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Stress fields in inland areas of the Japanese Islands reproduced by plate subduction and compression

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We calculated theoretically the stress accumulation rates generated by the subduction of plates surrounding Japan and by crustal compression, with a view to elucidating the origins of the overall stress distribution patterns in the Japanese Islands.

As in Hashimoto and Matsu'ura (2006), the stress accumulation rates were calculated by superposing analytic solutions for viscoelastic responses to dislocations along plate boundaries (Sato and Matsu'ura, 1991). Rates of relative motion between the Eurasian, North American, Pacific and Philippine Sea plates were derived from the NUVEL-1A model (DeMets et al., 1994). No relative motion was assigned to the Izu collision zone. We adopted the NIED's J-SHIS model for the geometry of the subducting Pacific plate and Nakajima et al.'s (2009) model for the geometry of the subducting Philippine Sea plate. Viscoelastic responses were calculated by using the analytic solution of Fukahata and Matsu'ura (2006) for an assumed elastic/viscoelastic two-layered structure (elastic layer thickness 40 km).

Calculations for individual plate subduction-zone segments produced stresses that tended to be of the normal-fault type inland in front of a subduction zone, of the reverse-fault type on both its sides, and of the strike-slip type diagonally to its front. The normal-fault type stresses in front of a subduction zone were also present in the results of Sato and Matsu'ura (1991), who pointed out the effects of plate bending.

Summing up the effects of all subduction zones resulted in the accumulation of strike-slip type stresses in the Izu area and to its front, whereas accumulation of normal-fault type stresses was seen nearly everywhere else in the Japanese Islands. In reality, by contrast, active fault surveys and seismic source mechanism analyses have revealed the following characteristics in the Japan area:
(i) Compressional stresses, tending roughly E-W, from eastern Hokkaido to northern Kyushu
(ii) Reverse-fault type stresses over broad areas in NE Japan, and strike-slip type stresses over broad areas in SW Japan
(iii) An island of reverse-fault type stresses in the Kinki triangular zone in SW Japan.
The above calculations have therefore not been able to reproduce the real stress fields.

On top of the calculation results described above, we added a homogeneous compressional stress rate of 3 kPa/y oriented N110E, which is the direction of motion of the Pacific plate. This changed the normal-fault type stresses into the strike-slip type. However, the reverse-fault type stresses in the Tohoku district could still not be reproduced.

Finally, we assumed crustal shortening localized in the Tohoku district and, instead of adding homogeneous E-W compression, we imposed normal, compressional stresses along the plate boundary off Tohoku.We then redid the calculations by slicing 25% off the plate subduction rates off Tohoku. This relies on the hypothesis of Takahashi (2006), who argued that the westward motion of the Philippine Sea plate necessitates westward motion of the Izu-Bonin trench, whereby the Japan trench also travels westward at a speed of 2-3 cm/y. The Tohoku district is thereby subject to horizontal compression from the east and, out of the approximately 10 cm/y in the relative plate motion rate, net subduction accounts for only 7-8 cm/y. These recalculations changed the stresses in Tohoku into the reverse-fault type, overall satisfying the characteristics (i)-(iii) . It thus became evident that the overall patterns of the stress fields in Japan can be explained by considering the combination of two factors, namely (1) subduction of the neighboring plates and (2) compression/shortening in the Tohoku district.

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Keywords: Stress field, Stress accumulation, Plate tectonics, Viscosity, Collision, Subduction