P-03-118

Forsmark site investigation

Element distribution in till at Forsmark – a geochemical study

Bengt Nilsson, MIRAB Mineral Resurser AB

December 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-03-118

Forsmark site investigation

Element distribution in till at Forsmark – a geochemical study

Bengt Nilsson, MIRAB Mineral Resurser AB

December 2003

Keywords: Geochemical anomaly, Till samples, Distribution pattern, Kriging, Factor analysis, AP PF 400-03-71, Field note: Forsmark 188.

Contents

1	**Introduction**	5
2	**Objective and scope**	7
3	**Equipment**	7
4	**Execution**	9
4.1	Selection of till samples	10
4.2	Preparation of selected till samples	10
4.3	Analytical method	10
4.4	Quality control of the values of the analysed elements	10
4.5	Statistical methods	11
4.6	Visualization of the geochemical distribution pattern	11
4.7	Evaluation and interpretation of the geochemical pattern	12
4.8	Data handling	12
4.9	Nonconformities	12
5	**Results**	13
5.1	General aspects	13
5.2	Copper, zink and lead	13
5.3	Gold	15
5.4	Factor analysis	15
5.5	Conclusion	16
6	**References**	17
Appendix 1	Table with analytical values of the elements Cu, Pb, Zn, Au and Ca together with depth, composition and colour of total 43 till samples	19
Appendix 2	Diagram with regression analysis and XY-plots of the element Cu	21
Appendix 3	Diagram with regression analysis and XY-plots of the element Pb	23
Appendix 4	Diagram with regression analysis and XY-plots of the element Zn	25
Appendix 5	Diagram with regression analysis and XY-plots of the element Au	27
Appendix 6	Combined contoured colour shaded map and circle map: copper (Cu)	29
Appendix 7	Combined contoured colour shaded map and circle map: lead (Pb)	31
Appendix 8	Combined contoured colour shaded map and circle map: zink (Zn)	33
Appendix 9	Combined contoured colour shaded map and circle map: gold (Au)	35
Appendix 10	Combined contoured colour shaded map and circle map of factor score 1	37
Appendix 11	Combined contoured colour shaded map and circle map of factor score 2	39
Appendix 12	Combined contoured colour shaded map and circle map of factor score 3	41
Appendix 13	Combined contoured colour shaded map and circle map of factor score 4	43
Appendix 14	Table with factor loadings and variances of factor 1–4	45

1 Introduction

After a resolution from the Swedish Government and the Municipality of Östhammar together with permission from local land owners, SKB performs a site investigation for location of a deep repository for high level radioactive waste at Forsmark. A general programme with presentation of the SKB methods for different site investigations has been stated /1/ including a site specific programme for the investigations at Forsmark /2/.

One part of the investigation programme includes mapping, sampling, classifying and data-storing of unconsolidated Quaternary deposits. This work has been carried out following the Activity Plan AP PF 400-02-12 (SKB internal controlling document) and the results have been presented in two reports /3/ and /4/. The mapping of the unconsolidated deposits aimed at describe the aerial distribution of the soils close to the surface, and if possible, at depth and to define their stratigraphic relationship, composition and the process of formation. The investigations of the Quaternary deposits included to collect and store such Quaternary information as, for example, the directions of ice striae and till fabric, which describe the movement of glaciers within the area during the late glacial period.

The investigated area is about 5 x 4 km^2 large (Figure 1-1). As a complement to the mapping of the uppermost layer of unconsolidated Quaternary deposits, a programme with stratigraphical mapping at depth by excavating trenches at selected locations has been carried out as well, following the Activity Plan AP PF 400-02-12.

Figure 1-1. Location of the area selected for the geochemical study.

Additional investigations for stratigraphic information of the Quaternary deposits within the area are different types of drillings (core- and percussion drill holes), so far concentrated to three drilling sites, DS 1–3 (Figure 1-1). These holes penetrate the unconsolidated sediments /5, 6, 7/. The study named: "Drilling and sampling in soil and installation of groundwater monitoring wells and surface water level gauges", which was carried out according to Activity Plan AP PF 400-02-31 (SKB internal controlling document), resulted in a large number of drill holes through the soil layer all over and immediately outside the candidate area shown in Figure 1-1. The activity was reported in /8/.

The present study aims at characterizing contents and distribution of metallic elements in the glacial till. The investigation was carried out according to Activity Plan AP PF 400-03-71 (SKB internal controlling document) and focused on interpretation and evaluation of the ore potential from a regional aspect. Earlier archived samples from unconsolidated Quaternary deposits at Forsmark have been used for geochemical analysis of major and trace elements.

The present study in general refers to geochemical and statistical methods described in Handbook of Exploration Geochemistry /9/ and Statistics and Data Analysis in Geology /10/.

2 Objective and scope

The aim of this investigation was to visualize, interpret and evaluate the geochemical distribution-pattern of trace elements in the bottom-most layers of the till, and to study if mineralization may occur in the bedrock surface below. A mineralization, in this sense, is defined as a zone in the bedrock with enhanced contents of metallic elements, like base metals and gold.

3 Equipment

During earlier work done by the Geological Survey of Sweden three different methods for drilling and till-sampling have been used. These methods are auger drilling, percussion drilling and bucket-sampling. In this study auger drilling and machine cut trenches have been used.

4 Execution

The execution has followed the Activity Plan AP PF 400-03-71 with minor exceptions described below.

Locations of the sampled drill holes and trenches are shown in Figure 4-1.

Figure 4-1. *Location of the geochemically investigated area, sampled drill holes and trenches.*

4.1 Selection of till samples

Till material was available from about 90 sites within the Forsmark area (SGU personal information). The intention of this study was to select samples from points evenly distributed over the entire area. Clusters of samples have been avoided. The till samples have been taken from the deepest part of each sampling profile, with the exception of five sampling sites, where both the deepest and the uppermost parts of the till was sampled. Grain size, colour of the till material and sampling depth has been documented for all samples.

After inventory of all stored samples in the archives of SGU in Uppsala and at SKB in Forsmark, till material from 28 sample sites was selected for analysis in this investigation.

4.2 Preparation of selected till samples

The risk of contamination from jewellery has been paid attention to throughout the study. This is especially important regarding gold.

The till material is stored in plastic cups of one litre. Prior to sampling, the cups were thoroughly shaken. Then 2–3 decilitres were transferred by "channel" sampling with a stainless steel spoon, from the top to the bottom of the till material in the cups, to 0.5 litres plastic cups. Samples from ten sites were duplicated in order to verify any analytical error, as well as the analytical precision of the laboratory. In total, 43 samples were prepared. These samples were assigned new randomized id-numbers before delivery to the laboratory for further preparation.

4.3 Analytical method

The randomized till samples were sent to Acme Analytical Laboratories Ltd. in Vancouver, Canada. Acme is accredited at ISO 9002.

At Acme, the till samples were dried and sieved to obtain a fraction < 0.063 mm (63 µm). This fraction was digested in Aqua Regia (NO_3:HCl:H_2O 2:2:2) for 1.5 hours and then analysed with ICP-MS for 35 elements including gold.

4.4 Quality control of the values of the analysed elements

Analytical precision of this type of geochemical analyses can be described by a simple regression line of duplicate samples and visualized in XY-plots. From the XY-plots and the calculated regression line it is possible to evaluate the quality of the analysis of each element. This control is important for further evaluation and interpretation of the element distribution-pattern.

4.5 Statistical methods

A descriptive statistics was performed on the values of the analysed elements. To study the relationship between the elements in the analysed population, a multivariate factor analysis has been applied. The factor analysis is of a varimax type. By this method, several factors or classes can be described; some may be related to geochemical signatures originated from for example the rock type or a mineralization. Only factors with a variance exceeding 5–10% of the total variance of the element values in the analysed population, and with factor loadings (a type of weighted property for each element to a factor) above 0.5, are suggested to be interpreted in a geochemically meaningful way. For each factor and each sample, a factor score value has been calculated.

4.6 Visualization of the geochemical distribution pattern

The element distribution has been visualized by using the data processing and analysis programme Oasis Montaj. By this programme values are first gridded with the Kriging Method of Spherical Variogram Model. From the variogram of each element, a range distance of influence in metres can be estimated (Figure 4-2). The search criterion is spherical without any correction for trends in the geochemical distribution-pattern. Contoured and colour shaded maps were produced from gridded values. For each sample point, a circle is shown overlain and combined with this contoured, colour shaded map. The circle size is proportional to the element value.

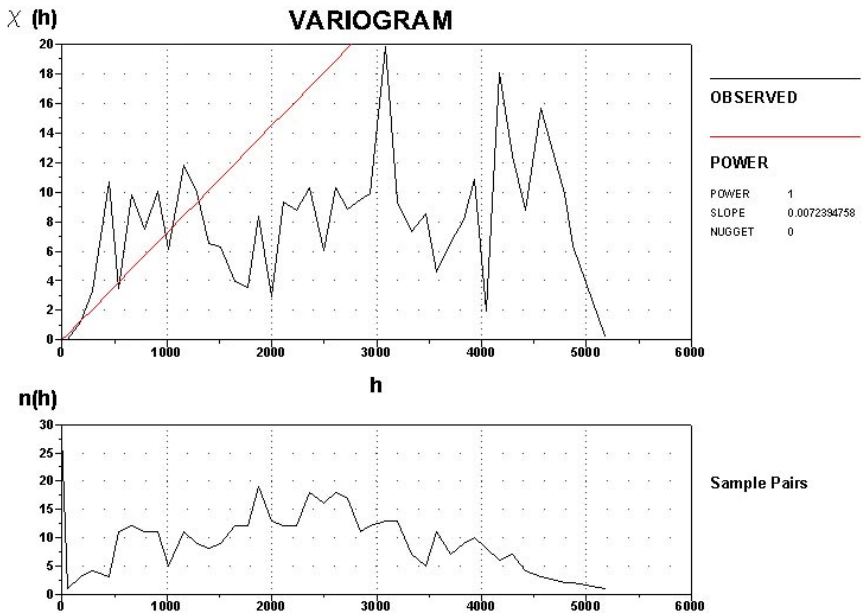


Figure 4-2. *Variogram of the element copper (Cu).*

4.7 Evaluation and interpretation of the geochemical pattern

By knowledge of the ice movement directions within the area and the thickness of the overburden, it is possible to evaluate the distribution-pattern of each element, estimate their concentrations and to interpret the potential of mineralization at or close to the bedrock surface.

4.8 Data handling

Analytical results from the laboratory have been reported to SKB for storage in the SICADA database under Field note: Forsmark 188.

4.9 Nonconformities

No deviations from the activity plan have occurred.

5 Results

5.1 General aspects

Analytical results from Acme-lab comprise 35 elements from totally 43 till samples including duplicate samples. Concentrations of Cu, Pb, Zn and Au together with sample depth, ocular classification of grain-size distribution and colour are presented in Appendix 1. The investigated area is about 20 km^2. Twenty-eight (28) sampling sites give an average sample density of about 1.4 samples per square kilometre.

The ranges of values and maxima for the base metals and gold are moderate to low compared to the distribution of element values from a regional, near-surface till survey carried out by the Swedish Geological Company (SGAB) /11/ in central Sweden during the years 1987–1991 (Table 5-1).

The regression-line analyses with XY-plots of the element values from duplicate samples result in a measure of the analytical precision of the laboratory as well as a validation of which elements are qualified to be included in the interpretation of the distribution patterns. It was apparent from the XY-plots that the analysis of the base metals Cu, Pb and Zn were precise and of good quality. Precision for the gold-analysis was not equally good, which is a well known common feature for gold in till material and especially at such low grades as in this study (Appendices 2–5).

5.2 Copper, zink and lead

The colour shaded maps show moderately enhanced and extended patterns (= anomalies) of the base metals Cu, Pb and Zn both at the north-eastern and the south-western part of the investigated area (Appendices 6–8). These geochemical anomalies encircle an area with low values of base metals around Lake Bolundsfjärden. In comparison with the bedrock map from this area (Figure 5-1), the zone with low values seems to coincide with the central part of the granitic bedrock occupying the candidate area at Forsmark. The extended base metal anomalies seem to be in accordance with NW-SE striking units of felsic to intermediate meta-volcanic rocks and amphibolites, occupying the north-eastern and south-western parts of the area. The dominant ice movements ranging in a small sector from N45°W to N10°W, which almost correspond with the strike of the bedrock units, have probably strengthened the linear pattern of the anomalies.

Table 5-1. Descriptive statistics from geochemical results of till samples from Forsmark and Central Sweden (SGAB).

Element	Cu_SKB ppm	Pb_SKB ppm	Zn_SKB ppm	Au_SKB ppb	Ca_SKB %	Cu_SGAB ppm	Pb_SGAB ppm	Zn_SGAB ppm	Au_SGAB ppb	Ca_SGAB %
Max	15.9	25.0	140.8	2.6	10.50	1190.0	345.0	283.0	95.7	11.00
Range	10.3	19.8	122.1	2.5	7.72	1189.0	344.0	280.6	95.6	0.01
Median	10.5	7.8	32.3	0.2	7.59	8.5	7.6	26.3	0.1	0.18
Cases	28	28	28	28	28	1986	1986	1986	1986	1986

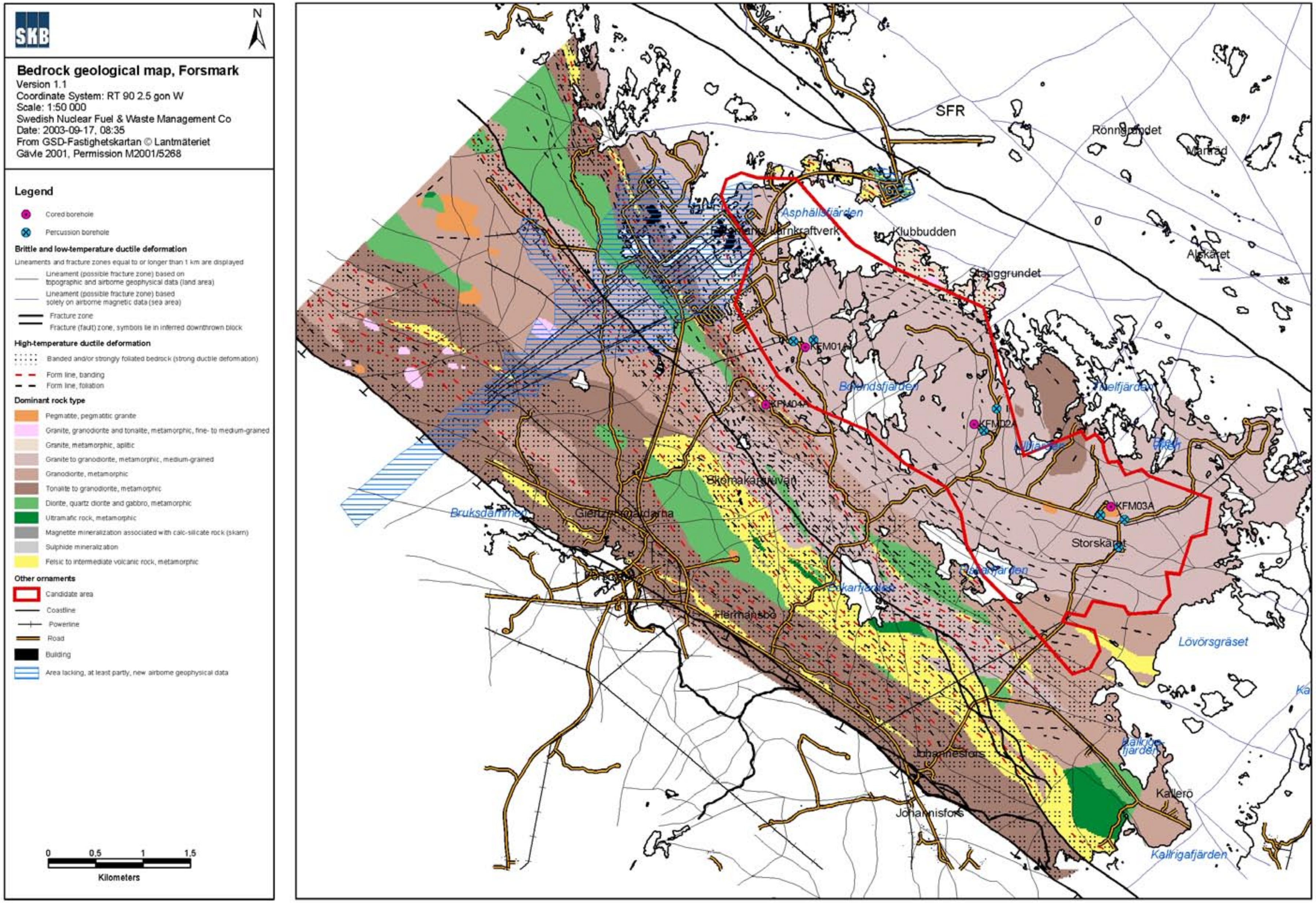


Figure 5-1. *The bedrock geology map version 1.1 from the Forsmark area.*

5.3 Gold

Gold shows two single "hot spot" anomalies in the north-western and south-eastern parts of the investigated area (Appendix 9). The gold grades are however too low to be of any interest as an exploration target for this metal.

5.4 Factor analysis

The results from the factor analysis distinguish at least four factors, which satisfy the criteria mentioned in section 4.5 regarding variances and factor loadings, and which can be attributed to bedrock geochemical features within the investigated area.

The first factor has a variance that can be estimated at 35.7% of the total variance. This factor is strongly described by the elements Mn, Zn, Fe, Al, Co, Mg, P and Pb. Such a strong factor can geochemically be attributed to the most common rock types within the area and to easily weathered rocks where major and trace elements tend to be dissolved. The north-west to south-east striking bedrock units composed of meta-volcanic rocks and amphibolites displayed on the geological map (Figure 5-1) are the probable anomaly-sources, showing a good coincidence with the score pattern for this factor (Appendix 10 and 14).

A second factor has a variance that can be estimated at 18.5% of the total variance. This factor is described by the elements K, Ba, Na, Ti and Mo and has an element association which geochemically may be related to a meta-tonalitic to meta-granodioritic rock type. The massive meta-tonalite north of Storskäret (see Figure 5-1) seems to give a small response in the score pattern for this factor (Appendix 11 and 14). The stronger, anomalous score pattern for this factor in the north-western part of the area, may be a response to the more extended massive of meta-tonalite south of the Forsmark nuclear plant.

A factor 3 with a variance estimated at 12.8% of the total variance, comprises the more mafic element suite of Ni, Cr and to a less extent the elements Mg and Co and, somewhat confusing, the element Pb. The colour-shaded score pattern from this factor in some parts of the area display a response to known ultramafic bodies occurring within the zone comprising meta-vulcanite – amphibolite (Appendix 12 and 14).

Regarding factor 4, the variance of which can be estimated at 9.5% of the total variance, is a strong two-element factor described by the elements Ca and As. The geochemical score pattern for this factor shows anomalous values in the north-eastern part of the investigated area (Appendix 13 and 14). This Ca-factor is a response to the easily weathered sedimentary Cambro-Silurian limestone occupying a widespread area in the Gävle Bay, north of Forsmark, upstream the ice movement direction. The limestone has been encountered as boulders and rock fragments in the Quaternary deposits of the eastern Uppland area, including the Forsmark area. Limestone radically increases pH and alkalinity in water. The content of Ca in the till is probably the highest noticed in crystalline rock areas in Sweden. The median value is about 7.5% Ca as compared to 0.18% Ca for the median from near-surface till samples from central Sweden (Table 5-1). The relation to arsenic of this factor is a geochemically well-known phenomenon, where oxidized arsenates in the soil ground-water together with calcite in a strong alkaline environment precipitates as Ca-arsenates.

5.5 Conclusion

The conclusion of this geochemical investigation at Forsmark is that there is probably no potential for base metals or gold mineralisations. Content of base metals and gold is generally low in the till samples. Even if the grades are low or very low, the anomaly patterns reflect the variation of the bedrock types as demonstrated on geological maps. The candidate area has in these respect extremely low metal grades.

6 References

/1/ **SKB, 2001**. Platsundersökningar. Undersökningsmetoder och generellt genomförandeprogram. SKB R-01-10, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2001**. Program för platsundersökning vid Forsmark. SKB R-01-42, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2002.** Sohlenius G, Rudmark L, Hedenström A. Mapping of unconsolidated Quaternary deposits, Field data 2002. SKB P-03-11, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2002.** Sohlenius G and Rudmark L. Forsmark site investigation. Mapping of unconsolidated Quarternary deposits 2002–2003. Stratigraphical and analytical data. SKB P-03-14, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003**. Claesson L-Å and Nilsson G. Forsmark site investigation. Drilling of a flushing water well, HFM01, and two groundwater monitoring wells, HFM02 and HFM03 at drill site DS1. SKB P-03-30, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2003**. Claesson L-Å and Nilsson G. Forsmark site investigation. Drilling of a flushing water well, HFM05, and a groundwater monitoring well, HFM04 at drillsite DS 2. SKB P-03-51, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2003**. Claesson L-Å and Nilsson G. Forsmark site investigation. Drilling of a flushing water well, HFM06, and two groundwater monitoring wells, HFM07 and HFM08 at drillsite DS3. SKB P-03-58, Svensk Kärnbränslehantering AB.

/8/ **SKB, 2002.** Johansson P-O. Forsmark site investigation. Drilling and sampling in soil. Installation of groundwater monitoring wells and surface water level gauges. SKB P-03-64, Svensk Kärnbränslehantering AB.

/9/ **Govett G J S (Ed), 1983**. Handbook of Exploration Geochemistry, Volume 1–7, Elsevier Scientific publishing Co, Amsterdam.

/10/ **Davis J C, 1986**. Statistics and Data Analysis in Geology. Second Edition. John Wiley & Sons Inc, New York.

/11/ **GVR, 93016**. Geokemisk moränprovtagning 1993-11-02.

Appendix 1

Table with analytical values of the elements Cu, Pb, Zn, Au and Ca together with depth, composition and colour of total 43 till samples

Sample_Id	Cons_Id	Rand_Id	Depth met	Composit	Colour	X_RAK	Y_RAK	Cu ppm	Pb ppm	Zn ppm	Au ppb
HFM11	1	MIR007	2,5	silt-sand	Grey	6697279,00	1631634,00	12,92	8,26	37,0	1,0
HFM13	2	MIR030	3,0	sand-silt	Grey	6699096,00	1631474,00	8,10	7,68	25,5	2,5
PFM002461	3	MIR009	2,0-2,4	sand-silt	Grey	6698021,09	1633434,72	11,48	7,86	33,7	0,4
PFM002572	4	MIR008	5,1-5,7	silt	Grey	6697247,28	1634551,89	9,90	7,36	33,5	< .2
PFM002573	5	MIR032	4,5-5,0	silt	Grey	6698062,05	1634435,69	7,96	6,71	26,7	0,5
PFM002576	6	MIR005	5,0	sand-silt	Grey	6699590,00	1631331,00	5,56	5,20	18,7	< .2
PFM002577	7	MIR040	0,6	sand-silt	Beige-grey	6699487,00	1633201,00	13,27	16,68	41,5	1,0
PFM002581	8	MIR015	2,4	silt	Dark grey	6699118,00	1630839,00	11,75	10,13	40,9	2,1
PFM002582	9	MIR004	1,7	silt-sand	Brown-grey	6698865,00	1630391,00	15,49	11,48	32,3	< .2
PFM002586	10	MIR016	1,4	sand-silt	(Brown)Gr	6696515,00	1631084,00	15,88	10,56	40,6	< .2
PFM002587	11	MIR021	3,0	sand-silt	Grey	6696764,00	1630497,00	11,79	6,21	24,1	0,2
PFM002588	12	MIR017	2,1	silt-clay	Dark grey	6698220,00	1633947,00	11,96	8,61	39,6	0,6
PFM002592	13	MIR035	2,8	silt-clay	Dark grey	6697082,00	1634790,00	14,09	8,08	44,8	1,3
PFM004514	14	MIR020	2,8	sand-silt	Grey	6696354,00	1633682,00	7,19	6,45	25,2	< .2
SFM0002D*	15	MIR034	1,0-1,5	sand-silt	Grey	6699585,84	1631377,69	6,65	6,55	23,3	0,9
SFM0002	16	MIR031	5,0-5,5	silt-sand	Grey	6699585,84	1631377,69	5,84	6,51	20,6	< .2
SFM0002DD*	17	MIR002	1,0-1,5	sand-silt	Grey	6699585,84	1631377,69	5,81	6,12	19,4	< .2
SFM0004D	18	MIR039	1,0-1,5	sand-silt	Grey	6698865,76	1633441,21	10,35	10,91	36,9	0,8
SFM0004	19	MIR022	4,5-5,0	sand-silt	Grey	6698865,76	1633441,21	7,72	7,28	27,2	0,2
SFM0004DD	20	MIR001	1,0-1,5	sand-silt	Grey	6698865,76	1633441,21	8,40	9,87	28,8	0,4
SFM0005D	21	MIR029	1,0	sand-silt	Dark grey	6698647,55	1633252,18	15,97	11,09	46,3	0,3
SFM0005	22	MIR013	1,5-2,0	silt-sand	Brown-grey	6698647,55	1633252,18	8,43	10,20	30,7	< .2
SFM0005DD	23	MIR019	1,0	sand-silt	Dark grey	6698647,55	1633252,18	15,19	10,65	46,5	0,7
SFM0007D	24	MIR033	1,0	sand-silt	Grey	6697688,66	1634780,08	14,76	11,29	47,5	0,4
SFM0007	25	MIR038	5,5	silt-sand	Brown-grey	6697688,66	1634780,08	9,61	7,79	32,3	2,6
SFM0007DD	26	MIR028	1,0	sand-silt	Grey	6697688,66	1634780,08	15,17	11,16	48,0	< .2
SFM0008D	27	MIR041	1,0	sand-silt	Grey	6697930,56	1634622,99	16,02	11,85	57,9	1,8
SFM0008	28	MIR026	5,5	sand-silt	Grey	6697930,56	1634622,99	7,34	7,86	27,0	< .2
SFM0008DD	29	MIR042	1,0	sand-silt	Grey	6697930,56	1634622,99	16,21	11,42	55,1	1,9
SFM0010	30	MIR023	0,8-1,3	sand-silt	Grey	6697313,87	1630734,94	13,21	9,86	44,5	< .2
SFM0010DD	31	MIR037	0,8-1,3	sand-silt	Grey	6697313,87	1630734,94	13,82	9,28	49,5	1,4
SFM0011	32	MIR036	3,0-3,5	silt-sand	Grey	6699117,11	1630711,39	9,22	5,27	23,4	0,4
SFM0011DD	33	MIR012	3,0-3,5	silt-sand	Grey	6699117,11	1630711,39	8,27	4,93	21,0	< .2
SFM0016	34	MIR025	6,6-7,2	sand-silt	Dark grey	6696976,14	1632173,94	11,45	25,04	107,6	0,3
SFM0016DD	35	MIR003	6,6-7,2	sand-silt	Dark grey	6696976,14	1632173,94	11,97	27,42	98,0	0,9
SFM0017	36	MIR018	3,7-4,0	sand-silt	Dark grey	6696504,81	1632138,16	13,79	14,34	140,8	< .2
SFM0019	37	MIR011	4,5-4,8	sand-silt	Grey	6697700,72	1632118,35	8,17	7,27	23,4	< .2
SFM0020	38	MIR027	2,3-2,8	sand-silt	Grey	6698126,80	1632993,65	7,09	6,28	23,6	< .2
SFM0021	39	MIR043	1,2-1,7	sand-silt	Grey	6699706,35	1632492,99	9,08	6,31	27,5	0,6
SFM0049	40	MIR024	1,5-2,5	silt-sand	Grey	6700027,55	1630533,06	13,32	13,23	36,6	< .2
SFM0049DD	41	MIR014	1,5-2,5	silt-sand	Grey	6700027,55	1630533,06	12,74	12,34	36,5	< .2
SFM0057	42	MIR006	1,0	sand-silt	Grey	6698979,93	1630949,38	11,10	5,71	42,1	0,5
SFM0057DD	43	MIR010	1,0	sand-silt	Grey	6698979,93	1630949,38	11,85	6,17	42,9	0,2

*D and DD in the end of Sample_Id means duplicate samples

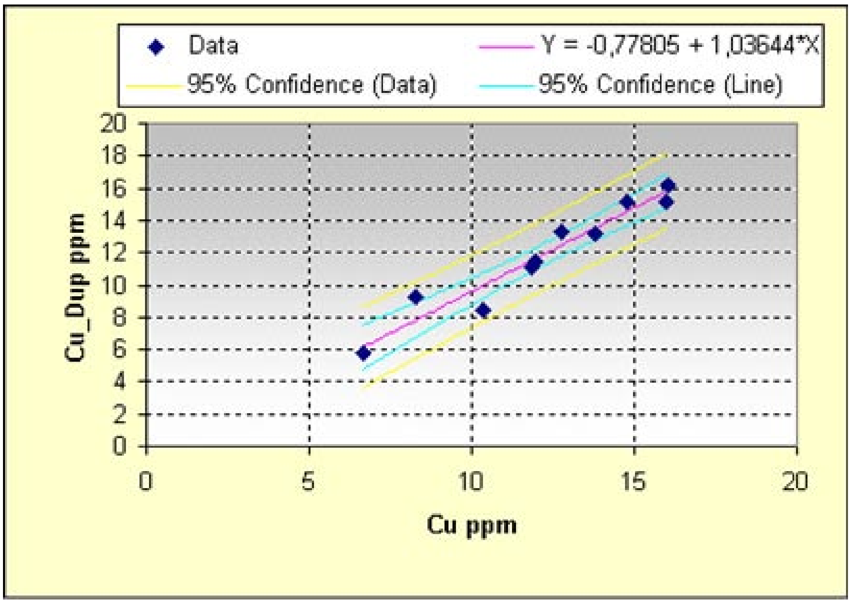
Appendix 2

Diagram with regression analysis and XY-plots of the element Cu

Simple Regression

X-Variable: Cu ppm
Y-Variable: Cu_Dup ppm

	N	A	B	R	R-Square
<u>**Y = A + B*X**</u>	10	-0,778051017	1,036442077	0,967116787	0,935314879



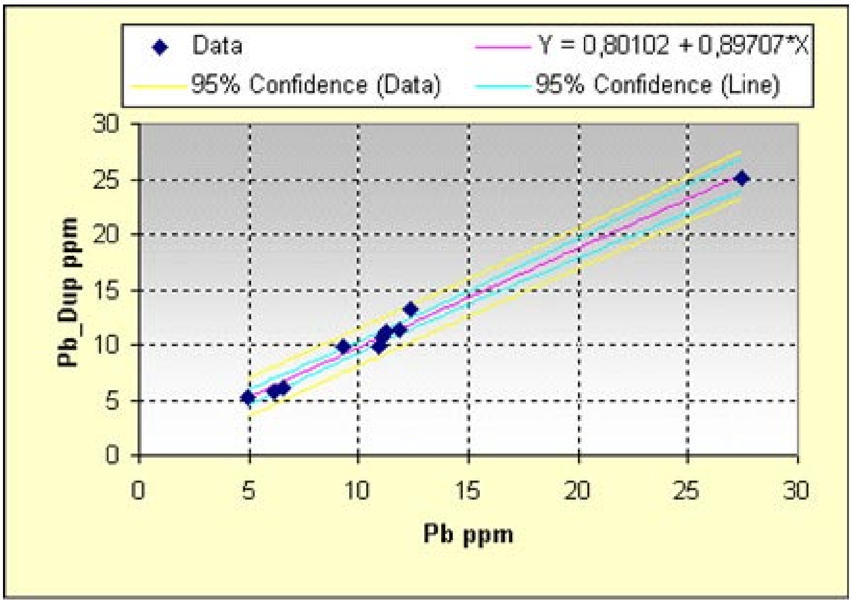
Appendix 3

Diagram with regression analysis and XY-plots of the element Pb

Simple Regression

X-Variable: Pb ppm
Y-Variable: Pb_Dup ppm

	N	A	B	R	R-Square
Y = A + B*X	10	0,801024387	0,897073738	0,993415381	0,986874119



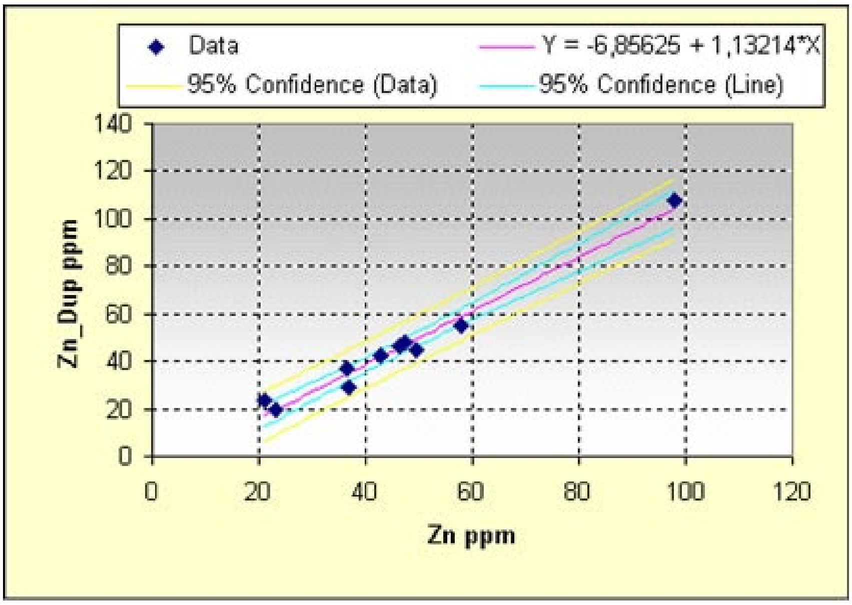
Appendix 4

Diagram with regression analysis and XY-plots of the element Zn

Simple Regression

X-Variable: Zn ppm
Y-Variable: Zn_Dup ppm

	N	A	B	R	R-Square
Y = A + B*X	10	-6,856256281	1,132149984	0,987789132	0,975727369



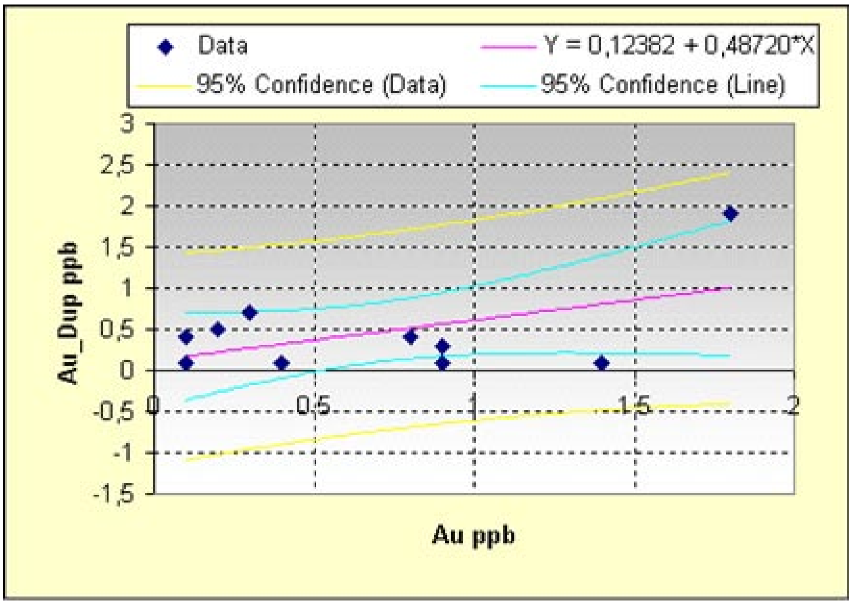
Appendix 5

Diagram with regression analysis and XY-plots of the element Au

Simple Regression

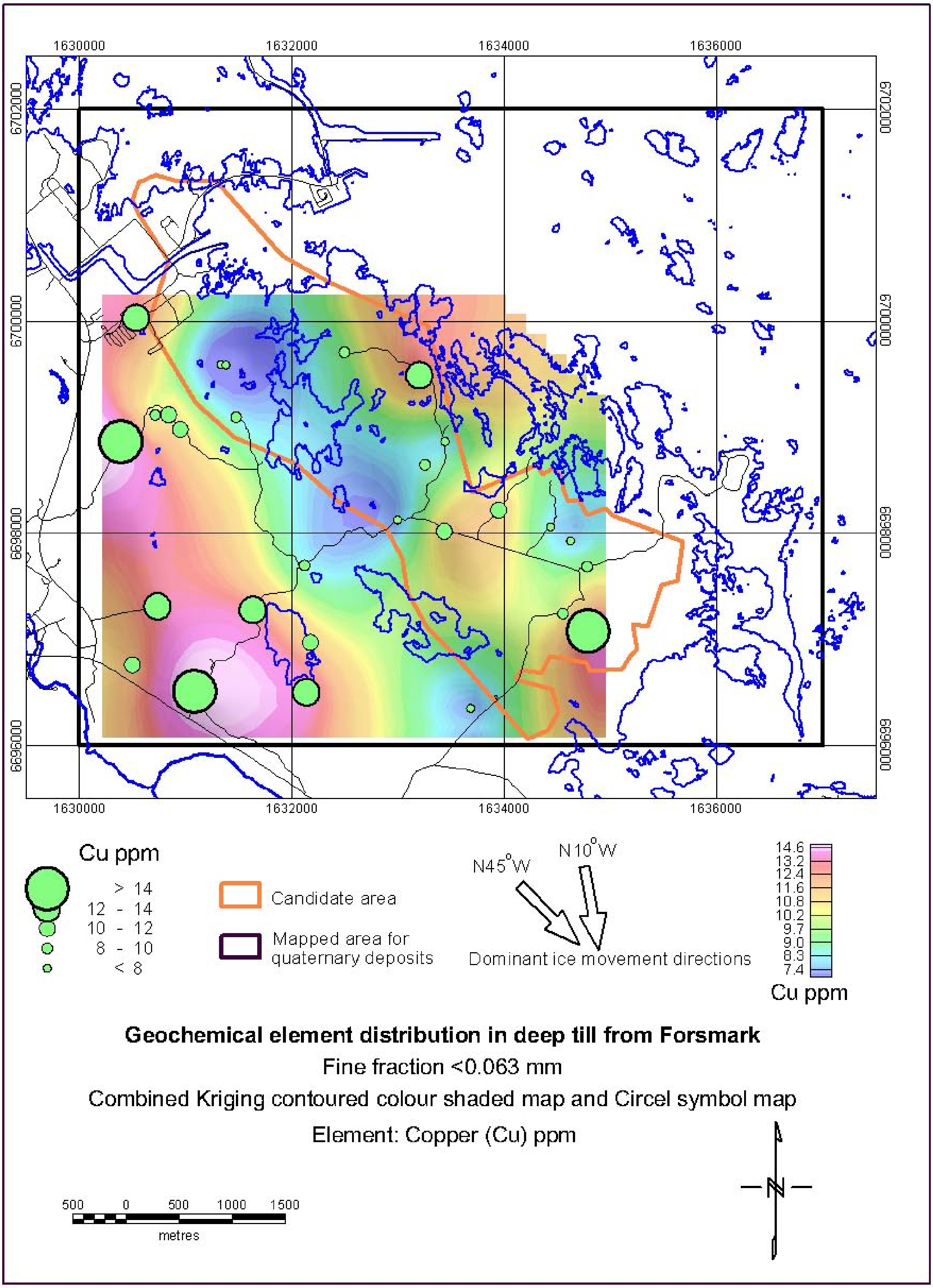
X-Variable: Au ppb
Y-Variable: Au_Dup ppb

	N	A	B	R	R-Square
Y = A + B*X	10	0,123828514	0,487205052	0,515859723	0,266111254



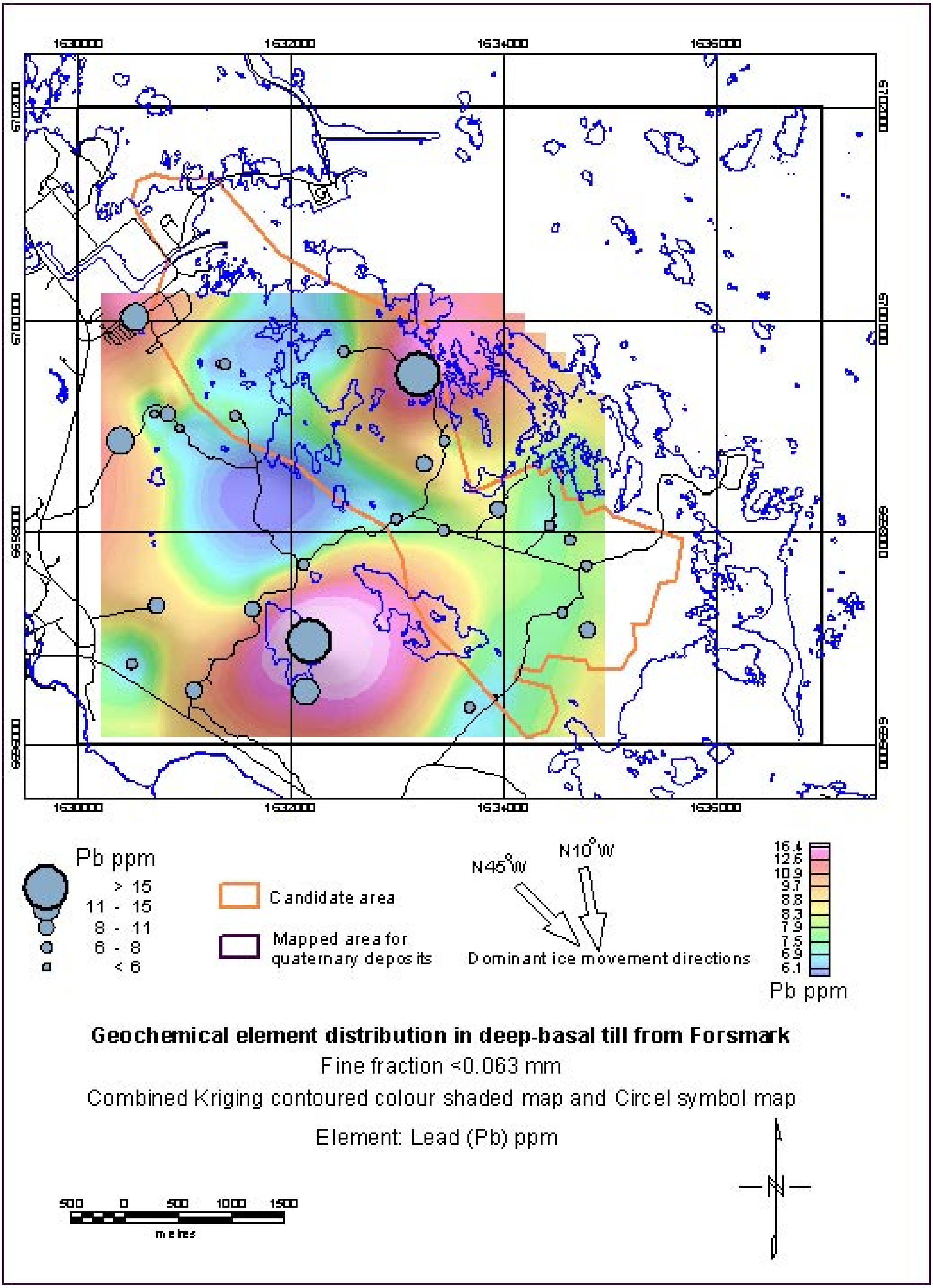
Appendix 6

Combined contoured colour shaded map and circle map: copper (Cu)



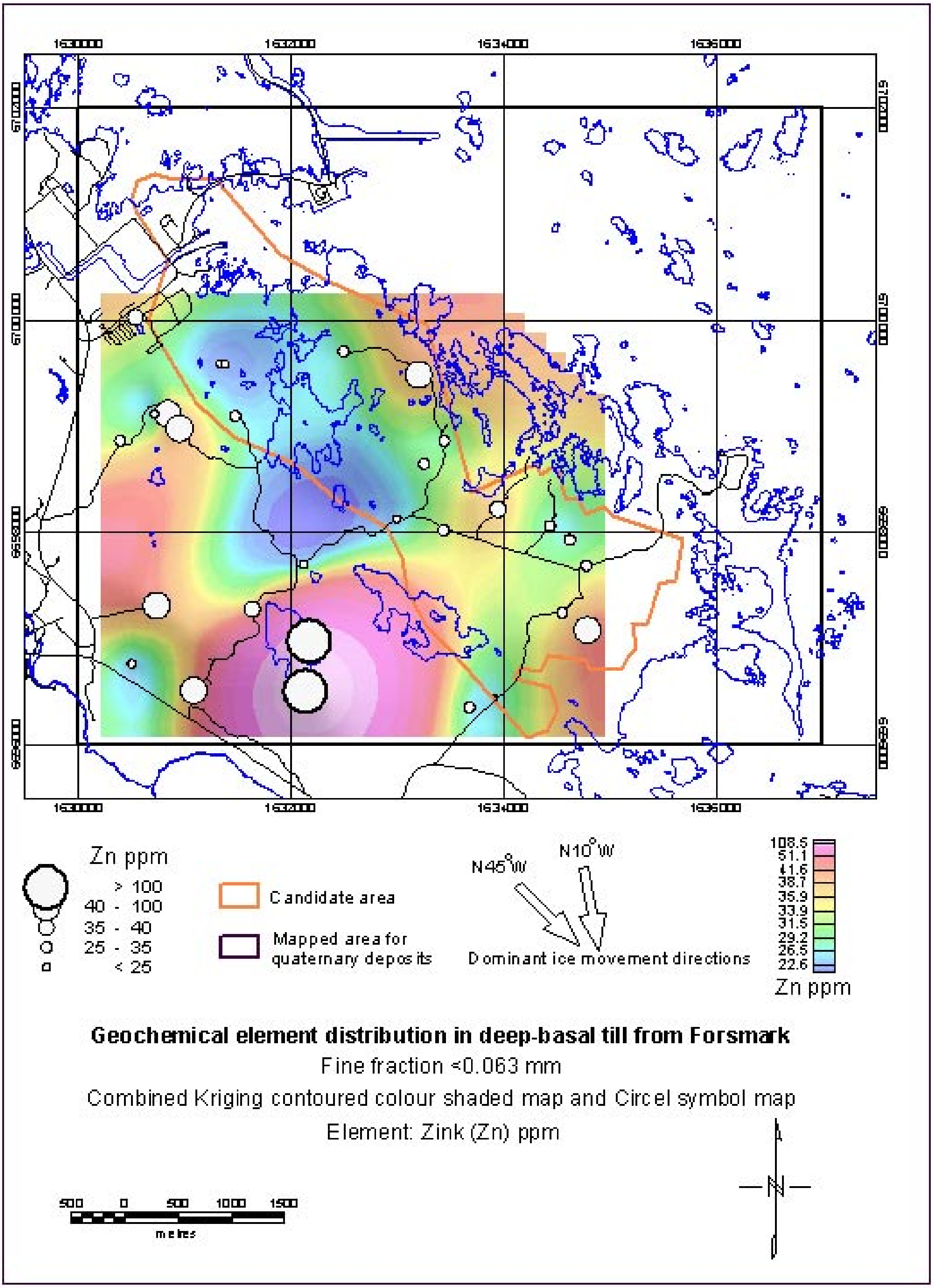
Appendix 7

Combined contoured colour shaded map and circle map: lead (Pb)



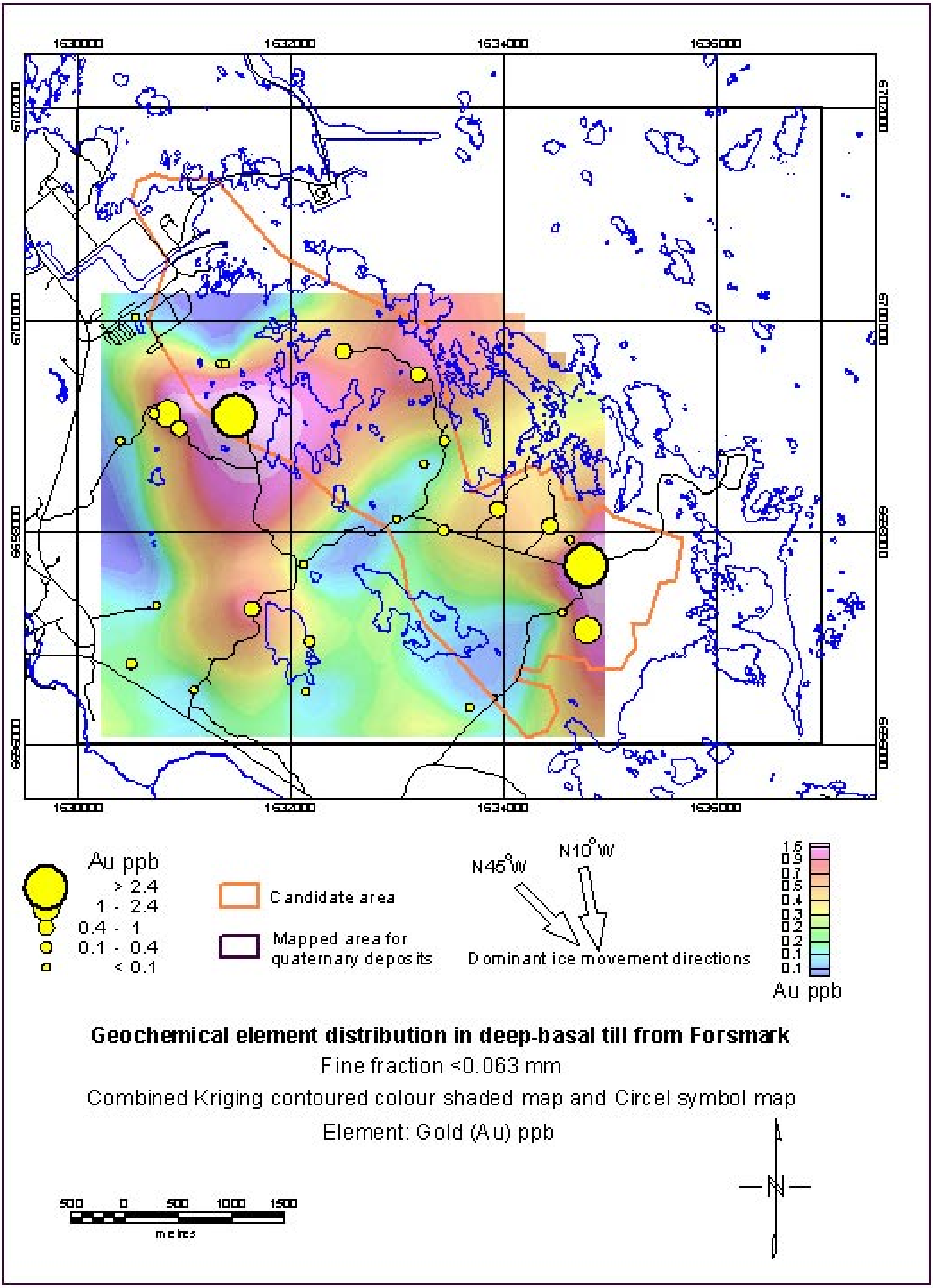
Appendix 8

Combined contoured colour shaded map and circle map: zink (Zn)

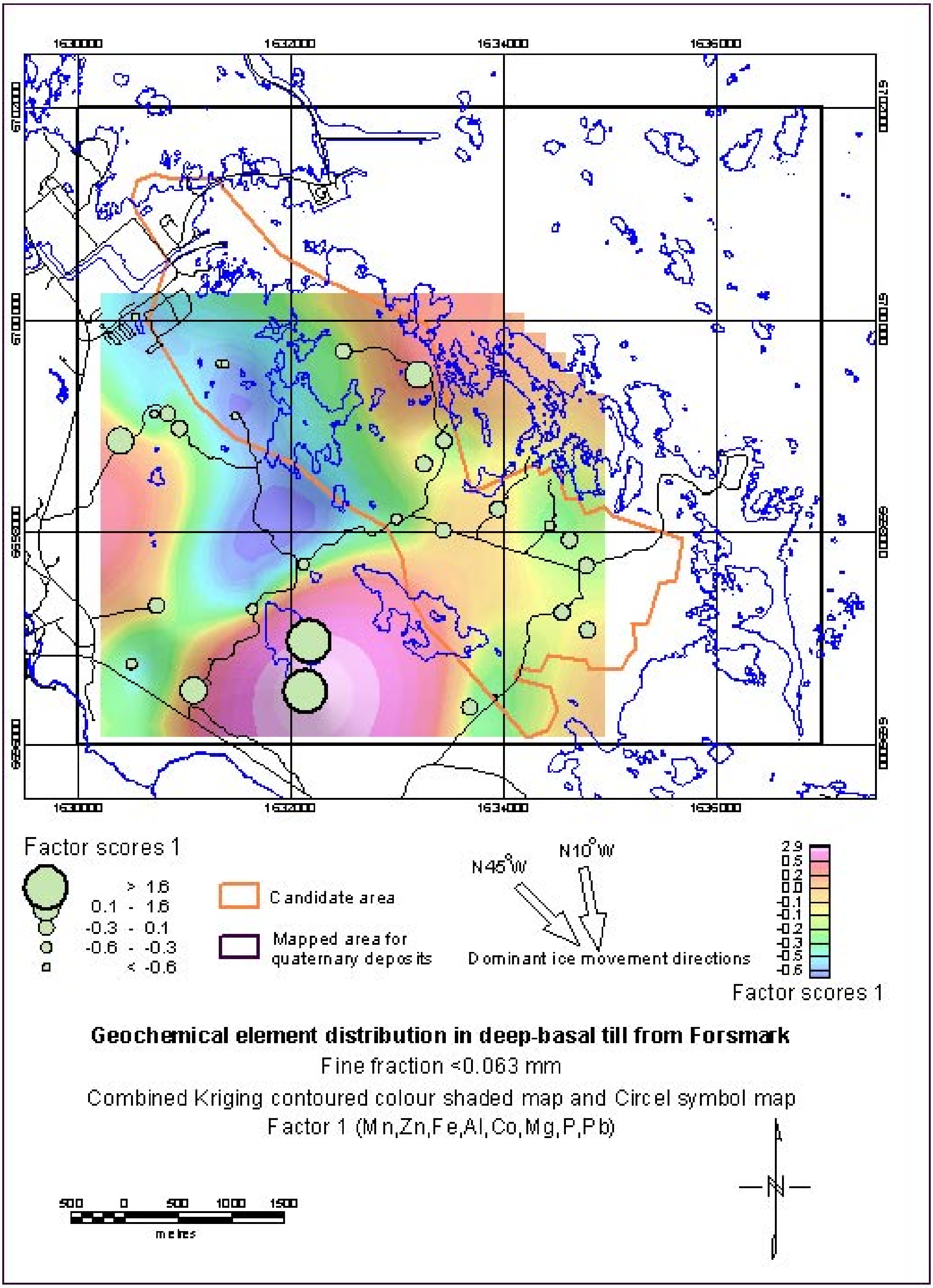


Appendix 9

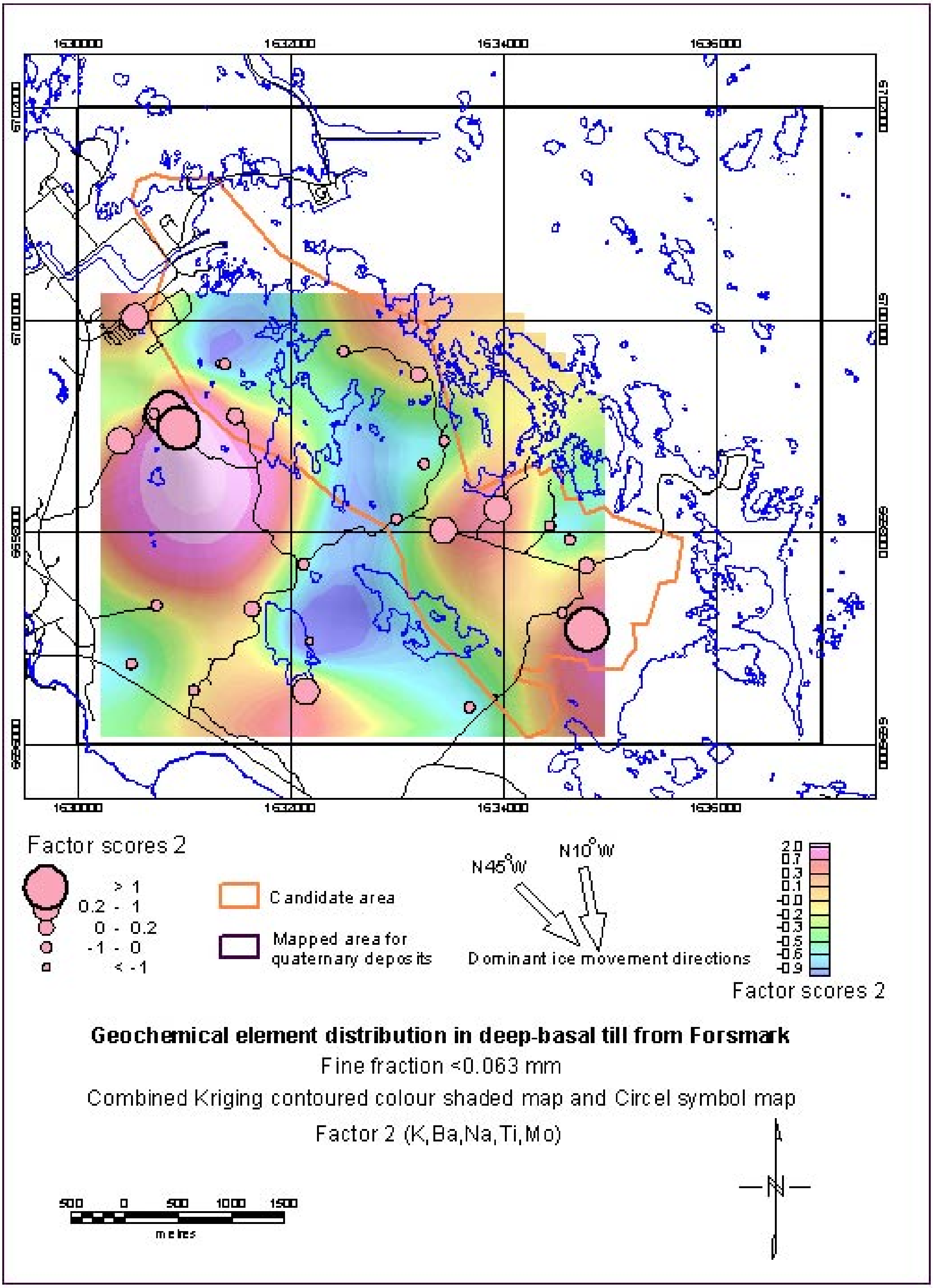
Combined contoured colour shaded map and circle map: gold (Au)



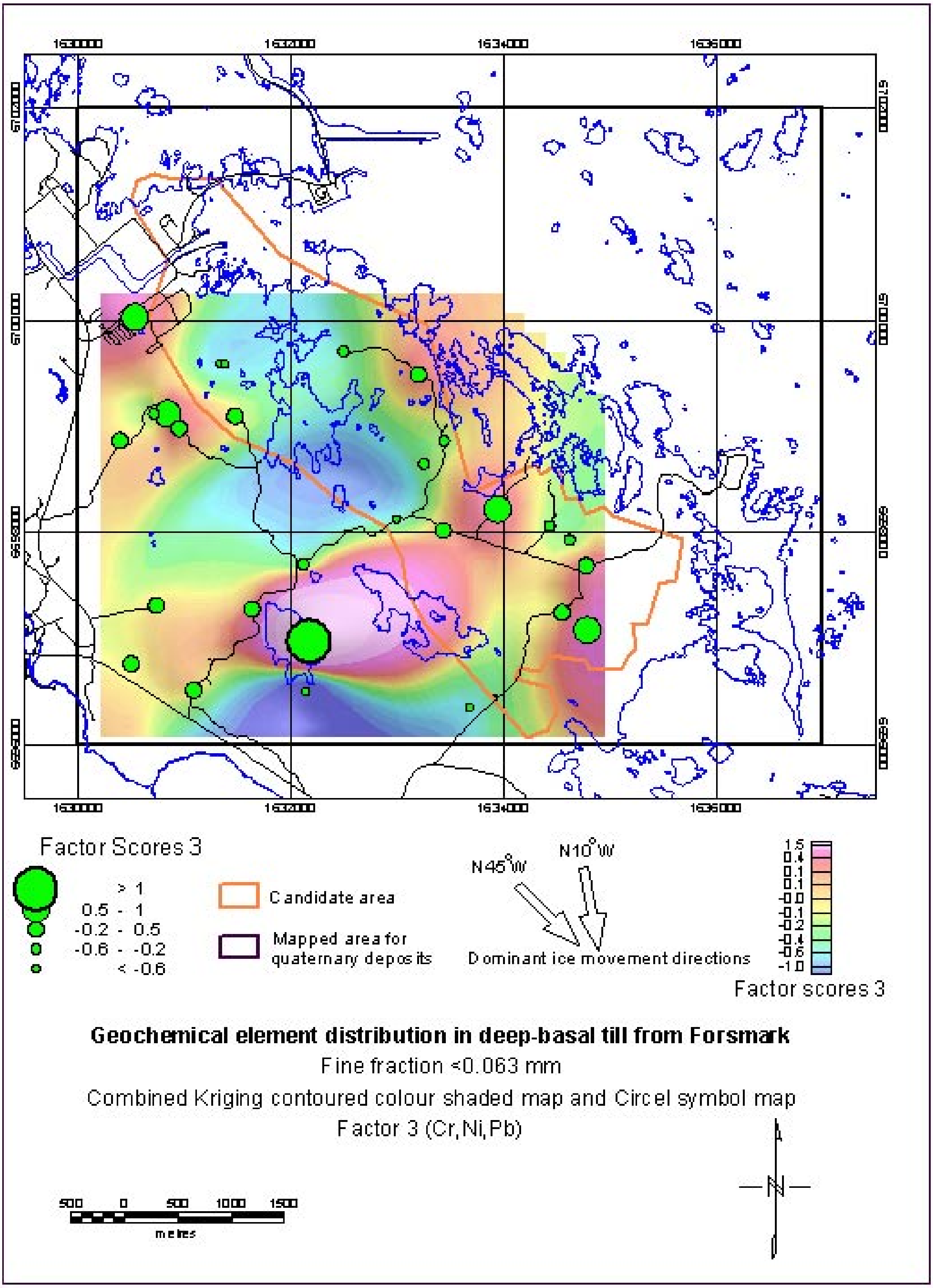
Combined contoured colour shaded map and circle map of factor score 1



Combined contoured colour shaded map and circle map of factor score 2

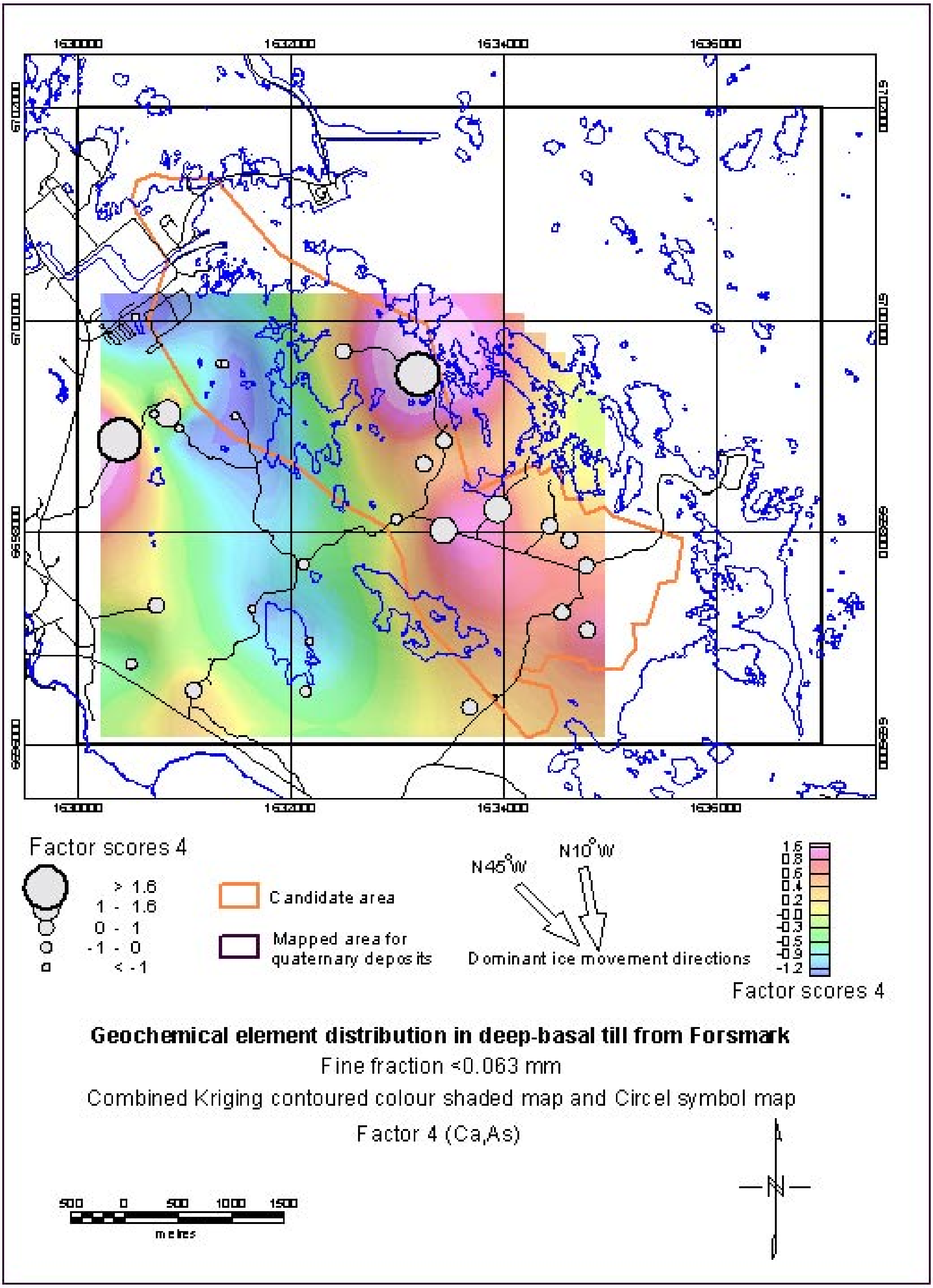


Combined contoured colour shaded map and circle map of factor score 3



Appendix 13

Combined contoured colour shaded map and circle map of factor score 4



Appendix 14

Table with factor loadings and variances of factor 1–4

Varimax factor loadings

	Factor 1	Factor 2	Factor 3	Factor 4	Commu-nality
Mn	0,983276306	0,064270087	-0,023557725	-0,14130354	0,991484597
Zn	0,973671273	0,106117989	0,142713822	-0,106504513	0,991007224
Fe	0,962684757	0,144168028	0,033996522	-0,220686627	0,997404714
Al	0,942627444	0,037623756	0,223253679	-0,225009513	0,990433533
Co	0,913053344	0,007424204	0,331614274	-0,217235186	0,990880682
Mg	0,886933133	-0,075874213	0,357357425	-0,26545121	0,990575955
P	0,734766092	0,378492653	-0,504597813	-0,113182909	0,950567224
Pb	0,650437115	-0,130284654	0,565296119	0,069192069	0,764389778
S	-0,345928333	-0,063446974	-0,083120172	0,016601697	0,13087651
K	-0,10501275	0,924368417	0,11767817	0,082305711	0,886107031
Ba	0,191458661	0,861792708	-0,11958343	0,010287325	0,793749116
Na	0,098761331	0,845621629	-0,078472624	-0,286222404	0,812910958
Ti	0,54653488	0,740102407	-0,240467768	-0,228023139	0,956271248
Mo	0,013080584	0,585533968	0,28553682	-0,562339625	0,740778259
Cu	0,344000719	0,368492229	0,221098515	0,168626778	0,331442561
Au	-0,127029368	0,241104339	0,15490402	0,097557926	0,107780567
Cr	0,401828782	0,047372788	0,843697732	-0,202105131	0,9163829
Ni	0,439872121	0,135200275	0,840570908	-0,096068105	0,92755513
Ca	-0,300997633	-0,338219129	-0,21584466	0,735107448	0,791963632
As	-0,174020582	0,201851059	0,026172153	0,724250429	0,596250679
La	0,316762521	0,308812661	-0,307427282	-0,35166449	0,413883202
Sum of Squares	7,500066752	3,875423543	2,697393025	1,999812161	16,07269548
Percent of Variance	35,71460358	18,45439782	12,84472869	9,522915053	76,53664514