thicknesses, vapor may move deep into the ground (see below) and refreeze atop the buried ice surface, producing visible pore ice (Marchant et al., 2002; Kowalewski et al., 2006). These secondary ice lenses contrast markedly with glacial ice by lying on a δD versus δ^{18}O slope of 5 rather than a precipitation slope of 8 and by possessing a strongly negative deuterium excess (Marchant et al., 2002).

3. Methods

Our numerical models for vapor diffusion through Mullins till require quantitative input regarding the thickness, texture (grain size and porosity), and thermal properties of Mullins till (specific to each facies), as well as the local meteorological forcing that drives vapor diffusion.

3.1. Thickness, texture and thermomechanical properties of Mullins till

Thickness data for Mullins till come from field measurements of over 250 soil excavations. Till thicknesses are based on the measured depth of the matrix fraction (± 1 cm) and do not include the height of surface cobbles and/or boulders that cap Mullins till (Fig. 3D). All measures for till thickness come from polygon centers, not from polygon margins where local thinning and thickening from minor mass wasting into polygon troughs obscures general trends in till thickness (Marchant et al., 2002; Levy et al., 2006).

Grain size data for each facies come from analyses of the <16-mm fraction using standard wet and dry sieving techniques (>50 samples, each ~2 kg, from 42 different soil excavations). To determine minimum porosity values for each facies, we collected *in situ* sediment samples from the finest grain size fraction observed in the field by inserting the leading edge of a 10-cm wide by 8-cm deep by 20-cm long aluminum C-channel into exposed soil sections. Areas with highest gravel content were avoided during sampling. Once removed, we wrapped the samples and aluminum casing with plaster of paris to prevent movement. At Boston University, we placed the samples in a bath of styrene monomer polyester resin, resulting in uniform impregnation and cementation through gravity and capillary action alone. The impregnated casts were allowed to harden in a drying oven at 70 °C for five days and then cut into thin sections for image analyses. We calculated pore size in two dimensions via MATLAB image analysis. Measures for the degree of soil development are based in part on visible staining (rubification) as gauged in the field by reference to standard Munsell color equivalents (MCE).

3.2. Meteorological data collection

To understand better the range of meteorological conditions in the study region, we installed a network of 10 micrometeorological stations (HOBO™ Smart Sensor weather probes, Onset Computer Corporation) at five locations (Fig. 2; Tables 1a, 1b, 1c) and collected data from December 2003 to December 2009. A detailed subset of meteorological data was collected from 3 to 24 December 2006. As noted in Tables 1a, 1b, 1c each meteorological station housed sensors for measuring a combination of solar radiance, relative humidity, atmospheric temperature, soil temperature, and soil moisture. Precise sensor placement depended on site-specific characteristics. However, in most cases soil temperature sensors were placed at the ground surface and at subsequent 10-cm depth increments; atmospheric temperature sensors were located 10 cm above the ground surface, with sensors housed in white PVC radiation shields supplied by Onset Computer Corporation (Tables 1a, 1b, 1c); soil moisture sensors were placed ~2 cm below the ground surface (and at two localities on the buried ice surface itself). Wind speed and wind direction were collected at a single locality halfway down Mullins Glacier (Fig. 2; Tables 1a, 1b, 1c); data collection for all sensors occurred at 15-min intervals. Our measured changes in soil temperature with depth enabled calculation of soil thermal diffusivities for each facies as described in Section 5.1 below.

4. Results

4.1. Variations in the thickness of Mullins till

The thickness of Mullins till increases downvalley, varying inversely with modern horizontal ice flow velocity (Fig. 4). In the region of relatively fast ice flow near the valley head, Mullins till is composed of scattered dolerite grus, rock fragments, and isolated cobbles; the debris covers <10% of the local glacier surface. At ~1300 m from the headwall,

Table 1a
Summer climate data from Mullins Valley, 3–24 December 2006.

Meteorological station	Elevation (m)	Distance down valley (km)	Depth to ice (cm)	Furthest penetration of 0°C isotherm (cm)[a]		Temperature (°C)					Atmospheric RH (%)			Solar radiance (W/m^2)		
						Mean	Min	Max	Diurnal variation (average)	Diurnal variation (max)	Mean	Min	Max	Mean	Min	Max
Site 1	1550	2.5	10	4.2	Atmosphere	−11.7	−18.1	−2.9	7.9	11.7	51.7	15.3	86.3	242.7	16.9	943.1
					Till surface	−7.6	−18.0	7.8	16.3	25.7						
					Till / ice contact (10 cm)	−10.6	−13.8	−6.9	3.7	5.7						
Site 2	1524	3.0	15	5.9	Atmosphere	−10.6	−18.1	−2.4	8.7	12.5	48.8	13.3	86.8	270.3	16.9	854.4
					Till surface	−8.2	−17.8	10.9	18.4	28.3						
					Till / ice contact (18 cm)	−12.1	−13.8	−11.0	0.7	1.3						
Site 3	1442	3.8	22	14.6	Atmosphere	−10.4	−16.7	−3.4	6.0	9.2	47.6	13.8	87.3	273.8	16.9	751.9
					Till surface	−4.5	−14.5	14.1	16.0	26.1						
					Till / ice contact (22 cm)	−7.9	−10.4	−5.0	2.3	3.5						
Site 4	1374	4.5	25	12.1	Atmosphere	−8.8	−14.7	−1.1	6.7	9.5	42.2	7.8	86.3	–	–	–
					Till surface	−2.8	−11.9	11.9	13.1	19.7						
					Till / ice contact (25 cm)	−9.7	−11.0	−8.3	0.6	0.8						
Site 5	1272	7.8	50	10.0	Atmosphere	−8.4	−13.5	−0.6	6.4	9.0	44.0	8.8	86.8	306.8	55.6	890.6
					Till surface	−3.8	−12.6	11.5	15.6	22.2						
					Till / ice contact (50 cm)	−11.8	−13.1	−11.1	0.2	0.5						

Atmospheric temperatures taken 10 cm above the till surface.
[a] Furthest penetration of 0 °C isotherm was calculated using a linear interpolation between measured soil temperatures.