Non-synchronous glacial advance and retreat, Clarks Fork of the Yellowstone River, northwest Wyoming

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INTRODUCTION

Eastward draining outlet glaciers of the Yellowstone ice sheet extended down the Clarks Fork river valley and its tributary drainage basins during late Pinedale glaciation. Pierce (1979) cited evidence for non-synchronous glacial activity in this region, but the cause was never fully resolved. The Clarks Fork ice sheet, Crandall Creek valley glacier, and the Beartooth ice sheet are the three major lobes of the Yellowstone ice sheet that affected the Clarks Fork valley. Carson et al. (1996) determined general ice flow direction in the Clarks Fork valley from well-preserved glacial striations carved in granitic roche moutonnées. The purpose of this project is to examine glacial striations and moraines in the valley and to provide a more complete understanding of the direction and timing of glacial activity during the last advance of the Yellowstone ice sheet.

TECHNIQUES

Field. Approximately eighty roche moutonnées were studied in search of glacial striae, from the southern border of the Cooke city to Dead Indian Hill (Fig. 1). Boulders frozen in the bottom of glaciers become tools to polish and carve bedrock as glaciers advanced. Most of the polished surfaces have been destroyed by weathering. However, some have been protected by boulders sitting on top of the roche moutonnées. Consequently, rolling boulders became an important part of data collection.

When possible, ten or more striation bearings were recorded for each roche moutonnée. Some polished surfaces initially have no apparent striations, but when the surface is moistened with water, hidden striations may appear. Striations are easier to see when the sun is low in the sky than when the sun is directly overhead, so morning and late afternoon are the best times to collect data.

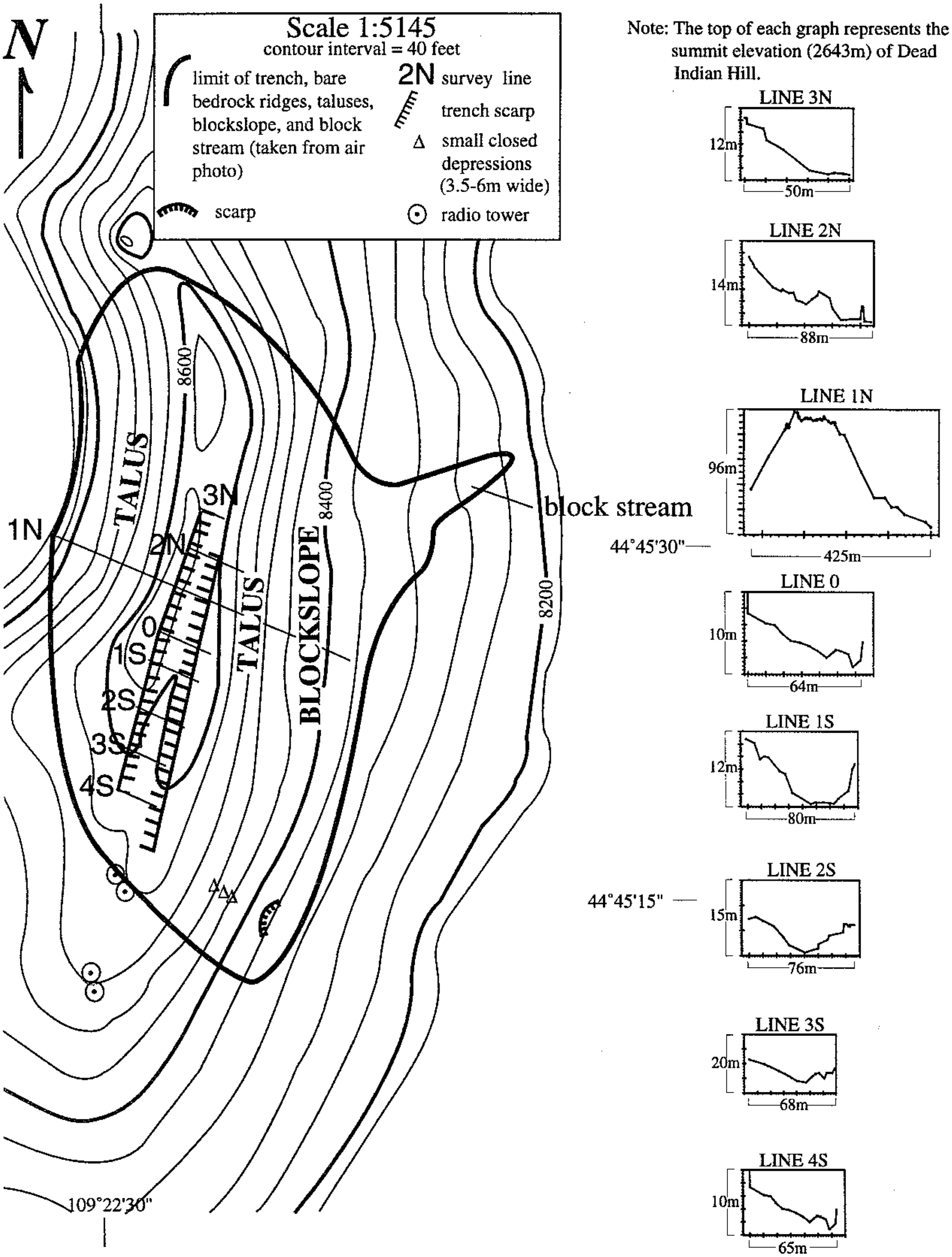
Striations varied in quality and were rated on a scale of 1 to 5.

1	hard to see with water added, but both observers agree on direction
2	cannot see without water, but confident when water is added
3	hard to see without water, but easy to see with water
4	plainly visible without water
5	very obvious and easy to see without water, sometimes have parallel grooves

Striation data were recorded on a base map of the study area (Fig. 1). Most striation data within the granitic valley walls of the Clarks Fork followed the local direction of the valley, as expected. However, cross-cutting striations were observed near Dead Indian Hill, the confluence of Clarks Fork river and Crandall Creek, and in the area between Hunter Peak and the Beartooth Mountains. Good samples of cross cutting striations show which striations were made last, because earlier striations are cut by younger, uncut striations.

At the confluence of Clarks Fork and Crandall Creek, Crandall striations (bearing 25°) cut across Clarks Fork striations (bearing 110°), indicating that the smaller Crandall valley glacier advanced across Clarks Fork river while the larger Clarks Fork ice retreated to the northwest (Fig. 1). An end moraine across Clarks Fork from the Crandall Creek valley lies perpendicular to the Crandall Creek striations, apparently produced by Crandall Creek valley glacier's last advance. A diversion channel from Clarks Fork is located on the north side of the moraine.

Laboratory. 1:24,000 (30m grid) and 1:250,000 (100m grid) digital elevation models were assembled into base maps for the study area. Because several striations were measured at every roche moutonnées, an average of all striations at one location was used for the direction of ice movement at that



Note: The top of each graph represents the summit elevation (2643m) of Dead Indian Hill.

Figure 2. Base map of Dead Indian Hill; topography from USGS Bald Peak, Pat O'Hara Mountain, Dead Indian Meadows, and Dillworth Bench quad sheets.

spot. Arrows were plotted on the base map, with the length of the arrow showing the confidence level of its direction, based on number of striations recorded at a location and average rating of the striations. Figure 1 shows a subset of the striation data.

In an attempt to explain why the smaller Crandall Creek valley glacier advanced while the larger Clarks Fork ice retreated, drainage basins for Clarks Fork and Crandall Creek were delineated on the digital elevation model (Fig. 1). Surface areas within each basin were computed and divided into elevation intervals of two-hundred meters. Hypsometric curves derived from these data show that Crandall Creek drainage basin has a greater percentage of surface area at higher elevations than Clarks Fork drainage basin (Fig. 2). Because Crandall Creek drainage basin has 95% of the surface area of Clarks Fork drainage basin, the relative proportion of surface area provided by the hypsometric curve is a good approximation for the absolute proportion of surface area in the basins. Therefore, during climate change Crandall Creek valley glacier maintained a positive ice budget longer than Clarks Fork ice due to lower percentage of intitial ice-melt. Additionally, the distance from the centroid of the drainage basin to the confluence of Clarks Fork and Crandall Creek is almost thirty percent greater for Clarks Fork basin than Crandall Creek basin. Average distance from the glacial equilibrium line (the line separating zone of accumulation from zone of ablation) to the confluence of Crandall Creek and Clarks Fork increases at a faster rate for Clarks Fork basin than Crandall Creek basin. During glacial maximum, when the zones of accumulation entirely cover both drainage basins, this fact is irrelevant. In a period of climate change, however, when the zone of accumulation lies near or above the centroids of the basins, Crandall Creek valley glacier's zone of accumulation is much closer to the confluence of the two rivers. Therefore it required less ice volume to reach the confluence.

GLACIAL HISTORY

Clarks Fork valley was occupied by three major ice lobes in this study area during the final stages of Pinedale glaciation. The Beartooth lobe advanced from the Beartooth Mountains bearing southwest. During glacial maximum, the Beartooth ice sheet joined the Clarks Fork ice and was turned southeast down the Clarks Fork valley, as indicated by cross-cutting striations found in the northeast area of the Clarks Fork drainage basin (Fig.1). Striations sub-parallel to the Clarks Fork valley cut across striations bearing southwest. The Clarks Fork lobe was the largest and dominant ice lobe in the valley and moved parallel to its valley walls. Crandall Creek lobe moved down-valley until it reached Clarks Fork ice, where it was assimilated into Clarks Fork ice.

When Clarks Fork ice reached Dead Indian Hill it turned sharply northeast, following the river valley. Cross cutting striations bearing 135° and 110° are found near the confluence of Clarks Fork and Dead Indian River, about five-hundred meters west of Dead Indian Hill (Fig. 1). Striations bearing 135° were likely made before the ice reached Dead Indian Hill. When Clarks Fork ice reached Dead Indian Hill and was forced to turn, 110° striations were made cutting across the 135° striations.

Cross cutting striations a few hundred meters north of the confluence of Crandall Creek and Clarks Fork indicate that the last glacial advance in that area was made not by Clarks Fork ice but by the Crandall Creek valley glacier ice. Largely because Crandall Creek drainage basin has a greater percentage of surface area at higher elevations than Clarks Fork drainage basin and a shorter distance from confluence to centroid, the Crandall ice advanced across the Clarks Fork river while the Clarks Fork lobe retreated to the northwest. The Crandall Creek valley glacier actually dammed the Clarks Fork river, diverting it approximately two-hundred meters to the north. The end moraine found perpendicular to the Crandall striations was formed by this advance of the Crandall Creek valley glacier, and made the south valley wall of the diverted Clarks Fork river. The paleo-river bed has gravels similar to those in Clarks Fork River today.

DISCUSSION

During glacial maximum, ice volume controlled the dominant and subordinate flow of glaciers in Clarks Fork valley. Clarks Fork lobe had greater ice volume at this time than Crandall Creek valley glacier or Beartooth lobe. During some period of climatic change, however, Crandall Creek valley glacier advanced while the larger Clarks Fork ice retreated. The current general warming trend that began in Late Pleistocene must be responsible for retreat of the Clarks Fork lobe, but the role of smaller temporary cooling trends lasting a few hundred years or more may be important for explaining the last advance of the Crandall Creek valley glacier.

The hypsometry and morphology of Clarks Fork and Crandall Creek drainage basins may best explain why the Crandall valley glacier dammed Clarks Fork river while Clarks Fork ice retreated. Because higher elevations remain in a glacier's zone of accumulation longer than lower elevations, drainage basin morphology and hypsometry becomes significant to timing of glacial activity for Clarks Fork and Crandall ice. Crandall Creek valley glacier may have crossed Clarks Fork river during a period of climatic warming, advancing because it maintained a positive ice budget longer than Clarks Fork ice lobe. Crandall valley glacier could also have advanced as a wet-bed glacier surging across Clarks Fork river during a climatic warming period. During a temporary cooling period within the Late Pleistocene warming trend, Crandall valley glacier could have easily advanced across Clarks Fork river. Crandall Creek valley glacier ice has increasingly shorter distances to travel to the confluence of Clarks Fork and Crandall Creek relative to Clarks Fork lobe ice. Crandall Creek valley glacier may have advanced across Clarks Fork river during a cooling trend that lasted a few hundred years or more while Clarks Fork lobe never reached the confluence of the two rivers.

Pronounced topographic barriers have a strong influence on ice flow direction. Dead Indian Hill was a major topographic barrier for the Clarks Fork ice lobe. The Clarks Fork lobe advanced down-valley bearing 135° until it reached Dead Indian Hill. When ice reached Dead Indian Hill flow divergence occurred. Ice advance down-valley bearing 110° and up valley into sunlight basin bearing 165°. Striations demonstrate this flow divergence up to five-hundred meters from Dead Indian Hill. Rheology of the Clarks Fork ice lobe could be investigated with this information (Paterson, 1994).

CONCLUSIONS

Non-synchronous glacial activity did occur in the Clarks Fork valley during Pinedale glaciation. Local basin morphology and hypsometry proved to be the major reasons for non-synchronous glaciation in the Clarks Fork valley.

REFRENCES

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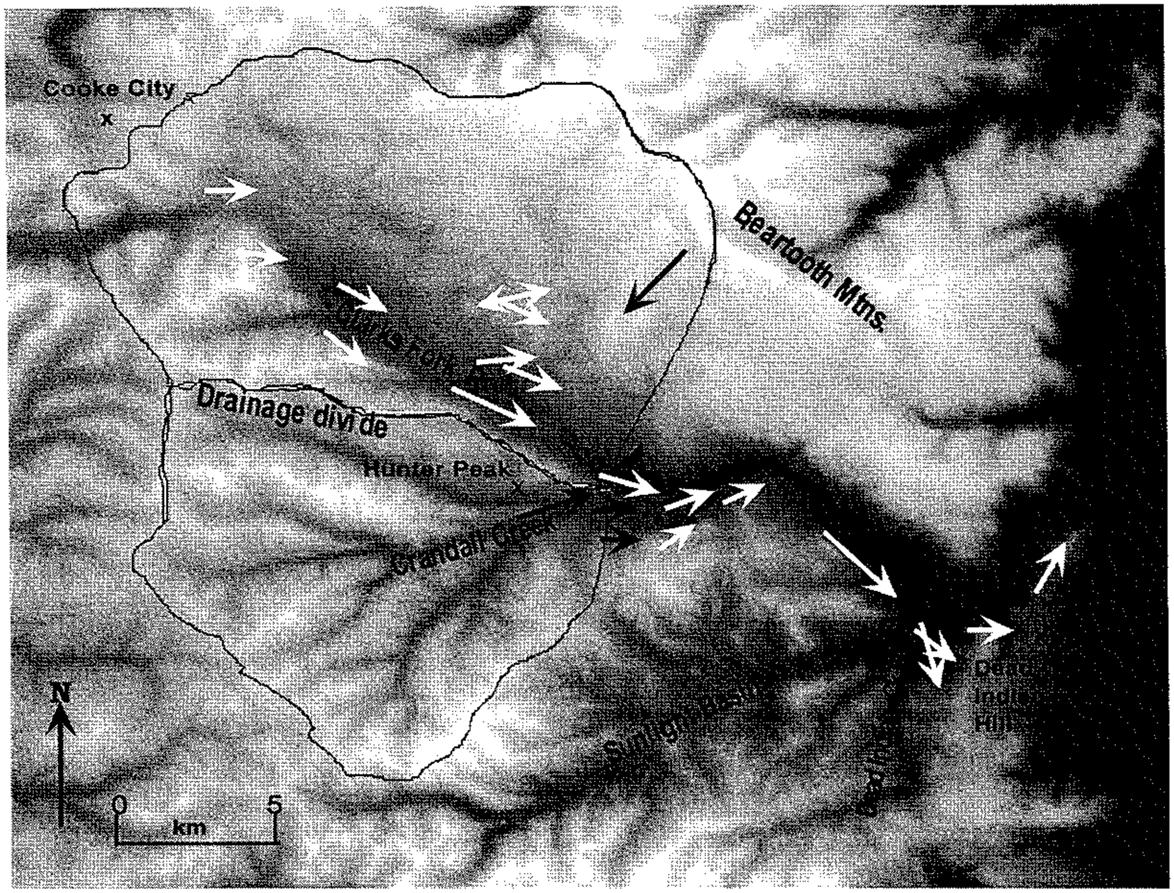

Fig. 1. 1:250000 map of field study area. White arrows indicate striation direction of Clarks Fork ice, black arrows indicate striations of Crandall Creek ice; the gray arrow is Beartooth ice. Clarks Fork and Crandall Creek drainage basins are delinieated by black lines.

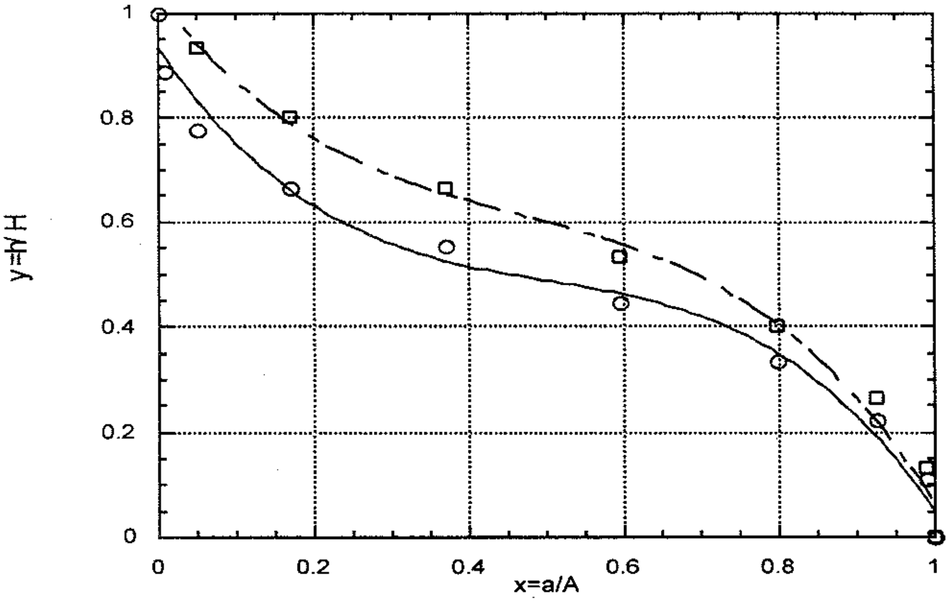

Figure 2. Hypsometric curves of Clarks Fork (solid line) amd Crandall Creek (dashed line) drainage basins. The relative height (y) is the ratio of the height (h) of a given contour above the horizontal datum plane to the total relief (H). The relative area (x) equals the ratio a/A, where *a* is the area of the basin above the givien contour and *A* is the total basin area.

LATE QUATERNARY DEGLACIATION, FLOODING, AND TECTONISM(?) OF UPPER CLARKS FORK VALLEY, PARK COUNTY, WYOMING

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INTRODUCTION & PURPOSE

During the Pinedale Glaciation, the Yellowstone ice sheet was centered over northwestern Wyoming. An outlet glacier of the Yellowstone ice sheet occupied the valley of Clarks Fork of the Yellowstone River; most of the ice forming this outlet glacier originated in cirques on the Beartooth Plateau to the north of Clarks Fork. Ice in transition from the ice sheet covering the Beartooth Plateau to the Clarks Fork outlet glacier may have had complex flow and deposition patterns. Thus the Clarks Fork outlet glacier may not have followed the model of a typical valley glacier advancing and retreating directly along the valley bottom. This study concerns the nature of deglaciation of the Clarks Fork outlet glacier upvalley from Crandall Creek.

GLACIAL EROSION: PLUCKING AND SCRATCHING

Roches moutonnées: Many roches moutonnées are located within this study area. They have abraded upvalley sides (often steep) and steep, plucked downvalley sides. Particularly large lodgment till ramps are found on the upvalley side of many of the roches moutonnées. These roches moutonnées are not considered to be excellent iceflow direction indicators because elongation is not consistent with ice flow direction. This is probably a result of strong joint control of the shape of the roches moutonnées.

Striations: To be certain that a given set of striations represented a "regional area" of ice flow direction, striations were measured on the tops of roches moutonnées, where ice flow was least constrained by local topography. Well preserved glacial striations are most commonly found under large boulders, were they are protected from weathering. Striations show ice flow direction in the vicinity of Clarks Fork to be consistent with the overall direction of the valley (Figure 1). However, roches moutonnées a few km northeast of Clarks Fork have cross-cutting striations and/or closely spaced striations that show 20-40° variation. One set of striations is oriented southeast (ice flowing roughly parallel to Clarks Fork). The second set averages to a northeast-southwest orientation which could conceivably have been ice flowing in either direction.

GLACIAL DEPOSITION: MYSTERIOUS MORAINES

The area contains many parallel to subparallel till ridges oriented in an east-southeasterly direction. There are at least six possible origins for these till ridges: 1) till ramps upglacier of roches moutonnées; 2) terminal/recessional moraines built by ice flowing southwest off the Beartooth Plateau; 3) left lateral moraines created by a narrow tongue of ice seated in the bottom of Clarks Fork valley; 4) interlobate moraines deposited between southwest-flowing ice from the eastern Beartooth Plateau and southeast-flowing ice form the central Beartooth Plateau; 5) medial moraines deposited by quick melting of clean stagnant ice; 6) drift drumlins.

1) Till ramps: Near Clarks Fork there are ramps of lodgment till on the upglacier ends of roches moutonnées. These till ramps could be misinterpreted as moraines because of their close alignment with other till ridges that probably are moraines.

This location of lodgment till upvalley of the roches moutonnées differs from the more common location of drift downvalley of a rock drumlin such as in a crag-and-tail landform. The till ramps are not lateral moraines because of their unusual shapes. The fact that they are aligned nearly parallel to regional ice flow direction indicates that they are not terminal or recessional moraines. The composition of the till ramps and of the till ridges farther north is similar: a layer of approximately one meter of ablation till over lodgment till (although the lodgment till is less compact in the till ridges farther north than in the till ramps).

2) Terminal/recessional moraines: The fact that the till ridges are nearly perpendicular to some of the bi-directional ice striations (figure 1) and that they are roughly perpendicular to ice flowing southwesterly from the eastern Beartooth Plateau suggests that they may be terminal/recessional moraines. However, there are many