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How 'refrigeration weakening' drives catastrophic subduction initiation

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New subduction zones have initiated repeatedly throughout Earth's history, meaning that some process inherent to the evolution of oceanic lithosphere regularly overcomes net resistance to subduction. However, thermal histories of metamorphic rocks formed during subduction initiation pose a rheological paradox: the highest temperatures, at which rocks are theoretically the weakest, coincide with a protracted phase of mechanical resistance to subduction. Moreover, rapid cooling and depression of slab-parallel isotherms (i.e., 'refrigeration'), during which rocks would be expected to stiffen, occurs at the onset of self- sustaining subduction when the lower plate collapses into the mantle. Here, we present microstructures from metamorphic rocks formed along ancient hot, warm, and cold plate interfaces and demonstrate that refrigeration drives changes in metamorphic phase stability, distributions of strainaccommodating minerals, and deformation mechanisms that dramatically weaken the developing plate boundary. Paleopiezometry and flow laws bracket rock strength, and quantify a ~2–3 order of magnitude viscosity reduction along the interface from ~1020 to 1017 Pa-s at a ~500°C/GPa threshold, facilitating feedbacks that accelerate subduction rates, sustain refrigeration, and maintain plate boundary weakness. The 'refrigeration weakening' hypothesis explains observed changes in upper plate stress state, inferred slab velocity, and timing of proto-forearc volcanism.

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