2D collision models with visco-elasto-plastic rheology applied to WNW-ESE shortening along the Niigata-Kobe Tectonic zone

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Niigata-Kobe Tectonic Zone (NKTZ) is experiencing an unusual spatially non-uniform strain rate concentration and a continuous shortening in the WNW-ESE direction whose amount is decreasing from NE toward SW direction. The NE part of the NKTZ is characterized by the presence of a 6-km thick sedimentary layer. The central and SW parts of the NKTZ are strongly influenced by volcanism and the interaction between the Philippine Sea (PHS) slab and the Pacific (PAC) slab. In order to explain the observed strain concentration, previous studies used numerical simulations with a viscoelastic rheology and suggested the existence of a weak, low-viscosity layer between the upper and lower crust in the central and SW regions of the NKTZ, possible related to the presence of magmatism and fluids. However, it remains unclear how this hypothesis elucidates the highest surface concentration observed in the NE part of the NKTZ. In this study, we employ two-dimensional high-resolution thermomechanical numerical models with visco-elasto-plastic rheology under a horizontal compressive regime. Our objective is to analyze whether surface high-strain rate along the NKTZ could be explained by the combination of a thick sedimentary layer with a low-viscosity layer located below the upper continental crust and precence of hydrated crust and, magmatic intrusions. We attempt to predict temperature, viscosity, surface strain rate and surface deformation, and three numerical setups were constructed across NE, central and SW parts of the NKTZ, aligned with the maximum compressive direction of principal strain to analyze the pattern of WNW-ESE shortening along the NKTZ: Model 1 incorporates a hydrated layer with low-viscosity between the upper and lower crust (Profile 1, SW part of the NKTZ). Model 2 incorporates a hot hydrated mantle plume intrusion below the lower crust (Profile 2, Central part of the NKTZ). We prescribed initial thermal anomaly (DT=150˚C) with a spherical shape (radius of 15 km). Finally, Model 3 (Profile 3, NE part of the NKTZ) incorporates a 6-km low density mechanically weak sedimentary layer (density= 2200 kg/m^3, Cohesion: 1x10^4, viscosity = 10^{17} Pa s). Lateral boundary conditions are used from plate motion velocities that represent the average from 1997-2022 (Kawabata, 2024), and increase from SW to NE across the NKTZ, and the total duration of the time evolution considered is 3 Myr. The numerical results for Model 1 with a hydrated crust between the upper and lower crust with a viscosity < 10^{18} Pa s, show strain concentration at the model surface with values ranging from 0-2 x 10^{-7} /yr. Model 2 in the presence of magmatic intrusion with a viscosity of 10^{16} Pa s shows an increased strain concentration at the model surface with values ranging from 2-5 x 10^{-7}/yr. Finally, Model 3 in the presence of a sedimentary layer shows the highest strain concentration at the model surface with values of 7-9 x 10^{-7} /yr. The predicted principal horizontal strain directions coincide well with the observed directions of maximum principal strain direction in WNW-ESE. Our study shows that the high-strain concentration at the Earth's surface in the NE part of the NKTZ is strongly related to the presence of low-viscosity layers (< 1x 10^{19} Pa s) due to the presence of fluids, magmatism intrusion released from the subducting slabs, and mechanically weak sediments.

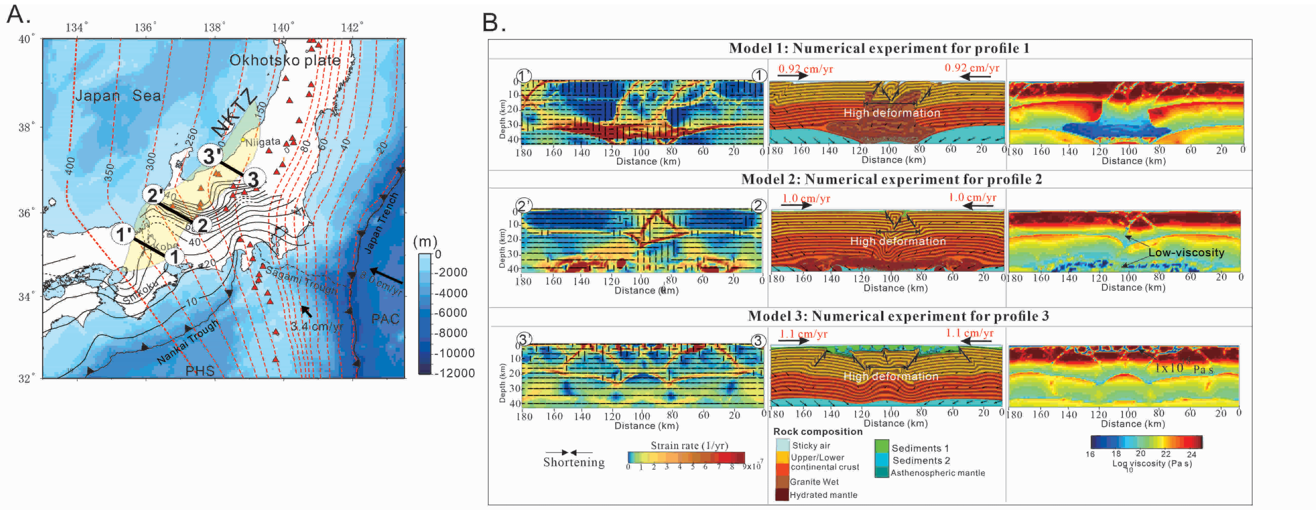

Figure 1. **A.** Map with the region and study profiles (Hirose et al., 2008). **B.** Results of 2D visco-elasto-plastic models in terms of strain rate, rock composition and viscosity for profiles 1, 2 and 3 with respective plate motion velocities taken from Kawabata (2024). The result shows strain concentration at the model surface and the horizontal directions of the strain rate on the surface of the numerical model. Note the strain and fault concentration where the low-viscosity layer is located. In the lower crust, the vertically located bars indicate extension.