MODELING STRAIN IN A GLACIOTECTONIC LOBATE MORAINE

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There is ample field evidence that the deformation of glacial sediment in the front of advancing glaciers produces distinct compressional features that are comparable to those in tectonic foldbelts. Like the deformation that occurs in thin-skinned contractional belts, glaciotectonic push moraines often possess an arcuate shape. In order to understand how glaciotectonic ridges are formed, and to provide a basis for comparison with field observations, it is essential to model this environment in the laboratory. By appropriately scaling the mechanics and composition of the push moraine, a laboratory model can encompass the basic physics that control the formation of glacial ridges and also allow the calculation of strain orientations resulting from their formation.

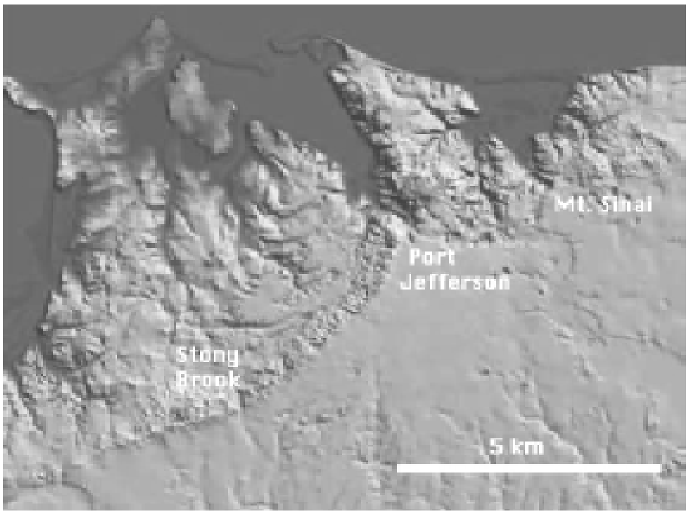

Figure 1 Map of the Stony Brook area Harbor Hill Moraine. The hills are anticlines and the push-moraine has a non-linear, but rather arcuate shape.

Push moraines (and foldbelts) are commonly found to have a lobate, arcuate shape: Figure 1 shows such a lobe in the Stony Brook area of the Harbor Hill moraine. It is reasonable to assume that the style of deformation associated with building such a push moraine will depend upon the conditions within and in front of the glacier. A relatively rigid, high yield-strength glacier/sediment mass can be assumed to advance with relatively little gravitational spreading in the direction of its lateral flanks, with finite strain axes that are nearly parallel, indicative of shortening that is primarily in one direction (Fig. 2a). Such a 'strong-push moraine' would likely be sediment-heavy, with relatively strong mechanical coupling at its base, high yield stress, and sediment that is permafrost. A weaker flowing glacier/sediment mass extends in all directions like a gel. In such a 'weak spread moraine' case there would probably be less sediment intermixed with the ice, and the sediment would, in general, not be permafrost. Displacements and strains are expected to be radially oriented in moraines formed by such ‘weak’ glaciers because yield stresses (and thus basal drag-forces and distally-transmitted stresses) would be small compared to gravitational slope-generated stresses of the sort that generally drive glaciers (Fig. 2b). It is possible to create laboratory analog models that possess the characteristics of either strong or weak glaciers to be related to strain data that have been collected in the field. In the initial phases of this study, we have concentrated upon evaluating the applicability of our new model strain analysis techniques to the problem of a 'strong push' moraine.

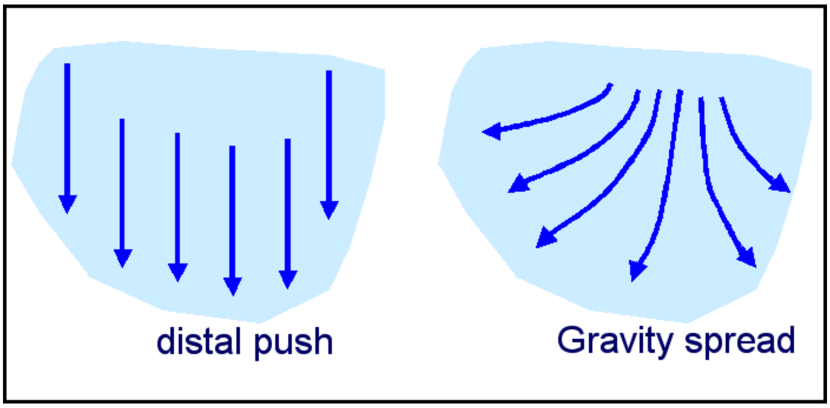

Figure 2 a) Representation of a rigid, sediment-heavy glacier. Strain axes are all nearly parallel to the movement of the advancing glacier, and there is hardly any effect of gravitational spreading. b) Representation of weak flowing glacier with gel-like qualities. Strain axes are arranged radially, with the front strain vector parallel to the movement of the advancing glacier. Gravitational spreading is the general driving force of the glacier.

Clast fabric orientation of glacial deposits can be used to measure strain. Strongly oriented clast fabrics are distributed in similar directions to finite strain vectors and fault slip axes. Such strain observations can be compared with laboratory models and can be used to constrain a landform evolution model (Klein, 2002). Laboratory modeling can quantify how strain might vary across an arc as a function of glacial geometry and composition. In the front of an arc, tectonic or glacial, the strain vector is expected to be parallel to the convergence direction - in the glacial setting, the direction of movement of an advancing glacier. Moving along the arc, the strain vectors rotate around toward the normal to the deformation front. Natural and laboratory structures show this fanning, as illustrated in Figures 3a and 3b. Additionally, if the two no-length change directions, that represents the direction of fault slip and the strike (e.g. Holt and Haines,1993; Shen-Tu et al., 1998), are determined we can ascertain the exact deflection of slip, from the distal glacial motion, at the front of the glacier. This should then correspond to the slip vector direction, as determined for faults and shear zones using small-scale secondary structures.

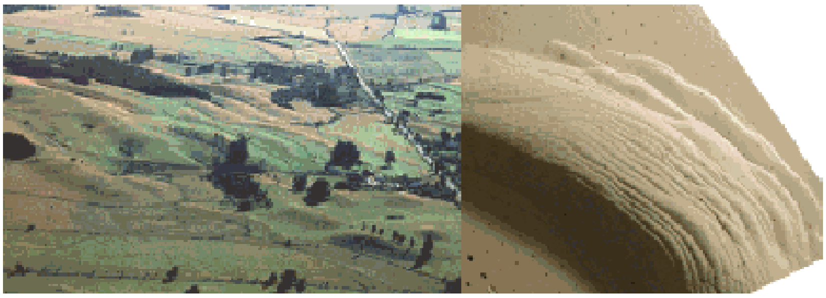

Figure 3 a) Aerial image of a set of proglacial folds in Chile, with undisturbed outwash at right (T. Lowell, U. Cincinnati web site). Note that fold amplitudes decreases away from the ice (to the right). b) Oblique view of simple ‘sandbox’ model for thrusting ahead of a curved indenter, such as a glacier front. Note the crude resemblance to the form of the folds in (a). It is of interest to discover whether such structures can be modeled more realistically and more quantitatively.

The laboratory models we have developed are qualitatively similar to what is observed in a natural setting, and can give a more quantitative understanding of the behavior of a glacial push moraine. By understanding behavior in a laboratory model, it becomes possible to understand better the significance of field data. In the model apparatus, a Plexiglas sheet with an arcuate shape, representing a relatively rigid, strong glacier was placed into the "sandbox" and a thin layer of sand was smoothed over it. Sand is used because, at the scale at which such laboratory experiments are conducted, it possesses properties similar to the bulk behavior of friction-dominated sediments. Colored sand dots were placed over a smooth layer of sand and were used as displacement markers. To quantify the evolution of our experiment, we used the method of Haq and Davis (2001), in images of the experiment taken with a multi-mega pixel digital camera are analyzed. The backwall of the "sandbox" is attached to a motor causing compressional motion along the arc as it moves forward. The digital images are taken at frequent intervals, and the positions of the marker dots were later compared, to determine displacement and strain. Displacements are determined directly from the changes in relative positions of the marker dots, and strains are calculated from the derivatives of the components of that displacement, with respect to position.

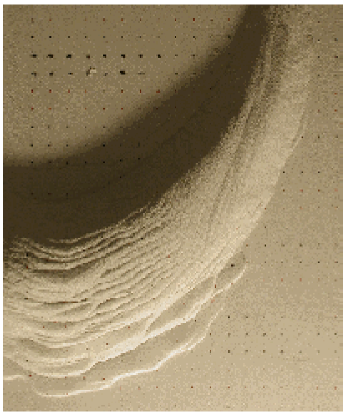

Figure 4 a) (above) Map view of a simple 'sandbox' analog modeling experiment. A curved indenter plate lies below the sand in the upper-left portion of the image. A motor-driven wall advances the plate toward the southern (lower) portion of the image. The sand has been sifted and smoothed to an initially uniform thickness. The topography develops at the front of the Plexiglas ('glacial ice') very much like sand in front of a bulldozer blade, or accretionary wedge at a forearc.. Marker dots are used for the calculation of displacements and strains (see Figure 4b).

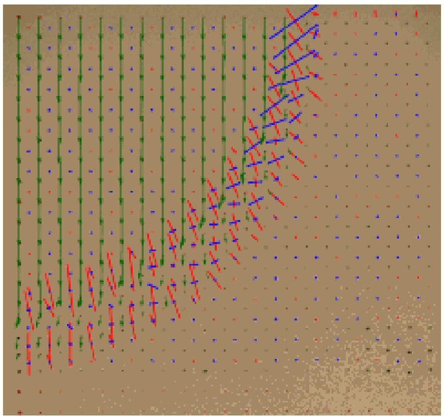

Figure 4 b) (above) Displacement vectors (green) and the horizontal components of compressional and extensional axes (red and blue, respectively) at an early stage of the experiment at left. A series of digital images have been processed (e.g., Haq and Davis, In Preparation) in which the motions of each marker dot are determined for the duration of the experiment, allowing the calculation of strain and displacement in the models to a high degree of precision. Note that in this model, the magnitudes and directions of strain vary systematically around the arcuate set of ridges. Thus, we can relate the conditions of deformation (e.g,, frictional, cohesive, or viscous) and the boundary conditions (e.g., ice indenter rate, shape and strength) to structures and fabrics observed in field studies of modern and Pleistocene proglacial deformation. This should help in interpreting field data to understand better the conditions under which relict proglacial ridge systems formed.

The final results were a series of strain field plots demonstrating the compression, extension, and shearing that that has occurred on and around the model glaciotectonic fold belt. The plots resemble the fanning structure that was predicted (Fig. 4). The rotation of the strain field can be compared to both weak and strong glaciers. The strain vectors are arranged in an array between the parallel strain vectors of the strong glaciers and the radial vectors of the weak glaciers. By modeling glacial lobes in the laboratory we will be able to understand the bulk mechanics of the ice-sediment mix. A clearer understanding of glacial formation can be obtained. In addition, these models might be able to calibrate field data that are collected.

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