TILL GENESIS AND MORAINE DEPOSITION DURING PLEISTOCENE GLACIATIONS IN THE UINTA MOUNTAINS, UTAH

by
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ABSTRACT

The record of Pleistocene glaciations in the western Uinta Mountains features well-preserved sequences of continuous moraines at the mouths of several valleys. Recent mapping of surficial geology in this area, cosmogenic-exposure dating of moraine boulders and glacier reconstructions provide insight to the timing and climate of glaciations in the Uintas, but processes of till genesis and moraine deposition during these events remain poorly understood. To address this issue, we studied three outcrops of moraine sediments in the Blacks Fork and Lake Fork valleys where Pleistocene glaciers deposited latero-frontal moraines on the piedmont, and in the Hades Creek valley where a glacier deposited a continuous lateral moraine. The moraines in these three areas are sharp-crested, narrow, continuous ridges with 30 – 70 m of relief and crest lengths of as much as 11 km.

The genesis of tills exposed in end moraines was inferred from pebble fabrics, grain-size analysis, sedimentary structures and stratigraphic observations. The most abundant till facies in all three moraines is a matrix-supported (60 – 85% matrix), light brown to reddish brown sandy loam to loamy sand diamicton, in which long axes of elongate pebbles display consistent trends, but eigenvalues suggest a weak pebble fabric ($S1 = 0.47 – 0.63$). I interpret this facies to represent deposition by sediment flow.

The Lake Fork moraine is composed entirely of sediment-flow deposits, whereas moraines at the Blacks Fork and Hades Creek sites are also composed of thin (~5 – 50 cm thick) lenses of sorted sand and gravel, indicating that ice-marginal melt water was partly responsible for moraine deposition. Evidence for deposition of melt-out till or lodgment till in the studied moraines is limited; only one till exposed in the Blacks Fork moraine was inferred to be deposited by lodgment based on its degree of compaction and high clay content relative to the sediment-flow deposits. The abundance of sediment-flow deposits suggests that ice surfaces in the Uinta Mountains were mantled by debris near their termini, and that moraines were constructed primarily by deposition of supraglacial sediment.

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Introduction

Debris carried either within or on a glacier can be deposited in a variety of ways. Much of the sediment deposited is poorly sorted, unstratified, and contains a wide range of particle sizes (Johnson, 1990); such material is classified as diamicton. The characteristics of diamicton deposited by glaciers vary greatly and depend on the processes involved in deposition. By studying the sedimentary processes of modern glaciers and by examining characteristics of their deposits we can infer the genesis of ancient glacial deposits. This has led glacial geologists to place a greater emphasis on sedimentological studies (Johnson, 1990; Dowdeswell and Sharp, 1986; Mark, 1973; Lawson, 1979; Kruger and Kjaer, 1999; Ham and Mickelson, 1994; Hansel *et al.*, 1985; Evans *et al.*, 2006; Carr and Rose, 2003) in order to understand the behavior of Pleistocene ice sheets.

Geologists have generally recognized three facies of glacial diamictons deposited at the glacier sole: glacitectonite, subglacial traction till, and subglacial melt-out till (Evans *et al.*, 2006). Facies classifications are based largely on the observations of diamicton at Matanuska Glacier in Alaska, where Lawson (1979) observed glacial depositional processes and their sediment source. A recent review by Evans *et al.* (2006) defines *glacitectonite* as "rock or sediment that has been deformed by subglacial shearing (deformation) but retains some of the structural characteristics of the parent material" (p. 169), *subglacial traction till* as "sediment deposited by a glacier sole either sliding over and/or deforming its bed, the sediment having been released directly from the ice by pressure melting and/or liberated from the substrate and then disaggregated and completely or largely homogenized by shearing" (p. 169), and *subglacial melt-out till* as "sediment released by the melting or sublimation of stagnant or slowly moving debris-rich glacier ice, and directly deposited without subsequent transport or deformation" (p. 169).

In all of these subglacial tills, the trend of the long axes of elongate pebbles and the plunge are generally parallel to the local directions of ice flow. However, in melt-out tills the range of pebble trends is less variable, resulting in a stronger fabric. Pebbles in basal ice and melt-out tills show a unimodal distribution of orientations with individual observations only slightly dispersed about the mean axis. The patterns of mean axes of basal ice and melt-out till pebble fabrics correspond approximately to the local and regional trends of ice flow (Lawson, 1979).

The pebble fabric in diamictons deposited by sediment flow is unrelated to the direction of ice flow, but rather originates from the depositional process. Pebbles are polymodal with a significantly larger amount of dispersion about the mean axis. The patterns of pebble fabrics in sediment flow deposits do not necessarily indicate the direction in which the ice flowed (Lawson, 1979).

A study by Dowdeswell and Sharp (1986) documented the characterization of pebble fabrics in modern terrestrial glacigenic sediments. Over 100 samples from modern environments were used to show fabrics characteristic of melt-out till, deformed and undeformed lodgment till, and sediment flow deposits. Lodgment till fabric variability was found to be related to a stuctureless, friable upper layer with low shear strength and high degree of compaction, and an overlying compact material of horizontal platy structure. Fabric strength was found to decrease and particle plunge was found to increase in association with the transition from melt-out tills, through undeformed and

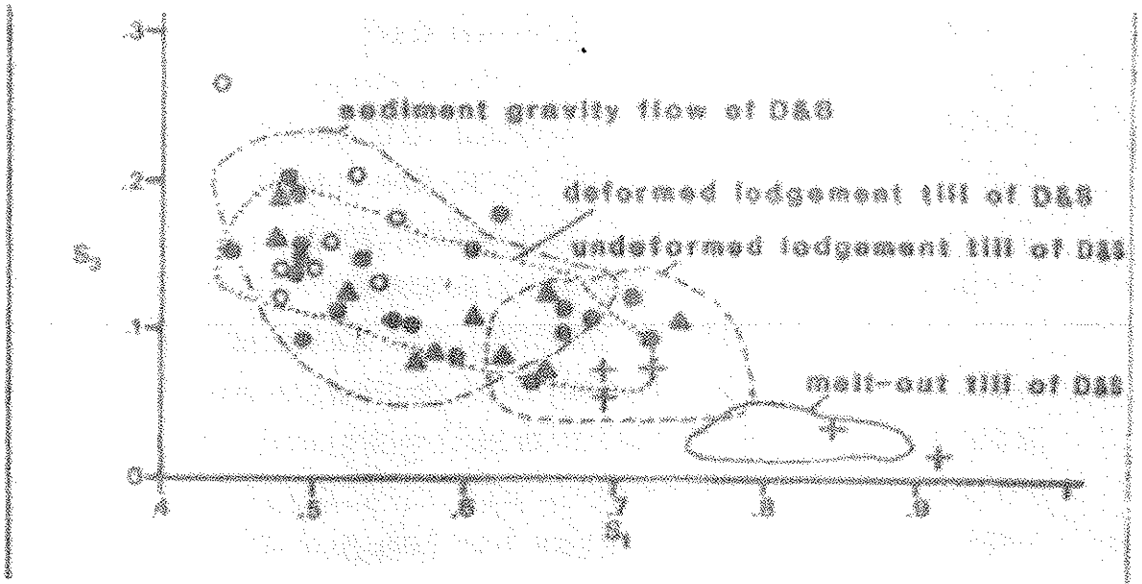

Figure 1: The pattern of S1 and S3 eigenvalues representing fabric strength in several facies of glacial sedimentation. From Dowdeswell and Sharp (1986) and Johnson (1990).

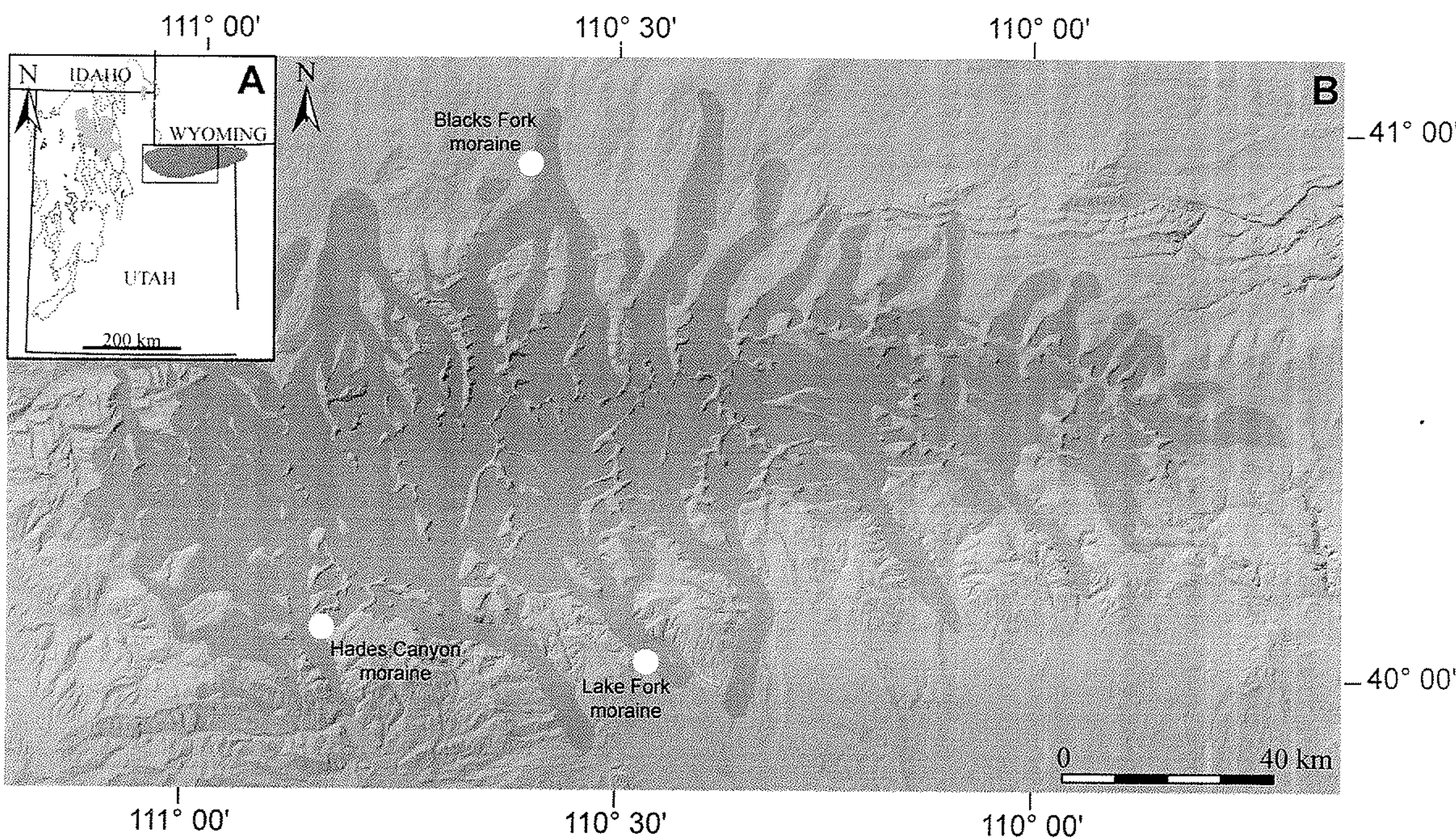

Figure 2: A) Location map of the Uinta Mountains in northeastern Utah. Dotted lines show extent of Lake Bonneville during the late Pleistocene. Dark gray area is the Uinta Mountains. Rectangle indicates the area shown in B. B) Shaded-relief map of the southern Uinta Mountains. Gray areas indicate maximum ice extent during the Pinedale Glaciation. Figure is from Laabs and Carson (2005).

Mark (1973). Johnson found four different facies to occur in the end moraines that he studied, and these findings were significant because they showed that there are multiple styles of glacial deposition possible.

In this study, I applied the methods of Dowdeswell and Sharp (1986) and Johnson (1990) to describe and interpret glacial deposits exposed in moraines of the Uinta Mountains in northeastern Utah. These methods are similar to methods used to infer till genesis in Pleistocene ice sheets (Lawson, 1979; Kruger and Kjaer, 1999; Ham and Mickelson, 1994; Kamb, 1959).

Background

Widespread glacial advances due to colder temperatures and greater effective precipitation characterized the last glaciation in the Rocky Mountains (Porter, *et al.*, 1983), which culminated at 23,000-16,000 years ago (Pierce, 2004). Quaternary glacial deposits and landforms in the southern Uinta Mountains record three glaciations: the Altonah (>700,000 years ago), Blacks Fork (180,000 – 130,000 years ago) and Smiths Fork Glaciations (19,000 – 16,000 years ago) (Laabs and Carson, 2005).

The Altonah and Blacks Fork Glaciations are represented by deeply eroded, low-relief moraines at the mouths of valleys in the central Uinta Mountains. The Smiths Fork Glaciation is represented by high-relief, sharp-crested moraines within and at the mouths of valleys throughout the Uinta Mountains (Laabs and Carson, 2005). The Blacks Fork and Smiths Fork Glaciations are correlated respectively to the Bull Lake and Pinedale Glaciations in the Wind River Mountains (Laabs and Carson, 2005). Based on cosmogenic ^{10}Be surface-exposure dating of moraine boulders, the Smiths Fork maximum occurred before 16.8 ±0.7 ka (Munroe *et al.*, 2006), which is somewhat later than the Pinedale maximum elsewhere in the Rocky Mountains (Pierce, 2004). Lake Bonneville covered much of the Great Basin region during the Smiths Fork Glaciation, including the current Great Salt Lake.

Patterns in the Uinta Mountain glacial record suggest that glaciers in the western and central Uinta Mountains were receiving more precipitation than glaciers in the eastern Uinta Mountains (Munroe and Mickelson, 2002). This is evidenced by lower reconstructed equilibrium line altitudes (ELAs) in the western Uintas than in the east. This inferred paleo-precipitation pattern has been explained by the presence of Lake Bonneville, which may have provided moisture for glaciers downwind (east) in the Wasatch Mountains and western Uinta Mountains, but did not supply excess moisture to the valleys in the eastern Uinta Mountains (Munroe and Mickelson, 2002).

Methods

Road cuts and mass wasting provide many exposures of moraine sediment in the Lake Fork (Figure 3), Blacks Fork (Figure 4), and Hades Creek (Figure 5) valleys. These sites were chosen for this study because they are easily accessible and expose thick sediment in well-preserved moraines. Detailed sketches and descriptions were taken of each outcrop, and samples of several facies were collected. The grain size distribution of the matrix of each facies was found using sieve and hydrometer techniques following the procedure of DonLevy (1987).

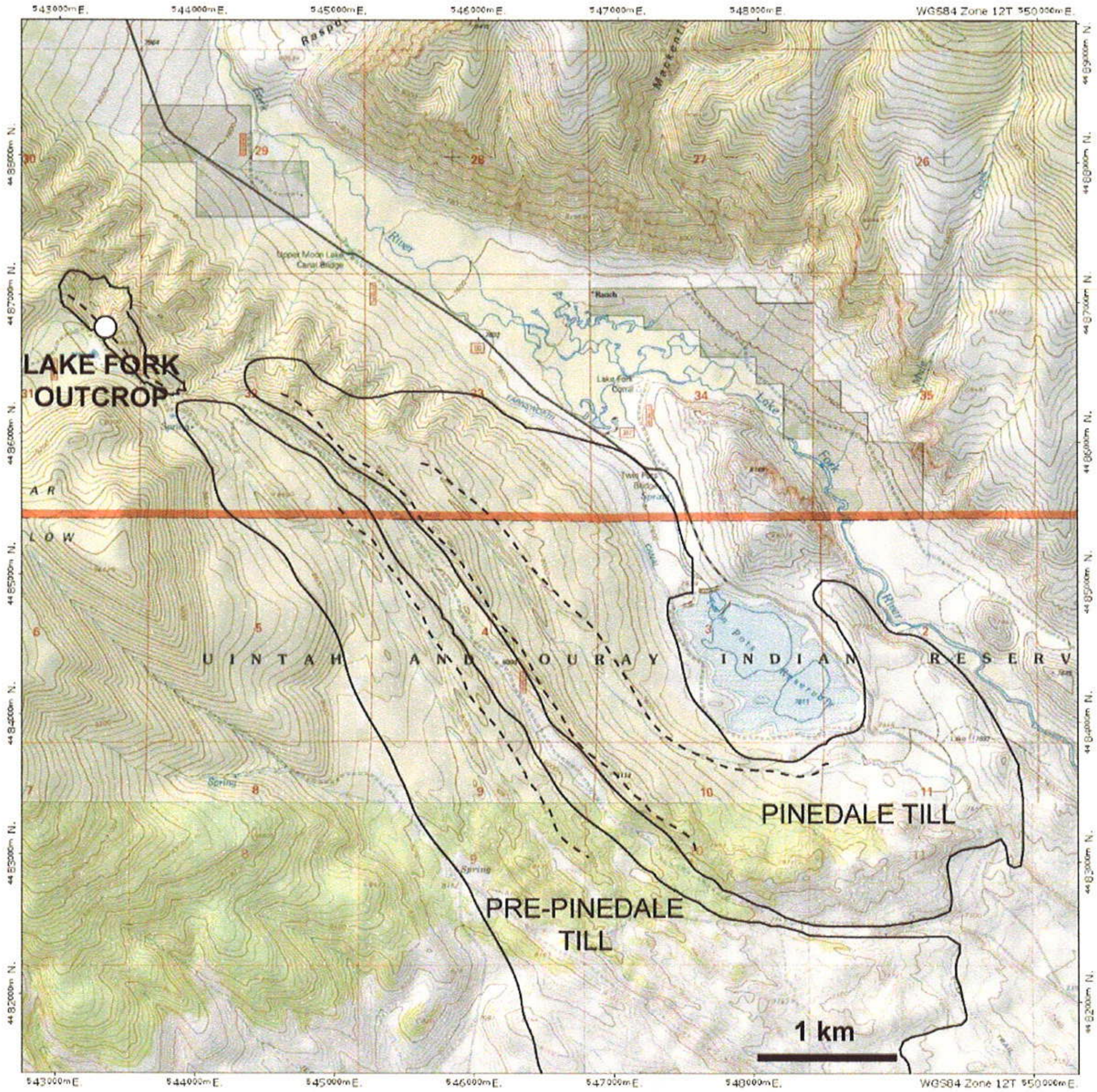

Figure 3: Topography and glacial geology near the study site in the Lake Fork drainage. Solid black lines outline the extent of Pleistocene tills. Dashed black lines indicate moraine crests.

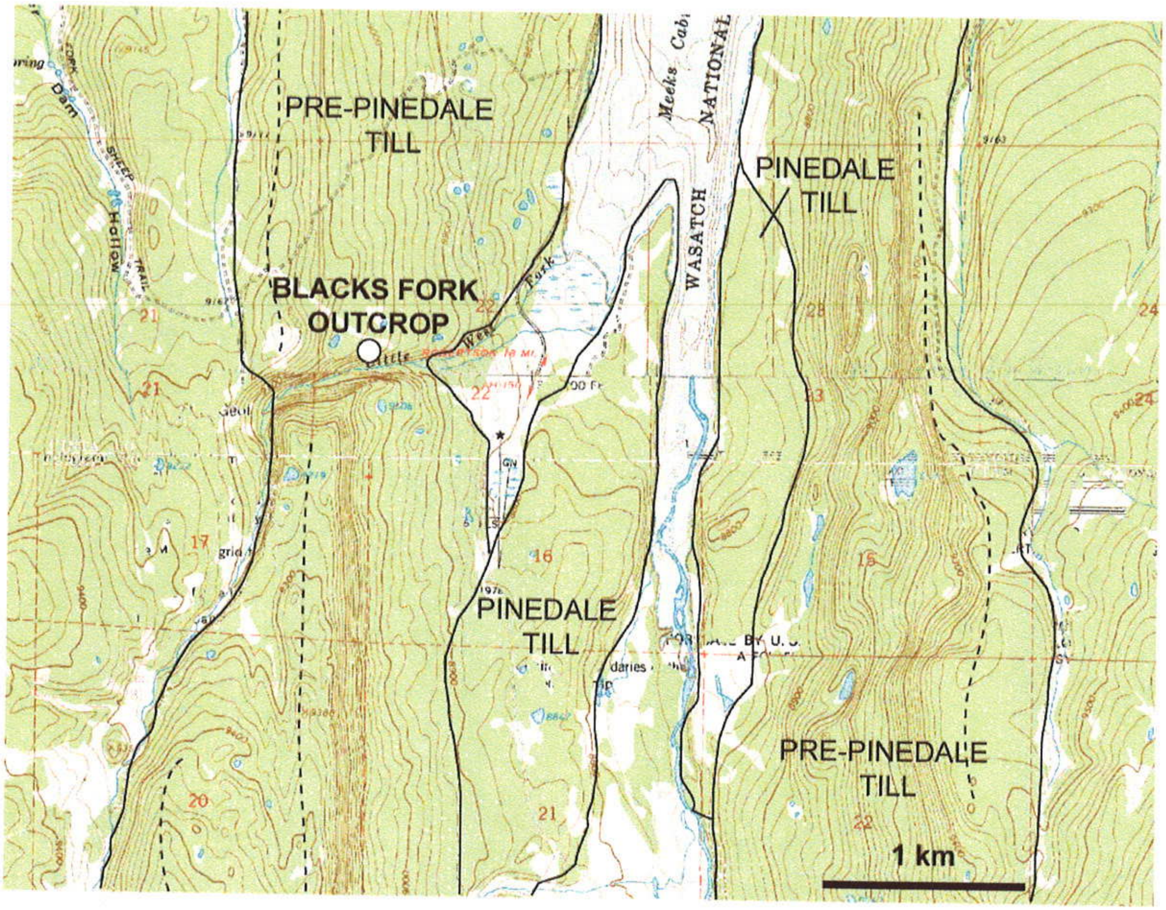

Figure 4: Topography and glacial geology near the study site in the Blacks Fork drainage. Solid black lines outline the extent of Pleistocene tills. Dashed black lines indicate moraine crests.

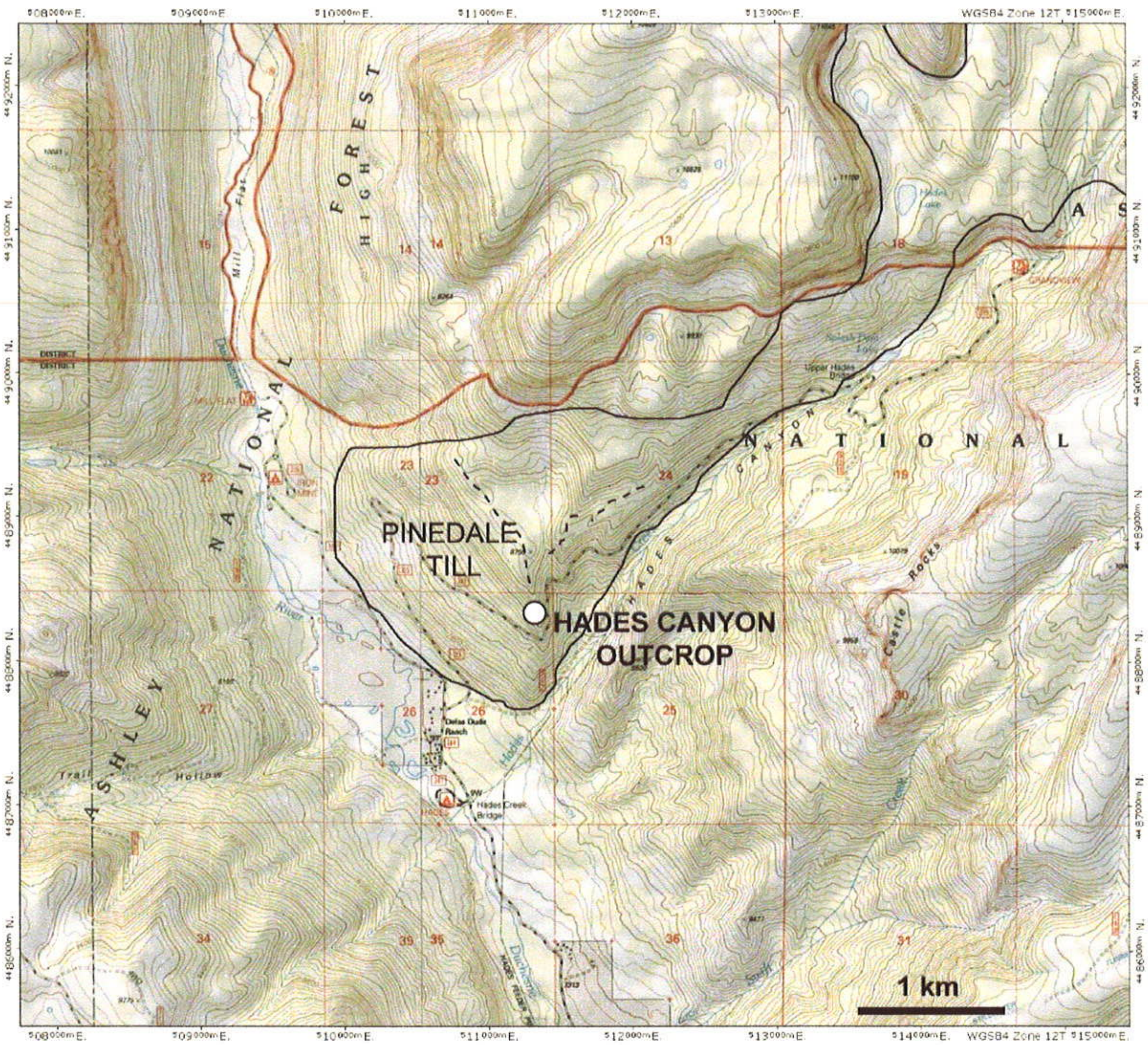

Figure 5: Topography and glacial geology near the study site in Hades Canyon. Solid black lines outline the extent of Pinedale till. Dashed black lines indicate moraine crests.

One hundred and thirty pebble-fabric measurements were taken from Blacks Fork, 50 from Hades Creek, and 100 from Lake Fork. These were taken by measuring the long axes of elongate pebbles that had a long-to-intermediate axis ratio of at least 1.5. Pebbles were measured from vertical exposures, and each set of pebble orientations were measured within an area less than 1 m^2 (Figure 6). The measurements were plotted on rose diagrams and contoured on equal area stereonets using the methods of Kamb (1959).

The eigenvalue method described by Mark (1973) was used to evaluate pebble fabric data mathematically. The eigenvalues (S_1, S_2, S_3) summarize fabric strength, which is the degree of clustering, about three principle axes. For a given set of fabric measurements, eigenvalue S_1 measures the strength of clustering about the mean axis, and eigenvalue S_3 represents fabric strengths about the axis of minimum clustering (Dowdeswell and Sharp, 1986). Testing for randomness has shown that S_1 values greater than 0.51 and S_3 values of less than 0.17 are significantly different from a random distribution at a 95% level of confidence for samples of 50 pebbles (Dowdeswell and Sharp, 1986; from Anderson and Stephens, 1972; Woodcock and Naylor, 1983). S_1 and S_3 values of different fabric strengths have been plotted by Dowdeswell and Sharp (1986) and Johnson (1990) and have been interpreted to represent several facies of glacial sedimentation (Figure 1).

This method is useful for describing strength of pebble fabrics because it accounts for both pebble trend and plunge, while rose diagrams and two-dimensional vector methods only use pebble trend. It is also useful because eigenvalue analysis has been used previously in studies of pebble fabrics in glacigenic sediments (e.g. Lawson, 1979;

Lake Fork moraine

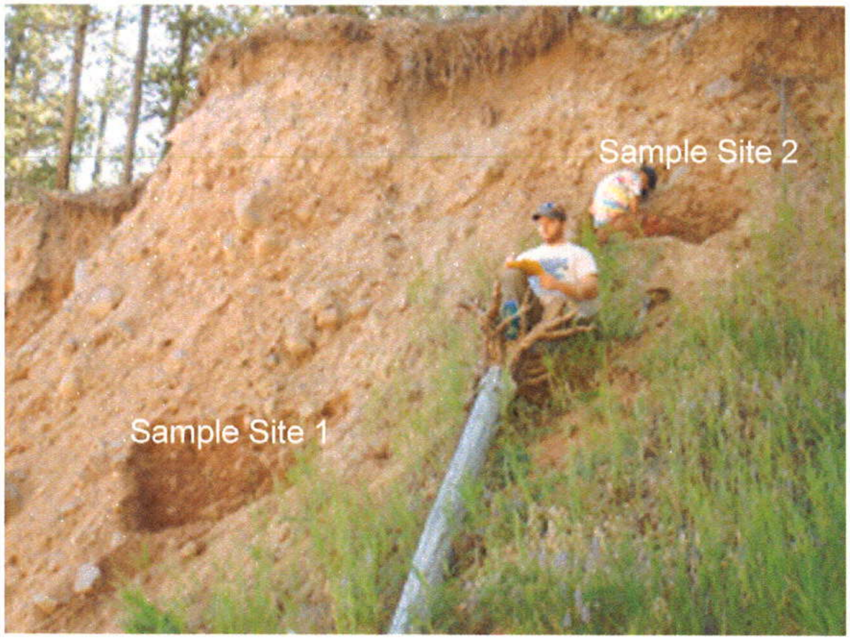

Figure 6: Outcrops of diamicton in a Pinedale latero-frontal moraine in the Lake Fork drainage. All exposures at this site reveal thick, uniform diamicton with no visible contacts. Photo on the bottom shows over 10 meters of diamicton.

Dowdeswell and Sharp, 1986; Johnson, 1990), and using the same approach is very helpful for comparisons. Some researchers have argued that pebble fabric data are ambiguous. For example, according to Bennet *et al.* (1999), pebble fabrics may have a role as an indicator of relative strain in glacigenic sediment, but offer limited use in the distinction of glacigenic facies.

Results

Lake Fork

The latero-frontal moraine at the Lake Fork outcrop exposes massive unstratified diamicton (Figure 6), with many striated boulders and clasts. Over 40 meters of visible outcrop is exposed on the moraine due to a blowout caused by mass wasting. Based on observations of a depression at the top of the moraine, there appears to have been a lake which slowly saturated the till and caused the land to fail creating a gulley with steep, unstable slopes. A lack of visible contacts in the exposed sediment suggests the moraine was deposited fairly continuously while occupied by glacier ice. The till in this moraine is 75% matrix, with striated quartzite clasts of the Uinta Mountain Group.

Pebble fabrics were measured at two sites on the south face of the outcrop. The rose diagrams and contour plots show a slight northwest/southeast trend (Figure 7), and the contour plots show plunges ranging from 20-30 degrees. As noted above, these plots qualitatively represent pebble orientations and the variability of fabric strength and the mode pebble orientation, whereas eigenvalues provide a quantitative method for describing fabric strength; eigenvalue S_1 represents the strength of clustering about the mean axis, and eigenvalue S_3 represents fabric strengths about the axis of minimum

Lake Fork

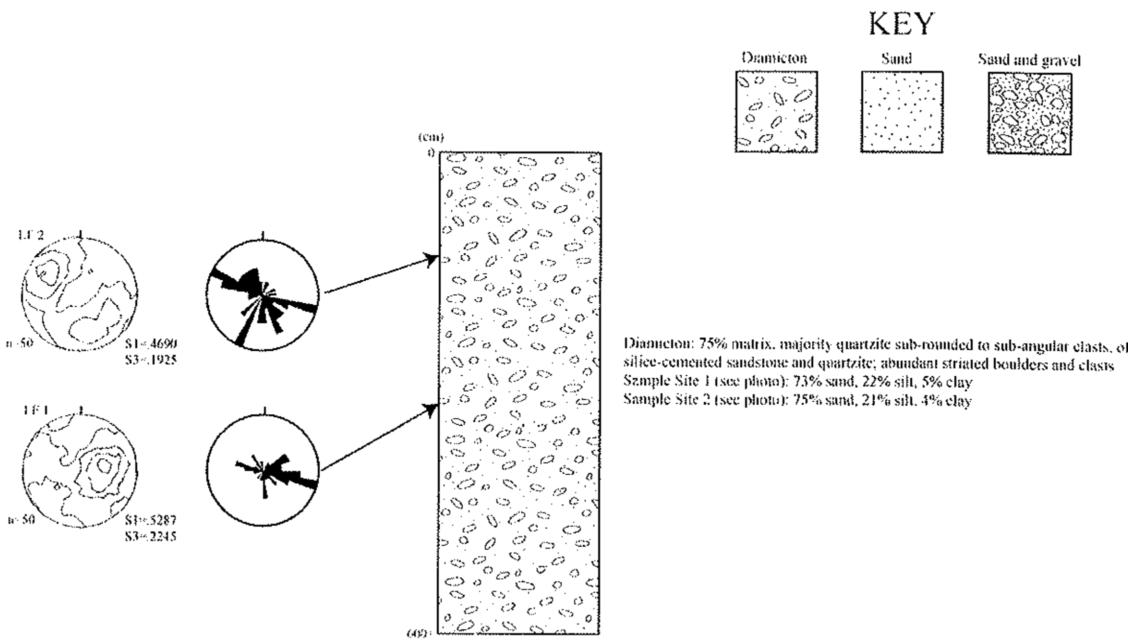

Figure 7: Pebble fabric and rose diagrams of Lake Fork with corresponding stratigraphic column. Fabric data plotted on equal-area net, contour interval 2. North is up on each diagram; fabric sample number in upper left (LF1-LF2=Lake Fork); S1 and S3 eigenvalues in lower right. Arrows point to locations in which fabric data were taken.

clustering. S_1 values of .53 and .47, and S_3 values of .22 and .19 derived from these plots express a low strength and reflect the multimodal character. These S_1 and S_3 values plot in the range of sediment flow deposits of Dowdeswell and Sharp (1986) and Johnson (1990) in Figure 1, suggesting that diamicton in the Lake Fork moraine is derived from dumping of sediment from the ice margin. Grain size analysis shows high sand content in the sampled layers (Table 1), which reflects the predominant lithologies (sandstone and quartzite) that are the source of glacially-derived sediment.

Blacks Fork

The latero-frontal moraine at Blacks Fork contains ten layers of diamicton, lenses of sorted and unsorted sand and gravel, and diamicton with a high degree of compaction compared to the others examined in this study (Figure 8). All of the diamicton at this moraine is matrix supported, with 60-80% matrix. Clasts are sub-rounded to sub-angular, with 90% of the clasts being quartzite. The other 10% of clasts consist mostly of limestone and shale. In contrast to the Lake Fork moraine, this moraine appears to not have been deposited continuously, suggested by alternating layers of diamicton, and sand and gravel.

Fabric measurements were performed at four sites on the moraine (Figure 9). The rose diagrams and contour plots show a general easterly trend, and the contour plots show plunges ranging from 20-30 degrees. However, S_1 values ranging from .54 - .63, and S_3 values ranging from .07 - .19 derived from these plots express a weak and multimodal fabric. These S_1 and S_3 values plot in the range of sediment flow deposits of Dowdeswell and Sharp (1986) and Johnson (1990) in Figure 1. Grain size analysis shows high sand

Sample Identity		Grain - Size Distribution			Mass Percent Finer (Sample Fraction < 2mm)							
		% Sand	% Silt	% Clay								
	Sample	(2.0 to	(0.0625 to		1	0.5	0.25	0.125	0.0625	0.00661	0.003094	0.001187
State	Number	0.0625mm)	0.002mm)	(<0.002 mr	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
UT	Lake Fork Site 1	73.09	21.55	5.36	95.8741	88.4290	64.2729	37.3738	26.9092	8.0674	6.9149	4.6100
UT	Lake Fork Site 2	75.38	20.67	3.95	95.0006	86.4686	61.6810	34.7978	24.6194	7.4842	5.9873	2.9937
UT	Hades Canyon 242-316	74.02	20.83	5.15	95.1989	86.7904	63.6670	36.8325	25.9846	7.7856	7.7856	3.8928
UT	Hades Canyon 184-242	77.30	16.86	5.84	93.5488	83.1567	57.4977	31.6051	22.7018	7.2978	5.8382	5.8382
UT	Hades Canyon Fabric Outcrop	88.40	13.18	-1.58	95.0768	83.8103	49.6321	20.6926	11.6037	-1.5779	-1.5779	-1.5779
UT	Blacks Fork 1090-1199	62.89	26.62	10.49	93.5651	82.3544	64.9555	47.5565	37.1082	16.8160	13.4528	8.9685
UT	Blacks Fork 785-910	59.11	31.58	9.31	94.9769	86.2330	72.4660	56.5595	40.8856	16.2785	11.6275	8.1393
UT	Blacks Fork 680-785	64.98	25.00	10.03	92.8381	79.5257	60.1995	44.0169	35.0235	16.4013	13.6677	8.2006
UT	Blacks Fork 663-680	37.33	41.60	21.07	96.2372	89.5502	79.6898	70.2147	62.6664	34.0015	26.0678	18.1341
UT	Blacks Fork 576-663	74.55	19.86	5.59	90.8706	74.1253	51.8783	34.4843	25.4510	9.6099	7.2074	4.8050
UT	Blacks Fork 456-507	44.04	46.44	9.51	97.2645	93.3208	86.0944	72.8727	55.9580	17.0971	12.5378	7.9786
UT	Blacks Fork 0-300	61.59	26.86	11.55	93.9615	83.4665	65.7520	48.1267	38.4115	17.8259	14.4835	10.0271

Table 1: Spreadsheet of grain size data.

Blacks Fork moraine

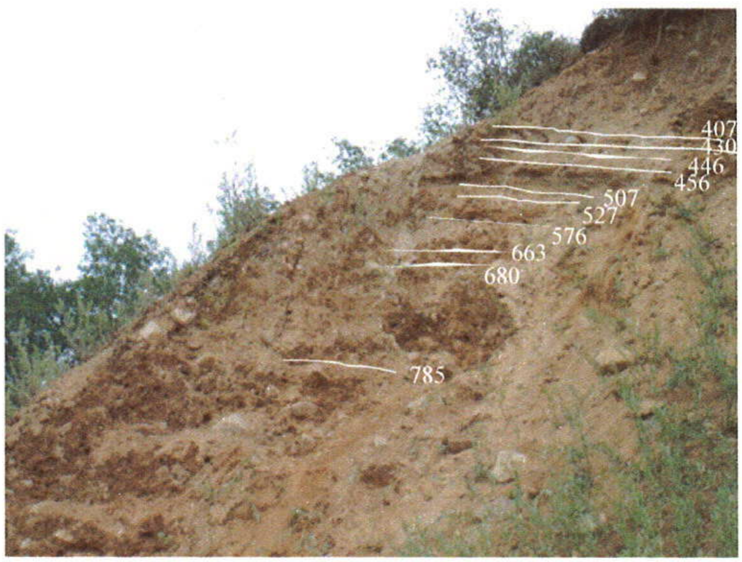

Figure 8: Outcrops of multiple diamictons in a pre-Pinedale latero-frontal moraine in the Blacks Fork drainage. Lower layers are composed of uniform diamicton. Photo on bottom shows contacts between diamictons and thin layers of sorted sand and sand and gravel.

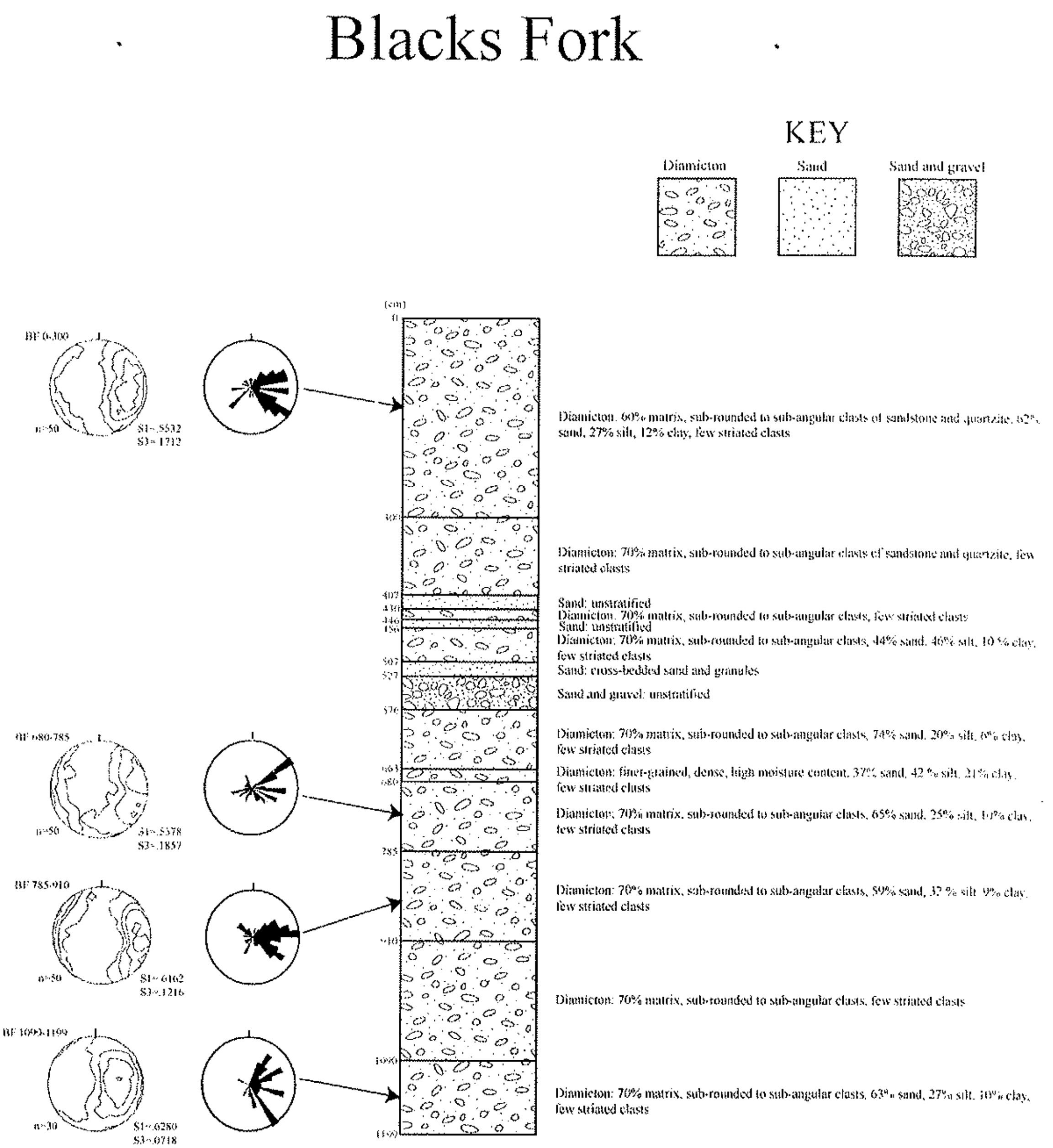

Figure 9: Pebble fabric and rose diagrams of Blacks Fork with corresponding stratigraphic column. Fabric data plotted on equal-area net, contour interval 2. North is up on each diagram; fabric sample number in upper left (BF 0-300=Blacks Fork); S1 and S3 eigenvalues in lower right. Arrows point to locations in which fabric data was taken.

content in all sampled diamictons except one layer with a denser, finer grained matrix (Table 1).

Hades Canyon

The continuous lateral moraine at Hades canyon reveals layers of diamicton, lenses of sand and gravel, and a mixture of sand and diamicton (Figure 10). The diamictons at this moraine are matrix supported, with 60-85 % matrix; clasts are sub-rounded to sub-angular quartzite, none of which were found with striations. The moraine appears to not have been deposited continuously because there are alternating layers of diamicton and sand and gravel (Figure 10).

Fabric measurements were taken from a diamicton at the top of the outcrop (Figure 11). Data plotted on rose diagrams and contour plots cluster around a northwest/southeast trend, and the contour plots show nearly horizontal plunges ranging from 0-10 degrees. An S_1 value of .49, and an S_3 value of .24 derived from these plots express a weakly-developed, multimodal fabric. These S_1 and S_3 values plot in the range of sediment flow deposits of Dowdeswell and Sharp (1986) and Johnson (1990) in Figure 1. Grain size analysis shows high sand content in the sampled layers (Table 1), reflecting the dominance of sandstone and quartzite bedrock at the head of Hades Canyon.

Discussion and Conclusions

Based on the results described above, I identify one dominant facies of diamicton in all three moraines, characterized by a homogeneous, coarse-grained matrix (60-85% matrix) and weak pebble fabric (S_1 = 0.47 - 0.63). The weak pebble fabric, lack of

Hades Canyon moraine

Figure 10: Outcrops of diamicton in a Pinedale lateral moraine Hades Canyon. Photo on bottom shows outcrop of diamicton and sorted sand and gravel dipping down valley.

least part of the year (usually during the melt season). This is consistent with previous suggestions that Pleistocene glaciers in the Uinta Mountains advanced under colder and wetter climate than modern.

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