SOME CHARACTERISTICS OF SOLUTE AND SUSPENDED SEDIMENT CONCENTRATION IN SKAFTAFELLSJÖKULL (S.E.ICELAND)

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Abstract The hourly variation of suspended load and electrical conductivity is studied during 24 hours in the proglacial outwash stream in Skaftafell (SE Iceland). Suspended load is well adjusted to the assumed fluctuations of discharge though the maximal sediment output peaks slightly before maximum discharge. The electrical conductivity shows an almost inverse curve, with high concentration of solutes in the base flow and dilution during the increase of discharge.

Keywords: meltwaters, suspended sediment, solutes, proglacial streams, Iceland.

Resumen. Se estudia la variación horaria de la carga en suspensión y la conductividad eléctrica en el río proglacial de Skaftafell (SE de Islandia) a lo largo de 24 horas. La carga en suspensión se ajusta muy bien a las supuestas fluctuaciones del caudal, aunque el pico de sedimentos se presenta inmediatamente antes del pico de caudal. La conductividad eléctrica desarrolla una curva casi inversa, con alta concentración de solutos durante el flujo de base y dilución con el aumento del caudal.

Palabras clave: aguas de fusión, sedimento en suspensión, solutos, ríos proglaciares, Islandia.

1. Introduction

Meltwaters emerging at the front of a glacier convey much information about the hydrological and geomorphological behaviour of the ice mass. Passing through cavities and conduits of the glacier, flowing meltwaters incorporate solute and suspended load, taken from sublgacial sediment layers and

bedrock surfaces. But sediment load is most variable in time, both in a yearly and a daily period, as a result of the fluctuations of discharge. The latter is well controlled by the seasonal and diurnal regime of ablation (Collins, 1979).

Generally, Alpine glaciers have an important sediment load, sometimes owing to the destruction of frontal moraines. In the glacier tongues of the southern face of Vatnajokull (Iceland) rivers run heavily loaded with clay, silt, sand and fine gravel, which gives the typical dark (almost black) colour to the waters,due particularly to the volcanic provenance of the material. Moreover, these sediments are suitable for the construction of a great outwash plain *(sandur)*, in which rivers adopt a braided pattern.

During a short expedition to Iceland, in July, 1988, information was recorded about the variability of sediment load, at a daily level, in order to obtain a first approximation on the hydromorphological functioning of a great and northern glacier. This paper presents and discusses the results of the field work.

2. The study area

The study was conducted at Skaftafellsjokull, surely the best known outlet glacier of the southern face of Vatnajokull, in Skaftafell National Park. It is a tongue of almost 10 km in length and 2 km in width, coming from the area of Oraefajokull. This is a well-know region from a geological point of view (see, Prestvik, 1979).Bedrock is mainly basalt at the lower levels, replaced by palagonites and rhyolites at the upper ones. Westward (Kjós area) granites of coarse grain apper, but rhyolite prevails with a great range of colours. The maximum altitude is reached at the peak of Hvanmadalshnúkur (2.119 m), at the border of the volcanic caldera of Oraefajokull.
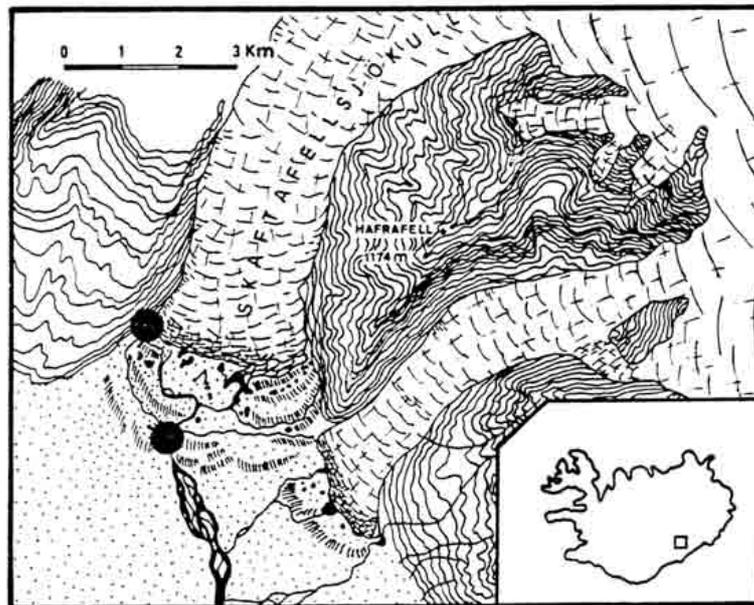

Fig. 1. Location of the study area
(Localización del área de estudio)

The Skaftafellsjokull ends at 100 m a.s.l. Until 1972 the front has retreated in a similar process to that suffered by neighbouring glaciers (Thorarinson, 1956; Ahlmann *et al*, 1937; Eythorson, 1963; Ives & King, 1954; King & Ives, 1955). Between 1974 and 1983, Rist (1985) points out a small advance.

Thompson (1988) has studied the evolution of the Skaftafellsjökull and has concluded a rapid recession since 1870 and a stabilization of the front in the last 20 years. Several very recent morainic arcs are located near the front, forcing the displacement of the river Eastward. Running waters visibly destroy the youngest moraine.

The characteristics of the proglaciar area have been frequently studied (i.e., Bogacki, 1973; Bluck, 1974; Price, 1971 and 1982; Krigstrom, 1962; Churski, 1973; Price, 1982; Thompson & Jones, 1986). A great outwash plain is developed from the external face of the moraines exhibiting complex sedimentary structures in which there are alternate braided channels and bars of very different types. Maizels & Dugmore (1985) distinguish three terrace levels, in the outwash of Myrdalsjökull, the oldest one dating from 1.840.

3. Measurement records

A sampling point was selected adjacent to the main spring of the subglaciar waters of Skaftafellsjökull. Water samples were collected at two-hourly intervals in one-litre polythene bottles. At the same time, air temperature, water temperature and electrical conductivity of the water were taken. The water samples were inmediately filtered with portable filtering equipment. In the laboratory, after oven-drying at 105º the filters were weighed. To verify the results, we took other samples 2 km downstream from the glacier front, also at a two-hourly interval. The measurements lasted 24 hours, between the days 23 and 24 july, 1988. The results are indicative of the evolution along a journey but they hardly express absolute values of sediment outputs, owing to the great variability of water turbidity and depth.

4. Results

At the front of the glacier the air temperature ranged between 3 and 12ºC. Two kilometers downstream from the front, air temperature ranged between 5 and 14ºC. In both cases the maximum temperature was reached at around 15.00 hours and the minimum one, at 01'30 hours. No rain occurred in the two days previous to the sampling, and during sampling the sky was free of clouds. So it can be expected that the water outputs are not conditioned by rainstorms and that the results reflect the characteristics of melting subglacial waters.

Water temperature was continuosly under 1ºC (near 0º at the glacier front and slughtly over 0.5ºC two kilometers downstream).

Fig. 2 shows the hourly evolution of suspended sediment concentration (in $g.l^{-1}$) and of electrical conductivity. In spite of the low absolute value, suspended sediment load gives much interesting information. The registered values range between 0.335 and 0.834 $g.l^{-1}$, relatively low in comparison with those obtained in other glacial environments. Maizels (1978) points out a suspended sediment concentration between 4.5 and 24.7 $g.l^{-1}$ in the meltwaters of the Bossons glacier (Swiss Alps). Nevertheless, the load is, in all cases, much higher than that corresponding to snowmelt water (see, for example, Puigdefábregas & Alvera, 1986, wich present data on sediment concentration in small watersheds of the Central Pyrenees).

The suspended sediment reaches its maximum value at 17.00 hours, and the minimum value at 07.00 hous, giving a daily regime that one can considerar as normal in glacial rivers. The regime from the data obtained 2 km downstream is very similar coinciding in the times of both high and low values. In all cases, suspended sediment concentration is higher at the portal of the glacier than 2 km downstream, that demonstrates the sedimentary importance of the nearest area to the glacier. Proofs made by JONES (verbal comm.) in the Neskvisl river (starting from the Svínafellsjökull) confirm this decreasing tendency.

The electrical conductivity shows an almost inverse curve, with the highest values between 04.00 and 06.00 and the lowest values at 17.00 and 19.00 hours. Several authors suggest an inverse relation between conductivity and discharge (Hem, 1970; Raiswell & Thomas, 1984; Rainwater & Guy, 1961;

Lemmens & Roger, 1978). Solutes reach high concentration values in the base flow because water slowly
percolates and has a greater residence time. On the contrary, solutes are diluted during the maximum snow and ice melting and during rainstorm events, owing to the quick runoff. Because of the lack of discharge measurements, the discharge regime must be deduced from the inverse of the curve of electrical conductivity. Thus, the peak flow is reached near 17.00 hours and the low flow, at 05.00 or 06.00 hours. In a melting period without rainstorms, this is the expected curve, and is also confirmed by the pattern of suspended sediment concentration. The rising limb of the curve starts at 07.00 or 08.00 hours and reach its peak two or three hours after the maximal air temperature. The lowest values of discharge are reached during the night, coinciding with the lowest temperatures.
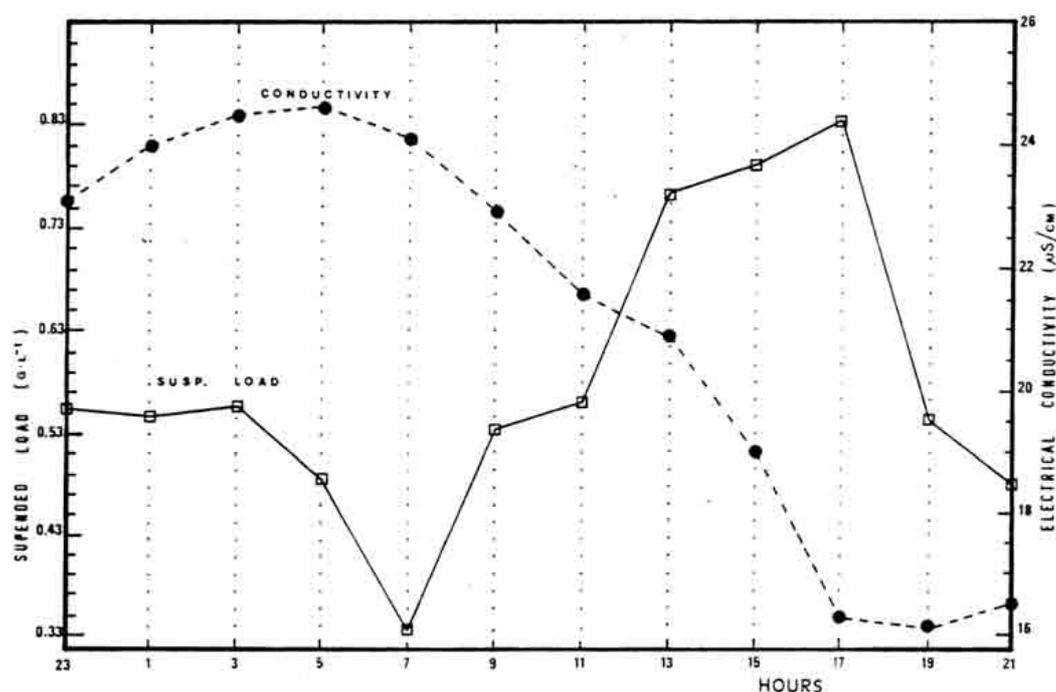

Fig 2. Hourly evolution of suspended load and electrical conductivity in the meltwaters of Skaftafellsjökull (23-24 july, 1988)
(*Evolución horaria de la carga en suspensión y la conductividad eléctrica en las aguas de fusión del Skaftafellsjökull, 23-24 de julio de 1988*)

The comparison of conductivity and suspended sediment concentration allows us to assess a little lead of sediment concentration versus discharge, as pointed out by Maizels (1978) and by other authors, in a number of environments (Puigdefábregas & Alvera, 1986; Arnáez-Vadillo & García-Ruiz, 1984).

Electrical conductivity ranges between 16.1 and 24.6 μ s/cm at 25ºC in the front of the glacier. Two kilometers downstream, conductivity slightly increases until a maximum value of 32.3 μs/cm at 25º is reached. These values are lower than those obtained by Jones (1987) in the neighbouring glacier front of Svinafellsjökull (47-75 μs/cm).

5. Discussion and conclusions

Raiswell & Thomas (1984) studied the behaviour of the solute load in the proglacial outwash stream of Fjallsjokull close to our sampling point. Later, Jones (1987) and Savage (1987) analyzed the solute and suspende load in the river merging from Svinafelljokull, the nearest glacier to Skaftafellsjökull, though to the present they have published only a preliminary report of their research. From other glaciers of the world there are similar results, specially in the Alps (Maizels, 1978; Collins, 1979, 1983 and 1987) and in the North American Cordillera (Rainwater & Guy, 1961; Slatt, 1970; Reynolds & Johnson, 1972).

Diurnal variations in proglaciar and nival rivers demonstrate a positive relationship between suspended sediment concentrarion and discharge, while solute concentration and discharge show and inverse relationship. Discharge and suspended sediments very often coincide, though, in general, the authors agree on the slight precession of the sediments (with, perhaps, a maximum of three hours difference). In the Skaftafell river (Skaftafellsá) a slight lead of the suspended concentration with respect to discharge (assumed as the inverse of the electrical conductivity) can be appreciated; and, it is most important, that after maximum peak flow is reached, a very rapid decrease of suspended load is produced, even coinciding with high discharge. This proves once again that when an increase of discharge begins, the sediments deposited in low-water periods are mobilized; such sediments are soon exhausted and the suspended load returns to middle and low levels even if there is a power surplus.

The results obtained in Skaftafellsjökull confirm the importance of residence time and of subglacial hydrologic presure (as already pointed out by Collins, 1987, in Alpine glaciers) to explain the solute concentration. The nightly decrease of discharge is accompanied by a progressive increase of electrical conductivity, which decreases to minimum during the peak flow. After this peak flow, solute concentration requires time to gather strength, surely because a generalized renewal of the subglacial water has occurred, and a greater residence time is necessary to incorporate important quantities of solutes. Raiswell & Thomas (1984) in the Fjalsjökull, conclude that between 3 and 4.30 hours a.m. the subglacial contribution to the discharge represents nearly 80 per cent of the total, which explains the momentary importance of solutes.

In the yearly sediment output we think that the suspended load has a much greater importance than the solutes, which explains the great ability of this type of river to develop large outwash plains. In other environments, several authors have tried to quantify the relative importance of every type of sediment; thus, in the Bossons glacier, Maizels (1978) values in 1% the solute sediment output, in 70% the suspended sediments and in 29% the bed load. Other authors, on the contrary, have demonstrated the great importance of chemical denudation in temperate glaciers (Reynolds & Johnson, 1972).

Finally, the quick loss of suspended sediment concentration between the first and the second sample points is a very extended phenomenon in other proglaciar environments. In fact, such a behaviour explains the quick evolution of the proglacial rivers, lakes and sedimentary structures, an example of this can be seen in the maps of stages of proglacial landform and drainage pattern development presented by Thompson (1988).

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