Sackung on Dead Indian Hill, Park County, Wyoming

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INTRODUCTION

The type of alpine gravitational spreading ridge known as a sackung (from the German word for sagging or subsidence) has only appeared in geological literature in the last 70 years. This spreading is commonly characterized by a main trench along the summit ridge as well as associated geomorphic features, including grabens, uphill-facing scarps, double-crested ridges, shallow linear trenches parallel to topographical contours, and in some cases a bulging of lower slopes. Topography seems to be the primary determinant of where such features occur, but joints and faults are also important factors (Varnes et al. 1989). The sackung most commonly cited in the literature are in the Tatra Range of eastern Europe, but other sites include the Swiss Alps, New Zealand's Southern Alps, and the Rocky Mountains.

Gravitational spreading of the ridge top of Dead Indian Hill (elevation, 2643 m) has resulted in a summit trench approximately 100m wide and 400m long as well as uphill-facing scarps and small linear trenches. Dead Indian Hill, a cuesta located just south of the mouth of the Yellowstone River's Clarks Fork Canyon, is part of a monocline of Paleozoic and Mesozoic sedimentary rocks with an east dip ranging from 6 to 15 degrees. Talus mantles both the east and west slopes, and a block slope and block stream extend beyond the talus on the east side. The blocks of these features as well as the bedrock at the sackung are competent Pennsylvanian Tensleep Sandstone. Beneath are the shales and limestones of the incompetent Amsden Formation.

The use of the words "sackung" and "sackungen" has varied in the literature; in this paper, "sackung" denotes the spreading process that creates the geomorphic features noted above, referred to as "sackungen."

METHODS

All field work was performed on foot at Dead Indian Hill, with the help of several assistants. Many qualitative observations were made, and a great deal of quantitative information was recorded as well. In order to map the micro-topography of the main summit trench, eight survey lines were run from the west ridge to the east ridge using an altimeter and a 50m tape. One of these lines was continued down the west talus, the east talus, and across the block field. Eight block surveys were conducted at various sites on the east talus and across the block field. At each site, 50 blocks were measured for strike and dip of the top face, long axis, number of weathering pits if any and their depths, and roundness of edges. The orientation of joints in intact bedrock was measured as well.

DISCUSSION

The main trench trends 015° and has an en echelon appearance when observed in air photos. This is roughly consistent with the vertical joint data recorded at Dead Indian Hill, which show a prominent joint set trending 020-030° and a secondary set at 120-130° (Fig. 1). This data agrees with the local pattern that shows a primary set at 010-020° and a secondary set at 90-120° (Ashley LaForge, written communication, 1997).

The main trench contains several smaller trenches which give clues to the formation of the larger structure. These are visible in the cross-sections derived from survey lines recorded in the field (Fig. 2). Also shown in the cross-sections are the locations and relative sizes of associated scarps and closed depressions. The time of the formation of this structure was of interest as well. Most previous studies on sackungen have cited glacial oversteepening of valley

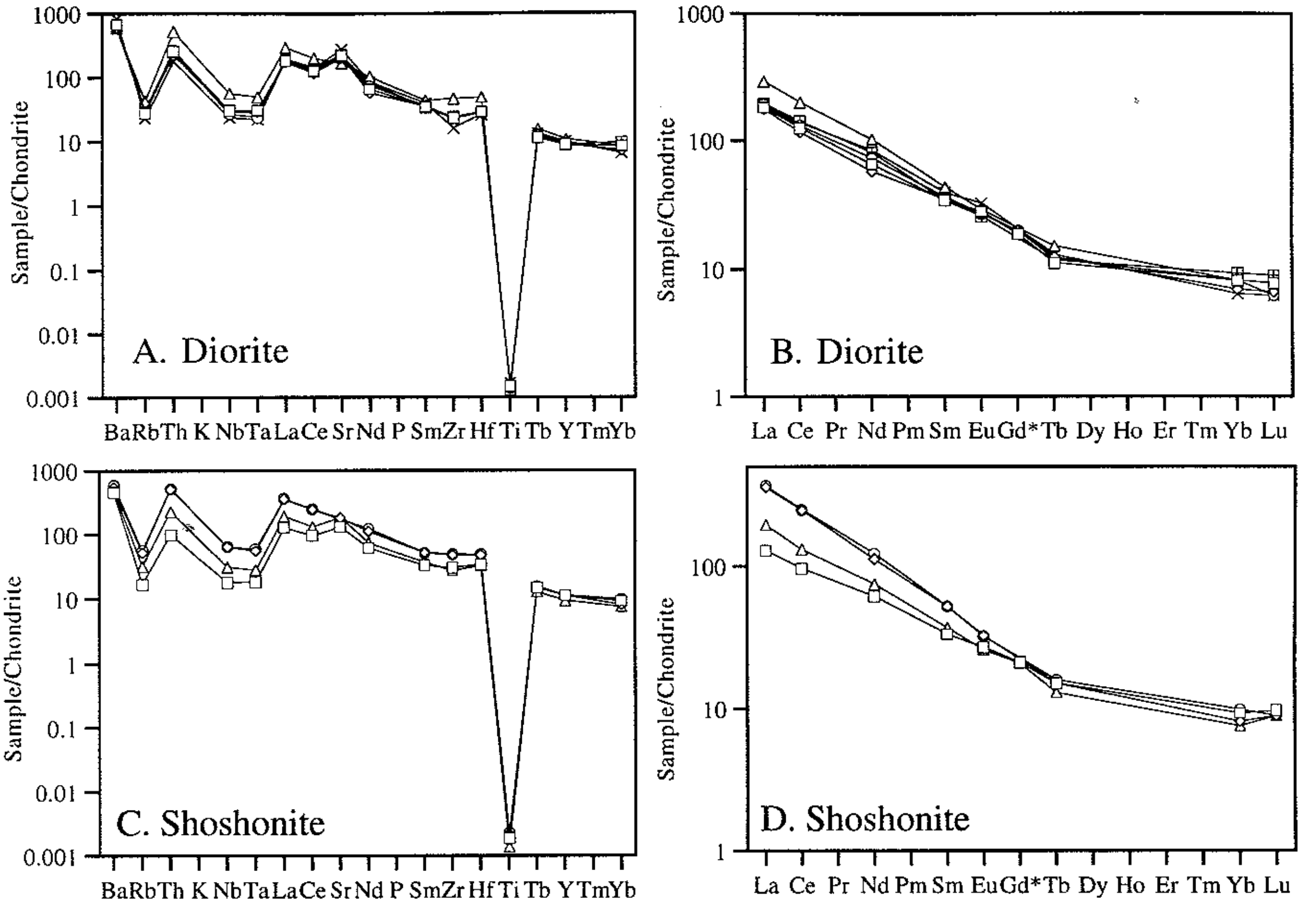

Figure 4. Spider diagram and REE plot for diorites and shoshonites (Gd* values estimated).

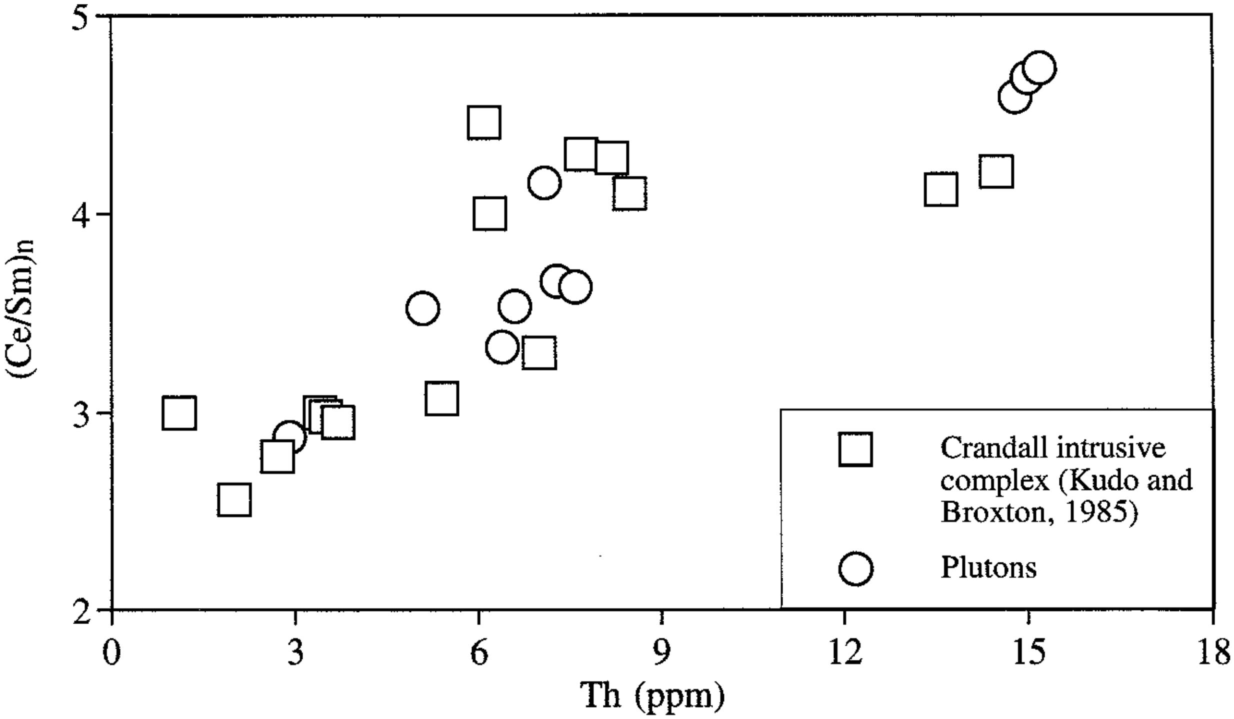

Figure 5. Plot of Th vs. $(Ce/Sm)_n$ illustrates first order relationship of Th and the LREE.

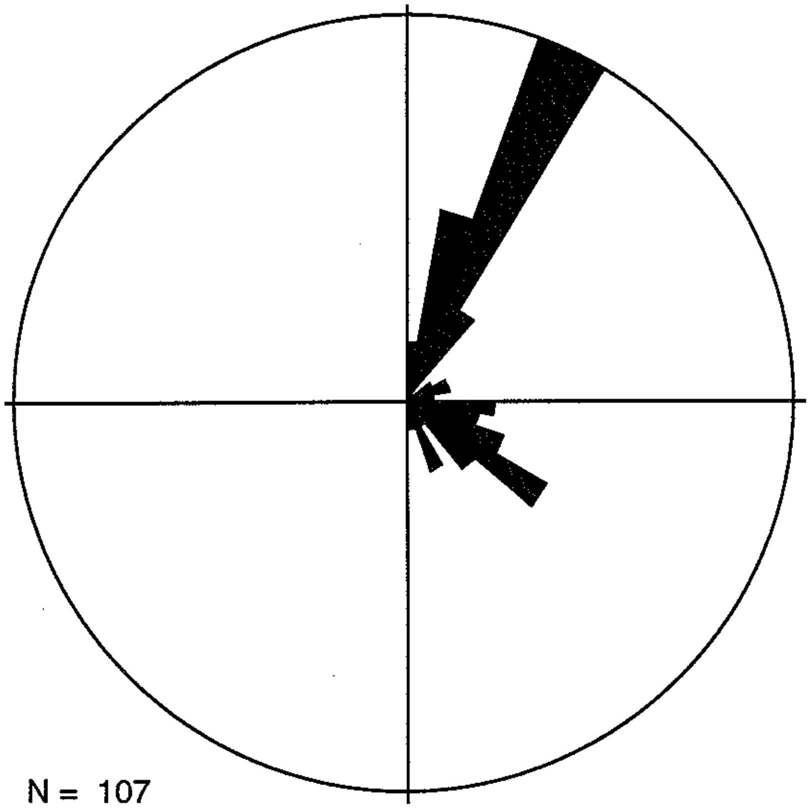

Figure 1. Rose plot of joint orientations from Dead Indian Hill showing a prominent set trending 020-030° and a secondary set at 120-130°.

walls, isostatic rebound and removal of lateral support during deglaciation as main causes of spreading. During the Pinedale, the Clarks Fork lobe of the Yellowstone Ice Sheet began to retreat from the area approximately 14 ka (Pierce, 1979). Varnes and others (1990) measured displacement rates as high as 5mm/yr at Bald Eagle Mountain in Colorado. If this rate is extrapolated back to the time of deglaciation, the summit trench would be 70m wide. The summit trench averages 100m wide, and it is likely that strain recovery after deglaciation did not begin immediately. Furthermore, the summit trench shows no signs of recent movement. It is likely, therefore, that 1) the spreading rate at Dead Indian Hill was faster than 5 mm/yr, and 2) that other factors were involved.

There are many other factors which in combination probably decreased the stability of the Tensleep Formation and initiated sackung. Beneath the Tensleep sandstone are weak shales in the Amsden Formation. The Madison limestone, which underlies the Amsden, exhibits several small caverns in the road cuts on US 296 which could be indicative of greater dissolution. There is also a sink in this formation in Sunlight Basin, between Trail Creek and Little Sunlight Creek (Bob Carson, written communication, 1996). Large and small landslides of Cambrian to Cretaceous aged shales are common. The Paleozoic strata and Archean basement have been downcut as much as 1200m in the Clarks Fork Canyon just north of Dead Indian Hill. The ice limit on the west side of Dead Indian Hill was 7185' (2190m) based on the highest appearance of erratics (Carson, oral communication, 1996). The ice was not responsible for much erosion, but there was a loss of lateral support upon deglaciation. Immediately to the east, Dead Indian Gulch represents more than 425m of fluvial incision below the summit. Spreading may have been triggered by seismic activity associated with the nearby Yellowstone hotspot. The last major earthquake in the area was in 1959, but the area has been seismically active for millions of years (Keefer 1973).

Some studies of sackung in sedimentary units have allowed the absolute dating of their origins using ^{14}C techniques on soils in a dug-out trench (McCalpin and Irvine 1995). Digging a trench was not feasible at this site because the whole summit is bedrock, joint blocks, and talus. There are areas of the talus and block field which are covered by forest. This suggests that these areas have stopped moving long enough to form a soil and support large trees; they may be a product of different movement rates and times or differential melting of seasonal snowpacks. Four trees from the block field and block stream were cored to make sure their small size was due to their age and not to stunted growth from alpine conditions; the oldest tree is 72 years old.

There is little sign of mass movement on the slope such as large rock falls, rock avalanches, or debris flows of any kind. Furthermore, data analysis turned up no prevailing orientation of joint blocks which could suggest emplacement by some sort of flow. There is a minor ridge at the east edge of the block field that is parallel to the summit ridge, but it is unlikely that this is the toe of some mass movement because there is nothing else to suggest such an event. There is a localized example of large block imbrication at the northeast end of the block field near this "toe," but again due to lack of other evidence this is considered more coincidence than anything else.

The only part of the area that appears to be active is the block stream which extends downslope from the northeast end of the block field. Signs of recent activity include abraded edges of blocks and tree trunks which bend downhill. Several tree trunks have sharp curves at their base with blocks wedged into the curves; this is interpreted as a sign that the vegetation grew as the blocks crept downslope. Further work may show whether this creep is due to solifluction, gelifluction, or some other process.

On the surfaces of many joint blocks south of the summit as well as on the blockfield, there are straight lines made up of concave marks. The lines are up to 2m long. The marks are white, parallel to each other, and perpendicular to the lines; the marks are about 5-20 cm long, about 0.2 cm wide, and spaced about 0.3cm apart. It is unknown whether they are natural (e.g. from lightning strikes) or a result of human activities (e.g. cable drag).

CONCLUSION

The summit trench is interpreted to have started along a fracture of the 010-020° joint set and then widened due to spreading caused by the various factors named above. This spreading may have been initiated by seismic shaking that destabilized the slopes to the point that they failed. Joint blocks fell into the fracture as it widened and formed the trench. Taluses developed on the slopes east and west of the trench. The east talus is transitional to a large blockfield farther east, and a small block stream to the northeast.

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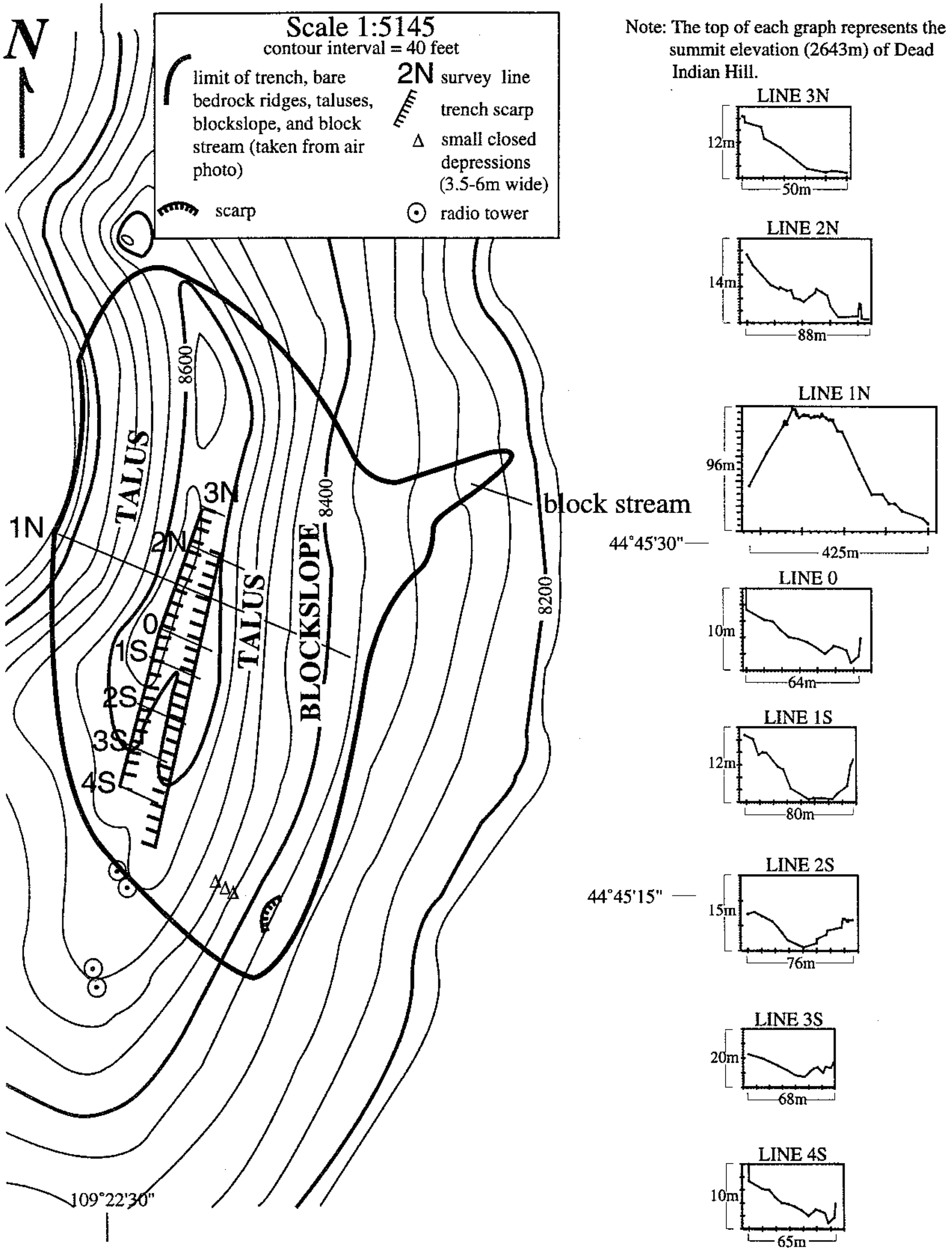

Note: The top of each graph represents the summit elevation (2643m) of Dead Indian Hill.

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.

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