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Formation of a Strandline during the 1984 Jökulhlaup of Strandline Lake

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ABSTRACT. Strandlines, diagnostic features of glacier-dammed lakes, may not always represent highwater markers. They can apparently be formed during jökulhlaups. An example of the formation of a strandline during the 1984 draining of Strandline Lake is given.

Key words: strandline, terracette, jökulhlaup, ice-dammed lake, Alaska

RÉSUMÉ. Les lignes de rivages, traits diagnostiques de lacs contenus par les glaciers, ne représentent pas toujours le niveau de l'eau à son point le plus élevé. Elles peuvent apparemment être formées lors de débâcles glaciaires. Le texte comprend un exemple de la formation d'une ligne de rivage durant le drainage du lac Strandline en 1984.

Mots clés: ligne de rivage, terrassette, débâcle glaciaire, lac contenu par des glaciers, Alaska

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INTRODUCTION

One conspicuous and diagnostic feature of glacier-dammed lake basins is the presence of numerous strandlines, also called beaches and terracettes (Pardee, 1942; Bretz *et. al.*, 1956; Stone, 1963; Post and Mayo, 1971; Embleton and King, 1975). They are formed in sand, gravel and talus slopes surrounding ice-dammed lakes. Many strandlines observed in Alaska consist of a nearly horizontal tread of less than 0.5 m to more than 2.0 m width, followed by a sloping riser. The slopes surrounding glacier-dammed lakes are usually ringed by consecutive strandlines one above the next. Vertical spacing is often 1-2 m. A transect from the bottom of the drained lake basin up a side slope may cross 20 or more of these strandlines. In some cases they extend nearly to the bottom of the lake basin, as has been observed in some glacier-dammed lakes when the water has drained (Embleton and King, 1975) (Fig. 1). Each strandline

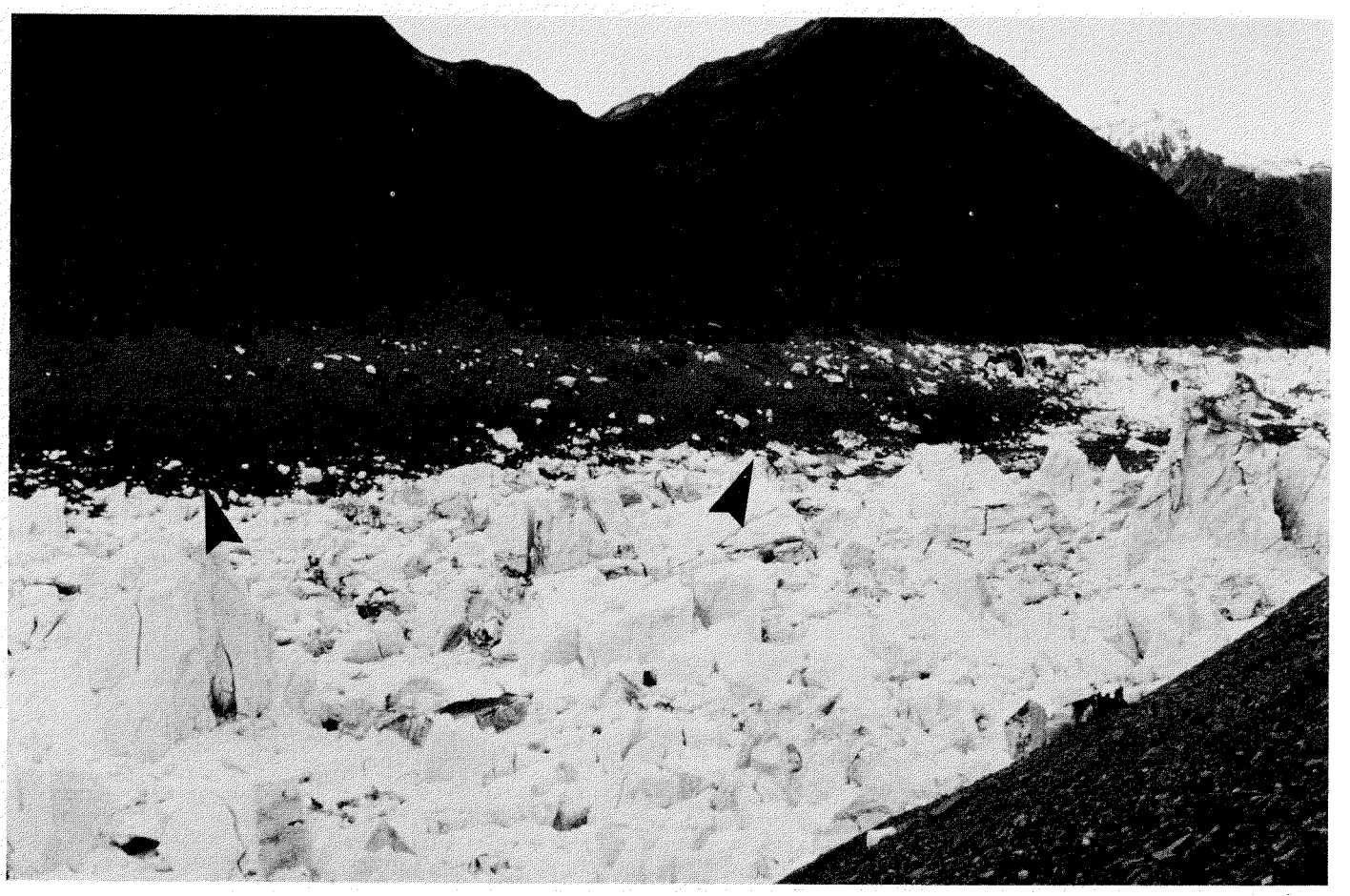

FIG. 1. View looking northwest across Strandline Lake after the jökulhlaup in mid-September 1984. Arrows indicate faint strandline features. Lowest strandline is approximately 90 m below the 1984 highwater mark, indicated by the highest stranded icebergs.

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appears to be horizontal and laterally continuous over great distance, if not around the whole lake basin. Some strandlines have even been observed to continue across vertical cliffs as stain lines.

FORMATION OF A STRANDLINE AT STRANDLINE LAKE

A widespread assumption is that each strandline represents a highwater standstill of the glacier-dammed lake, but observations made during the 1984 jökulhlaup (catastrophic draining) of Strandline Lake near the Triumvirate Glacier in south-central Alaska (Sturm and Benson, 1985) suggest that this assumption can be in error. On the evening of 8 September Strandline Lake, 7 km long, was draining at a rate of 300 $m^3 \cdot s^{-1}$, with the water surface dropping approximately 0.1 $m^3 \cdot h^{-1}$. The wind was calm. Between two measurements of the water surface elevation (approximately 3 h elapsed), a 1 m scarp formed in the scree slope at the water line (Fig. 2). This scarp could be seen to be laterally continuous for over 300 m, where it intersected an extensive series of cliffs beyond which we could not see. In one place the scarp was interrupted by a small cliff band, but it continued beyond the cliff at the same elevation. The scarp was caused by the slumping of the scree, which produced a new strandline tread approximately 1 m wide, just under the water surface. There was also considerable iceberg movement at this time.

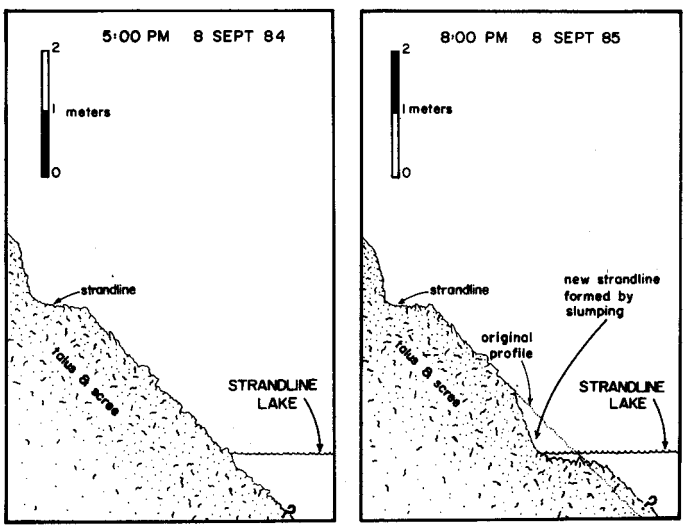

FIG. 2. Diagram indicating formation of strandline by slump failure of the scree slope. Slope angle and dimensions are approximate.

DISCUSSION

The strandline formed on 8 September by the slump failure of the scree had a lateral extent of 300 m, which suggests that the mechanism causing the failure operated over a large area, perhaps even lake-wide. The scree must have been unstable; excess pore water pressure in the scree, which was already at the angle of repose, could have caused this instability (Chowdhury, 1978). The rapid draining of the lake may have produced excess pore water pressure in a zone immediately above the dropping water surface. Unusual iceberg movements or water currents could trigger the collapse of this unstable zone, forming a strandline with a steep riser and a tread immediately beneath the water surface (Fig. 2).

Measurements of the drop rate of the water surface indicated that seiches (long period waves) with amplitudes of 4 cm or more took place during the jökulhlaup of Strandline Lake. The drop rate was highly irregular over short intervals, occasionally showing no change over 15 min periods even though the hourly drop rate was 0.1 m. Similar pauses and reversals in rate have been observed at Summit Lake during draining (Mathews, 1973) and attributed to seiches. Though the seiches might not be the cause of widespread slope failure and strandline formation, their presence is evidence that powerful disturbances affected the water in the lake during the draining. Iceberg calving or ice rising from the bottom of the glacier, possible sources of the seiches, might have created shock waves sufficient to cause widespread collapse of unstable slopes.

Alternatively, a general movement of icebergs may have triggered the collapse of the scree slope. Some of the larger bergs measured in 1984 after Strandline Lake had drained were over 120 m high (Fig. 3). While afloat these bergs had keels

FIG. 3. Icebergs on the floor of Strandline Lake after the jökulhlaup. Largest berg is over 70 m high. Strandlines can be seen above cliff bands on far shore.

projecting more than 100 m below the water surface. If one of these bergs dragged its keel while being pushed by current, significant disruption of the lake bottom would occur and this might be sufficient to cause widespread slumping of the side slopes.

Strandlines found nearly at the bottom of Strandline Lake suggest that they formed at times other than at high water (Fig. 1). Strandline Lake empties when the water reaches a depth sufficient to float the portion of the Triumvirate Glacier that impounds the lake (Sturm and Benson, 1985). Therefore the highwater level is limited by the glacier thickness. The altitude of the lowest identifiable strandline is approximately 300 m.a.s.l., over 80 m below the 1984 highwater level. If this strandline formed at a highwater level of the lake, the Triumvirate Glacier would have to have been approximately 90 m thinner than it is today. Trimlines, moraines and photographs suggest that the glacier has been thinning steadily for the past few hundred years. It is therefore unlikely that the glacier has been thinner any time in the recent past, which makes it unlikely that the strandlines found deep in the lake represent highwater standstills.

Embleton and King (1975) also noted the surprising depth at which strandlines are found. They suggested that the strandlines were formed during jökulhlaups by a diurnal cycle in which lake inflow was balanced by outflow during the day but was less than outflow at night. This mechanism seems unlikely for the larger glacier-dammed lakes where lake inflow is often two orders of magnitude less than outflow. Hydrographs from Strandline Lake (Sturm and Benson, unpubl. data) do not support a diurnal cycle. A possible alternative is that the strandlines formed during a jökulhlaup by slump failure, as described above.

If strandlines around an ice-dammed lake can form rapidly at other than highwater conditions, as appears to be the case, then a single draining event can generate numerous strandlines. Interpretation of similar features in the geologic record should consider this possibility.

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