

SHORT NOTES

SEDIMENT TRANSPORT DURING AN OUTBURST FROM GLACIER DE TSDJIORE NOUVE, SWITZERLAND, 16–19 JUNE 1981

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ABSTRACT. Between 16 and 19 June 1981 a large water pocket of volume $183\,000\text{ m}^3$ burst from glacier de Tsdjiore Nouve. From hourly stream discharge and suspended sediment concentration observations a suspended sediment output of $1\,674 \times 10^3\text{ kg}$ was calculated. The transport of bed-load was estimated at $3\,840 \times 10^3\text{ kg}$, hence a total quantity of around $5\,500 \times 10^3\text{ kg}$ of sediment were removed from the catchment, including the proglacial field, in the four days of the outburst.

RÉSUMÉ. *Transport de sédiments au cours d'une crue du glacier de Tsdjiore Nouve, Suisse, 16–19 juin 1981.* Entre les 16 et 19 juin 1981 une grosse poche d'eau de $183\,000\text{ m}^3$ de volume a crevé sous le glacier de Tsdjiore Nouve. A partir d'observations du débit horaire et de la concentration en sédiment en suspension on a calculé un transport de 1 674 tonnes. Le transport de fond a été estimé à 3 840 tonnes d'où une quantité d'environ 5 500 tonnes de sédiments enlevés du bassin versant, y compris l'aire proglaciaire, pendant les 4 jours de cet épisode.

ZUSAMMENFASSUNG. *Sedimenttransport während eines Ausbruchs am de Tsdjiore Nouve-Gletscher, Schweiz, 16.–19. Juni 1981.* Zwischen dem 16. und 19. Juni 1981 brach eine grosse Wassertasche mit $183\,000\text{ m}^3$ Inhalt aus dem de Tsdjiore Nouve-Gletscher. Aus den Beobachtungen des stündlichen Abflusses und der Konzentration an suspendiertem Sediment liess sich ein Sedimentausstoss von 1 674 to errechnen. Der Transport von Material aus dem Gerinnebett wurde auf 3 840 to abgeschätzt. Daraus ergibt sich eine Gesamtmenge von etwa 5 500 to Sediment, das in den 4 Tagen des Ausbruchs aus dem Gletscherbereich, einschliesslich des Vorfeldes, weggeräumt wurde.

INTRODUCTION

Sediment output in the melt water from glaciers has attracted considerable attention over the past 20 years. Such study has implications for down-stream fluvial systems, and when combined with other measurements, determination of rates of glacial erosion. Researchers, using a wide variety of approaches, have attempted to estimate suspended sediment output from glaciers (Borland, 1961; Rainwater and Guy, 1961; Mathews, 1964; Østrem and others, 1967; Church, 1974; Guymon, 1974; Østrem, 1975; Hasholt, 1975; Collins, 1979; Mills, 1979). Probably due to difficulties in measurement little attention has been paid to the output of bed-load. However, Østrem (1975) has measured coarse sediment output in the melt water below Nigardsbreen, Norway.

Glacial outbursts are a relatively common feature of the Alpine environment, though their nature and the magnitude with which they occur varies considerably. Outbursts can be produced by the release of ice-dammed or supraglacial water bodies. The annual drainage of the Gornersee creates a short-duration flood in which Collins (1979) has measured very high suspended sediment concentrations of up to 12 g/l. The well-documented outburst from glacier de Mont Miné in 1943 was the result of the catastrophic release of an extensive subglacial water body close to the glacier snout and resulted in considerable damage in the Val d'Hérens (Hagen, 1944).

Glacial outbursts, as high-magnitude, low-frequency events, are capable of considerable geomorphic work. This paper attempts to quantify sediment output during a relatively small outburst from glacier de

Tsidjiore Nouve in June 1981. The results of this case study may help to identify the role of the outburst in sediment transport from glaciated catchments.

The features of glacier de Tsidjiore Nouve, which covers an area of approximately 3.4 km² situated south-west of the village of Arolla, Valais, Switzerland, are described by Small and Clark (1974). Members of the Department of Geography at the University of Southampton have measured suspended sediment output from the glacier for the ablation seasons 1977, 1978, and 1981; and Gurnell (1982) has examined the spatial and temporal variations of suspended sediment concentration in the pro-glacial stream network.

The Tsidjiore Nouve outburst, which began shortly after midnight on the 15/16 June 1981, broke out from the northern flank of the glacier about 200 m above the snout (Fig. 1). The floodwater flowed alongside the glacier in a previously deserted marginal channel, then cut across the pro-glacial floodplain to join the existing melt-water stream. 360 m below the glacier snout the flood was taken into a water abstraction station of the Grande Dixence S.A. hydro-electric power scheme. The outburst was seen to carry with it large quantities of both suspended sediment and bed-load derived from beneath the glacier, from the base of a large lateral moraine adjacent to the northern flank of the glacier, and the pro-glacial outwash zone.

1. WATER OUTPUT

A hydrograph for the period of the outburst has been plotted from data provided by Grande Dixence S.A. (see Fig. 2); stream discharge was measured at the water abstraction station (Fig. 1). Hourly data, used to produce the outburst hydrograph, fail to reveal the actual peak discharge of over 2.5 m³/s as this occurred between the fixed readings. The hydrograph shows a sharp peak at the start of the outburst followed by a slow decline of the recession limb over the next four days. The rapid rise in stream discharge after midnight on the 15/16 June was not associated with any change in atmospheric temperature, in any case its scale and random nature could not be explained in terms of accelerated ablation. In order to isolate the discharge of the outburst from that resulting from normal glacial ablation, a discharge separation

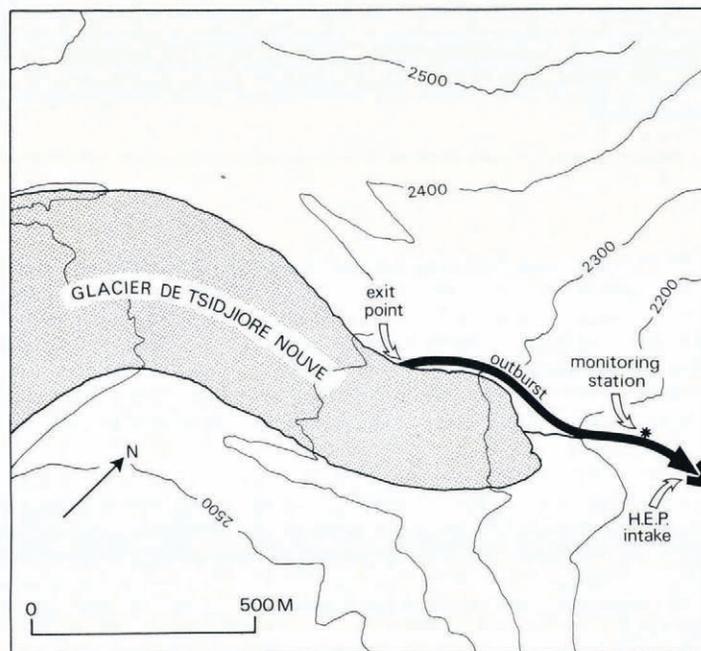


Fig. 1. Outburst route, glacier de Tsidjiore Nouve, 16–19 June 1981.

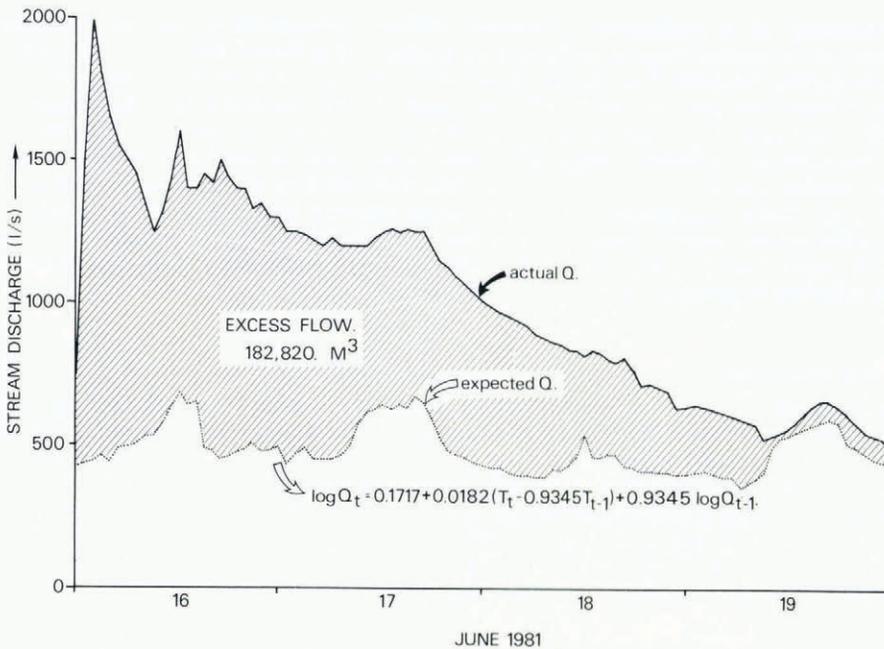


Fig. 2. Actual and expected discharge at glacier de Tsidjiore Nouve, 16–19 June 1981.

technique was required. This was achieved using a temperature-based prediction equation which was derived for glacier de Tsidjiore Nouve by C. R. Fenn using 1978 discharge and air temperature records:

$$\log Q_t = 0.1717 + 0.0182(T_t - 0.9345 T_{t-1}) + 0.9345 \log Q_{t-1} \quad (1)$$

where Q is the stream discharge (l/s), T the air temperature ($^{\circ}\text{C}$), t the present observation, and $t-1$ the previous observation.

In both 1978, and at the time of the outburst, air temperature was determined at the same site (near to the main monitoring station) and the prediction equation, based on two months of hourly observations, had a coefficient of determination (R^2) of 0.92. The close correspondence between observed and predicted discharge towards the end of the outburst gives considerable confidence in this method of hydrograph separation. The additional contribution of the outburst to the discharge was estimated by subtracting the temperature-predicted discharge from the recorded actual discharge, yielding a figure of 182 820 m^3 . There was no evidence of a pre-existing supraglacial water accumulation of this magnitude on the surface of the glacier so it was reasonable to assume that the water source was englacial or subglacial.

2. SUSPENDED SEDIMENT TRANSPORT

Water samples were taken every hour at the main monitoring station about 300 m below the glacier snout (Fig. 1). Samples, taken from the turbulent flow using a vacuum-operated automatic liquid sampler, were filtered through pre-weighed Whatman 40 filter papers. The automatic liquid sampler normally collected samples of between 250 and 350 ml. The suspended sediment concentration of the samples was determined by reweighing the filter papers. Samples of less than 100 ml (suggesting incomplete operation of the vacuum sampler) were rejected, giving a sample success rate of 89%. Calibration samples, to assess the efficiency of automatic sampling, were taken using a U.S.D.H. hand sampler and were filtered through Millipore 0.2 μm filters. Comparison between hand-sampler calibration samples and actual vacuum samples yielded an R^2 value of 0.97, indicating a very high degree of association hence the data are thought to be reliable.

Determinations of instantaneous suspended sediment concentration can be combined with measurements of stream discharge to give estimates of suspended sediment yield in 10^3 kg/h (Fig. 3). The maximum suspended sediment concentration sampled was 70.7 g/l; this extremely high value, combined with a concurrent stream discharge of $1.5 \text{ m}^3/\text{s}$, produced an estimated peak value of suspended sediment yield of 381×10^3 kg/h. It is interesting to note that, as has been described on numerous previous occasions, the suspended sediment concentration peak for this event preceded the stream discharge peak. The total suspended sediment output over the four days of the outburst was calculated as $1\,674 \times 10^3$ kg. This figure is of a similar magnitude to the total suspended sediment yield from glacier de Tsidjiore Nouve estimated under normal summer ablation conditions by C. R. Fenn over the two months of July and August 1978 which underlines the importance of this four-day event in terms of the seasonal suspended sediment yields from the glacier.

3. BED-LOAD TRANSPORT

An approximate value of bed-load transport during the outburst was obtained by measuring accumulation of coarse material in the Grande Dixence sediment trap, located immediately up-stream of the water intake and designed to prevent the entry of this material. When the trap is full it is automatically purged, and the sediment is washed down the dry channel below the intake. The capacity of the trap was calculated, and its flushing efficiency, and an approximate packing density for the sediment was estimated. The number of purges was then used to estimate bed-load transport during the outburst as $3\,840 \times 10^3$ kg. It must be emphasised that, because of the tentative nature of the assumptions of flushing efficiency and packing density, this value is probably accurate to only $\pm 40\%$.

4. CONCLUSIONS

The outburst at glacier de Tsidjiore Nouve was an important event in terms of the magnitude and nature of sediment output from the catchment. The total sediment output during the outburst was

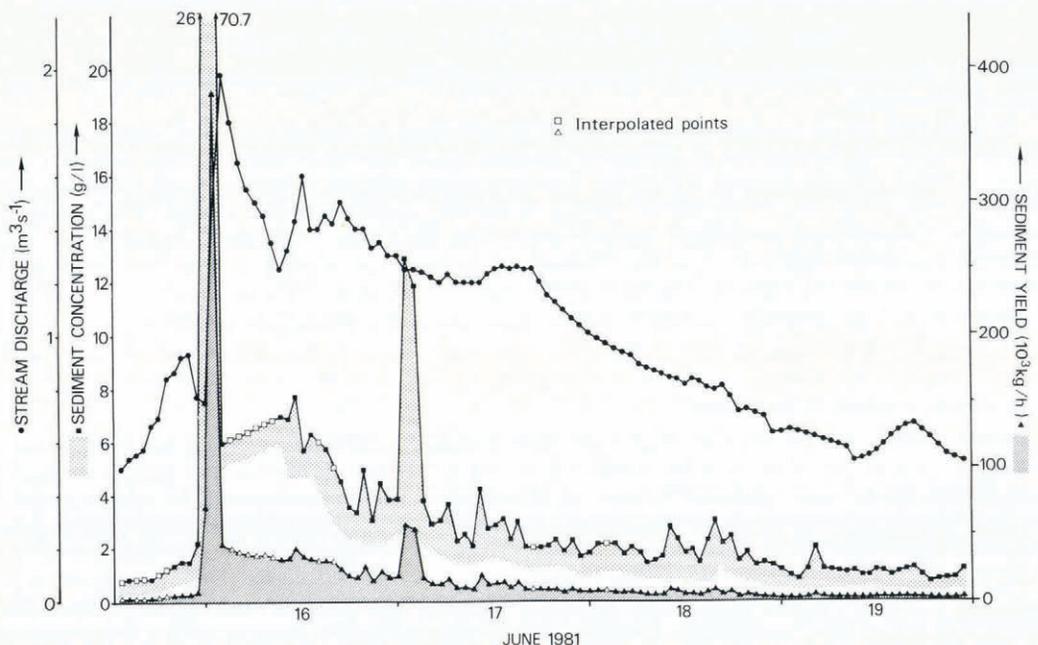


Fig. 3. Suspended sediment yield during an outburst from glacier de Tsidjiore Nouve, June 1981.

$5\,514 \times 10^3$ kg, this represents the equivalent of a vertical lowering on the entire 4.8 km^3 glacier catchment by 0.43 mm. It has been suggested that outburst activity increases under conditions of glacier advance (Grove, 1966). Since the arrival of the Grande Dixence scheme in the early 1960's, little outburst activity has been monitored at glacier de Tsidjiore Nouve. Later in summer 1981 another two outbursts, similar in magnitude to the June event, were observed. Since the mid 1970's many Swiss glaciers, including Tsidjiore Nouve, have been advancing substantially; given this situation, outburst activity, with its implications for sediment transport, could become more prominent in the near future. Increased outburst activity, and hence increased sediment output from glaciers, would cause major problems for hydro-electric power schemes abstracting glacial melt waters such as those of Grande Dixence S.A.

It is interesting to note that, during the outburst at glacier de Tsidjiore Nouve, bed-load output was at least twice as large as suspended load output. This could be caused by the high-magnitude outburst event transporting a disproportionately large bed-load component due to abnormal erosion of deposits outside the glacier.

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