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

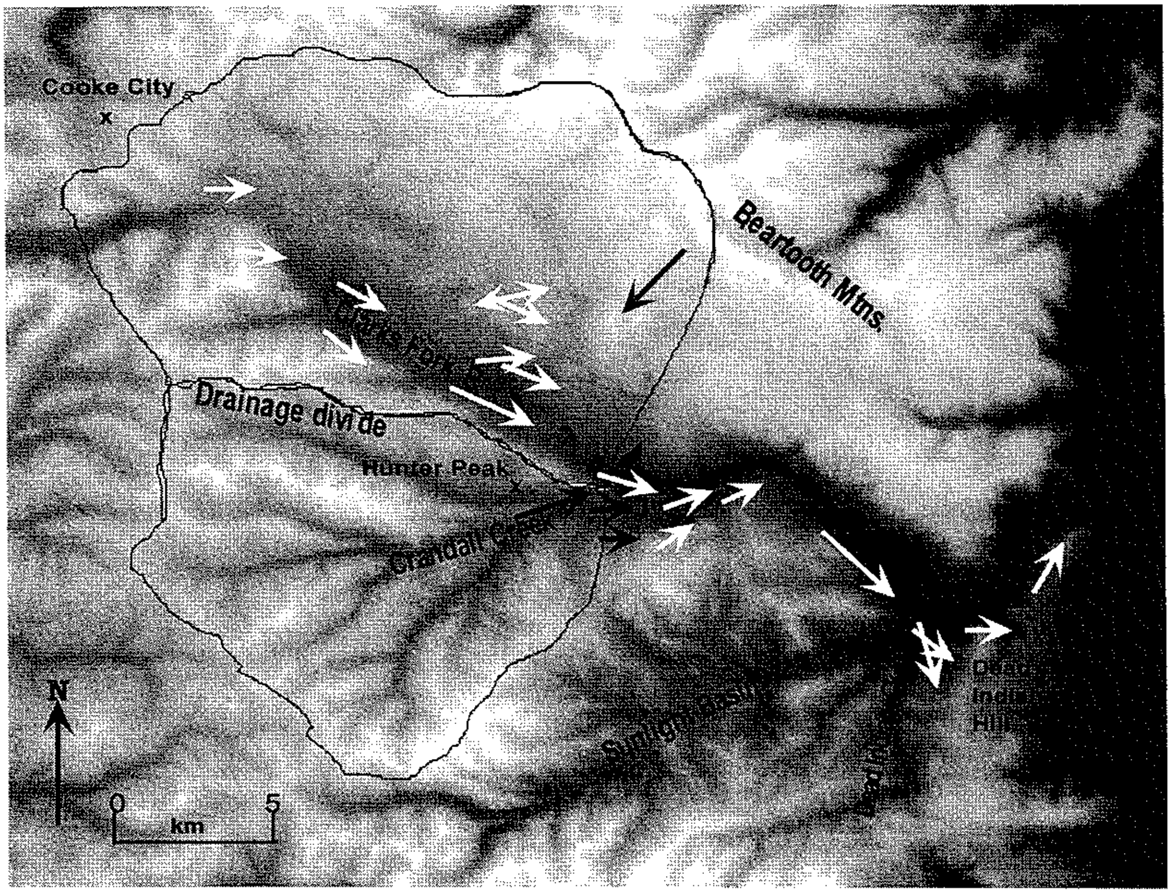

Fig. 1. 1:250000 map of field study area. White arrows indicate striation direction of Clarks Fork ice, black arrows indicate striations of Crandall Creek ice; the gray arrow is Beartooth ice. Clarks Fork and Crandall Creek drainage basins are delinieated by black lines.

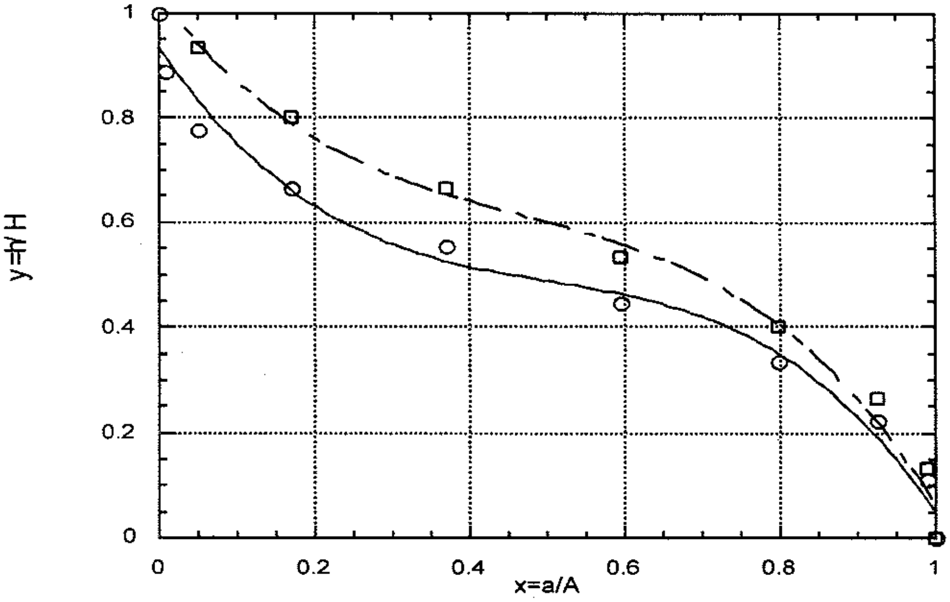

Figure 2. Hypsometric curves of Clarks Fork (solid line) amd Crandall Creek (dashed line) drainage basins. The relative height (y) is the ratio of the height (h) of a given contour above the horizontal datum plane to the total relief (H). The relative area (x) equals the ratio a/A, where *a* is the area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

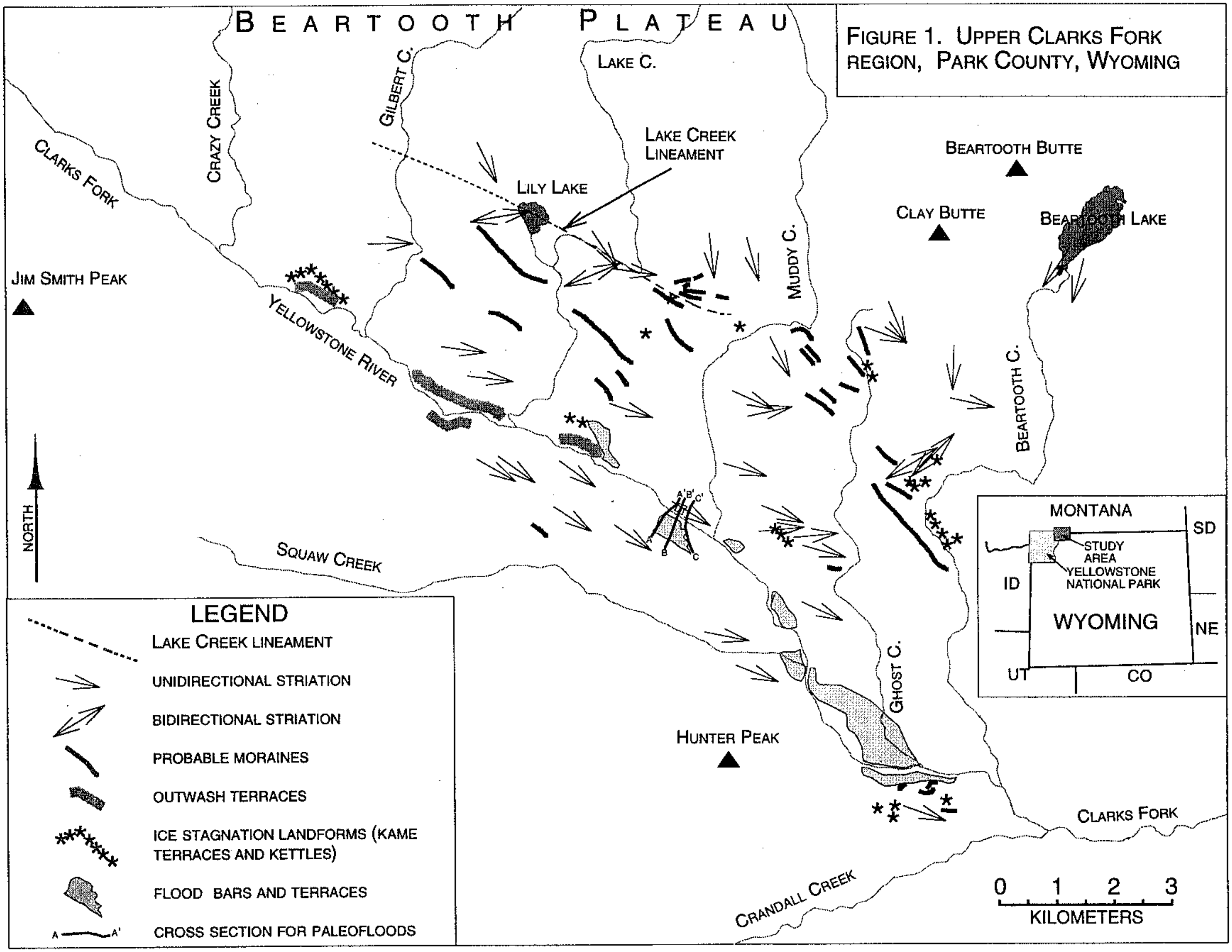
FIGURE 1. UPPER CLARKS FORK REGION, PARK COUNTY, WYOMING

meltwater channels located on the northeast sides of these till ridges, which is unlikely if ice from the northeast was building these moraines.

3) **Left lateral moraines**: Ice advanced from the central Beartooth Plateau southeasterly along Clarks Fork. This ice flow direction is confirmed by many striations parallel to the river (Figure 1). Clarks Fork valley is asymmetric, with a steep southwest side of Absaroka volcanics, and a gentle northeast side of Archean crystalline rocks. This asymmetry may have resulted in an abundance of large lateral moraines on the left (northeast) side of the retreating ice, and little drift on the right (southwest) side.

Kame terraces are located near these moraines and lodgment till ramps, but their small size suggests that stagnation of dirty ice played a small role in deglaciation of this area. Some of the kame deposits near Beartooth Creek may be kame deltas that were built into a small lake formed when Clarks Fork ice dammed Beartooth Creek. These kame terraces slope east and/or northeast 1-3 degrees away from the ends of southeast trending meltwater channels. This may indicate water building them in an easterly and/or northeasterly direction. Building in this direction would be from ice on the southwest side rather than to the northeast side. This is an indication that the Clarks Fork outlet glacier retreated as a narrow glacier up the center of the valley depositing these moraines as left laterals.

4) **Interlobate moraines**: Variation of striation direction within a region may be a result of radial flow of retreating ice lobes. Interlobate moraines could have been formed between a lobe of southeast flowing ice in the bottom of Clarks Fork valley and another lobe to the northeast flowing southwesterly off the eastern Beartooth Plateau.

One problem with the interlobate moraine, the left lateral moraine, and the terminal/recessional moraine scenarios is the scarcity of kettles on the till ridges.

5) **Medial moraines**: The relatively small area of stagnant ice topography and the consistently thin layer of ablation till covering the till ridges may indicate fast melting of clean ice, a process necessary for the preservation of medial moraines. The topography here is not unlike that near Tioga Pass in the Sierra Nevada, where there are well preserved medial moraines downglacier of a bedrock ridge (Clark and Clark, 1995). Evidence opposing the medial moraine hypothesis is the lack of appropriate ridges on the Beartooth Plateau for the formation of medial moraines.

6) **Drift drumlins**: A sixth hypothesis for these till ridges is that they are drift drumlins because of their shapes, large lodgment till component, and lack of kettles. The 4:1 to 12:1 length:width ratios are appropriate for drift drumlins (their size is too large for fluted drift). Their east-southeast orientation is consistent with active ice advancing down Clarks Fork valley. The lack of regularity in size and spacing which is typical of most drumlin fields is an argument against this hypothesis.

THE GREAT FLOODS

Ballard (1976) attributed flood features at the mouth of Clarks Fork Canyon to multiple late Pleistocene floods along Clarks Fork. Ballard mentioned Sunlight Basin and Placzek and Sneeringer (1996) named Dead Indian Creek as likely sources for floods from lakes dammed by the Clarks Fork outlet glacier. A third source for jökulhlaups (glacier outburst floods) is from the upper Clarks Fork valley. Flood features found along Clarks Fork from Lake Creek to Ghost Creek include gravel bars, boulder bars, and large boulders and were first pointed out to us by Ken Pierce of the U.S. Geological Survey. The largest boulders that appear to have been moved by flooding are 2-3 m in diameter. Minimum heights of bars and terraces are found at or near modern alluvial terrace heights, while the maximum heights are probably 30+ m, and possibly 50+ m above the present Clarks Fork.

Boulder bars are typically composed of well rounded crystalline boulders averaging 0.5-1 m in diameter. A surface layer 0.5-2.5 m thick has no matrix. Below this, boulders (clast supported) of similar size are found with a sandy and gravelly matrix.

The fact that the flood deposits terminate downvalley near the mouth of Ghost Creek is probably because Clarks Fork enters a narrow gorge there. The termination of flood deposits upvalley near the mouth of Lake Creek may indicate the presence of an ice terminus at this location at the time of the floods. All terraces upvalley from the mouth of Lake Creek are outwash, kame, or alluvial terraces. If the ice terminus did exist at this location, there are two potential scenarios: a subglacial flood exiting the ice at this point, or a flood coming down alongside the ice in a meltwater channel.

Evidence for the second scenario may exist within a meltwater channel southwest of the road to Lily Lake. This particularly large meltwater channel is as much as 40 m deep. Boulder deposits, boulder bars, and bare bedrock are found within this channel and at various points between the termination of this channel and the beginning of flood deposits along Clarks Fork. The meltwater channel extends upvalley across Gilbert Creek to Crazy Creek. A flood could have come from a subglacial lake high on the Beartooth Plateau southerly along the route of Gilbert and/or Crazy Creek, along the large ice-marginal meltwater channel, and finally into Clarks Fork.

Three cross-sections were surveyed across Clarks Fork and flood deposits. Paleoflood parameters were calculated using the Gauckler-Manning equation (Table 1). Paleodischarges are estimated to have been as high as 43 x 10^3 m^3/sec. There is much uncertainty with respect to each of the variables. The cross-section area does not accommodate eddies. The maximum height of flood deposits is in question. The slope was chosen for that of the present Clarks Fork because the flood deposits and terraces are not easily correlated. The roughness coefficient (0.1) was chosen from a table of various channel materials and configurations (Newson, 1994).

Flood Depth (m)	Slope	Roughness Coefficient	Discharge (1000 m^3/sec)	Velocity (m/s)
51	0.011	0.1	43	4.5
42	0.011	0.1	21	3.8
27	0.011	0.1	7	3.5

Table 1. Flood parameters for survey line C-C', using the Gauckler-Manning equation, $Q=AR^{2/3}S^{1/2}/n$ (Q = discharge in ft^3/sec, A = cross-sectional area in ft^2, R = hydraulic radius in ft, S = slope, n = Manning roughness coefficient) (Newson, 1994).

LAKE CREEK LINEAMENT

A lineament coincident with a mapped 1.8 km long fault cutting the Archean crystalline rock (Pierce and Nelson, 1971) is possible evidence for postglacial reactivation of the fault. The lineament goes through Lily Lake and strikes N 63° W. The lineament is most pronounced eastward from Lily Lake for 3.7 km, but may coincide with a meltwater channel as far as 4.7 km west of Lily Lake. East of Lake Creek, the lineament forms a 10-25 meter northeast facing scarp in till. Trees growing on the scarp exhibit curved trunks probably caused by creep of an over-steepened slope.

Minimum uplift for diversion of Lake Creek from old meltwater channels to its present course is only 1.5 m. These meltwater channels show miniature scabland topography. A reason for abandonment other than fault movement is unknown, but Lake, Muddy, and Beartooth Creeks all have segments which trend upvalley (abnormal for a glaciated area). Possible causes for late Quaternary fault movement include isostatic rebound upon deglaciation and the Yellowstone hot spot bow wave (Pierce and Morgan, 1992).

CONCLUSIONS

Ice flowed south into Clarks Fork valley from the Beartooth Plateau depositing many large till ridges, including till ramps, moraines, and possible drift drumlins. Although the moraines are likely to be left lateral, alternatives include terminal/recessional, interlobate, and medial. A radiocarbon age of 11,560 years for organic matter in the Corral Creek alluvial fan is the minimum date for deglaciation of the area. At some time during deglaciation one or more jökulhlaups occurred. A lineament near Lily Lake may be evidence for postglacial fault movement.

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Debris flows' effect on Holocene alluvial fan formation and record of environmental instability, Corral Creek, Park County, Wyoming

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INTRODUCTION

The traditional alluvial fan facies model considers stream deposition to be an important influence on fan construction. New work suggests that traditional models do not put enough emphasis on the influence of debris flows. The purpose of this study was to gauge the relative influence of stream versus debris flow deposition on the formation of the Corral Creek fan. A secondary goal was to use fan facies to determine the record of the area's environmental instability.

Background. Recently workers have debated the worth of current fan facies models. For example, Blair and McPherson (1992-1995) have stated that many facies models have inaccurately interpreted fan sediments as stream deposits, misjudged the effect of climate change on deposition, and incorrectly de-emphasized the influence of debris flow deposition on fan construction. In response, some researchers have questioned the accuracy of Blair and McPherson's model of debris-flow-dominated fans (Hooke, 1993; Nemec and Postma, 1995). It is necessary to examine fans in the field in light of these issues, so we can build a more correct model.

Geography. Corral Creek heads near Windy Mountain and flows north to join Clarks Fork of the Yellowstone River near Cathedral Cliffs, in the cool, semi-arid, mountainous Clarks Fork valley near the northeast border of Yellowstone National Park, in northwest Wyoming. Its upper drainage (upstream of the fan) is about 4 km^2 in area. It has slopes greater than 25° for much of its area and a maximum basin relief of about 1000 m. The Clarks Fork valley was last glaciated about 13,000 BP (Pinedale glaciation), so the Clarks Fork ice up Corral Creek probably deglaciated at about the same time.

Above the fan head, the stream cascades down the carbonate cliff formers, and is confined for about 100 m in shale bedrock, slumped carbonate bedrock blocks, and colluvium before its flow becomes unconfined on the fan. The fan (about 1 km^2 in area) is bordered on the east by the Cathedral Cliffs colluvial apron, and on the west by the Oliver Gulch stream (see figure 1). High spring runoff rates, severe rain storms, and mass wasting that includes landslides, slumps, and debris flows, mobilizes a fan sediment supply of bedrock (Eocene volcanics, Paleozoic carbonates, Cambrian shales), colluvium, and glacial material.

METHODS

The extent of surface deposits on the fan was mapped from photographs and by pace and compass. The fan morphology was recorded with a radial profile and a cross fan profile, measured with pace, compass, and altimeter (accurate to within 0.2 m); the profile and cross section morphology of the active channel were recorded in the same way. Cobble sizes of surface deposits keyed to these profile and cross section lines were measured by point counts with a Gravilometer.

Stratigraphic sections exposed in natural channels were described in the upper, middle, and lower fan. Facies relationships along survey lines were described as well. Sediment samples were taken from the described deposits. Geochron Laboratories, Massachusetts, analyzed three samples for radiocarbon, and the ages were calibrated with CALIB rev3.0.3A (Pearson and Stuiver, 1993).

RESULTS

Sediment. Point counts of surface cobbles show that between 50-80% are carbonates, 10-20% of the cobbles are shales, and 10-30% are volcanics (although as much as 50% of the cobbles may be volcanics). It is not surprising that carbonates are in the majority, since most of the cobbles observed in the upper reaches of Corral Creek were carbonates, weathered from the exposed bedrock above. Shale cobbles quickly weather on the fan surface, so the point counts may underestimate the shale fraction of surface cobbles actually transported onto the fan.

Colluvium enters the transport system to the fan through overland flow, creep, and as sediment remobilized by minor streams from landslides and earth flows on the colluvial apron of Cathedral Cliffs. Fine grained sediment