

## **Modeling of rheology structures and stress fields in Japan**

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Three-dimensional thermal and rheology structure models of the crust and upper mantle beneath Japan are created to numerically simulate the displacement rate, strain rate, and stress rate distributions in various areas in Japan. We have used the finite element method (FEM) to simulate deformation of the Japan islands under east-west horizontal compression. The resulting strain rates near the ground surface demonstrated a feature that is similar to the so-called Niigata-Kōbe Tectonic Zone which is discernible in the analysis results for geodetic data (e.g. Sagiya et al., 2000).

### **Creating a thermal structure model**

Before estimating a rheology structure, we have created a three-dimensional thermal structure model of the upper crust, lower crust and upper mantle. We first estimated a temperature distribution at depths D90, where ninety percents of hypocenters are distributed above that depth, by assuming that the brittle strengths estimated from the upper crust equal the flow strengths from the lower crust at D90. Secondly, we estimated the thermal structure below the depth 45 km with a method of Nakajima and Hasegawa (2008), using a tomography image of intrinsic attenuation (Nakamura, 2008) and actual temperature data of the mantle estimated from mantle xenoliths. Regions deeper than the upper surfaces of the Pacific and Philippine Sea plates (PSP) were excluded from the model. The temperatures on the upper surface of the PSP were given a priori as a function of depth when it lies shallower than 45 km. Finally, we spatially interpolated the rest part of the model and obtained a three-dimensional thermal structure of the lower crust and the upper mantle.

### **Viscosity structure model**

We have then modeled the viscosities of the crust and upper mantle using experimental results for the constitutive relations of quartz (wet), anorthite (wet) and olivine (wet), respectively (Bürgmann and Dresen, 2008). The distributions of the Conrad and Moho depths were taken from Katsumata (2010). This led us to obtain a crustal structure model based on power-law fluids, but we had to simplify this model so that we could implement the FEM using limited computer resources. We first linearized the power-law viscosities. More specifically, we imposed the temperature distribution of the thermal structure model described above and calculated the flow strengths and effective viscosities for an assumed strain rate of  $2 \times 10^{-15}$  [1/s]. Next, we remodeled all parts, exceeding  $1 \times 10^{22}$  Pa·s in effective viscosity (10,000 years in relaxation time) and exceeding 20 MPa in strength (5-10% of the maximum strength in the brittle-ductile transition zone) as elastic zones, and all other parts as viscous zones with an effective viscosity of  $1 \times 10^{21}$  Pa·s. In other words, we characterized the whole crust using two viscosity values. In this model, the elastic layer thickness ranged roughly between 10 and 30 km, with the layer thinning along volcanic fronts as in the model advocated by Shimamoto (1994).

### Three-dimensional FEM analysis

We divided the Japanese archipelago into several rectangles—or rectangular boxes with their faces perpendicular to the N90°E or the N110°E direction (to be designated the  $x$ -direction in each respective case). We used a three-dimensional FEM program (Aagaard et al., 2008) to analyze the spatiotemporal response (in terms of the displacement, strain and stress) in the interior of each rectangular box under uniform compression in the  $x$ -direction. We imposed step displacements, proportional to the length of the sides in the  $x$ -direction, on faces that were perpendicular to the  $x$ -direction (the displacements were adjusted so that the mean strain was  $5 \times 10^{-6}$ ). The displacement in the normal direction was set at zero on all other boundary faces. The ground surface was treated as a free surface.

The  $t \rightarrow \infty$  limit of the step response, thus calculated, may be regarded as the steady rate of response to a constant displacement rate input (e.g. Matsu'ura and Sato, 1988). In the present study, we extracted the displacement, strain and stress distributions (almost unvarying) a sufficiently long time of 100,000 years after the step input, and regarded them as the steady rates of displacement, strain and stress.

The resulting equivalent strains on the ground surface (Fig. 1(a)) tended to be large in areas that corresponded relatively well to the strain concentration zones (Niigata-Kōbe Tectonic Zone) indicated by geodetic data (Sagiya et al., 2000). The uplift rates on the ground surface (Fig. 1(b)) tended to be large along the Sekiryō (Backbone) mountain range in the Tōhoku district, in the Northern Alps and in the Central Uplift Zone.

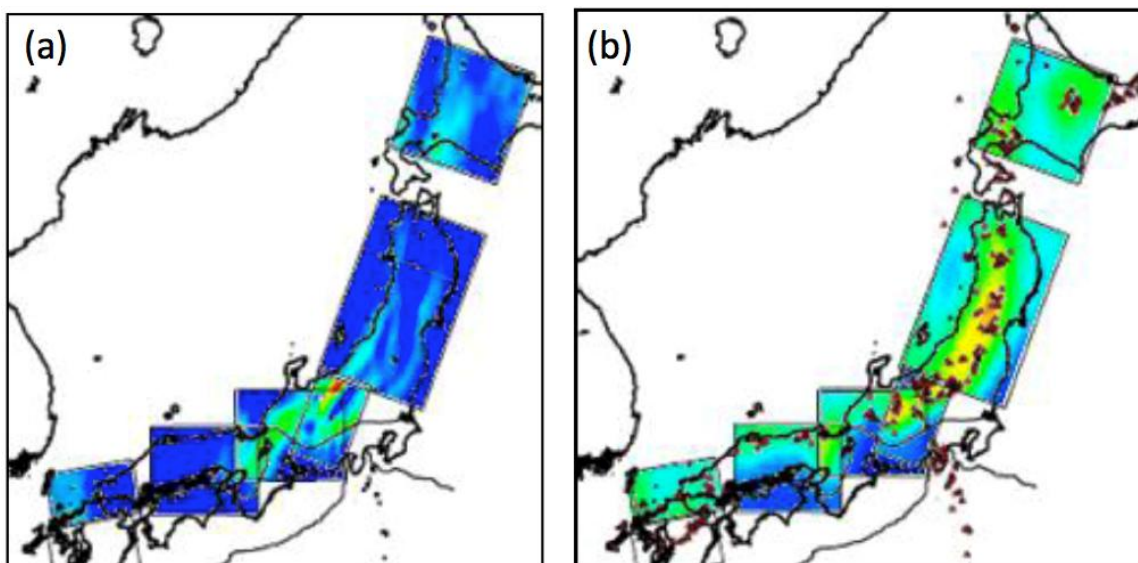


Fig. 1 Equivalent strain rate (a) and uplift rates (b) calculated from the FEM models.