ARCTIS,
Regional Investigation of Arctic Snow chemistry: Results from the Icelandic expeditions, 1997-1999

Sigurður Reynir Gíslason, Matthildur Bára Stefánsdóttir,
and Eydís Salome Eiríksdóttir

RH-05-2000

RAUNVÍSINDASTOFNUN HÁSKÓLANS
Science Institute
University of Iceland
Dunhaga 3, 107 Reykjavík

March 2000

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INTRODUCTION

The Arctic is one of the most remote region of any extent in the populated and industrialized northern hemisphere. By determining snow composition and deposition at a regional scale on one occasion, one may obtain a picture of the extent of long-range atmospheric transport and deposition of pollutants. This type of study could in effect "take the pulse" of the Earth when it comes to atmospheric pollution. If such survey is repeated, time-trends can be obtained, and it could be established whether conditions are improving or deteriorating.

A number of significant local pollution sources also exist in the Arctic or on its fringe. For instance large mining/exploration operations such as Sydvaranger, Kiruna, Kostomuksha, Norilsk, Faro, Pine Point, Marmorilik, and the coal, oil and gas industry in Svalbard, Barents Sea, Siberia, Chukotskiy, North Slope, Axel Heiberg and Ellesmere Islands. The impact these activities have on the atmosphere could be identified by the snow survey. Institutions like geological surveys or universities are best able to interpret the geochemical fingerprints these major operations impart to the environment. In view of potential future growth in the mining sector in the region, regional baseline investigations will be useful for environmental impact studies.

The objective of this report is to describe in detail the Icelandic samples, the sampling methods and analytical results.

Four ARCTIS snow samples, number 34, 35, 36, and 38, were taken from two Icelandic glaciers in 1997 (Table 1). One sample on the Langjökull glacier at 64°35'746 and 20°20'685, March 13, 1997, and three samples on the Vatnajökull glacier at 64°35'000 and 17°20'000, March 20, 1997. Two of the ARCTIS samples from the Vatnajökull glacier are duplicate samples of the 1996-1997 winter precipitation, but the third sample from the Vatnajökull glacier is a sample of the snow in contact with volcanic ash from the October 1996 Gjálp subglacial volcanic eruption in Vatnajökull (Gudmundsson et al., 1997). Three of the Science Institute samples are duplicates of three of the ARCTIS samples (34, 35, and 38; Table 1). For further study of the snow, nine Science Institute samples were taken in, above, and below the volcanic ash layer (Table 1 and Table 5).

The 1998 and 1999 March expedition were to the previous Langjökull sample spot, at 64°35'746 and 20°20'685.

GOAL OF THE ARCTIS PROJECT

- To establish the concentration levels of natural and anthropogenic elements and compounds in Arctic snow.
- To document the spatial variability of these elements/compounds in the Arctic region.
- To obtain winter deposition estimates of these elements/compounds in the Arctic.

DESCRIPTION OF THE ARCTIS PROJECT

Through a tightly knit network of enthusiastic partners, field workers and laboratories, collection of snow samples (cores) took place at the end of the winter 1997, at a low spatial density. This relayed mainly on expeditions going to the Arctic for other purposes, or through local environmental management authorities. Twenty two snow samples were taken in Russia, Alaska, Canada, Greenland, Iceland, Svalbard, Norway, Sweden and Finland. Of these, there are four pairs of duplicates, meaning we have covered 18 different locations. Ten additional snow samples were taken from one locality in Canada, which will be used for testing lab methods and QA/QC purposes, as well as testing the local chemical heterogeneity of the snow. This sample set adds one locality, bringing the total up to 19 localities sampled.

Snow samples were collected with the same type of equipment by all parties, and were sent frozen to a unique laboratory; the Geological Survey of Canada in Ottawa. Sample preparation included melting at room temperature and in-line filtering (0.45 µm) in an ultra-clean room facility. Both the meltwater and the filter residue were analyzed for major, minor, and trace elements, isotopes, and organic compounds. Meltwater and filter residue were subjected to somewhat different analytical programs. For instance, the filter residues were studied by SEM/EDX and/or electron microprobe for particle characterization.

Additional to this, duplicate samples of the winter precipitation from all the Icelandic sites were taken and analyzed at the Science Institute, Reykjavík, Iceland and the SGAB laboratory, Luleå, Sweden. The winter precipitation at the Icelandic site on the Langjökull glacier has been monitored since 1997. These samples have been analyzed at the Science Institute, Reykjavík, Iceland, the SGAB Laboratory, Luleå, Sweden, the Stockholm University and the LECO Corporation, U.S.A.

SAMPLING METHODS

Selection of sampling sites

Snow from last winter only was collected. Flat, open virgin area was chosen, with no ski, foot or other tracks, away from trees and where snow cover appeared to be regular in thickness with no major ridges or holes and minimal reworking of the snow with wind. Holes were poked in the snow layer down to the ground at 12 sites (see fig. 1) and the snow depth measured and recorded onto a special field sheet (Appendix 1). Walking was avoided where the snow cores were to be taken (see suggested path fig. 1). The five snow subsamples were collected at the corners and centers of a 20 by 20 m square, according to the procedure demonstrated on fig. 1.

Owing to the thickness of the snow layer on the Icelandic glaciers, PICO lightweight hand coring auger driven by a Honda generator was used during the first expedition in 1997 to drill exploratory holes , at the corners of a 40 m by 40 m square corresponding to sites 1, 3, 5, and 7 on fig. 1 (figs. 2 and 3). The clean core was taken from a trench that was dug in the middle of the square (fig. 4). The PICO core barrel, and extensions were made of fiber glass but fittings, adapters and cutting head were machined from aluminium (Koci, 1983). A 20 m extension cord was used from the Honda generator to the drill site in order to position the generator as far as possible and down wind from the clean core site in the middle of the square (fig. 4). In 1998 and 1999 no exploratory drill cores were taken on the Langjökull glacier, Iceland. Clean cores were taken from a trench.

Collection of snow cores

The equipment used for snow sampling was:

- One acid-washed polycarbonate (PC) snow corer, in sealed polyethylene (PE) sleeve and cardboard tube.
- One PC plate used for cleaning the core site.
- PE bags with closing strap
- Non-talced, clear plastic gloves
- Pre-labelled cooling box
- Field sheet (see Appendix 1)
- Tape measure, roll of film, roll of duct tape, marker, and rope
- Snow shovels, plastic and metallic
- Topographic map of the area
- GPS positioning equipment
- Temperature meter with a sharp probe
- Camera
- PICO lightweight hand coring auger
- Honda generator
- Gasoline and oil for the generator (kept in the car)

A trench, 3- 4 m deep, was dug in the middle of a 40 m by 40 m square (fig. 4). The clean core equipment was then brought close to and downwind from the trench. The enveloping PE sleeve was removed from the PC corer. The PE sleeve was opened at the top of the corer, i.e.

not at the sharpened end of the tool. Care was taken not to put fingers or any object inside the tube of the PC corer at any time. The corer and the PC plate were always handled with plastic gloves. No smoking was allowed during sampling. The corer was then pushed five times into the snow pack to "clean" it, avoiding contact with the underlying vegetation, soil or rocks, these cores were discarded (fig. 5). A vertical wall was cleared by a plastic shovel, down to the bottom of the 1996-1997 winter layer (figs. 6 and 7). Care was taken that the thickness of the layer was representative for the area, i. e. well within the range of the for previous measurements done at the corners of the 40 by 40 m square. The depth of the snow layer was measured and recorded . The shovelled wall was treated as contaminated from the shovel (e. g. it was not touched with the plastic gloves). The PC plate was plunged five times into untouched snow to "clean" it. Then 10 cm of the wall was scraped away with the PC plate to have an uncontaminated vertical working surface (fig. 8). The PC plate was again plunged 5 times into untouched snow to "clean" it, and then inserted horizontally into the scraped surface at a depth suitable for the corer. The PC corer was then pushed/rotated vertically down into the snow layer, about five cm behind the clean surface (figs. 6 and 7) until it hit the plate. The corer was then pulled towards the trench, while holding the plate in contact with it. The snow core was emptied into a pre-labelled PE bag. This procedure was then repeated until all of the snow layer was sampled. One continuous core, filled one PE bag. All surplus air was then pushed out of the bag, the plastic strap rolled down at least five times and finally looped together. The strap was then used as handel. The ARCTIS sample 38 and the Science Institute sample 97-S025 of the snow from the Vatnajökull glacier in contact with the ash from the October 1996 subglacial eruption were carved out from the wall close to the bottom of the trench by the PC plate (figs. 9. and 10). The 9 Science Institute samples intended for further study of the snow were taken from the PICO cores in, above, and below the volcanic ash layer (fig. 11, Table 1). Two ARCTIS sampling bags fitted into the styrofoam box. The box was filled with excess snow to minimize melting of snow samples during transportation to the laboratory.

The duplicate samples that were collected in 1997 that were analyzed at the Science Institute, Reykjavík, Iceland and the SGAB laboratory, Luleå, Sweden, were sampled as described above, except three sample bags were needed to contain the whole sample and these bags were not acid washed.

The sample collected in March 1998 was collected in 3 plastic bags, similar to the Science Institute samples from 1997. The samples collected on the Langjökull glacier in 1999 were sampled as described above, but duplicate samples were taken. One into 3 sample bags that were not acid washed, and another into 3 sample bags that were acid washed. The bags were washed for one hour in 1 N HCl acid and then washed several times with deionized water and the final remaining water shaken out of the bags. The corer and PC plate were washed in similar manner.

In all the expeditions, temperature profiles were measured in the trenches by thermistor meter using a sharp probe that was plunged 20 cm horizontally into the wall at a given depth in the trench. The result is given in Table 2.

An approximate density of the snow and ice from the winter precipitation of 1997-1998 and 1998-1999 on the Langjökull glacier was estimated from weight and geometry measurements (Table 3). The weight was measured by a spring scale and the volume was estimated by the length of each core and in the case of the ice layers, they were carved into a square and their sizes measured. These measurements were not accurate.

The density measurements were used to calculate the winter precipitation, equivalent to rainfall, at the sampling site (Table 4).

Sample treatment in the laboratory

The samples from the 1996-1997 winter precipitaion were both melted at the Science Institute, Iceland and were sent frozen to the Geological Survey of Canada in Ottawa. These duplicate samples were analysed in Canada, Iceland, and the SGAB Laborateory Sweeden. The 1997-1998 winter precipitation on the Langjökull glacier was melted and analysed at the Science Institute and also analysed at SGAB. The 1998-1999 winter precipitation on the Langjökull glacier was melted at hte Science Institute and analysed at the Science Institute, SGAB Sweden and the LECO Corporation, U.S.A.

Sample preparation at the Geological Survey of Canada in Ottawa included melting at room temperature and in-line filtering (0.45 µm) in an ultra-clean room facility. Both the meltwater and the filter residue were analyzed for major, minor, and trace elements, isotopes, and organic compounds. Meltwater and filter residue were subjected to somewhat different analytical programs. For instance, the filter residues were studied by SEM/EDX and/or electron microprobe for particle characterization.

Each of the Science Institute samples (three bags for each winter precipitation except 6 bags in 1999) were melted in the laboratory in one of the sampling bags, with an extra outer bag. The double bag was submerged into hot water (60-95 °C) in the laboratory sink. As the snow started to melt, the snow from the other two sampling bags were "pored" into the meltwater. This was done to minimize the contact of melt water with the surface of the bags. Once all the sample was melted, it was filtered through a 0.2 µm pore size cellulose acetate filter into polyethylene plastic bottles. The filter holder was 142 mm in diameter (Sartorius) and the contact area was made of teflon. The filter holder, tubing and filter was cleaned by 1 liter of sample previous to sampling. Sampling bottles were cleaned twice with the filtrated sample, and the 100 ml high density polyethylene sample bottle used for ICP-SMS, ICP-AES and Atom Fluorecens measurements were acid cleaned at the SGAB Laboratory in Luleå Sweden.

Conductivity and pH at a specific temperature were then measured, samples for nutrient analysis placed in a deep freezer at -18 °C and samples for ICP-SMS, ICP-AES and Atom Fluorecens measurements acidified by suprapure nitric acid, 1 ml to 100 ml, but samples for anion analyses were simply filtrated into a low density polyethylene bottle. All bottles, except the acid washed bottles, were new and were washed several times with the sample. Bottles used for samples to be measured by ICP-SMS were acid washed before they were washed by the sample. The concentration of solid particles were measured in the sample. The concentration of nutrients was measured by colourimetry on an auto-analyzer. The samples were taken out of the freezer the night before analysis. The results of these measurements are shown in Tables 5, 6 and 7, and results from various analytical methods are compared in Table 8.

The analytical work done at the SGAB Laboratory in Luleå Sweden was performed according to the so called V-2 analytical program. The V-2 program is a multi-element analysis of natural freshwater by a combination of inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma sector mass spectrometry (ICP-SMS), and atomic fluorescence spectrometry (AFS). Main elements (Ca, K, Mg...) are determined by ICP-AES together with minor and trace elements present in relatively high concentrations, while trace elements in low concentrations are determined by ICP-SMS. AFS is used specifically for mercury. Which ICP technique is used for which element in a specific sample is stated in the analytical report.

The methods used for ICP-AES and ICP-SMS are modified versions of the USEPA Methods 200.7 and 200.8, respectively. The AFS method is modified from the Swedish Standard Method 028175. Clean lab technology is applied and ultra-pure reagents are produced in-house by sub-boiling distillation of de-ionized water and analytical grade acid. Preparation of samples and standards is carried out in a Class 100 clean room. Quality control is performed in each analytical run by means of control blank samples, reference materials, and drift control samples. The results for the reference materials are evaluated by means of control charts. Results for a batch of samples are accepted only if the result for the accompanying reference material falls within statistically defined limits. The control charts are also evaluated regularly on a long-term basis for evaluation of accuracy, precision and long-term stability.
SGAB Analytica is accredited for the methods in V-2 by the Swedish accreditation body SWEDAC.

Duplicates of the 1998-1999 winter precipitation samples were analyzed by the LECO corporation U.S.A. Analysis was performed using the LECO Renaissance Time-of-Flight (TOF) ICP-MS. The analytical method is described in Appendix 2. Result are shown in Table 9.

SHIPMENT OF THE ARCTIS SAMPLES

The samples were kept at -18°C in the laboratory until shipped by air from Iceland to Ottawa, Canada. The samples arrived in Ottawa, after minimal melting.

ACKNOWLEDGMENTS

Vilhjálmur Kjartansson, technical leader of all the expeditions, Óliver Hilmarsson, Andri Stefánsson, and Eiríkur Björnsson all participated in the various expeditions and contributed to their success by hard work, often under rather strenuous conditions. We are grateful for their help.

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TABLES

Table 1. Snow samples from the Langjökull and Vatnajökull glaciers 1997-1999

ARCTIS sample nr.	Science Inst. sample nr.	Sample spot	GPS location	GPS elevation m.a.s.l.	Date	Time of sampling	Air temperature °C	Weather	Snow depth. corner 1, cm	Snow depth. corner 3, cm	Snow depth. corner 5, cm	Snow depth. copmer 7, cm	Sample trench cm	Part of the snow layer
34*	97-S026	Langjökull	64°35'746-20°20'685	1222	13.3.97	13:15-18:15	-18	clear and calm	350	330		320	320	all
35*	97-S027	Vatnajökull	64°35'000-17°20'000		20.3.97		-10.6	snow showers	270	296	280	270	275	0-280 cm
36*		Vatnajökull	64°35'000-17°20'000		20.3.97		"	but calm	270	296	280	270	275	0-280 cm
37*		Vatnajökull	64°35'000-17°20'000		20.3.97		"	"						no sample
38*	97-S025	Vatnajökull	64°35'000-17°20'000		20.3.97		"	"	270	296	280	270	275	280-305cm
	97-S028	Core 1	64°35'000-17°20'000		20.3.97		"	"						0-260 cm
	97-S018	Core I	64°35'000-17°20'000		20.3.97		"	"		ash layer				ash layer
	97-S019	Core 2	64°35'000-17°20'000		20.3.97		"	"			ash layer			ash layer
	97-S020	Core 2	64°35'000-17°20'000		20.3.97		"	"			below ash			below ash
	97-S021	Core 3	64°35'000-17°20'000		20.3.97		"	"	bottom					ash layer
	97-S022	Core 3	64°35'000-17°20'000		20.3.97		"	"	middle					ash layer
	97-S023	Core 3	64°35'000-17°20'000		20.3.97		"	"	top					ash layer
	97-S024	Core 4	64°35'000-17°20'000		20.3.97		"	"				ash layer		ash layer
	98-L1	Langjökull, 98-L1	64°35´746-20°20´685	1102	27.3.98	13:38-17:45	-8.8	Clear and calm					338	all
	99-L1	Langjökull, 99-L1	64°35´746-20°20´685		31.3.99	15:10-17:30	-10.7	Clear and calm					340	all
	99-L2*	Langjökull, 99-L2	64°35´746-20°20´685		31.3.99	15:10-17:30	-10.7	Clear and calm					340	all

* Acid washed sample bags

Table 2. Temperature profile from the Langjökull and Vatnajökull glacier sampling sites, 1997 - 1999

Site 1997	Depth cm	Temperature °C
Langjökull, 1997	0	-18.0
	5	-13.3
GPS location	20	-11.2
64°35'746-20°20'685	40	-8.3
	60	-7.4
GPS elevation	80	-7.3
1222 m.a.s.l.	100	-7.2
	120	-6.7
Date 13.3.97	140	-6.4
	160	-5.8
Weather	180	-5.4
Clear and calm, and -18°C	200	-5.1
Snow layer 320 cm	200	-5.5
	250	-4.6
	285	-4.0
Vatnajökull	0	-10.6
GPS location	5	-12.0
64°35'000-17°20'000	20	-13.7
	40	-13.3
Map elevation	60	-12.4
1675 m.a.s.l.	80	-11.9
	100	-11.2
Date 20.3.1997	120	-10.6
	140	-10.0
Weather	160	-9.4
Fogy, snow showers, but	180	-9.0
clear and calm, air	200	-8.6
temperature was -18 °C	250	-8.2
at the beginning	300	-7.4
of sampling		

Site 1998	Depth cm	Temperature °C
Langjökull, 1998	0	
GPS location	10	-6.1
64°35´746-20°20´685	20	-5.1
	30	-4.2
GPS elevation	40	-2.7
1102 m	50	-1.7
	60	-1.2
Date 27.3.98	70	-0.6
	80	-0.3
Weather	90	-0.2
Clear and calm, -10.0°C	100	-0.1
at the beginning	110	-0.1
of sampling	120	-0.1
	130	-0.2
Air temperature -6.0°C	140	-0.3
at the end	150	-0.5
of sampling	160	-0.8
	170	-1.4
	180	-1.1
	190	-1.2
Snow layer	200	-1.4
338 cm	210	-1.4
	220	-1.5
Air pressure	230	-1.6
1260 millibars	240	-1.7
	250	-2.2
	260	-1.9
	270	-2.0
	280	-1.0
	290	-2.0
	300	-2.1
	310	-2.1
	320	-2.0
	330	-2.1

Site 1999	Depth cm	Temperature °C
Langjökull, 1999	0	
GPS location	10	-11.0
64°35´746-20°20´685	20	-11.4
	30	-10.2
GPS elevation	40	-8.4
???	50	-7.6
	60	-7.0
Date 31.3.99	70	-6.6
	80	-6.5
Weather	90	-6.4
Clear and calm, -11.0°C	100	-6.6
at the beginning	110	-6.0
of sampling	120	-5.9
	130	-5.6
Air temperature -9.1°C	140	-5.8
at the end	150	-6.1
of sampling	160	-5.6
	170	-5.0
	180	-4.9
	190	-4.8
Snow layer	200	-5.1
340 cm	210	-5.3
	220	-5.4
	230	-4.6
	240	-4.8
	250	-3.7
	260	-3.8
	270	-4.2
	280	-3.5
	290	-3.2
	300	-2.9
	310	-3.0
	320	-2.7
	330	-2.9
	340	-2.7

Table 3. Density profile from the Langjökull glacier sampling site, 1998 and 1999

Sample depth cm	Sample description	Weight g	Length cm	r^2 cm	volume cm^3	Density g/cm^3
1998						
84	dense snow	1362	84	13.32	3516	0.39
132	wet snow	681	48	13.32	2009	0.34
189	snow	1589	80	13.32	3348	0.47
255	snow	1180	66	13.32	2762	0.43
260	ice lense	863			1350	0.64
330	snow	1226	61	13.32	2553	0.48
1999						
17	snow	370	24	13.32	1004	0.37
50	snow	409	25	13.32	1046	0.39
100	snow	321	19	13.32	795	0.40
150	snow	338	17	13.32	712	0.48
200	snow	625	25	13.32	1046	0.60
250	snow	446	20	13.32	837	0.53
272	ice lense	58		13.32	36	*1.61*
307	snow	284	12	13.32	502	0.57

Diameter of corer = 7.3 cm
Volume of a cylinder (the corer) = $\pi r^2 l$
Density =mass (g)/volume (cm^3)

Table 4. Winter precipitation, equivalent to rainfall, on the Langjökull glacier.

Measured March 29. 1998

Sample top *cm*	*Sample bottom* *cm*	*Sample thickness* *cm*	*Measured snow density* *g/cm3*	*Measured ice density* *g/cm3*	*Snow thickness* *cm*	*Ice-lense thickness* *cm*	*Thickness of snow as water* *mm/year*	*Thickness of ice-lenses as water* *mm/year*	*Thickness of snow and ice as water* *mm/year*
0	90	90	0.39	0.64	89.5	0.5	349.1	3.2	352.3
90	130	40	0.34	0.64	35.2	4.8	119.7	30.7	150.4
130	190	60	0.47	0.64	58.7	1.3	275.9	8.3	284.2
190	260	70	0.43	0.64	55.5	14.5	238.7	92.8	331.5
260	270	10	-	0.64	0	10	0.0	64.0	64.0
270	330	60	0.48	0.64	52	8	249.6	51.2	300.8
									1483.1

Measured March 31. 1999

Sample top *cm*	*Sample bottom* *cm*	*Sample thickness* *cm*	*Measured snow density* *g/cm3*	*Assumed ice density* *g/cm3*	*Snow thickness* *cm*	*Ice-lense thickness* *cm*	*Thickness of snow as water* *mm/year*	*Thickness of ice-lenses as water* *mm/year*	*Thickness of snow and ice as water* *mm/year*
0	50	50	0.37		50	0	185.0	0.0	185.0
50	100	50	0.39		50	0	195.0	0.0	195.0
100	120	20	0.40		20	0	80.0	0.0	80.0
120	150	30	0.44		30	0	132.0	0.0	132.0
150	170	20	0.48	0.64	18.8	1.2	90.2	7.7	97.9
170	200	30	0.54	0.64	27.7	2.3	149.6	14.7	164.3
200	240	40	0.60	0.64	39.5	0.5	237.0	3.2	240.2
240	300	60	0.53	0.64	57.3	2.7	303.7	17.3	321.0
300	340	40	0.57	0.64	35.2	4.8	200.6	30.7	231.4
									1646.8

Table 5. Chemical analysis of snow samples from the Langjökull and Vatnajökull glaciers, 1997

ARCTIS sample nr.	Science Inst. sample nr.	Sample spot	Part of the snow layer	Concentratiopn of volcanic ash, g/kg	Conduct. µS/cm	T/cond. °C	pH	T/pH °C	NH_4-N µg/l	NO_2-N µg/l	NO_3-N µg/l	PO_4-P µg/l	TDN µg/l	TDP µg/l
34	97-S026	Langjökull	all	0.00	26	24.8	5.40	21.1	15.3	<0,56	15.5	96.0	61.6	86.7
35	97-S027	Vatnajökull	0-280 cm	0.00	6.7	20.1	5.12	20.3	7.5	1.0	26.0	9.6	29.4	9.3
36		Vatnajökull	0-280 cm											
37		Vatnajökull	no sample											
38	97-S025	Vatnajökull	280-305cm	5.77	12.8	21.5	5.23	21.8	5.4	<0,56	7.8	3.2	23.7	15.5
	97-S028	Core I	0-260 cm	0.00	7.2	21.7	5.17	23.0	6.7	0.7	8.1	6.2	18.2	6.2
	97-S018	Core I	ash layer	8.66			5.01	43.1	33.8	<0,56	39.4	6.0		
	97-S019	Core II	ash layer	17.09			5.15	23.2	17.4	<0,56	<1,7	3.8		
	97-S020	Core II	below ash	0.02			5.63	27.3						
	97-S021	Core III	ash layer	0.68			5.23	12.4						
	97-S022	Core III	ash layer	12.18			5.06	38.8						
	97-S023	Core III	ash layer	4.82			5.55	39.5						
	97-S024	Core IV	ash layer	13.03			5.14	12.7						

All measurements done on samples from new bags, but not acid washed.

Nutrients were measured by an auto-analyser at the Science Institute, University of Iceland.

Tabel 6. Concentration of major, trace and nutrient elements in Langjökull and Vatnajökull glacier snow 1997-1999. Analysed at the Science Institute, Reykjavík Iceland and SGAB, Luleå, Sweden.

Sci. Inst. number	Date	ARCTIS number	Location	pH	pH ref, T °C	Conduct. µS/sm	SiO_2 mg/kg ICP-AES	Na mg/kg ICP-AES	K mg/kg ICP-SMS	Ca mg/kg ICP-AES	Mg mg/kg ICP-AES	SO_4 mg/kg ICP-AES	SO_4 mg/kg Dionex	Cl mg/kg Dionex	Cl mg/kg Ion sel.	TDS* mg/kg
97-S026	13-Mar-97	I-34	Langjökull	5.4	21.1	26	<0.064	3.37	<0.400	0.14	0.39	1.06			6.23	11.6
97-S027	20-Mar-97	I-35	Vatnajökull	5.12	20.3	6.7	<0.064	0.73	<0.400	0.10	0.09	0.31			1.22	2.9
97-S027	20-Mar-97	I-36	Vatnajökull													
97-S025	20-Mar-97	I-38	Vatnajökull, ash	5.23	21.8	12.8	<0.064	1.34	<0.400	0.63	0.20	7.73			0.51	10.9
98-L1	27-Mar-98		Langjökull	6.72	25.3	22.9	1.89	3.56	<0.400	0.15	0.26	1.22		4.38		11.9
99-L1	31-Mar-99		Langjökull	6.24	20.7	8.5	<0.064	0.94	<0.400	<0.100	0.12	0.58	0.36	1.92		4.1
99-L2	31-Mar-99		Langjökull	5.73	19.7	9.1	<0.064	1.00	<0.400	<0.100	0.12	0.47	0.35	1.99		4.1

Sci. Inst. number	S-isotopes ‰	F µg/kg Dionex	F µg/kg Ion sel.	NO_3-N µg/kg Colorim.	NO_2-N µg/kg Colorim.	NH_4-N µg/kg Colorim.	PO_4-P µg/kg Colorim.	PO_4-P µg/kg ICP-SMS	Al µg/kg ICP-SMS	Fe µg/l ICP-SMS	Mn µg/kg ICP-SMS	Ti µg/kg ICP-SMS	Hg µg/kg AFS	Pb µg/kg ICP-SMS	Cd µg/kg ICP-SMS
97-S026				15.5	<0.56	15.3	96.00	<0.15	1.45	0.80	0.17		0.0010	0.090	0.0052
97-S027			<20	26.0	1.00	7.5	9.60	0.16	0.88	0.40	0.04		0.0010	0.046	0.0030
97-S027															
97-S025			125	7.8	<0.56	5.4	3.20	<0.15	48.50	13.90	16.40		0.0117	0.052	0.0119
98-L1	12.98	20.0		28.9	1.34	32.7	6.22	≤15.33	6.87	4.40	0.80	0.050	<0.0022	0.169	0.0553
99-L1		6.30		9.4	<0.56		17.70	19.40	0.64	0.60	0.09	0.056	<0.0022	0.016	0.0128
99-L2		6.38		10.0	<0.56		3.41	2.05	0.73	<0.4	0.06	0.032	<0.0022	0.018	0.0106

Sci. Inst. number	V µg/kg ICP-SMS	Cr µg/kg ICP-SMS	Co µg/kg ICP-SMS	Ni µg/kg ICP-SMS	Cu µg/kg ICP-SMS	Zn µg/kg ICP-SMS	As µg/kg ICP-QMS	Sb ng/kg ICP-SMS	Sn ng/kg ICP-SMS	Mo µg/kg ICP-SMS	Li ng/kg ICP-SMS	Be ng/kg ICP-SMS	Sr µg/kg ICP-SMS	Ba µg/kg ICP-SMS	U ng/kg ICP-SMS
97-S026		0.075	0.005	0.250	0.062	0.290	<0.0200			<0.0100			2.37	0.0336	
97-S027		0.081	0.005	0.216	0.063	0.306	<0.0200			<0.0100			0.519	0.0193	
97-S027															
97-S025		0.091	0.154	0.434	1.070	1.220	<0.0200			<0.0100			1.71	0.198	
98-L1	0.142	0.024	0.0151	0.420	0.268	1.240	<0.0100	3.6	21.7	0.098	119	5.5	1.890	0.132	0.4
99-L1		0.011	0.0049	0.204	0.102	2.820	0.09			<0.0100			0.768	0.026	
99-L2		<0.010	0.004	0.184	<0.100	1.360	<0.0100			<0.0100			0.78	0.02	

ICP-AES: Inductively Coupled Plasma - Argon Emission Spectrometry
ICP-SMS: Inductively Coupled Plasma - High Resolution Mass Spectrometry
AFS: Atomfluorescence

Ion sel.: Specific ion selective electrode
Colorim.: Colorimetry, Autoanalyser
Dionex: High Pressure Ion Chromatograpy, Dionex

TDS*: Not including bicarbonate

Tabel 7. Concentration of major, trace and nutrient elements in Langjökull and Vatnajökull glacier snow 1997-1999. Analysed at the Canadian Geological Survey, Ottawa, Canada.

Sci. Inst. number	Date	ARCTIS number	Location	Conductivity µS/cm	pH	pH ref, T °C	SiO$_2$ mg/kg ICP-QMS	Na mg/kg ICP-QMS	K mg/kg ICP-QMS	Ca mg/kg ICP-QMS	Mg mg/kg ICP-QMS	SO$_4$ mg/kg ICP-QMS	Cl mg/kg Dionex	TDS* mg/kg
97-S026	13-Mar-97	I-34	Langjökull	17.87	5.35	21.1	<0,043	2.845	0.183	0.122	0.377	0.966	6.22	10.7
97-S027	20-Mar-97	I-35	Vatnajökull	< 5	5.45		<0,043	0.551	< 0.05	0.024	0.071	0.204	1.11	2.0
97-S027	20-Mar-97	I-36	Vatnajökull	< 5	5.42	20.3	<0,043	0.555	< 0.05	0.023	0.071	0.249	1.17	2.1
97-S025	20-Mar-97	I-38	Vatnajökull, ash	12.87	5.2	21.8	0.060	1.298	0.051	0.661	0.220	7.968	0.41	10.7

Sci. Inst. number	F µg/kg Dionex	Br µg/kg Dionex	NO3-N µg/kg Dionex	NO2-N µg/kg Dionex	PO4-P µg/kg Dionex	P µg/kg ICP-QMS	Al µg/kg ICP-QMS	Fe µg/l ICP-QMS	Mn µg/kg ICP-QMS	Ti µg/kg ICP-QMS	Hg µg/kg Hydride	Pb µg/kg ICP-QMS	Cd µg/kg ICP-QMS
97-S026	< 50	< 50	108	< 50	< 50	< 50	0.95	< 1	0.060	< 0.05	0.0091	0.062	0.0025
97-S027	< 50	< 50	< 50	< 50	< 50	51	< 0.5	< 1	0.035	< 0.05	< 0.002	0.027	0.0063
97-S027	< 50	< 50	< 50	< 50	< 50	< 50	< 0.5	< 1	0.036	< 0.05	0.0022	0.027	0.0015
97-S025	162.5	< 50	< 50	< 50	< 50	< 50	68.69	7.2	16.934	0.097	< 0.002	0.010	0.0143

Sci. Inst. number	Sc µg/kg ICP-QMS	V µg/kg ICP-QMS	Cr µg/kg ICP-QMS	Co µg/kg ICP-QMS	Ni µg/kg ICP-QMS	Cu µg/kg ICP-QMS	Zn µg/kg ICP-QMS	As µg/kg Hydride	Se µg/kg Hydride	Sb ng/kg Hydride	Te µg/kg Hydride	Bi µg/kg Hydride
97-S026	< 1	0.021	< 0.1	< 0.002	< 0.05	0.11	0.337	0.012	0.0261	0.0049	< 0.006	0.0033
97-S027	< 1	< 0.01	< 0.1	< 0.002	< 0.05	0.065	0.221	0.011	0.0117	< 0.003	< 0.006	0.0035
97-S027	< 1	< 0.01	< 0.1	< 0.002	< 0.05	0.052	0.238	0.013	0.0109	< 0.003	< 0.006	< 0.003
97-S025	< 1	< 0.01	< 0.1	0.1922	0.293	1.876	2.092	0.012	0.0121	0.0042	< 0.006	< 0.003

Sci. Inst. number	Li µg/kg ICP-QMS	Rb µg/kg ICP-QMS	Cs µg/kg ICP-QMS	Be µg/kg ICP-QMS	Sr µg/kg ICP-QMS	Ba µg/kg ICP-QMS	Y µg/kg ICP-QMS	Mo µg/kg ICP-QMS	Ag µg/kg ICP-QMS	In µg/kg ICP-QMS	U ng/kg ICP-QMS
97-S026	0.0523	< 0.05	< 0.01	< 0.005	2.180	< 0.2	< 0.001	< 0.005	< 0.01	< 0.0005	< 0.0005
97-S027	0.0099	< 0.05	< 0.01	< 0.005	0.425	< 0.2	< 0.001	< 0.005	< 0.01	< 0.0005	< 0.0005
97-S027	0.011	< 0.05	< 0.01	< 0.005	0.450	< 0.2	< 0.001	< 0.005	< 0.01	< 0.0005	< 0.0005
97-S025	0.5224	0.125	< 0.01	0.008	1.775	< 0.2	0.027	< 0.005	< 0.01	< 0.0005	< 0.0005

Sci. Inst. number	La µg/kg ICP-QMS	Ce µg/kg ICP-QMS	Pr µg/kg ICP-QMS	Nd µg/kg ICP-QMS	Sm µg/kg ICP-QMS	Eu µg/kg ICP-QMS	Gd µg/kg ICP-QMS	Tb µg/kg ICP-QMS	Dy µg/kg ICP-QMS	Ho µg/kg ICP-QMS	Er µg/kg ICP-QMS	Tm µg/kg ICP-QMS	Yb µg/kg ICP-QMS	Lu µg/kg ICP-QMS
97-S026	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
97-S027	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
97-S027	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
97-S025	0.009	0.018	0.002	0.010	0.002	< 0.001	0.004	< 0.001	0.004	< 0.001	0.002	< 0.001	0.002	< 0.001

TDS*: Not including bicarbonate

ICP-QMS: Inductively Coupled Plasma - Quadrupole Mass Spectroscopy

Dionex: High Pressure Ion Chromatograpy, Dionex

Hydride: Volatile Hydrides measured by Flameless Atomic Adsorption Spectroscopy

Table 8. Comparison of the results from the various analytical methods used for the 1996-1997 winter precipitation on the Vatnajökull and Langjökull glaciers

Sample nr.	Date	ARCTIS number	Location	Na mg/kg ICP-QMS	Na mg/kg ICP-AES	*Rel. error %*	K mg/kg ICP-QMS	K mg/kg ICP-SMS	*Rel. error %*	Ca mg/kg ICP-QMS	Ca mg/kg ICP-AES	*Rel. error %*	Mg mg/kg ICP-QMS	Mg mg/kg ICP-AES	*Rel. error %*	SO_4 mg/kg ICP-QMS	SO_4 mg/kg ICP-AES	*Rel. error %*
97-S026	13-Mar-97	I-34	Langjökull	2.845	3.37	*-17*	0.183	<0.400		0.122	0.14	*-10*	0.377	0.39	*-3*	0.966	1.06	*-9*
97-S027	20-Mar-97	I-35	Vatnajökull	0.551	0.73	*-28*	< 0.05	<0.400		0.024	0.10	*-124*	0.071	0.09	*-23*	0.204	0.31	*-43*
97-S027	20-Mar-97	I-36	Vatnajökull	0.555			< 0.05			0.023			0.071			0.249		
97-S025	20-Mar-97	I-38	Vatnajökull, ash	1.298	1.34	*-3*	0.051	<0.400		0.661	0.63	*5*	0.220	0.20	*9*	7.968	7.73	*3*

Sample nr.	Cl mg/kg Dionex	Cl mg/kg Ion sel.	*Rel. error %*	F µg/kg Dionex	F µg/kg Ion sel.	*Rel. error %*	Al µg/kg ICP-QMS	Al µg/kg ICP-SMS	*Rel. error %*	As µg/kg Hydride	As µg/kg ICP-SMS	*Rel. error %*	Ba µg/kg ICP-QMS	Ba µg/kg ICP-SMS	*Rel. error %*	Cd µg/kg ICP-QMS	Cd µg/kg ICP-SMS	*Rel. error %*
97-S026	6.220	6.230	*0*	< 50			0.95	1.5	*-42*	0.012	<0.0200		< 0.2	0.0336		0.0025	0.005	*-70*
97-S027	1.110	1.220	*-9*	< 50	<20		< 0.5	0.9		0.011	<0.0200		< 0.2	0.0193		0.0063	0.003	*71*
97-S027	1.165			< 50			< 0.5			0.013			< 0.2			0.0015		
97-S025	0.410	0.510	*-22*	162.5	125	*26*	68.69	48.5	*34*	0.012	<0.0200		< 0.2	0.198		0.0143	0.012	*18*

Co µg/kg ICP-QMS	Co µg/kg ICP-SMS	*Rel. error %*	Cr µg/kg ICP-QMS	Cr µg/kg ICP-SMS	*Rel. error %*	Cu µg/kg ICP-QMS	Cu µg/kg ICP-SMS	*Rel. error %*	Fe µg/l ICP-QMS	Fe µg/l ICP-SMS	*Rel. error %*	Hg µg/kg Hydride	Hg µg/kg AFS	*Rel. error %*	Mn µg/kg ICP-QMS	Mn µg/kg ICP-SMS	*Rel. error %*
< 0.002	0.005		< 0.1	0.075		0.110	0.062	*56*	< 1	0.80		0.009	0.001	*160*	0.060	0.17	*-95*
< 0.002	0.005		< 0.1	0.081		0.065	0.063	*2*	< 1	0.40		< 0.002	0.001		0.035	0.04	*-10*
< 0.002			< 0.1			0.052			< 1			0.002			0.036		
0.1922	0.154	*22*	< 0.1	0.091		1.876	1.070	*55*	7.2	13.90	*-64*	< 0.002	0.012		16.934	16.40	*3*

Sample nr.	Ni µg/kg ICP-QMS	Ni µg/kg ICP-SMS	*Rel. error %*	Pb µg/kg ICP-QMS	Pb µg/kg ICP-SMS	*Rel. error %*	Sr µg/kg ICP-QMS	Sr µg/kg ICP-SMS	*Rel. error %*	Zn µg/kg ICP-QMS	Zn µg/kg ICP-SMS	*Rel. error %*
97-S026	< 0.05	0.250		0.062	0.090	*-37*	2.180	2.37	*-8*	0.337	0.290	*15*
97-S027	< 0.05	0.216		0.027	0.046	*-53*	0.425	0.52	*-20*	0.221	0.306	*-32*
97-S027	< 0.05			0.027			0.450			0.238		
97-S025	0.293	0.434	*-39*	0.010	0.052	*-135*	1.775	1.71	*4*	2.092	1.220	*53*

Table 9. Comparison of the results from the various analytical methods employed for the 1998-1999 winter precipitation on the Langjökull glacier (see Appendix 2). The samples were analyzed by Renaissance TOF-ICP-MS (LECO Corporation) and ICP-SMS and ICP-AES (SGAB, Luleå, Sweden).

Element	99-L1 TOF-ICP-MS LECO [ppb =µg/L]	99-L2 TOF-ICP-MS LECO snow from acid washed bag [ppb = µg/L]	99-L1 ICP-SMS SGAB [ppb =µg/L]	99-L2 ICP-SMS SGAB snow from acid washed bag [ppb = µg/L]
Li	0.027	0.026		
Na	1000	1050	940**	1000**
Mg	122	125	120**	120**
Al	1.4	1.25	0.64	0.73
K	90	48	<400**	<400**
Ca	52	46.5	<100**	<100**
Cr	<0.04	<0.02	0.011	<0.01
Mn	0.096	0.07	0,09	0,06
Fe[1]	0.9	0.45	0.6	<0.4
Co	<0.006	<0.006	0.0049	0.004
Ni	0.29	0.25	0.204	0.184
Cu	0.09	0.08	0.102	<0.100
Zn	3	1.3	2.82	1.36
As	0.18	<0.05	0.09	<0,01
Rb	0.025	0.016		
Sr	0.75	0.75	0.768	0.78
Mo	<0.025	<0.025	<0.01	<0.01
Cd	<0.03	<0.03	0.0128	0.0106
Cs	<0.002	<0.002		
Ba	0.025	0.02	0.026	0.02
Pb_Cool	<0.005	<0.005		
Pb_USN	0.012	0.016	0.016	0.018
* Ga, Y, Nb, Ag, Rh, In, Sb, Ce, Ta, Re, Tl, Th, U	<0.006	<0.006		
* Pr, Nd, Eu, Dy, Yb, Er, Ho, Tb, Tm, Lu	<0.006	<0.006		
* Ge, Zr, Pt, W, Sm, Dy, Yb, Gd	<0.02	<0.02		
* Be, Se	<0.05	<0.05		

There was a somewhat higher Pb value measured by ultrasonic nebulizer compared to the cool plasma data: this could come from contamination of glass surfaces of the USN and washout of Pb by the sample.

*: Estimated from full spectrum scan: no visible peaks.

[1] See explanations in Appendix 2

** Measured by ICP-AES

FIGURES

Figure 1. Selection of sampling site

Figure 2. PICO lightweight hand coring auger driven by a Honda generator was used to drill exploratory holes, at the corners of a 40 m by 40 m square corresponding to sites 1, 3, 5, and 7 on fig. 1

Figure 3. The PICO lightweight hand coring auger fully extended.

Figure 4. The clean core was taken from a trench that was dug in the middle of the square up-wind from cars and equipment.

Figure 5. The PC corer was pushed/rotated vertically down into the snow layer, about five cm behind the clean vertical surface of the trench.

Figure 6. Snow sampling with the "clean" PC corer.

Figure 7. Snow sampling with the "clean" PC corer. Note the location of the PC plate.

Figure 8. Cleaning the face of the wall with the PC plate, wearing plastic gloves.

Figure 9. A piece of snow and volcanic ash from the Vatnajökull site.

Figure 10. A piece of snow and volcanic ash from the Vatnajökull site before melting in the laboratory.

Figure 11. Core from the PICO lightweight hand coring auger, showing the ash layer from the October Gjálp subglacial eruption 1996.

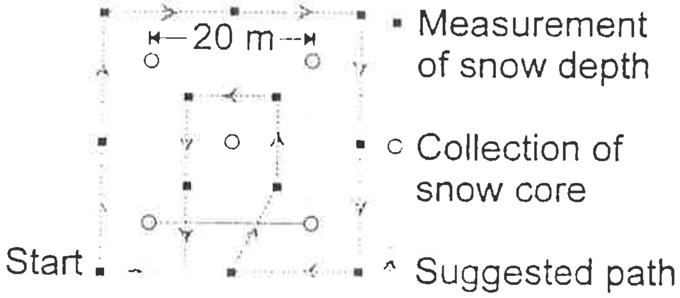

Figure 1. Selection of sampling site.

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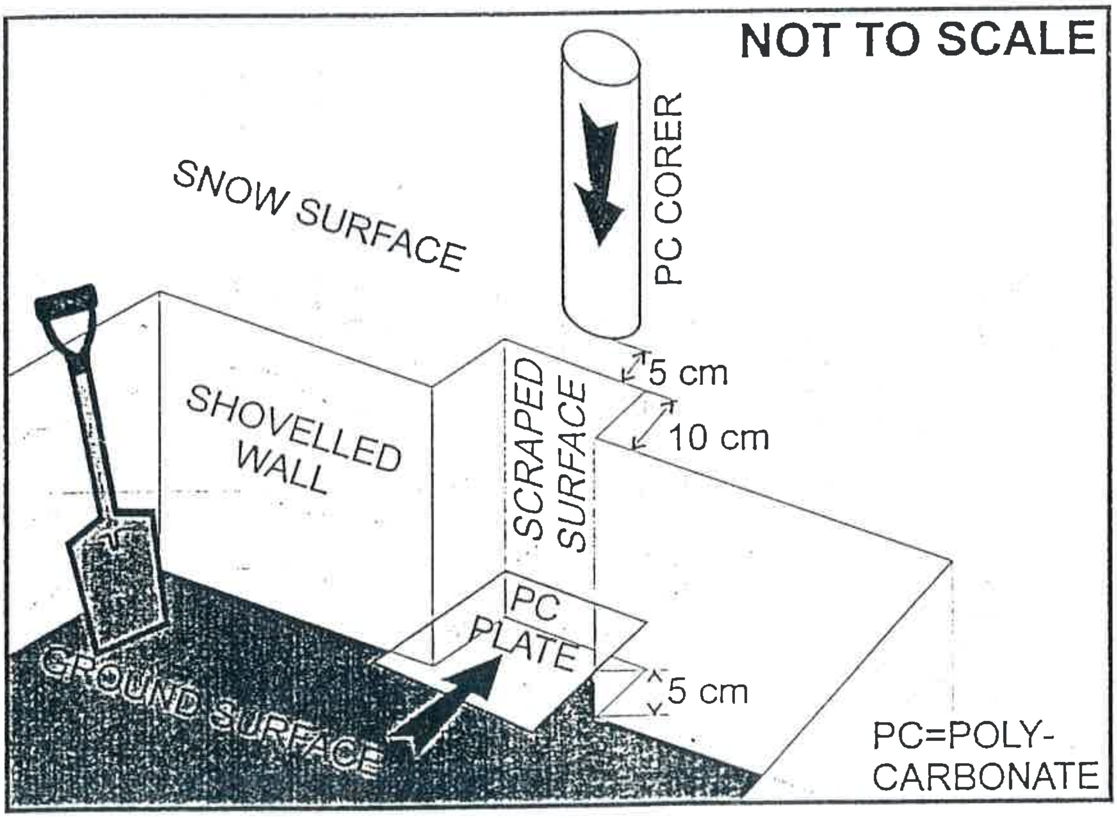


Figure 6. Snow sampling with the "clean" PC corer.

Figure 7. Snow sampling with the "clean" PC corer. Note the location of the PC plate.

Figure 8. Cleaning the face of the wall with the PC plate, wearing plastic gloves.

APPENDIX 1; FIELD SHEETS AND DESCRIPTION OF SNOW CORES.

1. Field sheet for ARCTIS sample nr. 34 from the Langjökull glacier.

2. Field sheet for ARCTIS sample nr. 35 from the Vatnajökull glacier.

3. Field sheet for ARCTIS sample nr. 36 from the Vatnajökull glacier.

4. Field sheet for ARCTIS sample nr. 37 from the Vatnajökull glacier.

5. Detailed description of PICO core nr. 3(I) from the Vatnajökull glacier.

6. Detailed description of the snow and ice layers in the trench in the Langjökull glacier in 1998.

7. Detailed description of the snow and ice layers in the trench in the Langjökull glacier in 1999.

1. Field sheet for ARCTIS sample nr. 34 from the Langjökull glacier.

Sample ID: 34 (see number on sample bag)

Name(s) of sampler(s): SIGURÐUR R. GISLASON

Date (day/month/year): 13 / MARS /1997 (please spell out the month, e.g. 'April')

Country: ICELAND
State/Province/Oblast/County: ____________
Commune/District: ____________
Closest town/village on map: ____________

Topographic map sheet used
Name: LANGJÖKULL Number: 1714 II Scale: 1:50,000

Coordinates of sampling site
System used (e.g. 'UTM'): ____________ Zone: ____________
Other info: ____________
Northing: 64°35'746 WE ~~E~~asting: 20°20'685 (GSM - LOCATION)

Snow depth, record 12 measurements (cm)

1) 350	2)	3) 330	4)	5)	6)
7) 320	8)	9)	10)	11)	12)

Thickness of snow sampled (cm) (collect enough cores to fill one PE bag, normally 5 cores)

1) 320	2)	3)	4)	5)	6)
7)	8)	9)	10)	11)	12)

General remarks about snow cover at this site
Is the snow clean or rather dirty here? clean
Are there icy layers in the snowpack? at the bottom of the core.
Has the springtime snowmelt already started here? no
Is there a risk that sample may be contaminated (plant material, soil)? no
Did you encounter problems during sampling? no (if 'yes', describe below)
Other comments/remarks: ____________

When fieldwork is completed, please send
- the topographic maps, with sampling locations and sample numbers indicated on them
- the original field sheets

to: *Patrice de Caritat, Geological Survey of Norway, P.O. Box 3006, N-7002 Trondheim, NORWAY*

Samples are to be sent frozen to: *Gwendy Hall, Applied Geochemistry, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, CANADA*

2. Field sheet for ARCTIS sample nr. 35 from the Vatnajökull glacier.

ARCTIS Project - FIELD SHEET

Sample ID: 35 (see number on sample bag)

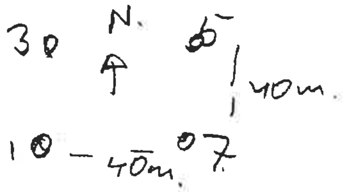
Name(s) of sampler(s): SIGURDUR R. GISLASON

Date (day/month/year): 20 / MARS /1997 (please spell out the month, e.g. 'April')

Country: ICELAND
State/Province/Oblast/County: VATNAJÖKULL
Commune/District: ______
Closest town/village on map: GLACIER.

Topographic map sheet used
Name: DYNGJUJÖKULL Number: 2014 II Scale: 1:50 000

Coordinates of sampling site
System used (e.g. 'UTM'): ______ Zone: ______
Other info: ______
Northing: 64°35'00 W Easting: 17°20'00



Snow depth, record 12 measurements (cm)

① 270	2)	③ I 296	4)	⑤ II 280	6)
IV ⑦ 270	8)	9)	10)	11)	12)

Thickness of snow sampled (cm) (collect enough cores to fill one PE bag, normally 5 cores)

1) ≈275	2)	3)	4)	5)	6)
7)	8)	9)	10)	11)	12)

General remarks about snow cover at this site
Is the snow clean or rather dirty here? Clear but volcanic ash layer below
Are there icy layers in the snowpack? see description
Has the springtime snowmelt already started here? NO
Is there a risk that sample may be contaminated (plant material, soil)? no
Did you encounter problems during sampling? ______ (if 'yes', describe below)
Other comments/remarks:
CORE WAS TAKEN FROM THE SURFACE DOWN TO 5 CM ABOVE THE VOLCANIC ASH LAYER.

When fieldwork is completed, please send
- the topographic maps, with sampling locations and sample numbers indicated on them
- the original field sheets

to: *Patrice de Caritat, Geological Survey of Norway, P.O. Box 3006, N-7002 Trondheim, NORWAY*

Samples are to be sent frozen to: *Gwendy Hall, Applied Geochemistry, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, CANADA*

3. Field sheet for ARCTIS sample nr. 36 from the Vatnajökull glacier.

ARCTIS Project - FIELD SHEET

Sample ID: 36 (see number on sample bag) is FIELD duplicate to sample 35

Name(s) of sampler(s): SIGURDUR GISLASON

Date (day/month/year): 20/ MARS /1997 (please spell out the month, e.g. 'April')

Country: ICELAND
Commune/District: ______
State/Province/Oblast/County: ______
Closest town/village on map: ______

Topographic map sheet used
Name: DYNGJUJÖKULL Number: 2014 II Scale: 1:50 000

Coordinates of sampling site
System used (e.g. 'UTM'): ______ Zone: ______
Other info: ______
Northing: 64°35'000 Easting: West 17°20'00

Snow depth, record 12 measurements (cm)
① 270 2) ______ ③ 296 4) ______ ⑤ 280 6) ______
⑦ 270 8) ______ 9) ______ 10) ______ 11) ______ 12) ______

Thickness of snow sampled (cm) (collect enough cores to fill one PE bag, normally 5 cores)
1) ≈275 2) ______ 3) ______ 4) ______ 5) ______ 6) ______
7) ______ 8) ______ 9) ______ 10) ______ 11) ______ 12) ______

General remarks about snow cover at this site
Is the snow clean or rather dirty here? CLEAN
Are there icy layers in the snowpack? YES, SEE CORE
Has the springtime snowmelt already started here? NO
Is there a risk that sample may be contaminated (plant material, soil)? YES
Did you encounter problems during sampling? YES. (if 'yes', describe below)
Other comments/remarks:
THE CORER GOT STUCK INTO THE ASH LAYER.
THE ASH LAYER WAS PULLED OUT USING
PLASTIC GLOVES.

When fieldwork is completed, please send
- the topographic maps, with sampling locations and sample numbers indicated on them
- the original field sheets

to: *Patrice de Caritat, Geological Survey of Norway, P.O. Box 3006, N-7002 Trondheim, NORWAY*

Samples are to be sent frozen to: *Gwendy Hall, Applied Geochemistry, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, CANADA*

4. Field sheet for ARCTIS sample nr. 37 from the Vatnajökull glacier.

ARCTIS Project - FIELD SHEET BAG NO. 37 - GO CUT BY THE ICY SAMPLE.

Sample ID: NO. 38 (see number on sample bag) - IS A SAMPLE OF THE JASH LAYER BELOW SAMPLES 36 AND 37

Name(s) of sampler(s): S.R. GÍSLASON

Date (day/month/year): 20/ MARS /1997 (please spell out the month, e.g. 'April')

Country: ICELAND
State/Province/Oblast/County: ______
Commune/District: ______
Closest town/village on map: ______

Topographic map sheet used
Name: DYNGJUJOKULL Number: 2014 II Scale: 1 : 50 000

Coordinates of sampling site
System used (e.g. 'UTM'): 64°35°000 Zone: 17°20'000
Other info: ______
Northing: ______ Easting: ______

Snow depth, record 12 measurements (cm)
① 270 2) ______ ③ 296 4) ______ ⑤ 280 6) ______
⑦ 270 8) ______ 9) ______ 10) ______ 11) ______ 12) ______

Thickness of snow sampled (cm) (collect enough cores to fill one PE bag, normally 5 cores)
1) 275 → 300 2) ______ 3) ______ 4) ______ 5) ______ 6) ______
7) ______ 8) ______ 9) ______ 10) ______ 11) ______ 12) ______

General remarks about snow cover at this site
Is the snow clean or rather dirty here? DIRTY WITH VOLCANIC ASH
Are there icy layers in the snowpack? YES
Has the springtime snowmelt already started here? NO
Is there a risk that sample may be contaminated (plant material, soil)? YES (VOL ASH)
Did you encounter problems during sampling? NO (if 'yes', describe below)
Other comments/remarks:
SAMPLED WITH THE PL-PLATE AND GLOVES ON.

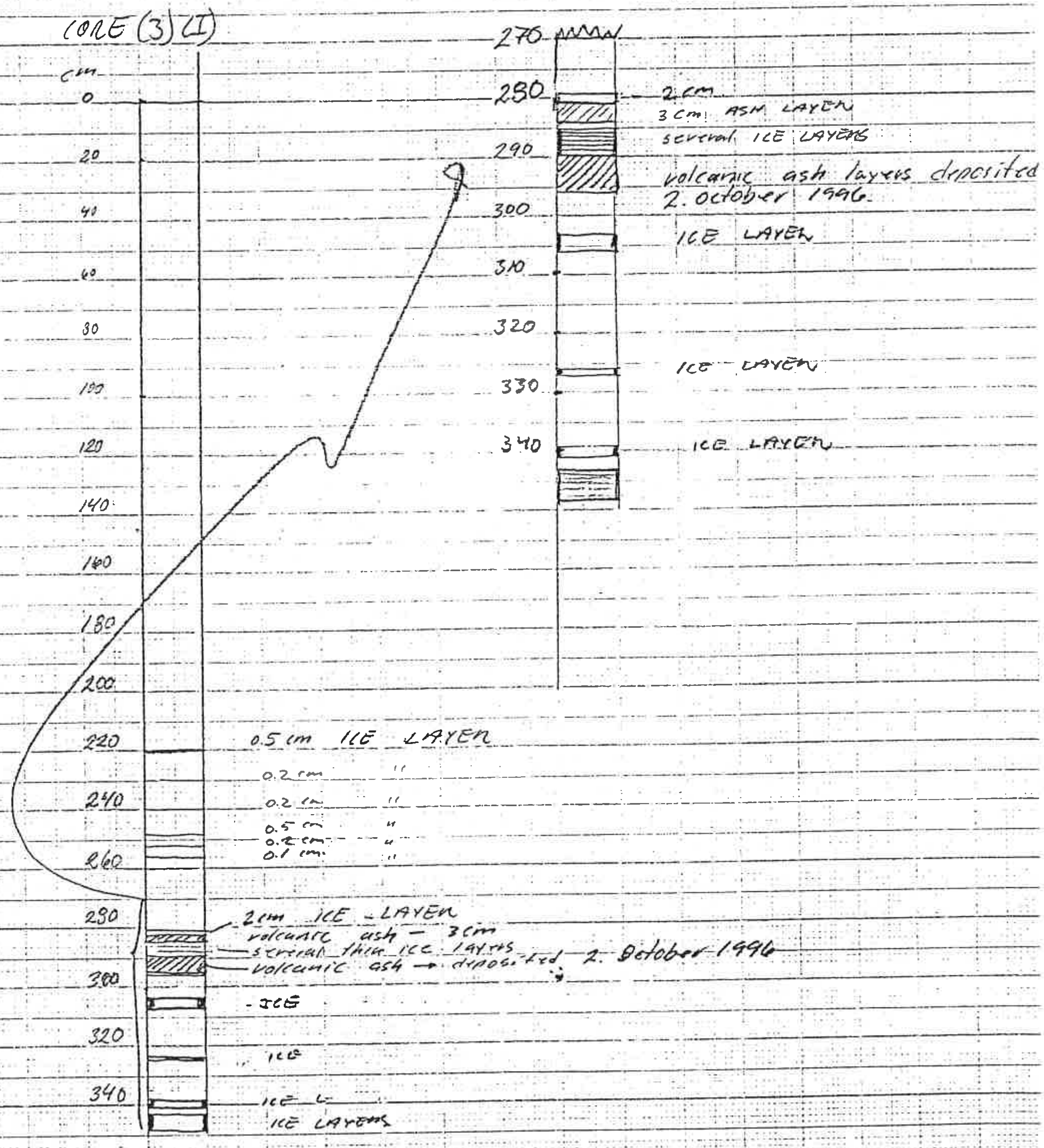
When fieldwork is completed, please send
- the topographic maps, with sampling locations and sample numbers indicated on them
- the original field sheets

to: *Patrice de Caritat, Geological Survey of Norway, P.O. Box 3006, N-7002 Trondheim, NORWAY*

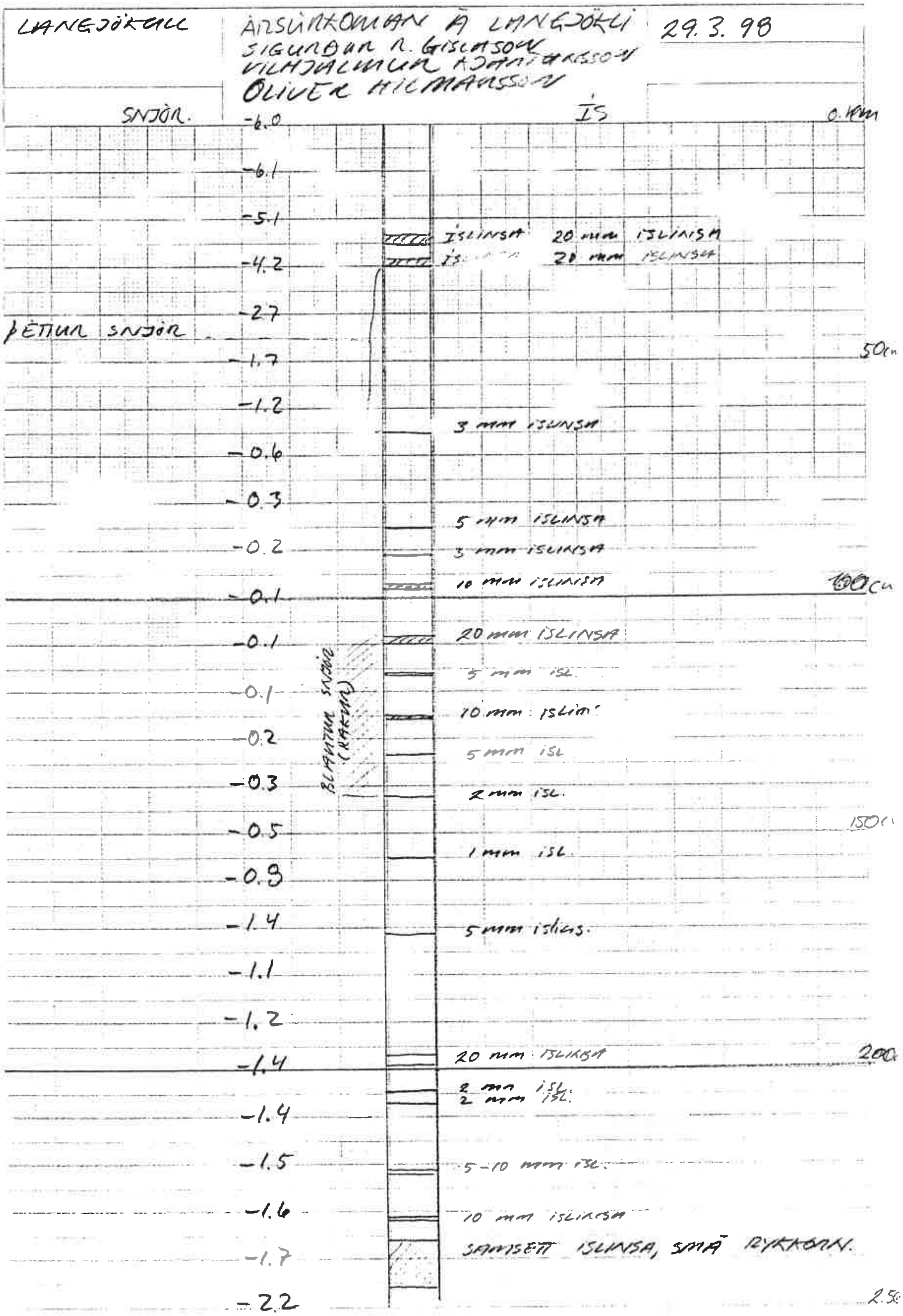
Samples are to be sent frozen to: *Gwendy Hall, Applied Geochemistry, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, CANADA*

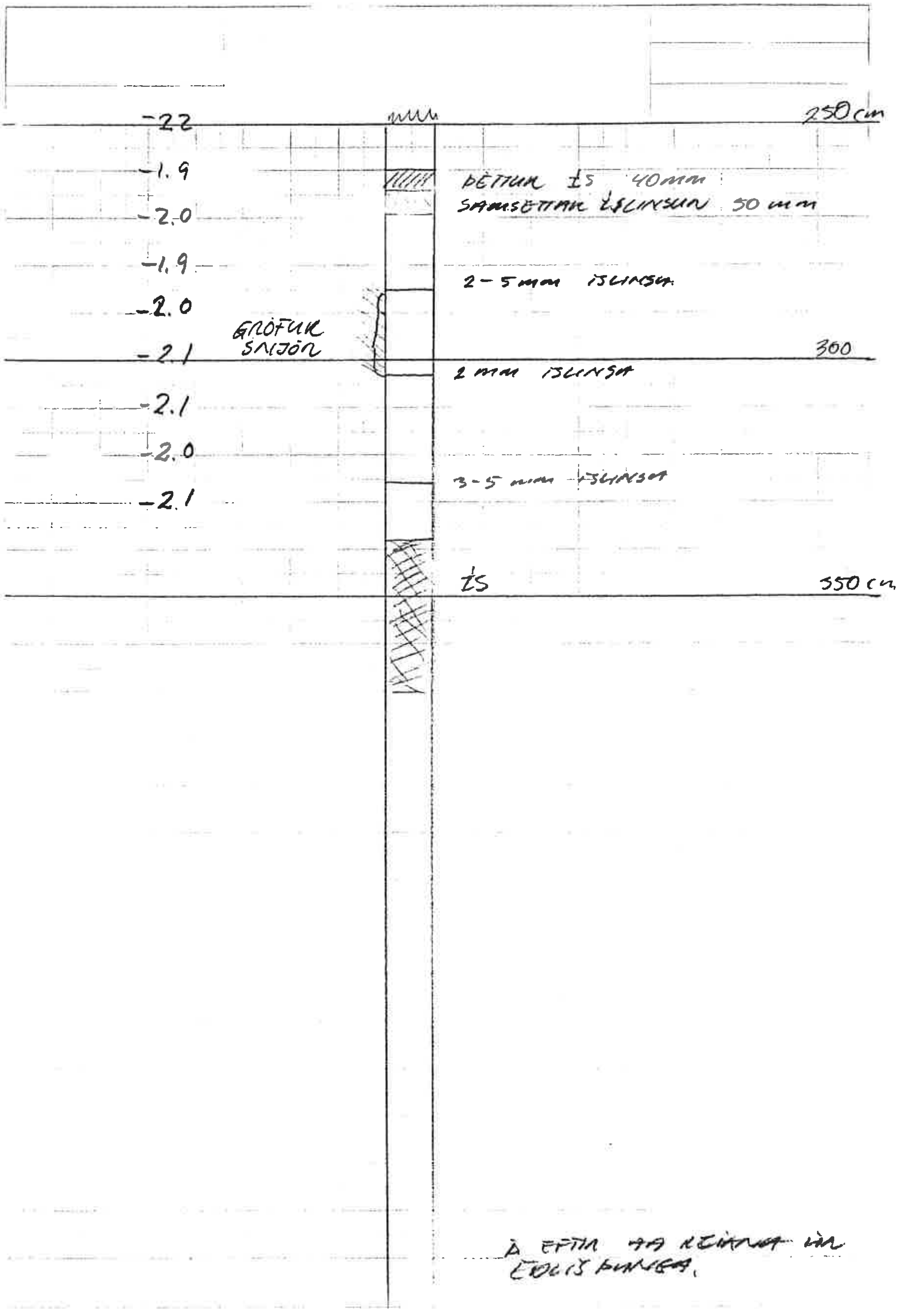
5. Detailed description of PICO core nr. 3(I) from the Vatnajökull glacier.

VATNAJÖKULL GLACIER ICELAND
S.R. GÍSLASON
CORE 3 (I)
20. MARS 1996
64°35'000 (N) – 17°20'000 (N)



6. Detailed description of the snow and ice layers in the trench in the Langjökull glacier in 1998.

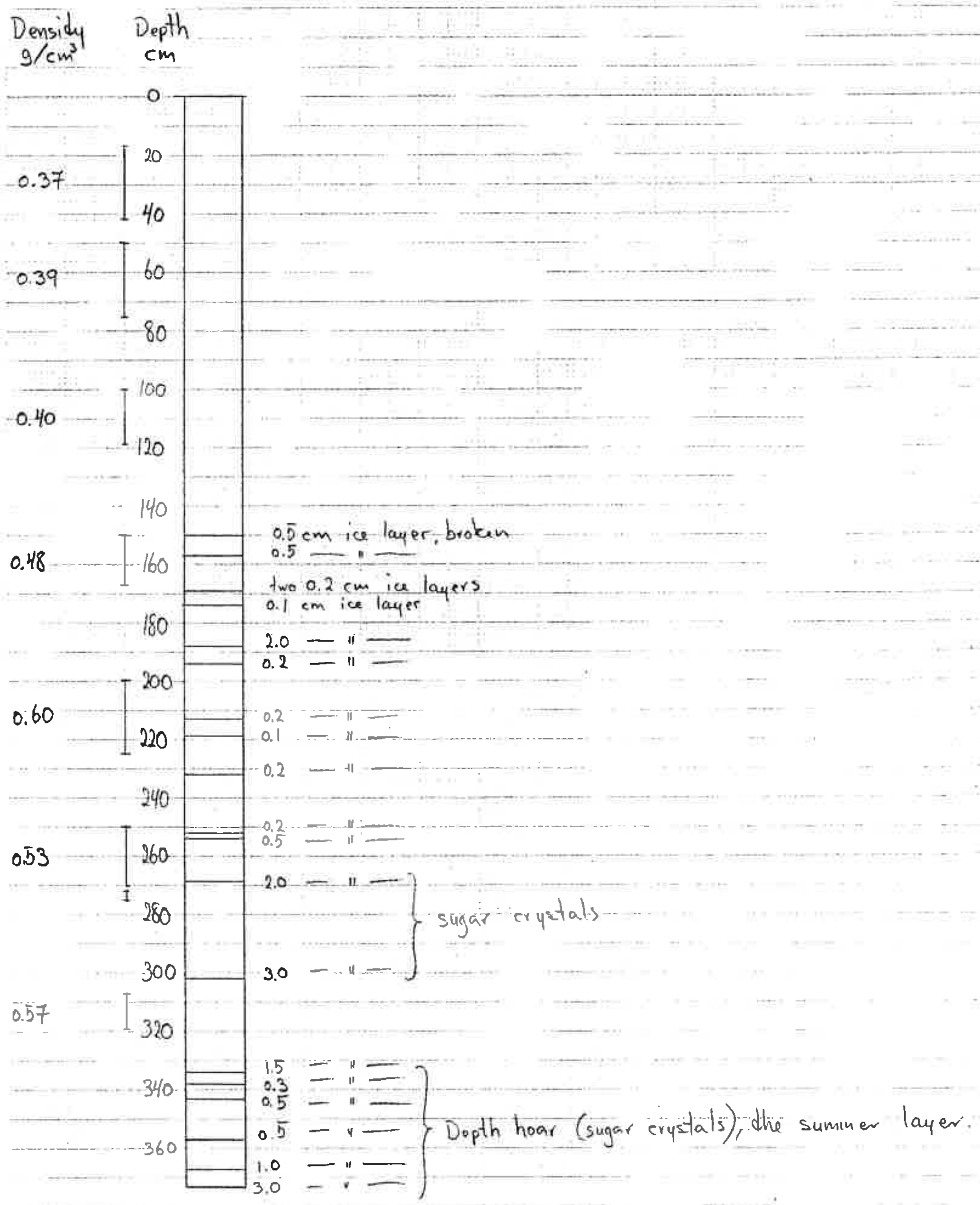




Á EFTIR AÐ REIKNA ÚT EÐLISÞUNGA.

7. Detailed description of the snow and ice layers in the trench in the Langjökull glacier in 1999.

Trench I | Langjökull Glacier, Iceland. | S.R. Gislason
31. march 1999



LECO Corporation

APPENDIX 2; Report on the measurements done by the "Time Of Flight Indcuctively Coupled Plasma Mass Spectrometer" (TOF-ICP-MS). By János Fuscó.

Analysis of Langjökull

Glacier Water Samples
for

ICETEC

February 9, 2000

János Fucskó Product Specialist,
TOF-ICP-MS Team, LECO Corporation

Table of Contents

Section

1

Overview

Two samples were sent in for analysis by TOF-ICP-MS.

The samples were labeled 99-L1 and 99-L2.

Analysis was performed using a conventional solution sample introduction system with a Meinhard concentric nebulizer and Wu-Hieftje cyclonic spray chamber. A few elements were checked with an ultrasonic nebulizer.

Most of the elements requested can be determined with these sample introduction systems. However, P, S and Si are difficult to determine due to interferences. An appropriate sample introduction system such as an electrothermal vaporization or a membrane desolvation system would likely improve determination of these elements.

Certain elements not contained in the list of requested elements were semiquantitatively determined based on the full mass spectra of the samples.

Section

2

Measurement - Analytical Method

The goal was to demonstrate the capability of TOF-ICP-MS for the measurement of water samples.

Analysis was performed using the LECO Renaissance Time-of-Flight (TOF) ICP-MS and simple sample introduction options for trace metal measurement, as:

1) The measurements were performed at 100, 10, 2 and 1X dilutions of the samples with conventional Meinhard concentric nebulizer and Wu-Hieftje glass cyclonic spray chamber, using 'cool' and 'hot plasma' modes. 'Cool plasma' means reduced power plasma with increased gas flow rates to reduce plasma temperature, while 'hot plasma' means the regular plasma parameters . See table 1 for instrument conditions.

2) Measurements were performed with cool plasma in two operation mode:
   - without Na deflection, measuring all major components of the samples
   - by deflecting Na, as the major metal component to decrease the overall ion current

3) Measurements were also done by regular or 'hot' plasma mode. Hot plasma measurements were performed using the conventional sample introduction systems and an ultrasonic nebulizer (USN).

4) Interference check measurements were performed using single element standard solutions for the major components of the samples (Na and Mg).

Measurement - Details

The samples were measured using normal TOF-ICP-MS methods and procedures.

1) Samples were acidified to 1% nitric acid concentration. Standards were also prepared with 1% nitric acid solution in a wide concentration range, so that instrument linearity can be demonstrated. Multielement standards were used for calibration, while single element high concentration standards were used for interference checks.

2) All samples were measured together after instrument optimization. The CETAC USN 5000 ultrasonic nebulizer was used for sample introduction to verify low concentration data of some elements. For similar relatively clean samples, application of the ultrasonic nebulizer (USN) may improve analyte transport efficiency and sensitivity by a factor of 10-20 resulting in better detection limits. Therefore USN can be recommended for more demanding applications, when lower detection limits are required. On the other hand, the washout time of USN is considerably longer, and more cleaning of the large glass surface is required to avoid memory and cross-contamination problems. Therefore, sample throughput is likely lower using the USN.

3) Seven replicate measurements, each with a 10 sec integration time were performed for each sample for quantitative analysis, resulting in an overall acquisition time of ~70 second. During this time period, ion signals from 100-120 isotopes can be acquired. Typical rinse and sample take up time between samples was ~60 seconds. Therefore, one single measurement is ~ 2-2.5 minutes. This time can be reduced to half, approximately, if detection limit is less critical: 5 second integration time, 7 replicates and 30-40 sec time between subsequent samples can give reasonably good detection limits, only ~ 2X higher than measured with the above conditions.

4) Full mass spectra were also collected with 10 sec integration time. These full mass spectra were used to analyze what other elements may be in the samples and what interferences may be expected. For full spectrum acquisition, only one replicate was measured with the same 10 sec integration time as for quantitative analysis. Data were collected and recorded in the 1 – 300 amu mass range providing a full picture of the sample composition.

Multielement simultaneous advantage of ICP-TOF-MS

It is important to keep in mind the simultaneous nature of the ICP-TOF-MS versus a sequential ICP-MS. The ICP-TOF-MS can easily demonstrate superior multielement sensitivity over a conventional quadrupole ICP-MS. This is because ions of all m/z are measured from the same time point of the plasma. The sensitivity of a quadrupole ICP-MS represents the ideal case where only one m/z is measured, while the sensitivity for the TOF represents a true multielement case. In this specific analysis, a 10 second integration time was used for all measurements. Using an extended integration time is helpful in several respects, namely improvement in instrument detection limit and improvement in measurement precision. Due to the simultaneous nature of the ICP-TOF-MS these improvements come with only a minimal effect on sample throughput.

As an example, during the 70 sec total measurement time in quantitative mode, 70 times more ions are measured than the reported counts per second (CPS) intensity. For instance, if the intensity of an ion signal is 1000 CPS, eventually 70*1000=70000 counts (ions) are measured. If 70 isotopes are required to analyze, the measurement time has to be divided up to 70 smaller intervals with a sequential system. Therefore an average of 70 times less ions are collected for each isotopes, if the count rate is the same as for ICP-TOF-MS. Compensating this loss would require a 70 times higher sensitivity.

The main instrument parameters are summarized in Table 1.

Table 1: Main instrument parameters

Parameter	Cool Plasma	Hot plasma
RF power	~800 W	~1300 W (1289 W)
Nebulizer gas flow	1.38 L/min	1.21 L/min
Plasma gas flow	16.15 L/min	13.8 L/min
Auxiliary gas flow	1.03 L/min	0.61 L/min
X position	0.7 mm	0 mm
Y position	-0.1 m	0 mm
Z position	5 mm	4.3 mm
Peristaltic pump	15 rpm	15 rpm
Detector voltage	-2400 V	-2400 V

Table 2. Trace metals in two glacier water samples (99-L1 and 99-L2) by Renaissance TOF-ICP-MS

	99-L1	99-L2	SGAB measurements ICP-SMS	
Element	**[ppb =µg/L]**	**[ppb = µg/L]**	**L1**	**L2**
Li	0.027	0.026		
Na	1000	1050	940*	1000*
Mg	122	125	120*	120*
Al	1.4	1.25	0.64	0.730
K	90	48	<400*	<400
Ca	52	46.5	<100*	<100
Cr	<0.04	<0.02	0.011	<0.01
Mn	0.096	0.07	0,09	0,06
Fe[1]	0.9	0.45	0.6	<0.4
Co	<0.006	<0.006	0.0049	0.004
Ni	0.29	0.25	0.204	0.184
Cu	0.09	0.08	0.102	<0.100
Zn	3	1.3	2.82	1.36
As	0.18	<0.05	0.09	<0,01
Rb	0.025	0.016		
Sr	0.75	0.75	0.768	0.78
Mo	<0.025	<0.025	<0.01	<0.01
Cd	<0.03	<0.03	0.0128	0.0106
Cs	<0.002	<0.002		
Ba	0.025	0.02	0.026	0.02
Pb_Cool	<0.005	<0.005		
Pb_USN	***0.012***	***0.016***	***0.016***	***0.018***
* Ga, Y, Nb, Ag, Rh, In, Sb, Ce, Ta, Re, Tl, Th, U	***<0.006***	***<0.006***		
* Pr, Nd, Eu, Dy, Yb, Er, Ho, Tb, Tm, Lu	***<0.006***	***<0.006***		
* Ge, Zr, Pt, W, Sm, Dy, Yb, Gd	***<0.02***	***<0.02***		

** Be, Se*	***<0.05***	***<0.05***		

* measured with ICP-AES

There was a somewhat higher Pb value measured by ultrasonic nebulizer compared to the cool plasma data: this could come from contamination of glass surfaces of the USN and washout of Pb by the sample.

*: Estimated from full spectrum scan: no visible peaks.

[1] See explanations in text

Table 3: Detection limits measured during analysis of two glacier water samples

Element	Hot plasma DL [ppb]	Cool plasma DL [ppb]
Li	0.012	0.00006
Be	0.050	NA
Na	0.080	0.0025
Mg	0.006	0.0003
Al	0.003	0.0020
K	NA	0.0070
Ca	1.500	0.0800
Cr	0.013	0.0007
Mn	0.002	0.0002
Fe	NA	0.0150
Co	0.003	0.0012
Ni	0.009	0.001
Cu	0.003	0.0005
Zn	0.008	0.0150
Rb	0.0015	0.0002
Sr	0.0015	0.0002
Mo	0.003	NA
Cd	0.007	NA
Cs	0.0005	0.0002
Ba	0.0008	0.0006
Pb	0.003	0.0010

NA: not measured/available with the given plasma condition

Na, Al, Ca, Fe and Zn detection limits could be 'blank limited' by the possible contamination in the blanks

Table 4: Major isotope sensitivity and instrument background during cool plasma measurement of glacier water samples

Elements	Major isotope Sensitivity CPS/ppb
Li	13954
Na	11047
Mg	8262
Al	8363
K	6946
Ca	*7344*
Cr	3308
Mn	7155
Fe	4733
Co	4363
Ni	2729
Cu	3064
Zn	218
Rb	6740
Sr	5994
Cs	5898
Ba	1980
Pb	733
Background	5-9 CPS/isotope
or	0.3-0.5CPS/point

Section

3

Results

The analytical results of samples are shown on Table 2.

The measured detection limits during these analyses are listed in Table 3 for both hot and cool plasma conditions. Instrument sensitivity and background is given in Table 4, for 'cool plasma' conditions.

Some spectra of samples are provided on figures, separately.

Detection limits at the ppt = ng/L and sub-ppt range were achieved.

Discussion

These samples were of relatively simple matrix, an excellent choice for testing instrument performance. Please, note, that many of the outstanding capabilities of axial ICP-TOF-MS could not be shown by these tests: measurement of microvolume samples, transient signal measurements, direct solid micro sampling. Information on these applications can be provided upon request.

Consideration of Interference and Corrections

The simultaneous nature of the ICP-TOF-MS can be very useful for measurement of multiple isotopes of the same element (isotopic confirmation) and for interference recognition and correction. As an example for this, all the isotopes of Sr and Pb (^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr, ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb) were measured. Obtaining the same results for each isotope can be very beneficial for confidence in the analytical data. Likewise, interference correction for overlapping isotopes (Rb/Sr and Sn/Cd) can also be performed more precisely by measuring all isotope at the same time (^{85}Rb used for correcting interference on ^{87}Sr, ^{118}Sn used for correcting interference on ^{114}Cd, in this case.) Using the ICP-TOF-MS, these features can be obtained without any sacrifice in analysis time. On-line interference correction equations with instrument background correction are demonstrated separately.

Matrix induced interferences must be considered during ICP-MS analysis, because of molecular ion formation and signal suppression or enhancement. This can be done with 'interference check standards' (Na, Mg), standard addition (spike) and addition of internal standards. Appropriate interference correction should be performed.

Therefore,

1. The effect of 'high' Na and Mg matrix was studied during cool plasma measurement 3839 ppb Na gave an equivalent signal of 0.151 ppb at K, as NaO^+ (and potentially, as K contamination in the standard, vial and reagents). This would translate to a < 0.05 ppb K contribution in the samples, therefore interference correction is not needed for K levels >40 ppb. The contribution of Na on the m/z=40 signal (as $NaOH^+$) seemed to be negligible too: <0.2 ppb. However, the ^{63}Cu signal is increased due to $ArNa^+$ formation. Therefore the non-interfered ^{65}Cu signal was used for quantitation, although interference correction is another possibility. The measured Fe concentration is nearly proportional to the K concentration. There is some possibility that the measured Fe value (0.9 and 0.45 ppb for L1 and L2 respectively) may come from interference of K as KOH^+, although the chemically similar Na showed very small $NaOH^+$ interference. This interference has not been checked, but can be done if specifically requested. Also, in case of As in sample L1, there is a possibility of interference ($Ar^{35}Cl^+$). However, the simultaneous monitoring of the 77 isotope ($Ar^{37}Cl^+$) in the blank and samples disapproved the chloride interference.

2. Standard addition was used to study matrix suppression-enhancement interferences. An ~20 element spike (~ 2 ppb level) of the 10X diluted sample was measured, and even the cool plasma response was within 85-105%, for most elements within 95-105% range. Correction of data of a few elements was performed (cool plasma) if precision was effected by matrix suppression.

3. Internal standard (Rb, Cs) was added to 2X diluted samples at 2 ppb concentration level and <5% signal suppression was observed in the samples compared to the blank with internal standard.

   Similar interference-check practices, even matrix matching blanks and standardization are common in routine ICP-MS work for most sample types. Unfortunately, high-resolution ICP-MS does not simplify this work considerably and adds more variables with the resolution selection.

Section

4

Conclusions

Two glacier water samples from the glacier Langjvkull were successfully analyzed, and the applicability of the Renaissance ICP-TOF-MS was proven for similar applications. Detection limits were measured at the single digit ppt and sub-ppt range for many elements. Similar detection limits, however, can be achieved by other ICP-MS systems as well. The true advantage of ICP-TOF-MS is for the simultaneous plasma sampling and simultaneous multielement analysis.

Excellent cool plasma capabilities help the measurement of several interfered isotopes in many matrices. Also, enhancement of sensitivity by improving sample introduction efficiency could further reduce detection limits.

In addition to this application, the versatility of ICP-TOF-MS can be a great advantage for a laboratory planning to analyze different sample types and use several different sample introduction systems. The simultaneous plasma sampling and multielement analysis fits particularly well to transient sample measurements and microvolume sample analysis. Transient and microvolume sample introduction such as ETV, laser ablation and low volume solution introduction systems show great promise when combined with ICP-TOF-MS.

Acknowledgment

Review of this report by Lloyd Allen, Product Specialist was very helpful and gratefully appreciated.