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Flexural modelling of circum-Pacific trench - outer-rise systems and its implications for mantle rheology

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The strength of the lithosphere is determined by its flexural rigidity, which is commonly expressed through the effective elastic thickness, T_e. In oceanic regions, it is widely accepted that T_e increases as a function of age at the time of loading due to thermal cooling of the lithosphere. A recent trench - outer-rise study, however, has questioned whether such a simple relationship exists. In order to reassess the relationship between strength and age, we use trench-normal, ensemble-averaged profiles of satellite-derived free-air gravity anomalies to model the trench - outer-rise of circum-Pacific subduction zones. A broken elastic plate model is used, with a finite difference solution that allows T_e to vary as a function of distance from the trench. We use an inverse approach, iterating T_e values and solving for a vertical shear force and a bending moment.

We first model the profiles using a plate of constant T_e. Results show that lithosphere younger than 100 Ma clearly strengthens with age. For example, the Middle America trench (6 - 29 Ma) has a mean T_e of 14.7 $\pm$ 2.0 km, the Aleutian trench (42 - 63 Ma) has a mean T_e of 29.8 $\pm$ 3.3 km, and the Kuril trench (97 - 129 Ma) has a mean T_e of 41.0 $\pm$ 3.8 km. For lithosphere older than 100 Ma, however, the relationship is not as clear.

For many subduction zones, a plate of constant T_e cannot fit the wavelength of the bulge and the high curvature of the seaward wall of the trench, suggesting localized weakening. We therefore model the profiles with a plate that is allowed to weaken trenchward of the outer-rise. This provides significantly improved fits to observations. We attribute this apparent weakening primarily to inelastic yielding - a combination of brittle fracture of the upper lithosphere and ductile flow of the lower lithosphere - due to high curvatures. Evidence for this can be seen in swath bathymetry and seismicity data, which reflect zones of pervasive extensional faulting in the trench outer-rise region.

Curvatures and strain rates derived from best-fit models are used, together with brittle-elastic-plastic yield strength envelopes, to calculate T_e. The calculated and inverted T_e values are then compared in order to constrain experimentally-derived low-temperature plasticity laws. We find that when inelastic yielding is taken into account, the flow law of Mei et al. (2010) accounts well for the inverted values. This result contrasts with that of Zhong and Watts (2013) who used a non-linear viscoelastic model to fit the seismically-constrained flexure beneath the Hawaiian Islands, finding that the Mei et al (2010) flow law produced a lithosphere that was too strong to fit observations. We discuss here the possible causes of the discrepancy between the trench – outer rise and Hawaiian Islands results and examine their implications for lithosphere rheology.