Erosional origin of hummocky terrain in south-central Alberta, Canada

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ABSTRACT

We propose that hummocky terrain in south-central Alberta is the product of subglacial erosion rather than supraglacial letdown during ice disintegration (a common view of hummock formation). Extensive exposures in hummocks contain sediments marking the history of Laurentide ice advance and deglaciation in the region. Regardless of the genesis of those sediments, units are abruptly truncated at the surface that represents the hummock and trough morphology, indicating that the hummocks are the product of differential erosion. Subglacial sediments predating the erosion and subglacial eskers overlying the erosion surface suggest that the erosion was also subglacial. Hummock morphology, lithostratigraphy correlated from hummock to hummock, truncation at the land surface, and widespread coarse boulder lags support a glaciofluvial origin for hummocky terrain in this region.

INTRODUCTION

Hummocky terrain is composed of tracts of hillocks and depressions of variable size and shape, and occurs in areas that have been glaciated. It is especially extensive in the northern Great Plains and occurs in large belts in the Canadian Prairies (e.g., Shetsen, 1987, 1990; Klassen, 1989), and the northwest United States (e.g., Clayton and Moran, 1974; Johnson et al., 1995). The terrain is commonly believed to represent the final stages of ice stagnation, when debris on the surface of the ice was slowly lowered as the ice ablated in marginal parts of the ice sheet (e.g., Gravenor, 1955), and hence is often used to reconstruct recessional patterns of the Laurentide ice sheet in North America (e.g., Dyke and Prest, 1987; Klassen, 1989). Some geomorphologists have noted, however, that not all hummocks are composed of sediments released at the ice surface (e.g., Hoppe, 1952; Menzies, 1982). On the basis of results presented here, we propose that many areas of hummocky terrain are the product of subglacial erosion, and not supraglacial letdown during ice stagnation. Consequently, we prefer to use the nongenetic term “hummocky terrain” throughout this paper, because it simply describes landscape topography and does not imply genesis.

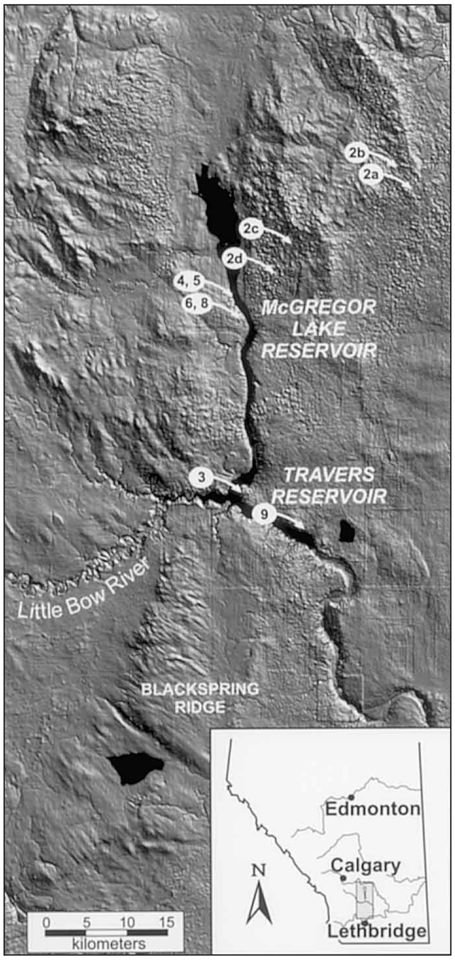

Figure 1. Digital elevation model of study area. Majority of hummock terrain occurs north of Little Bow River and Travers Reservoir. Fluted terrain on Blackspring Ridge grades southeastward into hummocky terrain. Circled numbers represent locations of other figures.

The study area is in south-central Alberta, Canada (Fig. 1). The damming of McGregor Lake and the Little Bow River (now Travers Reservoir) in the 1960s resulted in extensive shoreline erosion, creating more than 100 hummock exposures in a major north-south–trending hummocky zone, the Buffalo Lake moraine. Stalker (1977) thought that this “moraine” marked the western extent of the late Wisconsinan Laurentide ice, but it was later reinterpreted as an interlobate stagnation feature and renamed the McGregor moraine (Shetsen, 1984). Exposures range from 2 to 25 m high; to the best of our knowledge, no glaciogenic hummock exposures of comparable quality or quantity exist worldwide. The main aim of this paper is to demon-

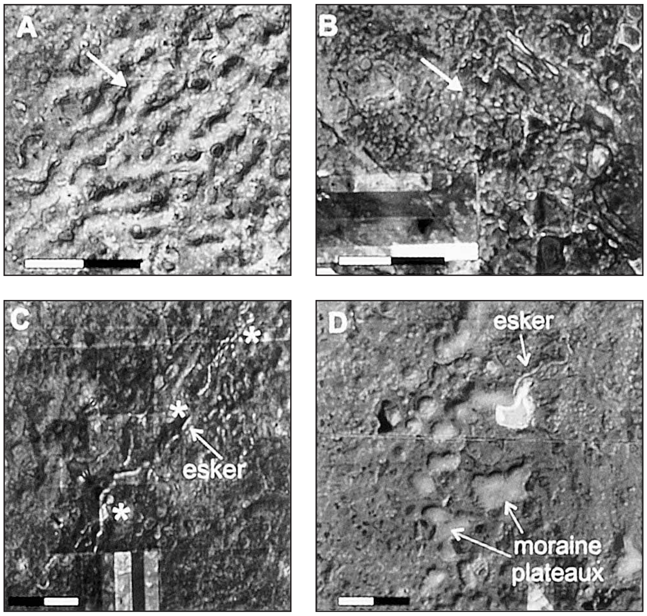

Figure 2. Types of hummocky terrain observed in study area. A—transverse ridges and depressions; B—longitudinal ridges and depressions; C—symmetric and asymmetric hummocks with eskers overlying them (indicated by asterisks); D—moraine plateaus (note esker). Scale bars represent 1 km. Arrows in A and B indicate flow trends.

strate and document the erosional nature of the Travers-McGregor hummocks.

GEOMORPHOLOGY AND SEDIMENTOLOGY

Hummocks in the study area have a variety of forms typical of many other hummocky regions in the Great Plains. These forms include: symmetric and asymmetric circular mounds that in places contain central depressions; transverse ridges that resemble giant ripple marks; elongate streamlined hummocks; linked hummocks; and moraine plateaus (Fig. 2). Most hummocks are between 1 and 50 m high and between 25 and 300 m wide. Slopes are in the range of 1° to 25°. Each hummock type occurs in tracts, and in each tract features are of similar dimensions. For example, transverse ridges occur together (Fig. 2A), and all ridges are of similar shape and size. Similarly, this applies to elongate mounds (Fig. 2B), and to symmetric and asymmetric mounds (Fig. 2C). Types are, however, transitional to each other. Similar patterns and trends have been noted in hummock distributions by other researchers and are explained as subglacial bedforms (e.g., Lundqvist, 1981).

Sediment in the hummocks includes a basal unit of tectonized lodgment till, usually associated with bedrock thrust by ice moving from the northeast (Fig. 3). This till is the oldest glaciogenic deposit and records initial Laurentide advance into the area. Subsequent decoupling of the ice from its bed, or ice retreat, resulted in deposition of thick sequences of subglacial or ice-proximal glaciolacustrine sediments (diamictons, gravels, cross-laminated and graded sand, and rippled, laminated, and rhythmically bedded sand, silt, and clay). These beds were subjected to intense shearing, faulting, and folding after their deposition by ice moving from the northeast (Figs. 4 and 5). Some rafts of the underlying lodgment till lie along shear planes (Fig. 4). Conformably overlying the glaciolacustrine sediments is the youngest unit in the hummocks: a stratified till that was probably deposited by direct melt-out at the base of the ice. It consists of homogeneous clayey diamicton containing undisturbed and approximately equally spaced interbeds of sand (Fig. 6). The sand laminae are truncated at hummock surfaces, but the same sequence can be recognized in one hummock after another. Clasts are commonly striated, and some larger boulders have sand-filled scours below them (Fig. 6), indicating that the boulders were held in ice and extended downward into flowing subglacial water (Shaw, 1982). Also supporting a subglacial origin for this unit is clast fabric analysis. Most of the 27 fabrics from this unit have strong principal eigenvalues (S1) and K values (degree of clustering) (cf. Woodcock, 1977) (see Table 1). Mean orientations indicate ice flow from the northeast (Fig. 7). Hummock after hummock contains the same lithostratigraphic sequence described above (Fig. 8), and that sequence can also be found under nonhummocky terrain at adjacent exposures.

Boulder lags (Fig. 9) and esker (Fig. 2C) sediments are the only significant materials overlying hummocky terrain in the region. Boulders in the lags are as much as 2 m across; some are heavily pitted by percussion marks, and they are lithologically similar to cobbles and boulders in the underlying sediments, indicating that they have not moved significantly. They are most numerous in areas underlain by boulder-rich sediment (Fig. 9), with sparse lags overlying finer grained sediments. The eskers contain intact arched sediments; in places, upslope paleocurrents indicate a subglacial origin.

NATURE AND ORIGIN OF THE EROSION SURFACE

Because the youngest unit within the hummocks is interpreted as subglacial, and subglacial eskers are superimposed on and are, therefore, younger than the hummocks, it is reasonable to assume that hummock surfaces represent subglacial erosion. The alternative that the hummock morphology was created by differential lowering and faulting during supraglacial letdown is contradicted by the continuous, unfaulted strata beneath depressions at some locations (e.g., Fig. 8). Moreover, erosion by surface processes is unlikely because downslope accumulation of sediments in the troughs between hummocks is minimal.

In a subglacial environment, ice, subglacial deformation, and water are all possible agents of erosion. The sharp erosion surface, boulder lags, lack of deformed material (deformation till) near the surface and, in places, intact sedimentary architecture make subglacial deformation the least likely of these possibilities. Direct erosion by ice is also unlikely because the expected downflow depositional products in the form of moraines, till

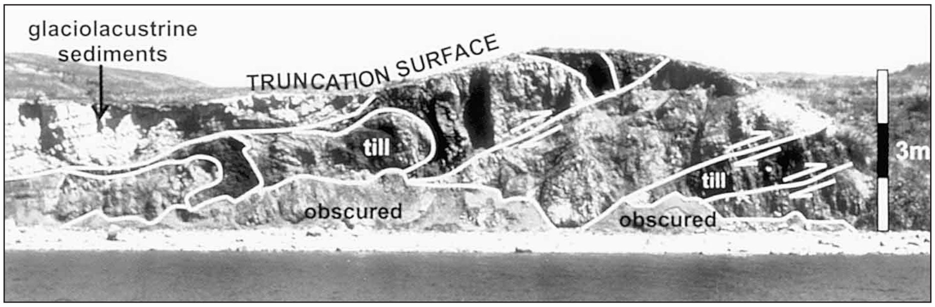

Figure 3. Oldest Quaternary unit in hummocks is lodgment till associated with thrust bedrock. All unmarked units are bedrock; darker units are coal-dominated. All units are truncated at hummock surface (including glaciolacustrine silts).

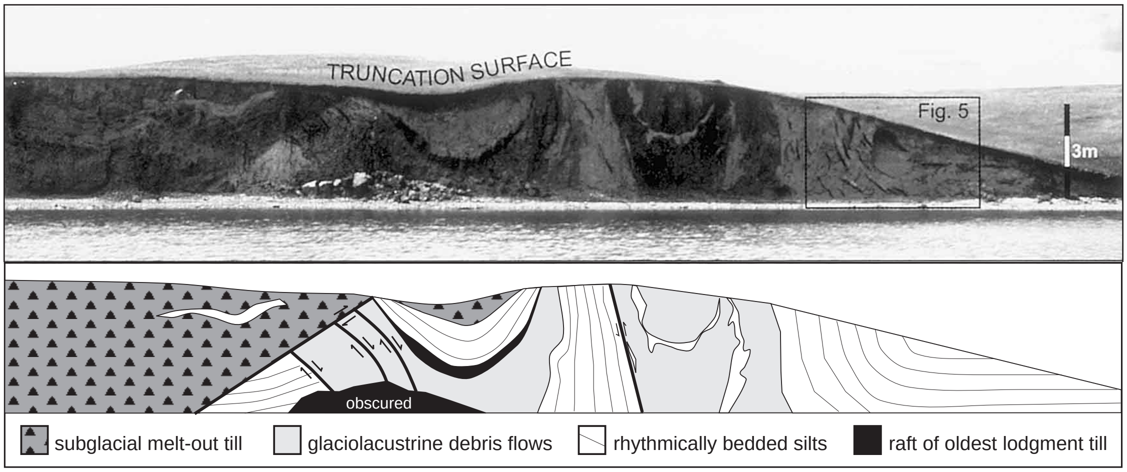

Figure 4. All three units are visible in this one exposure at McGregor Lake. Units have been faulted, folded, and sheared. Truncation of upstanding beds and synclines clearly documents erosional surface that delineates hummock form.

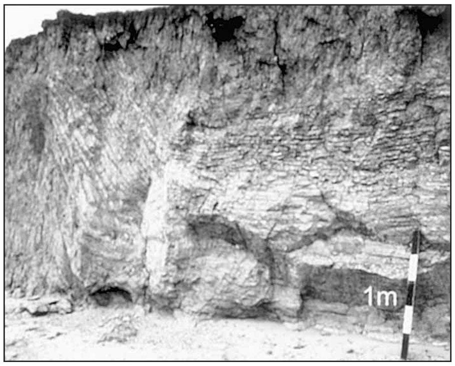

Figure 5. Close-up of truncated, rhythmically bedded silts and clays in Figure 4.

blankets, or glaciolacustrine materials beyond or within the zone of erosion are lacking. In addition, fabrics from the youngest till unit indicate ice flow from the northeast (Fig. 7, Table 1). This direction is oblique to the direction of flow indicated by fluting and oriented hummocks (see Figs. 1 and 2).

Evidence suggesting that meltwater eroded the hummock surfaces is much more convincing to us. First, surface boulders are best explained as lags left during fluvial transport, where flowing water was able to remove all but the largest boulders. Percussion marks on the boulders attest to possible clast-to-clast collisions during transport. The lags are unlikely to represent minor subaerial erosion (cf. Wright et al., 1973), because there are no deposits in the swales between hummocks. Moreover, stratigraphic relations suggest that the erosion was subglacial, and uphill trends in some of the hummocks indicate that erosion by meltwater could have occurred only in the subglacial environment. Subglacial and extraglacial water flows can transport sediment over large distances, perhaps as far as the Gulf of Mexico (Shaw et. al., 1996), thus explaining the scarceness of till above the erosion surface and the lack of complementary deposits immediately downflow. Some erosional forms in basalt scoured by the Lake Missoula floods are morphologically similar to hummocky terrain (Baker, 1978), indicating a strong plausibility that hummocky terrain can be the product of meltwater erosion. Also, streamlined loess hills in the Channeled Scabland, Washington, maintain undisturbed internal stratigraphy (like the Travers-McGregor hummocks), despite erosion by the Lake Missoula floods (Bretz, 1969).

TABLE 1. ORIENTATION DATA FROM CLAST FABRIC ANALYSIS ON THE MELT-OUT TILL UNIT

S1	S3	K	O
0.607	0.051	0.299	209.6
0.784	0.031	0.803	81.4
0.801	0.025	0.778	261.5
0.489	0.087	0.090	68.4
0.693	0.041	0.512	31.2
0.644	0.122	1.550	201.8
0.468	0.147	0.200	68.2
0.562	0.166	1.479	68.2
0.803	0.062	2.268	51.5
0.868	0.019	1.153	161.1
0.528	0.138	0.523	21.6
0.600	0.068	0.375	119.2
0.521	0.065	0.126	218.9
0.716	0.085	1.510	69.9
0.730	0.050	0.805	253.7
0.794	0.064	2.142	58.8
0.766	0.060	1.316	257.8
0.635	0.145	2.563	19.1
0.512	0.131	0.362	52.4
0.685	0.115	2.241	86.0
0.638	0.079	0.627	59.0
0.616	0.087	0.589	258.0
0.749	0.063	1.127	64.7
0.661	0.063	0.590	84.9
0.697	0.078	1.072	103.2
0.581	0.130	0.876	70.1
0.699	0.053	0.671	64.4

Note: S1 is the principal eigenvalue; S3 is the third eigenvalue; K is the degree of clustering; and O is the mean orientation.

DISCUSSION AND CONCLUSIONS

Hummocky terrain along McGregor and Travers reservoirs is clearly the product of erosion. This conclusion is supported by the widespread truncation of beds within hummocks. The evidence suggests that this erosion was subglacial, most likely by meltwater.

The amount of erosion is unknown, but formation of troughs between hummocks involved between 1 and 20 m of sediment removal. Trends in hummock form and flow directions inferred from aligned hummocks suggest that water flowed across the entire region from the northwest to the southeast. This was likely in the form of a large sheet flow. Although this cannot be proven, it is difficult to envisage piecemeal formation of wide bands of similarly oriented hummocks by narrower flows, and it is the best explanation for the wide array of sediments and morphological features observed. To account for the amount and extent of erosion, we propose that meltwater must have been stored upglacier from and, perhaps, within the hummocky zone, and then released catastrophically. The exact location and size of the reservoir(s) are unknown. Larger scale fluting in the areas north of the Little Bow River and in the Blackspring Ridge flute field also show northwest-southeast trends (Fig. 1). We have proposed (Munro and Shaw, 1996) that the Blackspring Ridge flutes represent sheetflow erosion at least 50 km wide. If the hummocks formed during the same meltwater erosional event as the fluting, flow may have been as wide as 120 km to account for all the erosional landforms. The scale and location of this proposed flow may support the idea that the study area was scoured by a branch of the subglacial Livingstone Lake megaflood (Rains et al., 1993). The detailed mechanics of this meltwater erosion are not well understood, and many questions remain. For example, we do not know the exact scale of the proposed flow, how the meltwater interacted with different substrates regardless of the scale of the flow, if different hummock forms are related to different substrates, or the locations of the removed sediment.

We realize that hummocks are polygenetic and that erosion cannot account for all hummocky terrain. For example, subaqueous outwash can appear hummocky (Rust, 1977), and ice-stagnation hummocks occur in front of many modern glac-

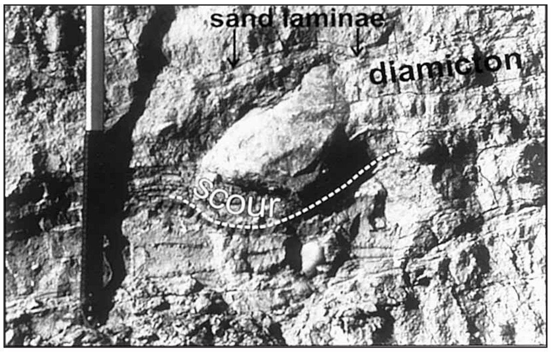

Figure 6. Youngest unit is interpreted as subglacial melt-out till. Thicker strata in this photo are clay-dominated diamicton. Sand strata are continuous for hundreds of meters and likely document periodic small-scale storage and release of subglacial meltwater. Sand-filled scour below boulder indicates that boulder must have been suspended from subglacial ice as water was flowing below it. Strata above scour are continuous to edge of boulder, indicating that boulder remained partially suspended from ice as adjacent strata were deposited. Finally, melt-out of boulder resulted in draping by overlying sediments.

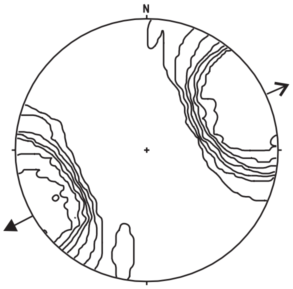

Figure 7. Clast fabric stereoplot for melt-out till in study region. Mean orientations indicated in Table 1, along with mean dips, are reanalyzed as composite sample and plotted on equal projection stereonet. Resultant principal eigenvector azimuth is 64° (line-head arrow), with S1 value of 0.773, and K value of 1.053. These values are statistically significant and indicate ice-flow direction toward southwest (solid-head arrow).

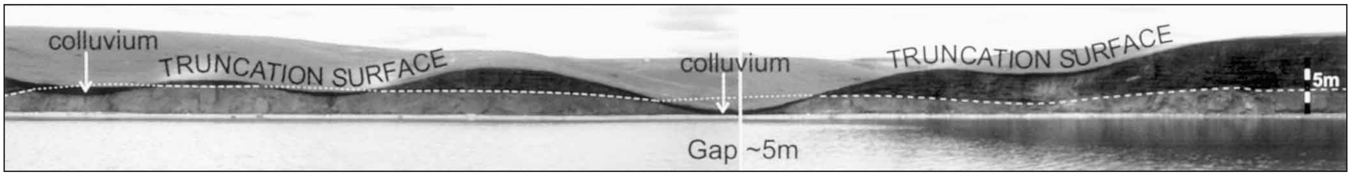

Figure 8. Two exposures at McGregor Lake clearly document continuous stratigraphy between mounds. Lower light colored unit is deformed lacustrine sediment, whereas upper dark unit is melt-out till shown in Figure 6. Dotted parts of lines indicate where units would have extended between hummocks.

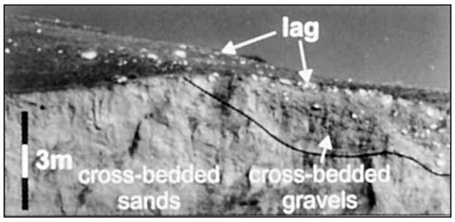

Figure 9. Study area has extensive boulder lags. They are most prominent where they overlie glaciofluvial sediments.

iers (e.g., Sharp, 1985). In general, though, authors of maps, reports, and papers refer to these features as "hummocky moraine," "stagnation moraine," and "ice-stagnation topography." This terminology assigns hummocky terrain to stagnant ice in marginal or near-marginal positions. According to our interpretation, such terminology does not apply to many hummocky areas of the Great Plains. For example, the McGregor moraine is not a moraine, and hence it should not be used to reconstruct ice margins. This conclusion must also stand for other hummocky landscapes that are dominated by landforms of similar form, magnitude, and pattern. The hummocky terrain discussed here is the product of subglacial erosion, most likely meltwater erosion. Because basal conditions have a direct bearing on ice-flow regime, ice thickness, and ice extent, the results of this paper also have major implications for ice-sheet modeling and ice-sheet reconstruction.

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