FLOW SEPARATION ON ZONGO GLACIER

PATRICK WAGNON, PIERRE RIBSTEIN AND BERNARD FRANCOU
ORSTOM, CP 9214, La Paz, Bolivia

INTRODUCTION

Measuring the electrical conductivity of meltwater runoff is a way to separate flow into two pathways through the glacial hydrological system (Collins 1979); englacial flow passes through ice-walled conduits or in surface channels where minimum chemical enrichment occurs whereas subglacial flow moves in contact with bedrock or sediments, thus becoming heavily solute-loaded (Lecce 1993). Field observations have been processed on Zongo Glacier not only during summer (which corresponds to a period of accumulation and strong ablation in this intertropical zone) but also during winter (which presents a limited ablation). This tropical glacier (2.1km^2) is located in the Cordillera Real, Bolivia (16°15'S, 68°10'W) and covers 77% of a southeast facing basin consisting of Triassic granodiorite (Ribstein et al. 1995). Two main proglacial streams, located on the right and left banks of the glacier, escape from the glacier tongue and feed a frontal lake drained by a unique stream. This discharge is permanently recorded by a limnimetric station. The objectives of this study are to examine diurnal variations of electrical conductivity as a function of discharge and to separate englacial and subglacial components.

METHOD

Continuity of flow brings the equation :

$$Qt = Qe + Qs \qquad (1)$$

where Q is discharge (l s^{-1}) and the subscripts, t, s, and e represent total, subglacial, and englacial respectively. Moreover, if C is solute concentration approximated by electrical conductivity (µS cm^{-1}), the following equation gives an estimation of the subglacial flow Qs.

$$Qs = [(Ct-Ce)/(Cs-Ce)]Qt \quad (2)$$

On the field site, the total discharge Qt is measured at the limnimetric station and a portable WTW LF 96 conductivity meter, which automatically standardises conductivity values to a temperature of 25°C, was used to get Ct. Ce and Cs had to be estimated in order to evaluate Qs from the equation (2). The conductivity of the meltwater, flowing at the glacier surface, gives an accurate estimation of Ce and the maximum conductivity value of the meltwater exiting from the glacier is the inferior limit of the Cs estimation.

RESULTS-DISCUSSION

During selected survey days, maximum discharge occurred between 1300h and 1600h and coincided with a decreasing of conductivity values (Figure 1). This is coherent with the fact that, during warm hours of the days, solute free surface meltwater contributes to a large part of the total discharge and lowers the conductivity (Lecce 1993).

Unlike Lecce's observations (1993) of the Conness Glacier, California, USA (Qs = 5-25%Qt), the amount of water routed through the subglacial system contributes most of the water to the proglacial stream (Qs = 60-98% Qt, except during exceptionally high discharge when Qs lowered to 33% of Qt : Figure 2). Since Lecce (1993) found a much smaller contribution for the subglacial flow, even though the bedrock is similar, the Zongo subglacial system may be more developed than the Conness one, due to size difference (Zongo : 2.1km^2, Conness : < 0.5 km^2). These results are sensitive to the estimates used for Ce and Cs, which are fairly good because of the direct conductivity measurements of clean meltwater at the glacier surface for Ce (Ce = 1 µS cm^{-1}) and various field surveys at different locations on the glacier for Cs (Cs = 40 µS cm^{-1}).

Results from the two streams escaping from the glacier tongue are different. The right bank stream shows the same behaviour as the main stream below the frontal lake, although the left bank stream is mostly supplied by the englacial flow (Qs = 19-43% Qt). This suggests that the bedrock is bent from the left to the right bank. Therefore, most of the subglacial flow is driven from the left to the right bank of the glacier, which is why the right bank stream is larger and more heavily solute- loaded.

The discharge peak is 2 to 4 hours in advance of the conductivity minimum (Figure 1). Also, Figure 2 shows that the subglacial discharge peaks two or three hours before the englacial discharge peak. This out-of-phase response suggests that englacial and subglacial conduits are widely interconnected (Collins 1979). During the day, assuming that the daily discharge peak is mainly due to surface melting and, therefore, due to an increasing of englacial water volume, if these two systems were not interconnected, the daily discharge peak would coincide with the daily minimum of conductivity. The fact that the discharge maximum and conductivity minimum are delayed in time proves that englacial conduits are connected to subglacial ones.

During the dry cold winter, when conditions are different from the wet warm summer, total discharge variations are low and the contributions of englacial and subglacial flows remain constant during the day (Qs = 55% Qt at the limnimetric station). This proves that the two drainage systems are not to be interconnected and are to flow independently.

REFERENCES

Collins, D. N., 1979. 'Quantitative Determination Of The Subglacial Hydrology Of Two Alpine Glaciers'. In *J. Glaciol.*, 23(89) (pp347-362).

Lecce, S. A., 1993. 'Flow Separation And Diurnal Variability In The Hydrology Of Conness Glacier, Sierra Nevada, California, U.S.A.' In *J. Glaciol.*, 39(132) (pp216-222).

Ribstein, P., Tiriau, E., Francou, B., & Saravia, R., 1995. 'Tropical Climate And Glacier Hydrology : A Case Study In Bolivia'. In *J. Glaciol.*, 165 (pp221-234).

Figure 1. Total discharge and conductivity on March 3, 1995

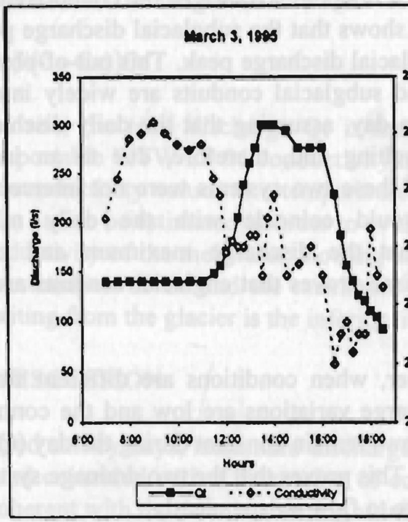

Figure 2. Flow separation on February 20, 1995