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The effect of the 2002 glacial flood on dissolved and suspended chemical fluxes in the Skaftá river, Iceland

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ABSTRACT

This study describes the chemical composition of dissolved, degased and suspended fluxes of the 2002 Skaftá glacial flood, which emerged from one of the Skaftá subglacial lake due to geothermal activity beneath the Icelandic Vatnajökull glacier. The dissolved and suspended fluxes during the flood are compared with those normally observed in the Skaftá river to determine the effect of such floods on the annual fluxes of material delivered to the coastal waters. Concentrations of most dissolved elements during the flood were significantly higher than those normally observed in the Skaftá river. In addition, dissolved concentrations of nutrients such as SiO_2, Fe, and V, increased more than an order of magnitude during the flood. These will affect biological processes on a local scale. The $\delta^{34}S$ composition in the flood water suggests that the dissolved SO_4 was derived from the oxidation of H_2S and the geothermal fluid. The total suspended particulate load measured in the Skaftá river during the 8-day 2002 flood was approximately half of the non-flood total annual Skaftá suspended load. As particles carry the bulk of limiting nutrients to the oceans, this demonstrates the importance of glacial floods for primary production of coastal waters. The composition of the flood water and the Skaftá subglacial lake, together with reaction path modelling suggest that substantial degasing of CO_2 and H_2S occurred at the glacial outlet during the flood. This degasing may have released as much as 262,000 and 7,980 tonnes of CO_2 and H_2S, respectively, to the atmosphere having a considerable impact on the local carbon and sulphur cycles during the flood event.

1. Introduction

Glacial outburst floods, called 'jökulhlaups' are common natural hazards in Iceland. These sudden bursts of water commonly originate from the melting of ice overlying active volcanic and geothermal areas (Björnsson, 1992, 2002, 2009). The floods consist of a mixture of water, dissolved constituents, sediments, volcanic materials, and ice (e.g. Gislason et al., 2002; Snorrason et al., 2002; Stefánsdóttir and Gislason, 2005). Depending on their size, formation mechanism, frequency, sub-glacial topography, suspended material load and ice, the impact on the flood plain and surrounding areas can be disastrous. For example, the Katla outburst flood associated with the 1918 subglacial eruption within the Mýrdalsjökull glacier (Fig. 1) reached a peak discharge of 300,000 m^3/s and inundated an area of 600–800 km^2 to the east of the volcano (Tómasson, 1996; Larsen, 2000). For comparison, discharge of the Amazon river — the world's largest, accounting for 15% of the Earth's continental runoff, attains a maximum discharge of 250,000 m^3/s (Gaillardet et al., 1997; Syvitski et al., 2014). After the 1918 Katla flood, the Icelandic coastline advanced 3 km towards the sea, as the sediments caused the land elevation to rise by a few metres. The total flood water volume was estimated to be 8 km^3 (Tómasson, 1996). Due to the enormous impact of these floods on ecosystems, such events have been extensively studied in terms of their hydromechanics, geomorphology and geochemistry (Björnsson, 1992, 1998, 2002; Gudmundsson et al., 1997; Maizels, 1997; Snorrason et al., 1997; Kristmannsdóttir et al., 1999; Geirsdóttir et al., 2000; Roberts et al., 2000; Gislason et al., 2002; Alho et al., 2005; Stefánsdóttir and Gislason, 2005; Russell et al., 2006, 2010; Galeczka et al., 2014a). The environmental implications of these floods have been far less studied (Gislason et al., 2002; Stefánsdóttir and Gislason, 2005; Galeczka et al., 2014a).

The Icelandic rivers can be affected by geothermal, volcanic, and/or glacial activity and therefore many are continuously monitored by the Icelandic Metrological Office (IMO; IMO, 2015). Some rivers used for hydropower production are also monitored by the Landsvirkjun Power Company (http://www.landsvirkjun.com/, 2015). Parameters recorded

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Fig. 1. Location of the sampling sites (black circles) in this study. The flood water drained from the Eastern cauldron into the Skaftá river. The dashed blue open circles and curves represent the Skaftá cauldrons and the flow path of the floods coming from both cauldrons.
Modified from Grunnkort, IMO, 2015.

at most of the river monitoring stations include discharge, water and air temperature, conductivity, and sometimes water transparency. This data can be viewed in real time on the web pages of the IMO (www.vedur.is; IMO, 2015). During the normal stage of the glacial river, when it is not affected by increased seismic/geothermal/volcanic activity, decreased conductivity is observed with rising discharge as rainfall or enhanced glacial/snow melting dilutes the river water (e.g. Eiriksdottir et al., 2013a). During glacial floods, increased conductivity is observed with increased discharge; this observation frequently indicates that the flood is impeding (e.g. Kristmannsdóttir et al., 1999, 2002, 2006; Galeczka et al., 2014a). Geophysical monitoring helps to identify if water is flowing underneath the glacier (Gudmundsson et al., 2008), but water discharge and conductivity monitoring data are the clearest signal of a forthcoming flood.

A number of risks are associated with these floods. Flood waters can become toxic depending on the mechanisms triggering the flood, distance between its source and threatened area, gas pressure, and temperature. For example, a high input of volcanic gases such as CO_2, SO_2, HCl, and HF can lower the flood water pH, increasing basalt dissolution, and enhancing release of toxic metals including Al, Cr, and As. Due to dilution of gas charged water with melting ice and sufficient water rock interaction there has been no record of toxic flood waters in Iceland (Sigvaldason, 1963, 1965; Steinþórsson and Óskarsson, 1983; Kristmannsdóttir et al., 1999; Gislason et al., 2002; Sigfússon, 2009; Galeczka et al., 2014a). Natural analogues and experimental work, however, confirms that the acidity caused by dissolved gases increases basalt dissolution, resulting in enhanced toxic metal release (Aiuppa et al., 2000a,b, 2003, 2005; Federico et al., 2002, 2004; Cioni et al., 2003; Marini et al., 2003; Taran et al., 2008; Flaathen et al., 2009; Ambrosio et al., 2010; Floor et al., 2011; Galeczka et al., 2014b). In addition, the glacial outbursts can result in substantial degasing of toxic gases. Gas toxicity depends on flood water saturation with gases, weather, and