Resedimentation of the late Holocene White River tephra, Yukon Territory and Alaska

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ABSTRACT

The Wrangell region of eastern Alaska represents a zone of extensive volcanism marked by intermittent pyroclastic activity during the late Holocene. The most recent and widely dispersed pyroclastic deposit in this area is the White River tephra, a distinct tephra-fall deposit covering 540 000 km^2 in Alaska, Yukon, and the Northwest Territories. This deposit is the product of two Plinian eruptions from Mount Churchill, preserved in two distinct lobes, created ca. 1887 years B.P. (northern lobe) and 1147 years B.P. (eastern lobe). The tephra consists of distal primary air-fall deposits and proximal, locally resedimented volcaniclastic deposits.

Distinctive layers such as the White River tephra provide important chronostratigraphic control and can be used to interpret the cultural and environmental impact of ancient large magnitude eruptions. The resedimentation of White River tephra has resulted in large-scale terraces, which flank the margins of Klutlan Glacier. Preliminary analysis of resedimented deposits demonstrates that the volcanic stratigraphy within individual terraces is complex and unique.

RÉSUMÉ

Au cours de l'Holocène tardif, des matériaux pyroclastiques ont été projetés lors d'importantes et nombreuses éruptions volcaniques, dans la région de Wrangell de l'est de l'Alaska. Le plus récent et vaste gisement pyroclastique de cette région est le téphra de White River; c'est un gisement de téphra unique d'une superficie de 540 000 km^2, qui couvre une partie de l'Alaska, du Yukon et des Territoires du Nord-Ouest. Il résulte de deux éruptions du mont Churchill et est préservé dans deux lobes distincts, qui se sont formés il y a environ 1887 (lobe septentrional) et 1147 (lobe oriental) ans avant le présent. Le téphra est constitué de dépôts pyroclastiques distaux principalement projetés et de dépôts proximaux resédimentés.

Des couches distinctives de téphra, comme le téphra de White River, fournissent d'importantes données chronostratigraphiques et peuvent servir à interpréter l'impact culturel et environnemental des anciennes éruptions de grande magnitude. La resédimentation du téphra de White River a entraîné la formation de terrasses de téphra de grandes dimensions en bordure du glacier Klutlan. D'après une analyse préliminaire des dépôts resédimentés, la stratigraphie volcanique de chacune des terrasses est complexe et unique.

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GEOLOGIC SETTING

The White River tephra deposit (540 000 km^2) is one of the most widely dispersed tephra-fall units in the Yukon-Alaska region (Fig. 1). It is comparable in size and magnitude to some of the largest tephra-fall deposits in the circum-Pacific, including Krakatoa in 1883 and Novarupta in 1912. The bilobate deposit of rhyodacitic tephra is the product of two Plinian eruptions from Mount Churchill (McGimsey et al., 1992), a stratovolcano located approximately 25 km (15 miles) west of the Yukon-Alaska border in Wrangell-St. Elias National Park (61°25'N, 141°70'W; Fig. 2). Mount Churchill belongs to the Wrangell volcanic field (WVF), a late Cenozoic continental volcanic arc system located 400 km from the more recently active Aleutian volcanic arc system in southeastern Alaska (Richter et al., 1990).

The division of the White River deposit into elongate northern and eastern lobes indicates that strong unidirectional northward and eastward blowing winds prevailed during the times of their respective deposition. Radiocarbon dating, based on numerous peat and wood samples at sites distal and proximal to the vent, indicate that the northern-lobe tephra was deposited ca. 1887 years B.P. (Lerbekmo et al., 1975). The most recent radiocarbon estimate for the eastern-lobe tephra (ca. 1147 years B.P.) is based on a sample taken from a stump killed in growth position from the latest eruption (Clague et al., 1995). This estimate is consistent with several other radiocarbon ages taken from sediments above and below the White River tephra east of Mount Churchill (Clague et al., 1995).

The White River tephra is primarily composed of glass, plagioclase, hornblende, hypersthene and magnetite (Lerbekmo and Campbell, 1969), with minor amounts of biotite. An abundance of long tube vesicles in both eastern and northern lobe tephras (Fig. 3) indicates that the eruptions responsible for both lobes were extremely violent. Although eruption cloud heights are estimated to be between 30 and 35 km for both eruptions (Downes, 1979), temperatures are estimated to be higher for the eastern lobe eruption (995-1030°C) than for the northern lobe eruption (950-990°C; Downes, 1985). This has been taken to suggest that the eastern-lobe eruption was more violent than the northern-lobe eruption (Lerbekmo et al., 1975). If so, the latest White River eruption may have been responsible for destroying a much larger massif between Mount Churchill and Mount Bona, which may be remnants of a much older, single volcano.

Primary air-fall deposits of eastern lobe tephra have been found in peatland areas up to 1300 km from the vent (Robinson, 2001), indicating that environmental disruption from the latest White River eruption was widespread over a large portion of northern Canada. In addition, several anthropologists have indicated that the cultural impact of this eruption on the region's Athapaskan peoples was substantial (Moodie et al., 1992; Workman, 1977, 1979). Although no clear evidence of this eruption has been found in Athapaskan oral traditions, it has been suggested that the migration and linguistic diversification of the ancestral Athapaskan peoples occurred as the result of the latest White River eruption.

Recent stratigraphic and sedimentological evidence bearing on the cultural impact of this event suggests that the eastern lobe tephra was deposited during the late fall

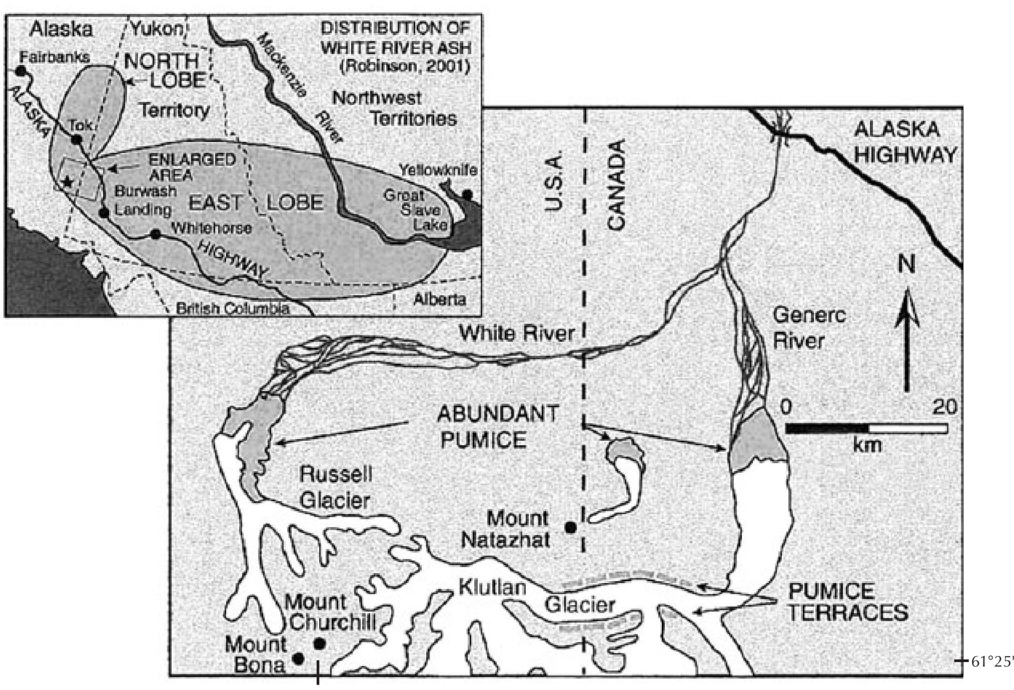

Figure 1. *Distribution of White River tephra, and location of proximal terrace deposits.*

Figure 2. *Source of the White River tephra, the Bona-Churchill complex. This is a view from the west, with Mount Bona (5005 m, 16,421 ft.) on the right, Mount Churchill (4766 m, 15,638 ft.) on the left, and Russell Glacier in the foreground.*

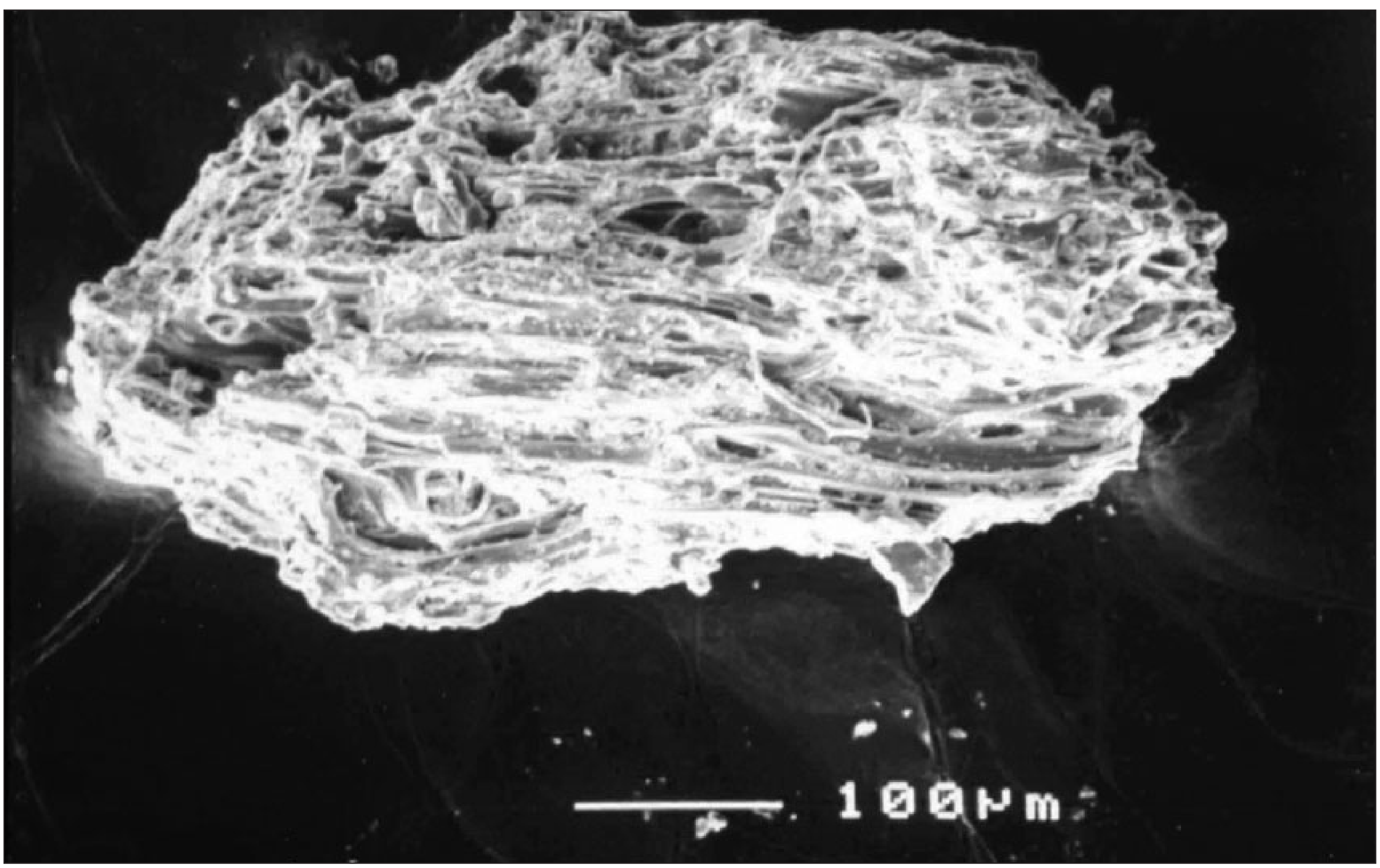

Figure 3. *Photomicrograph of long-tube vesicles in White River tephra.*

or early winter (West and Donaldson, 2001). Fieldwork in 2001 has provided preliminary stratigraphic data for resedimented tephra that forms terraces along the margins of Klutlan Glacier. Currently, work is being done to complete a detailed facies analysis and interpretation of these terrace deposits. Such information is essential in volcanic hazard assessment of the region, because pyroclastic activity in ice-covered regions can cause sudden melting of glaciers and snowfields, resulting in catastrophic flooding of surrounding drainage areas as demonstrated by the 1990 eruption of Mount Redoubt in Alaska (Alaska Volcano Observatory, 1990).

DISTAL TEPHRA DEPOSITS

Distal deposits of White River tephra display characteristic features of tephra-fall deposits, which form as pyroclastic material settles from a large-scale eruption column. These features include a good to moderate sorting of angular to sub-rounded fragments in slightly graded or laminated beds. In contrast, the proximal deposits of the White River tephra are commonly reworked, displaying less angular grains and an improvement in sorting (Donaldson et al., 1996). In addition, bed thickness and particle size show a gradual decrease as distance increases from the site of eruption.

In distal regions, the deposit occurs as a pristine, compositionally homogeneous layer of unconsolidated white to beige-coloured tephra. The white colour of the tephra is due to the presence of numerous glass shards, and the slight beige tinting of the ash is attributed to organic staining from the overlying organic horizon (Crampton, 1982). Deposits occur less than 1 m below the present surface level of the soil, commonly between beds of silt or peat. The tephra is commonly redistributed onto lower slopes and is notably thicker on slopes facing west towards Mount Churchill (Crampton, 1982). Distal deposits of eastern lobe tephra are significantly more coarse grained than their northern lobe equivalents. Differences in the Fe-Ti composition of hematite-ilmenite minerals in the northern and eastern lobes of tephra allow for geochemical distinction between the lobes (Lerbekmo et al., 1975).

PROXIMAL TEPHRA DEPOSITS

Proximal deposits of White River tephra are commonly reworked, and are primarily concentrated at the base and along the margins of Klutlan Glacier. As a result of reworking, these deposits are better-sorted and less angular in shape than their distal equivalents. At the summit region, resedimented deposits of ash, lapilli and blocks may reach thicknesses up to 50 m, and individual tephra blocks may be up to 50 cm in diameter (Richter et al., 1995). At 40 km east of Mount Churchill, thicknesses of sedimented deposits decrease to approximately 30 m. Geochemical analysis indicates that all proximal deposits from the summit of Mount Churchill represent material from the eastern lobe eruption of White River tephra (Richter et al., 1995).

EVIDENCE FOR WINTER ERUPTION OF EASTERN-LOBE TEPHRA

Modern high-atmosphere wind patterns in the Alaska-Yukon region indicate that winds blow eastward in the winter and northward in the summer. Similar wind patterns during White River tephra deposition may indicate that the eastern lobe tephra was deposited during the winter months, and the northern lobe tephra was deposited during the summer months (Hanson, 1965; Workman, 1979). The exceptional preservation of White River tephra on steep slopes throughout the region may provide further evidence that the eastern-lobe tephra was erupted during the winter season (Hanson, 1965). The following section summarizes recent evidence from a frozen layer of airfall tephra near Destruction Bay, Yukon, and from ice-cemented tephra clasts near the Donjek River, Yukon, which both illustrate that the eruption of eastern-lobe tephra must have occurred during the late fall or early winter (West and Donaldson, 2000).

BOCK'S BROOK

Evidence for late fall/early winter deposition of the eastern lobe tephra is based on a layer of airfall tephra preserved between beds of fluvial sand and gravel in the southern bank of Bock's Brook. This site is cut by the Alaska Highway, 4.2 km (3 miles) south of Destruction Bay and 100 km east of Mount Churchill. On the west side of the highway, the unit of tephra may be seen as a white granular layer with sharp boundaries that extends uninterrupted for more than 8 m. On the east side of the highway, the same bed may be followed discontinuously for 3-4 m. At this point, the bed disappears for another 3-4 m and is continuous thereafter, as far as can be seen downstream, along the banks of the channel.

The Bock's Brook tephra layer occurs as a distinctive, white, unconsolidated layer within an exposed succession of silt and gravel (Fig. 4). Minor amounts of sand occur within the vertical section, and discontinuous horizons of peat are abundant within the silt units (Fig. 5). The tephra layer displays normal graded bedding and faint horizontal laminations, attesting to its origin as an airfall deposit (Fig. 6). Particles within the tephra layer are granular, consisting of medium sand-sized ash, likely derived from the eastern lobe eruption. The tephra layer has a consistent thickness of 3.5 cm along its length and it

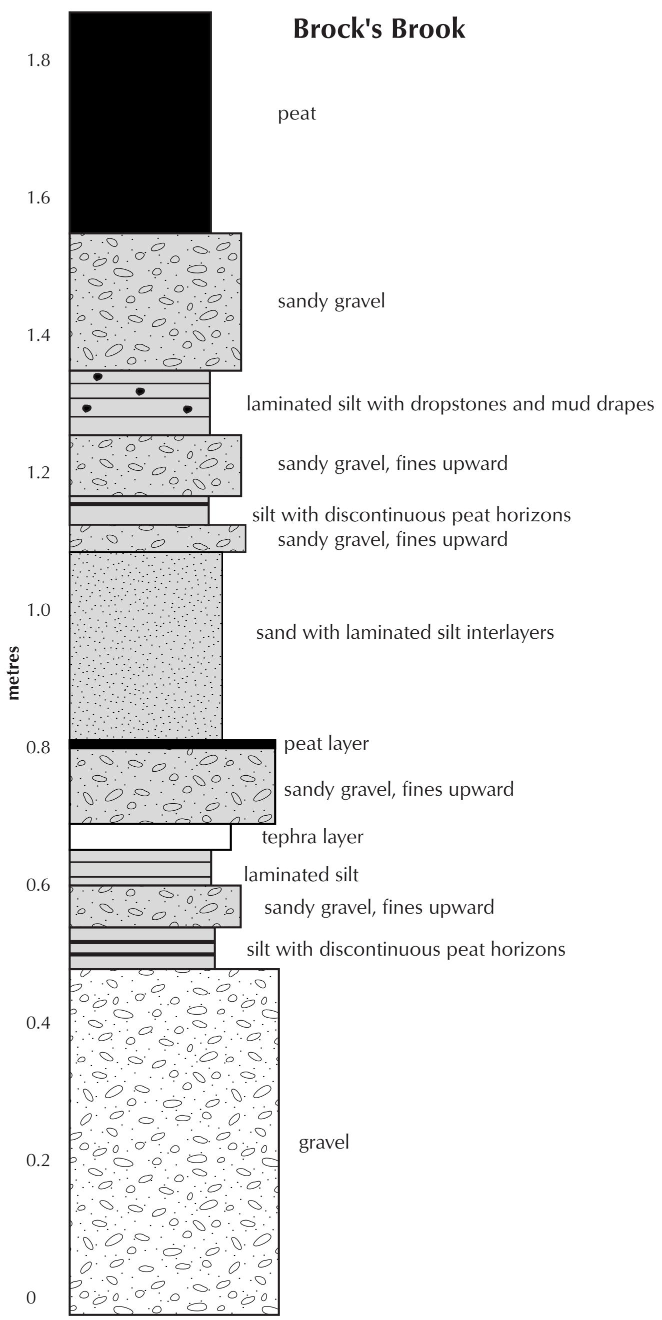

Figure 5. *Stratigraphy of the Bock's Brook vertical section.*

(above) ***Figure 4.*** *Overview of the vertical section exposed in the southern bank of Bock's Brook, 4.2 km south of Destruction Bay, Yukon. Trowel is approximately 30 cm in length. (middle)* ***Figure 6.*** *Airfall tephra embedded in a section of fluvial gravel and silt, Bock's Brook. This layer of tephra must have been frozen in order to escape reworking by fluvial currents. Penknife body is 8 cm long. (bottom)* ***Figure 7.*** *Truncation of airfall tephra layer by channel-fill deposits, Bock's Brook, Yukon. Penknife body is 8 cm long.*

occurs approximately 70 cm above the base of the vertical section. In some places, channel-fill deposits of sand and gravel abruptly truncate the tephra layer (Fig. 7).

The preservation of such a distinct layer of airfall tephra beneath deposits of fluvial sand and gravel requires that the tephra had to have been frozen in order to escape reworking. The tephra layer is inferred to have been deposited on a subaerially exposed overbank flood plain in the late fall or early winter, prior to the first major snowfall. Over the remainder of the winter season, it is inferred that the tephra layer would have become frozen and buried under a canopy of snow and ice. In the spring, the still-frozen tephra layer was subsequently buried by flood deposits of sand and gravel, sealing and protecting the layer against future erosion. Subsequent melting of ice in the pore spaces of the tephra layer produced post-depositional loading of epiclastic sediment along the boundaries of the tephra layer.

DONJEK RIVER

Further evidence for a late fall/early winter timing of the eastern lobe eruption is provided by ice-cemented tephra clasts of the Donjek River section. This site is located 200 m west of the Donjek River bridge on the Alaska Highway and 130 km southeast of Mount Churchill, within the north bank of the Donjek River. The section comprises glacial till, overlain by fluvial silt and an upper unit of sandy to pebbly silt (Fig. 8). The ice-cemented tephra clasts are embedded within the upper 30 cm of the fluvial silt unit. These tephra clasts are unconsolidated, consist entirely of medium sand-sized tephra particles, and are tabular, ovoid and irregular in shape (Fig. 9). Internally, the clasts display faint horizontal lamination parallel to elongation.

Figure 9. Unconsolidated tephra clasts in unit of fluvial silt. Angularity of the clasts and internal laminations suggest they were frozen prior to deposition. Penknife is 8 cm long.

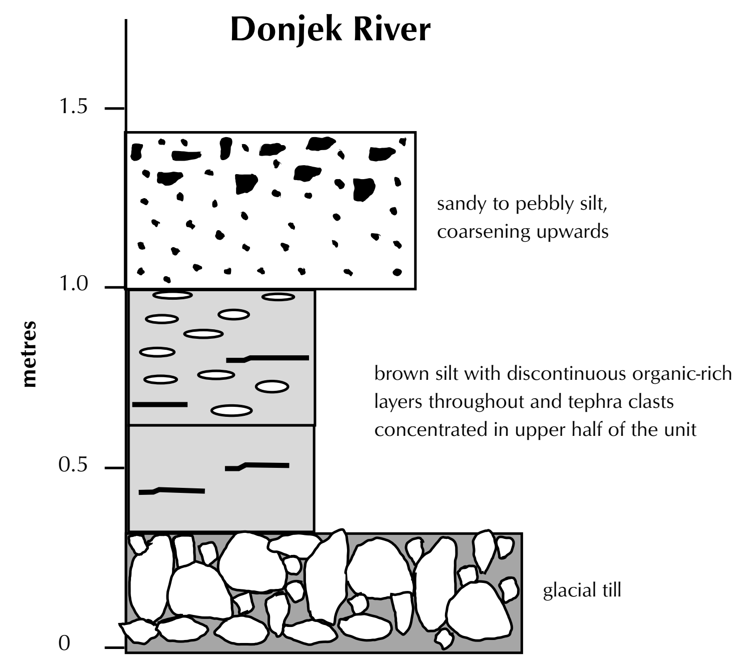

***Figure 8.** Stratigraphy of the Donjek River vertical section.*

The compositional homogeneity and internal laminations of the Donjek River clasts indicate they were originally deposited as an airfall layer of tephra, comparable to the Bock's Brook tephra layer. This tephra layer was similarly deposited on a subaerially exposed overbank plain during the late fall or early winter, and was subsequently frozen over the remainder of the season. During spring flooding, fragmentation of the ice-cemented tephra layer yielded the clasts now embedded in fluvial silt. In order to remain morphologically intact, the tephra clasts had to have remained ice-cemented during fragmentation in order to survive minimal abrasion, transport, and their subsequent burial in fluvial silt.

Stratigraphic evidence of ice-cemented tephra from the Donjek River and Bock's Brook sections indicate that the eastern lobe eruption of tephra must have occurred during the late fall or early winter in order for the tephra in both sections to be preserved as it is today. Further preliminary evidence supporting a late fall or early winter timing for the eastern lobe tephra is provided by locally resedimented proximal terrace deposits.

PROXIMAL TERRACE DEPOSITS

Discontinuous, locally resedimented terraces are prominent features along the lateral margins of Klutlan Glacier. These terraces extend for approximately 30 km on both sides of the Yukon-Alaska border in Kluane National Park (Yukon Territory) and Wrangell-St. Elias National Park (Alaska; Fig. 1). Individual terraces may reach more than 30 m in height and consist almost entirely of reworked pyroclastic material. The terraces stand more than 100 m above the present surface of Klutlan Glacier, indicating that significant melt-back of the glacier has occurred in the last 1200 years (Donaldson et al., 1996). The terraces are composed of white to light grey unconsolidated pyroclastics, and display steep (> 30 degree) angle of repose margins (Fig. 10). A discontinuous layer of granular airfall tephra up to 1 m thick caps individual terraces.

Detailed facies analysis of one terrace deposit, located 4 km east of the Yukon-Alaska border on the north side of Klutlan Glacier, has already been completed (Donaldson et al., 1996). Measured sections of this terrace contain silt and lithic-rich interlayers, in addition to pyroclastic material (ash, lapilli, agglomerate). Sedimentary structures within the terrace (large-scale crossbedding, normal and inverse graded bedding, linguoid and climbing ripples, and channels) indicate water transport. These terraces were likely deposited subglacially as a hyperconcentrated flow. Consensus has not been reached on whether pyroclastic deposits from the terraces represent eastern-lobe tephra, northern lobe tephra, or a combination of both.

Figure 10. *Proximal terrace deposit, north side of Klutlan Glacier. Terrace is approximately 30 m in height.*

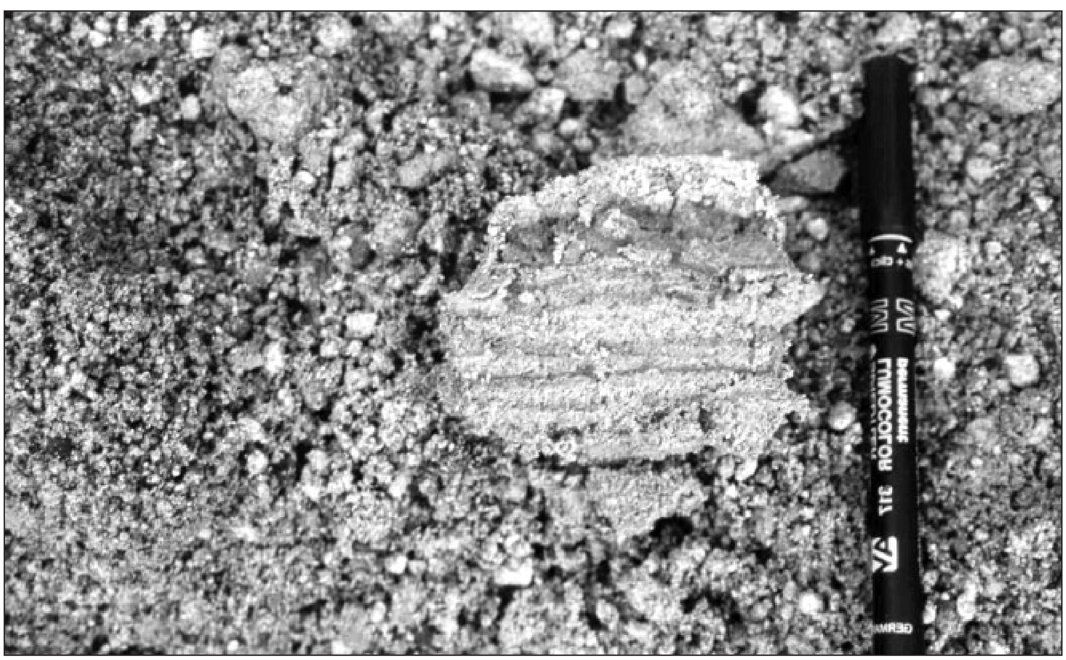

Figure 11. *Internally laminated tephra clast embedded in pyroclastic sediments, proximal terrace deposit, south side of Klutlan Glacier. Black marker is 14 cm in length.*

Further study of terraces 5 km west of the Yukon-Alaska border on the south side of Klutlan Glacier, and 15.5 km east of the Yukon-Alaska border on the north side of Klutlan Glacier indicates that the stratigraphy of individual terraces is unique. These terraces contain interlayers of clay, lithic-rich layers and finer-grained pyroclastic material (ash, lapilli). Sedimentary structures include horizontal laminations, crossbedding, asymmetric ripples, normal and inverse grading, channels, clay clasts/wisps, and internally laminated clasts of pumice grains, similar to the ice-cemented clasts discovered within the Donjek River section. Such clasts are inferred to have been frozen before reworking, thus providing an excellent analogue for our inference regarding origin of the Donjek River clasts (Fig. 11). Preliminary analysis of these terrace deposits indicates accumulation may have occurred in an area ponded by ice-blocks adjacent to Klutlan Glacier.

CONCLUSIONS

Recent stratigraphic evidence indicates that the eruption of eastern-lobe White River tephra occurred during the late fall or early winter. A precise timing of the eastern lobe eruption is essential for elucidation of the cultural and environmental effects of this volcanic event. The impact of such a large-magnitude eruption on vegetation, fauna, and the Athapaskan peoples subsisting on the land would vary during different times of the year. In addition, the effect of landslides, mudslides, and erosion in proximal and surrounding regions would also vary according to the season in which the eruption occurred. Detailed facies analysis of proximal terrace deposits, where they exist, is essential in documentation of the processes of volcanic resedimentation in glacial environments and provides essential background for comprehensive hazard assessment.

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