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Non-linear till waves

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The advance of a glacier over a deforming sediment layer is analysed numerically. We treat this problem as a contact problem involving two slowly-deforming viscous bodies. The surface evolution of both bodies, and that of the contact interface between them, is followed in time. Using various different till rheologies we show how the mode of advance depends on the relative effective viscosities of ice and till. Three modes of advances are observed: 1) overriding, where the glacier advances through ice deformation only and without deforming the sediment; 2) plug-flow, where the sediment is strongly deformed, the ice moves forward as a block and a bulge is built in front of the glacier; and 3) mixed-flow, where the glacier overrides deforming sediment. An inverse depth-age relationship is obtained for a glacier advance by both overriding and mixed-flow. An additional model experiment, using a till with near plastic rheology, shows that the contrast in effective viscosity between ice and till is the single most important model parameter defining the mode of advance and the resulting thickness distribution of the till. Furthermore, the model calculations imply that measurements of sediment thickness and sediment deformation taken closely to the glacier front significantly overestimate the average sediment thickness and displacement due to sediment deformation. A sediment bulge is formed in front of the glacier given sufficiently large contrast in effective viscosity between ice and till. During glacier advance, the bulge quickly reaches a steady state form strongly resembling single-crested push moraines. Inspection of particle paths within the sediment bulge, shows the material particle of the till to travel at different speed to that of the bulge itself, and the push moraine to advance as a form-conserving non-linear wave.