Journal of Glaciology, Vol. 22, No. 88, 1979

CORRESPONDENCE

The Editor,

Journal of Glaciology

SIR,

Speculation on jökulhlaup prediction

I would like to report some results of an unsupported reconnaissance study of the specific conductance (SC) of glacial melt-water streams in Washington, U.S.A. SC measurements were calibrated with KCl solution and results are given in μS at 25°C in accordance with established practice (Brown and others, [1970], p. 148–50; Hem, 1959). An instrument based on the Wheatstone bridge principle (cell constant = 0.466), was used to take measurements at the Coleman Glacier (Mount Baker), Nisqually Glacier (Mount Rainier), and the South Cascade Glacier (North Cascades) from March 1976 to October 1976. The Coleman and Nisqually Glaciers dominantly flow over volcanic bedrock, whereas the South Cascade Glacier is in a complex igneous and metamorphic terrain (Reynolds and Johnson, 1972).

Both seasonal and diurnal variation of SC were noted, based largely on the seasonal and daily timing of the ablation of snow and ice. Any combination of meteorological variables that significantly affect glacier ablation or associated run-off will affect the SC of the glacial melt-water stream. Dissolved rock, suspended sediment, and hydrolyzed carbon dioxide directly affect SC in the studied glacier systems. Throughout the summer melt season dilution by increased water flux is the dominant process affecting SC at the Coleman and Nisqually Glaciers. This has also been observed at the Chamberlin Glacier, Alaska, by Rainwater and Guy (1961). The lake at South Cascade dampens these variations.

Early spring represents a critical time in the Nisqually Glacier system. Stream water dominated by snow melt and base flow had an SC of 19 μS at 25°C on the morning of 27 April 1976. This clear water turned muddy in the afternoon as water flux increased and increased suspended sediment was carried. SC rose to 256 μS. Two possibilities exist: (1) subglacial plumbing began flushing water and sediment into the stream, or (2) stream waters were entraining material from the stream bed outside the glacier as the stream reached a critical discharge. Case (2) was an obvious answer, since clear water exited the glacier terminus and turned milky within 250 m down-stream. Hauser and Reed (1937) have shown that colloidal clays in suspension increase measured SC.

Measurements of water and sediment flux plus turbidity from the terminus of the Nisqually Glacier during winter, spring, and summer 1977 demonstrate that both case (1) and case (2) operate in April and May but that only case (1) operates in January, February, and March (Metcalf, unpublished [b]). This finding gives support to the proposal of Østrem ([c1975]) that subglacial plumbing flushes more sediment, for a constant discharge, early in the melt season. Additional support at the Nisqually is given by Hodge's (1974) inference of stored water seasonally affecting the glacier sliding rate and radio echo-sounding evidence of "comparatively large" water-filled cavities (Meier, 1976) within the glacier.

These preliminary results suggest that there is a seasonal storage of water within the Nisqually Glacier, which has resulted in four disastrous jökulhlaups in the past (Richardson, 1968) 50 years. Some short-term variations in the SC observed in the present study are only attributable to variations in solutes or suspended sediment concentration (Metcalf, unpublished [a]). The implication is that glacier outburst floods which originate from water stored at the ice–rock interface may be predictable by SC measurements of glacier streams. For *this* specific case of jökulhlaup, one would expect a decrease in monitored SC prior to each outburst flood, on an extended seasonal or yearly basis.

Decreasing SC of the glacier outlet stream may result when solutes and suspended sediment are stored in water-filled cavities at the glacier bed. SC would increase for the "stored" water and decrease for the melt water deprived of the "stored" contribution as it exits from the terminus. These presumed changes follow from the previously mentioned results that higher suspended sediment concentration can increase the SC and the well-known result that SC increases with greater solute concentration in dilute solutions. Full realization of possible, complex changes in the SC of the "stored" water is acknowledged; however, the gist is the hypothesized SC decrease of exiting water due to presumed limited supplies of suspended sediment and, to a lesser extent, solutes on a time scale of years. If subglacial streams scavenge new sources of sediments and solutes while bed-water storage would otherwise decrease their transported load, the SC prediction is invalid.

Dr D. N. Collins' (written communication in 1978) recent SC work at the Gornergletscher terminus has shown that such measurements must be almost continuous (avoiding water discharge rating curves for SC, solutes, or suspended sediments) to infer the detailed workings of subglacial plumbing systems. Since each glacier's liquid-water content, bedrock composition, and jointing, plus ice velocity and geometry combine to establish a subglacial water system, there is no basis for any speculation on a universal, detailed SC pattern to be expected in glacier streams before and after jökulhlaups. Instead, detailed SC patterns for individual glacier systems should be rigorously determined by continuous observation.

Remote monitoring of SC in glacial streams in Washington has already been demonstrated in conjunction with the recent thermal events on Mount Baker (personal communication from D. Frank in 1977). Park officials at Mount Rainier are quite interested in testing my hypothesis; the time is right for an enterprising glaciologist.

Esso Inter-America,
396 Alhambra Circle,
Coral Gables, Florida 33134, U.S.A.
20 June 1978

RICHARD C. METCALF

REFERENCES

Brown, E., *and others*. [1970.] Methods for collection and analysis of water samples for dissolved minerals and gases, by E. Brown, M. W. Skougstad, and M. J. Fishman. (*In Techniques of water-resources investigations of the United States Geological Survey*. Book 5. Laboratory analysis. Ch. A1. [Washington, D.C.], U.S. Dept. of the Interior.)

Hauser, E. A., *and* Reed, C. E. 1937. Studies in thixotropy. II. The thixotropic behavior and study of bentonite. *Journal of Physical Chemistry*, Vol. 41, No. 7, p. 911–34.

Hem, J. D. 1959. Study and interpretation of the chemical characteristics of natural water. *U.S. Geological Survey. Water Supply Paper* 1473.

Hodge, S. M. 1974. Variations in the sliding of a temperate glacier. *Journal of Glaciology*, Vol. 13, No. 69, p. 349–69.

Meier, M. F. 1976. [Contribution to] General discussion [on the thermal regime of glaciers and ice sheets]. *Journal of Glaciology*, Vol. 16, No. 74, p. 290.

Metcalf, R. C. Unpublished [a]. On the variation of specific conductance of glacial meltwater streams. [Student report, University of Washington, Seattle, Washington, 1977.]

Metcalf, R. C. Unpublished [b]. Physical and chemical processes associated with the erosional energy of the Nisqually Glacier. [M.S. thesis, University of Washington, Seattle, Washington, 1977.]

Østrem, G. [c1975.] Sediment transport in glacial meltwater streams. (*In* Jopling, A. V., *and* McDonald, B. C., *ed. Glaciofluvial and glaciolacustrine sedimentation*. Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, p. 101–22. (Special Publication No. 23.)

Rainwater, F. H., *and* Guy, H. P. 1961. Some observations on the hydrochemistry and sedimentation of the Chamberlin Glacier area, Alaska. *U.S. Geological Survey. Professional Paper* 414-C.

Reynolds, R. C., *and* Johnson, N. M. 1972. Chemical weathering in the temperate glacial environment of the Northern Cascade Mountains. *Geochimica et Cosmochimica Acta*, Vol. 36, No. 5, p. 537–54.

Richardson, D. 1968. Glacier outburst floods in the Pacific Northwest. *U.S. Geological Survey. Professional Paper* 600-D, p. D79–D86.

SIR,

Origin of foliation in glaciers: comments on a paper by R. L. Hooke and P. J. Hudleston

The origin of foliation in glaciers has occupied the minds of glaciologists and geologists for over 150 years, yet there is still argument as to how the structure actually develops. The controversy as to whether foliation was a primary or a secondary structure, which raged periodically until the 1950's, finally seemed to have been settled in favour of the latter following detailed work on glaciers by, for example, Schwarzacher and Untersteiner (1953), Meier (1960), and Allen and others (1960). A thought-provoking paper by Hooke and Hudleston (1978) questions these later conclusions by suggesting that bubbles and debris in glaciers are unable to migrate sufficiently rapidly to be responsible for the alternating layers of bubbly and clear ice, or dirty and clean ice which constitute foliation, and that the structure is inherited from earlier layering, such as stratification, crevasse fillings, or debris-layers frozen to the glacier bed.

https://doi.org/10.3189/S0022143000014544 Published online by Cambridge University Press