Quantitative Constraints on Pre-production Reservoir Stresses in Groningen: Project Overview

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Introduction

This study is part of the DeepNL-An integrated program to understand subsurface dynamics caused by human activities. Its aim is to constrain the natural stresses in the Groningen field before production initiated in 1960. This will help to understand why after 30 years of production, induced earthquakes started to occur in the reservoir at increasing numbers and magnitudes. **Figure 1** shows fairly consistent NW-SE horizontal compression directions throughout the Netherlands.

Figure 1: Horizontal directions of maximum compression from the World Stress Map (Heidbach et al., 2016).

As natural stresses are the consequence of tectonic processes, physically consistent models of the entire Eurasian plate will allow us to estimate the tectonic forces that result in the intraplate stress field.

Workflow

Our analysis of Eurasia's dynamics consists of two steps. Firstly, we identify physically realistic sets of tectonic forces that yield torque balance of the Eurasian plate. Secondly, the balanced force sets are used to calculate the resulting stresses, which are compared with observations.

Edge and Body forces plus mantle tractions

Plate boundary forces, tractions resulting from lithosphere–mantle coupling, and intraplate variations in topography, viscosity and density structure yield a range of acceptable force distributions. (**Figure 2**).

Stresses from FEM

Computation of stresses occurs on a viscous spherical thin sheet using a plane stress formulation. (**Figure 3**).

Fitting to Observations

Model estimates of stress and velocities will be compared with stress and GPS observations in order to find the parameter values resulting in the best-fitting models. (**Figure 4**).

Reservoir Stresses in Groningen

Consequently, the likely range of the direction and magnitude of natural stresses in Groningen from the models and the observations is determined. The stress range at reservoir depth in Groningen is computed from the lithospheric average stresses employing the finite difference method of Kusznir (1982)

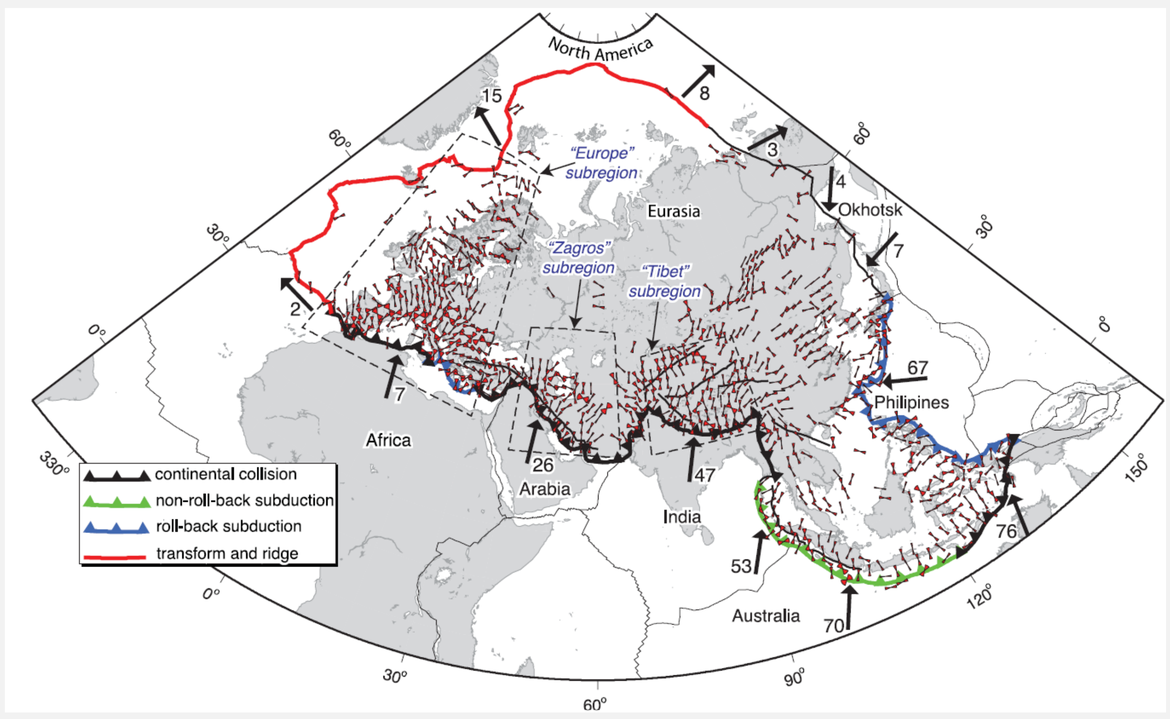

Figure 2: Plate boundary types and internal faults (thin black lines) of our model Eurasian Plate. Arrows denote NUVEL-1A velocities in mm yr-1 of adjacent plates. Red fans indicate directions of most compressive horizontal stresses including error margin from averaging World Stress Map observations. Dashed lines enclose subregions in which we separately evaluate model stresses.

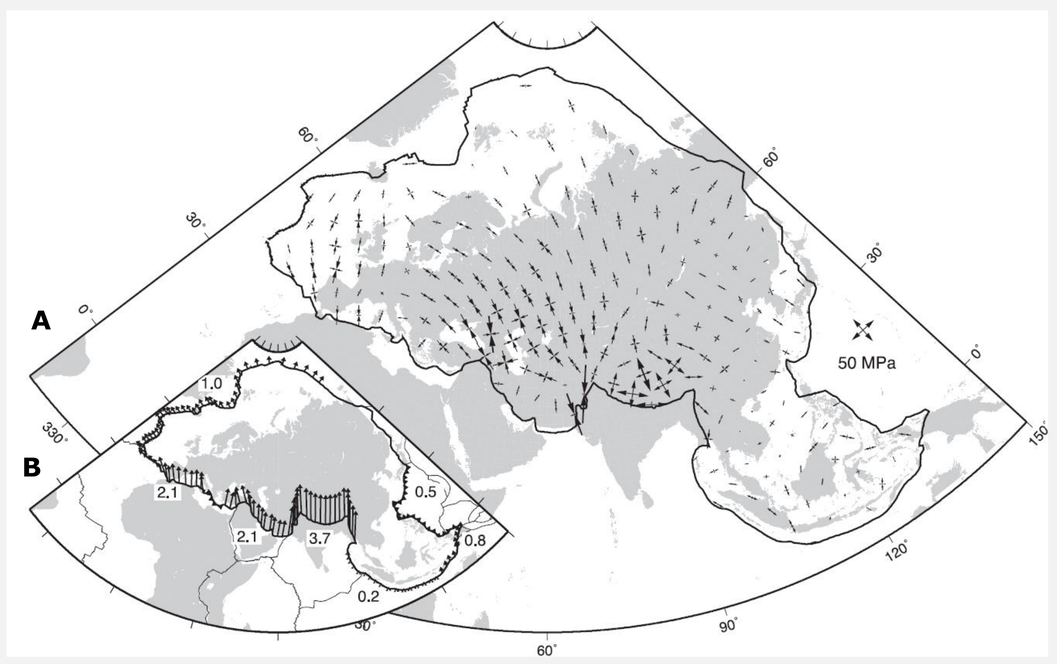

Figure 3: (A) Lithospheric stress model for the Lithospheric stress model for the Eurasia plate that fits observed stress directions best (Warners-Ruckstuhl et al., 2013). (B) Plate interaction forces for this model.

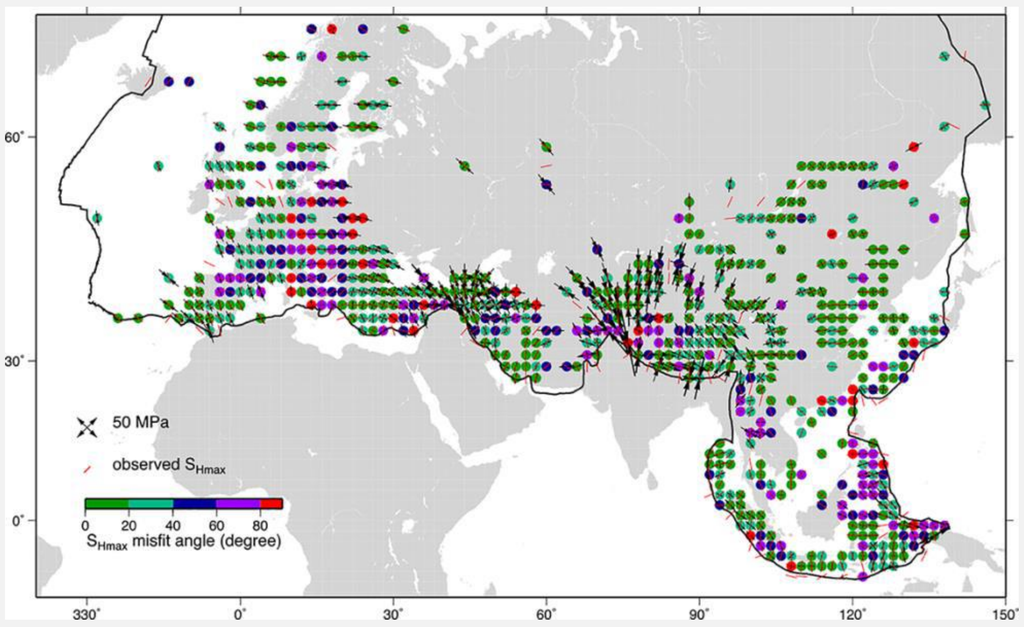

Figure 4: Comparison of model stress directions with observations (Warners-Ruckstuhl et al., 2013). The average misfit angle (32°) is larger than the average data uncertainty (24°). The stress model does not capture regional variations within Europe well.

References

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