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The long-term tectonic stress regimes generated by oceanic subduction: insights from 3D thermo-mechanical analogue experiments of subduction with force monitoring

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We present a new 3D thermo-mechanical analogue modeling of oceanic subduction with force monitoring developed to investigate the mechanics of subduction orogeny. We first model different subduction regimes which are characterized by the magnitudes of the depth-averaged non-hydrostatic normal stress and shear stress on the interface between the plates. The stresses are measured in the models by recording the horizontal force at the trailing edge of the subducting plate pushed at a constant rate. In the first experiments the density of the subducting plate equals the density of the asthenosphere and the slab-pull force is null. Furthermore, the surface of the upper plate is lubricated and the friction at the plate boundary is negligible. It follows that the recorded horizontal force corresponds to the force due to the flexural rigidity of the plate. The resistance to bending generates a compressive non-hydrostatic normal stress on the plate boundary and a compressive horizontal stress in the lithosphere. This non-hydrostatic normal stress is measured for various thickness of the upper plate. Next, the frictional coupling between the plates is enhanced by sifting sand grains on the surface of the subducting plate. The magnitude of the shear traction is deduced from experiments with and without shear traction. Various combinations of high or low non-hydrostatic normal stress and shear traction are then tested. Finally, the slab-pull force is introduced and, as expected, the recorded force reduces during the experiment as the length of the subducted slab increases. We identify 3 main regimes of subduction. If the subducting lithosphere is denser than the asthenosphere, the slab pull force generates suction on the interface and a tensile stress regime in the lithosphere. Otherwise a compressive stress regime is generated by either the non-hydrostatic normal stress due to flexural rigidity or the shear traction or both. However, there are two end-member compressive subduction regimes which generate different trench-parallel stress/strain in the 3D models. Compressive regime can be generated by the compressive non-hydrostatic normal stress only, in which case a convex toward the upper plate curvature of the plate boundary produces a trench parallel tension near the symmetry axis of the margin. Compressive regime can also be generated by the shear traction, in which case a trench-parallel compression is produced near the symmetry axis of a convex toward the upper plate margin. The latter scenario better fits the kinematic models of the Central Andes.