Deglaciation of Clarks Fork valley, Wyoming and Montana

Beth Ann Bartel
Whitman College, Walla Walla, WA 99362
Faculty sponsor: Bob Carson, Whitman College

INTRODUCTION

Clarks Fork valley was occupied by ice during at least the Bull Lake and Pinedale glaciations (Hilmoe, 1980). Studies date back as far as 1911 (summarized in Carson et al., 1996), with a concentration of efforts over the past four summers (1993-1997) by students and faculty during Keck projects. The purposes of this paper are (1) to synthesize preexisting data with data collected in the summer of 1997, including absolute dates pertaining to Pinedale glaciation; (2) to estimate the ELA at the maximum extent of Pinedale ice; and (3) to construct as accurately as possible a summary of the deglaciation history of Clarks Fork valley.

METHODS

Ice direction. Ice direction was determined by: (1) shapes of roches moutonnées; (2) glacial grooves; (3) striations on ice-polished surfaces on the tops of roches moutonnées; and (4) location of glacial erratics, particularly indicators (erratics with known sources). Shapes of roches moutonnées are strongly influenced by joint spacing and orientation, thus orientation of elongation of landforms alone is an inconclusive ice direction indicator. Attention was paid to abraded (gentle) vs. plucked (steep) sides of roches moutonnées.

Upper ice limit. Minimum elevations of the top of the ice were inferred from (1) highest elevations of glacially transported boulders; (2) uppermost polish, striations, and grooves; (3) cirque headwall elevations; and (4) col elevations.

Dating. Absolute dates were acquired by both radiocarbon and cosmogenic methods.

OVERVIEW OF THE NORTHEAST YELLOWSTONE ICE SHEET

Pierce (1979) studied the northern portion of the Yellowstone ice sheet, in Yellowstone National Park, but little literature exists detailing the glaciation of the eastern portion, which occupied Clarks Fork valley and herein is referred to as the Clarks Fork lobe of the Yellowstone ice sheet.

Contributing ice. Clarks Fork lobe consisted principally of four ice bodies feeding into Clarks Fork valley and becoming a single outlet glacier which spilled down Clarks Fork Canyon onto the Bighorn Basin as a piedmont glacier (Figure 1) (Hilmoe, 1980). The four contributing ice bodies, clockwise from the southwest, were: Crandall ice, Pilot ice, Clarks Fork ice, and Beartooth Lake ice, with Crandall and Clarks Fork ice as the principal contributors. An additional small ice body, here referred to as Deep Lake ice, flowed south from the easternmost region of the Beartooth Plateau and turned east onto the Bighorn Basin, never joining the Clarks Fork lobe.

Lithologies and topography. Both Crandall and Pilot ice originated southwest of Clarks Fork valley, in the Absaroka Mountains, in drainages carved exclusively of erodible Eocene volcanics. The area has steep topography and high relief. In contrast, the region north of Clarks Fork valley consists principally of resistant Precambrian crystalline rocks and is characterized by relatively gentle slopes. Paleozoic sedimentary rocks are stratigraphically between the Beartooth granitics and the Absaroka volcanics (Carson et al., this volume) and flank Clarks Fork valley. The contrast in lithologies is useful in determining direction of ice origin.

Ice divides. At the glacial maximum, most of the modern drainage divide between Clarks Fork (and its tributaries) and the Lamar River (in eastern Yellowstone National Park) was under ice; Crandall ice was probably supplemented by Yellowstone ice (Pierce, 1979). The northern border of the Clarks Fork lobe was also characterized by an ice divide, with ice on the northern side of the Beartooth Mountains flowing north into Montana and ice on the southern side flowing south into Wyoming.

Flow direction. During high ice levels, ice flowed perpendicular to the cirque headwalls of the Beartooths as indicated by striations on high landforms which were under ice at high levels and exposed as the ice thinned. Ice flowing southwest from the Beartooth cirques joined Crandall ice flowing out of the

Absarokas from the southwest and turned eastward down Clarks Fork Canyon. Striations in valleys are influenced by the local topography and indicate late flow; therefore, the striations do not necessarily indicate the general direction of ice flow at glacial maximum.

Ice thickness. Ice thickness was relatively thin in the high Beartooths, with a known thickness of approximately 100 m at the northern end of Clay Butte. Thickness increased as ice was channelled into Clarks Fork Canyon, where the thickness reached 570 m in the Sugarloaf Mountain area.

Crandall vs Clarks Fork ice. Ice from different sources dominated the valley at different times, as indicated by the complex of moraines near the mouth of Crandall valley (Heublein, this volume). The geometry of moraines dominated by Absaroka volcanics indicates that Crandall ice extended into Clarks Fork valley after Clarks Fork ice had retreated from the mouth of Crandall valley.

Pilot ice. There is also evidence for ice from different sources at the mouth of Pilot valley; crystalline erratics indicate Clarks Fork ice pushed up into the valley, whereas moraines dominated by volcanics but containing minimal amounts of crystalline erratics suggest subsequent reworking of Clarks Fork till by Pilot ice. Two adjacent moraines on the northern side of Pilot valley suggest a meeting of Pilot and Clarks Fork ice, as the downvalley moraine contains considerably more crystalline erratics than the upvalley moraine; thus the moraines are interpreted as Clarks Fork and Pilot moraines, respectively.

Easternmost Beartooth Plateau. The highest part of the easternmost Beartooth Plateau is characterized by patterned ground and tors (Adams, 1995), both of which are delicate features requiring much time to form. The presence of these forms and lack of glacial erosional features suggest that this area experienced little or no glaciation. An alternative possibility is a cold-based glacier, which might allow for the preservation of periglacial landforms. Minimal ice may be due to a precipitation shadow in this region, as the precipitation may have been concentrated on the ice sheet to the west; or to wind which kept snow from accumulating on the Plateau. South of the patterned ground and tors are cirque headwalls. The cirque glaciers merged into ice which split, the eastern portion entering the Deep Lake drainage. The remainder of this ice flowed south into Clarks Fork Canyon via the Canyon Creek glacial troughs and four adjacent glacial troughs to the east.

Northwestern ice divide. It is uncertain where the ice divide in the Colter Pass area was located. Pierce (1979) had the divide to the northeast, with ice from the high Beartooths flowing southwest into Soda Butte Creek valley, whereas modelling by Locke (1995) indicated a divide to the southwest with ice from Yellowstone National Park flowing easterly into Clarks Fork valley. Evidence was found to support both theories: striations slightly northeast of the Colter Pass area indicate a southwesterly ice flow, whereas metasedimentary erratics found in the Kelsey Lake area could only, of existing outcrops, have come from the Crown Butte-Fisher Creek area, indicating a southeasterly ice flow. The multiple-direction flow indicators suggest a fluctuating divide. The southeasterly transport of indicators could have occurred during the maximum of the last glaciation, with ice from the center of the Yellowstone glacier advancing radially in all directions, including eastward into the Clarks Fork area. The southwesterly striations were probably eroded later when the high Beartooths were a source area for ice advancing toward Yellowstone National Park. The shifting northwestern ice divide may have had influence on the advances of the Crandall vs. Clarks Fork ice.

GLACIAL MAXIMUM AND RETREAT

Pinedale ice reached its maximum in the Clarks Fork valley about 22,630 +/- 120 ka (see DATING below). At the maximum, Clarks Fork ice covered an area of approximately 1390 km^2. This figure includes only the ice which flowed out through Clarks Fork Canyon, and does not include the ice in the Deep Lake region north of the canyon. Different equilibrium line altitudes (ELA) of the Clarks Fork lobe at glacial maximum, based on varying accumulation area ratios (AAR), have been determined: ELA 3025 m at 60% AAR, ELA 2950 m at 67% AAR, and ELA 2875 m at 75% AAR. Most topography within the accumulation area was completely covered by ice, with the exception of relatively small nunataks both along divides and within the catchment.

Clarks Fork ice pushed up several creeks in the ablation area: Lodgepole Creek valley, where ice reached the divide and flowed down Trail Creek; Reef Creek valley and over a divide into the drainage of Painter Gulch; over several divides into Russell Creek valley; Sunlight Basin; Elk Creek valley; and Dead Indian Creek valley (Carson et al., 1996, Plate 1). Ice blocking the mouths of Sunlight Basin and Dead Indian Creek valley, and probably others, resulted in the formation of ice-marginal lakes. Lakebeds prove the existence of glacial lake Dead Indian, while the existence of glacial lake Sunlight is inferred. Jaworowski and Carson (1997) summarized the evidence for jökulhlaups from ice-dammed lakes and possibly from beneath the retreating ice. Dozens of moraines indicate episodes of active ice in equilibrium during overall retreat. In other places there is little or no drift, suggesting rapid retreat. Several pockets of ice-contact stratified drift suggest local ice stagnation.

DATING

Absolute dating of the Yellowstone ice sheet, as a whole, has been unsuccessful due to a lack of organic matter for radiocarbon dating. Other dating methods have been used in western Yellowstone to obtain absolute ages of glacial events. Obsidian hydration dating of obsidian-bearing lava flows scoured by ice yield an average age of 30,000 yr for Pinedale terminal moraines in west Yellowstone, with most age measurements between 20,000 and 35,000 yr (Pierce et al., 1976). Uranium-series ages of travertine in northwestern Yellowstone produce an approximate timeline for Pinedale glaciation of the area: extensive ice between 47,000 and 34,000 yr B.P.; retreat between 34,000 and 30,000 yr B.P.; advance between 30,000 and 22,500 yr B.P.; recession between 22,500 and 19,500 yr B.P.; a minor readvance after 19,500 yr B.P.; and recession before 15,500 yr B.P. (Sturchio et al., 1994).

Beds of glacial lake Cinderella contained enough organic matter to obtain a date of 22,630 +/- 120 radiocarbon yr. These beds (B on Figure 1) were deposited in an ice-dammed lake and subsequently overridden by the ice, as indicated by till on top of the lakebeds (Diez and Cuevas, 1996). The lake beds are found within 3 km of the terminus of Clarks Fork ice, and within 350 m of the top of the ice. The lake probably existed just before glacial maximum, although it is possible that the ice had already reached its maximum and retreated slightly, resulting in deposition of said lakebeds, and subsequently advanced over the lakebeds. In either case, the date acquired should represent the approximate time of glacial maximum. Peat deposited less than a meter above probable till yields a radiocarbon age of 13,482 +/- 180 yr B.P. (A on Figure 1), giving a minimum age of deglaciation of the central Clarks Fork valley (Oliver, 1997).

In addition to sediments taken for radiocarbon dating, nine samples of polished bedrock surfaces and ice-transported boulders were sampled for cosmogenic dating during summer 1997. Two additional samples were collected during 1996. Samples were taken at varying distances from the ice terminus and the cirque headwalls in an attempt to date the deglaciation of Clarks Fork valley. Results are pending.

The 22,630 +/- 120 years B.P. radiocarbon age is approximately 26,000 calendar years before present (Kitagawa and van der Plicht, 1998). This approximate date for the glacial maximum of Clarks Fork ice corresponds well to major advance between 30,000 and 22,500 yr by uranium series dating of travertine in northwestern Yellowstone, and also with the age of 20,000 to 35,000 yr for the ice maximum in west Yellowstone obtained by obsidian hydration dating. Cosmogenic dating of the glacial maximum in the Wind River Range, which lies approximately 160 km south and 30 km east of Clarks Fork valley, yields younger ages, 23 to 16 ka (Phillips et al., 1997).

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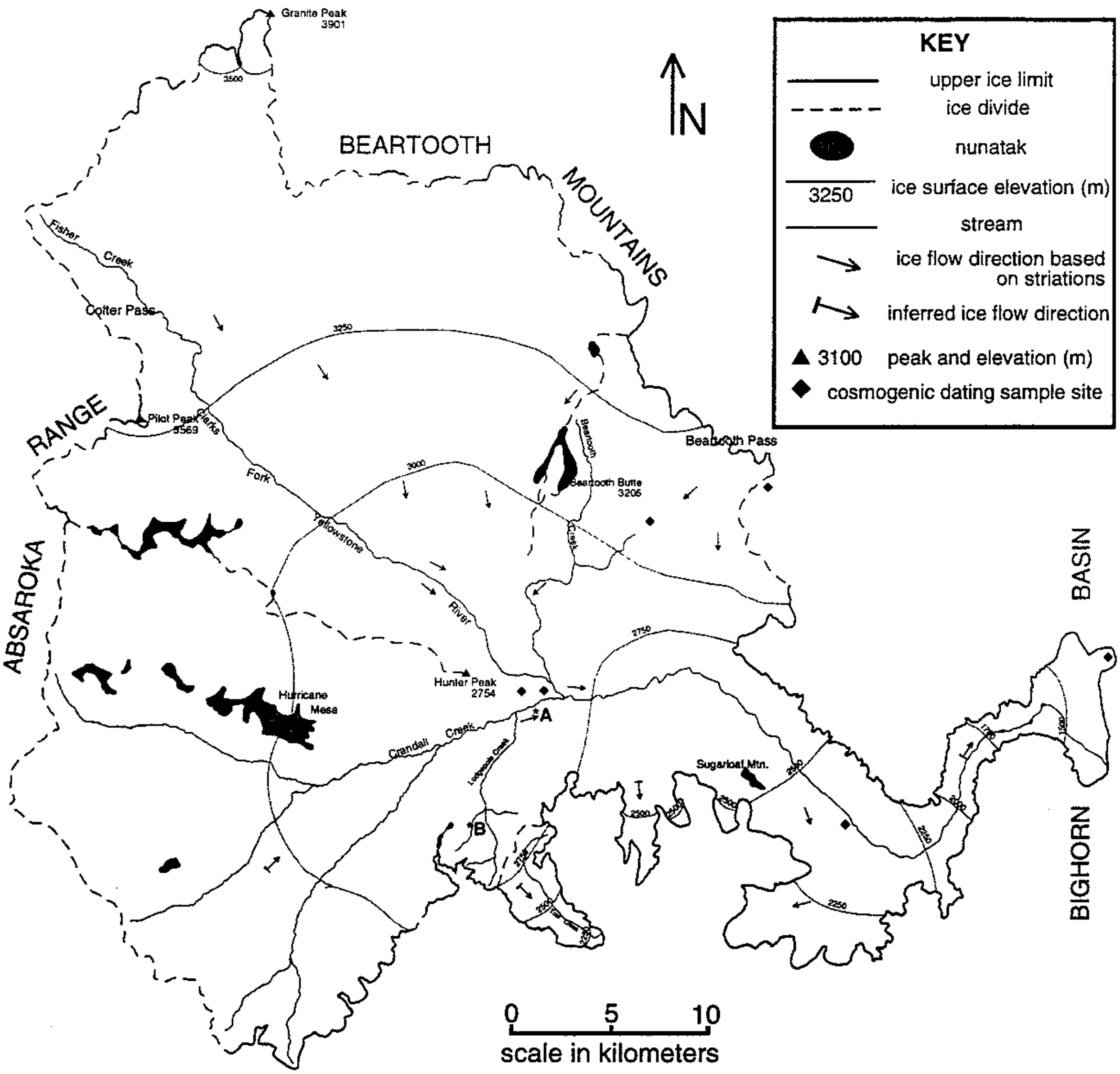

Figure 1: Maximum extent of Clarks Fork lobe of the Yellowstone ice sheet. Radiocarbon sample sites are indicated by ***A** and ***B**.