Geomorphology 167–168 (2012) 77–90

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Spatial variations of surface water chemistry and chemical denudation in the Erdalen drainage basin, Nordfjord, western Norway

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ARTICLE INFO

Article history:
Received 29 April 2011
Received in revised form 24 February 2012
Accepted 27 March 2012
Available online 4 April 2012

Keywords:
Water chemistry
Solute concentration
Chemical denudation
Spatial variability
Drainage basin
Cold climate mountain environment
Norway

ABSTRACT

This study conducted over an investigation period of six years (2004–2010) focuses on spatial variation in chemical components of drainage water from sub-areas within a confined drainage basin of 79.5 km^2 (Erdalen drainage basin, inner Nordfjord, western Norway) for detection of spatial diversity and relation to environmental factors. The Erdalen drainage basin is homogenously composed of gneisses, which is reflected in a homogenous relative (as a percentage) chemical composition of surface water across the entire drainage basin system. At the same time, the mean annual TDS values of surface water sampled in creeks draining defined subsystems within Erdalen show a rather high spatial variability. The main controls of this spatial variability are (i) differences in slope deposit/regolith thickness, (ii) differences in slope angle, (iii) differences in areal regolith cover, (iv) differences in vegetation cover, (v) differences in snow cover and ground frost conditions, and (vi) differences in elevation (m a.s.l.). Altogether, the mean annual TDS values in Erdalen are rather low, which can be explained by (i) the shallow thickness of regolith across the very steep drainage basin, (ii) the small percentage of surface areas showing a significant cover of regolith, (iii) the cool climate in the fjord landscape of western Norway and (iv) the weathering resistance of the predominant gneisses within Erdalen. The annual chemical denudation rates in Erdalen are in a similar range of magnitude to rates published for numerous other cold environment catchments worldwide. Despite the rather low mean annual TDS values, chemical denudation is a comparably important and spatially very variable denudational process and should therefore not be neglected when studying slope development as well as slope- and catchment-wide denudation rates and mass budgets in this kind of steep, mountainous cold climate drainage basins.

1. Introduction

There is still an obvious lack of investigations of chemical weathering and denudation compared to the number of studies on mechanical weathering and denudation in cold climate environments (e.g. Corbel, 1959; Clark, 1988; Summerfield, 1991; French, 1996; Gislason et al., 1996, 2006; Thorn et al., 2001; Beylich et al., 2003, 2004a, 2004b; Dessert et al., 2006, 2009). Early work by e.g. Von Lozinski (1909, 1912) and Peltier (1950) postulated a minor role of chemical weathering and denudation in cold climate environments. In contrast to this early opinion, Rapp (1960) concluded after his detailed and longer-term quantitative process studies in Kärkevagge (northern Swedish Lapland) that chemical denudation was the most important denudational process in this sub-Arctic oceanic environment. Subsequently, geomorphologic research in various cold climate environments worldwide has shown that chemical processes and denudation are significant in cold environments (e.g. Corbel, 1959; Thorn, 1975; Dixon et al., 1984, 1995, 2008; Caine, 1995; Gislason et al., 1996; Darmody et al., 2000, 2001; Campbell et al., 2001, 2002; Thorn et al., 2001; Beylich et al., 2003, 2004a, 2004b, 2005, 2006a, 2006b; Beylich, 2005, 2008, 2011).

In spite of these investigations, our knowledge of chemical activity and its dependence on local environmental factors in cold climate environments is still in its infancy.

Chemical weathering and denudation are dependent on several factors such as climate and connected ground frost, topography, lithology and regolith thickness. To better relate chemical weathering and chemical denudation to environmental factors in cold climate environments, investigations in a range of representative drainage basins with different but preferably individually homogeneous lithology, and with internal differences in slope angle, regolith thickness, aspect to radiation, vegetation cover as well as snow cover and frozen ground conditions is needed (Beylich et al., 2003; Beylich and Kneisel, 2009; Beylich, 2011). Different methods including continuous and year-round meteorological and hydrological measurements, rock and ground temperature monitoring, photo

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0169-555X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2012.03.030

monitoring of snow cover using both year-round operating automatic cameras and detailed manual photo documentation during field campaigns, extended rock and water chemistry analyses, detailed geomorphologic mapping as well as geophysical subsurface profiling and high-resolution DEM and GIS computing need to be combined in order to analyse the spatial variability and the absolute and relative importance of chemical weathering and denudation in relation to these factors. If such an integrated approach is applied improved chemical weathering and denudation rates can be calculated and related to local parameters within clearly defined landscape units such a drainage basins (e.g. Beylich, 2002; Beylich et al., 2003). With the identified existing gap in the literature the need of this type of quantitative and integrated study, combining a number of different methods and techniques, appears obvious.

In this paper, such a study is performed for the Erdalen drainage basin, a cold climate environment within a sub-Arctic oceanic mountainous gneiss area in western Norway (Fig. 1). The study focuses on spatial differences in chemical components of drainage water from sub-areas within a confined drainage basin for detection of spatial diversity and relation to environmental factors.

2. Study area

Erdalen is a steep and U-shaped valley system in the fjord landscape of western Norway (inner Nordfjord) (Figs. 1 and 2). The Erdalen drainage basin (surface area 79.5 km^2; elevation range 29 m–1888 m a.s.l.), situated at 61°50′N, 07°10′E, is connected to the Jostedalsbreen ice cap and is glaciated in its upper areas (Beylich et al., 2009, 2010; Hansen et al., 2009; Laute and Beylich, 2010, 2012-this issue). Geologically, the inner Nordfjord belongs to the Jostedals Complex and the lithology is primary composed of Precambrian granitic orthogneisses with some patches of quartz monzonites (Lutro and Tveten, 1996).

The Erdalen drainage basin is typical for the region and is considered to be a representative drainage basin system for the fjord landscape in western Norway. It is characterized by a valley deeply incised into bedrock (homogenous orthogneisses) and adjacent summits are up to 1200–1500 m above the valley floor. The width of the valley floor varies but rarely exceeds 700 m. Bedrock exposed across the valley bottom forms natural sills that control the incision of the main stream, and create natural boundaries of interconnected valley floor basin elements (Hansen et al., 2009). Along the valley walls, bedrock alternates with talus cones and alluvial as well as colluvial fans.

Fig. 2 shows the surface area percentages (as % of the total drainage basin area) of (i) bare bedrock, (ii) slope deposits/regolith, (iii) valley floor infill, (iv) lakes and (v) glaciers for the entire Erdalen drainage basin (79.5 km^2) as well as for the defined subsystems (i) lower Erdalen (30.2 km^2), (ii) middle Erdalen (9.4 km^2), (iii) upper Erdalen (49.3 km^2), (iv) entire Vesledalen (15.8 km^2), (v) entire Stordalen (24.1 km^2), (vi) lower Vesledalen (7.5 km^2), (vii) lower Stordalen (6.0 km^2), (viii) upper Vesledalen (8.3 km^2) and upper Stordalen (18.1 km^2). Only 32% of the Erdalen drainage basin surface area is covered by slope deposits/regolith and 63% of the surface area is bare bedrock and glaciers.

Annual precipitation at the closest meteorological station with an available long-term record (Oppstryn) is approximately 1100 mm yr^{-1}, with most precipitation occurring in autumn and winter. The mean annual temperature at the Oppstryn meteorological station (61°54′N, 07°03′E; 50 m a.s.l.) is 5.7 °C, with January and February being the coldest months (−1.5 °C) and July being the warmest month (14.2 °C) (Norwegian Meteorological Institute, 2012).

Since 2004 an automatic weather station has been in operation in Erdalen at 360 m a.s.l. (Fig. 3). The mean annual areal precipitation in the Erdalen drainage basin for the investigation period 2004–2010 (with the areal precipitation being based on measurements with the automatic weather station and 25 additional precipitation gauges, which were installed across the entire drainage basin area, see Fig. 3) is 1426 mm. The mean annual air temperature (2004–2010) at the automatic weather station is 6.0 °C and the mean annual ground temperature (at 20 cm ground depth) at this weather station is 5.4 °C. In the four-month period from December to March the mean precipitation (2004–2010) in Erdalen is 582 mm. From April to June it is 220 mm, from July to August 180 mm, and from September to November 444 mm. The mean air temperature at the Erdalen automatic weather station is 0.0 °C for the four-month period December to March, and it is 8.4 °C from April to June, 14.4 °C from July to August, and 5.8 °C from September to November. The mean soil temperature at the automatic weather station (at 20 cm ground depth) is 1.3 °C from December to March, and it is 5.2 °C from April to June, 11.7 °C from July to August, and 6.8 °C from September to November.

Relevant denudational surface processes in Erdalen include rock and boulder falls, snow avalanches, slush flows, creep processes, debris flows, wash denudation, chemical denudation and fluvial transport of solutes, suspended sediments and bedload (Beylich et al., 2009, 2010; Laute and Beylich, 2012-this issue). The mean annual runoff (2004–2010) is 1354 mm. Three different periods with a high frequency of high-runoff events can be identified over the year, with these three periods showing a significant inter-annual variability. High runoff in spring (April–June) is mainly thermally caused by snowmelt whereas major discharge events in summer (July–August) are due to thermally caused glacier melt. In autumn (September–November), major discharge events are associated with heavy rainfall events (Beylich et al., 2010). In the period from December to March

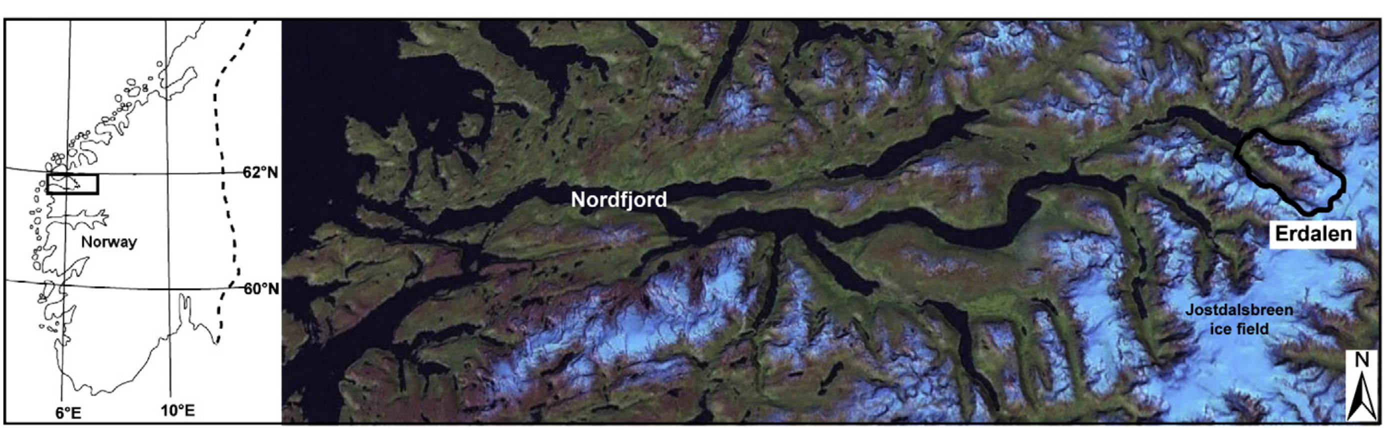

Fig. 1. Location of the Erdalen drainage basin in the inner Nordfjord, western Norway.