DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/56

Geochemistry of southern Steensby Land, North-West Greenland

Agnete Steenfelt

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MINISTRY OF THE ENVIRONMENT

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Contents

Abstract

This report documents the chemistry of 23 stream sediment samples collected in Steensby Land, North-West Greenland, as part of project *Qaanaaq 2001*, jointly undertaken by the Geological Survey of Denmark and Greenland and the Bureau of Minerals and Petroleum, Government of Greenland. The chemical data is used to describe the geochemical variation within the Dundas Group, a succession of sedimentary rocks deposited within the Mesoproterozoic Thule Basin, and the spatially associated intrusive complex of basic sills and dykes. The same kinds of rock underlie most of Pituffik/Thule Air Base, and the data obtained may serve as a documentation of the natural geochemical background against which human contamination within the base area may be assessed.

Introduction

The geochemical mapping programme of the Geological Survey of Denmark and Greenland (GEUS) is based on chemical analysis of systematically collected stream sediment samples. Since 1993 this programme has been supported financially by the Bureau of Minerals and Petroleum (BMP), Government of Greenland. The main aim of the programme is mineral exploration and mineral resource assessment, but the geochemical data also serve as documentation of the natural geochemical background variation in Greenland. The geochemical atlas of West and South Greenland (Steenfelt 2001) shows large regional chemical differences that essentially reflect the chemical variety of the underlying rock assemblages. This implies that an assessment of any induced chemical contamination of a local environment must be based on geochemical background data from the same area.

This report provides geochemical stream sediment data for an area north of Wolstenholme Fjord, North-West Greenland (Fig. 1). The area is geologically similar to the area around Pituffik/Thule Air Base just south of the fjord, and was sampled with the consideration that the data and the samples might be used in an assessment of the environmental impact of air base activities. The geochemical survey was conducted as part of the joint GEUS and BMP project *Qaanaaq 2001* (Thomassen *et al.* 2002).

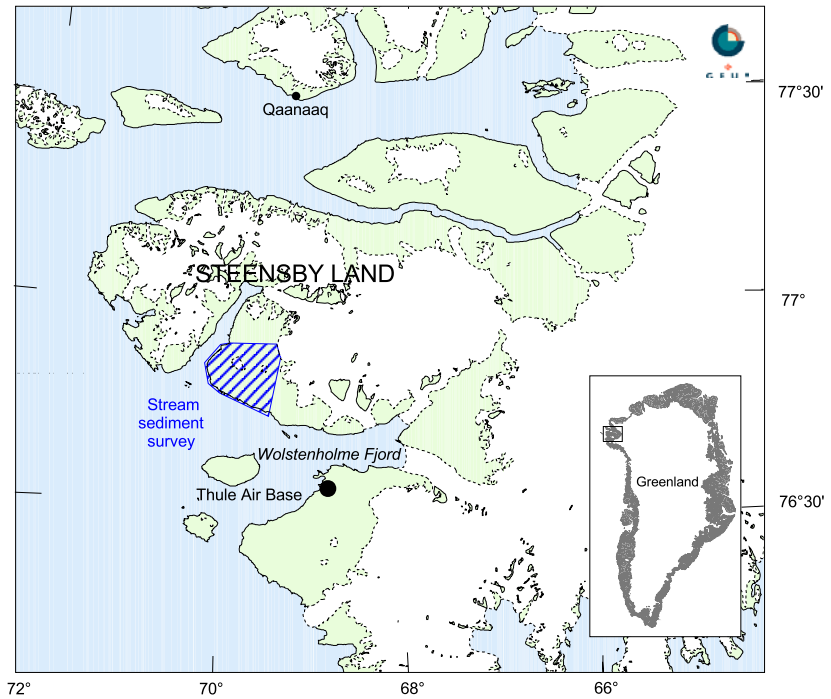


Figure 1. *Location of the study area and Pituffik/Thule Air Base. Topographic base G/250 vector. Copyright Kort og Matrikelstyrelsen 1998.*

Geology of the study area

The region of Pituffik/Thule Air Base comprises sedimentary rocks of the Dundas Group, part of the Mesoproterozoic Thule Supergroup (Dawes 1997). The sediments were deposited in a large intercratonic basin, the Thule Basin, now preserved in North-West Greenland and in Ellesmere Island, Canada. The Dundas Group comprises sandstones, siltstones and shales with lesser amounts of carbonate deposited in a deltaic to offshore environment. The sedimentary sequence has been intruded by a large number of Neoproterozoic dolerite sills and dykes (see Fig. 2). The subhorizontal sills are more resistant to erosion than the sedimentary rocks, and as a consequence table mountains are a characteristic landscape form, Dundas Fjeld at Thule Air Base being the most spectacular. The part of the Dundas Group around Wolstenholme Fjord is termed the Steensby Land Formation (see description in Dawes 1997).

The best region to obtain a geochemical signature of the rocks of the Steensby Land Formation including the dolerite sill and dyke complex was found in southern Steensby Land; here these rocks occupy a well-exposed area east of Granville Fjord and south of Iterlakkooriaq valley (formerly spelled Iterdlákôriaq; Figs 1 and 2). The streams north of Iterlakkooriaq also drain rocks of the Baffin Bay Group (see Fig. 2), and are therefore not included in the study. The survey area is about 230 km^2 in size and has a moderate topography with rounded mountains up to 700 metres above sea level. A well-developed drainage system including up to third order streams makes this area well suited for a stream sediment survey.

Erosion of the doleritic sills and dykes has provided material for large deposits of black sand now exposed in both active and uplifted beaches along the south coast of Steensby Land. The sands have been noted to have high concentrations of the titanium-rich mineral ilmenite. Ilmenite is harder and therefore more resistant during transport than the other minerals of the basalt, and its proportion has become gradually upgraded in the sands during reworking of the sand by streams and waves. The sands have been investigated for their economic potential, and contain up to 74 % absolute weight of ilmenite with around 46 % TiO_2 in samples of black sand from the village of Moriussaq and surroundings. The estimated average grade is 43 % TiO_2 in active beach sand and 12 % TiO_2 in old beach sand (Cooke 1978; Dawes 1989).

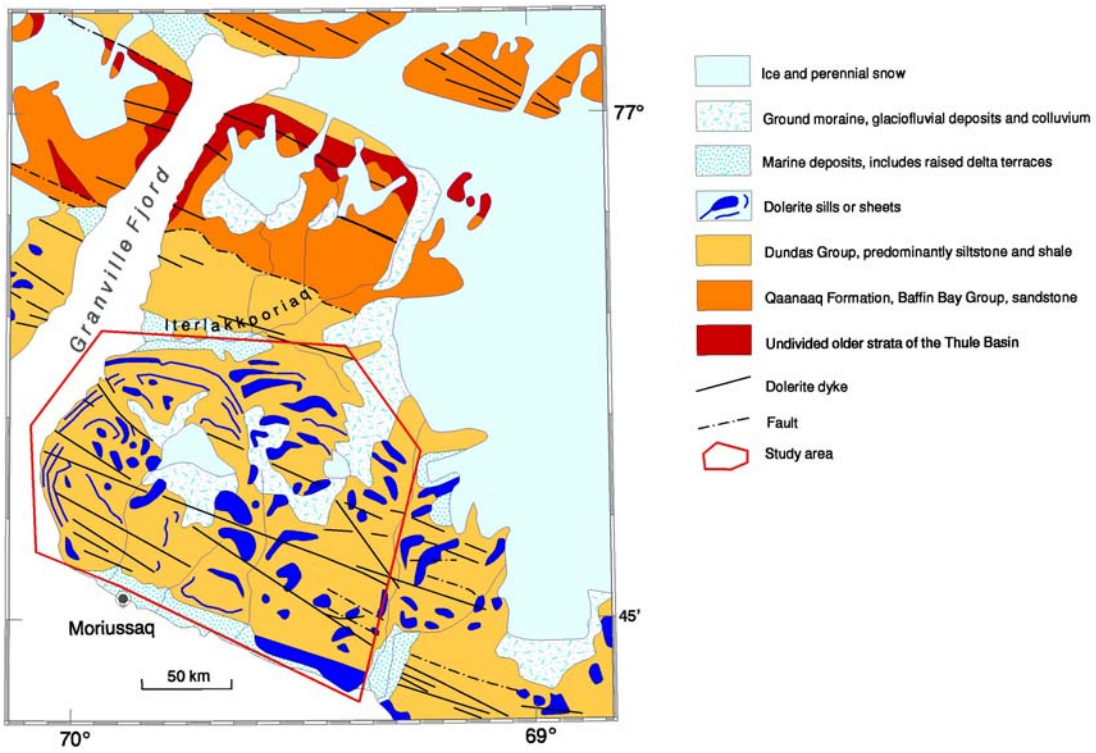


Figure 2. *Geological map of the study area and surroundings. Based on Dawes (1991).*

Sampling and analysis

Selection of sample sites

The sites were selected to provide material from the entire area. Thus, most of the significant first or second order streams depicted on the 1:250 000 topographic map were sampled. In addition, the main branches of the two major stream systems were sampled. An extra sample (505953) was collected in a small stream draining a sill with conspicuous malachite staining pointed out by villager from Moriussaq.

Sampling procedure

Sampling of stream sediments and rocks were carried out August 4, 2001, by a two-man team supported by helicopter. At each site, two stream sediment samples were collected in paper bags. Each sample was composed of material from up to ten places of sediment deposition within the stream or at the banks. The gamma-radiation of outcrops and boulder material along the stream banks was measured using a Scintrex manufactured SPP2 scintillometer, and the altitude, width and depth of the stream, and a short description of outcropping rocks and dominant boulder material was made, see Table 1. The sample locations were registered on aerial photographs and by GPS using WGS 84 ellipsoid and datum.

Sample #	Latitude	Longitude	Altitude	Stream width	Stream depth	Radiation
			m	dm	cm	counts/sec
505935	76.860255	-69.874699	20	30	40	30
505937	76.806675	-69.845989	200	15	25	50
505939	76.806611	-69.844374	200	25	40	40
505941	76.793693	-69.874549	135	25	30	50
505943	76.789563	-69.870182	115	20	30	50
505945	76.777343	-69.877403	60	30	25	50
505947	76.777718	-69.875885	60	40	50	50
505949	76.759855	-69.812209	50	15	20	50
505951	76.756765	-69.787892	40	30	40	60
505953	76.746342	-69.702222	15	7	15	
505954	76.743139	-69.614954	15	60	50	80
505956	76.753176	-69.531312	200	20	20	70
505958	76.727813	-69.451983	120	25	15	65
505960	76.727668	-69.455175	120	15	10	85
505962	76.807453	-69.291651	180	30	30	60
505964	76.783817	-69.588277	220	40	10	60
505966	76.783683	-69.585933	220	20	30	100
505968	76.782959	-69.585520	220	15	15	75
505970	76.768459	-69.609670	125	50	50	60
505972	76.768250	-69.609107	125	30	20	60
505974	76.778668	-69.685432	240	20	20	70
505976	76.861258	-69.671833	65	30	40	60
505978	76.863994	-69.459241	175	25	20	30

Table 1. *Location and stream data for stream sediment sample sites in Steensby Land (cf. Fig. 3). Radiation means gamma-radiation measured by a scintillometer in counts per second.*

Sample preparation

The sample bags were provisionally dried aboard the ship that served as base for the geological investigations in the Qaanaaq region in July and August, 2001. They were then wrapped, packed and shipped to GEUS, Copenhagen. Here they were oven-dried at 60º C. The samples were weighed and screened through polyethylene screens, into three grain size fractions: <0.1 mm for analysis, 0.1-1 mm for storage, and >1 mm discarded. In four cases the two samples collected at each locality were processed individually to document the compositional variation at a sampling site. In the remaining cases the < 0.1 mm fractions of both samples of the pairs collected were mixed and split in a stainless steel splitter before the amount necessary for analysis was taken out. Remaining sample material has been archived at GEUS in case more analyses are required in the future.

Chemical analysis

The samples from Steensby Land were analysed at Activation Laboratories Ltd., Canada, in the same way as the regional stream sediment samples collected within the *Qaanaaq 2001* project. Major elements were determined by X-ray fluorescence spectrometry using fused samples, trace elements were determined either by instrumental neutron activation analysis or by inductively coupled plasma emission spectrometry (using a 'near total' digestion by HF, $HClO_4$, HNO_3, HCl), see caption of Table 2.

Analytical quality

The *precision* (variability) of the analytical data is illustrated by results of repeated analysis of selected samples performed throughout the analysis of 370 samples collected within the regional sampling programme of the *Qaanaaq 2001* project. The *accuracy* is examined by means of international reference material, CANMET STSD-2, included in the batch of samples from Steensby Land submitted for analysis. Documentation of precision and accuracy is given in Appendix A for a selected suite of elements. Both accuracy and precision are high, although those for Pb and Y are slightly lower, which means that the analytical data are reliable.

Results

A total of 23 sites were sampled in the Steensby Land region (see Fig. 3). The localities depicted on the map of Fig. 3 are not accurate positions, but illustrate how the samples are situated in relation to the stream system. In reality, the samples from two stream branches were sampled so close to the stream confluence that their positions cannot be separated at the map scale used.

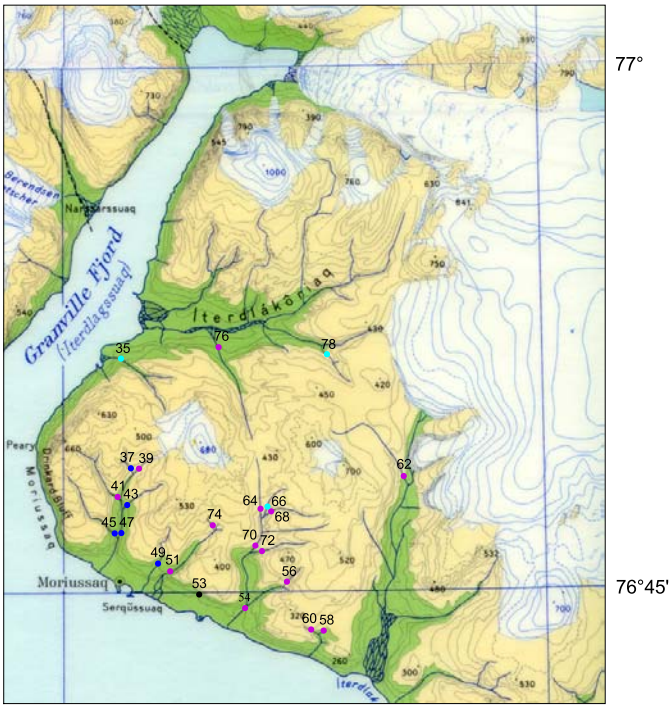


Figure 3. *Location of stream sediment samples and their chemical grouping, cf. Table 2. Samples are marked with the last two digits of their identification number, and the colour indicates the group: 1= dark blue, 2 = magenta, 3 = light blue. The map is based on topographic map 76 V 1, 1:250 000 by Kort og Matrikelstyrelsen (1974), © KMS.*

Field observations

Landscape morphology and the character of the streams are illustrated in a series of photographs in Appendix B. The streams flow in valleys carved into the sedimentary rocks. The valley bottoms are wider than the streams, are covered in boulders and pebbles, and have almost no vegetation. Stream sediment is abundant. The exposed rock cliffs and boulder assemblages are dominated by siltstones in shades of grey to buff. Intense rusty coatings of bedding planes and fractures characterise certain horizons. The rust colouration is typically developed in rocks situated immediately below the sills (Dawes 1997). Dark grey to black shale is locally the dominant lithology. Brownish-black rounded boulders of dolerite in various amounts are ubiquitous in the streambeds irrespective of proximity to outcropping sills or dykes.

Analytical Results

Local variation

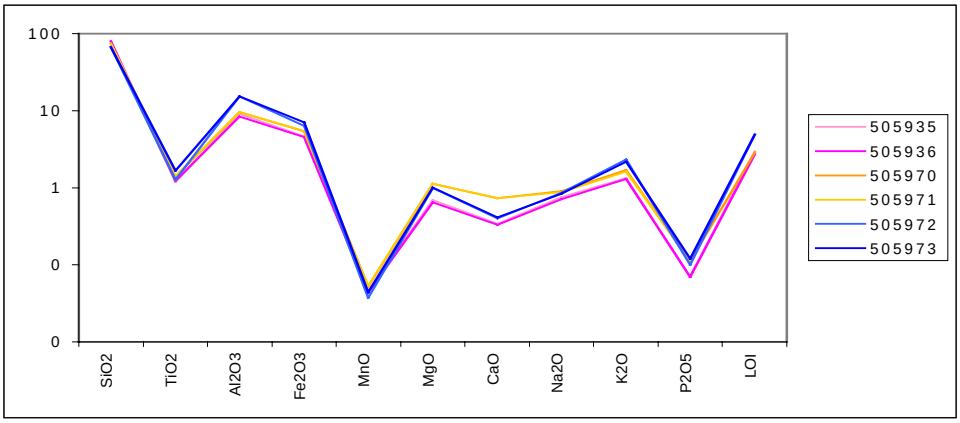
In Appendix C, Table C1, analytical data are listed for the four sample pairs to document the variability in stream sediment composition at a sampling site. One of the samples did not contain a sufficient amount of material in the < 0.1 mm fraction, so that data for major elements were only obtained for three pairs.

The diagrams in Fig. 4 illustrate for a selected suite of elements that the sample pairs are very close and that the differences between the sites are greater than between the samples. The regional variation, therefore, is statistically significant.

Regional variation in relation to lithology

Analytical data are listed in Table 2. In addition to the results given in the table, the analyses showed that all samples had Hg < 1 ppm, Ir < 5 ppm, and Sn < 100 ppm.

Chemically, the samples may be divided into three groups as illustrated by Table 2 and the diagram of SiO_2 versus TiO_2, Fig. 5. Sample 505953 is listed separately in Table 2 and has been omitted in Fig. 5, because its chemistry is very different from the rest of the samples.



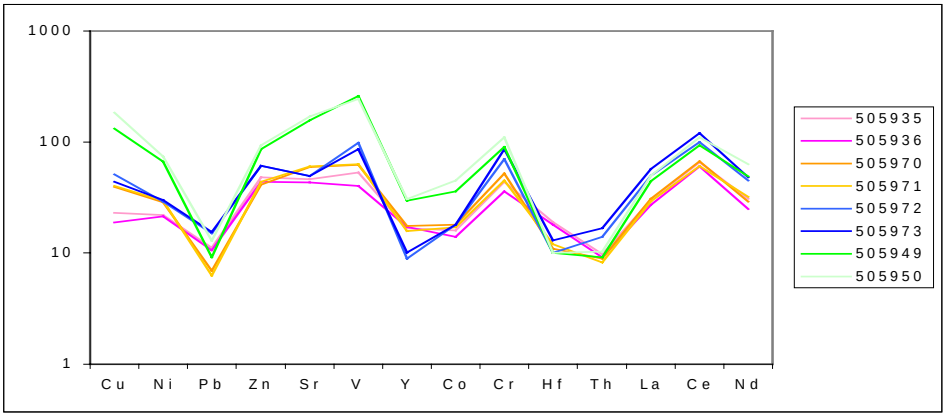


Figure 4. *Diagrams showing the variability in the chemical composition of sample pairs from three sites (major elements) and four sites (trace elements). Sample 505950 was not analysed for major elements due to insufficient amounts of fine-grained sample material.*

	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	LOI %	TOTAL %
Group 1												
505949	59.81	4.186	11.27	11.58	0.116	3.27	3.21	1.01	1.79	0.46	3.32	100.02
505947	61.34	5.081	11.62	11.92	0.127	1.79	2.12	1.09	1.48	0.29	3.06	99.92
505943	63.89	6.262	8.70	11.96	0.146	1.70	2.42	1.25	1.07	0.39	2.06	99.86
505945	60.62	6.358	10.68	12.69	0.142	2.08	1.92	1.09	1.71	0.15	2.37	99.81
505937	51.41	7.060	12.50	15.89	0.167	2.65	3.57	1.79	1.19	0.56	3.22	100.00
Group 2												
505974	64.09	1.082	17.66	6.58	0.027	0.96	0.25	0.90	2.56	0.09	5.85	100.07
505939	64.85	1.569	14.50	7.55	0.053	1.55	1.65	1.33	1.86	0.13	4.94	99.99
505972	67.38	1.269	15.36	6.41	0.037	0.99	0.40	0.86	2.33	0.10	4.86	100.00
505956	68.88	2.605	11.06	7.81	0.079	1.46	1.67	1.14	1.58	0.36	3.34	99.98
505962	69.37	1.831	12.52	6.39	0.049	0.99	0.42	0.82	1.81	0.07	4.70	98.96
505964	69.58	1.718	11.98	6.45	0.064	1.33	0.91	0.98	1.91	0.12	3.94	98.97
505976	70.16	1.693	12.40	6.70	0.061	1.27	0.72	0.81	1.93	0.09	4.28	100.13
505941	70.26	2.281	12.23	7.27	0.066	1.16	0.89	0.85	1.73	0.14	3.51	100.38
505951	71.17	1.466	12.77	6.21	0.042	1.11	0.40	0.67	1.93	0.09	4.30	100.17
505968	73.62	1.110	10.55	5.46	0.045	1.05	0.41	0.75	1.93	0.09	3.56	98.57
505954	74.20	1.684	10.82	5.78	0.049	1.25	0.60	0.70	1.95	0.11	3.20	100.32
505970	74.89	1.392	9.60	5.42	0.052	1.13	0.73	0.90	1.68	0.11	2.86	98.77
505958	73.88	0.797	13.39	3.53	0.020	0.90	0.10	0.69	2.98	0.06	3.84	100.18
505960	63.71	0.773	13.40	5.54	0.078	4.26	1.58	0.64	3.03	0.12	6.41	99.54
Group 3												
505935	79.07	1.195	9.04	4.63	0.045	0.69	0.34	0.75	1.33	0.07	2.96	100.11
505966	79.47	0.903	8.36	4.14	0.037	0.84	0.37	0.78	1.59	0.07	2.40	98.95
505978	82.44	0.654	7.45	3.42	0.032	0.59	0.35	0.74	1.27	0.06	2.50	99.50
Not grouped												
505953	34.41	15.066	7.54	26.73	0.286	4.53	6.59	1.31	0.64	1.85	1.52	100.48

	Ag ppm	Be ppm	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm	S %	Au ppb	As ppm	Ba ppm	Br ppm	Co ppm	Cr ppm	Cs ppm	Hf ppm
Group 1																			
505949	0.4	2	1.6	132	66	9	157	258	30	87	0.071	<2	3.8	450	3.2	36	90	3	10
505947	<0.3	2	1.4	56	51	9	137	95	31	86	0.027	5	3.7	320	2.8	27	77	2	13
505943	0.7	2	1.7	53	43	6	164	127	31	76	0.006	<2	1.3	250	2.9	28	60	<1	19
505945	<0.3	2	1.7	31	45	6	94	127	23	56	0.022	<2	1.9	400	<1	28	98	4	19
505937	0.6	2	2.5	119	80	5	240	166	34	104	0.019	<2	3.4	380	4.9	45	85	3	15
Group 2																			
505974	<0.3	2	0.7	51	26	17	38	117	8	59	0.069	<2	4.1	390	<1	13	79	4	8
505939	<0.3	2	1.0	72	37	17	97	141	14	60	0.123	<2	4	430	4	16	88	3	9
505972	0.4	2	0.9	51	29	15	49	98	9	61	0.028	4	4.7	370	2.6	18	70	5	10
505956	0.5	2	1.1	118	37	10	135	130	26	76	0.010	<2	6.1	< 50	5	24	57	2	14
505962	<0.3	2	0.6	34	31	16	61	59	23	66	0.023	<2	2.4	470	2.3	20	75	3	13
505964	0.3	2	1.0	52	34	10	71	95	20	58	0.019	<2	3.4	330	5.3	23	73	3	12
505976	<0.3	2	0.8	38	35	17	67	64	22	71	0.056	<2	3.9	460	2.2	23	63	2	11
505941	0.3	2	0.9	50	35	12	79	95	14	65	0.013	<2	2.5	370	2.5	22	68	3	12
505951	0.3	2	0.9	33	31	8	40	85	11	59	0.043	<2	3.3	300	2.8	17	73	3	14
505968	0.4	1	0.6	46	26	9	45	81	13	51	0.043	<2	3.3	230	2.4	18	61	2	12
505954	<0.3	1	0.8	27	29	9	49	60	14	47	0.022	<2	2	210	<1	17	56	3	14
505970	<0.3	1	0.9	39	29	7	60	62	17	41	0.014	<2	2.8	25	2.2	18	52	2	11
505958	0.6	2	0.6	21	18	15	22	63	11	27	0.031	<2	4	< 50	<1	11	63	4	13
505960	<0.3	2	1.0	49	36	19	48	87	25	81	0.159	<2	6.3	980	<1	23	69	5	9
Group 3																			
505935	0.4	1	0.8	23	22	11	46	53	17	48	0.012	<2	3.1	340	<1	16	44	3	19
505966	0.4	1	0.5	25	21	6	39	49	16	29	0.009	<2	1.7	240	<1	12	41	2	13
505978	0.5	1	0.5	18	15	15	61	54	14	41	0.011	<2	3.3	240	3.8	9	35	2	15
Not grouped																			
505953	1.0	1	3.9	419	89	<3	263	616	56	181	0.018	<2	2.9	460	6.8	83	140	<1	21

	Rb	Sb	Sc	Se	Ta	Th	U	W	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Group 1																
505949	64	<0.1	18	<3	0.5	9.2	3.1	<1	44	94	49	7.9	1.9	<1	2.3	0.35
505947	68	0.6	17	<3	3.7	10	2.4	<1	41	89	37	7.8	2.3	1	2.4	0.38
505943	75	<0.1	16	3	3.2	8.4	3.4	<1	39	89	44	9.2	3	1.4	2.5	0.38
505945	120	0.6	17	<3	0.5	12	4.7	<1	54	110	54	7.9	2.1	1.4	2.9	0.44
505937	52	<0.1	21	4	4.1	11	4.2	<1	51	120	74	13	3.7	1.6	3.3	0.5
Group 2																
505974	110	0.6	18	<3	0.5	17	5.3	<1	56	120	43	6.9	1.6	<1	2.6	0.4
505939	78	0.3	16	<3	0.5	13	4.3	<1	43	91	45	6.2	1.8	1	2.8	0.42
505972	170	0.6	15	<3	0.5	14	4	<1	50	100	45	6.7	1.6	<1	2.7	0.41
505956	110	0.4	13	<3	0.5	10	0.5	<1	44	98	52	9.1	2.5	1.3	2.8	0.42
505962	110	0.5	15	<3	0.5	13	3	<1	44	90	40	6	1.6	<1	2.5	0.39
505964	79	0.3	14	<3	2.1	11	3.7	<1	38	83	35	5.5	1.7	<1	2	0.3
505976	92	0.4	14	<3	1.9	11	3.2	<1	37	77	31	5.5	1.5	<1	2.4	0.35
505941	96	<0.1	14	<3	0.5	11	3.3	<1	42	91	31	6.3	2	0.8	2.3	0.35
505951	120	0.4	13	<3	0.5	13	2.8	<1	41	83	32	5.7	1.6	0.9	2.6	0.4
505968	100	0.4	12	<3	0.5	11	3.4	<1	37	81	31	5.3	1.5	<1	2	0.3
505954	100	<0.1	11	<3	1.7	10	2.7	<1	36	75	33	5.3	1.4	<1	2.3	0.35
505970	110	0.5	10	4	1.6	8.9	2.7	<1	31	67	29	4.7	1.3	0.6	1.8	0.26
505958	130	0.4	11	<3	0.5	12	4.7	<1	36	75	26	4.3	1.2	<1	2.3	0.36
505960	140	0.7	13	<3	0.5	13	3.2	2	44	96	37	5.7	1.5	<1	2.2	0.33
Group 3																
505935	90	0.4	9.9	<3	1.8	9.8	2.8	<1	30	66	31	4.6	1.4	<1	2.5	0.37
505966	78	<0.1	7.7	4	0.5	7.7	2.7	<1	26	57	20	3.7	1.1	0.9	1.7	0.25
505978	15	0.3	7.2	<3	0.5	9.1	2.6	<1	26	55	22	3.6	1.1	0.6	1.5	0.23
Not grouped																
505953	26	<0.1	28	<3	6.6	6.8	<1	<1	85	210	120	22	4.8	<1	4.2	0.62

Table 2. *Chemical composition of the < 0.1 mm grain size fraction of stream sediment samples from Steensby Land. Major element oxides (SiO_2 to P_2O_5) were determined by X-ray fluorescence spectrometry, loss on ignition (LOI) was determined during preparation of samples for X-ray fluorescence. Elements Ag to S were determined by inductively coupled plasma emission spectrometry and Au to Lu by instrumental neutron activation analysis. Units of concentration: ppm=parts per million equal to milligram per kg (mg/kg); ppb=parts per billion equal to microgram per kg (µg/kg).*

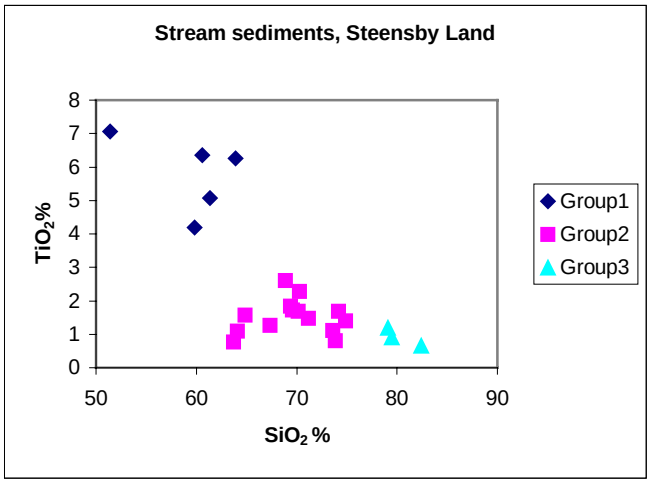


Figure 5. *Diagram illustrating the chemical diversity of the samples.*

Group 1, consisting of five samples with low SiO_2 and high TiO_2, represents samples with high proportions of dolerite material derived from the sills and dykes. These samples are enriched relative to the other samples in Fe_2O_3, MnO, MgO, CaO and P_2O_5 plus trace elements Cd, Cu, Ni, Sr, V, Y, Zn, Co and Sc.

The remaining samples are dominated by material from the sedimentary rocks, but three samples among these have considerably higher concentrations of SiO_2 than the rest and have been treated as Group 3.

Samples within Group 2 display some variation in major element concentrations but limited variation in trace element values. Fig. 6 shows that concentrations of Al_2O_3 and K_2O are correlated, with the exception of the two ringed samples (505958 and 505960). Increasing concentrations of Al_2O_3 and K_2O indicate an increasing proportion of shale components in the samples. Samples 505972 and 505974 have the highest shale component, in agreement with observations of abundant black shale as flat pebbles on the valley floor and in outcrop at the two sampling sites. Sample 505939 has high concentration of sulphur (S), in agreement with observation of stratabound pyrite in blocks of black shale at the sampling site.

The sample 505760 is different in composition from the other samples of Group 2. It has high MgO, CaO and high loss of volatiles. In addition it has high K_2O, S, As, Ba, Cs, Sb, and Zn. At the sampling site grey shale with desiccation cracks and yellowish brown coatings of bedding planes and joints were observed.

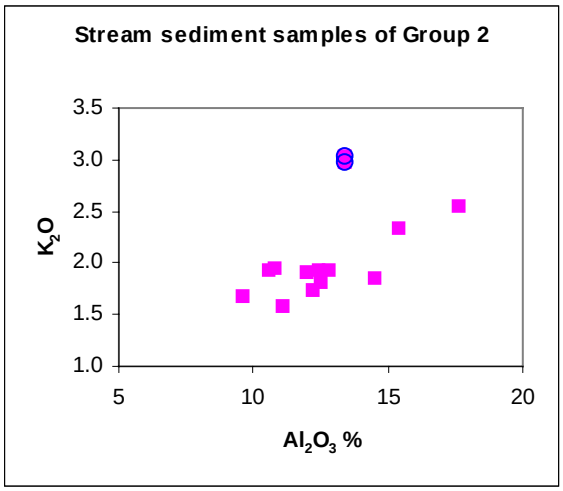


Figure 6. *Increasing Al_2O_3 and K_2O in stream sediment samples indicates increasing proportion of shale relative to siltstone.*

The chemistry suggests that the observed coatings or the sedimentary strata themselves contain carbonates and sulphates, and field observations point towards the presence of evaporites in this part of the sedimentary sequence. The neighbouring sample 505958 has the same high concentrations of K_2O relative to Al_2O_3 and low concentration of TiO_2 as 505960, see Table 2. In addition, it has low loss of volatiles and the lowest concentrations of Fe_2O_3 and MnO, MgO, CaO and P_2O_5 within Group 2. This is interpreted to reflect the composition of the grey shale without contribution from evaporite.

The variation in trace element concentrations in Group 2 is limited. Sample 505956 has elevated concentrations of the trace elements that are high in Group 1, which probably reflects a small contribution from dolerite in the sample.

The samples of Group 3 with high SiO_2 (505935, 505976 and 505978) were collected in streams draining high altitude parts of the survey area. High SiO_2 means a high proportion of quartz-rich rocks, e. g. sandstones, in the source areas of the streams. It is possible that the upper parts of the Steensby Land Formation within the survey area comprise sandstones, although sandstones are rare in the Dundas Group according to Dawes (1997). On the other hand, sandstones are typical of the Qaanaaq Formation of the Baffin Bay Group (see the geological map Fig. 2). The Qaanaaq Formation stratigraphically underlies the Dundas Group. However, due to faulting the Qaanaaq Formation outcrops at high altitudes north and east of the survey area. It is probable, therefore, that much of the glacial deposits occurring in the highest parts of the survey area represent material that has been transported by glaciers from the Qaanaaq Formation and subsequently brought down by the streams. Abundant boulders of both pale and pink sandstones resembling those of the Qaanaaq Formation were observed in the valley at the location of sample 505978.

Sample 505953 was collected in a small stream running over a raised beach of black titaniferous sand. The stream originates in hills and passes below a sill with conspicuous

malachite staining. The chemistry of the sample shows very high concentrations of TiO_2, Fe_2O_3, MnO, MgO, CaO and P_2O_5. Among trace elements Cu is remarkably high confirming a contribution from the observed copper mineralisation, and the concentrations of Cd, Ni, Sr, V, Y, Zn, Co, Cr, Sc, Ta and the rare earth elements, La to Lu, are higher than in Group 2. The sample has an extreme composition, which probably mostly represents the black sand rather than the rocks of the upper part of the stream.

Geochemical background estimation

The data obtained in the stream sediment survey describe the natural geochemical variation of the survey area in Steensby Land. The geochemical variation in the stream sediment composition reflects the contribution of two chemically distinct components, the sedimentary rocks and the dolerites of the sills and dykes.

An average chemical composition of the stream sediments is used to represent the geochemistry of the total area. The average figures are calculated as the mean of all samples that were collected in first order streams, i.e. samples 505947, 505954 and 505970 are omitted. Furthermore, the samples with suspected contribution from the Qaanaaq Formation (i.e. 505935, 505966 and 505978) have been omitted from the mean.

The resulting representative composition of the survey area is given in Table 3 together with an estimate for the composition of the upper continental crust (Taylor & McLennan 1985). It follows from the data that the survey area is significantly enriched in Fe, Ti, Co, Cr, Cu and V relative to average upper crust. This is clearly due to addition of material from the dolerites of the sills and dykes, since samples with the lowest contents of doleritic material (i.e. Group 2 samples of Table 2) are much closer to upper crustal composition.

The area mean also serves as a measure of the geochemical background in an environmentally scientific sense. The maximum concentrations measured in the samples give the order of magnitude for upper limits of natural element concentrations at a given site within this specific geological environment. The data for sample 505953 is shown for comparison as an example of the special enrichment of elements taking place in the beach environment. Also shown is the mean of chemical analyses of 7 samples of sills and dykes from the area (P.R. Dawes, personal communication 2002). The upgrading of ilmenite in the beach and stream environments is clearly illustrated by the much higher concentrations of Fe and Ti in the stream sediment than in the rocks themselves.

	Element name	Unit of con-centra-tion	Upper crust	Area mean (15 sites)	Std.dev. of area mean	Max. value in samples (22 sites)	Sample from ilme-nite-rich beach	Mean of seven dolerite samples	Action level, agricultural soil, Ger-many	Level of remediation, Holland
SiO_2	Silicium	%	66.0	66.10	5.88	82.44	34.41	48.11		
TiO_2	Titanium	%	0.5	2.71	2.17	7.06	15.066	4.80		
Al_2O_3	Aluminium	%	15.2	12.55	2.17	17.66	7.54	12.11		
Fe_2O_3	Iron	%	4.5	8.12	3.35	15.89	26.73	14.66		
MnO	Manganese	%	0.1	0.08	0.05	0.167	0.286	0.19		
MgO	Magnesium	%	2.2	1.71	0.98	4.26	4.53	6.15		
CaO	Calcium	%	4.2	1.34	1.08	3.57	6.59	9.42		
Na_2O	Sodium	%	3.9	0.99	0.30	1.79	1.31	2.54		
K_2O	Potassium	%	3.4	1.96	0.56	3.03	0.64	0.80		
P_2O_5	Phosphorus	%	0.2	0.20	0.16	0.56	1.85	0.42		
LOI		%		4.01	1.19	6.41	1.52	1.90		
S	Sulphur	%		0.046	0.044	0.159	0.018			
Ag	Silver	ppm		0.33	0.18	1	1.0			
Au	Gold	ppb		< 2		5	0			
As	Arsenic	ppm	1.5	3.67	1.37	6.3	2.9		20	
Ba	Barium	ppm	550	370.67	219.62	980	460	35		
Be	Beryllium	ppm		1.77	0.21	2.18	1			
Br	Bromine	ppm		3.39	1.19	5.3	6.8		10	
Cd	Cadmium	ppm		1.12	0.53	2	3.9		1.5	
Co	Cobalt	ppm	10	23.20	8.69	45	83		50	
Cr	Chromium	ppm	35	73.27	12.37	98	140	123	100	
Cs	Cesium	ppm	3.7	3.29	0.99	5	< 1			
Cu	Copper	ppm	25	61.12	34.10	132	419		100	
Hf	Hafnium	ppm	5.8	12.40	3.31	19	21			
Ni	Nickel	ppm	20	38.51	15.84	80	89	138		210
Pb	Lead	ppm	20	12.19	4.71	19	< 3		100	
Rb	Rubidium	ppm	112	101.73	30.80	170	26	8		
Sb	Antimony	ppm	0.2	0.47	0.13	0.7	< 0.1		5	
Sc	Scandium	ppm	11	14.89	2.57	20.5	28.3			
Se	Selenium	ppm		< 3		4	< 3		10	
Sr	Strontium	ppm	350	91.07	59.32	240	263	432		
Ta	Tantalum	ppm	2.2	< 1		4.1	6.6			
Th	Thorium	ppm	10.7	11.89	2.12	17.2	6.8			
U	Uranium	ppm	2.8	3.60	1.10	5.3	< 0.5		5	
V	Vanadium	ppm	60	113.90	50.49	258	616	433	50	
W	Tungsten	ppm	2	< 1		2	< 1			
Y	Yttrium	ppm	22	20.15	8.34	34	56			
Zn	Zinc	ppm	71	66.38	17.61	104	181	238	300	720
La	Lanthanum	ppm	30	43.85	6.31	55.8	84.8			
Ce	Cerium	ppm	64	94.33	13.79	120	210			
Nd	Neodymium	ppm	26	42.47	12.05	74	120			
Sm	Samarium	ppm	4.5	7.00	2.07	12.5	22			
Eu	Europium	ppm	0.9	1.95	0.66	3.7	4.8			
Tb	Terbium	ppm	0.6	< 1		1.6	< 1			
Yb	Ytterbium	ppm	2.2	2.51	0.35	3.3	4.2			
Lu	Lutetium	ppm	0.32	0.38	0.05	0.5	0.62			

Table 3. *Geochemistry of southern Steensby Land based on chemical analysis of the < 0.1 mm grain size fraction of stream sediment samples. Std.dev.=standard deviation. Max.=maximum. LOI=Loss on ignition when samples are fused prior to X-ray fluorescence spectrometry. Composition of upper continental crust from Taylor & McLennan (1985); action level and limits of remediation from Reimann & Caritat (1998).*

Table 3 contains examples of action levels or upper limits for agricultural soil in Germany and Holland for comparison (Reimann & Caritat 1998). It is observed that the natural concentrations obtained locally for Cd, Cr, Cu and V may exceed such European action levels. This emphasises the rationale of documenting the locally prevailing natural geochemical conditions before limits for remediation of anthropogenic contamination are determined.

Conclusion

The geochemistry of stream sediment from sedimentary rocks belonging to the Dundas Group of the Mesoproterozoic Thule Supergroup in southern Steensby Land is close to that of the upper continental crust. However, doleritic rocks of the abundant sills and dykes are chemically different and they increase the concentrations of iron, titanium, cobalt, chromium, copper and vanadium, in particular, in the estimated average composition for the area.

Acknowledgement

The members of the *Qaanaaq 2001* project have all contributed to the results presented in this report. Bjørn Thomassen led the project and Johan D. Krebs assisted in the sample collection. Peter R. Dawes provided geological information and chemical analyses of sills and dykes. Else Moberg handled the samples before analysis and also prepared Figures 1 and 3. Margareta Christoffersen prepared the geological map, Figure 2.

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Appendix A

Accuracy and precision of chemical analyses

	STSD2_meas.	stsd2_rec.
XRF		
SiO_2	53.80	53.70
TiO_2	15.76	16.1
Al_2O_3	7.27	7.50
Fe_2O_3	0.129	0.1
MnO	3.13	3.10
MgO	4.17	4.00
CaO	1.76	1.70
Na_2O	2.40	2.10
K_2O	0.737	0.80
P_2O_5	0.32	0.30
LOI	9.89	10.30
TOTAL	99.37	99.70
ICP		
Ag	0.5	0.5
Cd	1.7	0.8
Cu	46	47
Mo	15	13
Ni	58	53
Pb	75	66
Zn	237	246
Be	4.4	5.2
Bi	-2	
Sr	421	400
Ti	0.45	0.49
V	102	101
Y	30	37
S	0.051	0.060

	STSD2_meas.	stsd2_rec.
INA		
Au	5	3
Ag	< 5	0.5
As	42.1	42
Ba	580	540
Br	4.3	4
Co	20	19
Cr	116	116
Cs	12	12
Hf	5	5
Mo	15	
Ni	55	53
Rb	96	104
Sb	4.7	4.8
Sc	15.4	16
Se	-3	
Sn	-0.02	
Sr	0.05	0.04
Ta	1.8	
Th	17.3	17.2
U	18.3	18.6
W	7	
Zn	265	246
La	59.8	59
Ce	107	93
Nd	52	43
Sm	8.5	8
Eu	2.1	2
Tb	1.1	
Yb	3.6	3.7
Lu	0.54	0.7

Table A1. *Accuracy of chemical analyses. Results of analysis of international reference material SDST-2 from CANMET (Bowman 1994). Measured values (meas.)next to recommended values (rec.) Analytical methods: X-ray fluorescence spectrometry (XRF), inductively coupled plasma spectrometry (ICP) and instrumental neutron activation (INA).*

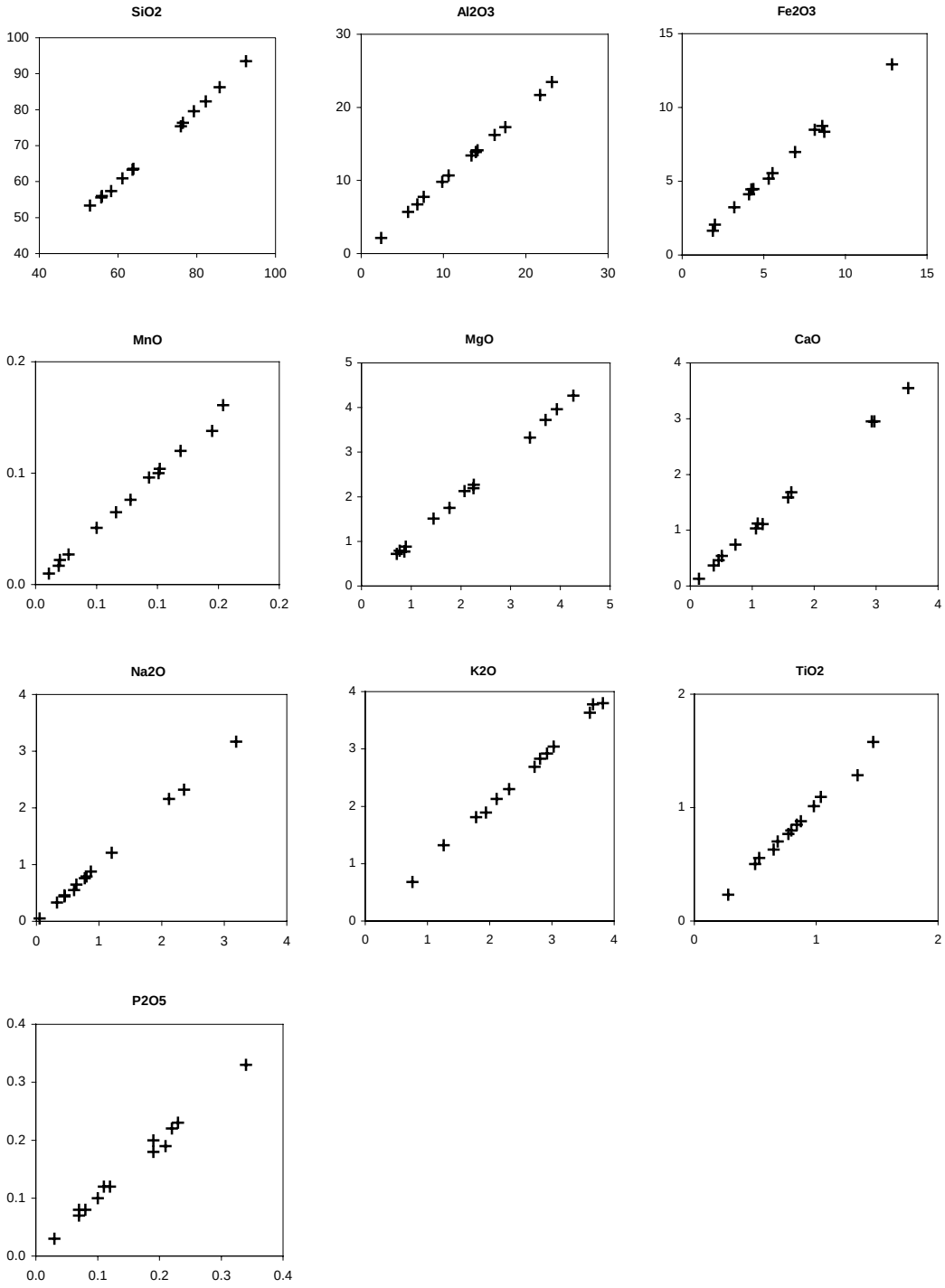

Figure A1. *Analytical precision of element concentrations determined by X-ray fluorescence spectrometry. Results of repeated analysis of 13 samples* .

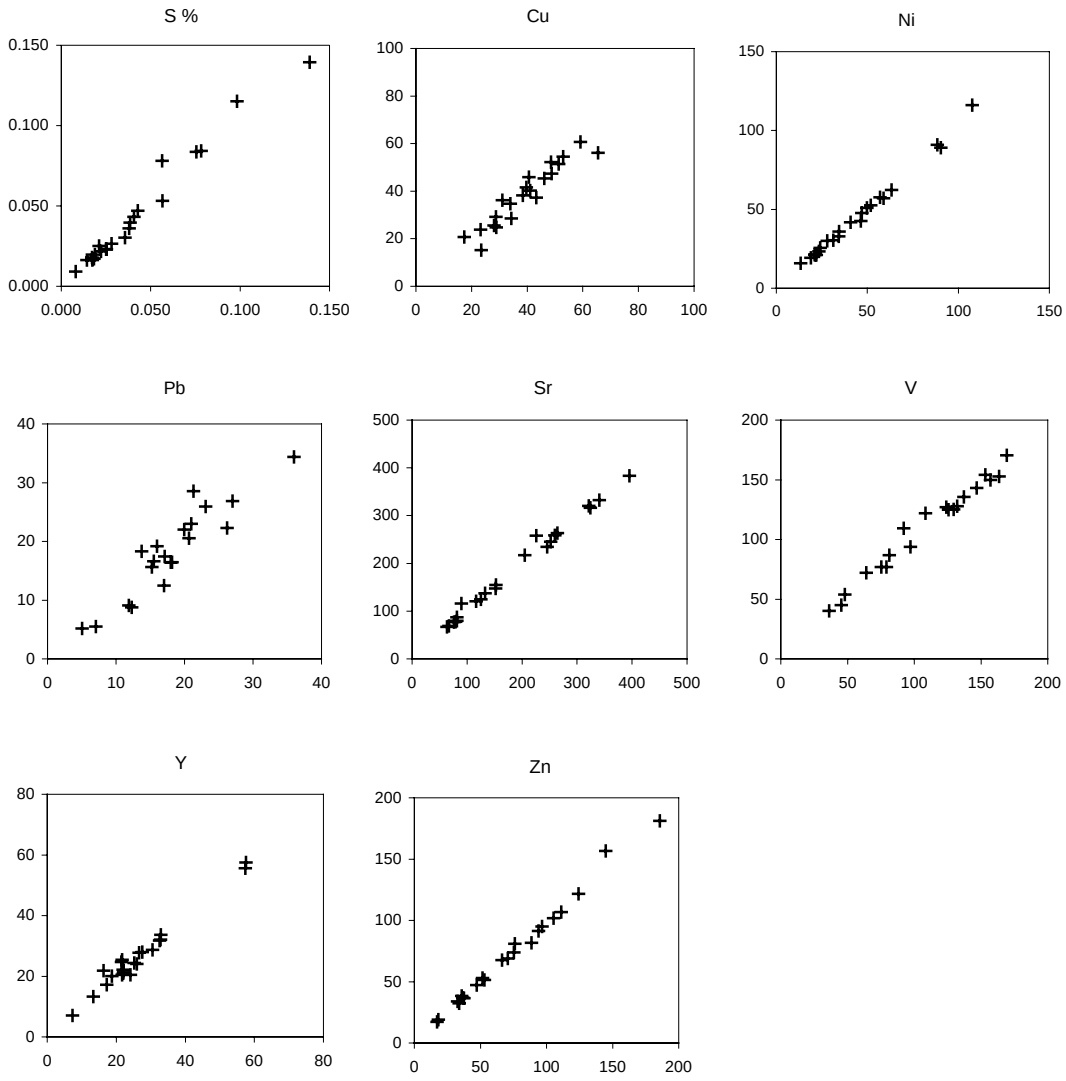

Figure A2. *Analytical precision of element concentrations determined by inductively coupled plasma emission spectrometry. Results of repeated analysis of 20 samples.*

Appendix B

Photographs of sampling sites and landscapes in the stream sediment survey area.

Figure B1. *Stream surroundings at sampling site 43 (location in Fig. 3).*

Figure B2. *Stream surroundings at sampling site 45 (location in Fig. 3).*

Figure B3. *Stream surroundings at sampling site 56 (location in Fig. 3).*

Figure B4. *Stream surroundings at sampling site 68 (location in Fig. 3). Outcrop of rust coloured silty shales.*

Figure B5. *Stream surroundings at sampling site 70 (location in Fig. 3). Outcrops of dark shale in background. Foreground with blocks of brownish weathering dolerite from sill.*

Figure B6. *Stream surroundings at sampling site 72 (location in Fig. 3). Grey siltstones predominates.*

Appendix C

Local variation

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	S
	%	%	%	%	%	%	%	%	%	%	%	%	%
505935	79.07	1.195	9.04	4.63	0.045	0.69	0.34	0.75	1.33	0.07	2.96	100.11	0.012
505936	80.04	1.224	8.42	4.53	0.044	0.64	0.33	0.71	1.29	0.07	2.72	100.02	0.012
505970	74.89	1.392	9.60	5.42	0.052	1.13	0.73	0.90	1.68	0.11	2.86	98.77	0.014
505971	75.08	1.412	9.60	5.46	0.053	1.12	0.73	0.87	1.63	0.11	2.73	98.79	0.015
505972	67.38	1.269	15.36	6.41	0.037	0.99	0.40	0.86	2.33	0.10	4.86	100.00	0.028
505973	66.59	1.658	15.29	6.98	0.044	1.01	0.41	0.84	2.18	0.12	4.86	99.97	0.028
505949	59.81	4.186	11.27	11.58	0.116	3.27	3.21	1.01	1.79	0.46	3.32	100.02	0.071
505950													0.074

	Ag	Cd	Cu	Ni	Pb	Zn	Be	Sr	V	Y	Au	As	Ba	Br	Co	Cr
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm	ppm	ppm
505935	0.4	0.8	23	22	11	48	1	46	53	17	-2	3.1	340	-1	16	44
505936	0.4	0.6	19	21	11	44	1	43	40	17	-2	3.1	140	3.2	14	36
505970	-0.3	0.9	39	29	7	41	1	60	62	17	-2	2.8	-50	2.2	18	52
505971	-0.3	0.8	40	30	6	44	1	60	63	16	-2	3	320	2.1	17	45
505972	0.4	0.9	51	29	15	61	2	49	98	9	4	4.7	370	2.6	18	70
505973	0.3	1.1	44	30	15	61	2	49	87	10	-2	5	380	-1	18	86
505949	0.4	1.6	132	66	9	87	2	157	258	30	-2	3.8	450	3.2	36	90
505950	0.4	1.8	184	74	13	94	2	170	245	31	5	1.8	490	2.2	45	110

	Cs	Hf	Sb	Sc	Ta	Th	U	W	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
505935	3	19	0.4	9.9	1.8	9.8	2.8	-1	30	66	31	4.6	1.4	-1	2.5	0.4
505936	3	18	0.4	8.9	1.8	9.2	4	-1	27	60	25	3.9	1.1	0.7	2	0.3
505970	2	11	0.5	10	1.6	8.9	2.7	-1	31	67	29	4.7	1.3	0.6	1.8	0.3
505971	2	12	0.3	10	-1	8.2	2.8	-1	29	61	32	4.6	1.3	-1	1.7	0.3
505972	5	10	0.6	15	-1	14	4	-1	50	100	45	6.7	1.6	-1	2.7	0.4
505973	5	13	0.5	16	2.2	17	4.2	-1	57	120	48	7.4	2	-1	3	0.5
505949	3	10	-0	18	-1	9.2	3.1	-1	44	94	49	7.9	1.9	-1	2.3	0.4
505950	3	10	0.4	21	2.2	10	1	-1	50	110	63	9.5	2.6	1.1	2.4	0.4

Table C1. *Chemical analyses of duplicate samples from Steensby Land. Negative values mark concentrations below the detection limit .*