Using Geochemical Evidence to Determine Provenance
in a High Arctic Glacier-Fed Lake, Linné Valley, Svalbard, Norway

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Submitted to the Department of Geology
of Smith College in partial fulfillment
of the requirements for the degree of
Bachelor of Arts with Honors

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May 9, 2005

Caveat lector:

This valley and many of the geomorphic features within the valley are named after the Swedish taxonomist, Carl von Linné (1707-1778). Throughout the explanation of my research, I will refer to these features by their Norwegian names. In Norwegian, "dalen" means "the valley", "vatnet" means "the lake", "elva" means "the stream", "breen" means "the glacier" and "kapp" means cape. The combination of these nouns and the name "Linné" yields the proper names for the features in the study area: Linnédalen, Linnévatnet, Linnéelva, Linnébreen and Kapp Linné.

Abstract

The sediment provenance in Linnédalen was studied as part of a larger project to monitor and calibrate lamination stratigraphy in proglacial Linnévatnet. Linnédalen is located at 78°N on the island of Spitsbergen in Svalbard, Norway. Meltwater from Linnébreen, a glacier, carries fine-grained sediment 5 km downstream to the lake. Other transport processes include hillslope alluviation and sidevalley avalanche activity. Linnédalen lends itself to provenance studies because it contains three distinct rock types: the mountains to the east are composed of carbonate rocks, the valley floor, eroded by Linnébreen, is composed of sandstone with coal seams and the mountains to the west, eroded in the past by small cirque glaciers, are composed of low-grade metamorphic rocks (phyllites). A provenance study that provides information about the source areas of the sediment flux to the lake allows for reconstruction of glacial history in the valley.

The principal sediment source streams were identified on aerial photographs and during field surveys. Fine-grained sediment samples were collected from sand bars and in the lee of boulders in each streambed. Littoral sediment samples were gathered from 1-2m depth at 200m intervals along the south shoreline where the main inflow streams enter the lake. Lake basin sediment samples were recovered from three levels within short cores taken in the three lake basins.

Samples were analyzed for major and trace element composition by X-Ray Fluorescence (XRF) and for organic carbon and carbonate content by loss on ignition (LOI). Unique geochemical fingerprints were identified for each source rock and then compared to inflow stream and lake basin sediment samples to identify the relative contributions of each primary bedrock source to the stream and lake sediments.

The sandstone and carbonate source sediments are distinguishable based on silica, calcium, organic carbon and carbonate contents. The phyllite source sediments have high concentrations of most of the major and the trace elements. The sandstone and phyllite

source rocks were the major sediment contributors to the 15m deep southern lake basins. The carbonate source rock is either dissolved into the water column or its geochemical fingerprint is overwhelmed by the other two source sediments. The 37m deep northern lake basin, distal to the main inflow streams, was dominated by a mix of material carried from the south end of the lake by currents within the lake and derived from marine terraces on the east and west shores of the lake. The lake basin sediments have higher concentrations of aluminum and organic carbon and lower concentrations of silica and carbonate than the source sediments. Grain size fractionation and carbonate leaching seem to have significant influence on the lake sediment geochemistry. Sediment in the southern lake basins was found to increase in aluminum content and decrease in silica content from top to bottom in the cores. Inversely, the northern lake basin sediments decreased in aluminum content and increased in silica content from the top to the bottom of the core. These geochemical changes may be a result of varying source contributions.

This study provides a basis for future geochemical studies that more closely examine these compositional changes through time. Future provenance studies in Linnédalen should separate each sample by grain size and analyze each size fraction, since grain size differences can cause dramatic geochemical differences between samples. Other methods that may be effective in determining provenance in Linnédalen include heavy mineral and clay mineral analysis. If the lake basin sediments are to be examined for geochemical fingerprints of source areas, it is imperative to determine the composition of the marine terrace sediment source. Examining the aqueous geochemistry of the inflow and outflow streams and of the lake would help to determine how and under what conditions carbonate leaching is affecting the lake water and sediment.

Acknowledgements

Table of Contents

List of Figures

1. Introduction

The sediment provenance, or the origin of sediments, in Linnédalen was studied as part of a larger project to monitor and calibrate the lamination stratigraphy of proglacial Linnévatnet. The bedrock geology of Linnédalen consists of three distinct rock types. Changes in organic carbon and carbonate content of the lake sediments have been interpreted as changing erosional conditions, which signify glacial and non glacial periods (Svendsen et al., 1989; Werner, 1988). The goal of this project was to determine a unique geochemical fingerprint for each primary source rock and to examine whether variations in lake sediment geochemistry could be correlated to changes in source sediment contribution.

1.1. Geographic setting

The study area was located in Linnédalen on the west coast of Spitsbergen, the largest island in the Svalbard archipelago (Figure 1). Linnédalen runs 15km north-south and is flanked on each side by 800m-high mountains. To the west, the mountains are bordered by a broad strand flat that slopes 3-5 kilometers west to the North Atlantic Ocean (Figure 1). To the east, the mountains descend sharply into Grönfjord, which joins with Isfjord just north of the valley. Linnébreen, a small (1.72km^2) alpine glacier, lies at the south end of Linnédalen (Figure 1). The meltwater stream from Linnébreen is the primary inflow stream for Linnévatnet. At 1km wide by 5km long, Linnévatnet (12m elevation) is one of the largest lakes on Svalbard (Svendsen and Mangerud, 1992; Svendsen et al., 1989). Small valleys, which contain cirque glaciers or small patches of
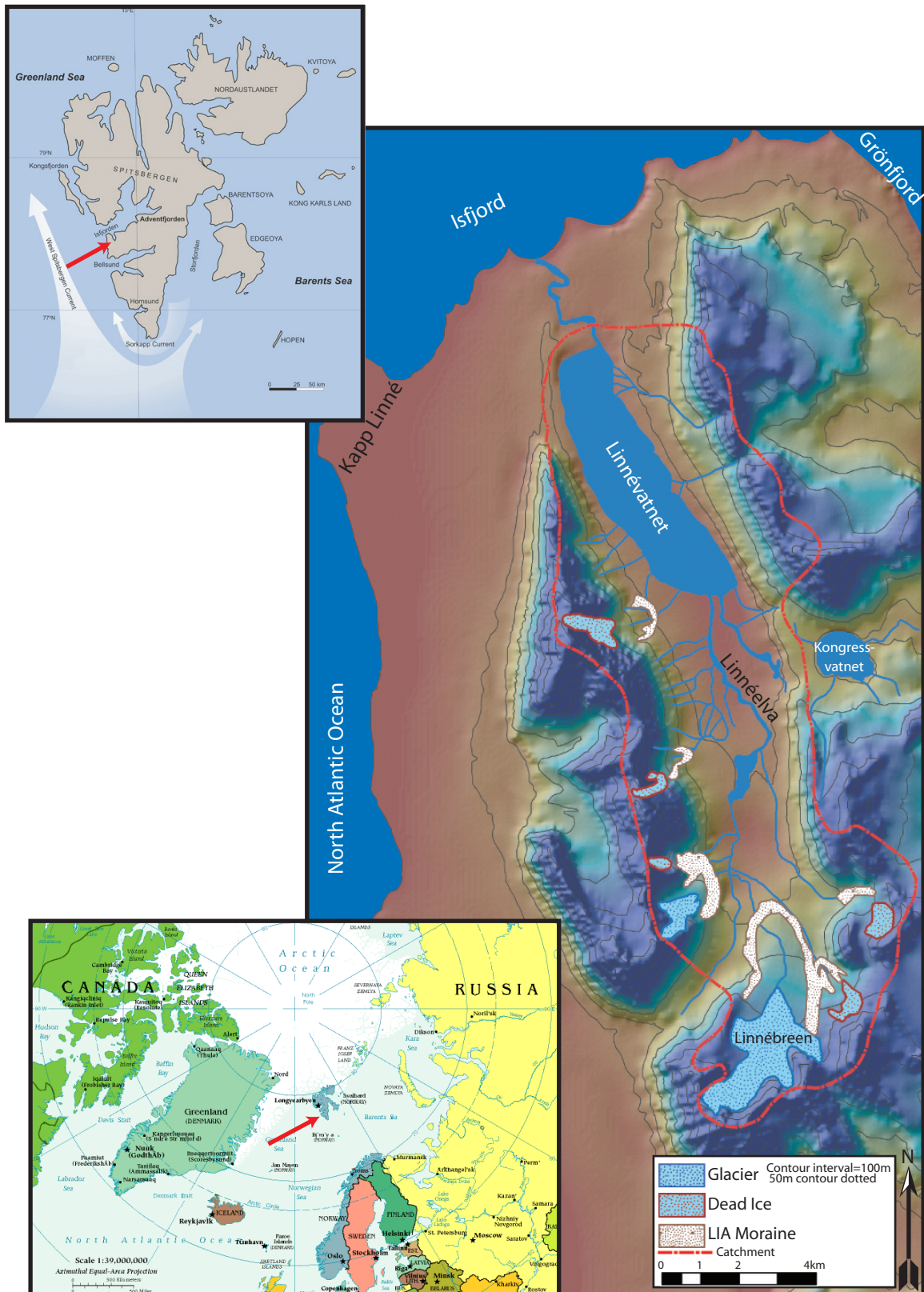
Figure 1. Map of Svalbard and study location. Red arrows point to study area. Circumpolar map modified from nsidc.org. Svalbard Archipelago map modified from www.iopan.gda.pl. Kapp Linné map modified from aerial photos, Norwegian Polar Research Institute, 1995 and from topographic maps of the area.

2

dead ice, occur on both the east and west sides of Linnédalen (Figure 1). Marine terraces of different ages and elevations are found along the sides of the valley, particularly around the lake.

1.2. Climatic setting

At 78°N, Svalbard is in the high Arctic. The northernmost branch of the Gulf Stream, the West Spitsbergen Current (Figure 1), creates a relatively warm maritime environment in this area. The average annual temperature for Linnédalen is -5°C (Svendsen and Mangerud, 1992). The warmest month is July with an average temperature of 4.7°C. The average annual precipitation in the valley is 400mm (Svendsen and Mangerud, 1992). Each winter the streams in the valley run dry and Linnévatnet freezes over. The ice breaks up from the lake any time between June and August for a short summer and then refreezes in September.

During the 2004 field season the temperature fluctuated between 1 and 16ºC as recorded by a local automated weather station (UTM Zone 33X, WGS 84, E: 473360 N: 8661662). The mean temperature from July 23 to August 7 was 8ºC, which is unusually warm. Wind speeds averaged 8 knots (9 mph), while gusts sometimes reached 43 knots (49 mph). Precipitation (78mm) fell in the form of fog and rain. Even in such a narrow valley, only 4.5km from the eastern mountain peaks to the western mountain peaks, microclimatic differences were observed. Clouds were more likely to clear from the eastern side of the valley. The small cirque at the southwest end of the lake almost always had colder, cloudier and wetter weather than elsewhere in the valley. The conditions at Linnébreen, as observed during field work and recorded by automated

3

temperature probes, were also normally colder and cloudier than in the northern part of the valley. These microclimatic differences may cause variations in erosion rates in different parts of Linnédalen, which would in turn influence lake sediment deposition and composition. Furthermore, changes in climate may alter these microclimatic variations.

1.3. Geologic setting

During the Precambrian Eon, when Svalbard was located near the South Pole, several mountain-building events created the highly deformed rocks that today form a belt along the west and north coast of Spitsbergen (Ingólfsson, 2005). Cambrian and Ordovician limestones also form part of this belt. Svalbard drifted north during the Paleozoic era. Devonian redbed sandstones, formed in an arid environment south of the equator, are found throughout north-central Spitsbergen. During the Carboniferous and the Cretaceous Periods, Svalbard drifted from the equator to 45°N (Ingólfsson, 2005). Sandstone and limestone strata deposited during this time cover the south and east sides of Spitsbergen (Ingólfsson, 2005). During the Tertiary Period, Svalbard collided with Greenland, causing folding of much of the older strata and deposition of sandstones and coal seams in a basin at the center of Spitsbergen (Ingólfsson, 2005). Svalbard reached its present location towards the end of the Tertiary Period, when extensive glaciations began (Ingólfsson, 2005). These glaciations continue into the present day.

A geologic map and description of the bedrock geology of Linnédalen was compiled by Dallmann et al. (1982; Figure 2). The mountains west of Linnédalen consist of steeply-dipping Middle Proterozoic areno-argillaceous phyllites. These phyllites are slightly metamorphosed siliceous sandstones and shales, with a lithology dominated by
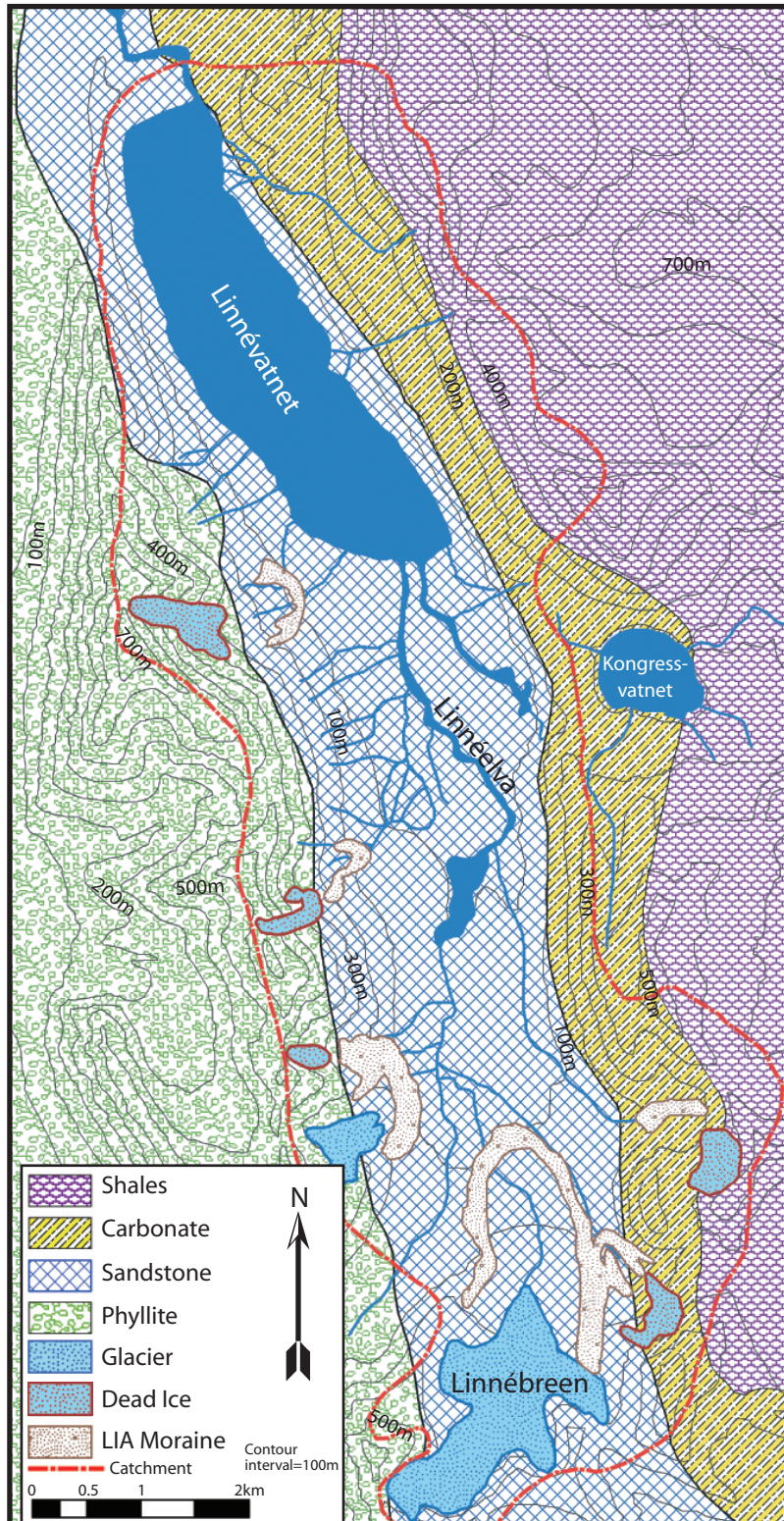
Figure 2. Geologic map of Linnédalen. The three principal source areas for this study are the carbonate, sandstone and phyllite. Only a small portion of the shales are within the Linnévatnet catchment so they are not considered a major source rock in this study. Adapted from Svendsen et al., 1989.

sericite and chlorite. The valley floor is composed of Lower Carboniferous quartz-rich sandstone containing non-vascular plant and tree fragments. Also in this formation are carbon-rich shale beds and coal. In contrast, the eastern mountains are composed of Mid Carboniferous to Early Permian fossiliferous carbonate (limestone and dolostone) rocks containing Upper Triassic to Lower Cretaceous dolerite intrusions.

1.4. Glacial and marine history of Linnédalen

The glacial and marine histories of Linnédalen are closely related. Svendsen and Mangerud (1992) have studied the glacial history of Svalbard extensively. The last glacial maximum in western Spitsbergen occurred during the Late Weichselian, when all of the glaciers terminated in the sea. At around 12,500yr BP (radiocarbon years before present), a rapid glacial retreat occurred. Svendsen and Mangerud (1992) examined cores taken from Linnévatnet to determine the history of the valley after this rapid retreat. The lacustrine sediments overlie a sequence of marine sediments which rest on till and/or bedrock. Radiocarbon dates on marine fossils suggest that continuous deposition of marine silt and clay occurred between 12,500 and 9,600yr BP (Svendsen and Mangerud, 1992). During this time, continuous glacioisostatic rebound and changing relative sea level (Figure 3; Forman et al., 1987) resulted in the deposition of a flight of marine terraces at different elevations throughout the valley (Svendsen et al., 1989). Today, these marine terraces are most prominent in the northern part of the valley around the lake. At 9,600yr BP, the lake was isolated from the sea due to isostatic rebound (Svendsen et al., 1989). Closer examination of the lacustrine sediments reveals that the

glacier in Linnédalen did not exist during most of the Holocene. Svendsen and Mangerud (1992) suggest that an increased sedimentation rate at 2,000-3,000yr BP indicates that glaciers began to form again in the valley at that time. The Holocene glacial maximum occurred during the Little Ice Age (LIA, <600yr BP). Large ice-cored moraines, deposited during the LIA (Werner, 1988; 1993) lie in front of Linnébreen and in front of each of the cirques carved into the mountains on either side of the valley (Figure 2). Even cirques that are now ice-free are fronted by prominent LIA moraines, which testifies to the significance of this cooling event and of the subsequent warming that has accelerated in the last century (Werner, 1993).
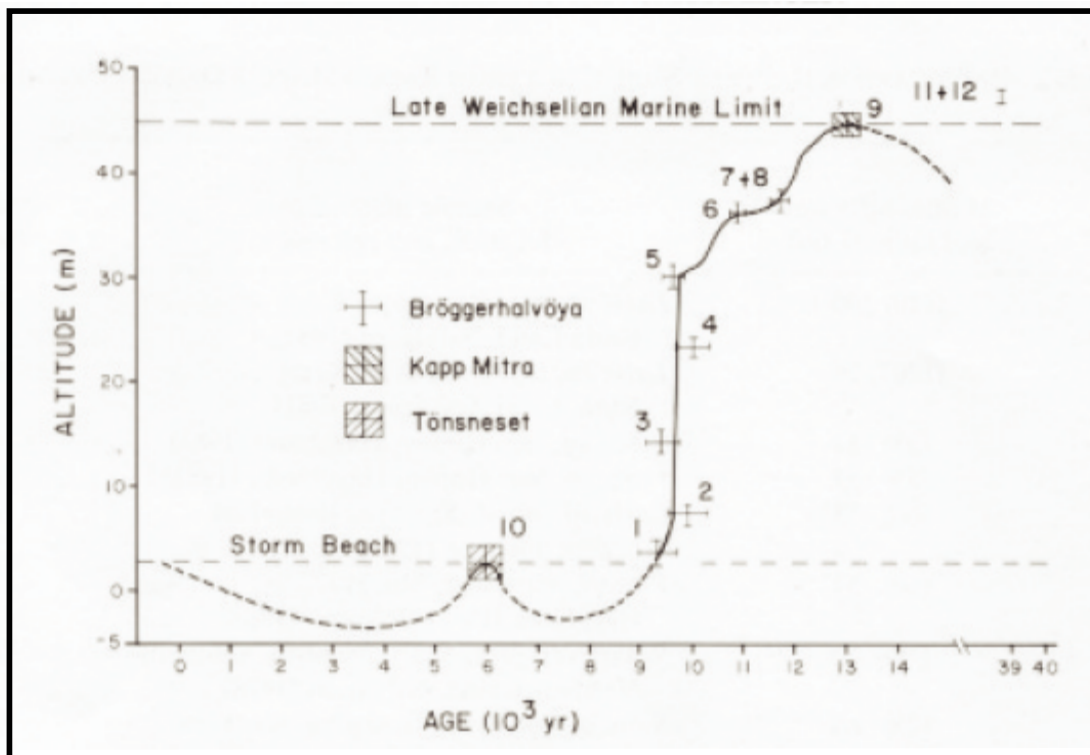
Figure 3. Late Weichselian and Holocene sea level curve for Brögger-halvöya, Spitsbergen. Linnédalen is approximately 100km south of Brögger-halvöya and has a similar sea level record, recorded by marine terraces on Kapp Linné and in the valley. Numbers refer to radiocarbon dates, explained in the original article. From Forman et al., 1987.

Linnébreen, the largest glacier in the valley, erodes exclusively the sandstone and coal formation. Additionally, four cirques are located on the west side of the valley in the phyllite rocks and two cirques are located on the east side of the valley in the carbonate rocks (Figure 2). These cirques probably contain only small patches of dead ice. Linnébreen has been retreating rapidly: aerial photos from 1936 show the glacier against the LIA moraine, while today, 69 years later, the glacier front is almost 2km back from the LIA moraine. Vertical ablation from April 14, 2004 to September 14, 2004 was measured to be at a rate of 1.2cm per day (C. Schiff, personal communication, 2005).

1.5. Bathymetry of Linnévatnet

Linnévatnet contains three main basins (Figure 4). The smaller basins in the southeast and southwest corners of the lake are both 15m deep and are separated by a bathymetric high. The southeastern basin is fed directly by the main inflow, Linnéelva. The southwestern basin is fed by a cirque stream that erodes solely the phyllite source rock. This basin does not receive much sediment from the main inflow because of the bathymetric high and because of the counterclockwise sense of circulation that transports sediments from the inflow along the eastern side of the lake (Svendsen et al., 1989). The large northern basin, 37m deep, is distal from the two major inlets.

Linnévatnet is a cold monomictic lake, maintaining a temperature below 4°C throughout the year (Bøyum and Kjensmo, 1978). The residence time of water in Linnévatnet influences sediment deposition in the lake: more fine sediment is deposited by water that stays in the lake longer. The shape and size of the lake basin, however, indicates that at least 95% of the sediment that is carried into the lake is deposited

8
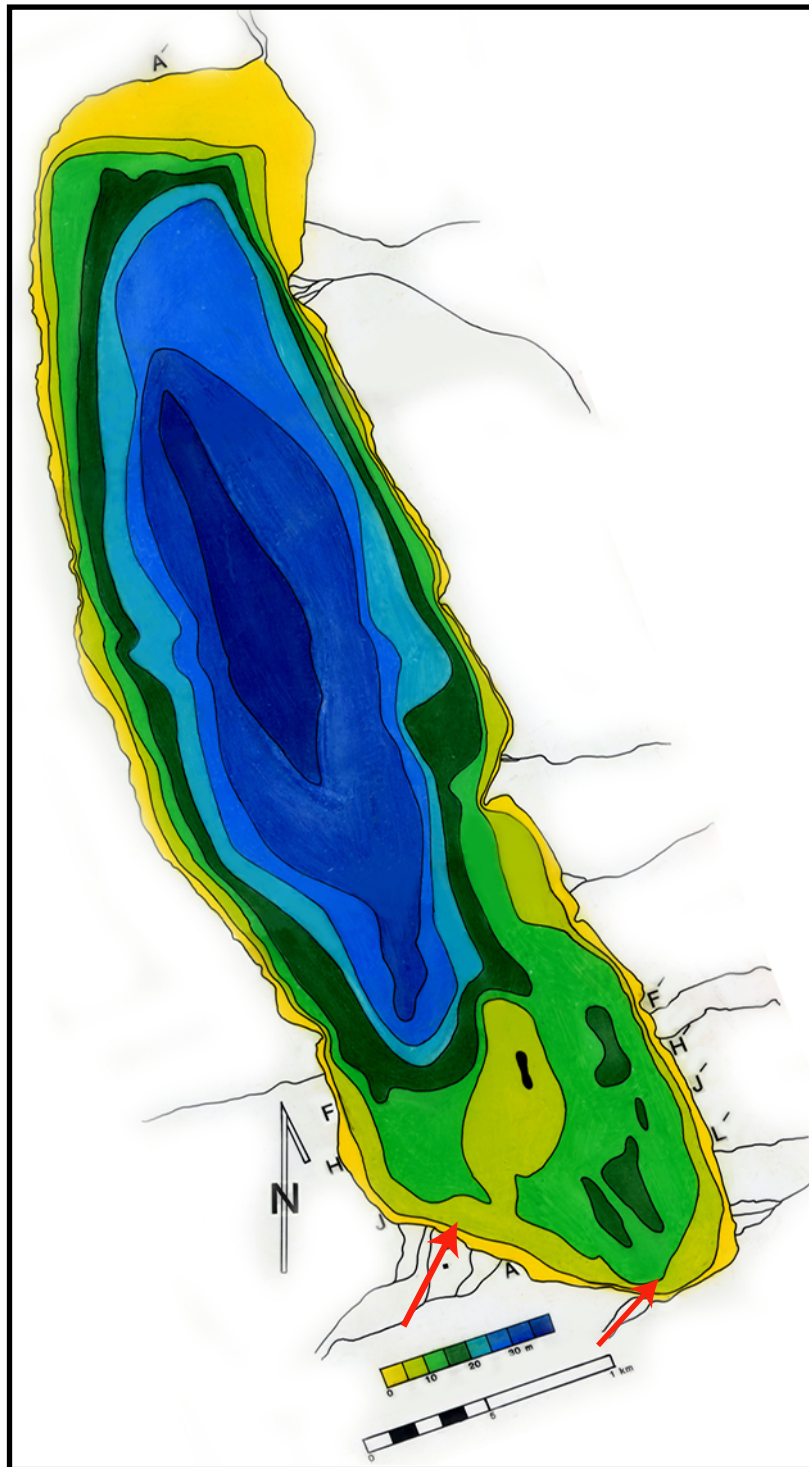
Figure 4. Bathymetric Map of Linnévatnet. The 15m deep south basins are fed by the two inflow streams (red arrows), while the 35m deep north basin is not fed directly by any major inflows. Adapted from Werner, 1988.

(Svendsen et al., 1989). Based on sediment trap data gathered in July and August 2004 it is likely that the spring melt is characterized by rapid sedimentation of coarse (up to medium sand) material, while the summer, fall and winter are characterized by decreasing sedimentation rates of fine (clay and silt) material (N. McKay, personal communication, 2005).

1.6. Sediment sources to Linnévatnet

Volumetrically, the majority of the sediment deposited in Linnévatnet is associated with fluvial transport by Linnéelva, the main inflow stream. In the upper parts of the watershed, streams are incised up to 1m through fluvial sediment and till. Streams exiting from each side valley cirque cut through the large LIA moraines, which are several tens of meters high. There is no soil in the valley and the scant vegetation, moss and herbs, do little to hold sediment in place.

During late July and early August 2004, Linnéelva discharge was measured daily at a site 1km upstream from the inflow mouth using a Swoffer current flow meter. A stage-discharge relationship was developed using these measurements. Stream stage was measured with a level logger 1km upstream from this gauging site. Ten-minute discharges were calculated from the stage measurements using the stage-discharge relationship. Because no discharge was measured for a stage value greater than 1.3m, the stage-discharge relationship is unreliable for stages greater than 1.3m. Reliable discharge values ranged from 0.8 to 13.1 m^3/s (Figure 5, solid line). The peak discharge, estimated from the stage-discharge relationship despite unreliability, was 31.1 m^3/s (Figure 5, dotted line). Suspended sediment concentrations, measured in samples collected daily at
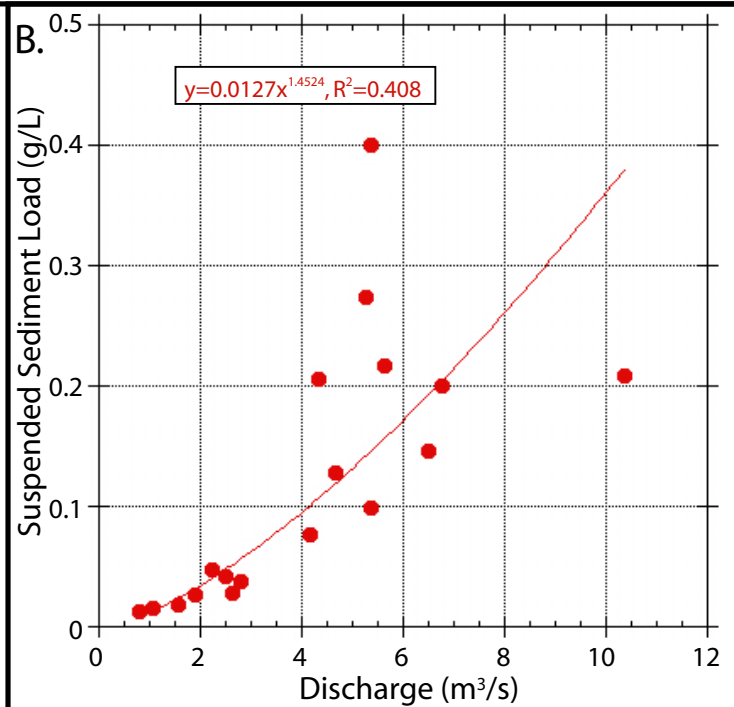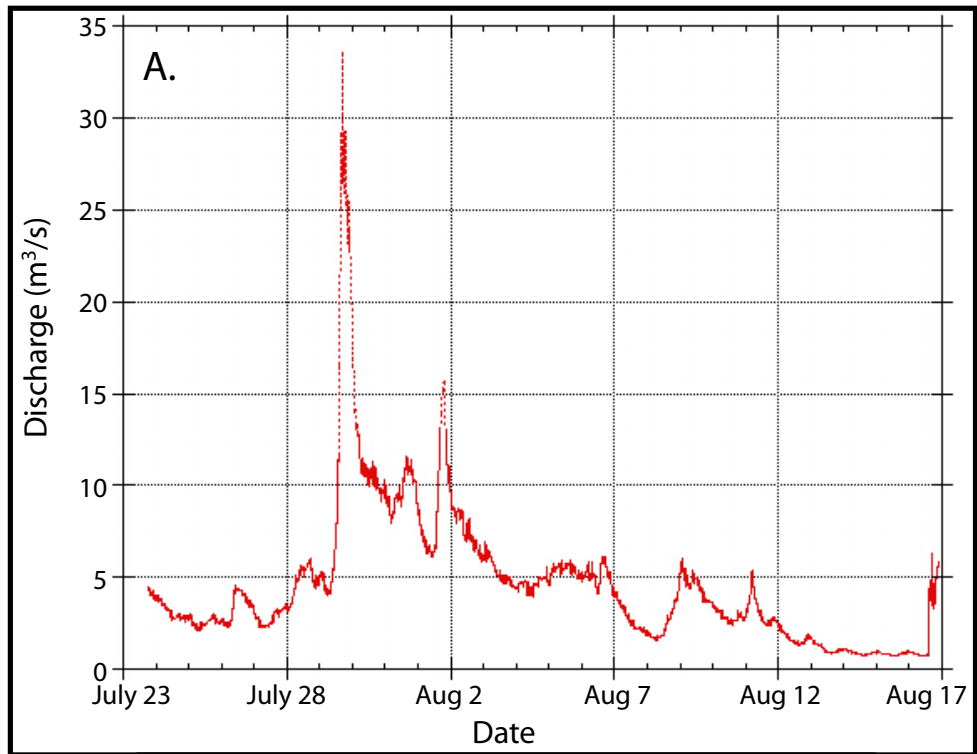
Figure 5. A. 10-minute discharge of Linnéelva calculated from measured stage based on stage-discharge relationship. Solid line shows discharge within measured range, dotted line shows discharge outside of measured range. B. Discharge versus sediment load for Linnéelva.

the mouth of the inflow stream, varied from 0.013g/l to 0.400g/l (Figure 5). Both discharge and suspended sediment concentration increased during rain and glacial melt events, and as a result sediment flux to the lake increased.

The glaciers in the side valley cirques have also been retreating since the LIA, to the point where some have completely disappeared. The glaciers release fine-grained sediment into Linnéelva. Because the glaciers are today in negative mass balance, previous work suggests that they release less sediment into Linnéelva than they did during the LIA, when they were advancing and at their maximum point (Svendsen and Mangerud, 1992; Menzies, 2002). Meltwater and sediment from thick accumulations of avalanching snow are also fed directly into Linnévatnet from a cirque located in the phyllite mountains, proximal to the southwestern end of the lake (Figure 2). Waves and runoff erode fine sediments from the marine terraces located throughout the valley. Finally, springs with very small discharges (they were only seeps during the 2004 field season) issue from the carbonate rocks on the east side of the valley and supply water and dissolved ions to the lake but do not appear to transport significant quantities of clastic sediment.

In addition to these fluvial sources, colluvial processes such as landslides and avalanches carry some sediment to the lake. Furthermore, wind may carry a minor amount of sediment into Linnédalen. The climate in this area is quite wet, however, and therefore aeolian sediment is probably a minor depositional factor compared to erosion and weathering by ice and water. For this study, streams were considered to be the major source of sediment to Linnévatnet.

1.7. Previous research

1.7.1. Sediment provenance studies

Provenance studies have been used to determine the origin and relative contributions of sediments in drainage basins (Kelley et al., 2002; Miller, et al., 2003). Provenance studies have also been used to determine changing lake levels (Vital and Stattegger, 2000), to decipher paleoclimate and tectonic setting of source rocks (Nesbitt and Young, 1982; Bhatia, 1983; Floyd et al., 1989; Das and Haake, 2003) and to track changing anthropogenic influences on lake sediments (Lord et al., 2001; Jonathan et al., 2004; Miller et al., 2003). In glaciated areas, provenance studies have been used to explore for ore deposits (Klassen, 2003) and to date glacial advances and retreats (Passchier, 2004).

Documenting mineralogy, including heavy mineral counts, of samples from a drainage basin is a method often used to determine provenance (Hussain, et al., 2004; Yu et al., 1997). Other methods utilized to determine provenance include pebble counts (Frisch et al., 1997), isotope ratios (Frumkin and Stein, 2004; Schwartz and Gromet, 2004) and magnetic susceptibility (Hoogakker, 2004; Vlag, 2004). The method that is most widely used to determine provenance is the examination of major and trace element geochemistry (Passchier, 2004; Das and Haake, 2003; Kelley, et al., 2002; Jonathan, et al., 2002; Vital and Stattegger, 2000; Floyd et al., 1989; Argast and Donnelly, 1987; Bhatia, 1983; Nesbitt and Young, 1982). Some of these studies (Jonathan et al., 2004; Passchier, 2004) also used carbonate content to aid in their determination of provenance.

In her study of provenance in the Transantarctic Mountains, Sandra Passchier evaluated the major and trace element geochemistry of glacially deposited sediments

(2004). Knowing that some of the source rocks in her study contained carbonate material, she also determined the percent carbonate contained within each sample. She used these data, coupled with grain size data, to identify geochemically unique sediments in the area. She interpreted these sediments as having been derived from different, identifiable source areas based on their unique geochemical fingerprints. Her results allowed her to determine the chronology of glacial advance and retreat in that part of the Transantarctic Mountains.

1.7.2. Sediment provenance studies in Linnédalen

Linnédalen lends itself to provenance studies because the three distinct rock types in the valley should theoretically also be geochemically distinct. Previous analysis of cores taken from Linnévatnet demonstrated that weight percent organic carbon and carbonate varied inversely throughout the Holocene (Svendsen et al., 1989; Werner, 1988). These variations were interpreted to be an indication of changing source contribution as the glaciers in Linnédalen grew and disappeared throughout the Holocene. Organic carbon in the lake sediments is derived from coal in the glacially-eroded sandstone/coal formation while carbonate is derived from side valley alluviation of the carbonate rocks (Svendsen and Mangerud, 1992; Svendsen et al., 1989; Werner, 1988). Caution must be taken, however, when concluding that sediment carbonate content accurately represents input from the carbonate rocks on the eastern side of the valley. Carbonate has been found to be easily dissolved into the stream and lake water, where it is carried through the lake and out to Isfjord, leaving little carbonate material in the lake sediments (Bøyum and Kjensmo, 1978). Using this model of source contribution, lake

sediment layers with high organic carbon content and low carbonate content were interpreted as glacial periods, while high carbonate and low organic carbon content in the early Holocene was interpreted to represent glacier free conditions. Layers with high organic carbon content were shown to correspond with periods of rapid sedimentation in the lake, whereas layers with high carbonate content were shown to correspond with periods of less sedimentation (Snyder et al., 2000). This increase in sedimentation further supports the hypothesis that glacial erosion of the coal formation resulted in these organic carbon-rich layers (Svendsen et al., 1989).

This project builds on the aforementioned studies and uses organic carbon and carbonate content as well as major and minor element geochemistry of sediments collected from around the valley to determine distinct fingerprints for each source rock type. These geochemical tracers are used to determine the relative contributions of these source areas to the sediments in Linnévatnet. Future studies in Linnédalen can use this information to document and interpret geochemical changes found in lake cores.

2. Field Methods

2.1. Primary source sediment collection

Aerial photographs and field surveys were used to identify the principal sediment source streams and sediment sample collection locations (Figure 6). Each stream grab sample was assumed to be a homogenous representation of the material from the entire subcatchment, as in Kelley et al. (2002). To avoid mixing between source areas, source samples were collected above tributary confluences. In each source stream, samples were collected from an area of exposed sediment within or adjacent to the flowing water,
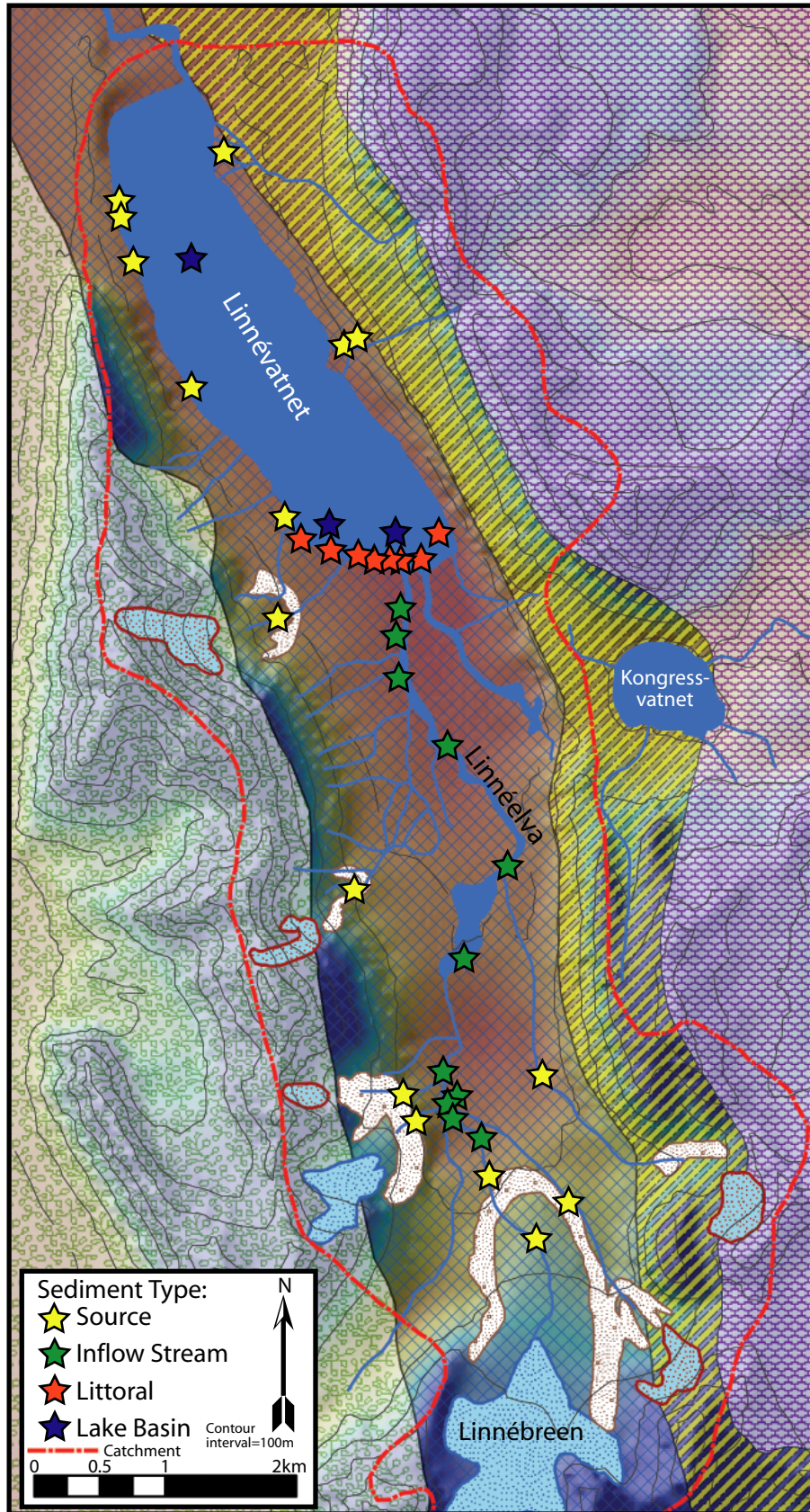
Figure 6. Sample location map for Linnédalen. Geologic units are shown.

16

usually on small sand bars or in the lee of boulders. In all cases an attempt was made to collect 200-400mL of the finest size fraction possible. In reality, however, the collected samples contained a range of particle size from clay to sand and sometimes gravel.

2.2. Source sample collection from around Linnévatnet

In addition to the source stream samples, source sediments were collected along the east and west shores of the lake. Marine terraces surrounding the lake are unlithified and could therefore be a significant source of sediment to the lake. There are two alluvial fans composed of coarse carbonate material along the eastern shore of the lake. During our month in Linnédalen, there was very little water flowing over these fans and into the lake. The fine sediment along the west shore and along the edge of the eastern alluvial fans is not carried by an inflow stream into the lake basin during the summer. The sediment was observed, however, being washed by wave action from beneath the gravel and boulders. Thus, although the sediment input from the sides of the valley seem to be relatively minor with respect to the main river inflows, under the right conditions (i.e., spring melt and high wave regimes) these areas could be more significant sediment sources. These lake shore source samples were gathered by digging beneath the large boulders and the gravel at the surface down to the very fine mud beneath.

2.3. Inflow stream sediment collection

Linnéelva, the main inflow stream to Linnévatnet, begins at the glacier and flows 5km north to the lake. Along the way, Linnéelva is joined by several tributaries that drain source area subcatchments on both the east and west sides of the valley. Using the

methods for stream sediment collection stated above, sediments were collected along Linnéelva below the confluence of each tributary stream (Figure 6). This sampling strategy allows the relative contribution of each of the tributary streams to be examined.

2.4. Littoral sediment collection

In order to characterize the sediment arriving at the lake, samples were collected from the littoral zone (generally 1-2m water depth) along the south shore of Linnévatnet. An initial attempt to collect samples using a Universal Short Corer by Aquatic Research™ failed because the sediments were too coarse (mixed mud, sand and some gravel) to stay in the coring device when brought up to the surface. As a result, a scoop built out of a 1 liter Nalgene™ bottle with the top cut off, a 3m aluminum pole and duct tape proved more successful in retaining sediment. Sediment was collected with this scoop at 8 equally spaced locations, 150-200m apart (Figure 6).

2.5. Lake basin sediment collection

Sediment cores were collected in each of the three lake basins using a Universal Short Corer (Figure 6). The cores were subsampled at three intervals: one at the surface and two at regular intervals down the core. The sediments contained in the cores are much finer than sediments collected from streams or from the littoral zone. Sedimentation rates in the lake basins distal from the inflow streams range from 0.2mm/yr (average Holocene rate; Svendsen et al., 1989) to almost ten times that (measured from July 2003 to July 2004; N. McKay, personal communication, 2005). The top two centimeters could therefore represent a range of 10-100 years of sedimentation.

2.6. Sample location identification and storage

Each sample was placed in an appropriately labeled 1-quart plastic Ziploc™ bag. While collecting the samples, a differentially corrected GPS reading was taken at each sample site. The base station that was used for differential correction was located at the hut at the south end of the lake (UTM Zone 33X, WGS 84, E: 473115 N: 8661920). At three of the sample sites the GPS coordinates were uncorrected, and at a six of the sites the location was estimated based on topography. At the end of four weeks in the field, 38 source, inflow stream and lake samples had been collected. The samples were brought back to Smith College, where they were stored in the original bags until they were dried for analysis. Appendix 1 lists the samples collected, along with the collection method, GPS location, and GPS correction method.

3. Laboratory Methods

3.1. Loss on ignition

Aliquots of the powder were also taken for loss on ignition (LOI) analysis. Porcelain crucibles were dried overnight in a furnace at 150°C. After cooling in a desiccator, they were weighed (W_{cruc}). Approximately one gram of the sample was placed in the crucible and returned to the oven to dry overnight. After cooling in a desiccator, they were weighed (W_{dry}). The crucibles were then placed in the furnace at 550°C for 2.5 hours (Heiri et al., 2001). Subsequent to heating, they were cooled in a desiccator and weighed (W_{550}). The percent weight lost at 550°C was calculated: $LOI_{550°C} = (W_{dry}-W_{550})/(W_{dry}-W_{cruc})*100$. Finally, the crucibles were placed in the

furnace at 950°C for 2 hours (Heiri et al., 2001). Subsequent to heating, they were cooled in a desiccator and weighed (W_{950}). The percent weight lost at 950°C was calculated: $LOI_{950°C} = (W_{550}-W_{950})/(W_{dry}-W_{cruc})*100$.

Each of seven samples was split and run in triplicate so that analytical error could be estimated. With the help of Professor Katherine Halvorsen, the standard error and its estimated degrees of freedom (2.928) were computed using a method proposed by Cochran (1954). The t-distribution was used to compute the within sample error: ±0.719%. This method assumes normal distribution of the data. These data are not, however, normally distributed. An outlier on one analysis in particular makes this assumption questionable. Therefore, a robust calculation of error (a calculation unaffected by outliers) based on the median of the within-sample standard deviations was determined: ±0.563%. This is used as an estimate of the analytical repeatability for the loss on ignition analysis.

3.2. X-Ray fluorescence

A portion (50-100ml) of each sample was dried at 60°C overnight and crushed to about 100-200 mesh in a Spex tungsten carbide shatterbox. 15g aliquots of the powder were taken for X-ray fluorescence analysis (XRF). The major element abundance (SiO_2, Al_2O_3, TiO_2, Fe_2O_3, CaO, MgO, MnO, NaO, K_2O, P_2O_5) was measured on fused La-bearing lithium borate glass discs in a Siemens MRS-400 spectrometer following the method described in Rhodes (1996). All samples were analyzed in duplicate. The trace elements Rb, Sr, Ba, La, Ce, Nb, Zr, Y, Pb, Zn, Ga, Ni, Cr and V were also measured using XRF. These were measured on pressed powder pellets using a Philips PW2400

sequential spectrometer as described in Rhodes and Vollinger (2004). These data differ in accuracy depending on the element being measured. The relative abundances of the elements, however, are considered comparable. The standard deviation for the major elements ranges from ±0.001 weight percent for MnO and P_2O_5 to ±0.06 weight percent for Na_2O. The standard deviation for the trace elements ranges from ±0.08 ppm for Rb to ±2.59 ppm for La. Detailed estimates of the precision and accuracy of the measurements for each element are given in Rhodes (1996) and Rhodes and Vollinger (2004).

4. Results

4.1. Loss on ignition

The results of the loss on ignition (LOI) analyses at 550ºC and at 950ºC are listed in Appendix 2. Both $LOI_{550°C}$ and $LOI_{950°C}$ are measures of the weight lost relative to the dry weight of the sample (see calculations in Laboratory Methods section). Following the recommendations by Smith (2003) and Heiri et al. (2001), $LOI_{550°C}$ can be used to estimate the amount of organic carbon in the sample. $LOI_{550°C}$ is also a measure of the loss of volatile salts and structural water in phyllosilicate minerals contained in the sample (Heiri et al., 2001). Because of these confounding factors, Heiri et al. (2001) caution that "small differences in LOI of sediments should not be over-interpreted". $LOI_{950°C}$ can be used to estimate the amount of carbonate in the sample (Smith, 2003; Heiri et al., 2001).

$LOI_{550°C}$ in the source samples ranged between 1.44 weight percent in the phyllite source and 4.62 weight percent in the sandstone source (Figure 7). $LOI_{950°C}$ in the source samples was the least in the southern west shore and the sandstone sources (0.7 and 0.91

Figure 7: Loss on ignition plots showing percent weight lost at 550°C and 950°C. Organic carbon rich sediment is found near the glacier (sandstone source), in the basins (core samples), in two of the near-shore samples and along the west shore. Inorganic carbon rich sediment is found at the carbonate source areas and at one point along the inflow stream where a carbonate-eroding tributary enters. Error bars represent one standard deviation.

weight percent, respectively) and was the greatest in the east shore and carbonate sources (20.15 and 16.06 weight percent, respectively; Figure 7). The phyllite and northern west shore source areas had an intermediate $LOI_{950°C}$, 3.87 and 4.61 weight percent respectively (Figure 7). These two source areas probably had a greater $LOI_{950°C}$ than the sandstone source because the phyllite parent material is cemented by carbonate in places, whereas the sandstone contains no carbonate.

$LOI_{550°C}$ was greater in the lake basin sediments than in the sandstone source (Figure 7). Along the inflow stream, $LOI_{550°C}$ was intermediate in samples E4, E8 and E10 and high in E6 in E12. Similar ambiguous results were observed in the littoral sediments. $LOI_{550°C}$ was high in L1 and L4, but low to intermediate in L2, L3 and L5-L8 (Figure 7). $LOI_{950°C}$ was high in E8, where a carbonate tributary entered Linnéelva. $LOI_{950°C}$ was below 4 weight percent for all of the littoral sediments (Figure 7). $LOI_{950°C}$ for the lake basin sediments ranged from 1.7 weight percent in the middle of core G (north basin, distal from main inflows) to 5 weight percent in the top of core C (southeast basin, fed by the main inflow; Figure 7).

4.2. X-Ray fluorescence

Up to four samples were analyzed for each source rock type or source area. Rollinson (1993) warns against using the arithmetic mean and the standard deviation as a method of averaging and determining the spread of geochemical data. Instead, he recommends using a robust estimate (one not affected by outliers) of average values, as described in Rock (1987). Following these recommendations, I calculated the median and the range as the robust estimate of average values for the source area data. These

values are displayed in Appendix 3. In contrast, the results for the inflow stream, shallow lake and lake basin sediments were not statistically manipulated and are listed individually.

4.2.1. Source compositions

The source compositions are determined from stream sediment samples collected in representative catchments. The median bulk compositions and trace element concentrations of these samples are illustrated in Figures 8 and 9. Elements that are significantly more concentrated in one source than in the other two may be valuable for fingerprinting that source.

4.2.1.a. Principal source areas

The carbonate source sediment contains 58 weight percent silica (Figure 8). When compared to other source samples, this source has the highest concentrations of calcium and magnesium oxides (20 and 6 weight percent, respectively). The carbonate source also has a high concentration of strontium (122ppm), 2.5 times greater than in the phyllite and the sandstone sources (Figure 9).

The sandstone source sediment has the highest source concentration of silica, 87 weight percent (Figure 8). This source also has high concentrations of zirconium, 505ppm and yttrium, 30ppm (Figure 9). Both of these elements are 1.3 times more concentrated in the sandstone than in the carbonate and the phyllite.

The phyllite source sediment has a silica concentration of 71 weight percent (Figure 8). When compared to the carbonate and the sandstone, the phyllite has the
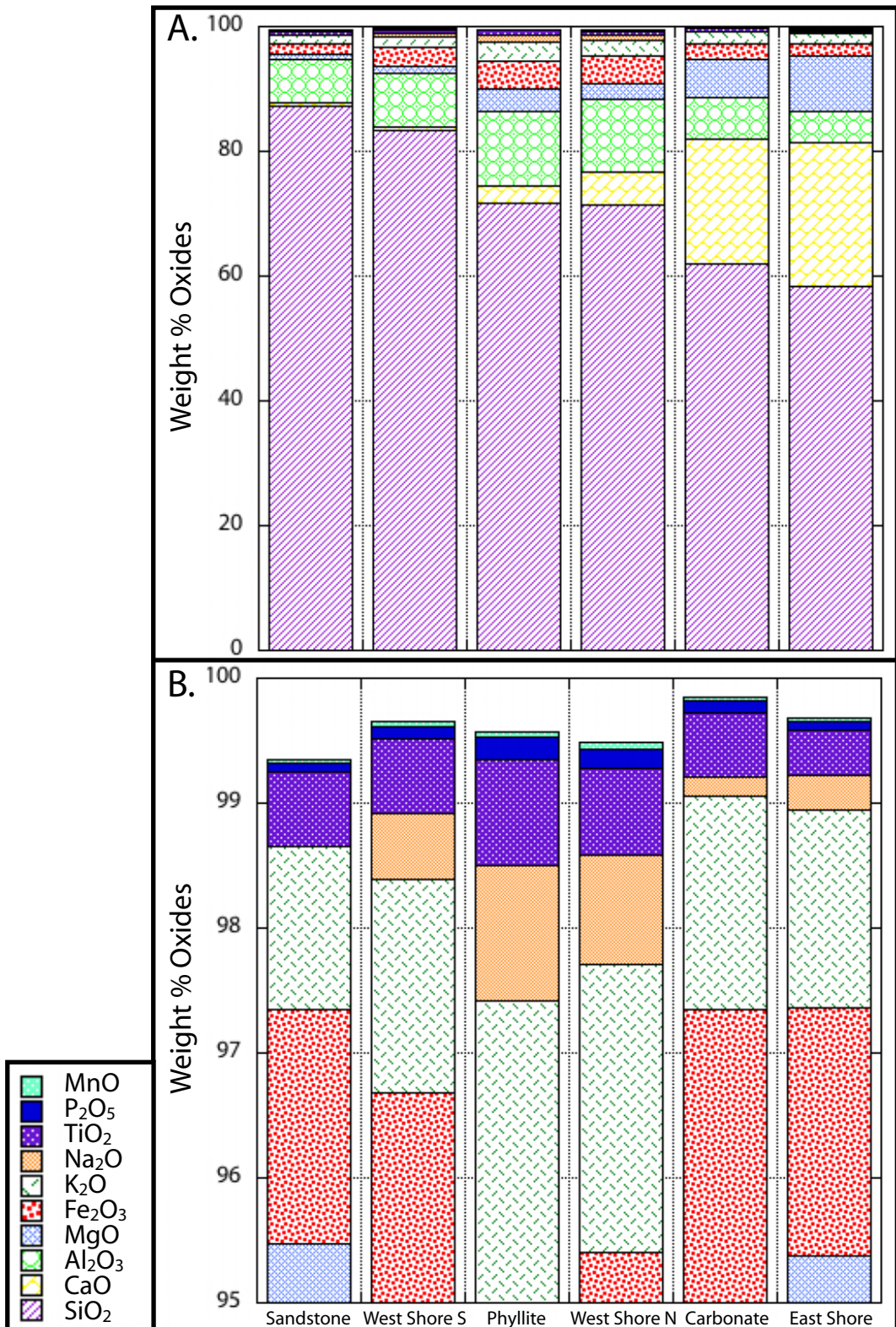
Figure 8. Major element composition of the source areas. A. Total composition of source samples. B. Scale showing top 5% of A. Bulk composition does not total to 100% because the data presented are the medians of two to four sample analyses, and the range within each element was between 0.012 weight percent for manganese and 5.4 weight percent for aluminum.
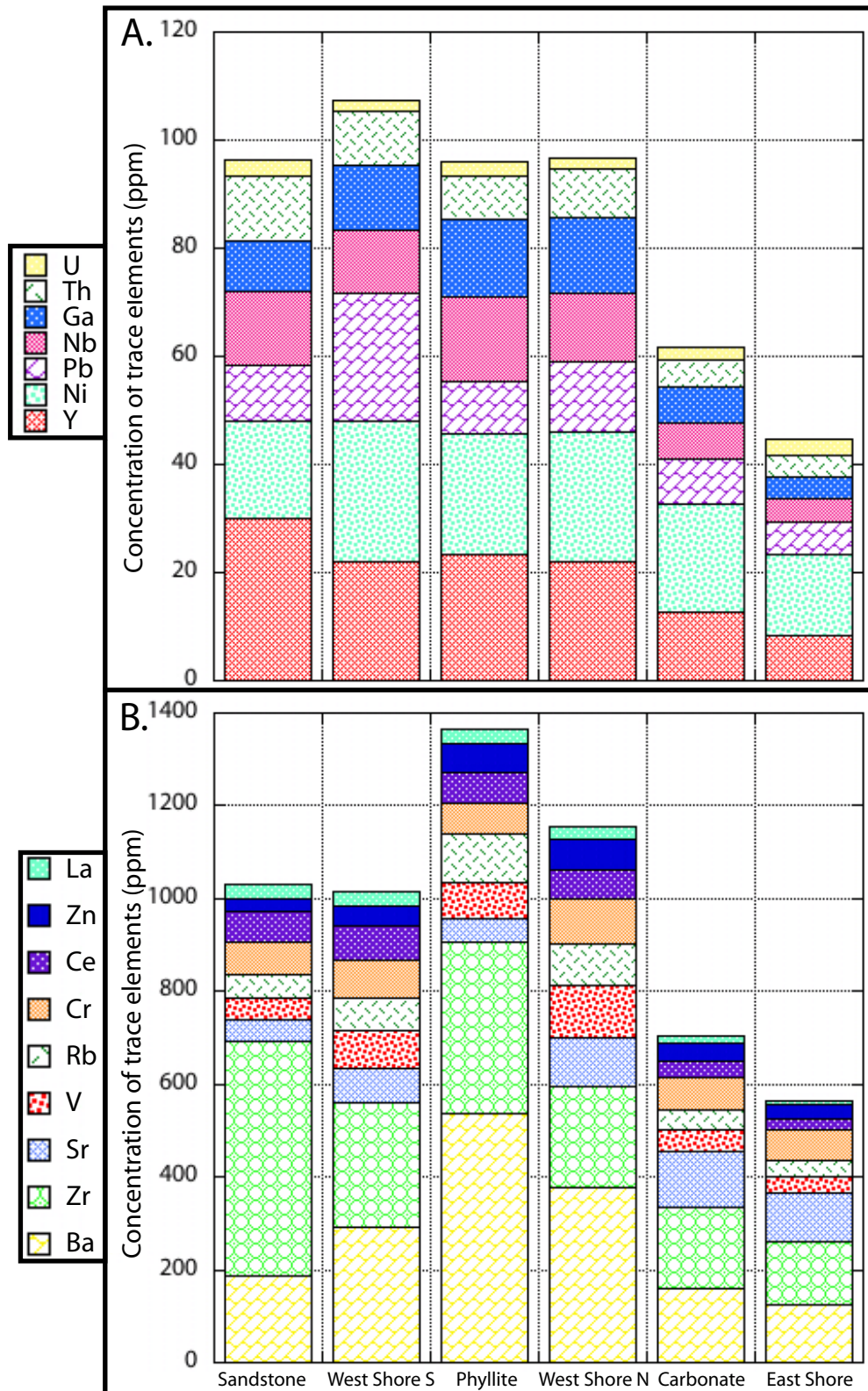
Figure 9. Trace element composition of source sediments. A. Trace elements with concentrations less than 30ppm. B. Trace elements with concentrations greater than 30ppm. Median values (two to four sample analyses) shown. Range varies from 1ppm in uranium to 226ppm in zirconium.

highest concentrations of aluminum, iron, potassium, sodium, titanium, phosphorous and manganese oxides (12, 4, 3, 1, 0.8, 0.2 and 0.04 weight percent, respectively; Figure 8). The phyllite contains 535ppm barium, 2.5 times more than the sandstone and the carbonate sources. Rubidium (103ppm) and zinc (65ppm) are 2 times more concentrated in they phyllite than in the other two sources (Figure 9).

4.2.1.b. Other source areas

The sample taken from the alluvial fan on the eastern shore of Linnévatnet has slightly less silica and slightly more calcium and magnesium than the carbonate source (Figure 8, "East Shore"). Otherwise, this source has slightly lower concentrations of the other major elements and significantly lower concentrations of trace elements than the carbonate source (Figures 8 and 9). The large difference in trace element composition between these two source areas suggests that some factor, such as marine terrace sediment, is influencing the composition of the east shore sediments.

The samples taken from the northwestern shore of Linnévatnet have a silica content almost identical to that of the phyllite source (Figure 8, "West Shore N"). These samples also have similar aluminum, iron, manganese and phosphorous oxide contents as the phyllite source (Figure 8). The northwestern shore samples also differ in composition from the phyllite source. There is less potassium and magnesium but twice as much calcium in the northwestern shore samples than in the phyllite (Figure 8). The trace element concentrations also differ between these source sediments. There is less barium, zirconium, rubidium and niobium in the northwestern shore sediments than in the phyllite (Figure 9). Vanadium, strontium, chromium and lead are more concentrated in

27

this source than in the phyllite source (Figure 9). Based on their silica, aluminum, iron, manganese and phosphorous content, these source areas are similar. The concentrations of other major and trace elements, however, suggest that there are significant compositional differences between these two source areas.

The samples collected from the southwestern shore of Linnévatnet have a slightly lower silica content than the sandstone source (Figure 8, "West Shore S"). These samples also have higher concentrations of aluminum, iron, potassium, magnesium and sodium than the sandstone source, probably due to the fact that these elements are not diluted by as much silica (Figure 8). The southwestern shore samples also have higher concentrations of most of the trace elements (vanadium, strontium, chromium, lead, nickel, zinc, rubidium, and barium) than the sandstone source (Figure 9). The southwestern shore and sandstone source areas appear to be similar based on their silica content. Like with the phyllite and northwestern shore sources, there are significant differences between their compositions.

The above evidence suggests that there is a factor besides one of the three main source rocks (e.g., mixing between sources, or the addition by a fourth source area) that is causing higher concentrations of trace elements in the sediments on the western shore of Linnévatnet. The phyllite mountains that flank the northwestern shore of Linnévatnet and ridges of the sandstone that outcrop along the southwestern corner of the lake are probably contributing a large amount of sediment to the shore sediments. The unlithified marine terraces may be causing measurable compositional differences between the principal source areas and the shore sediments. Samples were not taken directly from the marine terraces, so the geochemical composition of this source area is not known.

4.2.2. Spider diagrams: Multiple elements plotted for a single sample

Normalized multi-element diagrams are a useful method for comparing the bulk and trace element geochemistry of two samples. The elemental concentrations of a given lake or stream sediment are normalized to the corresponding concentrations in each of the source areas. These values are then expressed as the logarithm to the base 10 of the value and plotted on normalized multi-element diagrams, also known as spider diagrams (Rollinson, 1993). If the normalized result falls at unity (one), then the lake or stream sediment is similar to that source sediment. If, however, the result is variable and does not fall at unity, then that given sample is not similar to a single source sediment and other factors must have been involved in the transport and deposition of that sediment (i.e., source sediment mixing, fractionation by grain size and dissolution of minerals into the water column).

4.2.2.a Lake sediments

Sediments collected from the tops of the three cores do not fall at unity when normalized to any individual source sediment (Figure 10A-C). This indicates that lake basin sediment composition is not dominated by any one of the sources. Instead, lake basin sediment is a result of source sediment mixing and of other weathering and transport processes that have altered its composition. Conversely, sample L6, a littoral sediment collected near the southwest corner of the lake, falls close to unity when normalized to the phyllite source and does not fall near unity when normalized to the
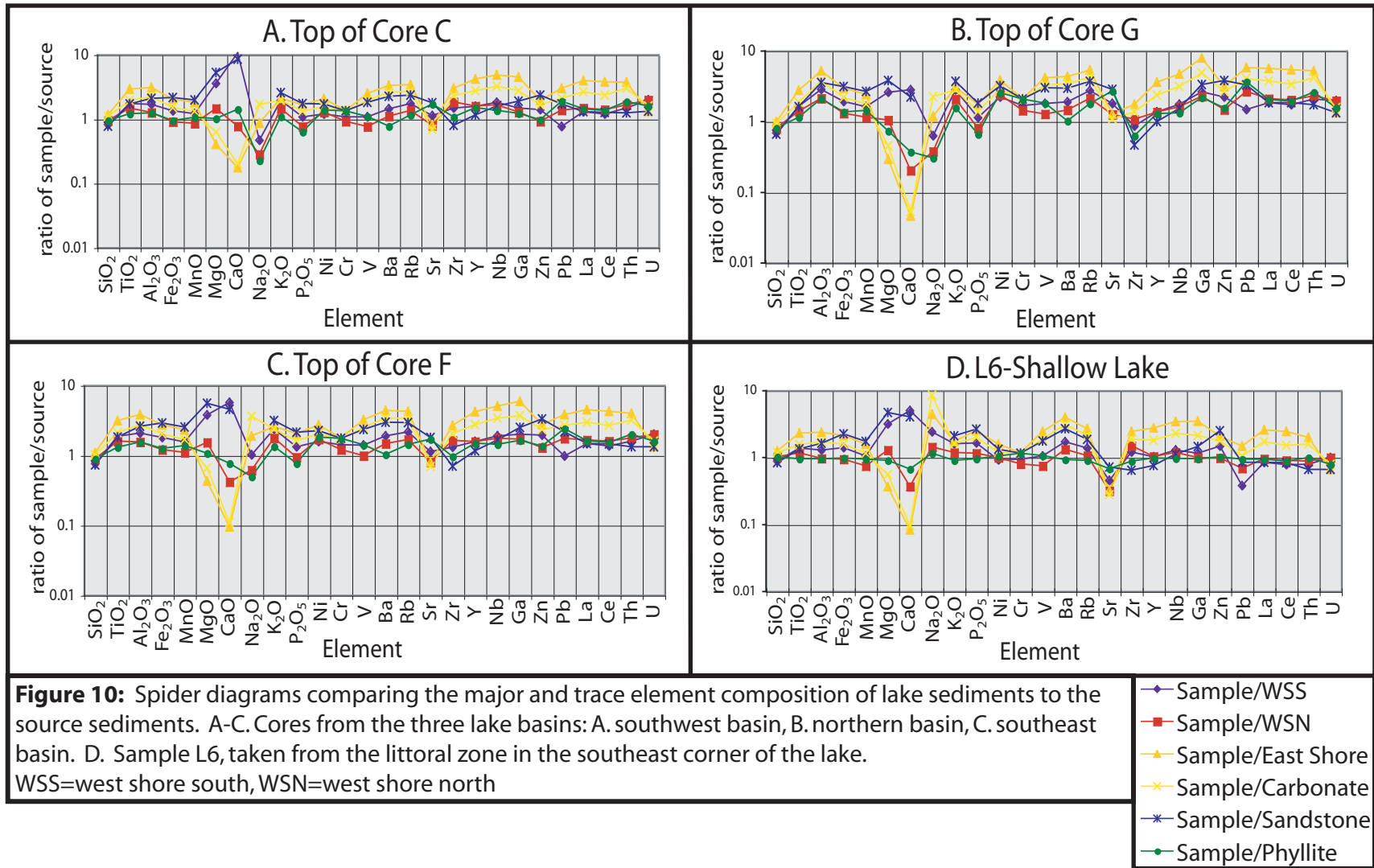
Figure 10: Spider diagrams comparing the major and trace element composition of lake sediments to the source sediments. A-C. Cores from the three lake basins: A. southwest basin, B. northern basin, C. southeast basin. D. Sample L6, taken from the littoral zone in the southeast corner of the lake. WSS=west shore south, WSN=west shore north

carbonate or the sandstone source (Figure 10D). This makes sense, as L6 was collected from a delta formed by a stream that drains the proximal cirque in the phyllite mountains.

4.2.2.b. Inflow stream sediments

When plotted on a spider diagram, samples E1, E4 and E6 from the inflow stream are nearly identical to the sandstone source (Figure 11A). Although E4 and E6 were collected below tributaries originating from the phyllite and the carbonate source rocks, the sandstone remained the dominant source of sediment in this part of the stream. Sample E8, collected further downstream below a tributary originating from the carbonate source, is still similar to the sandstone source, except that E8 has elevated concentrations of magnesium and calcium oxides (Figure 11B). Samples E10 and E12, collected close to the mouth of the inflow stream below a tributary that originates in the phyllite source, do not fall at unity when normalized to the source areas (Figure 11C, D). The normalized values for phyllite and sandstone for each of these samples are almost mirror images of each other, reflected through unity. This would imply that E10 and E12 are mixtures of the sandstone and the phyllite source areas, with little influence by the carbonate source.

Normalization by source sediments shows that, while some areas within the inflow stream and the lake are influenced by a single source, other areas are influenced by more than one source and by other erosional and depositional processes. Other methods must therefore be used to identify variations in geochemical composition and how these variations are influenced by different source sediments.

Figure 11. Spider diagrams comparing the major and trace element composition of stream sediments to the source sediments. Linear gradient along the inflow stream moving from the glacier (A.) downstream to the mouth of the inflow (D). Note the different scale in C.
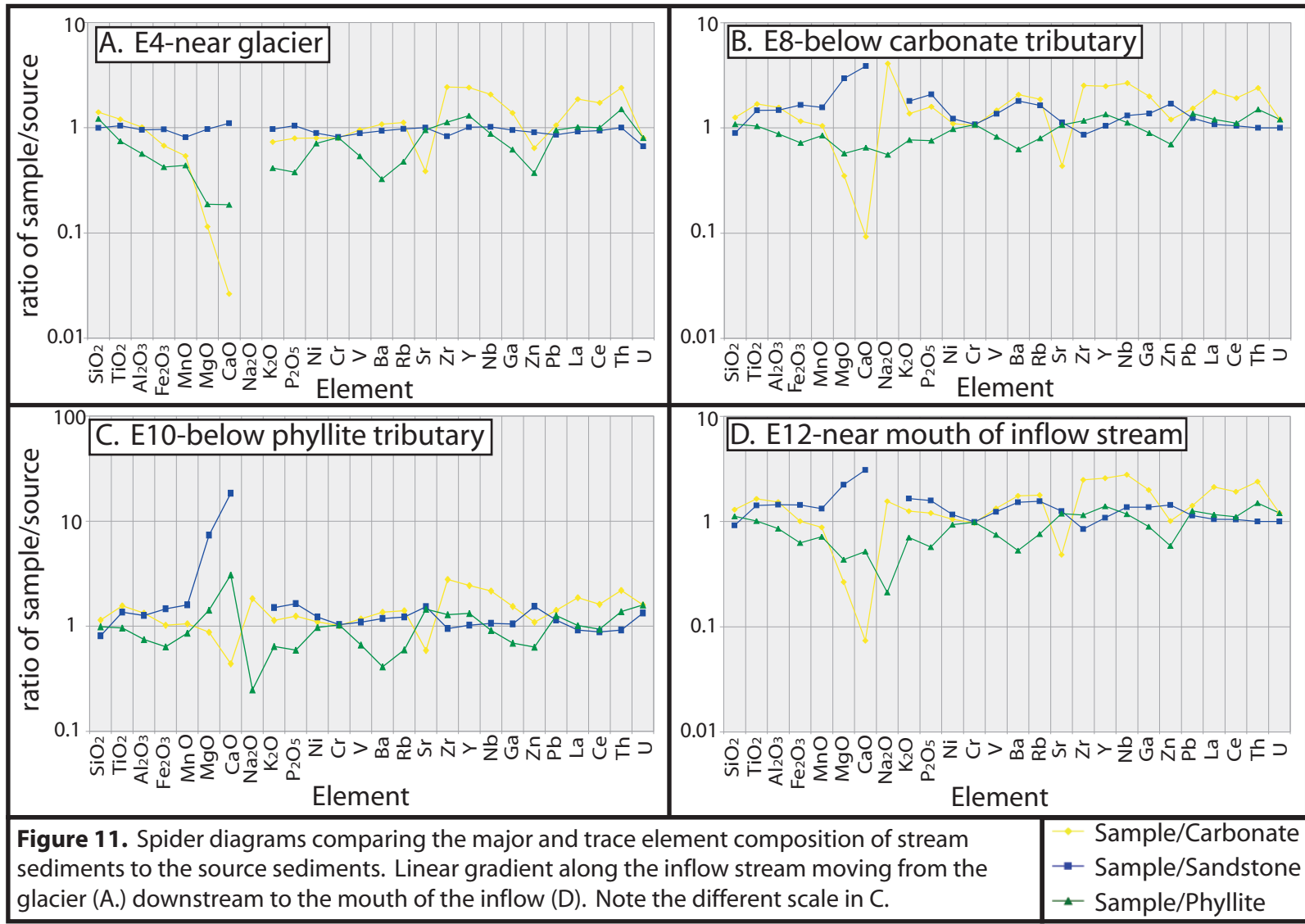
4.2.3. Bivariate plots: Two elements plotted for multiple samples

Bivariate plots are useful in illustrating interrelationships between elements and how composition varies among sources (Rollinson, 1993). Bivariate plots are also helpful in illustrating trends that occur along a linear gradient, such as along the inflow stream or along the southern shore of Linnévatnet. Furthermore, bivariate plots can illustrate mixing between two source sediments. If the composition of a lake sediment lies along a line drawn between two source sediments, this indicates that the two sources were mixed to form the lake sediment (Rollinson, 1993).

4.2.3.a. Inflow stream sediments

A bivariate plot was used to examine source sediment mixing along Linnéelva (Figure 12). The same trend that was discussed in the previous section is seen here: samples E1, E4 and E6 are indistinguishable from the sandstone source. Further downstream, however, where a tributary originating in the carbonate source enters Linnéelva, sample E8 reflects the influence of the carbonate sediment. E8 has a higher calcium and lower silica content relative to the sandstone source and the previous samples (Figure 12). Samples E10 and E12, collected below a tributary draining another cirque in the phyllite bedrock, have compositions that fall on a mixing line drawn between the sandstone and phyllite source compositions (Figure 12). This supports evidence seen in Figure 11 that E10 and E12 are a result of mixing sandstone and phyllite source sediments.
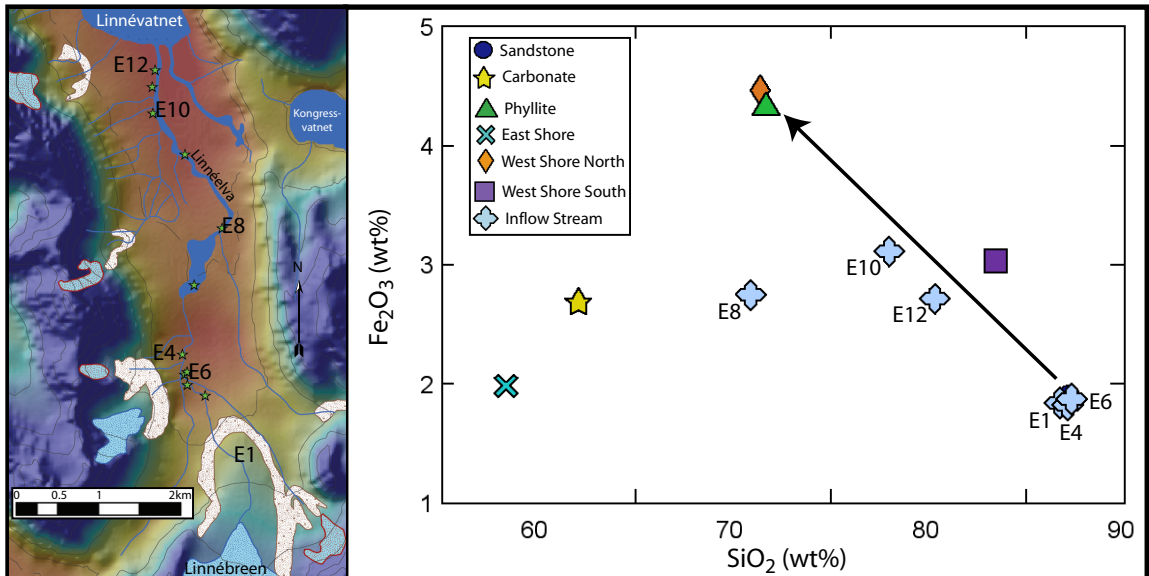
Figure 12: Source and inflow stream sediment silica versus iron weight percent. The arrow delineates a mixing line between the sandstone and the phyllite, and indicates the compositional direction in which the sediments tend to move from the glacier downstream to the lake. The map illustrates where each inflow stream sample was collected.
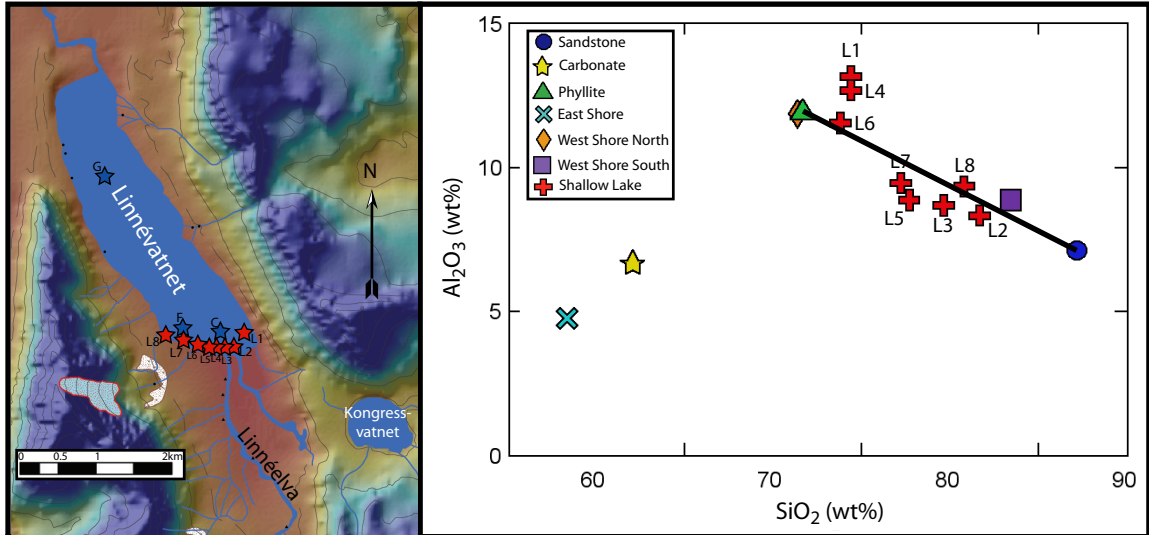
Figure 13: Source and shallow lake sediment silica versus aluminum weight percent. L1 is the easternmost sample collected, L8 is the westernmost. The shallow lake sediments lie along a mixing line between the sandstone and the phyllite source compositions. These sediments exhibit little influence by the carbonate source. L1 and L4 have slightly more aluminum than the phyllite source sediments. The map illustrates where each littoral and lake bain sample was collected.

4.2.3.b. Littoral sediments

Source sediment mixing in the littoral zone along the south shore of Linnévatnet was examined using bivariate plots (Figure 13). The compositions of the littoral sediments fall mainly along a mixing line drawn between the phyllite and the sandstone sources.

4.2.3.c. Lake basin sediments

Lake basin sediments contain lower silica content and higher aluminum content than the source sediments (Figure 14). The lake basin sediments also have higher concentrations of iron and potassium oxide (Figure 14). Figure 14 also includes a bivariate plot of silica versus nickel, a single example to illustrate the trend that most trace elements become more concentrated in the lake basins. Other trace elements that were more concentrated in the lake basins than in the source samples include chromium, vanadium, cerium, lanthanum, thorium, rubidium, gallium, zinc, lead, lanthanum and uranium. Although not illustrated in Figure 14, the lake basin sediments have lower concentrations of manganese, magnesium, calcium, phosphorous and sodium oxides than the source samples. The trace element zirconium is also found in lower concentrations in the lake basin sediments than in the sources. Because lake basin sediment composition rarely falls within the range of source sediment compositions, source and lake basin sediments cannot be directly compared and conclusions about relative contributions of source sediments to the lake basins cannot be made.

The geochemical composition of samples collected from different depths within the three cores varies between samples taken from the same core (Figure 15). The silica
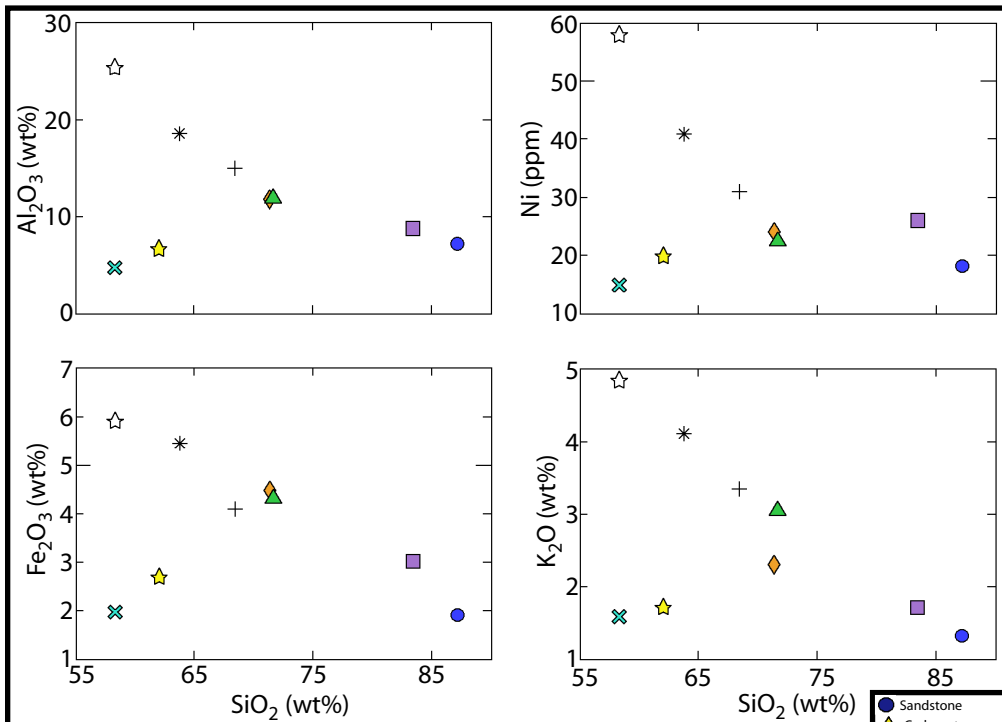
Figure 14: Silica versus aluminum, iron, potassium and nickel concentrations for source and lake basin sediments. Silica concentration is higher in the source areas than in the lake basins and aluminum, iron, potassium and nickel concentrations are higher in the lake basins. The other trace elements, except for zircon, follow the same pattern as nickel.

Legend:
- Sandstone
- Carbonate
- Phyllite
- East Shore
- West Shore North
- West Shore South
- Core C (SE basin)
- Core F (SW basin)
- Core G (N basin)
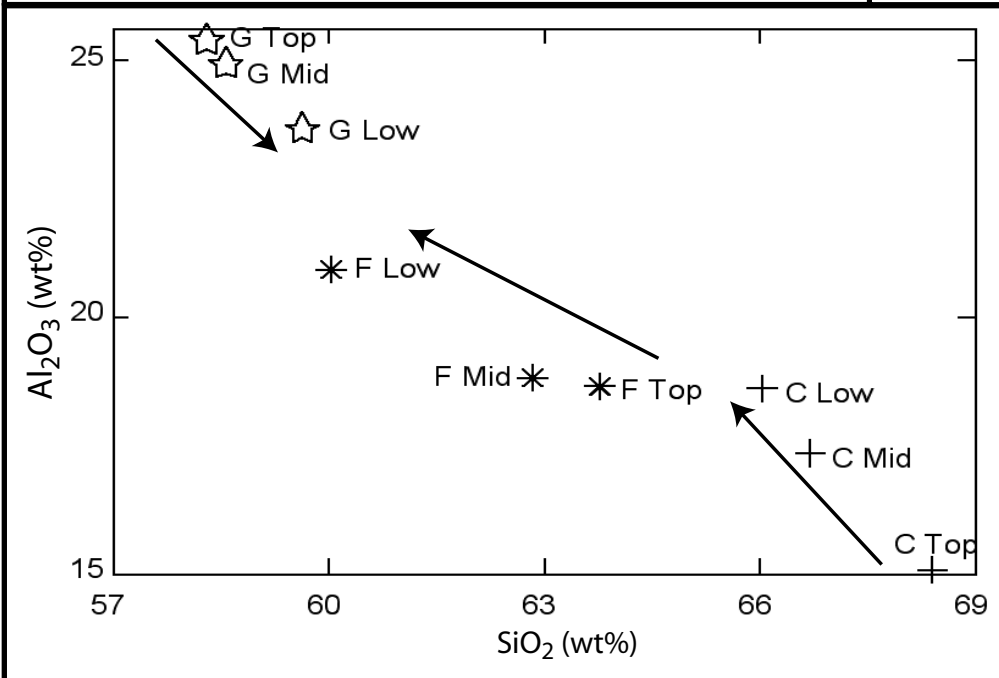
Figure 15: Silica versus aluminum composition of sediments collected from three different levels within the cores taken in the three basins in Linnévatnet. The arrows show trends from the top to the bottom of the cores, and thus show trends back in time.

36

content in cores C and F, taken from the 15m deep basins on the southeast and southwest corner of the lake, respectively, decreases from the top to the bottom. The aluminum content increases simultaneously in these cores (Figure 15). Core G, taken from the 37m deep northern basin manifests the opposite trends: the silica content increases from top to bottom as the aluminum content decreases. While these within-core variations were not explored extensively in this study, it is important to note that geochemical variations in the cores exist. Future studies can examine these variations more closely to determine relative source contributions, which can be interpreted to represent changes in climate and glacial conditions.

4.3. *Summary of results*

The sandstone and carbonate source sediments are distinguishable based on silica, calcium, organic carbon and carbonate contents (Figures 7 and 8). The phyllite source sediments have high concentrations of most of the major and the trace elements (Figures 8 and 9). Mixing, dissolution and dilution of these source sediments occurs along the inflow stream (Figures 11 and 12). Littoral sediments reflect the composition of the sediments carried by the inflow streams (Figures 10 and 13). The lake basin sediments have higher concentrations of aluminum and organic carbon and lower concentrations of silica and carbonate than the source sediments (Figures 7 and 14). The lake basin sediments also have higher concentrations of some trace elements than the source sediments (Figure 14). Finally, compositional differences between layers within cores were observed (Figure 15). These results are consistent with inflow stream sediment mixing and with predicted sediment distribution in the lake. Significant compositional

differences between lake basin and source sediments, however, make direct comparisons between these sediments difficult.

5. Discussion

5.1. *Composition of source sediments*

Source samples have geochemical attributes that allow for distinction between samples (Figures 8 and 9). This study identified (qualitatively) the geochemical fingerprint of each source area using spider and bivariate plots. It will be necessary to utilize statistical techniques, such as discriminant analysis (Vital and Stattegger, 2000) or factor analysis (Jonathan et al., 2004) in order to determine a specific quantitative fingerprint for each source area. Qualitative identification of source fingerprints is useful for identifying patterns of source sediment mixing along the inflow stream and in the lake.

5.2. *Stream and littoral sediments and mixing of sources*

Figures 10-13 illustrate that there are similarities between the source areas and sediments in Linnéelva and in the littoral zone of Linnévatnet. These figures also illustrate that there are variations in inflow stream and lake sediment geochemistry depending on location, source sediment flux and mixing. Inflow stream and shallow lake sediment compositional data can be used to determine the composition of the sediment that enters the lake from Linnéelva.

Linnébreen, which erodes the sandstone/coal formation, is thought to release large volumes of sediment compared to the smaller subcatchments (Svendsen et al.,

1989), thus overwhelming any geochemical signature released by the other source areas. Despite the fact that two phyllite tributaries and one carbonate tributary enter along the upper 3km of the inflow stream, the sandstone source dominates the composition of sediments in Linnéelva, supporting these previous findings (Figures 11 and 12).

Beginning 3km downstream from Linnébreen, the carbonate and phyllite tributaries do have a greater effect on the stream sediment geochemistry, although the sandstone source appears to maintain a strong influence on stream sediment composition (Figures 11 and 12). These tributaries may carry more sediment compared to the upstream carbonate and phyllite tributaries, which would explain their stronger influence on stream sediment composition.

When sediment is deposited by Linnéelva into the lake, its composition lies along a mixing line between the sandstone and the phyllite. The carbonate is either dissolved into the water column or its geochemical signal is overwhelmed by the other two source sediments. The sediment entering the southeastern corner of the lake by way of the inflow stream is the dominant contributor of sediments in that part of the lake. Even sediments collected at the base of a large alluvial fan (Figure 17) composed of coarse carbonate material are a mix of sandstone and phyllite source material (Figure 13). Sediments collected in the southwest corner of the lake are similar in composition to the phyllite source because of the large volume of phyllite source material brought into this part of the lake by the small inflow stream (Figures 10 and 13).

Just as the sediment that is deposited in the littoral zone reflects the composition of the sediment brought into that area by the inflow streams, the sediment in the lake

basins should reflect the composition of the sediment in the littoral zone and the sediment carried into that basin by inflow streams.

5.3. *Source contributions to the lake basins*

Each basin in Linnévatnet is fed by different inflow streams. During the four weeks from mid-July to mid-August 2004 discharge from Linnéelva entered the lake at the southeast corner and was carried northeast in the counter-clockwise circulation (personal observation, 2005; Svendsen et al., 1989). As a result, sediments in the southeast basin might be expected to have a geochemistry similar to the geochemistry of the sediments carried by Linnéelva: mainly mixed sandstone and phyllite sources. Also during these four weeks, discharge from Linnéelva would occasionally be carried northwest after entering the lake. Besides occasionally being fed by Linnéelva, the southwest basin is fed constantly by a small inflow stream that originates in a cirque cut into the phyllite source area. Therefore, sediment composition in the southwest basin would most likely be dominated by the phyllite source, with some sandstone influence. The deep northern basin is farther from any direct inflow stream than the other two basins. Therefore, only the finest grained material is carried out to this basin. There are different minor sources that feed this basin as well. The marine terraces that extend along the eastern and western shores of the lake may contribute more to the deposition in this basin than in the southern basins. The concentration of strontium is particularly high in sediments from this basin, perhaps indicating that the marine terraces that surround the lake are being reworked.

The composition of sediments in the cores does not fall within the range of the source sediment composition (Figure 14). Thus, mixing of source sediments is only one process that contributes to the composition of the cores. Grain size differences probably cause the observed geochemical differences. Because of these geochemical differences, lake basin sediments cannot be compared directly to source sediments.

5.4. Loss on ignition

The patterns in $LOI_{950^\circ C}$ are attributed to carbonate material in the samples. The high (16-20%) $LOI_{950^\circ C}$ for the carbonate and the east shore sources is at least four times greater than $LOI_{950^\circ C}$ for any of the other source areas and for most of the areas of transport and deposition (Figure 7). The exception to this is sample E8 from Linnéelva, which has a 10% $LOI_{950^\circ C}$, indicating that much of this sample is carbonate-derived. Because the lake basin sediments all have low $LOI_{950^\circ C}$, the carbonate source probably has little influence on lake basin sediment composition. Carbonate source sediment contribution will be discussed further in a later section (5.6.2. Dissolution of carbonate material).

The patterns in $LOI_{550^\circ C}$ are not as easy to decipher. The spikes in $LOI_{550^\circ C}$ are not as distinct as those for $LOI_{950^\circ C}$. Furthermore, many of the lake basin sediments illustrate greater $LOI_{550^\circ C}$ than the source samples (Figure 7). $LOI_{550^\circ C}$ can be due to loss of organic carbon but it can also result from the loss of structural water that is contained in phyllosilicate minerals (Smith, 2003). Svendsen et al. (1989) and Werner (1988) assumed that organic carbon contained in the lake cores is predominantly derived from the sandstone/coal formation (i.e. derived from sandstone source sediments). They also

found that variations in the amount of coal found in a core, determined by mineralogical identification methods, correlated well with variations in that core's organic carbon content measured by other means (A. Werner, personal communication, 2005). This evidence precludes any significant biological activity that may contribute organic carbon to the lake or structural water loss due to phyllosilicate minerals.

Mineral transport is directly influenced by mineral size and density (Pye, 1994). Heavy minerals, such as zircon ($ZrSiO_4$), would be deposited in the inflow stream, the littoral zone and in the proximal lake basins. Zirconium, an element found in the mineral zircon, is more concentrated in the sandstone source sediments than in the lake basin sediments (Figure 16). Coal, on the other hand, is less dense than silicate minerals, and therefore can be transported farther. The coal is pulverized by Linnébreen and therefore may also be very fine grained upon entering the lake. $LOI_{550^{\circ}C}$ is greater in the lake basin sediments than in the source sediments derived from the sandstone/coal formation (Figure 7). Its low density and small size may cause coal to be more easily transported to the lake basins than other minerals, therefore increasing the organic carbon content of the lake sediments and causing the high $LOI_{550^{\circ}C}$.

Figure 16. Silica versus zirconium concentration for source and lake basin sediments. The arrow denotes increasing distance from the main inflow stream of lake basin samples (C is proximal, G is distal). With increased distance from the main inflow stream, zirconium content decreases.
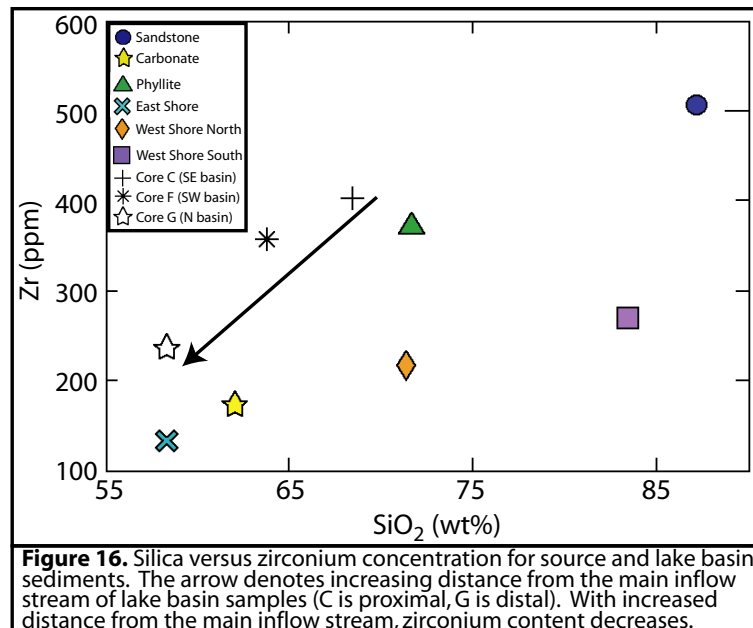
5.5. Statistical determination of geochemical fingerprints and source mixing

Studies that examine mixing between sources of known compositions utilize statistical techniques (e.g., Miller et al., 2003) that were not possible in the scope of this study. Instead, this study addresses the concept of sediment mixing in a qualitative manner. Spider plots illustrate similarities between source and lake sediments. Inflow stream sediments near the glacier and littoral sediments in the southwest corner of Linnévatnet are similar to a single source. Mixing between two sources can be seen in spider plots when the normalized values for each of the sources are mirror images of each other, reflected about unity. Bivariate plots also illustrate source mixing. Often, sediments in the inflow stream and in the littoral zone lie along a line drawn between the phyllite and sandstone compositions. This indicates that these two sources mixed to form the lake and inflow stream sediments (Rollinson, 1993).

5.6. Factors besides mixing that influence inflow stream and lake sediment geochemistry

5.6.1. Grain size

Sample grain size can influence the geochemical composition of the sample (Vital and Stattegger, 2000; Passchier, 2004). Silica rich non-clay minerals such as quartz and feldspar tend to be concentrated in particles coarser than $2\mu m$ (Grim, 1968). In contrast, aluminum-rich phyllosilicates can be found in the $<2\mu m$ fraction (Grim, 1968). Therefore, as the median grain size of a sample decreases, silica content decreases and aluminum content increases (Vital and Stattegger, 2000; Passchier, 2004). Similarly, elements that are often associated with phyllosilicate minerals such as potassium, magnesium and iron will increase as the median grain size of a sample decreases.

An effort was made to collect the fine-grained sediment fraction located on sandbars or in the lee of boulders within or adjacent to the stream flow. Qualitatively, however, these samples did contain a range of grain sizes from clay and silt to coarse sand. The samples collected with a Nalgene™ scoop from the south shore of the lake also had a wide size range of particles. When sediments enter the lake from the inflow stream, the velocity of the water slows and the coarsest fraction is deposited. As a result, the sediments that are carried to the lake basins are more fine grained than littoral sediments.

Because of these grain size differences, the composition of the lake basin sediments differs significantly from the composition of the source sediments. The lake sediments have a much higher concentration of aluminum, potassium and iron oxides than the source sediments (Figure 14). Most of the trace element concentrations are also greater in the lake basin samples than in the source samples (Figure 14). The phyllosilicate minerals that may be causing this change in composition are derived mainly from the phyllite source material. The lithologies of the other two source areas are described as "light grey quartzitic sandstone containing plant fragments" and "alternating dolomites and limestones, partly arenaceous or silicified" (Dallmann et al., 1992) and thus they contain little or no phyllosilicate minerals or minerals such as feldspar that weather into phyllosilicate minerals. The phyllite source rock contains the phyllosilicate minerals sericite and chlorite (Dallmann et al., 1992). The chemical formula for sericite is $KAl_2(AlSi_3O_{10})(OH_2)$ and for chlorite is $(Mg, Fe)_3(Si, Al)_4O_{10}(OH)_2(Mg, Fe)_3(OH)_6$ (Klein and Hurlbut, 1977). As is evident from their chemical formulas, these minerals contain more aluminum and potassium or iron and

44

magnesium relative to the amount of silica than does quartz (SiO_2) or feldspar ((K, Na)$AlSi_3O_8$-$CaAl_2Si_2O_8$). As sericite and chlorite (or their weathering products) become concentrated in the fine-grained lake basin sediment, the concentrations of aluminum, iron, magnesium and potassium will increase relative to silica. The difference in composition between the source areas and the lake basin sediments is enough so that comparisons analyzing for source sediment mixing within the lake cannot be made. Furthermore, there may be seasonal differences in lake basin sediment grain size as stream discharge fluctuates from the spring melt to the summer flow to the dry winter and back (N. McKay, personal communication, 2005). These grain size differences may cause changes in the geochemical composition of the lake basin sediments. To compare source sediment geochemistry directly to lake basin sediment geochemistry and to assess compositional changes within the lake basin sediments, samples should be separated by grain size. Each grain size fraction from source and lake sediments could then be analyzed and compared.

5.6.2. Dissolution of carbonate material

Bøyum and Kjensmo (1978 and 1980) examined the ionic composition of the water in Linnévatnet and the composition of sediments from a core taken in the northern basin. They found high concentrations of calcium, magnesium, carbonate and sulfate ions in the lake water (1978). Bøyum and Kjensmo concluded that these ions are derived from the rocks in the Linnévatnet catchment area. Furthermore, they found a sharp decrease in the percent weight carbonate in lake sediments when the valley switched from a fjord (marine) to its present-day lake condition (freshwater) 9,600 yr BP (1980).

They concluded that the decrease in carbonate content is due to leaching of the carbonate material in the freshwater environment (1980). Carbonate sediment is leached by water in the streams during transport. Leaching may also occur after deposition, as the sedimentation rate is slow (0.2-2mm/yr; Svendsen et al., 1989; N. McKay, personal communication, 2005) and sediments interact with the lake water for a long time after deposition (Bøyum and Kjensmo, 1980). Sediments in the deep distal basin that are deposited more slowly and at a greater distance from the inflow stream contain less carbonate material than the two basins that are closer to the main inflow (Figure 7). These results support Bøyum and Kjensmo's findings (1980), that carbonate material is dissolved and flushed down Linnéelva, through Linnévatnet and out to Isfjord without leaving a strong signature in the lake sediments.

5.6.3. Seasonal flushing of trapped sediments

The sediment composition in different basins in Linnévatnet is affected by erosional processes in the different source areas, transport through the fluvial and lacustrine system and by reworking of previously deposited material. Thus, the composition of sediments in a given layer of lake sediment may not closely reflect the erosion occurring at that time. As sediment is released from beneath the glacier and from the cirques, it can be temporarily deposited and stored on bars and in ponded areas along the inflow stream. In the 1995 aerial photo of Linnédalen (Figure 17), there is a small ponded area ($0.04km^2$) between Linnébreen and the LIA moraine. By the summer of 2004, this ponded area had filled in with fine-grained glacially-derived sediment. Also in the aerial photo there is a large mud flat and several smaller ponded areas downstream
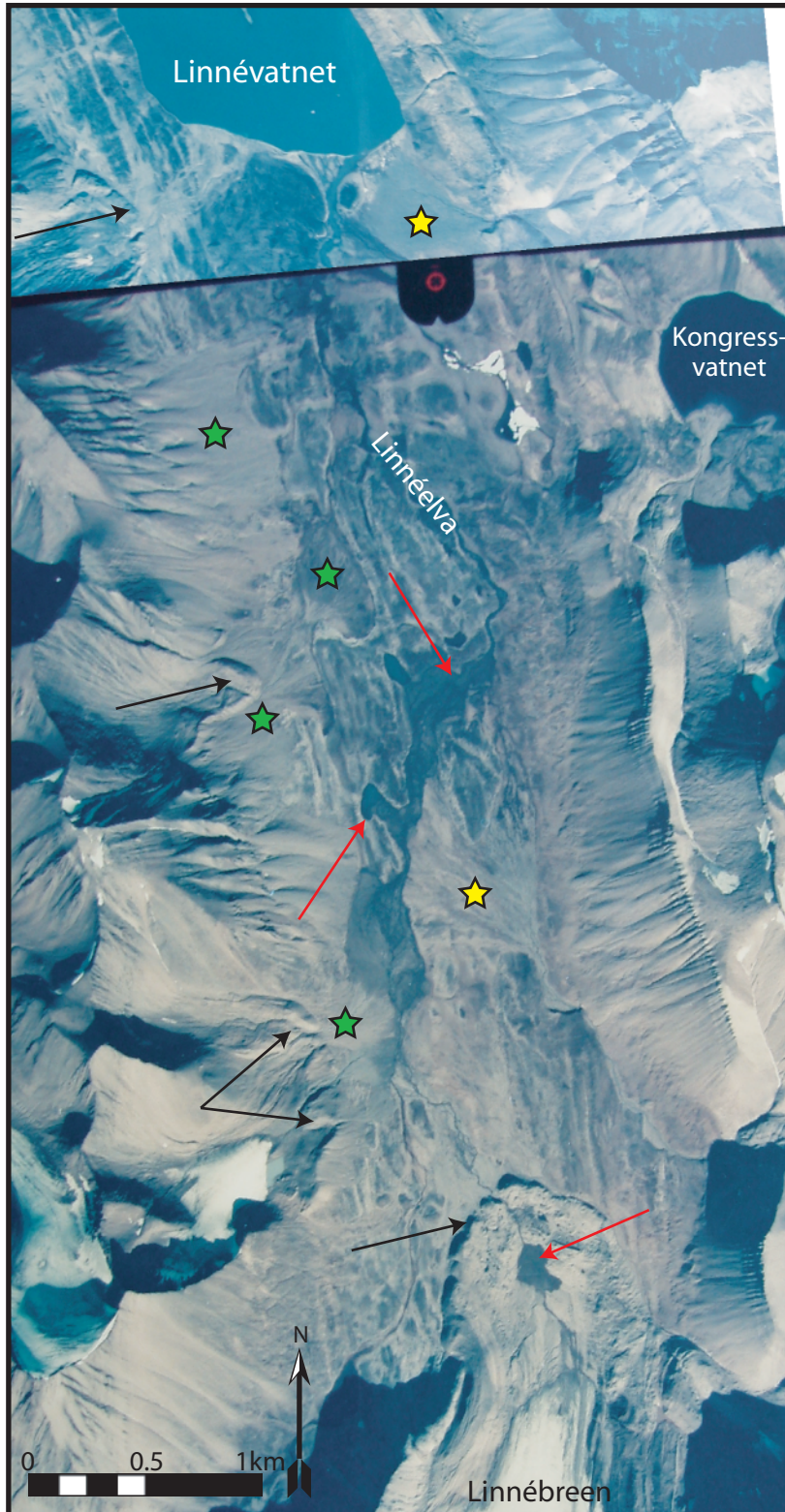
Figure 17. Aerial photos of Linnédalen. Red arrows point to ponded areas, black arrows point to LIA moraines, yellow and green stars are on carbonate and phyllite alluvial fans, respectively. Norwegian Polar Research Institute, 1992.

from the glacier that also may serve as areas of temporary sediment storage. Finally, several phyllite and carbonate-derived alluvial fans lie on either side of the valley. In times of low flow, sediment is deposited in these areas. During rain events or the spring melt, inflow stream discharge increases. An increase in discharge in a graded stream such as Linnéelva will cause the stream to incise its channel and carry more sediment downstream (Easterbrook, 1999). Thus, increased discharge will flush sediment from these ponded areas, mudflats and fans and into Linnévatnet.

The amount of sediment stored or flushed from the fluvial system may also depend upon the climate. If a colder climate regime is characterized by low annual precipitation, the total annual discharge from the inflow stream will also be low. As discharge decreases, suspended sediment load also decreases, and less sediment is brought to the lake (Easterbrook, 1999). Conversely, if the annual precipitation increases, discharge will increase, resulting in a greater suspended sediment load being brought to the lake. As suggested by previous studies (Werner, 1988, 1993; Svendsen et al., 1989), climate change results in changes in glacial, erosional and weathering conditions, which in turn may have an impact on the relative source contributions to the lake basins. Colder periods with more glacial activity will be characterized by greater sandstone source contribution, while warmer periods with little or no glacial activity will be characterized by the fluvially eroded phyllite and carbonate source rocks.

The composition of the sediment that is carried into the lake also may be influenced by the location of Linnéelva. Linnéelva is a broad braided meltwater stream and its course can change dramatically across the broad valley floor. If the main flow is on the west side of the valley, the sediment carried in the stream will likely be more

influenced by the phyllite source. If, however, the main flow is along the east side of the valley, the sediment composition will probably be more influenced by the carbonate source.

6. Conclusions

Unique geochemical fingerprints are distinguishable for the three source rock types in Linnédalen. These chemical differences can be utilized to examine linear variations in relative source contributions within the inflow stream and in the littoral zone of Linnévatnet. Sediment mixing occurs both along the inflow stream and in the lake. Stream and littoral sediment composition depends on tributary stream sediment load and the direction that the inflow stream takes upon entering the lake. Direct comparisons of source and lake basin sediment composition cannot be made due to differences in geochemical composition. These differences in composition allow for the identification of grain size differences between sediments in the deep lake basins and the source areas.

Changes in organic carbon and carbonate content of the lake sediments have been interpreted as signifying glacial and non glacial periods (Svendsen et al., 1989; Werner, 1988). This may be the best geochemical fingerprint of the different source areas in this valley. The presence and abundance of organic carbon and carbonate are easy to interpret, since organic carbon is derived only from the sandstone and carbonate is derived only from the eastern mountains. Loss on ignition requires only 1g of dried sediment per sample, so a high-resolution study can be conducted on each core to determine changes in composition over small scales. Carbonate content may be affected, however, by carbonate leaching from the sediment into the water column. Thus,

inferences made about source contributions based on relative carbonate and organic carbon content may not accurately represent the carbonate source.

7. Future work

There are several factors that influence lake basin sediment composition that have been to difficult to address in the scope of this study. It is essential to understand these confounding factors if changes in sediment chemistry are to be used to identify changes in erosional, glacial and climate conditions.

1. Future provenance studies in this valley should separate each sample by grain size and analyze each size fraction, since grain size differences can cause dramatic geochemical differences. Data for each size fraction would allow the lake sediments to be compared directly to the source and inflow stream sediments. Statistical methods such as discriminant analyses and mixing models could be used to quantitatively describe the individual source areas and the mixing processes that are occurring in the valley. Other methods that may be effective in determining provenance in Linnédalen include heavy mineral and clay mineral analysis.

2. The composition of the sediments in the unlithified marine terraces probably has a strong influence on the composition of the eastern and western shore sediments, as well as the sediments deposited in the northern basin. If the lake basin sediments are to be examined for geochemical fingerprints of source areas, it is imperative to determine the composition of this sediment source.

3. Carbonate leaching from the sediment into the water column affects both the water and the sediment chemistry. A study building on the information from this

provenance study and Bøyum and Kjensmo's work (1978, 1980) and examining the aqueous geochemistry of the inflow and outflow streams and of the lake would help to determine how and under what conditions this carbonate leaching is affecting the lake water and sediment.

4. Sediment storage in and erosion from sandbars and ponded areas between the glacier and the lake may influence the geochemistry of the lake sediments. Changes in the magnitude of the spring melt and the amount of annual precipitation would influence erosion and deposition in these storage areas, and as a result influence lake sediment composition. Future studies could examine the sediments contained in these sediment storage areas and the influence of peak flow events, such as the spring melt, on erosion from these storage areas.

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Appendix 1. List of samples collected, along with the sample type, collection method, GPS location and correction type. * Sample was not analyzed for this study.

Sample Number	Sample Type	Collection Method	Easting (WGS 84, Zone 33N)	Northing (WGS 84, Zone 33N)	Correction Type
S1	West Shore South	Grab	471877	8663444	Differential
S2	West Shore South	Grab	471876	8663444	Differential
S3	West Shore North	Grab	471387	8664545	Hand Drawn
S4	West Shore North	Grab	471292	8664910	Uncorrected
S5	West Shore North	Grab	471261	8665035	Hand Drawn
S6	East Shore	Grab	472137	8665485	Hand Drawn
S7	East Shore*	Grab	473186	8663806	Hand Drawn
S8	East Shore*	Grab	473287	8663825	Uncorrected
S9	Carbonate	Grab	474887	8657558	Hand Drawn
S10	Carbonate	Grab	475104	8656456	Hand Drawn
S11	Sandstone	Grab	474433	8656688	Differential
S12	Phyllite	Grab	473804	8657172	Differential
S13	Phyllite	Grab	473691	8657390	Differential
S14	Phyllite	Grab	473270	8659155	Differential
S15	Phyllite	Grab	472620	8661476	Differential
E1	Sandstone	Grab	474819	8656122	Differential
E2	Inflow Stream*	Grab	474116	8657165	Differential
E3	Inflow Stream*	Grab	474080	8657310	Differential
E4	Inflow Stream	Grab	474050	8657591	Differential
E5	Inflow Stream*	Grab	474361	8657016	Differential
E6	Inflow Stream	Grab	474115	8657347	Differential
E7	Inflow Stream*	Grab	474212	8658555	Differential
E8	Inflow Stream	Grab	474590	8659349	Differential
E9	Inflow Stream*	Grab	474087	8660376	Differential
E10	Inflow Stream	Grab	473647	8660949	Differential
E11	Inflow Stream*	Grab	473638	8661317	Differential
E12	Inflow Stream	Grab	473678	8661552	Uncorrected
L1	Shallow Lake	Nalgene Scoop	473991	8662193	Differential
L2	Shallow Lake	Nalgene Scoop	473838	8661976	Differential
L3	Shallow Lake	Nalgene Scoop	473687	8661976	Differential
L4	Shallow Lake	Nalgene Scoop	473569	8661974	Differential
L5	Shallow Lake	Nalgene Scoop	473460	8661971	Differential
L6	Shallow Lake	Nalgene Scoop	473314	8662011	Differential
L7	Shallow Lake	Nalgene Scoop	473086	8662079	Differential
L8	Shallow Lake	Nalgene Scoop	472821	8662159	Differential
C	Core	Universal Short Corer	473630	8662208	Differential
F	Core	Universal Short Corer	473069	8662267	Differential
G	Core	Universal Short Corer	471897	8664550	Differential

Appendix 2. Loss on ignition results for samples taken throughout Linnédalen. Values given for source areas are the median and the range of the samples measured. Values given for inflow stream and lake sediment samples are the values for a single sample.

Sample Type and Name	% weight lost at 550	% weight lost at 950
WEST SHORE SOUTH SOURCE (2)		
Median	**3.87**	**0.70**
Maximum	4.83	0.90
Minimum	2.91	0.49
WEST SHORE NORTH SOURCE (3)		
Median	**2.85**	**4.61**
Maximum	3.00	5.09
Minimum	2.63	4.51
EAST SHORE SOURCE (1)		
S6	2.32	20.15
CARBONATE SOURCE (3)		
Median	**2.45**	**16.06**
Maximum	3.00	16.76
Minimum	1.90	15.35
SANDSTONE SOURCE (2)		
Median	**4.62**	**0.91**
Maximum	4.81	1.13
Minimum	4.43	0.70
PHYLLITE SOURCE (4)		
Median	**1.44**	**3.87**
Maximum	1.94	5.52
Minimum	1.07	2.18
INFLOW STREAM		
E4 (South)	2.44	1.09
E6	4.39	1.04
E8	2.99	10.25
E10	3.21	3.15
E12 (North)	4.17	2.48
SHALLOW LAKE		
L1 (East)	7.22	3.55
L2	3.10	3.02
L3	2.35	3.11
L4	4.92	3.63
L5	1.73	3.97
L6	1.45	2.61
L7	1.04	3.36
L8 (West)	1.83	1.54
CORES		
C Top	5.02	5.47
C Mid	5.84	2.94
C Low	6.53	2.57
F Top	5.48	3.51
F Mid	4.61	2.50
F Low	4.58	2.27
G Top	7.47	2.01
G Mid	7.33	1.71
G Low	6.47	1.98

Appendix 3. X-Ray Fluorescence results for samples taken throughout Linnédalen. Values given for source areas are the median and the range of the samples measured. Values given for inflow stream and lake sediment samples are the values for a single sample.

Sample Type and Name	SiO2 wt%	TiO2 wt%	Al2O3 wt%	Fe2O3 wt%	MnO wt%	MgO wt%	CaO wt%	Na2O wt%	K2O wt%	P2O5 wt%	Total wt%	Ni ppm	Cr ppm	V pmm	Ba pmm	Rb ppm	Sr ppm	Zr ppm	Y ppm	Nb ppm	Ga ppm	Zn ppm	Pb ppm	La ppm	Ce ppm	Th ppm	U ppm
WEST SHORE SOUTH SOURCE (2)																											
Median	83.39	0.59	8.84	3.03	0.04	1.03	0.38	0.53	1.72	0.11	99.66	26.00	83.50	81.50	290.00	68.10	74.50	270.50	22.15	11.80	12.00	45.00	23.50	30.50	72.00	10.00	2.00
Maximum	84.35	0.63	9.17	3.05	0.04	1.30	0.54	0.78	1.82	0.13		29.00	90.00	91.00	296.00	70.10	83.00	301.00	22.60	12.80	12.00	46.00	32.00	35.00	80.00	11.00	2.00
Minimum	82.43	0.55	8.52	3.01	0.04	0.77	0.22	0.27	1.61	0.09		23.00	77.00	72.00	284.00	66.10	66.00	240.00	21.70	10.80	12.00	44.00	15.00	26.00	64.00	9.00	2.00
WEST SHORE NORTH SOURCE (3)																											
Median	71.33	0.69	11.83	4.47	0.06	2.54	5.24	0.88	2.30	0.15	99.48	24.00	98.00	114.00	376.00	87.50	106.00	218.00	22.00	12.80	14.00	68.00	13.00	27.00	62.00	9.00	2.00
Maximum	72.25	0.71	11.97	4.78	0.06	2.68	5.81	0.98	2.48	0.18		25.00	99.00	121.00	392.00	90.40	110.00	224.00	22.80	13.30	15.00	70.00	14.00	29.00	64.00	9.00	2.00
Minimum	71.12	0.69	11.48	4.36	0.05	2.36	5.00	0.82	2.26	0.15		24.00	97.00	109.00	372.00	84.10	95.00	213.00	21.90	12.80	14.00	63.00	13.00	27.00	62.00	9.00	2.00
EAST SHORE SOURCE (1)																											
S6	58.28	0.35	4.79	1.98	0.03	9.10	23.20	0.28	1.59	0.07	99.68	15.00	67.00	35.00	126.00	34.90	105.00	133.00	8.30	4.40	4.00	32.00	6.00	10.00	23.00	4.00	3.00
CARBONATE SOURCE (3)																											
Median	61.98	0.52	6.67	2.69	0.04	5.91	20.09	0.15	1.72	0.09	99.85	20.00	69.00	45.00	161.50	43.85	122.00	172.50	12.60	6.60	6.50	37.50	8.50	15.00	37.00	5.00	2.50
Maximum	62.19	0.57	7.99	2.79	0.04	6.67	20.41	0.20	2.03	0.10		20.00	71.00	46.00	191.00	52.70	126.00	176.00	13.40	7.10	8.00	42.00	10.00	18.00	43.00	6.00	3.00
Minimum	61.77	0.47	5.35	2.59	0.04	5.16	19.77	0.09	1.40	0.08		20.00	67.00	44.00	132.00	35.00	118.00	169.00	11.80	6.10	5.00	33.00	7.00	12.00	31.00	4.00	2.00
SANDSTONE SOURCE (2)																											
Median	87.22	0.60	7.07	1.88	0.02	0.70	0.48	0.00	1.30	0.07	99.34	18.00	67.50	48.50	186.00	50.25	47.00	505.50	30.00	13.45	9.50	26.50	10.50	30.50	68.00	12.00	3.00
Maximum	87.75	0.63	7.17	1.93	0.03	0.74	0.64	0.00	1.30	0.07		19.00	71.00	52.00	201.00	51.60	49.00	545.00	30.10	13.60	10.00	30.00	12.00	32.00	73.00	12.00	3.00
Minimum	86.69	0.57	6.96	1.84	0.02	0.66	0.32	0.00	1.30	0.06		17.00	64.00	45.00	171.00	48.90	45.00	466.00	29.90	13.30	9.00	23.00	9.00	29.00	63.00	12.00	3.00
PHYLLITE SOURCE (4)																											
Median	71.64	0.85	11.93	4.31	0.05	3.62	2.86	1.09	3.05	0.19	99.58	22.50	68.00	80.00	535.50	102.90	49.50	371.50	23.25	15.65	14.50	64.50	9.50	27.50	64.00	8.00	2.50
Maximum	73.47	1.18	15.50	5.35	0.05	3.74	4.63	1.34	3.94	0.23		25.00	83.00	93.00	580.00	148.30	55.00	471.00	34.20	18.80	20.00	94.00	11.00	36.00	83.00	12.00	3.00
Minimum	69.12	0.58	10.10	3.93	0.04	2.00	1.31	0.90	2.50	0.14		20.00	61.00	69.00	441.00	83.80	27.00	245.00	16.60	10.50	12.00	58.00	9.00	21.00	46.00	6.00	2.00
INFLOW STREAM																											
E4 (South)	87.12	0.63	6.76	1.82	0.02	0.68	0.53	0.00	1.26	0.07	98.89	16.00	55.00	43.00	174.00	49.10	47.00	420.00	30.40	13.70	9.00	24.00	9.00	28.00	64.00	12.00	2.00
E6	87.31	0.67	6.98	1.87	0.03	0.75	0.64	0.00	1.28	0.08	99.61	18.00	62.00	45.00	170.00	47.50	51.00	430.00	30.10	13.70	9.00	25.00	10.00	26.00	59.00	11.00	3.00
E8	70.89	0.82	8.91	2.75	0.04	5.18	8.82	0.27	1.95	0.11	99.75	22.00	70.00	53.00	220.00	61.50	72.00	480.00	30.70	14.30	10.00	41.00	12.00	28.00	60.00	11.00	4.00
E10	77.97	0.88	10.46	3.11	0.04	2.08	1.86	0.60	2.34	0.14	99.49	22.00	73.00	66.00	335.00	82.10	53.00	436.00	31.40	17.60	13.00	45.00	13.00	33.00	71.00	12.00	3.00
E12 (North)	80.24	0.86	10.21	2.71	0.03	1.57	1.48	0.23	2.15	0.11	99.60	21.00	67.00	60.00	284.00	78.20	59.00	429.00	32.50	18.40	13.00	38.00	12.00	32.00	71.00	12.00	3.00
SHALLOW LAKE																											
L1 (East)	74.35	1.01	13.16	3.32	0.05	2.51	2.58	0.21	2.74	0.10	100.02	29.00	86.00	77.00	341.00	98.40	80.00	406.00	34.30	21.10	16.00	406.00	18.00	36.00	84.00	14.00	3.00
L2	81.60	0.46	8.31	2.96	0.05	1.86	2.46	0.45	1.79	0.08	100.03	19.00	56.00	56.00	305.00	64.80	51.00	206.00	18.60	10.00	11.00	65.00	9.00	21.00	46.00	7.00	1.00
L3	79.62	0.55	8.68	3.39	0.05	2.25	2.66	0.59	1.91	0.10	99.81	19.00	60.00	60.00	322.00	68.10	50.00	249.00	19.80	11.00	9.00	54.00	9.00	21.00	50.00	7.00	2.00
L4	74.37	0.97	12.66	3.46	0.04	2.68	2.70	0.29	2.78	0.12	100.06	28.00	80.00	81.00	382.00	102.60	73.00	436.00	34.70	21.10	16.00	58.00	16.00	38.00	83.00	14.00	4.00
L5	77.64	0.54	8.88	3.64	0.06	2.70	3.42	0.89	2.01	0.11	99.88	20.00	59.00	62.00	350.00	69.50	52.00	206.00	19.00	10.40	10.00	11.00	10.00	20.00	46.00	7.00	1.00
L6	73.78	0.82	11.56	4.27	0.05	3.32	1.94	1.27	2.77	0.18	99.96	24.00	79.00	86.00	505.00	94.20	34.00	329.00	23.00	15.30	14.00	67.00	9.00	26.00	57.00	8.00	2.00
L7	77.21	0.61	9.45	3.85	0.05	2.90	2.51	1.05	2.22	0.13	99.98	19.00	58.00	69.00	413.00	74.70	37.00	287.00	18.20	11.00	12.00	56.00	8.00	19.00	43.00	6.00	2.00
L8 (West)	80.76	0.64	9.32	3.39	0.03	1.89	0.61	0.81	1.99	0.13	99.57	23.00	76.00	77.00	367.00	74.00	44.00	277.00	20.90	12.50	12.00	57.00	11.00	28.00	62.00	8.00	2.00
CORES																											
C Top	68.40	1.03	14.97	4.09	0.05	3.71	4.08	0.25	3.35	0.12	100.05	31.00	91.00	88.00	420.00	119.30	85.00	403.00	35.00	21.50	18.00	63.00	18.00	40.00	87.00	15.00	4.00
C Mid	66.71	1.13	17.28	4.42	0.06	2.99	2.33	0.33	3.76	0.12	99.12	34.00	95.00	94.00	462.00	133.30	82.00	384.00	36.20	22.90	20.00	67.00	20.00	43.00	93.00	16.00	4.00
C Low	66.04	1.11	18.51	4.46	0.05	2.69	1.95	0.28	3.85	0.11	99.04	37.00	101.00	100.00	454.00	137.90	93.00	368.00	36.30	23.80	22.00	68.00	22.00	45.00	102.00	17.00	4.00
F Top	63.75	1.11	18.55	5.46	0.06	3.93	2.20	0.54	4.10	0.14	99.84	41.00	119.00	114.00	554.00	148.90	85.00	358.00	34.90	22.50	24.00	88.00	23.00	45.00	99.00	16.00	4.00
F Mid	62.84	1.14	18.72	5.98	0.07	3.97	1.41	0.72	4.28	0.17	99.28	41.00	109.00	119.00	606.00	150.10	70.00	344.00	33.70	22.60	24.00	91.00	22.00	44.00	98.00	15.00	4.00
F Low	60.05	1.12	20.82	6.77	0.09	4.18	0.91	0.79	4.74	0.16	99.62	50.00	140.00	199.00	737.00	181.10	74.00	330.00	35.20	24.30	29.00	115.00	25.00	50.00	110.00	17.00	4.00
G Top	58.30	0.98	25.31	5.90	0.07	2.70	1.08	0.34	4.84	0.12	99.62	58.00	142.00	147.00	554.00	187.20	135.00	236.00	30.30	20.90	32.00	101.00	35.00	57.00	126.00	21.00	4.00
G Mid	58.56	1.00	24.84	6.11	0.07	2.72	0.91	0.34	4.87	0.12	99.54	61.00	159.00	292.00	633.00	198.30	132.00	259.00	33.00	22.80	33.00	114.00	40.00	64.00	136.00	22.00	4.00
G Low	59.63	0.93	23.56	6.42	0.08	2.88	1.11	0.43	4.63	0.14	99.79	60.00	155.00	174.00	579.00	191.90	129.00	235.00	31.90	20.30	31.00	112.00	32.00	57.00	124.00	20.00	4.00