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Direct evidence of the feedback between climate and nutrient, major, and trace element transport to the oceans

Eydis Salome Eiriksdottir [a,*], Sigurður Reynir Gislason [a], Eric H. Oelkers [a,b,c]

[a] *Institute of Earth Sciences, Sturlugata 7, 101 Reykjavík, Iceland*
[b] *GET, CNRS/URM 5563 – Université Paul Sabatier, 14 rue Edouard Belin, 31400 Toulouse, France*
[c] *Earth Sciences, University College London, Gower Street, London WC1E 6BT, United Kingdom*

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Abstract

Climate changes affect weathering, denudation and riverine runoff, and therefore elemental fluxes to the ocean. This study presents the climate effect on annual fluxes of 28 dissolved elements, and organic and inorganic particulate fluxes, determined over 26–42 year period in three glacial and three non-glacial river catchments located in Eastern Iceland. Annual riverine fluxes were determined by generating robust correlations between dissolved element concentrations measured from 1998 to 2003 and suspended inorganic matter concentrations measured from 1962 to 2002 with instantaneous discharge measured at the time of sampling in each of these rivers. These correlations were used together with measured average daily discharge to compute daily elemental fluxes. Integration of these daily fluxes yielded the corresponding annual fluxes.

As the topography and lithology of the studied glacial and non-glacial river catchments are similar, we used the records of average annual temperature and annual runoff to examine how these parameters and glacier melting influenced individual element fluxes to the oceans. Significant variations were found between the individual elements. The dissolved fluxes of the more soluble elements, such as Mo, Sr, and Na are less affected by increasing temperature and runoff than the insoluble nutrients and trace elements including Fe, P, and Al. This variation between the elements tends to be more pronounced for the glacial compared to the non-glacial rivers. These observations are interpreted to stem from the stronger solubility control on the concentrations of the insoluble elements such that they are less affected by dilution. The dilution of the soluble elements by increasing discharge in the glacial rivers is enhanced by a relatively low amount of water–rock interaction; increased runoff due to glacial melting tend to be collected rapidly into river channels limiting water–rock interaction. It was found that the climate effect on particle transport from the glacial rivers is far higher than all other measured fluxes. This observation, together with the finding that the flux to the oceans of biolimiting elements such as P and Fe is dominated by particulates, suggests that particulate transport by melting glaciers have a relatively strong effect on the feedback between continental weathering, atmospheric chemistry, and climate regulation over geologic time.

1. INTRODUCTION

This study is based on a set of fluid and suspended particulate samples collected from three sampling sites in two glacial rivers and three sampling sites in non-glacial rivers located in the basalts of Eastern Iceland. In total, 220 water samples were collected from these rivers from 1998 to 2003. A total of 28 distinct dissolved element concentrations and the suspended inorganic and organic material concentration of these samples were measured, for a total of 6600 distinct concentration data. Elemental concentration and suspended inorganic material – discharge rating curves created for each river was used together with daily measured river discharge to calculate the daily elemental fluxes

* Corresponding author.
E-mail address: ese@hi.is (E.S. Eiriksdottir).

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towards the oceans over a 26–42 year period. This extensive dataset was used in four previous papers to illuminate various aspects of chemical transport to the oceans. Gislason et al., 2006 calculated the daily dissolved and sediment fluxes of Ca towards the ocean and concluded that the latter flux dominated the feedback between climate and continental weathering. Gislason et al. (2009) used this dataset to calculate the annual fluxes of Ca and bicarbonate to the oceans and showed that these annual fluxes have increased substantially in response to increased temperature over the past 40 years. Eiriksdottir et al. (2008) used this dataset to assess the validity of steady-state weathering models. Eiriksdottir et al. (2013) used instantaneous dissolved Na fluxes from these rivers to determine the distinct effects of temperature versus runoff on chemical weathering. This study aims to use this dataset to illuminate the distinct effects of (1) climate (temperature and runoff), and (2) glacial cover, on the riverine fluxes of the elements to the oceans, highlighting the distinct behavior of trace elements and nutrients.

Riverine transport of elements to the oceans plays a major role in moderating global climate on a geological time scale. Increased flux of major elements and alkalinity due to increasing temperature promotes drawdown of CO_2 from the atmosphere through the formation of carbonate minerals in the oceans, providing a negative feedback between climate and chemical weathering (Walker et al., 1981; Amiotte-Suchet and Probst, 1993; White and Blum, 1995; Berner and Caldeira, 1997; Dessert et al., 2001, 2003; Gislason et al., 2006, 2009; Gaillardet and Galy, 2008; Ferrier et al., 2012; Eiriksdottir et al., 2013). An additional feedback between continental weathering, riverine transport, and climate is the transport and subsequent burial of organic carbon (e.g. Berner, 1982, 2004; Berner and Raiswell, 1983; Arthur et al., 1988; France-Lanord and Derry, 1997; Burdige, 2005; Galy et al., 2007; Hilton et al., 2012; Smith, 2013). Critical to this feedback between organic material transport to the oceans and global climate is that it is buried prior to its degradation (Raven and Falkowski, 1999; Berner, 2004).

Rivers transport a large quantity of essential nutrients to the oceans. Of particular interest are the macronutrients N, P, and Si which may limit primary production in various Earth surface environments (Egge and Aksnes, 1992; Jickells, 1998; Falkowski, 2004; Galloway, 2004; Ruttenberg, 2004; Ólafsson et al., 2008; Statham, 2012; Hartmann et al., 2014), and the trace elements Fe, B, Mn, Zn, Cu, Ni, Mo and V which are needed either to build organic cells or to catalyze biochemical transformations (e.g. Martin et al., 1994; Falkowski, 1997; Cullen et al., 1999; White, 1999; Lane and Morel, 2000a,b; Morel and Price, 2003; Raiswell and Canfield, 2012). Variations in nutrient transport to the oceans could also provide a feedback between weathering and climate if an increase in nutrients leads to increased primary productivity and organic carbon burial (e,g, Falkowski et al., 1998; Bains et al., 2000; Jickells et al., 2005; Jeandel et al., 2011; Pearce et al., 2013).

Weathering has been observed to be greatly effected by the presence of glaciers (e.g. Gislason et al., 1996; Hallet et al., 1996; Tranter, 2003; Anderson, 2005, 2007; Gislason, 2008; Li et al., 2012; Opfergelt et al., 2013). Evidence shows that sediment yields increase with the temperate glacier coverage of catchments in Alaska (Hallet et al., 1996) and in Iceland (Gislason et al., 1996). The average mechanical denudation rate in Iceland is 650 t/km^2/yr, excluding bedload and major floods (Tómasson, 1990); this is equivalent to 0.24 mm/yr assuming rock density of 2.7 g/cm^3 and considerably higher than the global average mechanical denudation rate of 230 t/km^2/yr (Milliman and Syvitski, 1992) equal to 0.085 mm/yr. Mechanical denudation in the glaciated areas of Iceland can be two orders of magnitude higher than in non-glaciated areas (Tómasson, 1990). This agrees with studies summarized by Hallet et al. (1996) showing that river basins with greater than about 30% glacier cover yield about an order of magnitude more suspended sediments than glacier-free basins. In the extreme, mechanical erosion rates greater than 27,000 t/km^2/yr or 10 mm/yr have been measured in the glaciated catchments of southern Alaska (Hallet et al., 1996). The suspended material in glacial rivers in NE-Iceland are highly reactive basaltic glass (Eiriksdottir et al., 2008), and play a major role in ocean chemistry (Oelkers et al., 2012; Jones et al., 2014; Morin et al., 2015). The high adsorption potential of the sediment surfaces contribute to ocean chemistry due to desorption in the coastal waters (Ruttenberg, 2004; Sinkko et al., 2013). This desorption process is particularly significant for phosphorus, an essential nutrient for primary productivity (Ruttenberg, 2004; Raiswell and Canfield, 2012). Glaciers have also been observed to increase chemical weathering rates; the average chemical denudation rates in Iceland is 35 t/km^2/yr (Gislason, 2008) compared to the 24 t/km^2/yr on the continents (Gaillardet et al., 1999), which are dominated by carbonate weathering.

In this study, which builds upon that of Gislason et al. (2009), the annual elemental fluxes of suspended organic and inorganic material and 28 dissolved elements in the rivers are used to determine the distinct behavior of each in response to climate change and the presence of glaciers. Focus will be placed on the role of nutrients essential for the primary productivity in the oceans including Si, P, and Fe. The purpose of this paper is to report the results of this study, which illuminates how climate change and glacial melting might affect the chemistry and primary productivity in the oceans.

2. STUDY AREA AND METHODS

Samples of water and suspended inorganic particulate matter were collected from six river catchments located in Eastern Iceland (Fig. 1). Samples were collected 44 times from each sampling site, from 1998 to 2003, except Fjardará, which was sampled 20 times from 1998 to 2000, and Jökulsá á Dal at Brú, which was sampled 24 times from 2000 to 2003. Discharge, air, and water temperature were measured at the time of sampling. Three of the studied catchments, Jökulsá á Dal at Brú, Jökulsá á Dal at Hjardarhagi, and Jökulsá í Fljótsdal at Hóll are glaciated, and three are non-glaciated, the direct runoff rivers,