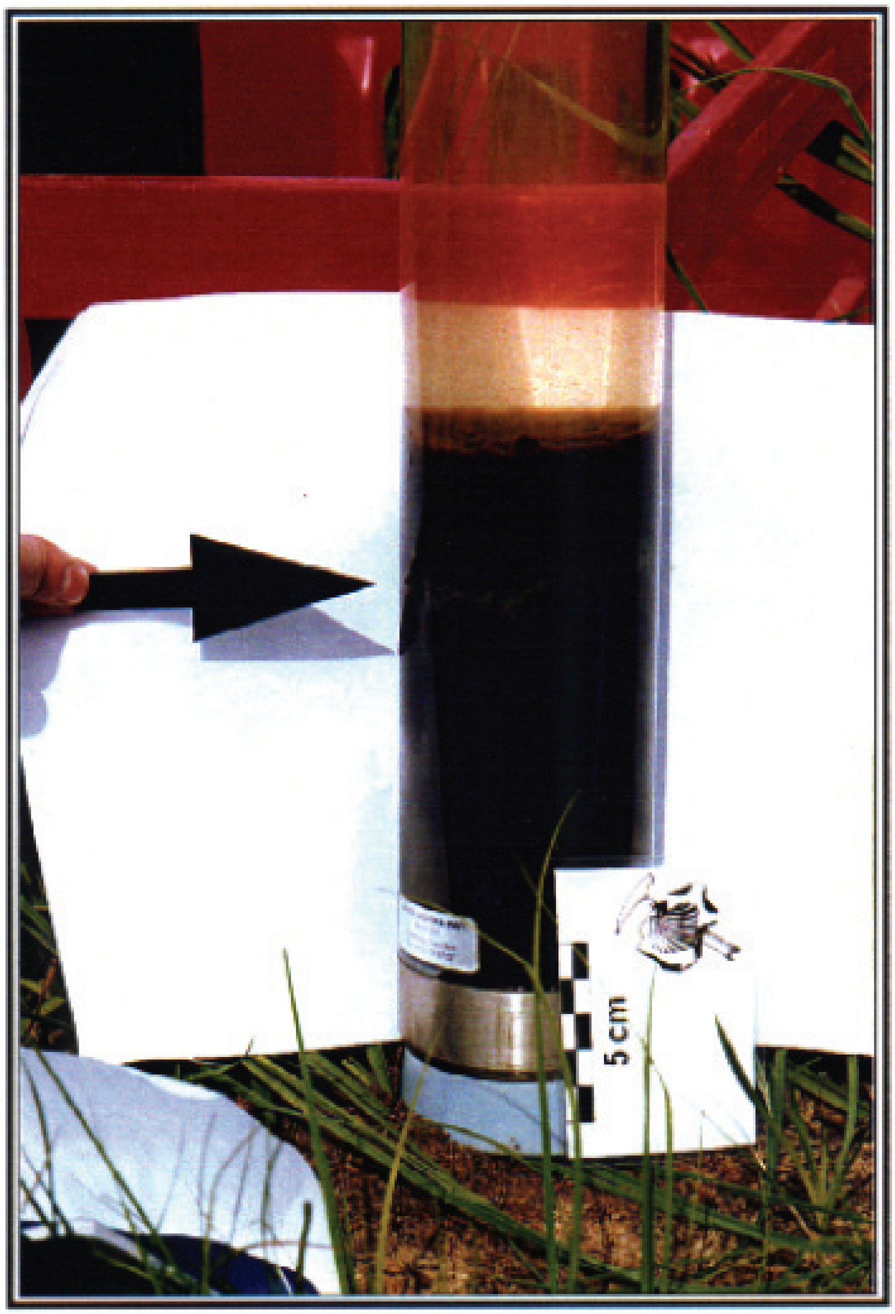
BASELINE METAL DISTRUBUTIONS IN LAKE SEDIMENTS OF NORRBOTTEN



LÄNSSTYRELSEN
I NORRBOTTENS LÄN
RAPPORTSERIE
NUMMER 8/1997

BASELINE METAL DISTRIBUTIONS IN LAKE SEDIMENTS OF NORRBOTTEN

Författare:	Joanne Deely
	Isabell Olevall
Referent:	Lisa Lundstedt
Omslagsbild:	Joanne Deely
Tryck:	Länsstyrelsens tryckeri
Tryck omslag:	Printor, Luleå
Upplaga:	100 ex
ISSN:	0283-9636

Länsstyrelsen i Norrbottens län
Sektor Livsmiljö
Postadress: 971 86 Luleå
Besöksadress: Stationsgatan 5
Telefon: 0920-960 00

FÖRORD

Inom miljöarbetet kommer vi ofta i kontakt med prover från förorenade områden bl a sjösediment i gruvrecipienter. Ofta saknas det dock relevanta verktyg för bedömningar av kontamineringsgrad. För att öka kunskapen om naturliga förhållanden genomförde länsstyrelsen under sommaren 1997 en undersökning av bakgrundshalter av metaller i Norrbottniska sjösediment.

Arbetet är utfört av Dr. Joanne Deely från Environment Bay of Plenty, Nya Zeeland, som en del i ett utbyte mellan länsstyrelsen och Environment B.O.P. Gunnar Brännström, länsstyrelsen, har varit projektledare och Lisa Lundstedt, länsstyrelsen, har planerat och lett projektet. Den slutliga rapporten har skrivits av Joanne Deely samt Isabell Olevall, Limnologiska institutionen, Uppsala universitet. Projektet har finansierats av länsstyrelsen.

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Summary

This report presents an investigation of levels of metals in sediments from 11 lakes in Norrland, Sweden (see map, Figure 4.1), along with a literature review of metals in Swedish lake sediments. The report focuses on lakes in anthropogenically non-impacted (or relatively non-impacted) areas and its main objective is to map the distributions of metals in the sediments of these lakes. The levels of arsenic, cadmium, copper, mercury, nickel, lead and zinc i the sediments of the investigated lakes are compared with the Swedish Environmental Protection Agency (EPA) guidelines for metals in sediments.

The natural metal content of sediment is mainly dependent on the local geological conditions. However, large amounts of metals are deposited annually through the atmosphere. The anthropogenic activities which contribute to the atmospheric deposition is among other things the combustion of coal, oil and gasoline, and also pyrometallurgical processes in different industries.

Commonly, metal levels in sediments increase the further south in Sweden one travels and it is considered that Sweden receives its largest atmospheric deposition of metals from Europe. Small variations in (natural) levels of metals within the same area is thought to originate from differences in geochemical conditions, rather than from differences in local anthropogenic emissions.

I the northern parts of Sweden large parts of the ground is covered by tills, as a result of the most recent ice age. Till is naturally low in heavy metals, which leads to generally very low natural levels of metals in Norrland. According to the guidelines erected by the Swedish EPA levels of metals in this investigation are in most cases very low (class 1), even though there are certain exceptions (the levels of copper, for instance, are labelled as low (class 2) to moderate/high (class 3)).

It is clear that several metals are connected to the organic matter in the sediment, as the covariation is large (see profile diagrams in Appendix 5). Some metals (for instance titanium and aluminium) show the opposite pattern and instead covariate with the total solids content. This owes to the way these metals are bound to mineral particles, which implies that they are not affected by redox processes to the same extent as other metals.

Many metals show local maxima in the upper 10 cm of the sediment, which in previous reports have been related to different peak industrial emissions. Such relationships are not as clear in this investigation. A decrease in metal levels in the top sediments may be the result from reduced metal deposition and/or changes waterchemical conditions. Several of the metals have probably been redistributed by redox processes and bound to different compounds at different depths in the sediment.

Sammanfattning

I denna rapport presenteras en undersökning av metaller i 11 Norrländska sjöars sediment (se karta, Figur 4.1), samt en litteraturstudie över metaller i svenska sjösediment. Rapporten är fokuserad på sjöar i antropogent opåverkade (eller relativt opåverkade) områden och har som huvudsyfte att kartlägga fördelningen av metaller i sådana sjöars sediment. Halterna av arsenik, kadmium, koppar, kvicksilver, nickel, bly och zink i de undersökta sjöarna jämförs med Naturvårdsverkets riktlinjer för metaller i sediment.

Det naturliga metallinnehållet i sediment beror till största delen på de lokala geologiska förhållandena, men stora mängder metaller deponeras även årligen via atmosfären. De antropogena aktiviteter som bidrar till metallinnehållet i atmosfären (och slutligen till metallinnehållet i sedimenten) är bland annat förbränning av kol, olja och bensin och processer i olika industrier.

Generellt sett ökar metallhalterna i sedimenten ju längre söderut i Sverige man kommer och det anses att Sverige får sin största atmosfäriska deposition av metaller från Europa. Små variationer i (naturliga) metallhalter i samma område anses härröra från skillnader i geokemiska förhållanden, snarare än skillnader i lokala antropogena utsläpp.

I norra Sverige täcks stora delar av marken av morän som ett resultat av den senaste istiden. Morän innehåller låga halter av tungmetaller, vilket leder till att de naturliga nivåerna av metaller i Norrland i allmänhet är väldigt låga. Enligt Naturvårdsverkets riktlinjer är metallhalterna i den här undersökningen i de flesta fall väldigt låga (klass 1), även om det finns vissa undantag (till exempel kopparhalten, som klassas som låg (klass 2) till medel/hög (klass 3)).

Det är tydligt att flera metaller är kopplade till sedimentets organiska innehåll, då samvariationen är stor (se profildiagram i Appendix 5). Ett par metaller (till exempel titan och aluminium) uppvisar ett motsatt mönster och samvarierar istället med torrsubstanshalten. Detta beror på att dessa metaller binds till mineralpartiklar på ett sätt som gör att de inte påverkas av redoxprocesser i samma utsträckning som övriga metaller.

Många metaller uppvisar lokala maxima i de översta 10 cm av sedimentet, vilket i tidigare undersökningar har kopplats bland annat till olika punktutsläpp. Sådana samband är inte lika tydliga i denna undersökning. En minskning av metaller i de ytligaste sedimenten kan bero på minskad extern tillförsel och/eller ändrade vattenkemiska förhållanden. Flera av metallerna har troligen blivit omdistribuerade av redoxprocesser och bundits till olika föreningar på olika djup i sedimentet.

Chapter 1: INTRODUCTION

It is of great importance and interest to distinguish between the patterns and trends found in contaminated sediments and in sediments with no or low perturbation. To be able to determine which peaks in heavy metal levels are caused by anthropogenic perturbation, it is required that the patterns of the metal levels within the sediment profile are known. It is also of interest to map the background levels of heavy metals in sediments, to be able to determine different degrees of contamination.

In this report, an investigation of 11 small lakes in relatively non-impacted areas of Norrbotten is presented. The objective of the investigation was to map the background metal levels and distributions in sediment profiles from Norrbotten lakes. Since arsenic (As) is associated with the same compounds as heavy metals, and originates from the same contamination sources, it is included in this investigation, although it is a non-metal. Sampling of sediment was conducted during March, June and July 1997. The metal (and arsenic) concentrations and depth distributions are discussed and compared to the Swedish EPA guideline assessment criteria. In this report, the term *Background concentration* or *Background value* refers to sediment data from lakes in non- or low-impact areas.

Also, this report contains a review of available published and unpublished data on metal sources, concentrations and distributions in lake sediments of Sweden (Chapter 2).

Chapter 2: BACKGROUND INFORMATION: EPA GUIDELINES AND LITERARY REVIEW

2.1 SWEDISH ENVIRONMENTAL PROTECTION AGENCY (EPA) GUIDELINES

The Swedish EPA guidelines were designed to allow simple reporting of conditions in lakes, rivers and streams on the degree to which waters have been disturbed by human activities. The guidelines focus on the aquatic environment and not on the water quality standards that may be required to maintain the waters for drinking, irrigation and other such purposes. The areas covered by the guidelines include nutrient status, oxygen status, light conditions, acidity status and concentrations of metals.

For metals in sediments, there are five status classes that apply (Tables 2.1 and 2.2). The classification is based on variations of concentrations of metals in surface sediments in Swedish lakes. In the 1991 EPA guidelines (Table 2.1), class 1 is for uncontaminated sediments and classes 2 to 5 apply to increasing concentrations of metals, where the metals have originated from anthropogenic sources.

Table 2.1 *Background and guideline concentrations of metals in Swedish sediments (Swedish EPA, 1991). All levels are given as mg/kg dw.*

	Background	**Status classes**				
		1 (Very Low)	2 (Low)	3 (Moderate/High)	4 (High)	5 (Very High)
As	10	≤5	5-15	15-75	75-250	>250
Cd	0.4	≤0.2	0.2-0.7	0.7-2	2-5	>5
Cr	20	≤10	10-25	25-75	75-300	>300
Cu	20	≤10	10-25	25-50	50-150	>150
Hg	0.10	≤0.05	0.05-0.15	0.15-0.3	0.3-1.0	>1
Ni	30*	≤10	10-30	30-75	75-300	>300
Pb	50/10**	≤5	5-30	30-100	100-400	>400
Zn	175	≤70	70-175	175-300	300-1000	>1000

* Ni background levels may be as high as 50-100 mg/kg in areas with bedrock containing limestone.
** 50 mg/kg applies to sediments in the south-west of Sweden, whereas 10 mg/kg applies to Northern Sweden.

Table 2.2 shows the suggested status classes for the revision of the Swedish EPA guidelines (as of 27/04/98). Class 1 - 3 includes approximately 95 % of the measurements in the background material. Classes 4 and 5 represent levels that are generally found in locally impacted areas. The highest class includes only the highest levels measured in Sweden.

Table 2.2 *Background and guideline concentrations of metals in Swedish sediments (Swedish EPA, as suggested on 4/27/98). All levels are given as mg/kg dw. The natural, original levels are estimates based on present levels in northern Sweden.*

	Background		**Status classes**				
	N Swe/ S Swe*	natural, original levels	**1** (Very Low)	**2** (Low)	**3** (Moderate/High)	**4** (High)	**5** (Very High)
As	10/10	8	≤5	5-10	10-30	30-150	>150
Cd	0.8/1.4	0.3	≤0.8	0.8-2	2-7	7-35	>35
Co		15					
Cr	15/15	15	≤15	15-25	25-100	100-500	>500
Cu	15/20	15	≤15	15-25	25-100	100-500	>500
Hg	0.13/0.16	0.08	≤0.15	0.15-0.3	0.3-1.0	1-5	>5
Ni	10/10	10	≤5	5-15	15-50	50-250	>250
Pb	5/80	5	≤50	50-150	150-400	400-2000	>2000
V	20/20	20					
Zn	150/240	100	≤150	150-300	300-1000	1000-5000	>5000

* N Swe = north Sweden, S Swe = south Sweden

The EPA guideline assessment criteria for metals in sediments are intended for use throughout Sweden. However due to the paucity of published data (only Johansson, 1989) on lakes in northern Sweden, it is uncertain as to whether or not the classes of the 1991 EPA guidelines apply to lake sediments in Norrbotten. In the investigation presented in this report, the element concentrations are compared with the 1991 EPA guidelines, as well as with the suggested 1998 EPA guidelines.

2.2 BACKGROUND DATA ON PHYSICAL AND CHEMICAL PARAMETERS, METALS AND OTHER ELEMENTS

Tables 2.3 and 2.4 list information on background levels of metals in sediments of Swedish lakes. Generally, the concentrations of most metals in uncontaminated sediments do not vary significantly between lakes in impacted areas, mineralised areas and remote and forested parts of Sweden. This phenomenon is probably due to the thick blanket of glacial tills that cover basement rocks across Sweden (Öhlander *et al.*, 1991, 1996).

However, data from Johansson (1989) show Cd, Cu, Pb and Zn levels in remote and forested parts of Sweden to be approximately half the background value of the respective metal in similar environments in southern Sweden.

Table 2.3 *Background values of various elements and physical and chemical parameters in Swedish lake sediments.*

Lake/location in Sweden	Summary statistic (X,M,R,E*)	Number (n)	Type of lake bottom**	Depth (cm) Surface or down core	Water content (%)	LOI (% dry weight)	Reference
Lakes in remote and forested parts of Sweden							
Northern Sweden	M	~14	A	below 15	95-98#	30-50#	(1) Johansson, 1989
South/central Sweden	M	~40	A	below 15	95-98#	30-50#	(1)
South-west/central Sweden	E	8-12	A	10- below 20	93-99	30-40	(2) El-Daoushy & Johansson (1983)*
Impacted lakes south of Norrbotten							
Lake Gårdsjön	E	6	T	10- below 15	~50		(3) Renberg, 1985
Lake Vänern	R of X	~120	T/A	4-38	56-65	3-4.5	(4) Håkanson, 1977.
Lake Vättern	R of X	4	T/A	0-1	51-81	3-9	(4)
Lake Vänern	X+SD	>100	E/T/A	0- ~40	<40- >70	5	(4)
Lake Vättern	X+SD	>100	E/T/A	0- ~40	<40- >70	4	(4)
Lake Mälaren	X+SD	>100	E/T/A	0- ~40	<40- >70	7	(4)
Central/east Sweden	E	~15	T	below 15	<40- >70		(5) Renberg, 1986
Central/south Sweden	X	14	A	9-10, 19-20	86.8#	12#	(6) Håkanson, 1984.
Lakes in mineralised areas of Norrbotten							
Lake Småtrasken***	E	5	E	14-20		38	(7) Ljungberg & Öhlander, 1996
Lake Småtrasken***	X	5	E	14-20		38	(8) Ljungberg, 1995
Oinakkajärvi	E	~6	A	21-32	>70		(9) Ponter 1993
Jukkasjärvi	E	~6	A	21-32	>70		(9)
Sakajärvi	E	3-6		30-40			(10) Ponter & Ljungberg 1995
Vettasjärvi	E	3-6		30-40			(10)

* X = mean, SD = standard deviation, M = median, R = range of values, E = estimate taken from 1 or more graphs of 1 or more lakes cited in the reference.
** A = accumulation, T = transportation, E = erosion (Håkanson, 1982)
*** The pre-industrial sediments were deposited in a stream bed environment prior to the start of mining operations in Laver in 1936.
# Sediment depth 0-1 cm

Table 2.3 *continued*

Lake/location in Sweden	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Reference
	mg/kg	mg/kg	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
Lake in remote and forested parts of Sweden											
North		0.2 (0.1-0.5)		8 (4-15)	2.0-7.5				<10	50 (25-90)	(1)
South/central		0.3 (0.2-0.4)		16 (11-30)	2.0-7.5				<10	100 (50-200)	(1)
South-west/central		≤0.5		<20	1.0-10.0	<0.1-0.2			<50-100	100-200	(2)
Impacted lakes south of Norrbotten											
Lake Gårdsjön		<0.5	~20	<20	1.0-2.0		~200	5-10	<50	~50	(3)
Lake Vänern		<1		17-21		0.01-0.03		23-28	24-43	66-87	(4)
Lake Vättern				17-50		0.03-0.13		40-46	75-150	170-450	(4)
Lake Vänern		~0.5	<50	25		0.03		35	40	100	(4)
Lake Vättern		<1	<50	25		0.04		40	80	200	(4)
Lake Mälaren		<1	130	65		0.095		85	135	145	(4)
Central/east		≤1				≤0.1			50-100		(5)
Central/south		0.61	20.2	18.6	7.81	0.076	4300	11.7	32.4	186	(6)
Lakes in mineralised areas of Norrbotten											
Lake Småtrasken***				25						~150	(7)
Lake Småtrasken***	21	0.7	17	55	8,89	0,06	882	5	6	170	(8)
Oinakkajärvi		0.6-0.8		~60	~7.0	0.04-0.05	~2000		~10		(9)
Jukkasjäarvi		0.6-0.8		~60	~7.0	0.04-0.05	~2000		~10		(9)
Sakajärvi				60-100		0.05-0.1					(10)
Vettasjärvi				60-100		0.05-0.1					(10)

*** The pre-industrial sediments were deposited in a stream bed environment prior to the start of mining operations in Laver in 1936.

Table 2.4 *Background values of various trace and major elements found in Swedish lakes sediments.*

Lake/location in Sweden	Al %	Be mg/kg	Ca %	Co mg/kg	K %	Mg %	Mo mg/kg	N mg/kg	P mg/kg	Sn mg/kg	Ti mg/kg	V mg/kg	W mg/kg	Reference (Table 2.3)
Impacted lakes south of Norrbotten														
Lake Gårdsjön	2.0-2.5		0.2		0.1			15000				~20		(3)
Lake Vänern								300-320	700-1600			113-141		(4)
Lake Vättern								1020-3330	600-1250			84-100		(4)
Lake Vänern		<1					<20	1500	2000	<20		160		(4)
Lake Vättern		<1					<20	1500	1000	<20		100		(4)
Lake Mälaren		<1					<20	3000	1500	<20		100		(4)
Central/south								3540	1350					(6)
Lakes in mineralised areas of Norrbotten														
Lake Småtrasken***	2	2.3	0.432	13	0.19	0.11	24		2400		480	48		
Oinakkajärvi									~2000			~20	0.3	(8)
Jukkasjäarvi									~2000			~20	0.3	(8)
Sakajärvi				5-10										(9)
Vettasjärvi				5-10										(9)

*** The pre-industrial sediments were deposited in a stream bed environment prior to the start of mining operations in Laver in 1936.

2.3 ANTHROPOGENIC SOURCES OF METALS TO EUROPE AND SCANDINAVIA

The natural metal content of sediments is thought to be primarily dependent on local geology (Förstner and Wittman, 1981; Horowitz, 1985; Håkanson and Jansson, 1983).

Several reviews of sources of metals to the environment claim that pyrometallurgical processes in non-ferrous metal industries are the main sources of As, Cd, Cu, In, Sb, Zn and to a lesser extent Pb and Se to northern Europe (Nriagu and Pacyna, 1989; Pacyna, 1997). Other major sources of metals (As, Cr, Mn, Sb, Ti, Hg, Mo, U, Ni and Se) include coal and oil combustion in power plants, industrial, commercial and residential burners. Iron and steel industries also supply Cr and Mn via the atmosphere to Scandinavia. However gasoline combustion is still considered the major contributor of anthropogenic Pb to the environment (Pacyna, 1997).

In Scandinavia, the anthropogenic metal component of lake sediments is thought to be derived primarily from atmospheric deposition (AMAP, 1997; Johansson *et al.*, 1995; Mannio *et al.*, 1997; Pacyna, 1997; Renberg, 1985, 1986; Rognerud and Fjeld, 1993; Rose *et al.*, 1997; Ross and Granat, 1986; Tarrason *et al.*, 1997; Tolonen and Jaakkola, 1983 and Verta *et al.*, 1989).

Figure 2.1 illustrates Europe's decline in atmospheric emissions of Cd, Pb and Zn since the mid 1960's and 70's (Pacyna, 1997). Pacyna stated that Central and Eastern Europe have also experienced a similar decrease in Hg since the early 1990's. However, high deposition of Ni, Cu, Cr (and to a lesser extent Pb and Zn) in north-eastern Finland and Norway probably relates to emissions from major industries at Kola Peninsula in Russia (Dauvalter, 1994, 1997).

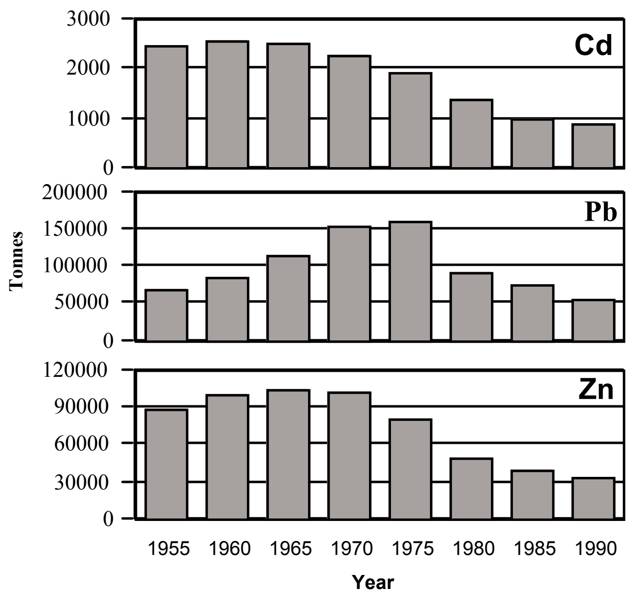


Figure 2.1 *Emission trends of atmospheric Cd, Pb, and Zn in Europe (Pacyna, 1997).*

Measurements of metals in mosses, rainfall and the atmosphere show that only the northernmost parts of Norway and Finland are affected by the industries at Kola Peninsula (Miljö 2000, 1995; Nordiska ministerrådet, 1992; Ross, 1990). The dominating wind directions in the area are north and north-west, which suggest that impact on Sweden from industrial emissons at Kola Peninsula is low.

High quantities of Fe, Mn and other metals deposited in areas of Norrbotten may reflect to emissions from mining operations at several localities such as Kiruna and Gällivare (Miljö 2000, 1995).

Table 2.5 lists quantities of metals deposited at several sites in Sweden, Norway and Finland during 1990 and 1991. These sites are located in Figure 2.2. Generally the highest level of metal deposition was measured in southern Sweden at Aspvreten. These data support the other evidence discussed in this section indicating that Sweden mainly receives anthropogenic metals from industries in Europe via the atmosphere.

Table 2.5 *Wet deposition of metals ($\mu g/m^2$) at various sites in Sweden, Norway and Finland in 1990 and 1991 (Miljö 2000, 1995). The highest deposition recorded for the respective element is given in bold.*

Metal	Liehittäja Norrbotten **Sweden** 1990	Bredkälen Jämtland **Sweden** 1990	Aspvreten Östergötland **Sweden** 1990	Noatun northern **Norway** 1991	Värriö northern **Finland** 1991
Cadmium, Cd	27	11	**96**	32	31
Copper, Cu	447	165	1007	1525	**2130**
Iron, Fe	5459	3686	**30522**	-	-
Manganese, Mn	1084	1225	**8232**	-	-
Lead, Pb	506	307	**2515**	502	1310
Zinc, Zn	2745	1459	**8325**	2603	4530
Chromium, Cr	47	36	120	102	**360**
Nickel, Ni	94	65	387	**974**	-
Vanadium, V	208	104	**1040**	-	-
Arsenic, As	104	43	**304**	205	-

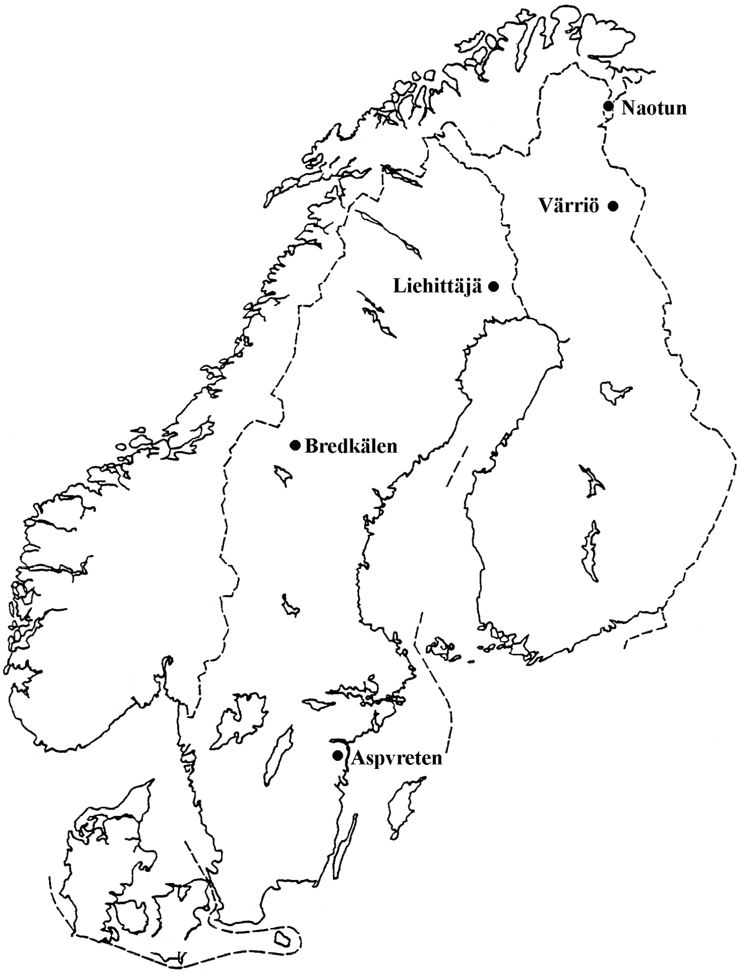


Figure 2.2 *Localities where metal deposition has been measured in Scandinavia, as referred to in Table 2.5.*

2.4 SEDIMENT PROFILES AND METAL DISTRIBUTIONS

2.4.1 Sediments in accumulation zones

Accumulation zones are normally found in the deepest parts of lakes (Håkanson, 1982). The sediments are very fine grained and contain >70 % water and >7 % organic matter. The structure of sediments from accumulation zones is very loose and the grain size is in the clay size range of <6 µm. The water content of such sediments decreases with increasing sediment depth. Concurrently the overall metal content in sediments tends to decrease as the organic matter decreases (Håkanson, 1981).

Most lakes in northern Sweden are oligotrophic and naturally low in nutrients and productivity. The organic matter in the sediments is derived from the surrounding terrestrial environment. Most of the detrital inorganic sediment particles deposited in these lakes are derived from till which is naturally low in heavy metals (Öhlander *et al.*, 1991, 1996). Hence, clay mineral rich layers in accumulation zone sediment profiles will tend to be diluted in metals relative to clay poor layers.

2.4.2 Sedimentation rates

El-Daoushy and Johansson (1983) studied 4 small Swedish lakes (areas of 0.25 to 1.5 km^2) and found sedimentation rates varied from 0.5 to 1.2 mm/y for sediments with 93 to 99 % porosity. Converting Pb-210 data from a varved sediment profile from Lake Grånästjärn (Renberg, 1986) to sedimentation rates gives deposition ranging from <0.2 to 1.6 mm/y (assuming a sediment density of 2.5 g/cm^3). Similar sedimentation rates (0.2 to 1.2 mm/y) were calculated for accumulation zone sediment data from Lakes Hauklampi and Häkläjärvi in Finland (Tolonen and Jaakkola 1983). Generally, these deposition rates are thought uniform over time and unrelated to water depth, pH or humic content (Johansson, 1989).

2.4.3 Metal distributions in lake sediments

Depth distributions

The majority of published studies of metal distributions in lake sediments of Sweden show peaks for many metals in the top 10 cm (El-Daoushy and Johansson, 1983; Håkanson, 1983, 1990; Holmström and Wennström, 1996; Johansson, 1989; Johansson *et al.*, 1985; Renberg, 1985, 1986; Widerlund, 1996). These peaks have been found in both contaminated and uncontaminated sediments. In most cases, the Pb maximum is attributed to rising atmospheric emissions from coal burning in 1800's and peaking in 1970's and 80's due to petrol combustion. Maxima in other metals at similar depths were thought to be caused by peak industrial emissions in Sweden and Europe as discussed in the above section 2.3.

In some lakes, the recent reduction of Zn, Cu and other metals in near surface sediments is thought to be a result of a combination of a reduction in metal deposition and also leaching of metals back into overlying water. In the case of Lake Gårdsjön, which has undergone a reduction in water pH from 6 to 4.5 over recent decades, metal migration from the sediment back into the overlying water is considered more important (Renberg, 1985).

Areal distributions

Generally metal concentrations in surface sediments gradually decrease from the highest levels in lakes of south Sweden to the lowest levels in lakes of northern Sweden (Håkanson, 1990; Johansson, 1989; Johansson *et al.*, 1995). For example, Pb concentrations have been measured up to 50 times higher in lakes of the south compared to those of the north (Johansson, 1989). A similar gradation has been found for other metals and also for Hg in mor layer soils of forests (Håkanson, 1990). Most workers attribute this decreasing northward trend to increasing distance from the atmospheric sources of the metals in Europe (such as East and West Germany, United Kingdom, and Poland as discussed in section 2.3). Slight variation in the natural metal content of sediments from different lakes in the same area are considered the result of differences in local geology, transport mechanisms, sediment processes and sediment chemistry (section 2.3)

2.4.4 The influence of redox chemistry on the distributions of metals in sediments

The redox cycles of Fe and Mn in sediments have been well documented over several decades (Davidson, 1985; Garrett and Hornbrook, 1976; Håkanson and Jansson; 1983, Hamilton-Taylor and Morris, 1985; Sigg, 1985; Sholkovitz, 1985; Tipping, 1984). Other heavy metals are also affected by the same cycles, which result in their solubility and mobility within the pore waters, and across the sediment water interface. These processes are also responsible for metal precipitation onto Fe-sulphides and Fe- and Mn-oxy-hydroxy compounds at different levels in the sediment (Figure 2.3).

Because many lakes in Norrbotten are oligotrophic, the bottom waters remain oxygenated all year round. Oxygen penetrates into the sediments down to varying depths. The orange-brown colour of surface sediments indicates the presence of oxygen as Fe-oxides. Deeper in the sediments oxygen becomes depleted and Fe(III)- and Mn(IV)-hydroxy compounds dissolve releasing the free metal ions, Fe(II) and Mn(II), into the pore waters. Other elements such as As, Cu, Cd, Hg, Pb, and Zn behave in the same way as Fe and Mn. The dissolved ions migrate upwards and downwards, precipitating with Fe- and Mn-oxy-hydroxy compounds in shallower oxic sediments and as Fe-sulphides in anoxic sulphur rich zones (Figure 2.3). A colour change to black or grey black indicates anoxic conditions prevail where Fe has precipitated as sulphides. A certain amount of Fe, Mn and other metal ions will migrate upwards through the sediment water interface into the overlying water.

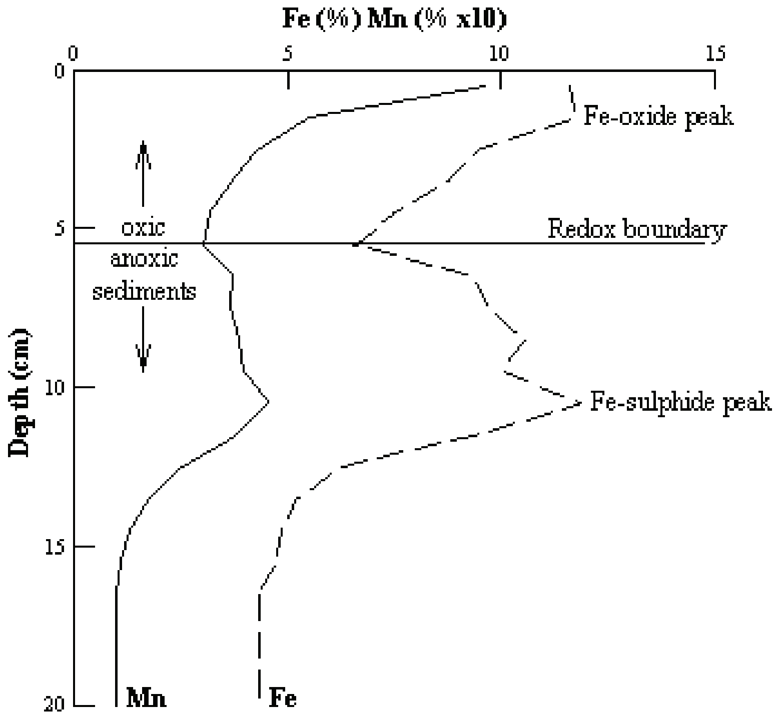


Figure 2.3 *Diagram illustrating typical Fe and Mn distributions in oligotrophic lake sediments of Djupträsket (Sweden).*

Mn-oxy-hydroxy particulates (with associated metals) generally overlie Fe-oxy-hydroxy precipitates in the sediment (Sholkovitz, 1985). The reasons are:

1) the reduction of Mn(IV)-oxides to dissolved Mn(II) occurs at a higher redox potential (2-3 ml/l of dissolved oxygen) than Fe(III) reduces to Fe(II) (approximately anoxic conditions) and

2) the re-oxidation of Fe(II) free ions to Fe(III)-oxy-hydroxy particulates is more rapid than Mn(II) to Mn(IV)-oxides.

In addition, more Mn(II) should make it into the overlying water than Fe(II) because Fe(II) ions are rapidly precipitated in Fe(III) compounds above the oxic/anoxic boundary. Consequently lake sediment profiles should naturally show maxima in Mn-oxy-hydroxy compounds (and associated heavy metals) nearest the surface and overlying peaks in Fe-oxy-hydroxy compounds (and metals associated with Fe). In some cases Fe-oxide maxima may occur below the redox boundary and well into the anoxic sediment.

Under certain conditions, as soon as Mn(II) and Fe(II) compounds are formed they are immediately precipitated as Mn-carbonates (such as rhodosite) and Fe-sulphides (such as pyrite). However lake sediments are often low in sulphides and carbonates and therefore Fe(II) and Mn(II) may remain in solution even in organic rich sediments (Davidson, 1985). In lakes where the redox boundary coincides with the sediment water interface most of the free metal ions migrate into the water column. More Mn than Fe is lost this way because Fe will rapidly precipitate as oxides and then drift back onto the sediment. This behaviour is common in freshwater sediments and results in high concentrations of red-brown Fe (and Mn to a lesser degree) precipitates at the sediment water boundary.

Chapter 3: METHODS

3.1 SAMPLING DATES AND SAMPLING SITES

Sediment cores were collected near the end of March and between 5 June and 16 July 1997, from 10 oligotrophic lakes in the county of Norrbotten (Figure 4.1). Three of the lakes were covered with ice on the sampling date; Vaimok (24 March), Njalakjaure (25 March) and Latnjajaure (5 June). The data discussed in this report from Kutsasjärvi were provided by Elsa Peinerud (Division of Applied Geology, Luleå University). The lakes are presented in Chapter 4 and maps showing the sampling sites are presented in Appendix 1.

Most sites were in accumulation zones, which are below wave base, not affected by strong internal currents and inflows, in the deepest areas of the lakes and receive a continuous supply of fine organic material.

3.2 SAMPLING

The sediments were cored with a sampler similar to a Willner sampler. This type of sampler yields a sample with an undisturbed sediment water interface (Figures 3.1, 5.1 and front cover). In some parts of some cores, vertical smearing over approximately 1 cm was observed. This applied to <1 mm of sediment around the perimeter and was not considered significant enough to warrant concern. One core was analysed from each lake. Water depth and sediment appearance was noted at each site (Table 5.1). In some lakes cores were collected from more than one location (see sediment descriptions in section 5.1, p 19), but only one core per lake was analysed.

Figure 3.1 *Core S2 (Djupträsket) from a depth of 38 m showing an undisturbed sediment-water interface and a thick mud layer at the base of the core.*

For each core, after carefully draining off overlying water, the core was sub-sampled into 1 cm segments from the surface down to a maximum depth of 20 cm. It was necessary to sample the cores in the field because the sediment texture varied from thin to thick soup and in most cases contained over 90 % water and therefore cores could not be transported intact. Sub-sampling was performed with clean plastic implements. Each 1 cm sample was put in a clean plastic container.

3.3 ANALYSIS

All analyses were performed at Svensk Grundämnesanalys AB (SGAB) in Luleå. For all samples, total solids and organic matter (as LOI) were measured. For most lakes, the first 8 cm and the basal cm of the cores were analysed for metals. *Basal cm* refers to the bottom cm of the cores. The reason for analysing this sediment is that it is likely to be older than 100 years, and thus represent sediment rather unaffected by anthropogenic activities (Sedimentation rates given in section 2.4.2 and basal cm being between 16 and 38 cm down in the sediment gives an age of 100-1900 years, depending on sedimentation rate and how far down in the sediment the basal cm is taken.). In addition to this, the full cores of Voulgamjaure (S1), Djupträsket (S2), Valkeajärvi (S9) and Kutsasjärvi (S11), were analysed for a limited number of metals. All analysis results can be found in Appendices 2 through 4.

3.3.1 Dry matter and organic matter content

The dry matter (total solid) content of each sub-sample was determined by measuring the residual after heating to 105 °C for approximately 12 hours. The organic matter content was determined by measuring the weight loss on ignition (LOI) of dried samples after 2.5 hours in a furnace at 550 °C.

3.3.2 Metal analyses

After being dried at 105 °C (50 °C for Hg), the samples were analysed in two different ways. For **As**, **Cd**, **Co**, **Cu**, **Hg**, **Ni**, **Pb** and **Zn** (given in bold in the first row of Table 3.1) samples were microwave digested with nitric acid in closed Teflon bombs (to prevent losses of volatile components). For the other elements (not given in bold in Table 3.1) 0.125 g samples were melted together with 0.375 g $LiBO_2$ and dissolved in nitric acid. This technique yields the total amount (including the crystalline forms) of the elements. The samples were centrifuged before set volumes were analysed by ICP MS and ICP AES. All results are given in either mg/kg or % dry weight.

The Swedish EPA have set up guidelines for levels of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. In this investigation it is possible to make comparisons for almost all of these elements (chromium being the exception). Because the Swedish EPA has not used the $LiBO_2$-technique described above (which yields the total amount of the elements analysed), chromium levels are bound to be higher in this investigation than the levels the EPA status classes are based upon. This is noted in section 5.2.3 (Comparison with EPA status classes and EPA background values).

The analysed elements and compounds are displayed in Table 3.1, with available detection limits in mg/kg. All data presented in this report are in elemental form. Table 3.2 presents the relative standard errors on the final metal values (Instrumental standard errors, originating from SGAB; no duplicate analyses have been performed by SGAB).

Table 3.1 *Analysed elements and compounds, with available detection limits in mg/kg (as given by SGAB). Elements given in bold are analysed with the same technique as used by the Swedish EPA, which means that the levels for these elements are comparable with the EPA guidelines. Elements and compounds not given in bold are not comparable with the EPA guidelines, since they are analysed with another technique (see section 3.3.2 for reference).*

As 0.1	**Cd** 0.01	**Co** 0.01	**Cu** 0.1	**Hg** 0.04	**Ni** 0.08	**Pb** 0.1	**Zn** 0.7
Al_2O_3	Ba 2	Be 0.5	CaO	Cr 10	Fe_2O_3	K_2O	La 5
MgO	MnO	Mo 5	Na_2O	Nb 5	P_2O_5	S	Sc 1
SiO_2	Sn 20	Sr 2	TiO_2	V 2	W 20	Y 2	Zr 2

Table 3.2 *Relative (instrumental) standard error (%) on the elements of this study (as given by SGAB).*

Al 1	As 15	Ba 4	Be 4	Ca 2	Cd 10	Co 12	Cr 16	Cu 10	Fe 4	Hg 15
K 2	La 4	Mg 1	Mn 4	Mo 4	Na 9	Nb 10	Ni 10	P 4	Pb 10	Sc 2
Si 1	Sn 10	Sr 4	Ti 1	V 4	W 10	Y 2	Zn 4	Zr 2		

Chapter 4: DESCRIPTIONS OF THE INVESTIGATED LAKES

4.1 LAKE GEOGRAPHICS

The geographical locations of the investigated lakes are shown in Figure 4.1 (Detailed maps with the location of the sampling site of each lake are shown in Appendix 1.). Almost all of the lakes are small forest lakes. Three of the lakes, Latnjajaure, Vaimok, and Njalakjaure, are mountain lakes situated in the alpine region of Norrbotten. Figure 4.2 shows the altitudes above sea level for the lakes. The lakes are situated at higher altitudes above sea level towards the north-west part of the county.

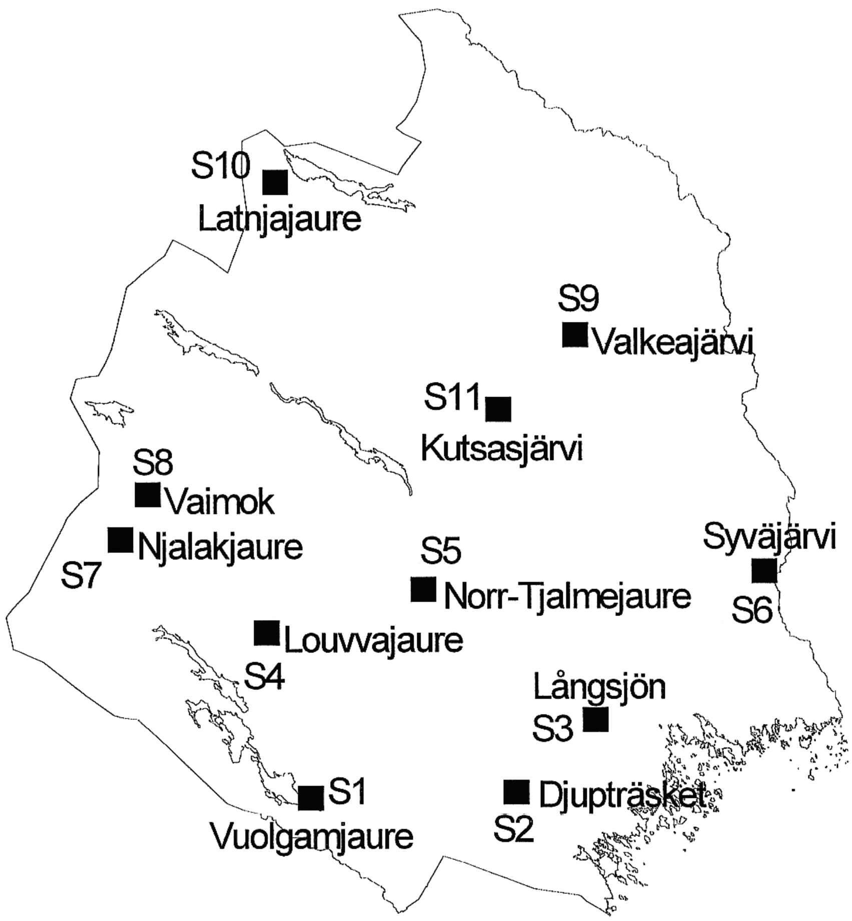


Figure 4.1 *Map of Norrbotten County showing the position of lakes in this study.*

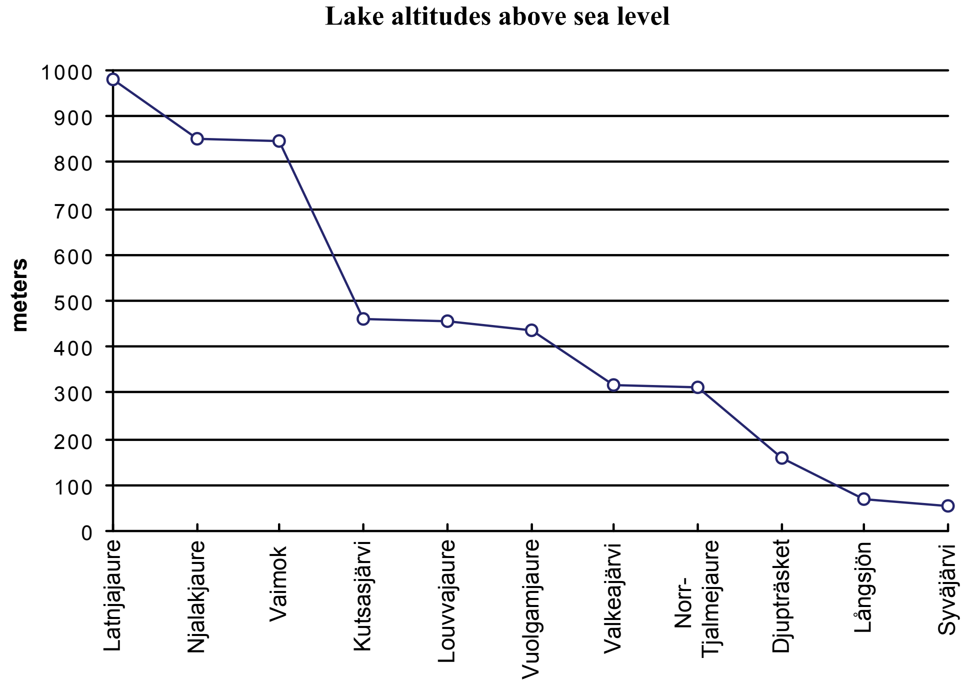


Figure 4.2 *Lake altitudes above sea level.*

The Swedish Register of Lakes contains information about the geographic position of each lake in Sweden, as well as information about which drainage area the lakes are situated within and which size class each lake belongs to (SMHI, 1983). For the lakes in this investigation, this information is displayed in Table 4.1. The different size classes are signified by area codes; **A** >100 km^2, **B** 10-100 km^2, **C** 1-10 km^2, **D** 0.1-1 km^2, **E** <0.1 km^2.

Table 4.1 *The lakes investigated; Core refers to the core name used in this study, X and Y signifies the coordinates of the outlet of each lake (Swedish national coordinate system, Rt90), Drainage area signifies which of the major rivers' drainage area each lake is situated within. The size classes are explained in the text.*

Name	**Core**	**Map** topographic	**X**	**Y**	**Drainage area** no. (name)	**Area code** (Size class)
Vuolgamjaure	S1	24 I	728744	162653	20 (Skellefteälven)	C (1-10 km^2)
Djupträsket	S2	24 K NO	729023	172515	13 (Piteälven)	C (1-10 km^2)
Långsjön	S3	25 L NV	732566	176330	9 (Luleälven)	C (1-10 km^2)
Louvvajaure	S4	26 I	736804	160569	13 (Piteälven)	C (1-10 km^2)
Norr-Tjalmejaure	S5	26 J NO	738907	168105	9 (Luleälven)	C (1-10 km^2)
Syväjärvi	S6	26 M NO	739775	184441	1 (Torneälven)	D (0.1-1 km^2)
Njalakjaure	S7	27 G	741340	153576	20 (Skellefteälven)	D (0.1-1 km^2)
Vaimok	S8	27 G	743506	154909	13 (Piteälven)	11.4*
Valkeajärvi	S9	29 L SV	751252	175433	1 (Torneälven)	D (0.1-1 km^2)
Latnjajaure	S10	30 I	758677	161050	1 (Torneälven)	D (0.1-1 km^2)
Kutsasjärvi	S11	28 K NV	747651	171735	4 (Kalixälven)	C (1-10 km^2)

* Vaimok should have area code B, but since it is close to the smaller size class (C) its area is noted instead of its area code.

4.2 PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE LAKES

Six lakes in this investigation are used as reference lakes in Swedish environmental monitoring programs; Vaimok and Valkeajärvi in the regional program and Vuolgamjaure, Louvvajaure, Njalakjaure and Latnjajaure in the national program. Data from the analyses performed within the environmental monitoring programs are available from the Swedish EPA (Table 4.2). Physical and chemical data for the rest of the lakes in this investigation are not available.

All lakes in this investigation are oligotrophic in character and freeze over from November to May each year. The mountain lakes (Latnjajaure, Njalakjaure and Vaimok) often stay frozen until July. All the lakes studied have clear surface waters and low conductivity, total-N and total-P.

Table 4.2 *Physical and chemical data on the lake waters.The data are averages from 1991 to 1997; early March-late April/mid August-late August (winter/summer) [n=2-6].*

Lake	Sample depth (m)	Temperature (°C) Winter/ summer	pH Winter/ summer	Conductivity (mS/m 25°C) Winter/ summer	Secchi depth (m) Aug-Sep	Total-N (µg/l) Winter/ summer	Total-P (µg/l) Winter/ summer
Vuolgamjaure	2	1.6/14.7	6.6/6.9	2.6/2.2	4.9	242/241	8/10
Louvvajaure	2	1.4/15.7	6.8/7.3	2.9/2.9	9.4	185/211	8/5
Njalakjaure	2	0.7/9.2	6.3/6.5	1.2/0.9	5.0	147/228	8/6
Vaimok	2	0.5/7.2	6.2/6.4	1.0/0.9		234/214	7/8
Valkeajärvi	2	1.9/13.9	6.5/7.1	3.1/2.7	6.3	230/173	7/12
Latnjajaure	2	0.0/7.4	6.2/6.5	2.0/1.8	9.0	215/124	6/7

Chapter 5: RESULTS AND DISCUSSION

5.1 DESCRIPTION OF THE SEDIMENT IN THE CORES

Most cores contained sediment that had a texture like homogenised soup, having greater than 95 % water at the surface which graded to approximately 90 % water at depths of around 20 cm (Figure 5.1, Table 5.1). The organic matter content was ~30 % (15-50 %) at the surface and ~25 % (5-45 %) at depths of around 20 cm (Appendix 5). In most cases, the top 0.5 to 2 cm of sediment was a definite orange or orange brown colour rich in Fe oxides. Below the top layer, the sediment was generally homogeneous, brown or green-brown and thickened with depth.

Figure 5.1 *Core S9 (Valkeajärvi) showing the homogeneous, soup-like, texture of the core. This texture is typical of most cores taken*

The mountain lakes, Vaimok (S8) and Latnjajaure (S10), were lower in water content (~80 %), higher in mineral particles (Table 5.1) and had variable coloured sediment layers ranging from yellow, brown, black to blue-grey. In the case of Latnjajaure, the sediment had shiny particles that resembled muscovite and occasional angular pebbles of a quartzo-feldspathic nature. The organic matter content for these two lakes, along with Djupträsket (S2), was slightly lower than for the rest of the lakes; ~15 % at the top and ~10 % (5 % for S2) at the bottom of the cores (Appendix 5).

Cores S2 (Djupträsket, Figure 3.1) and S6 (Syväjärvi, figure on front cover) had blue-grey muddy horizons that indicated periods of enhanced siltation in recent times. In both lakes the mud horizons were found to have uniform thickness and extend horizontally across the entire lake area. In the case of Syväjärvi, there was evidence around the lake of extensive tree clearing and planting in recent decades. Hence, a major tree clearing event may have exposed soils that were subsequently washed into Syväjärvi forming the 0.5 cm or so of muddy sediment found at a depth of 3 cm throughout the lake (Table 5.1). In some areas of the lake, the sediment was black (anoxic) below this layer which suggested that the mud may form a barrier to downward penetrating oxygen.

In contrast, the thicker layer of mud observed in Djupträsket (Figure 3.1) was found at sediment depths ranging from the surface to 15 cm down in the cores from several deep holes in the lake. This silt layer, which was found to be at least 5 to 7 cm thick indicates a much more significant erosive event than the thin skin of mud observed in Syväjärvi. There was no evidence of recent land clearing in the forests surrounding Djupträsket. However, a railway causeway runs across the north-western corner of the large neighbouring lake Stor-Teuger and it is possible that during the building of the causeway, dams, stream diversions and wide areas of exposed land and soils may have been significant enough to have supplied a thick layer of mud to Djupträsket.

Table 5.1 *Description of the sediment cores*

Lake	Core	Water depth (m)	Sediment colour and description
			All sediment had a texture like homogenised soup and thickened with depth.
Vuolgamjaure	S1	15	The top 1 cm was orange-brown then green-brown to the base.
Djupträsket	S2	38	The top layer was orange-brown which changed at 7 cm to grey-black. Below 15 cm a blue-grey puggy mud layer formed the basal 5 cm (Figure 3.1).
Långsjön	S3	20	The top 0.5 cm was orange, then brown-orange through the top 10 cm and then green-brown to the base.
Louvvajaure	S4	11	The top 2 cm was brown grading to green-brown to the base.
Norr-Tjalmejaure	S5	7	The top 2.5 cm was orange-brown which graded to green-brown and was very watery to the base.
Syväjärvi *	S6	7	The top 0.5 cm was orange then brown-orange through the top 3 cm. A thin blue-grey mud layer (<0.5 cm) appeared at 3 cm below which the sediment was brown-black to the base.
Njalakjaure	S7	10	Coarse organic rich brown particles at the surface becoming finer towards the base.
Vaimok	S8	40	The top 1 cm was dark brown grading to lighter brown. At 7-8 cm, dark grey-brown layer. At 11-12 cm small black particles decreasing downwards. At 15 cm the colour changed from yellow to orange-brown and at 20 cm to blue-grey.
Valkeajärvi	S9	8	The top 0.5 cm was orange-brown which changed to brown down to approximately 15 cm and then green-brown to the base (Figure 5.1).
Latnjajaure	S10	24	The top 2 cm was light brown grading green-brown to 6 cm, then green-black at 6-7 cm through black to grey-black at the base (17 cm). Angular pebbles were found amongst the sediment at various depths.
Kutsasjärvi**	S11	36	The top 0.5 cm was red-orange, then the core was brown in colour to the base.

* A photo of core S6 is on the front cover of this report.
** Data from Elsa Peinerud, Division of Applied Geology, Luleå University.

5.2 LEVELS AND COMPARISON WITH EPA GUIDELINES

5.2.1 Levels of total solids, organic matter and elements analysed

All results for total solids (TS), organic matter (OM) and for each element analysed are presented in Appendices 2-4. Mean and median values for three different sediment layers (0-1 cm, 7-8 cm and basal cm) are displayed in Table 5.2. EPA status classes are available for eight of the elements, and the assigned status classes (according to the 1991 guidelines as well as to the 1998 suggsted guidelines) are presented in Table 5.3, along with mean and median values.

Since S11 (Kutsasjärvi) has been analysed in 0.5 cm layers down to 10 cm, the 0-0.5 and 7.5-8 cm layers have been selected to represent the 0-1 and 7-8 cm layers, respectively. Although S11 (Kutsasjärvi) has been analysed as far down as 36-38 cm, the 19-20 cm layer has been selected as basal cm. This is becasue almost all of the other cores have their basal cm at 19-20 cm, and it is more appropriate to compare between sediments at similar depths (for S2 (Djupträsket), S10 (Latnjajaure) and S8 (Vaimok) the basal cm is at 16-17 cm, 16-17 cm and 17-18 cm, respectively). For S11 (Kutsasjärvi), all levels are lower at 36-38 cm than at 19-20 cm (exceptions are P and Si, which have somewhat higher levels further down).

Table 5.2 *Mean and median values for three different sediment layers from 11 Norrbotten lakes. Levels are expressed as mg/kg, unless stated.*

	0-1 cm*		**7-8 cm***		**Basal cm****	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
TS %	7	5	12	11	11	11
OM %	28	29	25	25	24	23
As	18	13	8	9	6	4
Cd	0.66	0.57	0.58	0.64	0.38	0.28
Cr	77	60	52	56	56	48
Cu	33	23	20	22	22	26
Hg	0.13	0.12	0.11	0.09	0.08	0.08
Ni	19	13	10	10	11	12
Pb	44	41	27	19	12	12
Zn	155	123	117	125	131	108
Ba	413	461	401	421	336	390
Be	0.95	0.65	1.5	1.2	1.8	1.5
Co	31	11	9	8	8	9
La	89	79	98	99	109	87
Mo	35	13	20	12	16	8
Nb	9	8	9	6	10	6
S	2764	2210	3019	3410	2738	2810
Sc	7	7	9	8	9	9
Sn	25	23	23	24	23	23
Sr	104	119	102	120	107	119
V	68	60	53	56	50	52
W	33	31	24	24	24	23
Y	56	56	64	67	65	56
Zr	127	122	138	125	134	99
Si %	22	23	25	25	25	25
Al %	4.1	3.5	4.4	3.5	4.6	4.3
Ca %	0.96	1.1	0.94	1.1	0.98	1,0
Fe %	8.9	7.7	5.8	4.9	5.3	4.3
K %	1.1	1.2	1.2	1.1	1.2	0.88
Mg %	0.59	0.46	0.60	0.43	0.60	0.45
Mn	4366	2482	1489	781	868	621
Na %	0.83	0.97	0.84	0.94	0.89	0.81
P %	0.19	0.19	0.17	0.17	0.19	0.16
Ti %	0.24	0.25	0.26	0.25	0.25	0.22

* For S11 (Kutsasjärvi), the 0-0.5 and 7.5-8 cm sediment layers have been selected to represent 0-1 and 7-8 cm, respectively.

** Basal cm is represented by the 19-20 cm sediment layer for all cores, except forS2 (Djupträsket), where the 16-17 cm sediment layer is the basal cm.

5.2.2 Differences between mean and median values

Because of variances, there are differences between the mean and median values. On an average, the mean values in this investigation are higher than the median values, particularly for the 0-1 and basal cm sediment layers (Table 5.2). The bias towards high mean values is caused by higher concentration values for some metals. The differences between mean and median values result in differences in assigned status classes (Table 5.3). In approximately half of the cases, both values belong to the same status class. In the other half of the cases, the mean values generally belong to a higher status class than the median values (for Ni, 7-8 cm, and Cu, basal cm, the median values belong to a higher status class than the mean values).

5.2.3 Comparisons with EPA status classes and EPA background values

In this investigation (as mentioned in section 3.3.2) the only elements that are comparable with the EPA guidelines are **As**, **Cd**, **Cu**, **Hg**, **Ni**, **Pb** and **Zn**. To simplify the following comparison, only mean values are used. All data are presented in Table 5.3.

As
According to both sets of EPA status classes, the arsenic level is moderate/high (Class 3) in the 0-1 cm sediment and low (Class 2) further down. The level at 0-1 cm is about twice as high as EPA background values, while levels further down in the sediment are lower.

Cd
According to the 1991 guidelines, cadmium levels are low (Class 2) and according to the 1998 guidelines levels are very low (Class 1). All three levels are lower than the 1998 EPA background value, but above the natural, original level (EPA 1998).

Cr
Chromium is not comparable with the EPA guideline levels, because the method of analysis in this investigation differs from the one used by the EPA (see section 3.3.2). The $LiBO_2$-method used in this analysis yields a concentration of chromium that is up to several times higher than the EPA background values, which would result in a high (Class 4) surface (0-1 cm) concentration. This is in no way surprising, as this method yields the total concentration of the element analysed.

Cu
According to both sets of guidelines, copper levels are low (Class 2) to moderate/high (Class 3). The highest levels are found in the 0-1 cm sediment. All three levels are higher than the EPA background values.

Hg
According to the 1991 guidelines, mercury levels are low (Class 2), and according to the 1998 guidelines levels are very low (Class 1). All three levels are between the highest and lowest 1998 EPA background values.

Ni
According to the 1991 guidelines, nickel levels are low (Class 2) at the 0-1 and basal cm, and very low (Class 1) at 7-8 cm. The 1998 guidelines changes the status classes for 0-1 and 7-8 cm to classes 3 and 2, respectively. The nickel level at 0-1 cm is midway

between the 1991 and the 1998 background values. The other two levels are about the same as the lower EPA background value.

Pb
According to the 1991 guidelines, lead levels are moderate/high (Class 3) to low (Class 2). The highest levels are found in the 0-1 cm sediment. The 1998 guidelines states that all lead levels are very low (Class 1). All levels are higher than the 1991 background value, lower than the 1998 background value and much higher than the natural, original levels (EPA 1998).

Zn
According to the 1991 guidelines, all nickel levels are low (Class 2). The 1991 guidelines states that the level in the 0-1 cm sediment is low (Class 2), and that the levels further down in the sediment are very low (Class 1).

Table 5.3 *Mean and Median values for three different sediment layers from 11 Norrbotten lakes, together with corresponding Swedish EPA status classes and EPA background values (from 1991 and suggested revision 1998).*

		Mean	Class		Median	Class		Background values		
			91	98		91	98	1991**	1998**	1998***
As	0-1 cm	18	3	3	13	2	3	10	10	8
	7-8 cm	8	2	2	9	2	2			
	basal cm	6	2	2	4	1	1			
Cd	0-1 cm	0.66	2	1	0.57	2	1	0.4	0.8	0.3
	7-8 cm	0.58	2	1	0.64	2	1			
	basal cm	0.38	2	1	0.28	2	1			
Cr*	0-1 cm	77	4	3	60	3	3	20	15	15
	7-8 cm	52	3	3	56	3	3			
	basal cm	56	3	3	48	3	3			
Cu	0-1 cm	33	3	3	23	2	2	20	15	15
	7-8 cm	30	2	2	22	2	2			
	basal cm	22	2	2	26	3	3			
Hg	0-1 cm	0.13	2	1	0.12	2	1	0.10	0.13	0.08
	7-8 cm	0.11	2	1	0.09	2	1			
	basal cm	0.08	2	1	0.08	2	1			
Ni	0-1 cm	19	2	3	13	2	2	30	10	10
	7-8 cm	10	1	2	10	2	2			
	basal cm	11	2	2	12	2	2			
Pb	0-1 cm	44	3	1	41	3	1	10	50	5
	7-8 cm	27	2	1	19	2	1			
	basal cm	12	2	1	12	2	1			
Zn	0-1 cm	155	2	2	123	2	1	175	150	100
	7-8 cm	117	2	1	125	2	1			
	basal cm	131	2	1	108	2	1			

* Chromium has been analysed with a different method than the Swedish EPA uses, and is in reality not comparable with the EPA guidelines.
** Background values for north Sweden, where available
*** Natural, original levels

5.3 METAL PROFILES

5.3.1 General trends and peaks

Appendix 5 presents profiles for arsenic, sulphur, organic matter (OM), total solids (TS) and a selection of metals in the sediment cores of this investigation.

The diagrams show that despite the generally low metal concentrations in the sediment, most metals have been redistributed. Differences between lake profiles may partly result from differences in redox conditions, variation in sedimentation, deposition etc. Because of the large variation, it is not easy to sort out uniform trends for each parameter displayed in Appendix 5. However, concentrations of several elements (As, Cd, Fe, Hg, Mn, Ni, Pb and Zn) tend to decrease with depth, even though there are exceptions (e.g. Fe in Kutsasjärvi and Ni in Djupträsket increase with depth) and the levels may peak several times. Also, some elements show slight or no variation in some lakes (e.g. Cu in Norr-Tjalmejaure, Mn in Vuolgamjaure and Zn in Valkeajärvi). The most common feature for the profiles are peaks at different depths. Some peaks are easily recognised, and are associated with the probable redox conditions of the lakes (see sections 5.3.2 and 5.3.3 below). Figure 5.1 shows examples of three different kinds of profile trends.

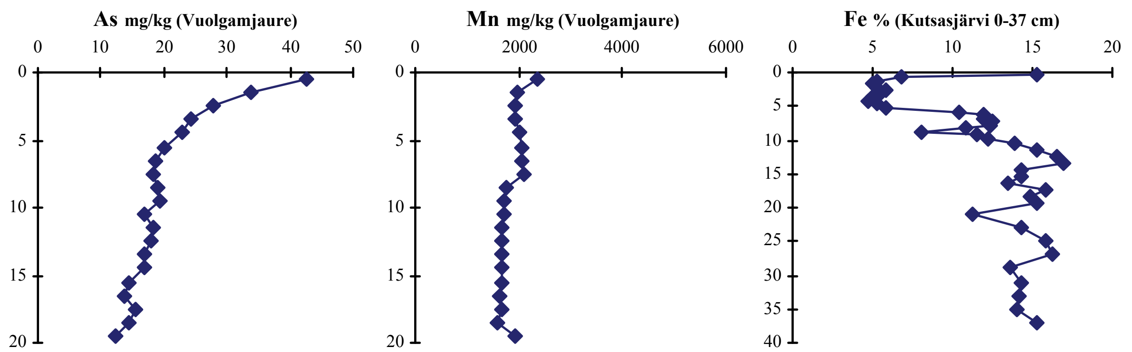


Figure 5.1 *Diagrams showing three different kinds of profile trends found in sediment in this investigation. Y-axis shows depth in cm.*

5.3.2 Oxy-hydroxy peaks

Generally Fe, Mn and the other metals peak on or just below the surface (0-3 cm; Figure 5.2). These peaks coincide with the orange-brown coloured sediment described in Table 5.1 and indicate that metals are either precipitated with or adsorbed onto Fe- and Mn-hydroxy compounds. In some core profiles, certain metal concentrations decrease in an upward direction within the top 1-2 cm of sediment (e.g. Cd in Kutsasjärvi, Figure 5.2)). This decrease may result from lower deposition, or changes in pH or other processes, causing metals to bond to the sediment to a lesser extent.

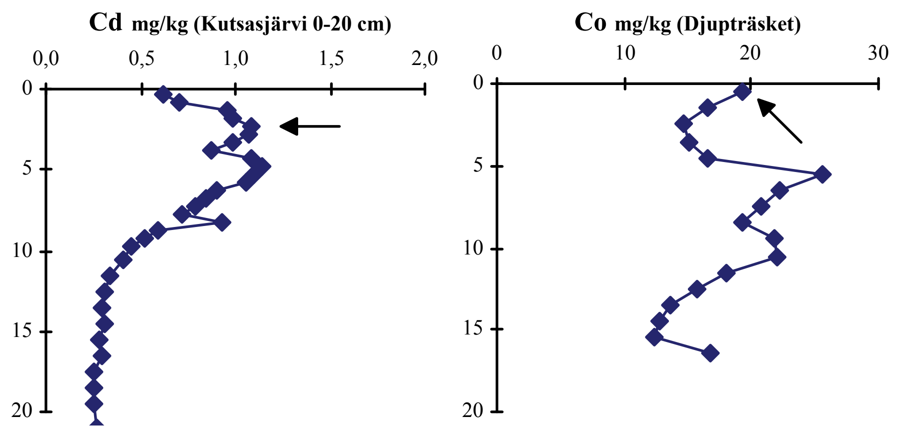


Figure 5.2 *Diagrams showing profiles for Cd in Kutsasjärvi and Co in Djupträsket. Arrows indicate the peaks mentioned in section 5.3.2 (oxy-hydroxy peaks at 0-3 cm). Y-axis shows depth in cm.*

5.3.3 Sulphide peaks

Further down in the profiles, between 4-6 cm, most metals also peak on or a short distance above the distinctive sulphur peak (Figure 5.3). These lower peaks are most likely due to either metals precipitating or adsorbing onto Fe sulphides. In the case of Syväjärvi, the sulphur peak (and corresponding metal maxima) occur at 4 cm which indicates that anoxic conditions must have prevailed in the lake sediments directly beneath the mud horizon. The presence of anoxic conditions is supported by the sediment colour change to brown/black observed immediately below the mud layer.

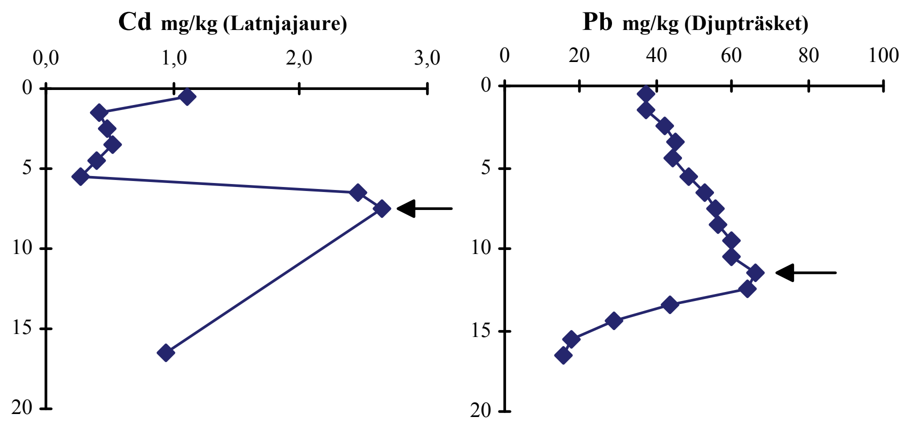


Figure 5.3 *Diagrams showing profiles for Cd in Latnjajaure and Pb in Djupträsket. Arrows indicate large sulphide peaks. Y-axis shows depth in cm.*

5.3.4 Organic matter

Generally metal distributions parallel organic matter (OM) distributions where there are no clear sulphur peaks. This behaviour indicates, as in most sedimentary environments (Horowitz, 1985; Deely and Fergusson, 1993 and Deely, 1994), that large proportions of most metals are associated with organic matter. However in the top 8-10 cm of Norrbotten's lakes, metals have been remobilised and subsequently either adsorbed or precipitated onto Fe and Mn hydroxy and sulphide compounds. The similarity in shape of the Fe, Mn and organic profiles in the top 3 cm of most cores (e.g. Njalakjaure, Figure 5.4) indicates that in these lakes Fe and Mn oxy-hydroxy compounds are associated with organic matter.

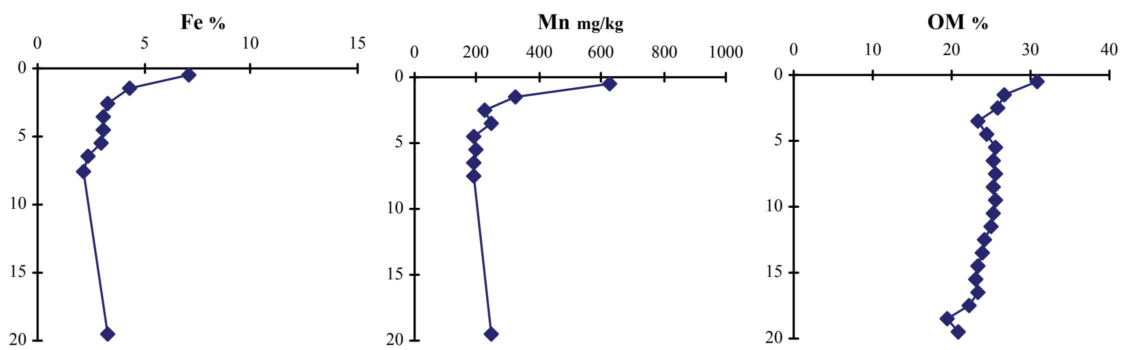


Figure 5.4 *Diagrams showing profiles for Fe, Mn and OM in Njalakjaure. Y-axis shows depth in cm.*

5.3.5 Titanium (Ti) and total solids

Total solids (TS) content increases with depth in the sediment cores (as opposed to organic matter content), as the water content decreases and the sediment is more densely packed. Whereas most metals show distributional patterns similar to organic matter, Ti profiles closely parallel total solids distributions. This is clearly visible in the profiles from Djupträsket, where both Ti and total solids peak just below 15 cm down in the sediment whereas organic matter has its minimum level at the same depth (Figure 5.5).

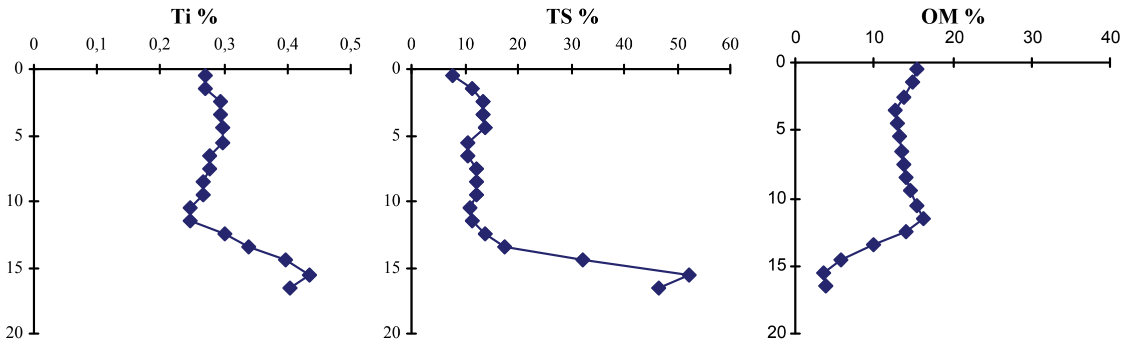


Figure 5.5 *Diagrams showing profiles for Ti, TS and OM in Djupträsket. Y-axis shows depth in cm.*

Ti (as well as Al and Zr) is a metal that is lattice bound within mineral grains and therefore not influenced by the redox processes discussed above and in section 2.4.4. In general, the mineral component (including Ti, Al and Zr) of Norrbottnian lake sediments is derived from the blanket of glacial tills that cover northern Sweden. These tills have similar or slightly lower concentrations of heavy metals compared to global baseline values for sediments (Table 5.4; Bowen, 1979; Öhlander *et al.*, 1991 and 1996).

Table 5.4 *Ranges of metals in glacial tills of northern Sweden (i) and global baseline values for metals in sediments(ii).*

Reference	**As**	**Co**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
i)	0.65-1.65	<5-15	50-100	<10-50	<0.04-0.14	<6-35	3-10	20-70
ii)	7.7	14	72	33	0.19	52	19	95

i) Öhlander et al. 1991, 1996 (mg/kg)
ii) Bowen 1979 (mg/kg)

Generally, the top 20 cm of most till deposits have been chemically weathered to the extent that metal concentrations are at the lower end of the ranges given in Table 5.4. These surface tills are eroded, transported by wind and water and eventually make up the detrital mineral component of soils on land and sediments in lakes and rivers of Norrbotten. The low metal content of the soils and sediment derived from the tills is reflected in the mud rich layers of Djupträsket (below 15 cm, Figures 5.5 and 5.6) and Syväjärvi (at 3 cm, Figure 5.6), where peaks in Ti and total solids concentrations correspond to zones of diluted metal concentrations.

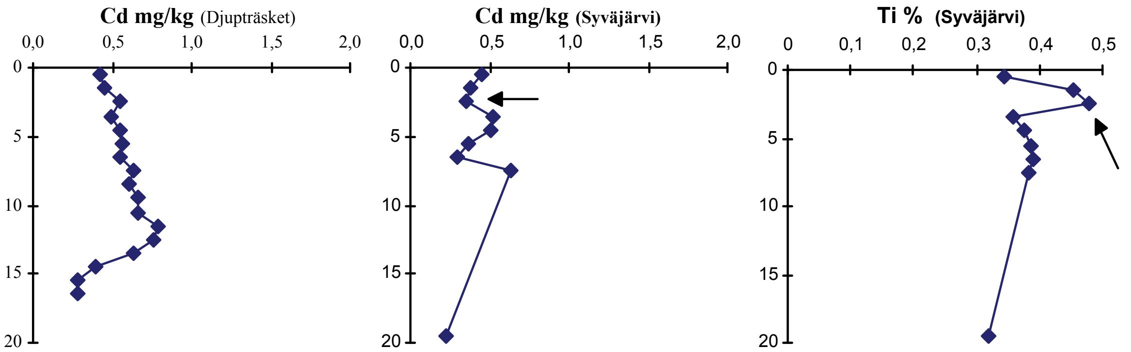


Figure 5.6 *Diagrams showing profiles for Cd in Djupträsket and Cd and Ti in Syväjärvi. Arrows indicate corresponding maxima and minima in the Syväjärvi profiles. Y-axis shows depth in cm.*

Acknowledgements

We would like to thank the following people: Elsa Peinerud (for assisting with sampling and allowing us to use her data from Kutsasjärvi in this study), Christer Ponter and Johan Ljungberg from SGAB (for supplying literature, assisting with interpreting the results and providing high quality analytical services, Peter Silverplatz from SGAB (for assisting with sampling) and Dr Johan Ingri of Luleå University for reviewing the text. In addition Joanne Deely would like to thank Environment BOP, New Zealand Ministry for Science and Technology (MORST) and Länsstyrelsen i Norrbotten Län (for funding this project).

Joanne would also like to thank Sean Hodges (for his time and expertise in preparing the figures for this document), Gunnar Brännström, Gunnar Nilsson and Lisa Lundstedt (for their time and patience in waiting while the manuscript was being prepared in New Zealand). Lastly, Joanne would like to extend a very special thanks to Gunnar, Ingrid, Hanna, Lisa and Dan for taking care of her needs while she visited Sweden.

Isabell would like to thank Anders Broberg of Department of Limnology at Uppsala University, for supplying his expertise and comments on the manuscript, and Lisa Lundstedt for valuable comments on the manuscript and for equally valuable help with the appendices.

References

Arctic Monitoring and assessment Programme (AMAP) 1997: Arctic pollution issues: a state of the arctic report. AMAP, PO Box 8100 Dep., N-0032, Norway.

Bowen, H.J.M. 1979: Environmental chemistry of the elements. Academic Press, London.

Davidson, W. 1985: Conceptual models for transport at a redox boundary. Chapter 2 in Stumm, W. Chemical processes in lakes. John Wiley & Sons, Inc: 31-53.

Dauvalter, V. 1994: Heavy metals in lake sediments of the Kola Peninsula, Russia. *The Science of the Total Environment*, **158**: 51-61.

Dauvalter, V. 1997: Heavy metal distribution in lake sediments on the Kola Peninsula and border areas between Finland, Norway and Russia. In: The AMAP International Symposium on Environmental Pollution in the Arctic. Extended abstracts. Tromsø, Norway June 1-5 1997: 324-325.

Deely, J.M. 1993: The impact of Christchurch City (New Zealand) on heavy metals and sedimentation in the Avon-Heathcote Estuary. *Water Science and Technology*, **28 (8/9)**: 369-382.

Deely, J.M.; Fergusson, J.E. 1994: Heavy metals and organic matter concentrations and distributions in dated sediments of a small estuary adjacent to a small urban area. *The Science of the Total Environment*, **153**: 97-111.

El-Daoushy, F.; Johansson, K. 1983: Radioactive lead-210 and heavy metal analyses of four Swedish lakes. *Ecol. Bull.*, **35**: 555-570.

Förstner, U.; Wittman, G.T.W. 1981: Metal pollution in the aquatic environment. 2nd edition. Springer-verlag, Berlin, Heidelberg, New York: 486p.

Garrett, R.G.; Hornbrook, E.H.W. 1976: The relationship between Zn and organic content in centre-lake bottom sediments. *Journal of Geochemical Exploration*, **5**: 31-38.

Hamilton-Taylor, J.; Morris, E.B. 1985: The dynamics of iron and manganese in the surface sediments of a seasonally anoxic lake. *Arch. Hydrobiol./Suppl.*, **72 (2)**: 135-165.

Holmström, H.; Wennström, M. 1996: Geokemiska undersökningar av sediment från fem sjöar i Svappavaaraområdet. Luleå University of Technology, Examensarbete 1996: **050 E**

Horowitz, A.J. 1985: A primer on trace element-sediment chemistry. *United States Geological Survey Water Supply Paper*, **2277**: 67p.

Håkanson, L. 1977: Sediments as indicators of contamination-investigations in the four largest Swedish lakes. NLU Rapport **92**, 159p.

Håkanson, L. 1981a: Determination of characteristic values for physical and chemical lake sediment parameters. *Water Resources Research*, **17(6)**: 1625-1640.

Håkanson, L. 1981b: Principles of lake sedimentology. 2nd edition, Springer-Verlag, 316p.

Håkanson, L. 1982: Bottom dynamics in lakes. *Hydrobiologia*, **91**: 9-22.

Håkanson, L. 1984a: Metals in fish and sediments from the river Kolbäcksån water system, Sweden. *Arch. Hydrobiol.*, **101(3)**: 373-400.

Håkanson, L. 1984b: On the relationship between lake trophic level and lake sediments. *Water Res.*, **18(3)**: 303-314.

Håkanson, L. 1990: Mercury in the Swedish mor layer- linkages to mercury deposition and sources of emission. *Water, Air and Soil Pollution*, **50**: 311-329.

Johansson, K.1989: Metals in sediments of Northern Sweden. *Water, Air and Soil Pollution*,**47**: 441-455.

Johansson, K.; Andersson, A.; Andersson, T. 1995: Regional accumulation pattern of heavy metals in lake sediments and forest soils in Sweden. *Science of the Total Environment*, **160/161**: 373-380.

Länsstyrelsen i Norrbottens län 1995: Miljö 2000, Länsstyrelsens rapportserie 1995/9, 257p.

Ljungberg, J. 1995: Vittrande Gruvavfall: Den geokemiska dynamiken och spridningen av tungmetaller från sandmagasinet vid Lavergruvan i södra Norrbotten. Länsstyrelsen i Norrbottens län rapportserie 1995/2.

Ljungberg, J.; Öhlander, B. 1996: The geochemical dynamics of oxidizing mine tailings at Laver, Northern Sweden. Submitted to *Science of the Total Environment*.

Mannio, J.; Porvari, P.; Vartiainen, T.; Witick, A.; Kinnunen K.; Verta M. 1997: Lake sediments as indicators of airborne pollution in Lapland. In: The AMAP International Symposium on Environmental Pollution in the Arctic. Extended abstracts. Tromsø, Norway June 1-5 1997:410-412

Nordiska ministerrådet 1992: Athmospheric heavy metal deposition in northern Europe 1990. Nord 1992/12.

Nriagu, J.O.; Pacyna, J.M. 1989: Quantitaive assessment of worldwide contamination of air, water and soils by trace metals. *Nature*, **333**: 134-139

Pacyna, J.M. 1997: Sources of heavy metal pollution in the Arctic. In: The AMAP International Symposium on Environmental Pollution in the Arctic. Extended abstracts. Tromsø, Norway June 1-5 1997: 140-141.

Parslow, G.R. 1977: A discussion of the relationship between Zn and organic content in centre-lake bottom sediments. *Journal of Geochemical Exploration*, **7**: 383-384.

Pontér, C. 1993: Geokemisk status i Luossajoki & Torneälvs vattensystem. Unpublished. Svensk Grundämnesanalys AB, rapport för LKAB och Kiruna Kommun, 67p.

Pontér, C.; Ljungberg, J. 1995: Geokemiska processer i Sakajärvi. Unpublished. Svensk Grundämnesanalys AB, rapport för Boliden Mineral, 35p.

Renberg, I. 1985: Influences of on the sediment chemistry of Lake Gårdsjön, SW Sweden. *Ecol.* Acidification *Bull.*, **37**: 246-250.

Renberg, I. 1986: Concentration and annual accumulation values of heavy metals in lake sediments: Their significance in studies of history of heavy metal pollution. *Hydrobiologia*, **143**: 379-385.

Rognerud, S.; Fjeld, E. 1993: Regional survey of heavy metals in lake sediments in Norway. *AMBIO*, **22**: 206-212.

Rose, N.L.; Rose, C.L.; Boyle, J.F.; Appleby, P.G.; Grimalt, J.O.; Jones V.J.;Monteith D.T.; Birks, H.J.B. 1997: The spatial and temporal distribution of atmospherically deposited pollutants on Svalbard as recorded by lake sediments. In: The AMAP International Symposium on Environmental Pollution in the Arctic. Extended abstracts. Tromsø, Norway June 1-5 1997: 86-88.

Ross, H.B.; Granat, L. 1986: Deposition of atmospheric trace metals in northern Sweden as measured in the snowpack. *Tellus*, **38B**: 27-43.

Ross, H. 1990: Övervakning av tungmetaller i nederbörden. Rapport från verksamheten 1990.

Sholkovitz, E.R. 1985: Redox-related geochemistry in lakes: alkali metals, alkaline-earth elements, and ^{137}Cs. Chapter 6 in Stumm, W. Chemical processes in lakes. John Wiley & Sons, Inc: 119-142.

Sigg, L. 1985: Metal transfer mechanisms in lakes; the role of settling particles. Chapter 13 in Stumm, W. Chemical processes in lakes. John Wiley & Sons, Inc: 283-310.

Swedish Environmental Protection Agency (EPA) 1991: Quality criteria for lakes and watercourses: A system for classification of water chemistry and sediment and organism metal concentrations [Allmänna råd 90:4]. Swedish Environmental Protection Agency, 32p.

Swedish Environmental Protection Agency (EPA) 1998: Quality criteria for lakes and watercourses. Chapter 6: Metals. Suggested revision for EPA guidelines, as of 4/27/98. Swedish Environmental Protection Agency. 18-23.

Swedish Meteorological and Hydrological Institute (SMHI) 1983: Svenskt Sjöregister (SSR) [Swedish Register of Lakes]. Sjöfartsverkets tryckeri, Norrköping.

Tarrasón, L.; Bartnicki, J.; Iversen, T. 1997: Sources, transport and atmospheric distribution of sulphur and lead in the Arctic. In: The AMAP International

Symposium on Environmental Pollution in the Arctic. Extended abstracts. Tromsø, Norway June 1-5 1997: 239-241.

Tipping, E. 1984: Temperature dependence of Mn (II) oxidation in lakewaters: a test of biological involvement. *Geochimica et Cosmochimica Acta*, **48**: 1353-1356.

Tolonen, K.; Jaakkola, T. 1983: History of lake acidification and air pollution studied on sediments in South Finland. *Ann. Bot. Fennici*, **20**: 57-78.

Verta, M.; Tolonen, K.; Simol, H. 1989: History of heavy metal pollution in Finland as recorded by lake sediments. *The Science of the Total Environment*, **87/88**: 1-18.

Widerlund, A. 1996: Suspended particulate matter, sedimentation and early diagenetic processes in the Kalix River estuary, northern Sweden. Luleå University of Technology Doctoral Thesis, 1996: **200 D**.

Öhlander, B.; Ingri J.; Pontér C. 1991: Geochemistry of till weathering in the Kalix river watershed, northern Sweden. In Chemical weathering under field conditions (ed. RosÈn, K.), Report **63**: 1-18, ISBN 91-576-4423-3.

Öhlander, B.; Land M.; Ingri J.; Widerlund A. 1996: Mobility of rare elements during weathering of till in northern Sweden. *Applied Geochemistry*, **11**: 93-99.

Appendix 1: Location maps

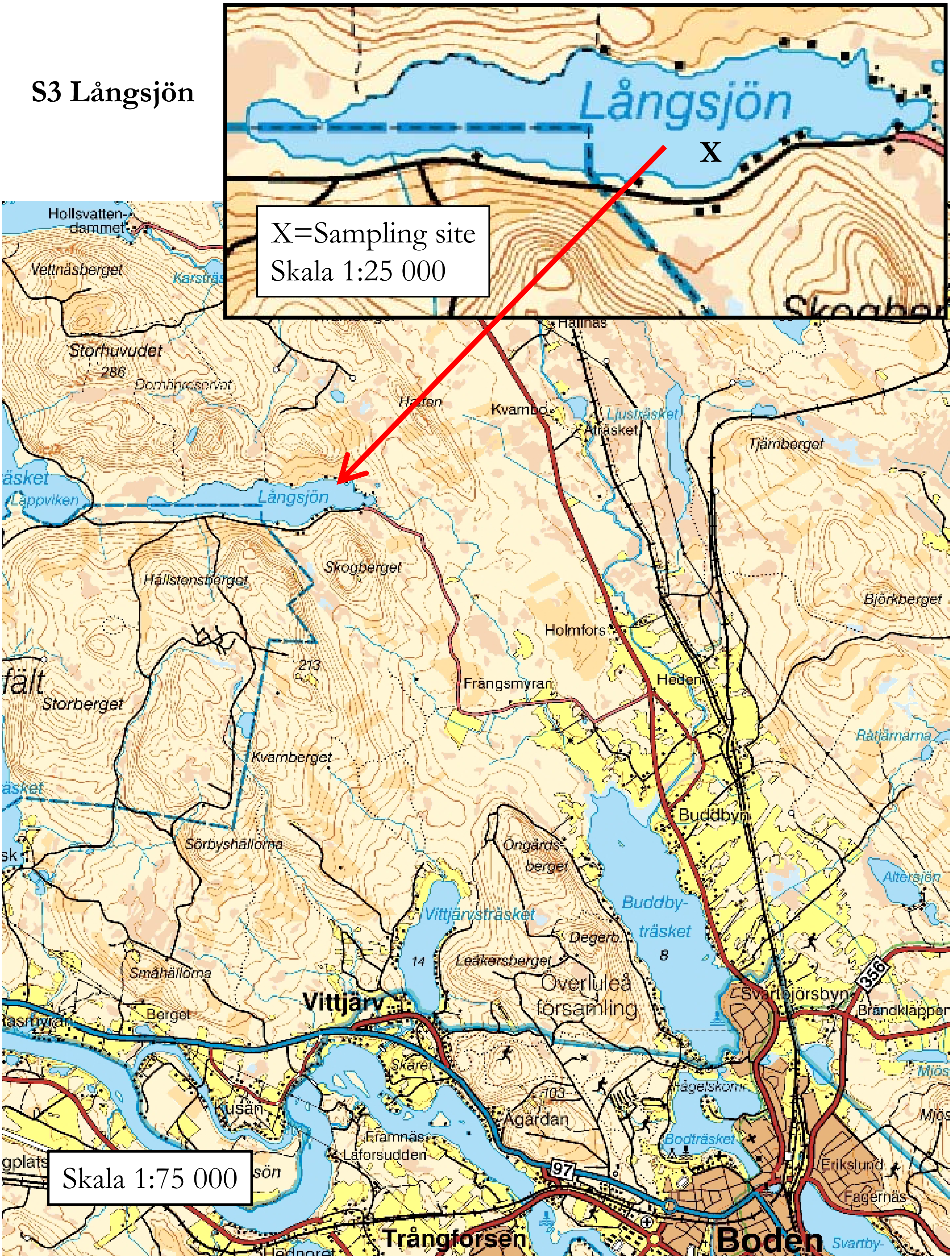
CONTENTS

core name (page)

S1 Vuolgamjaure

S2 Djupträsket

S3 Långsjön



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Kvarnbo
Ljusträsket
Aträsket
Tjämberget
Lappviken
Långsjön
Skogberget
Hällstensberget
Björkberget
Holmfors
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Frängsmyran
Heden
Storberget
Kvarnberget
Råtjärnarna
Buddbyn
Sörbyshällorna
Öngårds-
berget
Altersjön
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träsket
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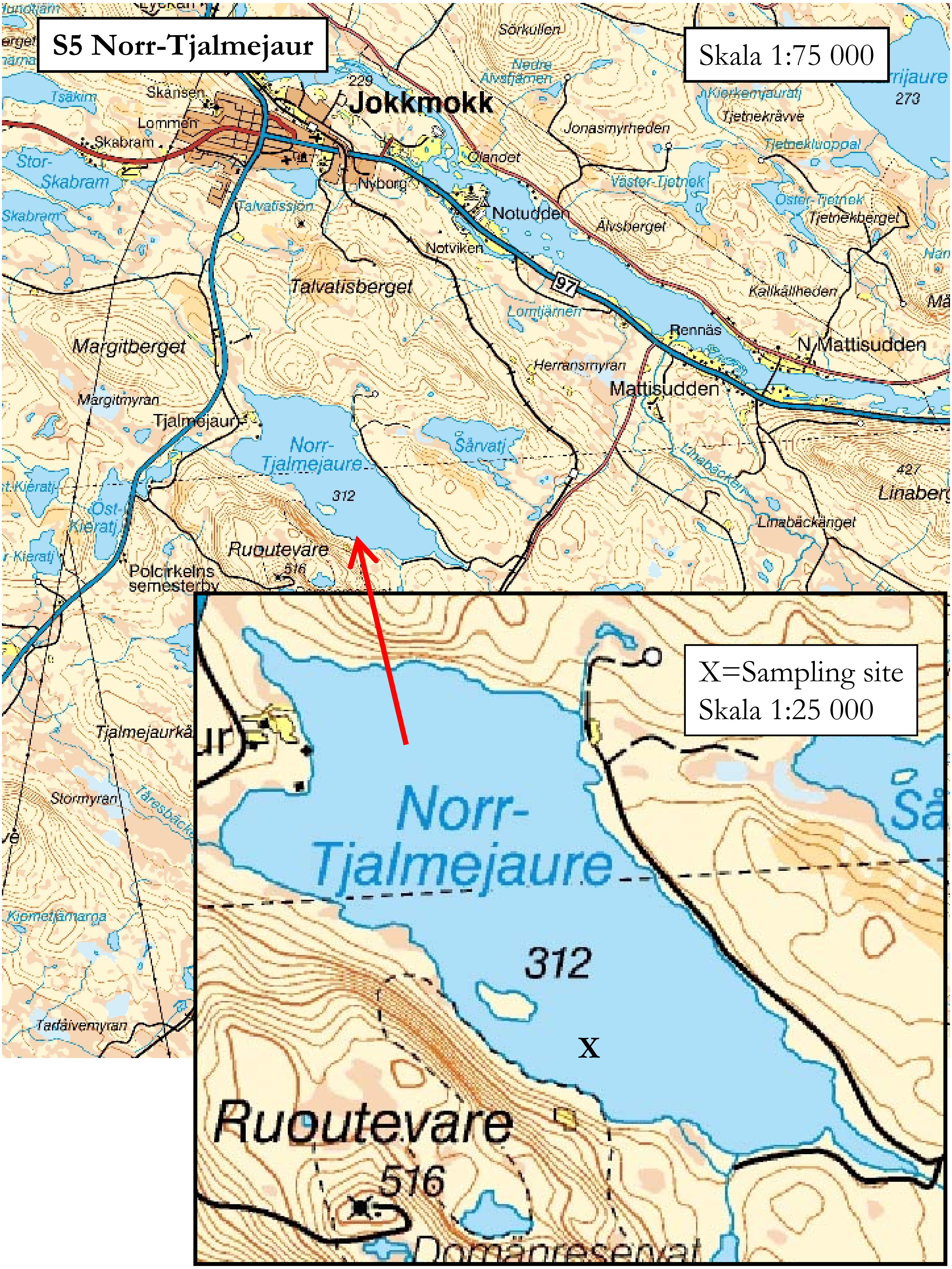
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Tsakim
Sörkullen
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Tjetnekrävve
Jonasmyrheden
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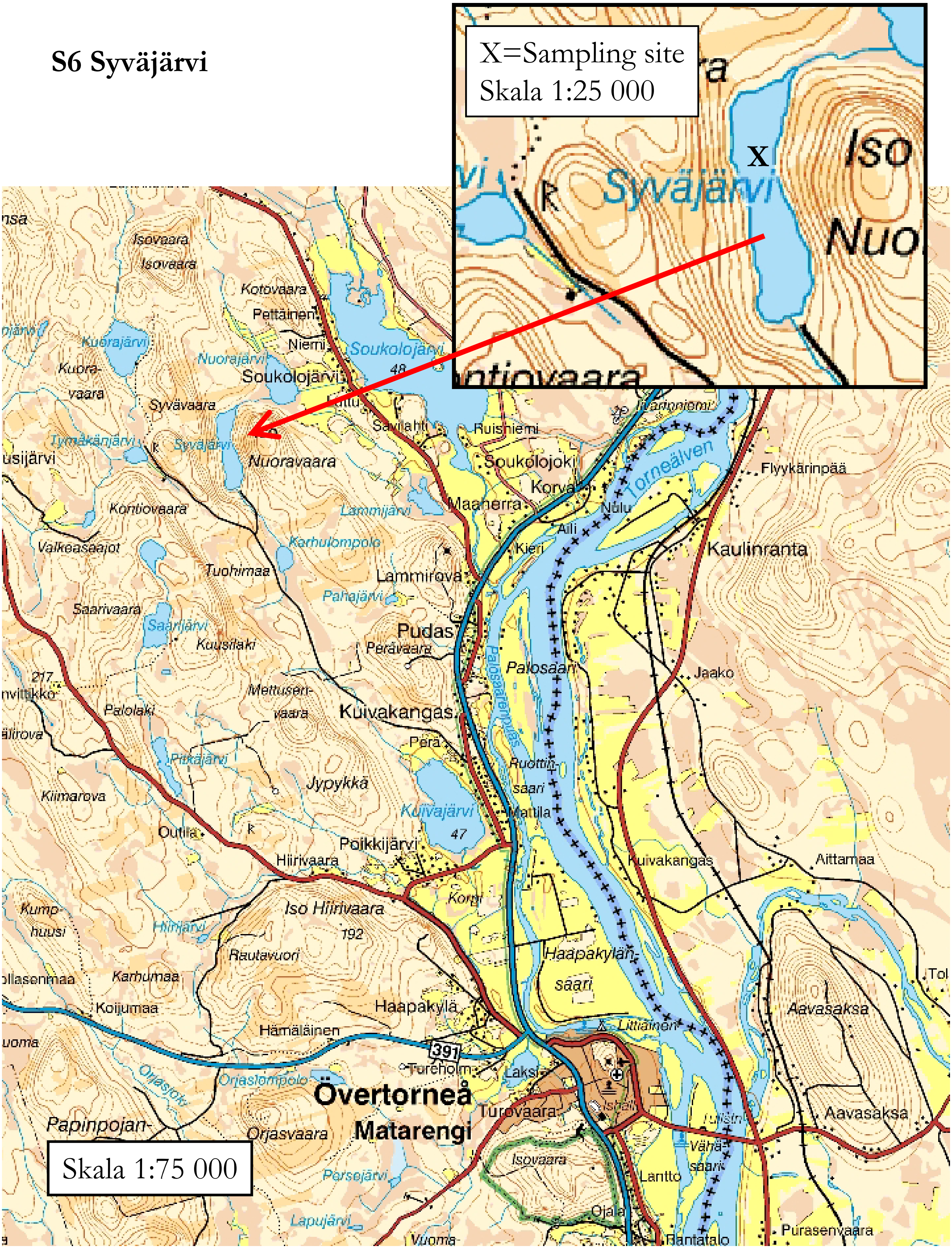
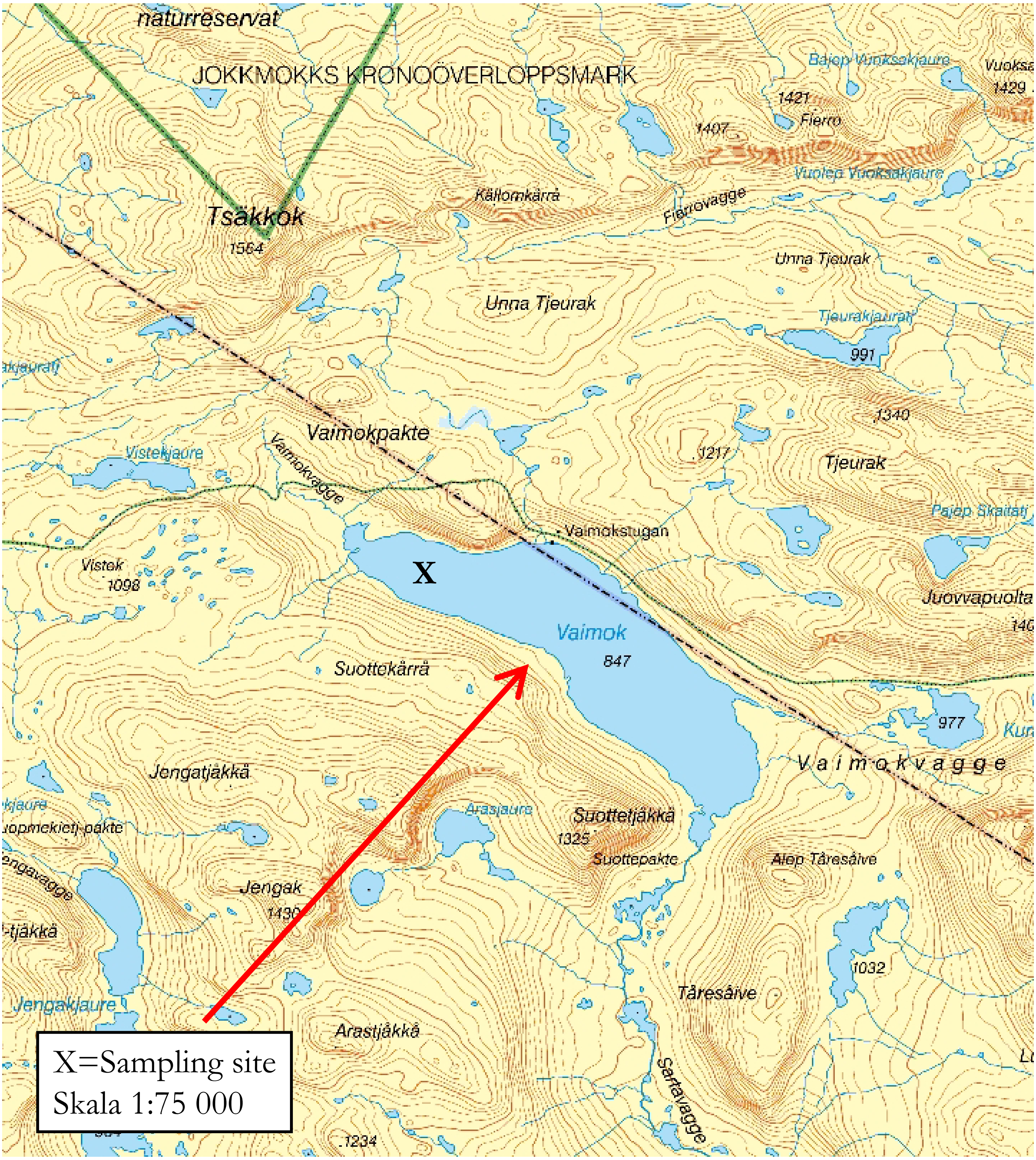


S7 Njalakjaure

S8 Vaimok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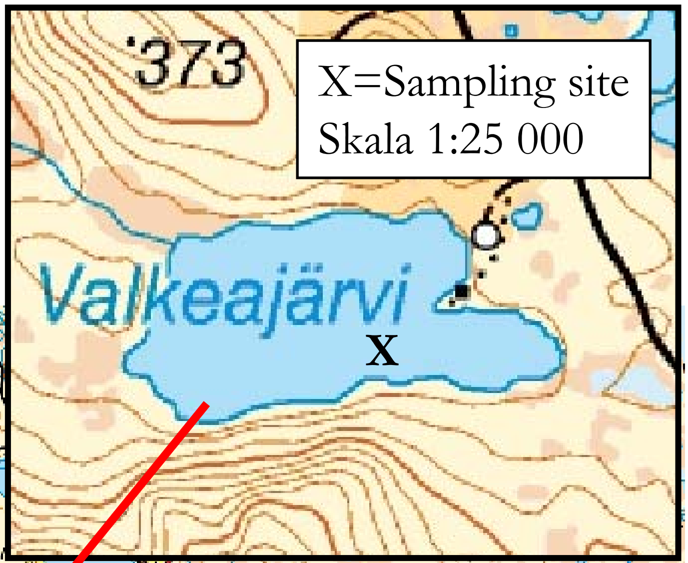
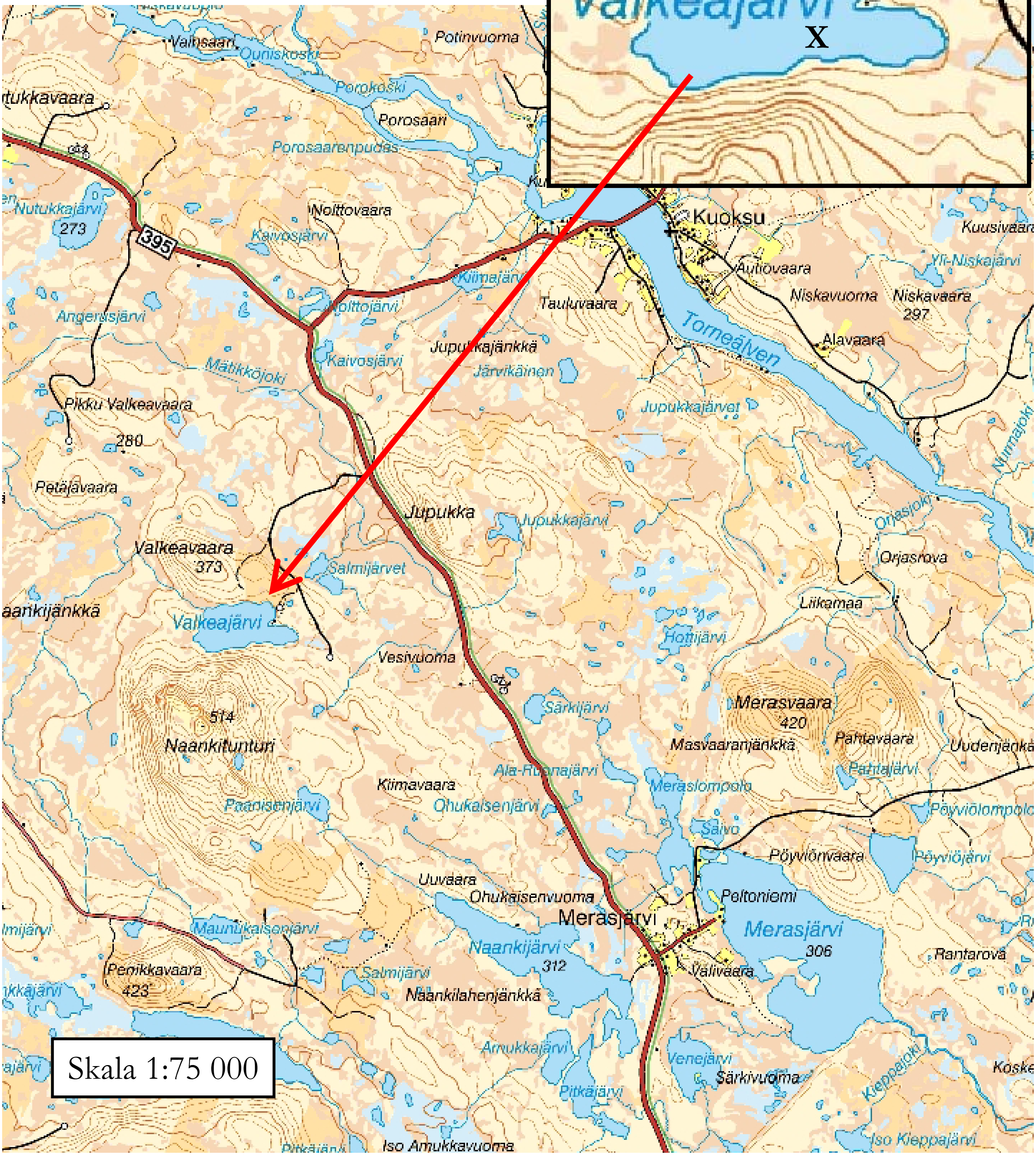
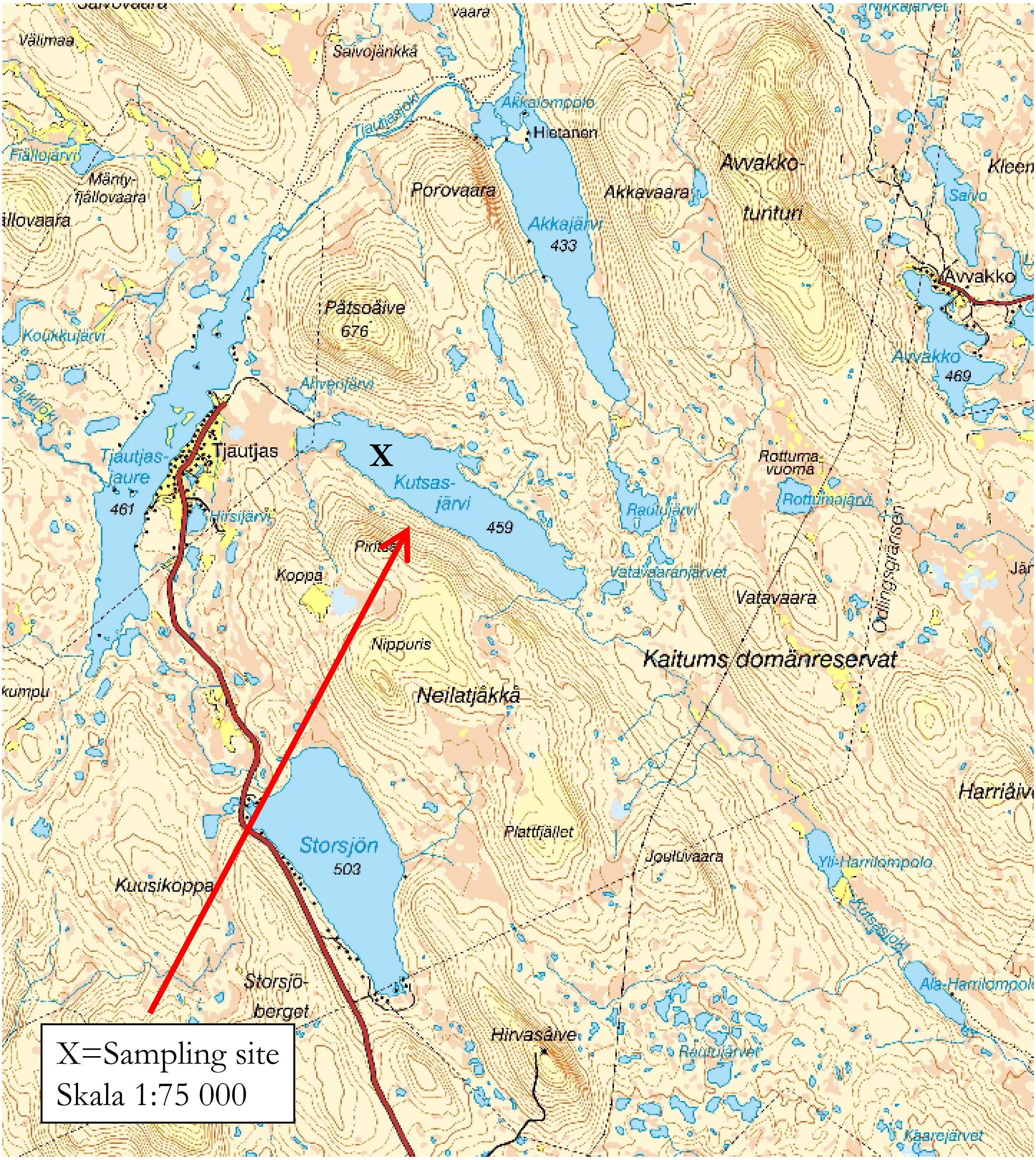




S10 Latnajaure

S11 Kutsasjärvi



Appendix 2: Analysis results 1

CONTENTS

APPENDIX 2

	TS	LOI	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	S	Zn	Mn
	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/kg
S1 0-1	2,4	36,7	42,7	0,954	8,05	37,8	9,96	0,25	6,11	45,4	5470	426	
S1 1-2	4,8	36,1	33,9	1,1	7,95	37,3	10,9	0,269	7,04	45,8	6340	528	
S1 2-3	5,5	34	27,8	1,21	8,72	33,9	11,4	0,289	7,34	54,1	7310	578	
S1 3-4	5,8	34,2	24,2	1,28	10	33,6	11,3	0,275	7,36	63,6	4000	296	
S1 4-5	5,7	33,7	22,9	1,35	11,1	37,5	11,5	0,256	7,14	69,4	4140	310	
S1 5-6	6,3	33,5	20,1	1,31	13	37,5	11,6	0,262	7,72	67,3	4370	317	
S1 6-7	6,7	33,4	18,6	1,3	14	42,7	12,3	0,331	7,99	58,4	3860	294	
S1 7-8	6,5	34,1	18,2	1,32	15,4	35,5	12,8	0,288	8,77	60,3	3920	303	
S1 8-9			19,1	1,41	14,9	12,6	14,4	0,273	9,17	52,3	3270	297	1750
S1 9-10			19,3	1,27	16,6	12,4	13,8	0,221	9,33	46,2	3160	272	1700
S1 10-11			17	1,2	17,5	12,1	13,8	0,163	9,75	41	3530	276	1710
S1 11-12			18,2	1,18	17,4	11,5	28,6	0,144	22,4	35,7	3300	271	1660
S1 12-13			18,1	1,15	16,7	12,5	11,4	0,149	8,81	34,4	3260	264	1690
S1 13-14			16,8	1,08	13,5	11,7	15,6	0,123	9,7	31,7	3080	270	1680
S1 14-15			16,8	1,05	18,6	13,2	24,7	0,131	14,3	31,6	3150	276	1670
S1 15-16			14,5	0,949	20,9	17,7	18,4	0,0954	21,2	24,5	3480	272	1650
S1 16-17			13,9	0,905	19,8	12	15,1	0,0784	12,2	21,4	3360	256	1640
S1 17-18			15,6	0,889	16	13,1	14,2	0,0806	10,7	21,4	2990	252	1650
S1 18-19			14,5	0,846	13,1	12	11,1	0,175	8,48	25,3	2900	245	1600
S1 19-20	6,7	31,5	12,4	0,804	11,9	32,1	10,5	0,185	7,91	28,2	3080	246	
S2b 0-1	7,7	16,9	49,4	0,424	19,2	56,3	21,4	0,219	14,4	37,1	959	123	
S2b 1-2	11,5	16,2	85,9	0,444	16,6	66,4	21,5	0,171	13,9	37,6	959	129	
S2b 2-3	13,3	14,5	89,7	0,547	14,6	59,9	22	0,183	14,3	42,1	1190	142	
S2b 3-4	13,5	14,2	56,3	0,493	15,1	61,3	21,4	0,24	15,2	45,4	1620	147	
S2b 4-5	13,9	14,4	33,9	0,552	16,5	65,1	23,1	0,239	15,9	44,3	1650	145	
S2b 5-6	10,6	14,7	29,7	0,557	25,5	70,1	28,2	0,191	19,2	48,7	2730	148	
S2b 6-7	10,6	14,8	51,8	0,552	22,3	71,6	26,3	0,181	17,8	52,5	1720	144	
S2b 7-8	12,2	15,1	53,7	0,636	20,8	62	28,3	0,204	19,1	55,9	1410	154	
S2b 8-9	12,2	15,4	58,9	0,603	19,4	62,7	27,9	0,225	17,9	56	1450	151	
S2b 9-10	12,3	16	52,1	0,669	21,8	62,3	28	0,224	17,8	59,9	1750	156	
S2b 10-11	11,2	16,8	71,3	0,66	22	63,7	26,6	0,238	16,6	60,2	1730	152	
S2b 11-12	11,3	17,6	45,8	0,795	18	58,5	28,9	0,222	17	66,2	1920	170	
S2b 12-13	13,9	14,5	24,5	0,755	15,8	70,8	26,5	0,229	16,6	64,3	2230	168	
S2b 13-14	17,8	10,5	16,3	0,632	13,7	68,7	23,5	0,225	16,2	43,9	1700	161	
S2b 14-15	32,2	5,9	9,42	0,395	12,8	69,3	22,2	0,117	16,8	28,7	803	143	
S2b 15-16	52,3	3,9	6,84	0,276	12,3	74,6	18,6	0,0661	16,9	17,6	456	120	
S2b 16-17	46,6	3,9	8,09	0,28	16,8	55,5	26	0,0954	17,5	15,4	620	119	
S3 0-1	3,9	8	21,1	0,607	9,07	92,1	27,9	0,203	13,7	71,6	2130	138	
S3 1-2	5,0	5,4	19	0,595	7,9	81,7	26,5	0,212	12,7	74,7	1950	146	
S3 2-3	7,1	24,8	17,8	0,813	8,06	68,9	27,4	0,233	13,1	82,9	2780	167	
S3 3-4	9,0	3,8	16,8	1	8,84	90,2	28,4	0,203	13,8	96,9	3550	179	
S3 4-5	10,7	23,6	15,5	0,999	9,1	63,8	26,1	0,231	12,9	84,9	3460	167	
S3 5-6	11,3	22	14,2	0,884	10,3	67	22,5	0,212	12,1	64,3	3370	148	
S3 6-7	13,0	20,2	11,7	0,766	8,61	64,5	22,1	0,152	11,6	52,7	2820	131	
S3 7-8	13,5	20,4	9,5	0,624	7,59	61	21,7	0,179	11,3	43,9	2350	125	
S3 19-20	11,1	28	4,27	0,275	4,86	49,5	23,5	0,126	8,43	19,2	1920	105	
S4 0-1	5,1	28,7	15,8	1,31	8,09	44,9	19,6	0,157	8,78	61,1	3470	187	
S4 1-2	5,6	25,4	9,69	1,12	4,8	35,2	20,2	0,122	7,76	49,9	3650	163	
S4 2-3	5,6	34,4	8,88	0,923	3,96	31,5	20,1	0,143	7,21	38,3	3660	164	
S4 3-4	5,7	33,5	9,73	0,84	4,19	34,2	18	0,143	6,46	30,9	3230	159	
S4 4-5	5,9	33,1	5,12	0,885	3,78	31,1	20,6	0,166	6,56	20,6	3530	133	
S4 5-6	6,1	22	4,4	0,824	4,12	66,1	22,7	0,108	6,93	13	3830	137	

	TS	LOI	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	S	Zn	Mn
	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/kg
S4 6-7	6,4	20,2	2,98	0,692	3,4	45,1	22,2	0,0951	7	7,59	3620	138	
S4 7-8	7,1	20,4	4,12	0,661	3,5	31,9	20,9	0,0959	6,75	8,21	3500	156	
S4 19-20	8,2	30,2	2,93	0,514	4,01	36,7	31,8	0,109	8,07	4,55	4750	167	
S5 0-1	6,8	35,2	13	0,415	6,9	40,7	12,9	0,0612	12,2	28,7	2190	92,4	
S5 1-2	9,0	35,7	7,64	0,462	4,16	39,6	13,1	0,0711	10,1	28,2	2120	81,6	
S5 2-3	10,6	34,4	4,09	0,788	3,46	44,6	13,7	0,0841	9,64	27,6	2270	101	
S5 3-4	9,4	33,5	4,9	0,628	3,95	43,7	13,7	0,0653	10,4	22,6	2650	118	
S5 4-5	9,0	33,1	4,2	0,376	4,26	45,9	14,1	<0,0400	11	17,5	2910	91	
S5 5-6	9,1	33,3	4,05	0,278	4,17	44	14	0,0666	10,9	15,5	3050	74,6	
S5 6-7	9,7	32,2	4,01	0,222	3,89	39,1	13,2	<0,0400	9,97	13,7	2850	71,2	
S5 7-8	9,3	33,6	3,54	0,223	3,82	50,4	14,2	0,0667	10,2	12,4	2930	75,8	
S5 19-20	9,7	30,2	4,02	0,164	4,54	40,8	15	<0,0400	11,5	3,94	2810	59,6	
S6 0-1	4,3	23,3	4,23	0,455	11,1	96,5	30,5	0,176	21,4	27,5	2080	99,9	
S6 1-2	13,8	14,8	3,66	0,384	14	109	38,7	0,108	26,2	25,8	1950	107	
S6 2-3	23,1	11,9	4,63	0,348	15,5	110	39,1	0,102	26,2	27	2240	101	
S6 3-4	14,6	21,1	8,88	0,522	13,6	99,4	37,3	0,148	28,7	35,7	2740	132	
S6 4-5	14,6	18,9	7,34	0,513	14	94,7	31	0,117	23,9	26,6	2050	132	
S6 5-6	14,8	18,9	6,98	0,36	13,7	104	33,4	0,0937	30,7	19,8	1780	116	
S6 6-7	16,2	18,4	5,95	0,296	16,6	95	33,1	0,093	30,6	17,4	1740	111	
S6 7-8	16,3	18,8	7,25	0,627	2,96	94,3	21,1	0,107	6,5	7,07	3410	147	
S6 19-20	14,4	23,2	5,18	0,224	17,2	91,2	29,7	0,0775	22,2	11,4	2310	108	
S7 0-1	5,4	24,3	31,1	0,413	14,4	44,5	25,4	0,115	10,5	50,6	4080	195	
S7 1-2	8,8	21,3	13	0,18	7,82	61,1	24,8	0,0777	10,3	36	4030	70,4	
S7 2-3	9,2	21,4	8,27	0,946	7,11	40,9	23	0,0758	10,1	27,9	4220	59,1	
S7 3-4	9,5	23,4	7,37	0,232	6,73	33,2	23,1	<0,0400	9,16	20,6	3940	54,7	
S7 4-5	10,2	24,4	8,54	0,349	5,89	39,3	41,8	0,0818	14,7	18,2	3920	55,9	
S7 5-6	8,7	25,5	7,81	0,126	5,84	42,2	19,8	<0,0400	8,85	14,7	3850	53,1	
S7 6-7	8,9	25,3	14,6	0,108	4,66	36,1	21,1	0,0498	8,18	12,7	3900	48,6	
S7 7-8	9,8	25,6	15	0,671	4,56	38,3	21,5	<0,0400	7,88	14,8	3970	44,8	
S7 19-20	10,5	20,8	11,5	0,33	7,81	46,7	30,6	<0,0400	11,5	11,3	3280	220	
S8 0-1	16,4	14,9	11,2	0,365	20,5	63,2	36,2	0,0661	12,9	56,2	2210	119	
S8 1-2	20,3	11,3	7,84	0,164	18,6	64,2	30,6	<0,0400	11,9	30,5	1880	59	
S8 2-3	19,7	11,3	6,95	0,138	19,2	78,6	30,6	<0,0400	12,2	20,1	1830	56,9	
S8 3-4	17,9	12,2	6,81	0,136	21,5	74,7	33,9	<0,0400	13,1	17,7	2050	60,4	
S8 4-5	16,2	13,5	7,42	0,118	22,3	75,9	34,7	<0,0400	12,7	14,5	2320	59,9	
S8 5-6	14,9	13,8	7,85	0,116	23,2	63,7	36,5	<0,0400	13,6	13,1	2370	63,5	
S8 6-7	16,9	12,2	7,85	0,129	24,4	79,7	34,8	<0,0400	13,6	13,3	2210	62,3	
S8 7-8	15,7	12,3	8,71	0,223	30,1	69,6	37,7	<0,0400	14,7	14,6	2340	67,5	
S8 17-18	22,3	9,6	9,33	0,16	9,93	72,7	34,9	<0,0400	14,4	11	1290	103	
S9 0-1	1,8	48,3	3,52	0,568	12,3	203	22,6	<0,100	14,8	31,4	3660	76,7	
S9 1-2	3,2	48	3,02	0,538	7,53	34,5	23,8	0,0742	14,9	35,5	4090	71,4	
S9 2-3	4,1	47,7	2,38	0,613	6,67	33,4	26,5	0,0681	16,8	35,3	4630	80,4	
S9 3-4	4,2	47,2	1,81	0,676	7,3	71,6	23,8	0,125	18,5	36,6	5200	92,1	
S9 4-5	4,1	46	1,67	0,699	7,18	41,3	22,2	0,107	17	39,2	4910	90,5	
S9 5-6	4,4	45,2	1,99	0,706	7,36	34	22,4	0,0983	17,2	39,9	4910	91,4	
S9 6-7	4,5	40,8	2,53	0,74	8,23	36,8	23,5	0,0843	16,4	38,2	4810	92,2	
S9 7-8	4,8	38,1	2,01	0,627	7,66	27,8	22,3	0,0935	14,3	29,7	4470	74,7	
S9 8-9			1,9	0,536	7,83	21	25,2	0,0726	14,5	24,5	3760	63	541
S9 9-10			1,8	0,495	8,91	23,6	27,5	0,0917	16,2	22,5	3890	63,1	555
S9 10-11			1,55	0,433	9,42	23,5	28,5	0,0834	17,8	20,3	4090	61,5	557
S9 11-12			1,57	0,363	9,22	23,4	26,9	0,0606	17,4	17	3860	48,7	531
S9 12-13			1,04	0,309	9,06	24,3	29,3	0,0726	17,5	16,3	3790	48,8	547

APPENDIX 2

	TS	LOI	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	S	Zn	Mn
	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/kg
S9 13-14			1,15	0,323	8,68	24,1	28,8	0,0616	16,9	15,7	3880	47,5	541
S9 14-15			0,878	0,304	9,52	25,2	30,3	0,0704	17,4	15,2	3880	49	522
S9 15-16			0,647	0,273	9,11	19,4	28,2	<0,0397	16,1	13,4	3940	48,9	532
S9 16-17			0,604	0,278	8,82	20	24,4	<0,0396	15,3	15	3800	47,7	521
S9 17-18			0,379	0,275	7,41	18,1	22,3	0,0733	14	12,6	3770	46,6	513
S9 18-19			0,493	0,275	7,3	18,4	23,9	0,0467	13,5	11,5	3860	48,2	504
S9 19-20	5,5	34,3	0,398	0,231	8,55	41,5	23,3	0,0634	14,4	13	4230	55	
S10 0-1	16,9	12,8	2,51	1,11	228	93	136	0,0571	91,2	26,2	1250	165	
S10 1-2	23,4	10,6	3,56	0,425	108	99,7	108	0,0669	53,3	21,9	914	141	
S10 2-3	25,7	9,9	5,37	0,483	38,3	90,1	94,6	<0,0400	32,4	15,5	539	119	
S10 3-4	25,5	9,5	3,61	0,524	29,2	108	97,4	<0,0400	35,4	16,4	446	126	
S10 4-5	22,6	10,3	3,45	0,394	37,6	104	139	<0,0400	54	22,2	595	176	
S10 5-6	20,9	11,2	4,3	0,276	33,5	98,2	138	0,0409	49,4	20,9	641	173	
S10 6-7	19,0	13	7,14	2,45	63,6	98,1	164	0,0437	90	22,3	920	193	
S10 7-8	19,9	12,2	11,2	2,64	207	115	156	0,062	204	23,4	1320	221	
S10 16-17	26,3	8,3	2,77	0,942	143	96,8	135	0,056	108	18,6	976	185	
S11 0-0,5		41,6	6,51	0,616	3,1		15,1	0,055	7,01		2910	82,4	368
S11 0,5-1		37,1	5,53	0,703	3,2		14,9	<0,152	6,89		3140	92,8	542
S11 1-1,5		36,3	4,12	0,951	3,39		15,6	0,132	7,08		3300	108	417
S11 1,5-2		38,1	4,2	0,98	4,86		15,6	0,085	7,78		3520	136	394
S112-2,5		39,5	4,52	1,09	6,87		15,8	0,28	8,07		3830	152	362
S11 2,5-3		40,2	5	1,07	6,69		16,7	0,117	8,18		3890	135	373
S11 3-3,5		40,1	4,4	0,986	6,36		16,1	0,0686	8,22		3940	141	343
S11 3,5-4		39,6	3,54	0,877	5,17		13,3	0,106	6,7		3830	133	335
S11 4-4,5		41	4,13	1,08	6,44		16,5	<0,0715	8,07		4040	140	312
S11 4,5-5		41,5	4,58	1,14	6,85		16,4	0,137	7,97		3820	141	336
S11 5-5,5		42,4	4,55	1,1	7,78		17,5	0,139	8,7		3720	142	338
S11 5,5-6		42,4	4,98	1,05	5,94		16,9	0,154	7,15		3770	135	389
S11 6-6,5		42,8	5,01	0,9	6,75		17,3	0,139	8,18		3620	123	396
S11 6,5-7		43,4	4,68	0,852	7,06		16,9	0,0676	8,28		3870	129	399
S11 7-7,5		43,6	4,26	0,795	6,11		15,3	0,0761	7,14		3750	122	398
S11 7,5-8		42,9	4	0,714	6,11		15,7	0,0818	7,29		3590	106	385
S11 8-8,5		43,6	3,79	0,933	6,45		15,9	0,054	7,45		3660	110	362
S11 8,5-9		36,4	3,65	0,595	6,8		16,2	<0,0566	7,45		3820	109	613
S11 9-9,5		43,9	3,32	0,522	7,97		17,1	0,0602	8,38		3900	105	336
S11 9,5-10		44,7	3,23	0,456	7,96		16,5	0,0501	7,75		4020	107	345
S11 10,5		42,9	2,63	0,402	7,18		13,9	0,0713	6,73		3860	90,5	357
S11 11,5		41,7	2,93	0,336	6,72		13,6	0,0466	6,2		3910	81,1	367
S11 12,5		40,2	3,2	0,314	7,03		12,4	0,04	5,87		4180	77,2	358
S11 13,5		39,4	3,2	0,292	7,39		12,1	<0,0397	5,86		4380	74	374
S11 14,5		39,8	3,21	0,311	7,78		13,1	0,0454	6,31		4340	81,1	360
S11 15,5		39,5	3,4	0,285	7,64		13,1	0,0454	6		4360	79,3	370
S11 16,5		40,7	3,41	0,3	8,12		14,6	0,0678	6,75		4500	84,1	333
S11 17,5		39,2	3,26	0,253	7,3		12,6	0,062	5,83		4460	73,4	364
S11 18,5		40,6	3,33	0,25	6,83		14,4	<0,0388	5,85		4660	74,6	341
S11 19,5		39,8	3,51	0,254	7,15		13,5	0,0794	6,02		4850	70,5	330
S11 21		43,8	3,61	0,266	7,33		13	<0,0395	6,21		4870	68,8	347
S11 23		36,6	3,51	0,209	5,06		11,7	0,0699	5,08		4040	59,8	336
S11 25		35,9	3,37	0,185	5,24		11,4	0,0513	5,27		4320	57,6	352
S11 27		37,5	3,4	0,211	6,82		11,8	0,0409	5,77		4440	58,2	323
S11 29		38,6	3,15	0,22	6,56		12,5	<0,0394	5,83		4530	68	282
S11 31		37,7	3,29	0,193	6,34		13,3	0,0667	6,04		4400	61,6	294

APPENDIX 2

	TS	LOI	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	S	Zn	Mn
	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/kg
S11 33		36,8	3,21	0,176	6,07		13,4	0,0575	6,12		4080	61	294
S11 35		35,4	2,55	0,156	6,13		12,6	<0,0396	6,4		3980	55,5	293
S11 37		34,7	2,59	0,16	5,7		11,7	0,0451	5,61		4090	52,9	296

Appendix 3: Analysis results 2

CONTENTS

SiO_2
Al_2O_3
CaO
Fe_2O_3
K_2O
MgO
MnO_2
Na_2O
P_2O_5
TiO_2

Si
Al
Ca
Fe
K
Mg
Na
P
Ti

Total sum

APPENDIX 3

	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO_2	Na_2O	P_2O_5	TiO_2	Si	Al	Ca	Fe	K	Mg	Na	P	Ti	Summa
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
S1 0-1	35,4	4,53	1,04	19,4	0,551	0,225	0,373	0,443	0,43	0,138	16,6	2,40	0,75	13,58	0,46	0,14	0,328	0,189	0,083	62,5
S1 1-2	38,9	4,99	0,63	16,9	0,563	0,236	0,312	0,467	0,409	0,16	18,2	2,64	0,45	11,83	0,47	0,14	0,346	0,180	0,096	63,6
S1 2-3	41,3	5,4	0,646	15,7	0,588	0,245	0,307	0,502	0,409	0,175	19,3	2,86	0,47	10,99	0,49	0,15	0,371	0,180	0,105	65,3
S1 3-4	41,5	5,42	0,663	15,2	0,612	0,252	0,304	0,52	0,428	0,175	19,4	2,87	0,48	10,64	0,51	0,15	0,385	0,188	0,105	65,1
S1 4-5	41,5	5,56	0,725	15,9	0,663	0,265	0,317	0,531	0,478	0,182	19,4	2,95	0,52	11,13	0,55	0,16	0,393	0,210	0,109	66,1
S1 5-6	41,2	5,68	0,771	16,3	0,672	0,273	0,327	0,539	0,459	0,188	19,3	3,01	0,56	11,41	0,56	0,17	0,399	0,202	0,113	66,4
S1 6-7	40,2	5,88	0,602	17,2	0,533	0,233	0,329	0,513	0,38	0,177	18,8	3,12	0,43	12,04	0,44	0,14	0,380	0,167	0,106	66
S1 7-8	41,1	5,8	0,626	16,7	0,541	0,234	0,335	0,501	0,376	0,175	19,2	3,07	0,45	11,69	0,45	0,14	0,371	0,165	0,105	66,4
S1 19-20	46	5,93	0,536	13,1	0,466	0,206	0,303	0,472	0,329	0,17	21,5	3,14	0,39	9,17	0,39	0,13	0,349	0,145	0,102	67,5
S2b 0-1	47,5	10,1	1,57	16,6	2,35	1,26	1,53	1,84	0,424	0,452	22,2	5,35	1,13	11,62	1,95	0,77	1,362	0,187	0,271	83,6
S2b 1-2	48,6	10,1	1,44	16,8	2,34	1,24	0,871	1,83	0,453	0,45	22,7	5,35	1,04	11,76	1,94	0,76	1,354	0,199	0,270	84,1
S2b 2-3	52,2	11	1,5	13,6	2,57	1,34	0,686	2,01	0,539	0,49	24,4	5,83	1,08	9,52	2,13	0,82	1,487	0,237	0,294	85,9
S2b 3-4	53	11,1	1,46	12,6	2,57	1,33	0,584	2,02	0,498	0,493	24,8	5,88	1,05	8,82	2,13	0,81	1,495	0,219	0,296	85,7
S2b 4-5	54,4	11,2	1,44	10,7	2,55	1,33	0,503	2,02	0,419	0,496	25,5	5,94	1,04	7,49	2,12	0,81	1,495	0,184	0,298	85,1
S2b 5-6	56,4	11,2	1,61	9,42	2,67	1,37	0,478	2,03	0,486	0,497	26,4	5,94	1,16	6,59	2,22	0,84	1,502	0,214	0,298	86,2
S2b 6-7	53,2	10,5	1,52	13,4	2,5	1,28	0,585	1,9	0,502	0,462	24,9	5,57	1,09	9,38	2,08	0,78	1,406	0,221	0,277	85,8
S2b 7-8	52,8	10,5	1,53	13,9	2,5	1,28	0,579	1,9	0,552	0,464	24,7	5,57	1,10	9,73	2,08	0,78	1,406	0,243	0,278	86
S2b 8-9	51,6	10,2	1,42	15,1	2,37	1,23	0,612	1,8	0,499	0,445	24,1	5,41	1,02	10,57	1,97	0,75	1,332	0,220	0,267	85,3
S2b 9-10	52,5	10,4	1,42	14,4	2,43	1,26	0,625	1,82	0,504	0,447	24,6	5,51	1,02	10,08	2,02	0,77	1,347	0,222	0,268	85,8
S2b 10-11	50,3	9,64	1,32	17	2,24	1,16	0,721	1,67	0,482	0,412	23,5	5,11	0,95	11,90	1,86	0,71	1,236	0,212	0,247	84,9
S2b 11-12	51,8	9,91	1,27	13,4	2,21	1,16	0,599	1,67	0,429	0,413	24,2	5,25	0,91	9,38	1,83	0,71	1,236	0,189	0,248	82,9
S2b 12-13	56	11,5	1,49	8,91	2,67	1,38	0,398	2,04	0,402	0,5	26,2	6,10	1,07	6,24	2,22	0,84	1,510	0,177	0,300	85,3
S2b 13-14	58	12,6	1,77	7,47	3,13	1,6	0,281	2,38	0,403	0,564	27,1	6,68	1,27	5,23	2,60	0,98	1,761	0,177	0,338	88,2
S2b 14-15	60,9	14,5	1,9	6,9	3,45	1,89	0,209	2,78	0,254	0,662	28,5	7,69	1,37	4,83	2,86	1,15	2,057	0,112	0,397	93,4
S2b 15-16	61,3	14,8	2,21	6,77	3,89	2,03	0,172	3,02	0,307	0,723	28,7	7,84	1,59	4,74	3,23	1,24	2,235	0,135	0,434	95,2
S2b 16-17	62,7	14,5	2,2	6,19	3,51	1,78	0,161	3,1	0,259	0,675	29,3	7,69	1,58	4,33	2,91	1,09	2,294	0,114	0,405	95,1
S3 0-1	55,3	9,96	1,79	17,6	1,68	1,22	0,394	1,64	0,533	0,527	25,9	5,28	1,29	12,32	1,39	0,74	1,214	0,235	0,316	90,6
S3 1-2	58,4	10,5	1,95	16,2	1,9	1,31	0,327	1,8	0,568	0,57	27,3	5,57	1,40	11,34	1,58	0,80	1,332	0,250	0,342	93,5
S3 2-3	48,6	8,91	1,59	10,7	1,5	1,05	0,201	1,51	0,399	0,463	22,7	4,72	1,14	7,49	1,25	0,64	1,117	0,176	0,278	74,9
S3 3-4	63,1	11,3	2,08	11,7	2	1,36	0,203	1,93	0,568	0,604	29,5	5,99	1,50	8,19	1,66	0,83	1,428	0,250	0,362	94,8
S3 4-5	52,1	9,55	1,78	8,56	1,61	1,11	0,144	1,64	0,443	0,49	24,4	5,06	1,28	5,99	1,34	0,68	1,214	0,195	0,294	77,4

APPENDIX 3

	SiO2	Al2O3	CaO	Fe2O3	K2O	MgO	MnO2	Na2O	P2O5	TiO2	Si	Al	Ca	Fe	K	Mg	Na	P	Ti	Summa
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
S3 5-6	52,7	9,98	1,84	8,04	1,68	1,14	0,131	1,79	0,398	0,516	24,7	5,29	1,32	5,63	1,39	0,70	1,325	0,175	0,310	78,2
S3 6-7	54,3	10,5	1,96	7,62	1,81	1,2	0,129	1,93	0,423	0,549	25,4	5,57	1,41	5,33	1,50	0,73	1,428	0,186	0,329	80,4
S3 7-8	54,5	10,5	1,99	7,18	1,82	1,19	0,124	1,95	0,438	0,556	25,5	5,57	1,43	5,03	1,51	0,73	1,443	0,193	0,334	80,2
S3 19-20	52,6	8,06	1,42	6,76	1,06	0,733	0,116	1,09	0,569	0,366	24,6	4,27	1,02	4,73	0,88	0,45	0,807	0,250	0,220	72,8
S4 0-1	51,5	5,38	1,46	8,97	0,592	0,367	0,957	0,442	0,399	0,187	24,1	2,85	1,05	6,28	0,49	0,22	0,327	0,176	0,112	70,3
S4 1-2	57	5,65	1,73	6,69	0,627	0,419	0,334	0,5	0,418	0,228	26,7	2,99	1,25	4,68	0,52	0,26	0,370	0,184	0,137	73,6
S4 2-3	52,6	5,31	1,5	5,21	0,472	0,291	0,132	0,374	0,302	0,165	24,6	2,81	1,08	3,65	0,39	0,18	0,277	0,133	0,099	66,4
S4 3-4	51,5	5,66	1,52	5,87	0,459	0,299	0,138	0,399	0,279	0,219	24,1	3,00	1,09	4,11	0,38	0,18	0,295	0,123	0,131	66,3
S4 4-5	53,4	5,38	1,54	4,56	0,442	0,32	0,114	0,375	0,288	0,175	25,0	2,85	1,11	3,19	0,37	0,20	0,278	0,127	0,105	66,6
S4 5-6	64,9	5,32	1,72	3,92	0,452	0,294	0,0944	0,281	0,351	0,158	30,4	2,82	1,24	2,74	0,38	0,18	0,208	0,154	0,095	77,5
S4 6-7	66,9	5,36	1,76	3,5	0,423	0,284	0,0631	0,271	0,359	0,143	31,3	2,84	1,27	2,45	0,35	0,17	0,201	0,158	0,086	79,1
S4 7-8	65,8	5,74	1,77	4,18	0,47	0,298	0,078	0,35	0,366	0,175	30,8	3,04	1,27	2,93	0,39	0,18	0,259	0,161	0,105	79,2
S4 19-20	55,8	6,88	1,75	2,82	0,495	0,354	0,0391	0,426	0,363	0,216	26,1	3,65	1,26	1,97	0,41	0,22	0,315	0,160	0,130	69,1
S5 0-1	44,4	6,02	1,71	7,17	1,4	0,757	0,899	1,41	0,246	0,412	20,8	3,19	1,23	5,02	1,16	0,46	1,043	0,108	0,247	64,4
S5 1-2	45,8	6,37	1,82	4,56	1,5	0,789	0,294	1,51	0,238	0,457	21,4	3,38	1,31	3,19	1,25	0,48	1,117	0,105	0,274	63,3
S5 2-3	48,1	6,77	1,87	2,95	1,59	0,802	0,0879	1,64	0,21	0,48	22,5	3,59	1,35	2,07	1,32	0,49	1,214	0,092	0,288	64,5
S5 3-4	49,9	6,62	1,92	2,84	1,54	0,801	0,0858	1,57	0,239	0,464	23,4	3,51	1,38	1,99	1,28	0,49	1,162	0,105	0,278	66
S5 4-5	51	6,38	1,86	2,66	1,44	0,763	0,0823	1,49	0,214	0,447	23,9	3,38	1,34	1,86	1,20	0,47	1,103	0,094	0,268	66,3
S5 5-6	51,4	6,06	1,75	2,57	1,33	0,715	0,0794	1,36	0,187	0,43	24,1	3,21	1,26	1,80	1,10	0,44	1,006	0,082	0,258	65,9
S5 6-7	51,9	6,3	1,83	2,66	1,41	0,741	0,0848	1,47	0,217	0,432	24,3	3,34	1,32	1,86	1,17	0,45	1,088	0,095	0,259	67
S5 7-8	51,2	6,04	1,74	2,56	1,34	0,708	0,075	1,37	0,186	0,411	24,0	3,20	1,25	1,79	1,11	0,43	1,014	0,082	0,247	65,6
S5 19-20	53,4	7,11	1,99	2,48	1,64	0,82	0,0733	1,7	0,202	0,472	25,0	3,77	1,43	1,74	1,36	0,50	1,258	0,089	0,283	69,9
S6 0-1	49,1	10,1	2,05	8,66	1,66	1,74	0,301	1,87	0,652	0,572	23,0	5,35	1,48	6,06	1,38	1,06	1,384	0,287	0,343	76,7
S6 1-2	54,4	12,7	2,34	6,96	2,22	2,29	0,151	2,56	0,383	0,757	25,5	6,73	1,68	4,87	1,84	1,40	1,894	0,169	0,454	84,8
S6 2-3	56,1	13,2	2,55	7,2	2,35	2,43	0,159	2,73	0,414	0,795	26,3	7,00	1,84	5,04	1,95	1,48	2,020	0,182	0,477	87,9
S6 3-4	50,9	10,8	1,92	7,55	1,72	1,82	0,192	1,89	0,576	0,595	23,8	5,72	1,38	5,29	1,43	1,11	1,399	0,253	0,357	78
S6 4-5	53	11,4	1,9	7,11	1,87	1,99	0,185	1,98	0,519	0,629	24,8	6,04	1,37	4,98	1,55	1,21	1,465	0,228	0,377	80,6
S6 5-6	53,5	11,8	1,95	7,07	1,94	2,06	0,191	2,04	0,543	0,644	25,0	6,25	1,40	4,95	1,61	1,26	1,510	0,239	0,386	81,7
S6 6-7	53,8	12	1,93	7	1,96	2,05	0,194	2,05	0,522	0,649	25,2	6,36	1,39	4,90	1,63	1,25	1,517	0,230	0,389	82,2
S6 7-8	52,9	11,7	1,9	6,95	1,88	2,01	0,199	1,96	0,568	0,636	24,8	6,20	1,37	4,87	1,56	1,23	1,450	0,250	0,382	80,7
S6 19-20	50,9	10,6	1,73	6,63	1,6	1,77	0,282	1,57	0,844	0,531	23,8	5,62	1,25	4,64	1,33	1,08	1,162	0,371	0,319	76,5

APPENDIX 3

	SiO2	Al2O3	CaO	Fe2O3	K2O	MgO	MnO2	Na2O	P2O5	TiO2	Si	Al	Ca	Fe	K	Mg	Na	P	Ti	Summa
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
S7 0-1	54,3	6,61	0,914	10,1	1,14	0,588	0,0992	0,772	0,386	0,342	25,4	3,50	0,66	7,07	0,95	0,36	0,571	0,170	0,205	75,3
S7 1-2	60,7	7,52	1,07	6,23	1,31	0,663	0,0519	0,936	0,401	0,393	28,4	3,99	0,77	4,36	1,09	0,40	0,693	0,176	0,236	79,3
S7 2-3	64,5	7,33	0,898	4,68	1,07	0,563	0,0354	0,762	0,354	0,343	30,2	3,88	0,65	3,28	0,89	0,34	0,564	0,156	0,206	80,5
S7 3-4	59,4	7,38	0,924	4,44	1,09	0,584	0,0391	0,82	0,299	0,352	27,8	3,91	0,67	3,11	0,90	0,36	0,607	0,132	0,211	75,3
S7 4-5	60,2	6,96	0,779	4,33	0,855	0,482	0,0303	0,65	0,287	0,302	28,2	3,69	0,56	3,03	0,71	0,29	0,481	0,126	0,181	74,9
S7 5-6	59,8	6,88	0,804	4,28	0,842	0,473	0,0313	0,633	0,29	0,291	28,0	3,65	0,58	3,00	0,70	0,29	0,468	0,128	0,175	74,3
S7 6-7	61,9	6,72	0,784	3,43	0,822	0,459	0,0306	0,635	0,284	0,286	29,0	3,56	0,56	2,40	0,68	0,28	0,470	0,125	0,172	75,4
S7 7-8	61,3	6,68	0,791	3,1	0,818	0,453	0,0298	0,618	0,29	0,283	28,7	3,54	0,57	2,17	0,68	0,28	0,457	0,128	0,170	74,4
S7 19-20	62,3	8,51	0,845	4,72	1,03	0,585	0,0396	0,745	0,412	0,353	29,2	4,51	0,61	3,30	0,85	0,36	0,551	0,181	0,212	79,5
S8 0-1	60,5	11,1	1,94	5,06	1,98	1,36	0,237	1,74	0,323	0,659	28,3	5,88	1,40	3,54	1,64	0,83	1,288	0,142	0,395	84,9
S8 1-2	63,4	11,4	2,01	4,75	2,13	1,29	0,193	1,92	0,31	0,684	29,7	6,04	1,45	3,33	1,77	0,79	1,421	0,136	0,410	88,1
S8 2-3	63,1	11,8	2,03	5,05	2,15	1,37	0,193	1,89	0,355	0,695	29,5	6,25	1,46	3,54	1,78	0,84	1,399	0,156	0,417	88,6
S8 3-4	62,7	11,7	2	5,07	2,06	1,35	0,205	1,84	0,378	0,676	29,3	6,20	1,44	3,55	1,71	0,82	1,362	0,166	0,406	88
S8 4-5	61,7	11,2	1,95	4,97	1,93	1,29	0,209	1,69	0,398	0,653	28,9	5,94	1,40	3,48	1,60	0,79	1,251	0,175	0,392	86
S8 5-6	60,9	11,6	1,82	5,26	1,96	1,31	0,219	1,66	0,396	0,653	28,5	6,15	1,31	3,68	1,63	0,80	1,228	0,174	0,392	85,8
S8 6-7	61,3	11,8	1,84	5,31	1,99	1,31	0,326	1,75	0,369	0,665	28,7	6,25	1,32	3,72	1,65	0,80	1,295	0,162	0,399	86,7
S8 7-8	60,8	11,7	1,86	5,54	1,95	1,29	0,851	1,72	0,395	0,665	28,5	6,20	1,34	3,88	1,62	0,79	1,273	0,174	0,399	86,8
S8 17-18	63,3	12	2,2	5	2,12	1,36	0,0742	1,94	0,443	0,706	29,6	6,36	1,58	3,50	1,76	0,83	1,436	0,195	0,424	89,1
S9 0-1	33,7	2,11	0,71	12,9	0,22	0,554	0,645	0,32	0,3	0,095	15,8	1,12	0,51	9,03	0,18	0,34	0,237	0,132	0,057	51,6
S9 1-2	37,9	2,19	1,13	8,02	0,32	0,379	0,254	0,35	0,39	0,118	17,7	1,16	0,81	5,61	0,27	0,23	0,259	0,172	0,071	51,1
S9 2-3	41,4	2,43	0,951	5,28	0,303	0,381	0,139	0,376	0,356	0,125	19,4	1,29	0,68	3,70	0,25	0,23	0,278	0,157	0,075	51,7
S9 3-4	42,3	2,54	0,841	4,5	0,296	0,452	0,132	0,391	0,333	0,135	19,8	1,35	0,61	3,15	0,25	0,28	0,289	0,147	0,081	51,9
S9 4-5	44	2,47	0,866	4,6	0,319	0,397	0,141	0,384	0,384	0,13	20,6	1,31	0,62	3,22	0,26	0,24	0,284	0,169	0,078	53,7
S9 5-6	45,2	2,52	0,892	4,34	0,318	0,399	0,133	0,389	0,367	0,134	21,2	1,34	0,64	3,04	0,26	0,24	0,288	0,161	0,080	54,7
S9 6-7	50,4	2,58	0,895	3,74	0,314	0,381	0,118	0,391	0,332	0,131	23,6	1,37	0,64	2,62	0,26	0,23	0,289	0,146	0,079	59,3
S9 7-8	54	2,4	0,826	3,19	0,254	0,333	0,11	0,347	0,279	0,118	25,3	1,27	0,59	2,23	0,21	0,20	0,257	0,123	0,071	61,9
S9 19-20	56,9	2,69	0,968	2,7	0,296	0,392	0,0986	0,408	0,283	0,139	26,6	1,43	0,70	1,89	0,25	0,24	0,302	0,125	0,083	64,9
S10 0-1	50,3	15,4	0,738	11	3,26	2,28	2,13	1,31	0,427	0,767	23,5	8,16	0,53	7,70	2,71	1,39	0,969	0,188	0,460	87,6
S10 1-2	48	14,8	0,677	17	3,09	2,21	1,01	1,28	0,411	0,75	22,5	7,84	0,49	11,90	2,56	1,35	0,947	0,181	0,450	89,2
S10 2-3	48,7	15,2	0,648	17,9	3,17	2,22	0,342	1,27	0,442	0,741	22,8	8,06	0,47	12,53	2,63	1,35	0,940	0,194	0,445	90,6
S10 3-4	51,6	16,6	0,675	12,9	3,5	2,41	0,172	1,33	0,435	0,819	24,1	8,80	0,49	9,03	2,91	1,47	0,984	0,191	0,491	90,4

APPENDIX 3

	SiO2	Al2O3	CaO	Fe2O3	K2O	MgO	MnO2	Na2O	P2O5	TiO2	Si	Al	Ca	Fe	K	Mg	Na	P	Ti	Summa
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
S10 4-5	51,6	16	0,63	12,6	3,29	2,54	0,175	1,35	0,466	0,866	24,1	8,48	0,45	8,82	2,73	1,55	0,999	0,205	0,520	89,5
S10 5-6	46,1	15,9	0,589	16,6	3,21	2,32	0,163	1,27	0,604	0,801	21,6	8,43	0,42	11,62	2,66	1,42	0,940	0,266	0,481	87,6
S10 6-7	45	16,5	0,567	15,8	3,32	2,4	0,15	1,24	0,6	0,8	21,1	8,75	0,41	11,06	2,76	1,46	0,918	0,264	0,480	86,4
S10 7-8	49,6	17,4	0,639	10,5	3,57	2,59	0,158	1,27	0,483	0,848	23,2	9,22	0,46	7,35	2,96	1,58	0,940	0,213	0,509	87,1
S10 16-17	53,7	16,8	0,641	10,8	3,42	2,45	0,277	1,34	0,367	0,839	25,1	8,90	0,46	7,56	2,84	1,49	0,992	0,161	0,503	90,6
S11 0-0,5	31,1	3,21	0,763	21,8	0,391	0,36	0,0584	0,514	0,677	0,179	14,6	1,7	0,55	15,26	0,32	0,22	0,38	0,298	0,107	59,1
S11 0,5-1	47,1	2,59	0,737	9,8	0,427	0,348	0,0861	0,515	0,578	0,165	22	1,37	0,53	6,86	0,35	0,21	0,381	0,254	0,099	62,3
S11 1-1,5	50	2,79	0,736	7,47	0,465	0,353	0,0662	0,528	0,452	0,176	23,4	1,48	0,53	5,23	0,39	0,22	0,391	0,199	0,106	63
S11 1,5-2	48,6	2,87	0,749	7,17	0,464	0,362	0,0625	0,538	0,384	0,184	22,7	1,52	0,54	5,02	0,39	0,22	0,398	0,169	0,11	61,4
S112-2,5	47	3,37	0,795	7,63	0,478	0,378	0,0575	0,605	0,369	0,211	22	1,79	0,57	5,34	0,4	0,23	0,448	0,162	0,127	60,9
S11 2,5-3	44,7	3,17	0,756	8,31	0,484	0,367	0,0592	0,562	0,424	0,197	20,9	1,68	0,54	5,82	0,4	0,22	0,416	0,187	0,118	59
S11 3-3,5	45,6	3,16	0,765	7,65	0,491	0,374	0,0545	0,575	0,389	0,201	21,3	1,67	0,55	5,36	0,41	0,23	0,426	0,171	0,121	59,3
S11 3,5-4	47,7	3,23	0,787	7,22	0,501	0,382	0,0531	0,592	0,368	0,203	22,3	1,71	0,57	5,05	0,42	0,23	0,438	0,162	0,122	61
S11 4-4,5	45,9	3,22	0,764	6,82	0,472	0,369	0,0495	0,608	0,324	0,204	21,5	1,71	0,55	4,77	0,39	0,23	0,45	0,143	0,122	58,7
S11 4,5-5	44,4	3,35	0,802	7,48	0,498	0,386	0,0533	0,585	0,334	0,206	20,8	1,78	0,58	5,24	0,41	0,24	0,433	0,147	0,124	58,1
S11 5-5,5	42,4	3,41	0,803	8,35	0,495	0,392	0,0536	0,582	0,345	0,208	19,8	1,81	0,58	5,85	0,41	0,24	0,431	0,152	0,125	57
S11 5,5-6	37	3,35	0,82	14,9	0,467	0,382	0,0617	0,582	0,594	0,195	17,3	1,78	0,59	10,43	0,39	0,23	0,431	0,261	0,117	58,4
S11 6-6,5	33,6	3,19	0,75	17	0,44	0,366	0,0629	0,514	0,869	0,183	15,7	1,69	0,54	11,9	0,37	0,22	0,38	0,382	0,11	57
S11 6,5-7	33,6	3,38	0,786	17,1	0,453	0,381	0,0634	0,549	0,901	0,195	15,7	1,79	0,57	11,97	0,38	0,23	0,406	0,396	0,117	57,4
S11 7-7,5	32,4	3,32	0,748	17,9	0,44	0,364	0,0632	0,53	1,09	0,185	15,2	1,76	0,54	12,53	0,37	0,22	0,392	0,48	0,111	57
S11 7,5-8	32,8	3,39	0,739	17,6	0,44	0,362	0,0611	0,526	1,02	0,186	15,4	1,8	0,53	12,32	0,37	0,22	0,389	0,449	0,112	57,1
S11 8-8,5	34,7	3,47	0,784	15,4	0,457	0,384	0,0575	0,547	0,801	0,2	16,2	1,84	0,56	10,78	0,38	0,23	0,405	0,352	0,12	56,8
S11 8,5-9	46,8	2,39	0,748	11,6	0,426	0,34	0,0973	0,464	0,7	0,153	21,9	1,27	0,54	8,12	0,35	0,21	0,343	0,308	0,092	63,7
S11 9-9,5	33,3	3,71	0,802	16,5	0,471	0,398	0,0533	0,556	0,471	0,203	15,6	1,97	0,58	11,55	0,39	0,24	0,411	0,207	0,122	56,5
S11 9,5-10	32	3,63	0,819	17,4	0,453	0,397	0,0547	0,559	0,487	0,201	15	1,92	0,59	12,18	0,38	0,24	0,414	0,214	0,121	56
S11 10,5	31,6	3,53	0,803	19,8	0,446	0,386	0,0566	0,56	0,566	0,198	14,8	1,87	0,58	13,86	0,37	0,24	0,414	0,249	0,119	57,9
S11 11,5	30,9	3,19	0,757	21,9	0,396	0,363	0,0583	0,507	0,665	0,184	14,5	1,69	0,55	15,33	0,33	0,22	0,375	0,293	0,11	58,9
S11 12,5	30,7	3,05	0,727	23,7	0,383	0,343	0,0568	0,49	0,622	0,172	14,4	1,62	0,52	16,59	0,32	0,21	0,363	0,274	0,103	60,2
S11 13,5	31,1	3,09	0,731	24,2	0,406	0,354	0,0593	0,515	0,842	0,172	14,6	1,64	0,53	16,94	0,34	0,22	0,381	0,37	0,103	61,5
S11 14,5	34	3,48	0,783	20,4	0,439	0,385	0,0571	0,565	0,758	0,197	15,9	1,84	0,56	14,28	0,36	0,23	0,418	0,334	0,118	61,1
S11 15,5	34,3	3,39	0,781	20,5	0,43	0,384	0,0587	0,551	0,708	0,195	16,1	1,8	0,56	14,35	0,36	0,23	0,408	0,312	0,117	61,3

APPENDIX 3

	SiO2	Al2O3	CaO	Fe2O3	K2O	MgO	MnO2	Na2O	P2O5	TiO2	Si	Al	Ca	Fe	K	Mg	Na	P	Ti	Summa
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
S11 16,5	33,6	3,65	0,818	19,2	0,463	0,401	0,0528	0,605	0,486	0,211	15,7	1,93	0,59	13,44	0,38	0,24	0,448	0,214	0,127	59,5
S11 17,5	32,6	3,31	0,767	22,7	0,426	0,381	0,0578	0,547	0,742	0,191	15,3	1,75	0,55	15,89	0,35	0,23	0,405	0,326	0,115	61,7
S11 18,5	32,5	3,29	0,742	21,3	0,392	0,365	0,0541	0,511	0,648	0,185	15,2	1,74	0,53	14,91	0,33	0,22	0,378	0,285	0,111	60
S11 19,5	32,4	3,29	0,741	21,8	0,422	0,372	0,0524	0,512	0,608	0,182	15,2	1,74	0,53	15,26	0,35	0,23	0,379	0,268	0,109	60,4
S11 21	33,8	3,54	0,79	16,1	0,456	0,389	0,0551	0,551	0,568	0,199	15,8	1,88	0,57	11,27	0,38	0,24	0,408	0,25	0,119	56,4
S11 23	37,3	3,06	0,7	20,5	0,387	0,35	0,0533	0,495	0,717	0,169	17,5	1,62	0,5	14,35	0,32	0,21	0,366	0,315	0,101	63,7
S11 25	35,8	3,18	0,697	22,6	0,391	0,349	0,0558	0,513	1,1	0,171	16,8	1,69	0,5	15,82	0,32	0,21	0,38	0,484	0,103	64,9
S11 27	34	3,19	0,802	23,2	0,394	0,413	0,0512	0,519	0,6	0,169	15,9	1,69	0,58	16,24	0,33	0,25	0,384	0,264	0,101	63,3
S11 29	36,1	3,56	0,725	19,5	0,399	0,36	0,0448	0,528	0,374	0,177	16,9	1,89	0,52	13,65	0,33	0,22	0,391	0,165	0,106	61,8
S11 31	36,4	3,18	0,696	20,4	0,399	0,357	0,0467	0,48	0,53	0,166	17	1,69	0,5	14,28	0,33	0,22	0,355	0,233	0,1	62,7
S11 33	37	3,28	0,698	20,3	0,392	0,355	0,0467	0,493	0,613	0,169	17,3	1,74	0,5	14,21	0,33	0,22	0,365	0,27	0,101	63,3
S11 35	38,9	3,2	0,681	20	0,4	0,353	0,0465	0,497	0,652	0,17	18,2	1,7	0,49	14	0,33	0,22	0,368	0,287	0,102	64,9
S11 37	37,9	3,03	0,659	21,9	0,365	0,335	0,047	0,47	0,711	0,158	17,7	1,61	0,47	15,33	0,3	0,2	0,348	0,313	0,095	65,6

Appendix 4: Analysis results 3

CONTENTS

	Ba	Be	La	Mo	Nb	Sc	Sn	Sr	V	W	Y	Zr
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
S1 0-1	303	<0,712	77,3	47,1	<7,12	2,16	<28,5	44,1	26,2	<28,5	69,5	67,8
S1 1-2	321	1,54	93,1	44,7	<5,88	3,27	<23,5	43,2	26,3	30,2	78,1	81,7
S1 2-3	337	2,01	96,3	46,3	<5,94	4,48	<23,8	46,1	22,9	<23,8	83	90,4
S1 3-4	345	2,06	97,4	47,7	<5,66	3,57	<22,6	46,9	27,9	30,6	86,2	80,4
S1 4-5	352	1,76	99,2	49,9	<5,83	3,11	<23,3	48	29,5	<23,3	87,1	83,5
S1 5-6	351	2,19	106	54,7	<5,80	4,17	<23,2	48,8	30,8	45,3	91,2	92,4
S1 6-7	346	2,59	97,4	52,7	<6,02	4,34	<24,1	46,8	22,4	<24,1	82,6	76,1
S1 7-8	352	2,37	103	53,8	9,07	4,3	<24,3	46,4	19,5	<24,3	82,1	82,9
S1 19-20	367	3,2	115	46,8	10,1	4,64	<23,7	45,4	17,2	<23,7	87,9	79,6
S2b 0-1	615	<0,571	80,9	29,2	7,17	9,35	<22,8	127	71,2	52	63,1	124
S2b 1-2	607	<0,600	84,4	30,1	11,2	8,88	<24,0	123	75,7	66,8	68,4	123
S2b 2-3	638	0,958	86,4	15,4	9,66	9,72	<23,7	130	79,4	32,8	73,2	133
S2b 3-4	623	1,2	86,1	9,74	14,8	10,9	<23,0	130	78,2	52,9	72,8	141
S2b 4-5	631	1,27	87,8	<5,52	11	10,3	<22,1	131	75,6	57,1	70,7	140
S2b 5-6	631	1,55	67,4	<5,83	<5,83	9,51	<23,3	130	80,4	57,7	67,6	129
S2b 6-7	579	0,979	78,6	<5,89	<5,89	10,1	<23,6	121	76,1	30,3	69,8	122
S2b 7-8	571	0,603	95,6	<5,57	<5,57	10,7	<22,3	120	76,2	<22,3	76	133
S2b 8-9	553	0,778	91,5	<5,26	<5,26	10,3	<21,0	115	75,8	46,5	73,5	128
S2b 9-10	561	0,579	83,4	<5,78	7,11	9,79	<23,1	116	77,6	39,9	74,1	122
S2b 10-11	519	<0,561	85,7	<5,61	<5,61	8,42	<22,4	107	72,7	39,8	75,9	115
S2b 11-12	530	0,841	94,5	<5,49	6,61	9,88	<21,9	109	76,7	49	77,3	117
S2b 12-13	642	2,08	97,9	7	11,4	11,9	<23,3	134	84,5	63,8	76,8	139
S2b 13-14	699	2,22	87,6	<5,78	6,75	12,2	<23,1	151	79,2	29,9	66,7	156
S2b 14-15	772	2,57	72,2	<5,76	16	12,2	<23,0	170	76,2	<23,0	57,9	175
S2b 15-16	830	2,43	67,7	<5,25	13	11,3	<21,0	189	85,1	41,9	59,2	204
S2b 16-17	750	2,45	64,6	<5,31	20,5	12,1	<21,2	182	69,2	22	35,5	193
S3 0-1	498	<0,580	65,3	<5,80	8,86	7,99	<23,2	168	103	37	49,6	149
S3 1-2	530	<0,584	59,2	<5,84	10	8,64	<23,3	176	101	33,7	50,4	151
S3 2-3	418	<0,601	46,1	<6,01	10,4	6,91	<24,0	139	73,9	<24,0	34,8	132
S3 3-4	555	<0,605	54,8	<6,05	<6,05	8,14	<24,2	188	107	40,4	55,7	174
S3 4-5	427	0,558	49,3	<5,48	7,67	7,68	<21,9	147	73,4	<21,9	35,2	149
S3 5-6	453	0,772	52,4	5,55	9,53	7,83	<19,6	159	70,3	<19,6	34,8	171
S3 6-7	478	0,886	53,8	<6,07	7,22	7,77	<24,3	170	68,9	<24,3	35,8	205
S3 7-8	481	0,804	47,1	<5,13	<5,13	8,01	<20,5	173	67,9	<20,5	35	206
S3 19-20	301	0,569	55,8	<5,66	<5,66	5,28	<22,7	109	56,7	<22,7	40,1	105
S4 0-1	225	2,47	125	187	<5,90	5,11	<23,6	53,5	44,6	32,7	103	104
S4 1-2	187	3,06	146	105	<5,90	6,97	<23,6	53,9	39,9	44,3	111	138
S4 2-3	157	3,1	123	69,9	<6,14	5,26	<24,6	44,1	28,1	<24,6	85,3	79,9
S4 3-4	158	3,7	121	85	<5,64	5,89	<22,6	45,8	33,5	<22,6	87,4	63,6
S4 4-5	147	3,34	120	62,8	<6,12	5,83	<24,5	43,7	30,8	<24,5	86,2	82
S4 5-6	168	3,66	147	53,3	<5,94	8,52	<23,7	48,1	42,5	54,5	114	62,1
S4 6-7	159	3,84	145	45,1	<5,49	8,6	<22,0	47,6	39,2	31	115	97,1
S4 7-8	171	3,82	155	48,9	<5,88	6,27	<23,5	52,5	32	24,8	120	97,3
S4 19-20	154	4,52	189	19,6	<5,52	8,64	<22,1	49,5	28,2	<22,1	131	64,6
S5 0-1	424	<0,549	46,1	14,5	8,09	6,42	<22,0	122	45,1	46,6	40	193
S5 1-2	390	0,996	47,3	9,05	9,07	7,14	<24,5	128	49,9	31,6	44,4	207
S5 2-3	409	0,951	40,6	<5,11	<5,11	6,81	<20,4	134	43,1	<20,4	40,2	239
S5 3-4	399	1,13	46,8	<5,95	<5,95	7,73	<23,8	132	48,2	<23,8	44,8	201
S5 4-5	383	1,34	52,1	9,63	<5,69	6,44	<22,8	129	50,5	28,6	48,1	198
S5 5-6	362	1,21	56,8	9,31	9,62	8,06	<20,8	121	45,3	45,2	47,1	211
S5 6-7	366	1,06	51,7	7,37	7	7,49	<22,7	125	41,2	<22,7	47,4	212
S5 7-8	361	1,1	49,9	6,6	<5,40	7,43	<21,6	120	45	27,7	47,3	207

	Ba	Be	La	Mo	Nb	Sc	Sn	Sr	V	W	Y	Zr
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
S5 19-20	412	1,45	57,4	9,79	<5,50	8,65	<22,0	144	46,4	33,2	56,2	220
S6 0-1	554	<0,521	52,4	<5,22	14,9	10,7	<20,9	150	94,1	<20,9	21,6	119
S6 1-2	686	1,02	46,5	6,23	13,2	13,1	<21,6	186	105	<21,6	19,1	147
S6 2-3	704	1,05	48	<5,27	14,4	13	<21,1	197	108	<21,1	19,3	156
S6 3-4	570	0,781	54,8	<5,34	13,8	11,5	<21,3	146	98	<21,3	22,8	122
S6 4-5	598	0,762	53	<5,60	14,5	11,9	<22,4	148	97,9	<22,4	20,5	116
S6 5-6	617	0,835	54,6	7,62	12	12,2	<23,1	151	96,9	<23,1	20,4	120
S6 6-7	628	0,84	54,3	4,96	11,2	12	<19,8	154	99,3	<19,8	21	119
S6 7-8	614	0,861	59,1	8,14	15,6	12,3	<23,5	149	98	<23,5	19,9	117
S6 19-20	585	0,676	65,5	6,29	16,3	11	<22,9	139	89,9	<22,9	23,7	90,3
S7 0-1	280	<0,549	168	11,3	7,78	6,76	<22,0	81,6	49,3	29	87,4	95,1
S7 1-2	325	1,07	169	<5,90	<5,90	6,26	<23,6	95,2	56,8	<23,6	94,7	111
S7 2-3	275	1,17	192	10,9	<5,82	6,63	<23,3	78,5	45	27,5	101	92,5
S7 3-4	281	1,03	161	6,06	<5,57	6,35	<22,3	80,4	39,4	<22,3	76,9	102
S7 4-5	231	1,05	191	14	9,08	6,56	<22,6	67	38,6	<22,6	72,7	84,1
S7 5-6	222	1,33	203	16,5	10,1	7,21	<21,3	65,7	43,7	<21,3	77,9	82,4
S7 6-7	215	0,979	205	12,8	<5,68	5,62	<22,7	64,2	30,8	<22,7	76,5	79,7
S7 7-8	210	1,32	205	12,6	<5,95	6,7	<23,8	63,5	36,2	<23,8	78,2	73,3
S7 19-20	265	1,48	216	22,6	<5,95	7,89	<23,8	74,1	41,2	<23,8	103	93,6
S8 0-1	501	1,35	97,9	10	14,3	11,8	<24,0	137	75,7	<24,0	40,4	191
S8 1-2	548	1,6	80,4	5	6,99	11,9	<19,9	150	73,1	20,4	39,7	210
S8 2-3	540	1,36	101	11,8	16,8	12,2	<23,7	147	71,7	<23,7	41,6	228
S8 3-4	520	1,4	98,7	9,9	10,1	12,5	<21,5	144	69	<21,5	44,4	198
S8 4-5	486	1,31	112	11	16,9	11,8	37,4	136	71,5	<22,4	48,9	190
S8 5-6	495	1,12	112	<5,43	5,86	10,9	<21,7	134	67	<21,7	51	173
S8 6-7	516	1,4	124	8,15	13,5	12,8	<24,4	142	73,3	<24,4	53,5	179
S8 7-8	505	1,32	134	11,9	17	12,1	<23,5	141	72,6	<23,5	57,8	211
S8 17-18	539	1,43	108	<5,31	15,6	12,4	<21,3	157	71	<21,3	55,9	248
S9 0-1	198	<1,03	17	38,1	<10,3	<2,06	<41,3	44,6	34,7	<41,3	<4,13	26
S9 1-2	193	<0,497	29	22,2	6,74	3,41	<19,9	45,5	32,4	<19,9	14	27,6
S9 2-3	198	<0,615	26,2	18,5	<6,15	3,29	<24,6	42,7	34,9	<24,6	18,5	31,9
S9 3-4	194	<0,451	29	19,3	7,24	3,68	<18,0	42,2	36,5	<18,0	20,6	27
S9 4-5	190	<0,548	24,4	20,8	<5,48	3,63	<21,9	40,6	34,5	<21,9	20	26,5
S9 5-6	187	<0,569	23,2	21,5	<5,69	2,96	<22,8	41,6	35,9	<22,8	20,5	30,8
S9 6-7	183	<0,602	29,9	27,6	<6,02	3,59	<24,1	39,7	36,5	<24,1	21,3	25,6
S9 7-8	167	<0,605	29,1	26,7	<6,05	3,7	<24,2	36	31,5	<24,2	20,6	22,2
S9 19-20	172	<0,616	29,2	28,3	<6,16	4,25	<24,6	40,6	31,2	<24,6	21,2	29,4
S10 0-1	527	1,16	161	<5,59	9,02	11,9	<22,3	115	133	<22,3	83,8	200
S10 1-2	498	<0,609	148	12,9	21,5	11,8	<24,4	114	129	<24,4	65,5	193
S10 2-3	505	<0,564	156	20,2	17,9	11,5	<22,6	112	135	<22,6	71,9	193
S10 3-4	549	1,22	155	9,78	19,2	14,3	<21,9	122	160	<21,9	70,1	213
S10 4-5	494	1,15	168	14,5	23,7	12,4	<24,3	117	153	<24,3	70,7	215
S10 5-6	518	<0,594	175	19,9	23,8	12,2	<23,7	118	148	<23,7	90,6	216
S10 6-7	536	0,827	232	23,2	19	14	<21,0	119	158	<21,0	126	218
S10 7-8	573	1,77	224	20,3	16,6	14,3	<23,0	122	167	<23,0	105	231
S10 16-17	561	1,45	193	<6,10	6,36	14,6	<24,4	129	152	<24,4	95,3	218

Appendix 5: Profile diagrams

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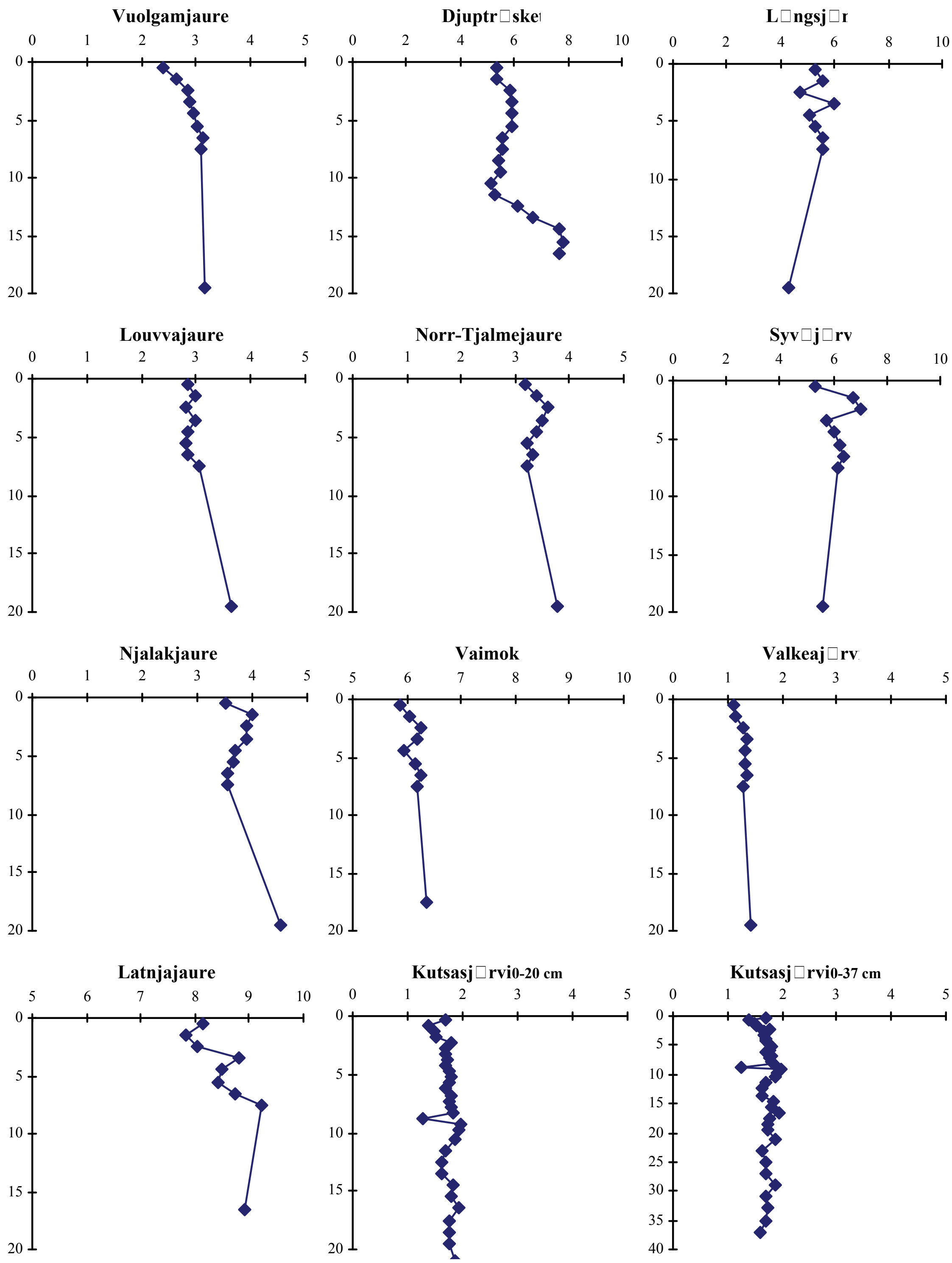
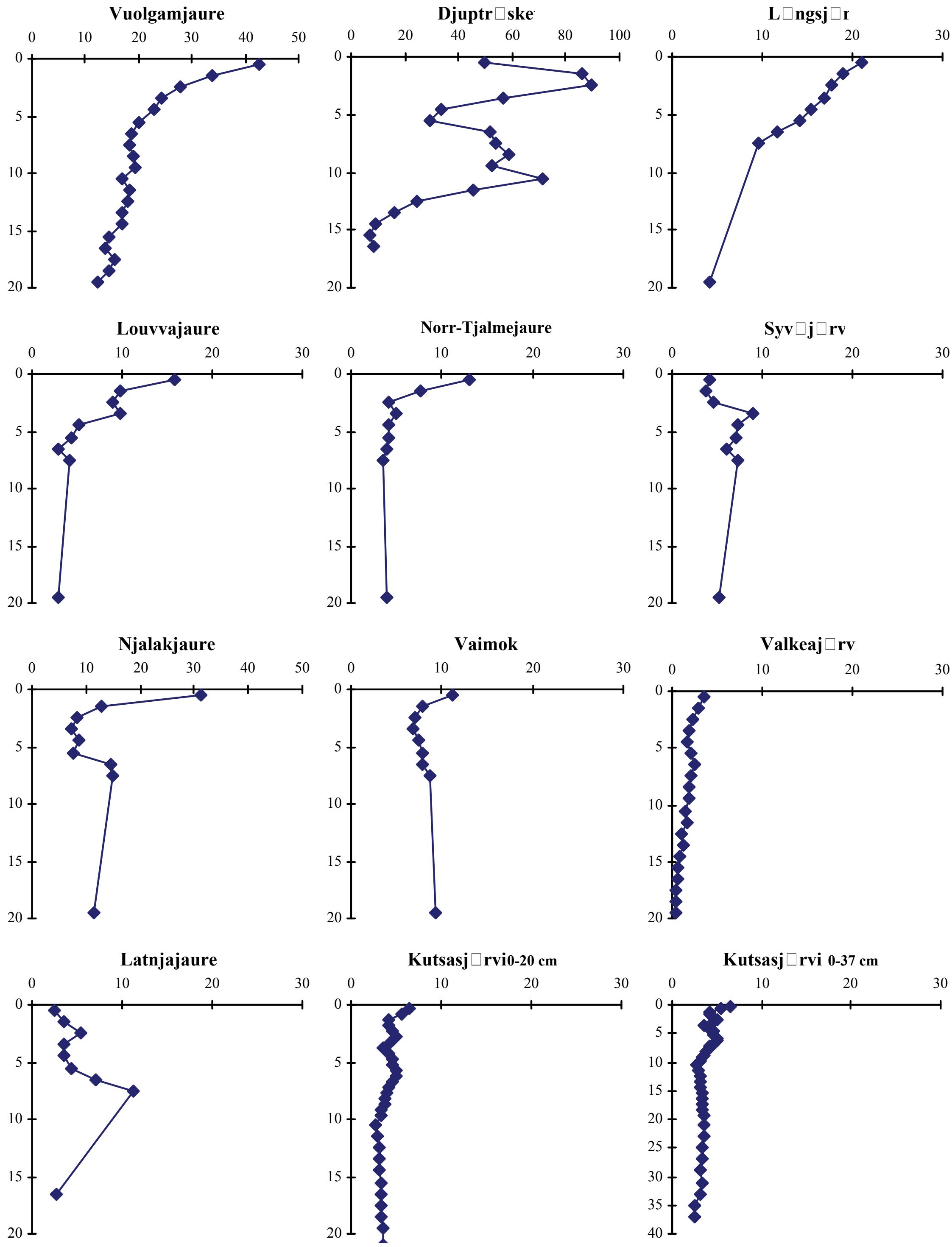
Al



X-axis: %
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

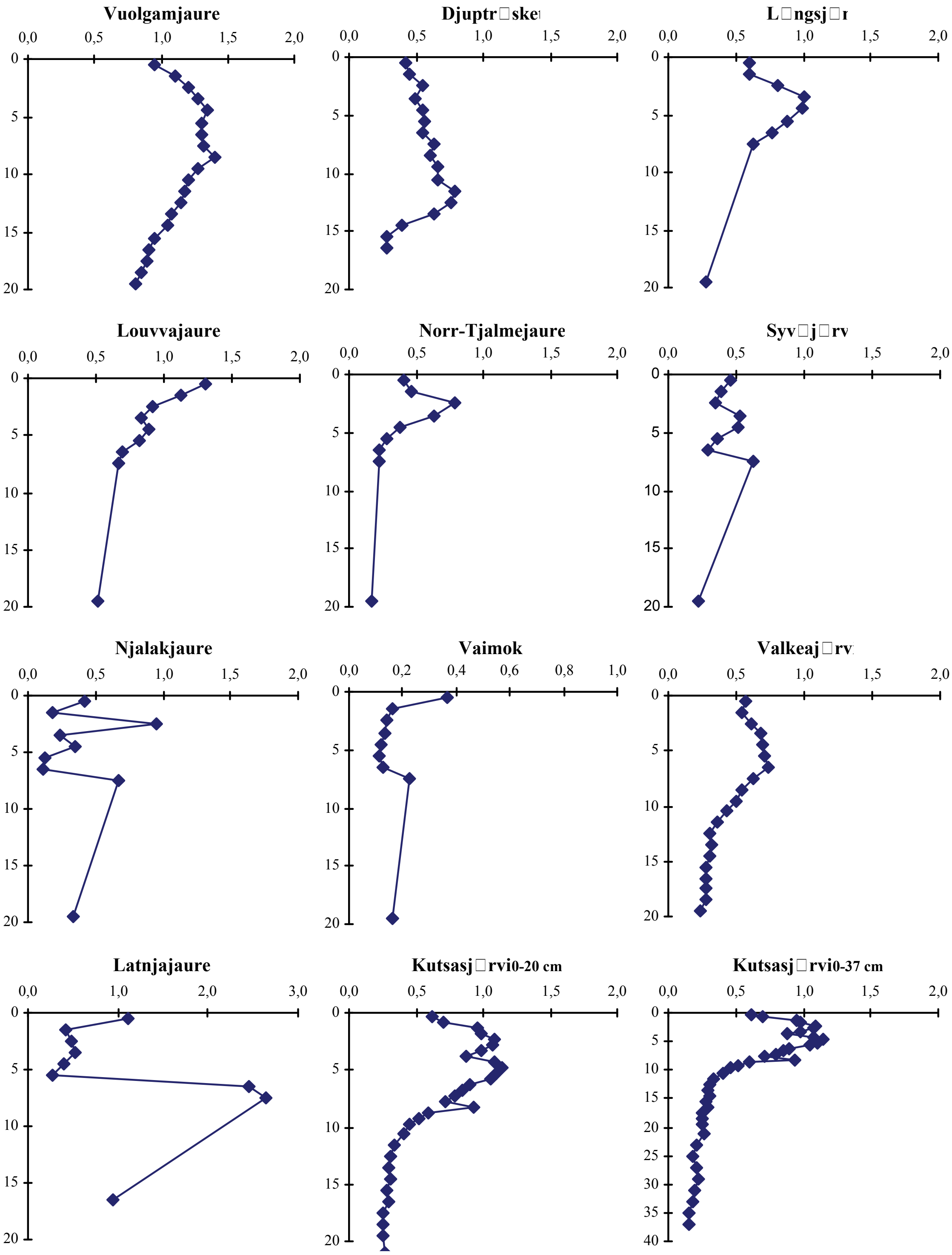
As



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

Cd



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

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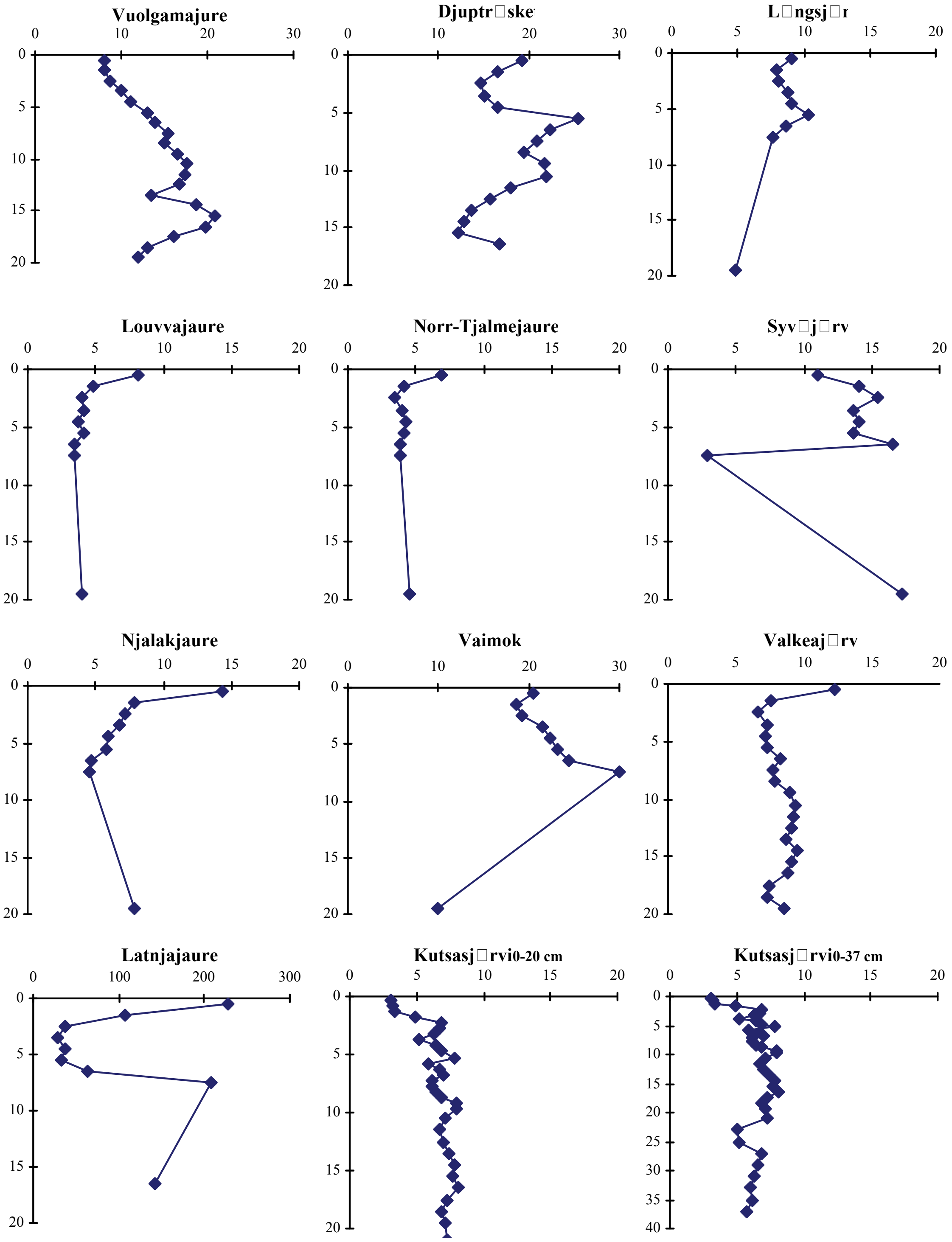

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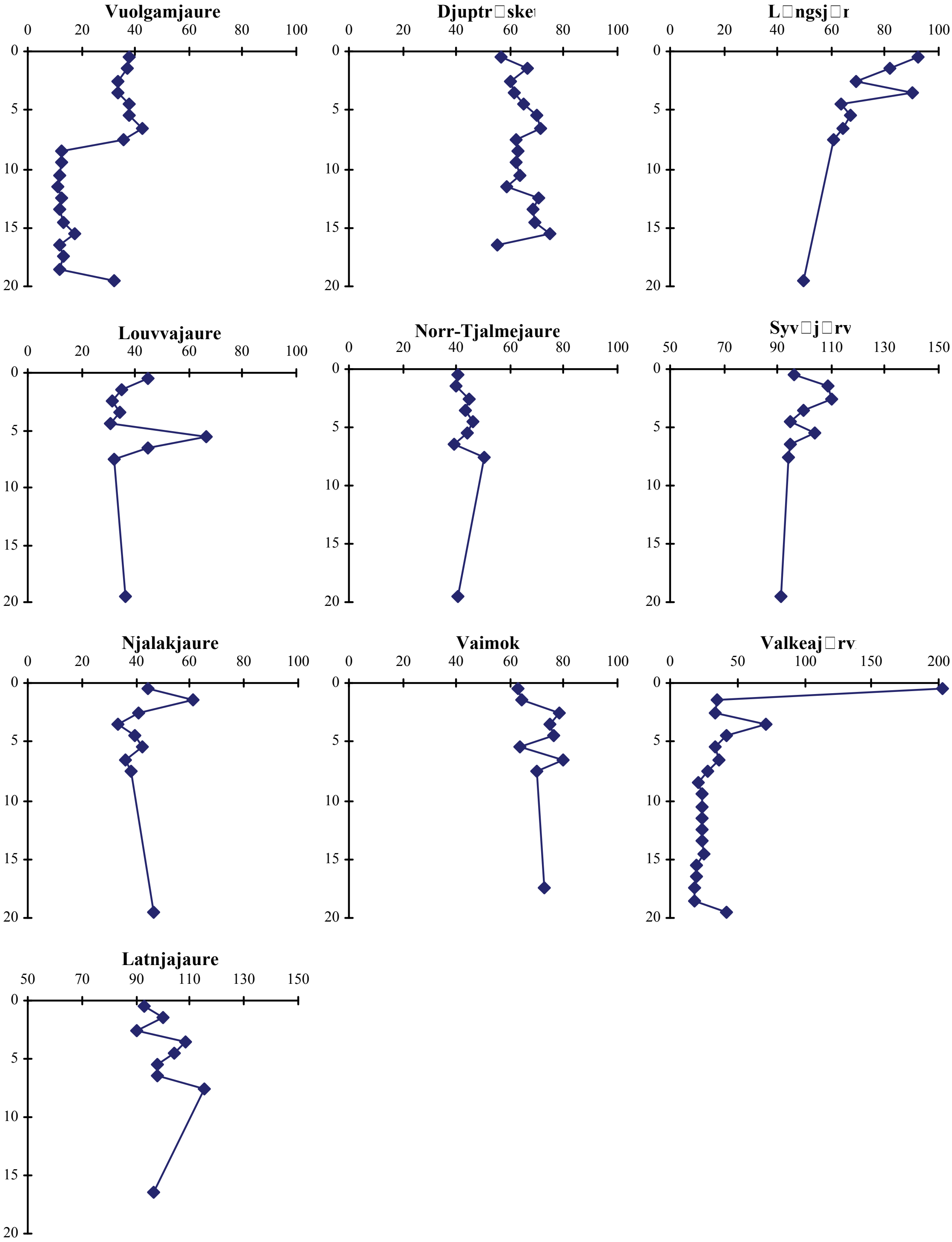
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

Cr



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

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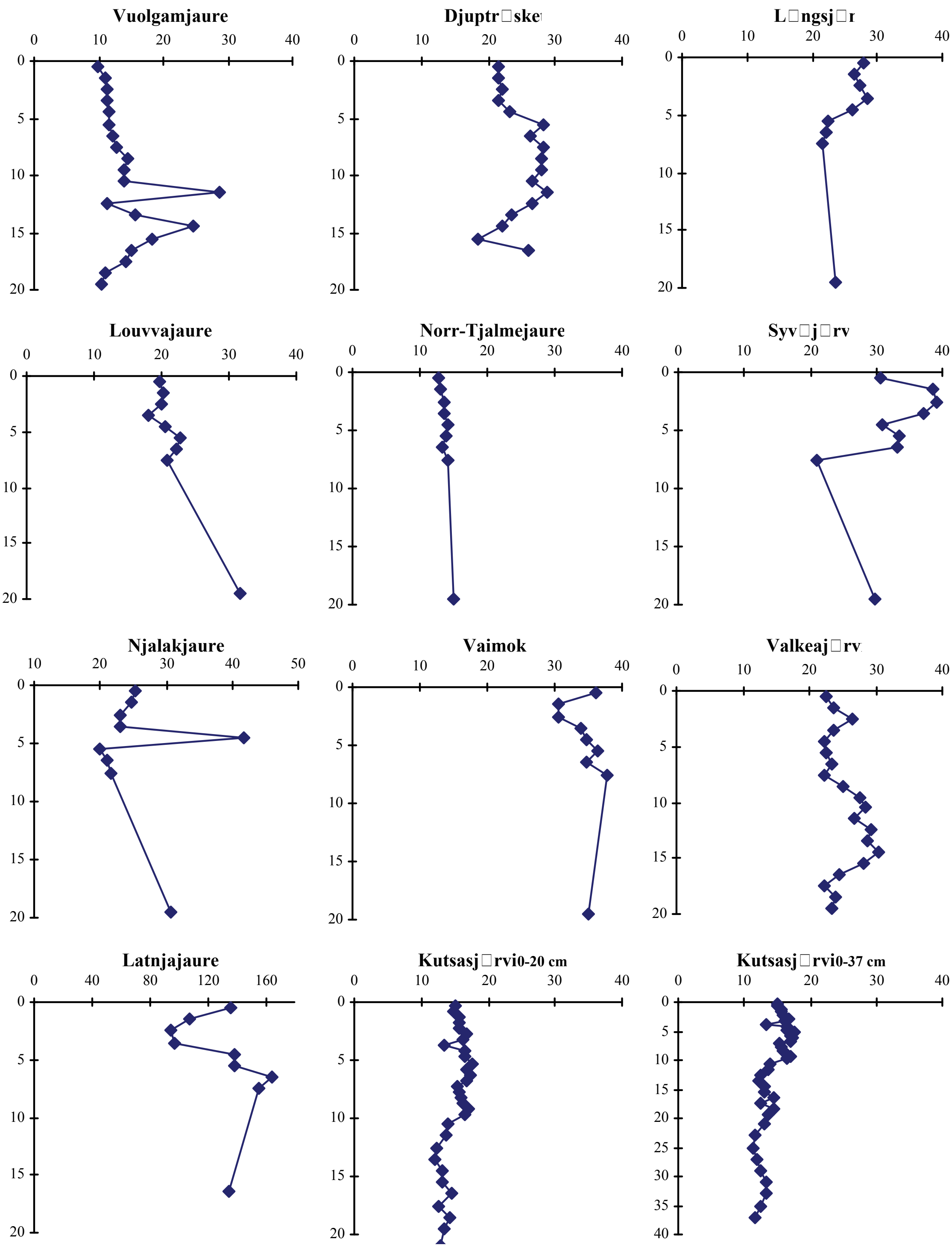

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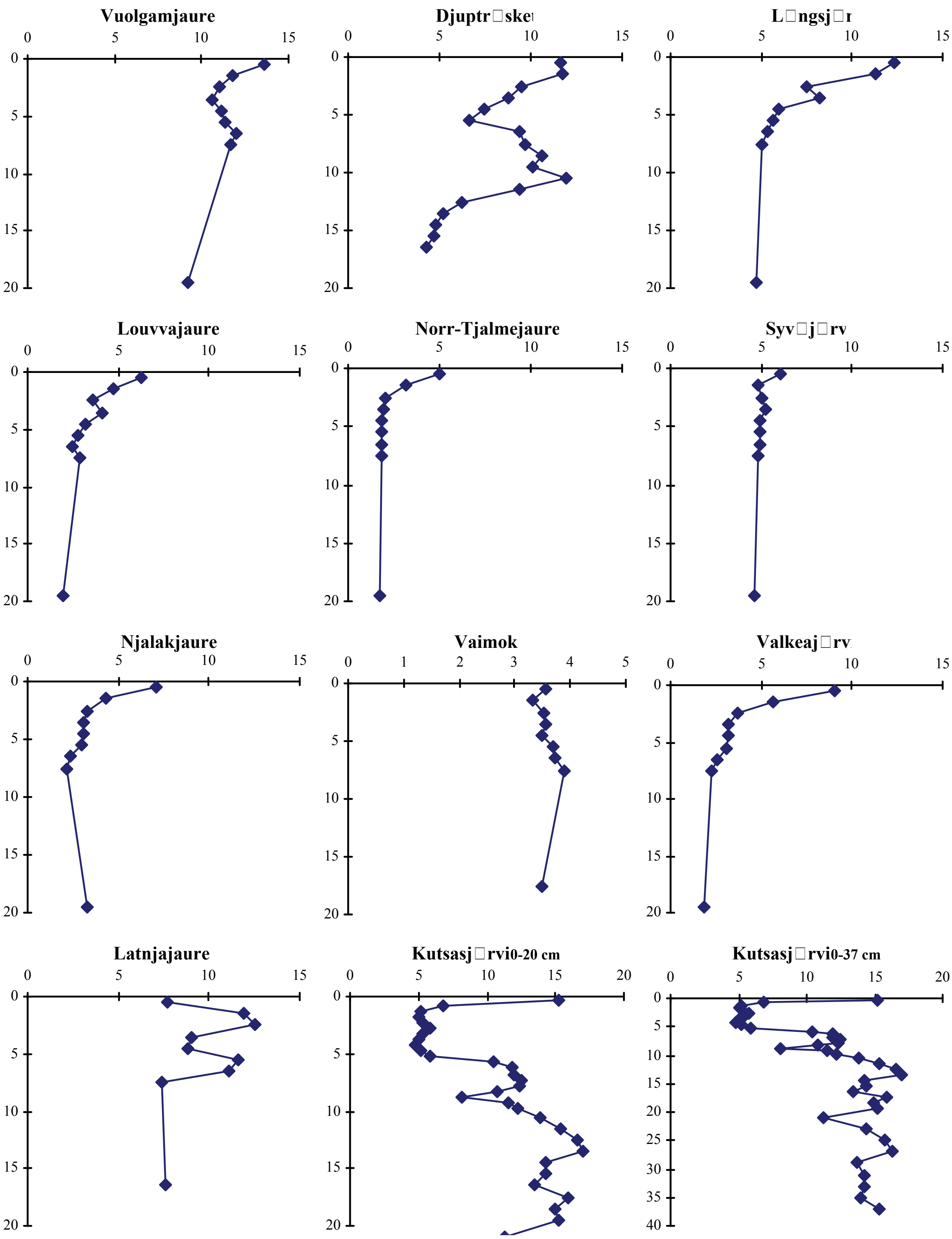
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

Fe



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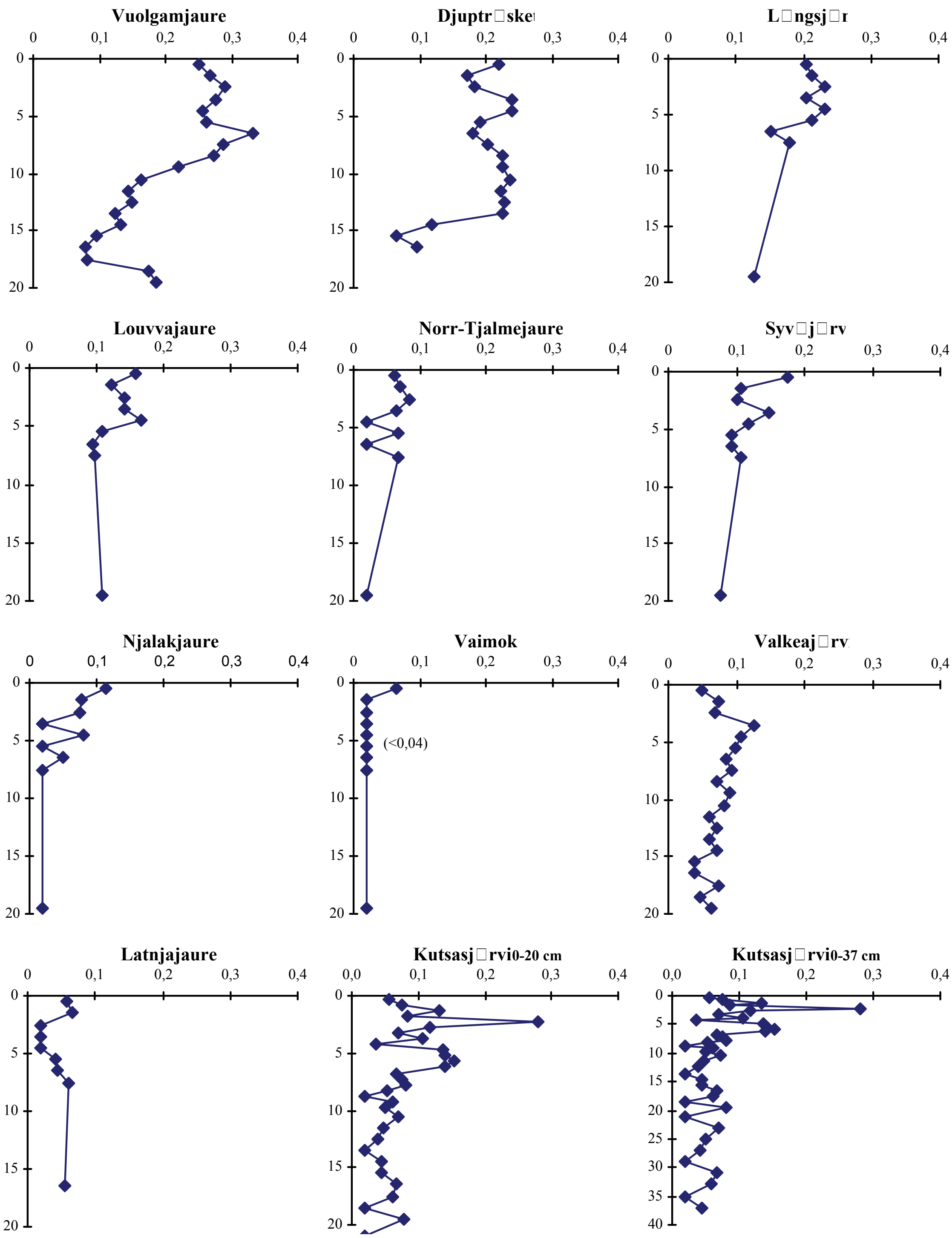
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

Hg

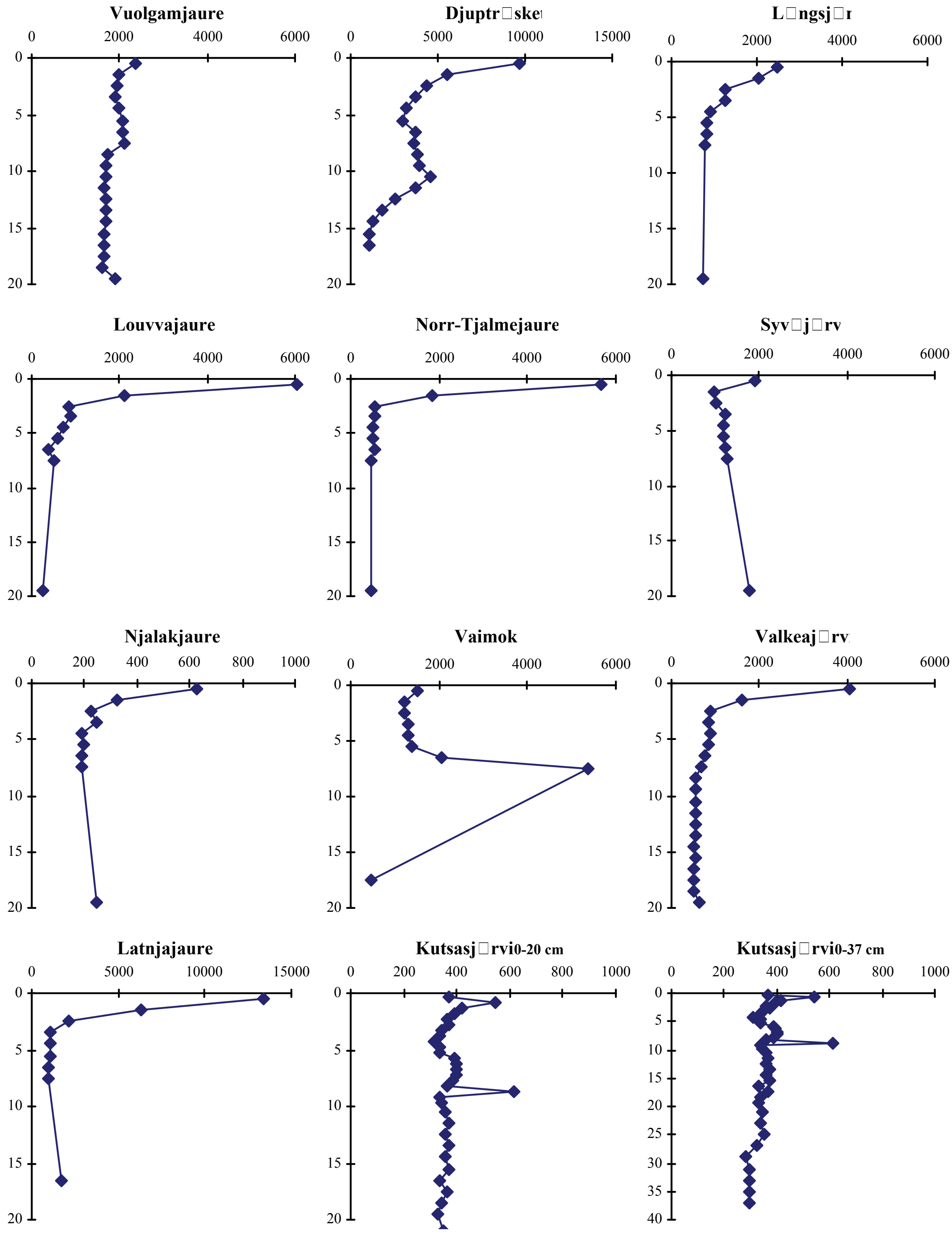


X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

APPENDIX 5

Mn



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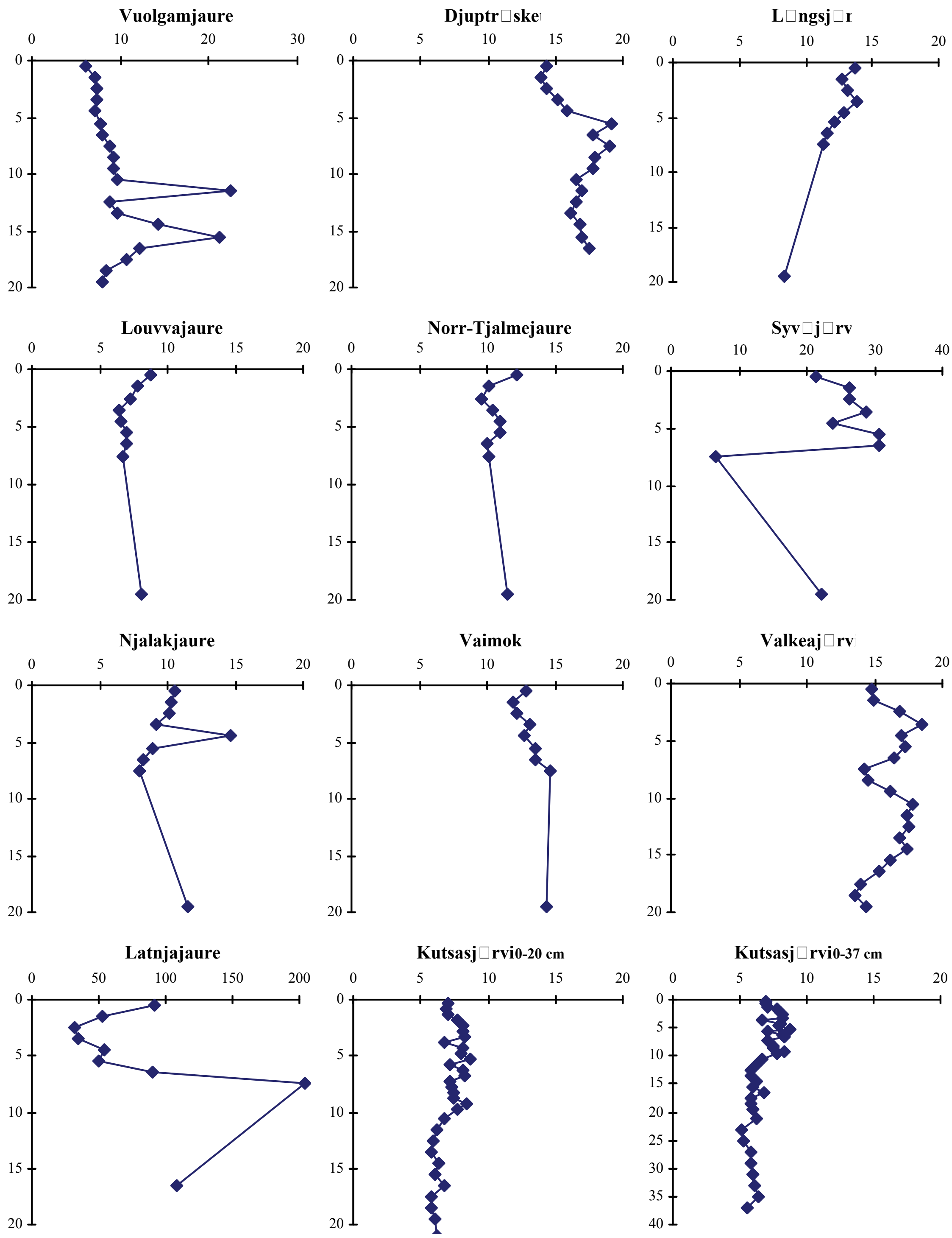
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

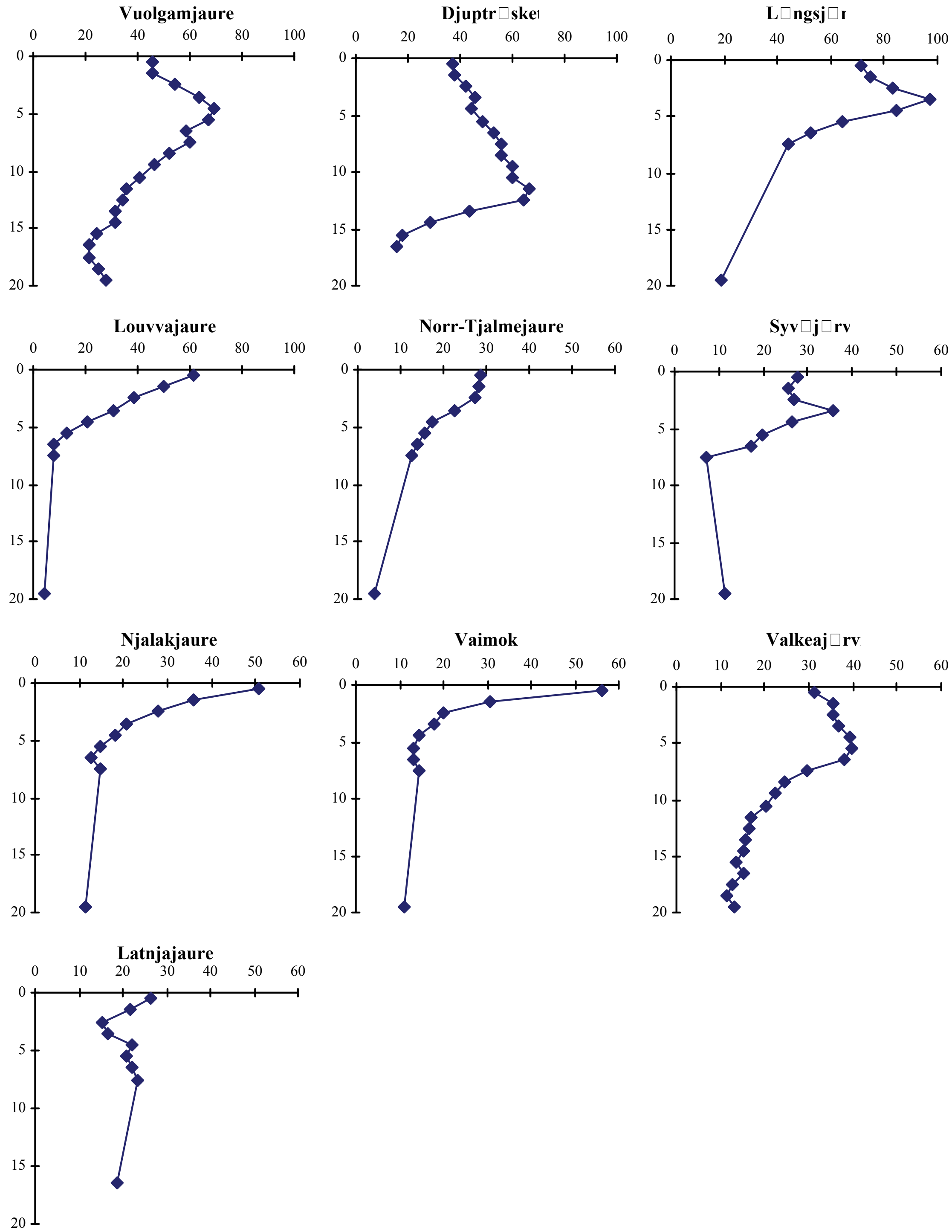
Ni



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

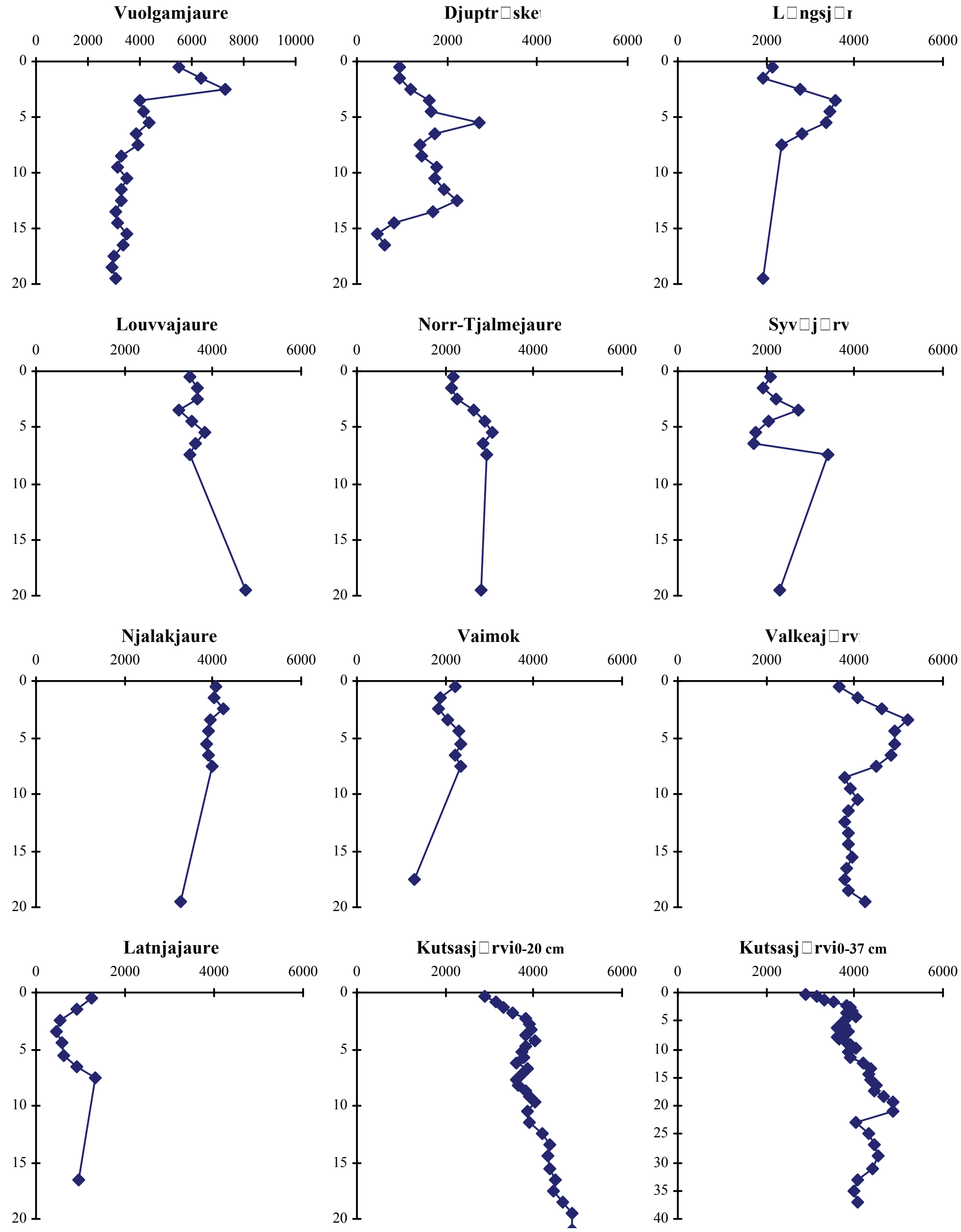
Pb



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

S



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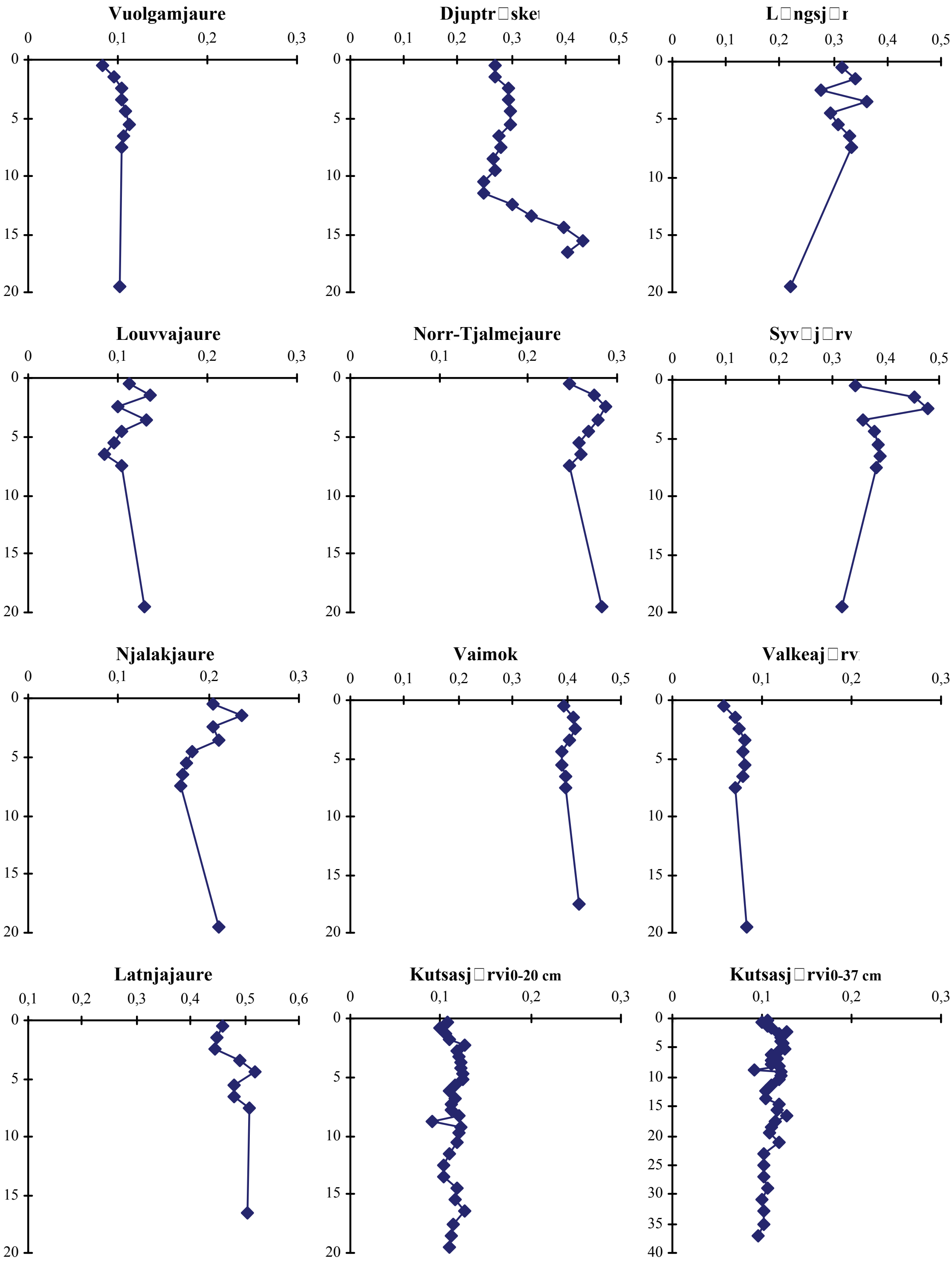
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

Ti



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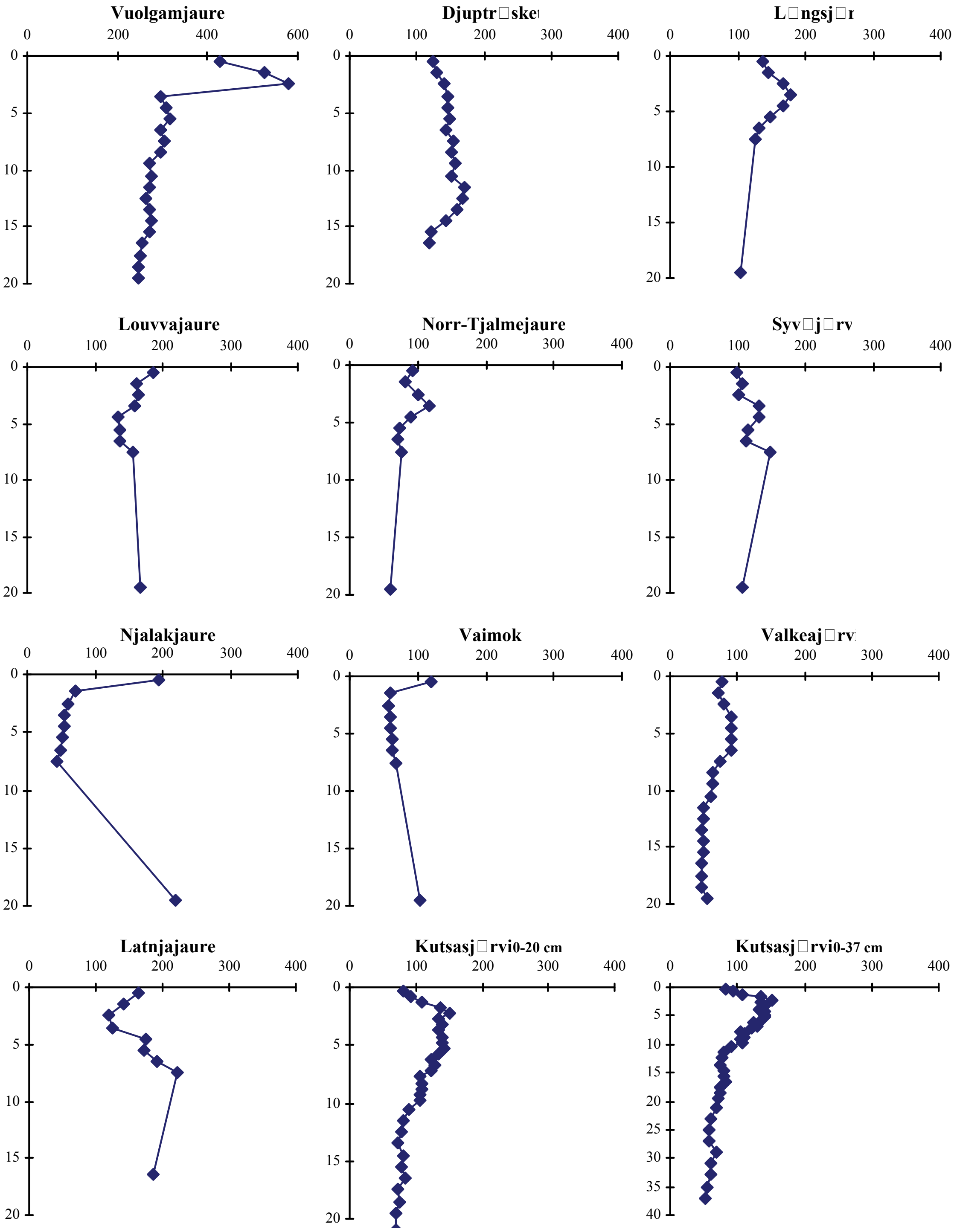
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

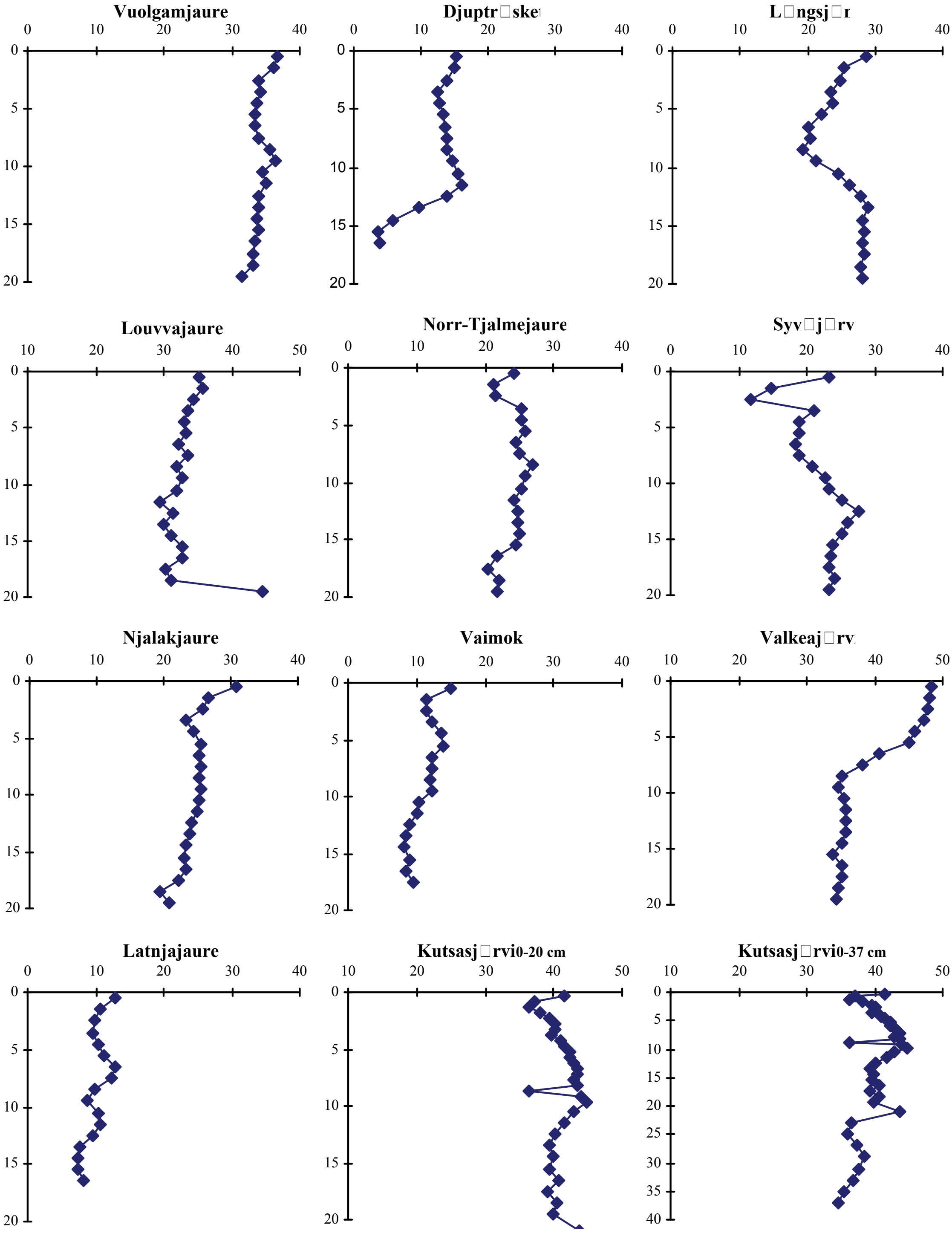
Zn



X-axis: mg/kg
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

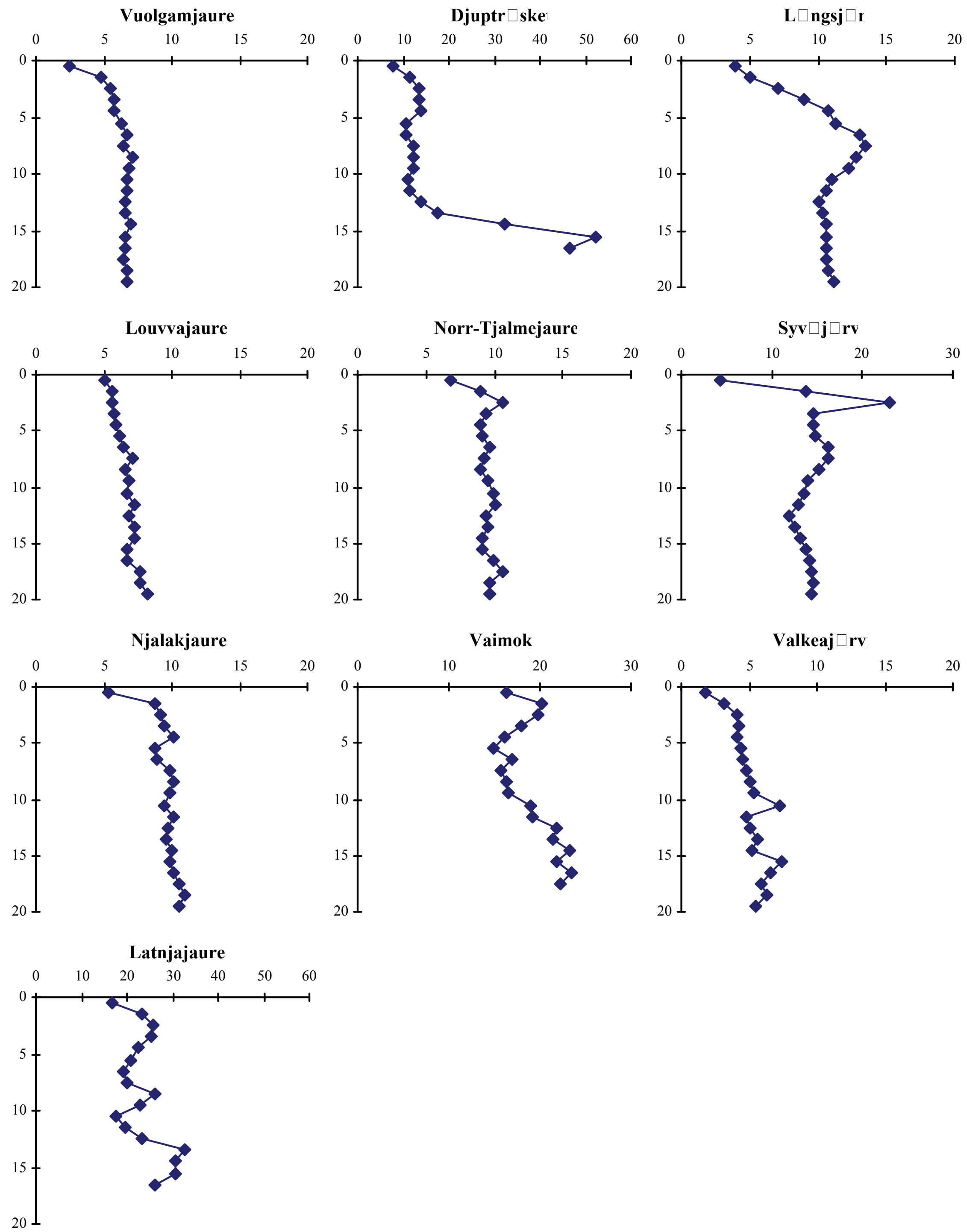
OM



X-axis: % (of dry sediment)
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range

TS



X-axis: % (of wet sediment)
Y-axis: Depth (cm)

Bold axis indicates a differing scale or a differing scale range