Evolution of water quality characteristics over a proglacial fluvial system in a high-latitude glacierised catchment.

Introduction

The study programme was successfully completed and entailed four weeks intensive field work in the proglacial fluvial system draining the Russell and Leverett glaciers. Both are land based outlet glaciers draining the western margin of the Greenland Ice Sheet (GrIS) at around 67^{o}N outside Kangerlussuaq (Appendix 1).

The aim of this project was to investigate the link between chemical weathering in a proglacial stream from a terrestrial outlet glacier at the margin of the GrIS, and the sequestration of atmospheric carbon dioxide. In order to address this aim more specific objectives were determined:

- The spatial variations in meltwater solute concentrations along a proglacial stream from a land based outlet glacier of the GrIS through electrical conductivity measurements.
- The nature of glacially derived meltwater composition and how that composition can change during flow through the proglacial fluvial system through measuring the chemical composition of meltwaters.

Broader Context

Brown (2002), in his review of glacier meltwater hydrochemistry, highlights the characteristics of glacierised areas that enable them to be an ideal environment for which to study water-rock interactions. Despite displaying low temperatures, sparse vegetation and poorly developed soils that are common to glacierised catchments, Brown (2002) highlights that the high meltwater fluxes they receive and the access to large quantities of highly reactive fine sediments in their meltwaters outweigh these negative effects. Anthropogenic influences are also at a minimum, allowing the investigation of natural controls on meltwater quality. Sharp *et al.* (1995) reinforces this further by indicating that chemical weathering rates can be between 1.2-2.6 times the continental average in glacierised catchments. Chemical weathering processes in proglacial environments could act as a sink for atmospheric CO_2, particularly during periods of extended high discharge levels (Sharp *et al.*, 1995). Therefore, major deglaciation events could remove carbon dioxide from the atmosphere contributing to counteract any trend in global climate warming at that time (Brown, 2002). This relationship has been studied in detail with regards to Alpine glacierised basins (Anderson *et al.*, 1997) but not to high latitude ice masses (Hodgkins *et al.*, 1997). This project will investigate a proglacial fluvial environment at the margin of the GrIS, through electrical conductivity measurements of the proglacial meltwater, helping to develop this lack in understanding of solute acquisition across the complete range of glacierised environments. Previous studies have used electrical conductivity to determine characteristics of meltwater hydrochemistry with particular success (Collins, 1979). However, few (Gurnell and Fenn, 1985) have looked at the specific spatial variation in electrical conductivity measurements within a proglacial fluvial system identifying further gaps in the literature that this research project will help to fill.

Methods

Electrical conductivity has been used in several investigations before, such as Collins (1979) and Gurnell and Fenn (1985), as an indicator of meltwater solute concentration. Its use is warranted on two clear points; it is able to act as a surrogate for total solute concentration and hence provide information on chemical weathering characteristics, and it is also a relatively easy and economical method of measurement.

A key element of this study was to build upon theories of spatial site to site variations of solute concentrations initially investigated by Gurnell and Fenn (1985). This therefore required the mobile measurement of electrical conductivity to assess the evolution of a body of water as it passes down the proglacial fluvial system. This was achieved by using a hand held device that involved immersing a conductivity cell within the fluid being analysed. A continuous record of electrical conductivity was also recorded at the mouth of the proglacial stream by a stationary data logger. This was set up in order to achieve a basic understanding of solute behaviour in the glacial waters.

Chemical composition of meltwater was collected as a measure of water quality down the proglacial fluvial system. Samples were taken from along the proglacial fluvial system and then filtered and bottled on site for analysis back in the laboratory in the United Kingdom. The more laborious option of hand sampling and filtering the proglacial water was chosen due to the flexibility of spatial measurements required in the study.

In order to accurately measure the spatial variation in electrical conductivity measurements as a water body moves through a glacierised catchment the velocity of the proglacial stream needed to be identified. This was achieved using dye tracer techniques that involved the input of dye, Rhodamine WT due to its fluorescence and favourable characteristics such as being soluble in cold water, upstream and its detection further down the proglacial fluvial system. The time taken for the dye to travel the known distance was recorded and the velocity of the stream calculated. However, if straight line distance is used in calculation then calculated velocity is only a minimum.

Results

The first stage of analysis was to identify what was happening on a basic level with regards to solute concentration in the proglacial fluvial system draining Russell Glacier. Graph 1 (Appendix 2) illustrates temporal variations in electrical conductivity and a clear diurnal variation. Collins (1979) has shown that this is a typical relationship found on alpine glaciers that is inversely proportional to discharge.

The second stage of analysis was to concentrate on the spatial variation of electrical conductivity of the proglacial waters to investigate the extent of any down stream changes in chemical weathering patterns that could potentially impact on changes in the climate. Graph 2 (Appendix 3) illustrates these spatial variations at both maximum and minimum discharge periods and suggests that there is little impact of post-mixing reactions as electrical conductivity levels are generally constant around 5 and 2 respectively.

Discussion and Conclusions

The small changes in electrical conductivity over the proglacial fluvial environment are most likely down to instrumental error so leading us to two possible conclusions:

1) Proglacial stream may not be flowing over reactive bedrock and therefore not acquiring solutes as readily as imagined.

2) Whole process of solute acquisition is slow and solutes are not being acquired from chemical weathering processes in the time period of study.

Further analysis of water samples is being done to identify specific solute concentrations. This could have the potential to illustrate what chemical weathering process are taking place and whether or not the proglacial waters are interacting readily with the bedrock and also provide a further insight into the evolution of chemical weathering processes in the short time period of the study.

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Budget Breakdown

Awards	
Mackay Greenland Fund (UoE)	£250
Student Travel Fund (UoE)	£109
Small Project Grant (UoE)	£450
The Explorers Club Youth Activity Fund	£450
Total	**£1259**
Expenditure	
Travel	£800
Accommodation	£100
Food/Maintenance	£140
Insurance	£100
Equipment (Analytical, Field etc.)	£250
Total	**£1390**

Personal Statement

The experience of being able to conduct fieldwork in such a remote location as Greenland is one that I will always be grateful for. Below is a list of adopted skills that are directly transferable into all other aspects of my life.

- Initiative and Problem Solving – Involved extended periods of unsupervised work that challenged me to adapt to the ever changing environment that is associated with fieldwork. Variables such as the dramatic climate and reliability of field equipment meant I was constantly adapting my research methods to ensure the fieldwork was always carried out efficiently and successfully in this remote location.
- Analytical – Write-up requires a 12,000 word report to be completed. For this to be a successful, high quality report, strong analytical skills will be needed to break down the initial, smaller elements of evidence collected, so that a clear picture of the problem can be formulated.
- Interpersonal – In order to undertake fieldwork in adventurous locations such as Greenland it was crucial for me to work alongside, and interact constructively with, more senior academic members, such as department professors, to collaborate and develop research ideas for my research projects.
- Communication – Communication skills are invaluable in these environments to ensure that you can work efficiently with research partners to collect the necessary data for your own independent project, despite the limited time period often allocated to undergraduate research.

Bibliography

Anderson, S.P., Drever, J.I. and Humphrey, N.F. (1997), Chemical weathering in glacial environments, **Geology**, 25 (5), pp. 399 – 402.

Brown, G.H. (2002), Glacier meltwater hydrochemistry, **Applied Geochemistry**, 17, pp. 855 - 883.

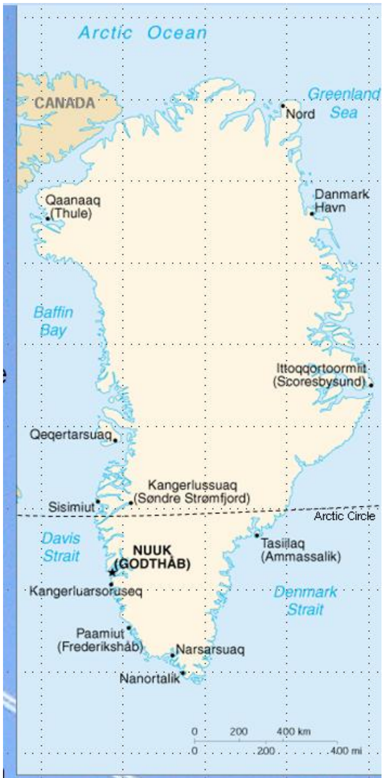
Collins, D.N. (1979), Hydrochemistry of meltwaters draining from an Alpine glacier, **Arctic and Alpine Research**, 11 (3), pp. 307 – 324.

Gurnell, A.M. and Fenn, C.R. (1985), Spatial and temporal variations in electrical conductivity in a pro-glacial stream system, **Journal of Glaciology**, 31 (108), pp. 108 – 114.

Hodgkins, R., Tranter, M. and Dowdeswell, J.A. (1997), Solute provenance, transport and denudation in a high arctic glacierised catchment, **Hydrological Processes**, 11, pp. 1813 – 1832.

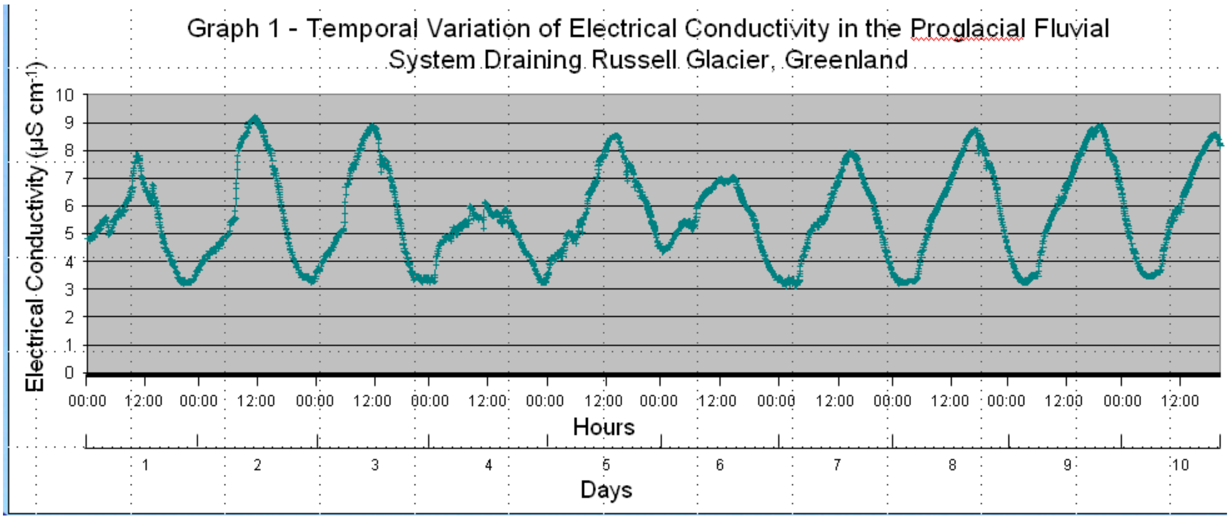
Sharp, M., Tranter, M., Brown, G.H. and Skidmore, M. (1995), Rates of chemical denudation and CO_2 drawdown in a glacier-covered alpine catchment, **Geology**, 23 (1), pp. 61 – 64.

Appendix 1



A map of Greenland illustrating the location of Kangerlussuaq in relation to the article circle.

Appendix 2



Appendix 3