the stress and deformation field.

The margin within the range of the Central Andes can be subdivided in two major earthquake segments separated by the Mejillones Peninsula near Antofagasta (Victor et al., 2011). The Iquique segment reaches approx. from 18°S to 23°S and the last great earthquake happens there more then 130 years ago in 1877. The recurrence rate in this region is about 111±33 years (Comte and Pardo, 1991) and therefore a great earthquake is expected for this region. Hence, the area between 16°S-22°S and 78°W-63°W was chosen for the dynamic modelling with realistic geometries (Fig. 1).

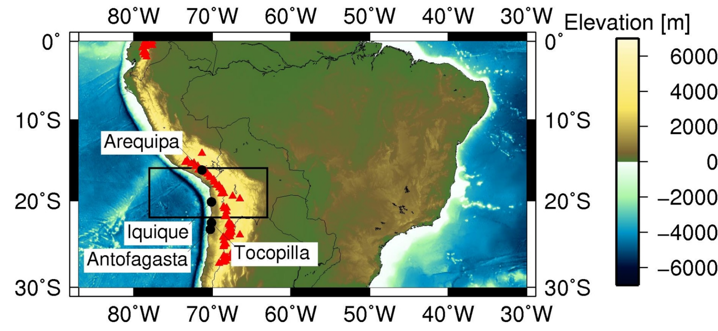

Fig. 1: Investigation area in South America. Red triangles denote volcanoes. Rectangle marks the area of the model.

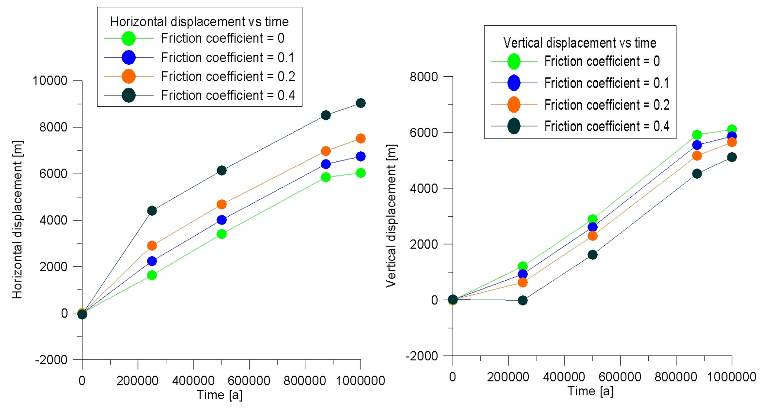

Fig. 2: Effect of friction coefficient on horizontal (x direction) and vertical displacement for a point approx. 60 km away from the trench. Generic model is pure elastic and an oblique convergence of 6.5 cm/a over 1 million years was applied.

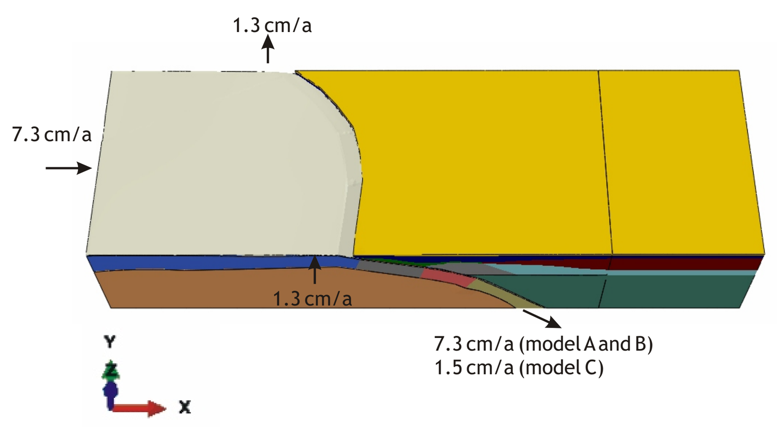

Fig. 3: To achieve an oblique convergence of 20° the velocity of 7.8 cm/a was split in components and applied in x and y direction. The y component was divided by two and applied at the north and south side of the oceanic lithosphere.

Model structure and parameter

Generalised models with generic geometry are sufficient for parameter study (Fig. 2) and first order approximation of geodynamic processes. The friction coefficient is proportional to the displacement and leads to a higher horizontal but lower vertikal deformation (Fig. 2).

For a closer look geometry plays an important role (Zeumann et al., 2011). To achieve a more realistic structure the geometry has been adopted from a well constrained gravity model (Tassara et al., 2006, Köther et al., 2011).

The model is 410 km deep and 2230 x 725 km² wide. The Nazca plate was moved with an oblique convergence of 20° and a velocity of 7.8 cm/a (Somoza, 1998), whereas the South America plate was fixed. The coupling zone between the two plates is only in the uppermost 50 km with a friction coefficient of 0.1. The east and west edges of the model were not allowed to move in x direction, the north and south edges were fixed in y direction, bottom fixed in in z direction, except where velocities were applied (Fig. 3). The right block at the continent side was only placed to avoid edge effects and will not be shown in the next pictures.

Viscosity is essential. Thus, the asthenosphere is visco-elastic but the lithosphere is pure elastic (Fig. 4). Temperature and mantle flow are not included in the model.

Results

To investigate the effect of viscosity and slab pull different models were created. For model A and B the slab pull has the same value as the slab push (~7.3 cm/a) but model A has higher viscosities of 1e22 Pas for the oceanic and continental upper asthenosphere and 5e19 Pas for the upper continental asthenosphere. Model B and C have the same viscosities as fig. 3 but in model C the slab pull is reduced by the factor 5 to ~1.5 cm/a. GPS measurements mirror short time deformation only (<100 000 years). On the geological time scale (100 000 to millions of years) the deformation patterns are changing e.g. convergence velocities (Somoza, 1998) or friction coefficient. To compare the results with observations all models run for 100 000 years. For the last 5000 years the development of the results were assumed as linear, and the difference per year was calculated.

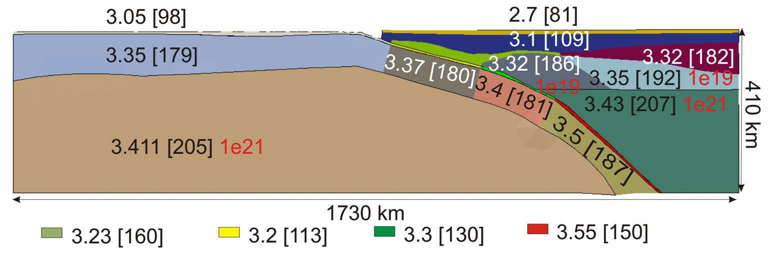

Fig. 4: Parameter for the visco-elastic models B and C. Geometry and densities [$*10^3$ kg/m^3] were taken from the gravity model (Tassara et al. 2006). In brackets Young's modulus [GPa] calculated from the densities and seismic velocities from Ancorp profile (ANCORP working group, 2003) and viscosities [Pas] in red are given.

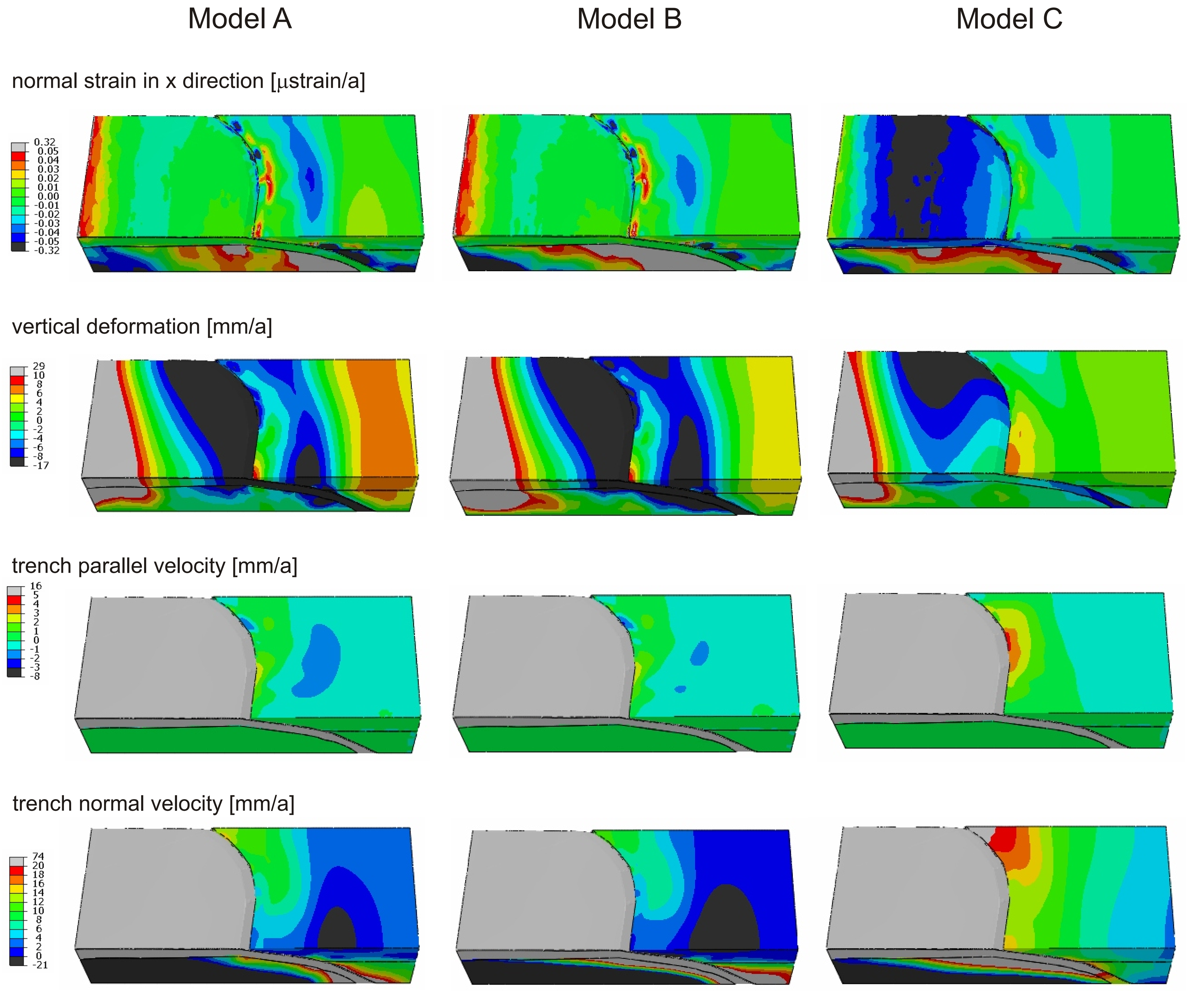

Fig. 5: Displacement and strain components of different models: Variation per year.

The results (Fig. 5) show, that higher viscosities lead to higher deformations especially in vertical direction. A reduced slab pull also increases the displacements.

A comparison of the modelled horizontal displacements with observed GPS data (Fig. 6) shows that the modelled values of the models A and B are a little bit to low but model C fits very well. The observed uplift is less then 2 mm/a (Klotz et al., 2006). Models A and B show a wide subsidence region and uplift only in the fore-arc and on the east flank of the Andes but model C shows an uplift.

The normal strain shows a region of compression (negative) of -0.05 µstrain/a which is in good agreement to the observed value of -0.06 µstrain/a for a region south of the model area (28°S) (Klotz et al., 2006).

For the case of smaller slab pull the stress in the oceanic crust is higher but lower in the continental crust (Fig. 7).The stripe pattern of stress accumulation is similar to the earthquake distribution in the investigation area.

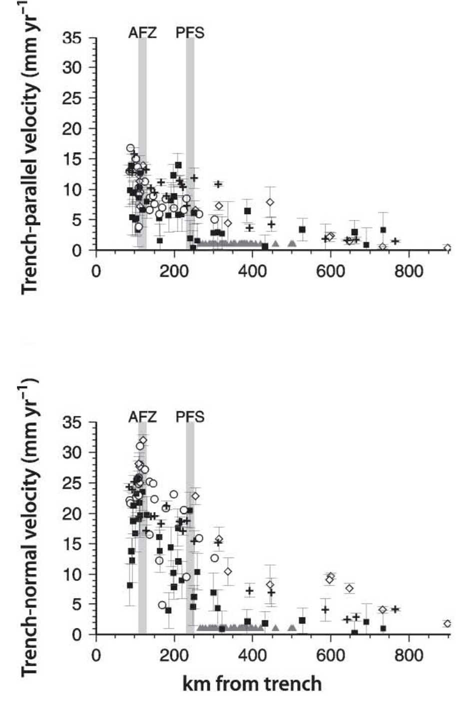

Fig. 6: Observed displacements from various GPS data for north Chile between 20°S and 30°S. Top: Trench parallel component. Bottom: Trench normal component. Grey triangles at the botttom give the projected positions of volcanoes active in Holocene. Grey vertical bars indicate positions of margin-parallel strike-slip fault systems, Atacama fault zone (AFZ) Precodilleran fault system (PFS) (Hoffmann-Rothe et al., 2006).

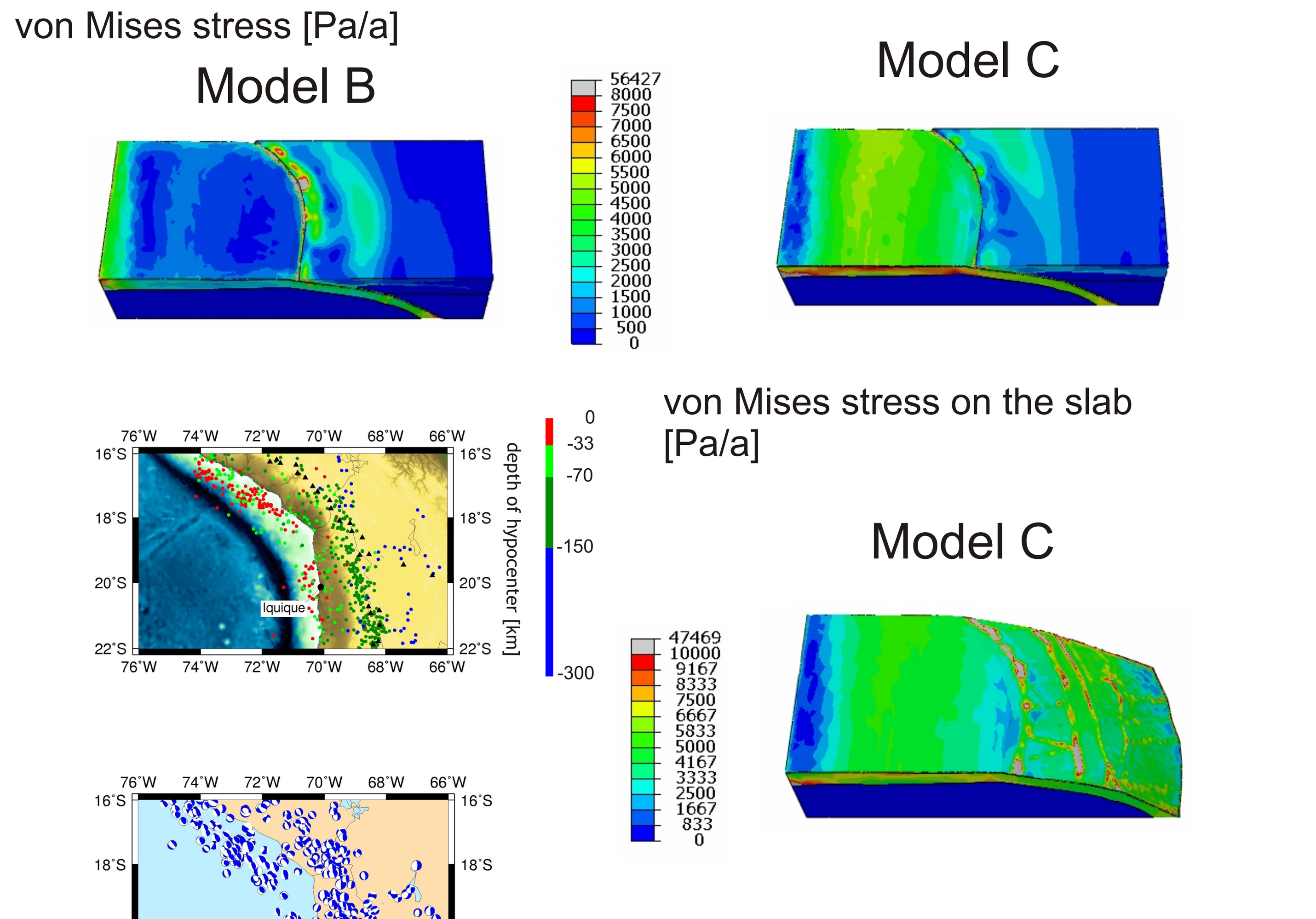

Fig. 7: Von Mises stress for two different model types. The stress accumulation tends to follow the earthquake distribution in the investigation area. Only events with M > 5 are displayed. The stripe pattern of regions with high and low seismicity is also visible in the stress field.

The focal mechanisms reveal that most earthquakes are of normal type, and only some have strike slip components.

Conclusions

Friction coefficient affects displacements proportional. Increased friction coefficient leads to higher horizontal and lower vertical displacement.

Viscosities and slab pull play an important role for the modelling results. The displacements obtained for model C are consistent with observed GPS data and the normal strain in x direction is in agreement with observation. The stress pattern fits well to the earthquake distribution and reveals a stripe pattern of higher and lower seismicity.

In future models plasticity for the lithosphere will be included in order to achieve more realistic scenarios for the subducting process.

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