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Fabric development as the key to forming ductile shear zones and enabling plate tectonics

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The Earth is the only object in the solar system to feature plate tectonics, a thick, oxygen-rich atmosphere, liquid surface water, and life. These unique traits are likely interlinked. Comparing Earth to Venus leads in particular to the conjecture that water is key to explaining plate tectonics, but how does this link work? Plate tectonics requires not only sufficient heat sources in the planetary interior but also the development of weak, narrow deformation zones, or plate boundaries. On Venus, such deformation zones are observed only where divergence is present. As brittle failure is observed both on Earth and on Venus, the difference in tectonics style between these planets is probably due to ductile localization. I examine several ductile localization processes that have been proposed based on field observations on Earth and evaluate their localization potential, defined as the maximum narrowing of a deformation zone that accompanies a change in deformation condition or rock microstructure. This analysis shows that shear heating and grain size reduction are not efficient enough to localize deformation unto a plate boundary. However, the development of a fabric in deformed rocks, which switches the control of the rheology of a multiphase aggregate from the strongest to the weakest phase, can have an extremely high localization potential. This occurs if a highly non-linear phase, like mica, is present in the rock, or if there is a significant strength contrast between the various rocks. According to this model, localization is possible on Earth thanks to the presence of hydrated minerals such as micas and serpentine in ductile rocks. Even the strength contrast between wet olivine and diabase in the mantle or between wet feldspar and quartzite in the crust is sufficient to induce localization upon fabric transition. On Venus, similar phyllosilicates are not expected to be stable, and the strength contrast between dry mineral phases is not sufficient to produce localization. In a rifting environment, melt may act as a weak phase, but otherwise, the high surface temperature and extreme dryness of the Venus environment prevents effective ductile localization and therefore the development of plate tectonics.