A SHEET OF AUFEIS IN THE KHARKHIRAA MOUNTAINS, MONGOLIAN ALTAI

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INTRODUCTION

Aufeis, also known as icings or by the Russian term *naled*, is a sheet-like mass of layered ice that forms from successive flows of ground water during freezing temperatures (Harden et al., 1977; Hu and Pollard, 1997). In the river channels of permafrost regions aufeis is evidence for perennial groundwater discharge (Clark and Lauriol, 1997). Aufeis typically melts out during a summer and will form in the same place year after year (Hu and Pollard, 1997).

Sheets of aufeis may block stream channels and cause their flood plains to widen as spring floodwaters are forced to flow around the ice (Harden et al., 1977). Research on aufeis has to a large extent been motivated by the variety of engineering problems the ice sheets can cause (e.g. blocking drainages and causing flooding of roads) (Kane, 1981). Sheets of aufeis have been observed in Alaska (Harden et al., 1977; Kane, 1981), Arctic Canada (Veillette and Thomas, 1979; Reedyk et al., 1995; Clark and Lauriol, 1997; Priesnitz and Schunke, 2002), Russia (Sokolov, 1978) and Mongolia (Froelich, 1982).

STUDY AREA

The Ugwi Yamaa Valley is located in the Kharkhiraa Mountains in the northeasternmost part of the Mongolian Altai. Long valley glaciers radiate from the high peaks. During retreats and advances these glaciers left many terminal and lateral moraines from the Last Glacial Maximum until today. Temperature data from Ulaangom shows that for the year from 7/1/2003 to 6/30/2004 there were 168 days that had a mean temperature below 0°C (NCDC, 2004). The study area is at an elevation of ~2900 m while Ulaangom is at ~935 m. It is very likely, because of this difference in altitude, that more than 168 days are below freezing at the site of the aufeis.

The Ugwi Yamaa Valley has a drainage area of ~15.2 km^2. The water in the valley is a result of rain, snow melt, glacial melt and the melt of ice cored morraines. The stream through the valley is braided for much of its length but also cuts through bedrock to form two canyons with steeper gradient and much narrower channels. The gradient of the stream through its braided portions is ~1.5°-2.0°, while in the upper canyon the gradient steepended to ~9°. Crude discharge estimates show a discharge of ~0.8 m^3/s above the ice sheet and ~1.4 m^3/s below.

AUFEIS EFFECT ON CHANNEL MORPHOLOGY

During July of 2004 aufeis covered most of the channel on a 0.8-km section of the stream (Fig. 1). From 7/21-7/29, and most likely earlier in the summer as well, the stream was blocked from usual down gradient flow by the ice, causing it to turn and its flow to be directed straight toward the right bank of the channel. The resulting cut bank was 3.9 m high. The bank had a 1.5-m thick layer of pure ice 1.5 m below the surface. While this ice could be due to segregated permafrost, Kane (1981) proposes that hydrostatic pressures can cause separation in the soil that lead to the development of laterally extending ice wedges in the soil adjacent to stream

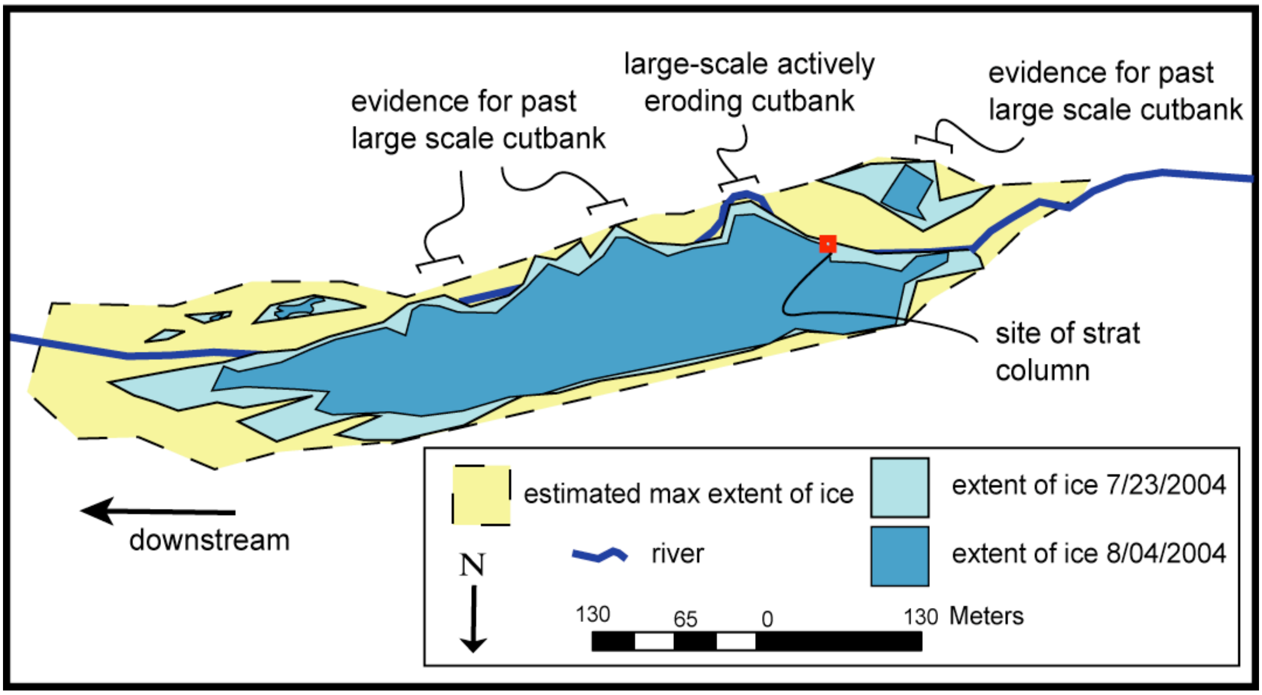

Figure 1. Map of aufeis sheet made with GPS measurements taken at the beginning of student (7/23/2004) and the end (8/04/2004). Features such as the stream, major cutbanks and the location of the stratigraphic column (see Fig. 2) were also mapped with a GPS.

banks. This ice supported the bank and allowed it to be undercut ~4 m by the stream. On the inside bank of the active meander, 5.5 m away from the current bank, there was grass that was still green under the ice suggesting that the inside bank had been the outside bank the summer before. This, combined with evidence of very active bank failure (e.g. chunks of soil in the stream), suggests that the bank had retreated the 5.5 m during that melt season.

Near the end of the field season (7/30/04), the stream cut through the part of the ice that had been damming it, bypassing the meander and cut bank. After the stream left this part of the channel, the undercut bank continued to collapse. This erosional event caused significant widening of the river channel. Evidence of similar past erosional events on river right both above and below the ice sheet suggests that aufeis has played an important role in widening the channel. It is not that there are no cut banks in other, aufeis-free, parts of the channel. Where there is aufeis, however, the cut banks can be much taller. The tallest observed cut bank in the Ugwi Yamaa valley that was not associated with aufeis was 0.95 m, as opposed to the 4-m cutbank observed in the aufeis choked part. Because aufeis is known to form preferentially in wider parts of channels (Hu and Pollard, 1997), there is a positive feedback cycle associated with its development: aufeis forms in a wider part of the channel, aufeis diverts stream flow creating cut banks, channel widens, and the next winter a wider sheet of aufeis forms. The limiting factor on channel width is the angle of repose of the slope that only allows the stream channel to widen so much before the edge is covered in talus.

AUFEIS STRATIGRAPHY

Each lamination of the aufeis represents an overflow event (Williams and Smith, 1989). Two sections of ice were measured in detail. One 2.15-m section of the ice had 90 laminations (Fig. 2) while another section of 2.35 m had 64. The 2.15-m section was a fresher surface and likely represents a more complete record of deposition. As the aufeis reached a thickness of 4.3 m, it is possible that 180 laminations are present in the entire sheet. The stream made these sections inaccessible so the number of laminations in the sections of such thickness could not be confirmed. The 2.15-m section was recently exposed as it was next to the stream that had undercut the sheet and caused blocks to break off, exposing fresh faces of ice. In constructing a stratigraphic

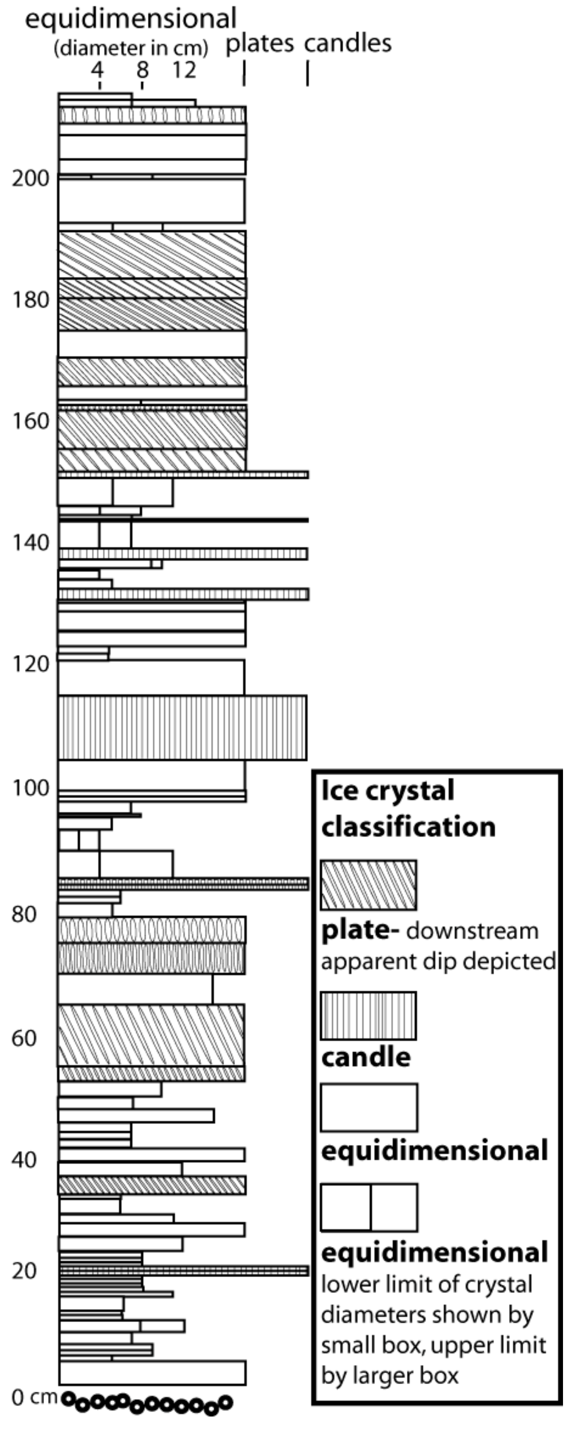

Figure 2. Stratigraphic column for a 2.15-m section of the aufeis sheet comprised of 90 laminations. Ice crystals are grouped into three morphologies: equidimensional, candle, and plate. Often the plates of ice align so they dip downstream. Where this is measured, the dip angle of the plate is shown except where there was no recognized preferential orientation.

column, ice was grouped into three categories based on ice crystal morphology: equi-dimensional crystals, candle ice, and plate ice.

Equidimensional ice makes up the most layers of the section. It is the primary kind of ice that forms from overflow events and freezes to the underlying ice. Since these crystals form in overflow slush, their vertical growth is limited and they do not progress to the columnar growth phase, unlike candle ice (Schohl and Ettema, 1986). Candle ice occurred both in lenses and in distinct beds. Lenses of candle ice have a characteristic convex up shape. These lenses are recognized in the literature; Hu and Pollard (1997) attribute their formation to hydrostatic pressure forcing water through fractures and forming an “icing blister.” This hydrostatic pressure is aided by the upward forces of c-axis growth to create a convex lense. These upward forces of c-axis growth can be significant. This is evidenced by the fact that channel cobbles were lifted by growing crystals in the study area. Candle ice grows parallel to the temperature gradient (Lock, 1990). This was observed in the Ugwi Yamaa ice sheet, as candle ice usually was vertical but in places orientations were tilted so that the crystals remained normal to the boundary of the lenses. The ice described as plates were amalgamations of equidimensional crystals. Often the plates of ice align so that they dip downstream. In some layers the crystals were of plate morphology but were not organized to dip in a certain direction. In the literature reviewed for this study no authors described or discussed the downstream dipping amalgamations of crystals (plates) as observed in the Ugwi Yamaa ice sheet.

COBBLE PAVEMENT

The weight of the ice on the channel gravel aligned the cobbles to form an alpine sub-aufeis cobble pavement. This pavement existed in places where the ice had been that had not been since disturbed by the stream. It was used to map out the maximum extent of the aufeis on the river channel. Similar sub-nival pavements have been described in the literature (Pissart and Francou, 1992).

CONCLUSIONS

1. Aufeis widens stream channels through a positive feedback cycle.
2. Aufeis stratigraphy contains a record of overflow events and internal blistering.
3. Aufeis can create pavements in channel gravels.

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