Reconnaissance geochemical mapping of southern West Greenland from 62°30'N to 64°00'N – 1991 results

Peter Erfurt, Agnete Steenfelt
and Else Dam

Open File Series 91/9

December 1991

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Kalaallit Nunaanni Ujarassiortut Misissuisoqarfiat
GEOLOGICAL SURVEY OF GREENLAND

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Kalaallit Nunaanni Ujarassiortut Misissuisoqarfiat
GEOLOGICAL SURVEY OF GREENLAND

The Geological Survey of Greenland (GGU) is a research institute affiliated to the Mineral Resources Administration for Greenland (MRA) within the Danish Ministry of Energy. As with all other activities involving the non-living resources in Greenland, GGU's investigations are carried out within the framework of the policies decided jointly by the Greenland Home Rule Authority and the Danish State.

Open File Series

The Open File Series consists of unedited reports and maps that are made available quickly in limited numbers to the public. They are a non-permanent form of publication that may be cited as sources of information. Certain reports may be replaced later by edited versions.

Citation form

Open File Series Grønlands Geologiske Undersøgelse

conveniently abbreviated to:

Open File Ser. Grønlands geol. Unders.

GGU's Open File Series består af uredigerede rapporter og kort, som publiceres hurtigt og i et begrænset antal. Disse publikationer er midlertidige og kan anvendes som kildemateriale. Visse af rapporterne vil evt. senere blive erstattet af redigerede udgaver.

ISSN 0903-7322

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Open File Series 91/9

Reconnaissance geochemical mapping of southern West Greenland from 62°30' N to 64°00' N - 1991 results

Peter Erfurt, Agnete Steenfelt and Else Dam

December 1991

CONTENTS

ABSTRACT

The geochemical survey of the area from latitude 64°N to Frederikshåb Isblink (62°30'N) in southern West Greenland is based on the analysis (Au, As, Zn, Cu, Pb, Cr, Ni, Pt, Pd, Fe, Co, Na, Ba, Sc, Th, U, Ce, La, Nd, Eu, Lu, Yb) of 277 samples of fine fraction of stream sediment and 268 samples of stream water (conductivity, U and F). The results for noble and base metals, Cr, and REE are relevant to mineral exploration particularly with respect to gold. A large number of the geochemical anomalies are associated with occurrences of supracrustal rocks which appear to represent the most promising exploration target for Au. A possible target for PGE is indicated in the northeastern part of the Fiskenæsset layered anorthosite-gabbro complex.

The results are also relevant for the study of composition and structure of the Precambrian shield in Greenland.

INTRODUCTION

The work carried out from 64°N and southwards to Frederikshåbs Isblink is part of the Geological Survey of Greenland's (GGU's) geochemical mapping programme based on drainage samples. The purpose of the programme is to provide reconnaissance geochemical data which may be used together with geophysical and geological information to outline areas with a potential for mineral resources.

The samples were collected in several periods: 12th to 18th July and 15th to 19th August 1991 by P. Erfurt and K. Bollingberg Sørensen (1:250 000 topographic map sheets 63 V.1 and 63 V.2), and 18th July to 10th August by M. Lind, J. Sangstad and P. Erfurt (1:250 000 topographic map sheet 62 V.1). Sampling was conducted partly from the base camp Midgård situated some 16 km NNE of Fiskenæsset town and partly from camps in the Bjørnesund area (Fig. 1). A Bell 206 (Jet Ranger) helicopter was used for transportation.

The survey reported here was financed by the Mineral Resources Administration for Greenland (MRA) of the Danish Ministry of Energy. Administratively, the surveyed area belongs to the southern part of the municipality of Nuuk (Godthåb), the capital of Greenland.

PREVIOUS WORK

The study region is covered by a geological map in the scale 1:500 000 with description by Kalsbeek and Garde (1989) as well as by 5 geological maps in 1:100 000 scale with description for one of them by Chadwick & Coe (1983). During the eighties GGU carried out a stream sediment sampling programme mainly concerned with heavy mineral investigations in coastal areas and extensive tungsten occurrences in the northern Nuuk region have been described (Appel 1989, 1990). Limited exploration has been carried out by private sector companies outside the Fiskenæsset area (Fig. 1). Inside this area, considerable activity was centered on chromite occurrences and possible platinum mineralisation in a regional gabbro-anorthosite complex. A comprehensive list of released company reports, copies of which can be purchased at GGU, is included in Appel (1989).

Charter Consolidated Ltd. has performed diamond prospecting in large parts of West Greenland, mainly based on stream sediment sampling in selected areas. In 1972 the company participated in a joint programme with Renzy Mines Ltd. and Platinomino A/S in the Frederikshåb and Fiskenæsset areas. In 1977 sampling was performed under Charter's own concession in the Nuuk region,

including parts of the area under consideration in this report. The stream sediment samples were examined for diamonds and kimberlite indicator minerals, as well as analysed for base metals. A summary of kimberlite occurrences and investigations is given by Larsen (1991).

In 1985 Greenex A/S carried out reconnaissance geochemical prospecting in the Bjørnesund and Ravns Storø supracrustal rocks. The highest values recorded are 35 ppb Au and 2929 ppm Cu in stream sediment samples and 56 ppb Au in a chip sample.

GEOLOGY

General

Geologically, the area covered lies within the central part of the Archean gneiss complex of West Greenland. Except for local Proterozoic and Mesozoic dykes, the exposed rocks are Archean, comprising c. 80% granitoid gneisses, 10% supracrustals and 10% anorthosites and related rocks. A terrane model interpretation of the northern Nuuk region has been advocated by Friend et al. (1988, 1990) and Friend & Nutman (1991). These workers subdivide the region into three distinct crustal blocks (terranes) which were juxtaposed in the late Archean, the terrane boundaries being represented by mylonites or thrusts.

Two of the terranes recognised by Friend and Nutman (1991) are represented in the survey area. Rocks of the Tasiusarsuaq terrane comprise about 97%, the remaining 3%, west and north of Buksefjorden, belongs to the Akulleq terrane (Fig. 1).

The oldest rocks of the Tasiusarsuaq terrane are the supracrustal rocks occurring as large units enclosed by the gneisses throughout the block (Fig. 1). Similar supracrustal rocks in the Nuuk region were previously known under the term of Malene supracrustals (McGregor, 1969). In the light of the terrane model the "Malene"-type supracrustals of the different areas are now considered originally unrelated and of different age (Friend et al., 1988).

Within the Tasiusarsuaq terrane a layered gabbro-anorthosite complex, the Fiskenæsset complex, intruded the supracrustal rocks. The time of intrusion has been dated at 2860+/-50 Ma (Ashwal et al. 1989). Shortly after, the complex and the host supracrustals were intruded by large volumes of calc-alkaline granitoids (tonalites, granodiorites and granites) as sub-concordant sheets and larger complexes. The area was variously affected by metamorphism up to granulite facies at c. 2800 Ma ago, and at the same time a large porphyritic granite complex, the 'Ilivertalik granite', was emplaced into the

gneisses in the central part of the survey area (Pidgeon & Kalsbeek, 1978; Fig. 1). Hence, most of the tectonic evolution of the Fiskenæsset region apparently took place within a short time span (Kalsbeek & Garde, 1989) before the assembly of the different terranes in the late Archean, post-2750 Ma (Friend & Nutman, 1991). Late granitic sheets intruded into the Ravns Storø supracrustal belt at c. 2660 Ma (Pidgeon & Kalsbeek, 1978).

Further descriptions of the rock units most likely to have an economic potential, namely the anorthosites and the supracrustal rocks, are given below.

The Fiskenæsset complex

This comprises a deformed and metamorphosed sheet-like layered anorthosite-gabbro intrusion occurring as thin layers and trains of inclusions within the gneisses. The sheets have an average thickness of 380 m and a total strike length of more than 200 km (Ghisler, 1976). The intrusion was divided into seven major lithostratigraphic units by Myers (1985). In ascending order these are: the Lower gabbro (50 m), Ultramafic (40 m), Lower leucogabbro (50 m), Middle gabbro (40 m), Upper leucogabbro (60 m), Anorthosite (250m) and Upper gabbro (50 m) units.

Deformation was locally heterogeneous, and all stages can be seen from undeformed to very strongly deformed rocks. Recrystallisation took place at both granulite and amphibolite facies, and most rocks have equigranular textures. Locally igneous structures and cumulate textures are preserved. Myers (1985) suggests that the major part of the Fiskenæsset complex formed by crystal fractionation and gravity settling of individual cumulus crystals (olivine, pyroxene, plagioclase and chromite), clusters of plagioclase crystals and giant poikilitic pyroxene crystals (enclosing plagioclase). The influx of three successive pulses of tholeiitic magma seems involved in the formation of the complex (Myers, 1985) which has the average chemical composition of a calcic high-alumina leucogabbro with olivine-tholeiitic affinities (Ghisler, 1976; Weaver et al., 1981).

Chromite and chromitite rock (strictly defined, chromitite is a monomineralic rock consisting of chromite, but here it denotes a rock with chromite as a major phase) are mainly confined to the Upper leucogabbro and Anorthosite units. By far the major part is concentrated in the latter unit where chromite concentrations occur as discontinuous layers and lenses usually between 0.5 and 3 m thick (Myers, 1985). A maximum thickness of 20 m is reached locally, mainly as a result of tectonic thickening. Two main types of chromitite are distinguished by Ghisler (1976):

Augen chromitite, which is the most common type, comprises spotted rocks consisting of white plagioclase in a black host of chromite and hornblende, the latter often altered to biotite. The plagioclase augen, usually 0.5 to 2 cm in size, consist mostly of a mosaic textured mass of grains 1-2 mm across, but single crystal augen occur. The cumulus plagioclase can dominate the rock, making up as much as 80%, reducing the chromite content to about 10%.

Hornblende chromitite usually forms layers 0.5 to a few cms thick. Horizons containing this rock are generally composed of several tens of hornblende chromitite layers with an equal number of anorthosite layers of similar thickness, but plagioclase-free seams of almost massive chromite and hornblende up to 1 m thick are found at several localities. The hornblende-chromitite is nearly always fine-grained and appears black, massive and homogeneous, with hornblende often partly altered to biotite.

All gradations between the two types are found. The chromitites are variably deformed, the end product of progressive deformation being a schistose chromitite with distinct metamorphic banding (Ghisler, 1976). As a result of hydrothermal alteration secondary minerals such as fuchsite and chrome-epidote were formed.

The chromitite associated with anorthosite contains visible sulphide in rare cases. A bulk sample with 0.8% sulphides had a concentration of 0.35% Ni, 0.11% Cu, 4 ppm Au and 31 ppm Ag in the sulphide phase (Ghisler, 1976). Sulphide showings are found throughout the complex, the largest amount in association with ultramafic rocks. The sulphides are commonly pyrrhotite, chalcopyrite and pentlandite. Mineralised ultramafics on average contain 0.1-0.3% Cu and 0.1-0.2% Ni. Generally, the Fiskenæsset chromite occurrences have a striking similarity to the Sittampundi chromite deposits, with respect to geology, mineralogy and chemistry (Ghisler, 1976). However, there are also similarities to the Merensky reef chromites of the Bushveld complex, in particular with respect to Cr/Fe ratios. For this reason some analyses for platinum group elements (PGE) have been made on Fiskenæsset rocks. The highest PGE-values recorded are from a hornblende peridotite which over a few metres is mineralised with 1-5% disseminated sulphides. One grab sample with 0.54% Cu and 0.13% Ni contained 0.4 ppm Pt, 2.0 ppm Pd, 0.03 ppm Rh, 0.2 ppm Au and 2.7 ppm Ag (Ghisler, 1976). Page et al. (1980) investigated the contents of some PGE in relation to primary stratigraphy, and concluded that the highest values (310 ppb Pt, 175 ppb Pd and 220 ppb Rh in their investigation, which concerned geochemistry and not exploration) occurred in thin, lenticular ultramafic channel deposits in the upper part of the Lower leucogabbro unit and throughout the Middle gabbro unit. The channel deposits were formed by

magmatic currents which were believed to act as important carriers and concentrators of PGE. Chromitites in general had low PGE-values, except were they appeared to be channel deposits within the Upper leucogabbro unit (Page et al., 1980). The chromite occurrences of the Fiskenæsset complex constitute a large uneconomic low-grade deposit ranging in the order of a 100 million tonnes of "ore", on the average containing 14% Cr_2O_3.

The supracrustal rocks

The lithology of the supracrustal rocks varies considerably from north to south in the survey region. The area between the eastern part of Buksefjorden and Sermilik (Fig. 1) described by Chadwick and Coe (1983), and the Ravns Storø supracrustal belt described by Friend (1975) serve to illustrate the lithological diversity.

Chadwick & Coe (1983) divide the the supracrustal rocks in the Buksefjorden area into an eastern and a western part. The boundary between the two parts coincides with the terrane boundary of Friend & Nutman (1991). The western part of the supracrustals lies within the Akulleq terrane, the eastern part within the Tasiusarsuaq terrane. Lithological variation is greater in the western part and only a few of the metasedimentary units known from there occur in the eastern part. Sedimentary rocks were not a significant part of the eastern succession which is dominated by both homogeneous and banded amphibolites with ultramafic rocks and rare paragneisses occurring as small enclaves (Chadwick & Coe, 1983). From Buksefjorden south to Sermilik the amphibolites are mainly metagabbros and metabasites. Diopside-hornblende-plagioclase ± quartz ± garnet is a common assemblage. Boudinaged lenses of calc-silicate rocks are also present. On the north coast of Sermilik a supracrustal sequence shows more varied lithology. It includes garnet-clinopyroxene-hornblende banded rock in layers up to 100 m thick resembling deformed pillow rocks (Friend et al., 1981), garnet-sillimanite-plagioclase-biotite metasediments interlayered with metabasite and clinopyroxenite, and grey marble with thin layers of quartzite presumed to represent original bedding. Megacrystic metagabbro with abundant plagioclase-rich aggregates are also present.

The Ravns Storø supracrustal belt (Andersen & Friend, 1973; Friend, 1975; Fig. 1) is up to 4.5 km wide and dominated by different types of amphibolites, with subordinate metasediments and leucocratic schists of uncertain origin. Relatively undeformed primary structures such as pillows and agglomerates can be recognised at places, with transitional deformation to completely metamorphic textured rocks. Friend (1975) divided the main part of the Ravns

Storø belt stratigraphically into two parts, the Ikatoq and Ikatup units.

The Ikatoq unit consists of hornblende porphyroblastic amphibolites concordantly interlayered with up to 30 cm thick irregular, boudinaged horizons of metasediments, and with two types of pale grey leucocratic schists. The latter comprise staurolite-cordierite rocks with anthophyllite, plagioclase and quartz constituting the other main phases, and anthophyllite-cummingtonite schists with plagioclase plus minor quartz and garnet. The hornblende porphyroblastic amphibolites may be regarded as sills. The leucocratic schists and metasediments intruded by these may be seen as a suite displaying a primary depositional composition variation in the scale of from a few centimetres to 2 metres (B. Chadwick pers. comm., 1991). The sequence grades into hornblende porphyroblastic amphibolites containing reddish brown weathering tremolite-rich ultramafic bodies ranging in size from a few metres to lengths of about 500 metres (Friend, 1975).

The Ikatup unit consists of a layered amphibolite series partly intrusive in origin, and a series of rocks dominated by pillow lavas. The layered amphibolites are c. 220 m thick and, apart from minor pillow lavas and leucocratic schists, consist of seven cycles of ultramafic to mafic rocks. Each cycle grades from pale green tremolite schist to a more "typical" amphibolite, with the introduction of plagioclase and hornblende at the expense of tremolite. The pillow lava series is 300-500 m thick and formed of several sub-units. The relatively less-deformed pillows are uniformly grey and commonly measure 30x15 cm. They consist of a plagioclase-rich core with specks of black hornblende and a mafic hornblende-rich margin. The interpillow material is a dark grey hornblende amphibolite. With increasing metamorphism the pillows become yellow-green as plagioclase is converted to epidote, and with increasing deformation the pillows are destroyed, resulting in the formation of grey and grey/yellow-green banded amphibolites.

Agglomerates are associated with the pillow lavas. They consist of variously shaped blocks, usually 10-15 cm in size, set in a grey amphibolite matrix. The fragments consist partly of broken-up pillows similar in mineralogy to the pillow cores and partly of wholly felsic material. The felsic agglomerate fragments are of unknown origin, there are no major similar stratigraphic horizons in the area (Friend, 1975).

The value of the stratigraphy suggested by Friend (1975) is questioned by B. Chadwick (pers. comm.) after the 1991 field work in the area. The deformation and metamorphism have almost obliterated the original stratigraphy, and even in the best preserved pillow structures the state of strain is such that unambiguous way-up criteria are not evident.

According to B. Chadwick (pers. comm. 1991) the supracrustal association may include sheets of rocks of widely different ages and tectonic setting brought together by major Archean tectonic displacements.

Friend (1975) and Friend et al. (1981) relate the Ravns Storø supracrustal rocks to an oceanic environment where the amphibolites originally were erupted as submarine volcanic rocks, intruded by gabbros. The rocks have, allowing for the high MgO content of early Archean crust, typical low-K tholeiitic compositions, as found in modern mid-oceanic basalts. This affinity, however, is also found in basalts of modern marginal basins. Seen in conjunction with the occurrence of metasediments and felsic agglomerate clasts of unknown provenance, some sort of back-arc formational environment may be suggested for the Ravns Storø belt. Although highly speculative, and contrary to Friend (1975), it links the supracrustal belt to the model favoured by Windley (1984) for Archean greenstone belts.

The leucocratic schists are compositionally very different from the other supracrustal rocks. They have SiO_2-contents ranging from c. 50-75%, and for a specific SiO_2-value chosen, they have too low K_2O-contents and too high Na_2O and/or $MgO/Fe_2O_3/TiO_2$-contents to clearly represent either metasediments, rhyolites or other volcanic rocks. A possible explanation is that the leucocratic schists are metamorphosed equivalents of hydrothermally altered volcanic rocks or exhalites (Beeson, 1988).

PHYSIOGRAPHY AND CLIMATE

The relief of the surveyed region varies considerably. A western coastal belt with poorly developed drainage comprises about one-fifth of the region. The elevations range from 0 to 300 m and the northern part of the belt is almost flat terrain, while low ridges striking roughly NE-SW and reflecting geological structure predominate in the southern part. In the inland and remaining four-fifths of the region, drainage is well developed due to the mountainous alpine-like terrain with high relief and an elevation ranging from 0 to 1800 m, with an average of about 600 m. Erosion rate is high due to the seemingly perennial (except for the winter freeze) nature of most streams, of which many drain ice/snow fields.

In the general area, temperatures below freezing prevail from October to April and temperatures above freezing from May to September. The annual mean temperature (-1.0 °C in the central coastal part of the area) is too high for permafrost to occur at sea level. Average temperatures will decrease with elevation by about -6 to -10 deg/km, but summer temperatures may also increase

inland from the coast due to "continentality" (Braithwaite, 1991). Discontinuous permafrost may occur at higher elevations. The mean annual precipitation in the area is high, c. 765 mm, fairly evenly divided between winter and summer. Most precipitation from October to April is snow, the main snowmelt occurs in May.

The 1990/91 season was fairly normal in the surveyed area with regard to temperatures and precipitation, and consequently runoff and stream sediment transport probably occurred on an average level.

The meltwater from the Inland Ice cap drains through narrow canyons and/or large lakes into fjords dissecting the landscape. Glaciers protuding from the main ice cap at places drain directly into fjords, e.g the Sermeq glacier (Fig. 1). Valleys and gentle slopes are generally covered with till and talus, and marine deposits occur inland at the mouths of some larger rivers. Older and recent moraines, as well as glaciofluvial deposits, cover large parts of areas close to the Inland Ice.

The vegetation cover (herbs, low scrub, grass) is moderate in the coastal low relief area and the bedrock exposure is about 25-30 %, best where ridges dominate the landscape. Inland, the exposure is generally 50-60 %, except in larger broad valleys which tend to support vegetation.

SAMPLING

The 277 sample sites in the surveyed area are distributed over 7500 km^2, giving an average sampling density of 1 site per 27 km^2. In the northern part the sampling of 197 sites by P. Erfurt and K. Bollingberg Sørensen was performed during 12 days using 33 helicopter hours. About 10 flying minutes were spent per sampling site, corresponding to 22 seconds per square km. The remaining 80 stream sediment and water samples were chosen from 227 sites sampled with higher density as part of more detailed work in the Bjørnesund region.

The sites were selected prior to the field season and marked on areal photographs using principles of even distribution of the sites, a reasonable size of upstream drainage area, and a reasonable slope dip. Large ice/snow covered domains in the eastern part of the region made compromise necessary on the even site distribution principle.

At each sample site about 500 g of stream sediment were collected in a paper bag and 100 ml of stream water in a polyethylene bottle. The radioactivity (total gamma radiation) was measured on the surface of outcrops or stream boulders using a Scintillometer (Table 1). At one site the stream

was dry and no water was sampled; at several other sites radiation measurement was impossible due to lack of nearby outcrops or locally derived boulders in streams. Each stream sediment sample was composed of subsamples from 4 to 8 different locations of sand and silt deposits in the stream beds or banks, thus ensuring representative sampling. Duplicate samples of both sediment and water were collected at 15 sites which corresponds to 5.4% of the total of 277.

SAMPLE PREPARATION AND ANALYSIS

Sediment

The sample bags were air/sun dried in the base camp and then sent by ship to Denmark, where at GGU they were further dried at 65°C and sieved into three grain size fractions using sieve apertures of 1mm and 0.1mm. The coarse fraction was discarded, the medium fraction archived and the fine fraction used for analysis. All samples were analysed for trace and some major elements at Activation Laboratories Ltd., Canada, by instrumental neutron activation (INAA). 104 samples (from regional and detailed surveys) were analysed for Au, Pt and Pd by fire assay combined with inductively coupled plasma emission spectrometry (ICP-ES), and 48 samples were analysed for Pb, Cu and Zn by aqua regia digestion and atomic absorption spectrophotometry (AAS). Table 2 lists the elements analysed for, and the analytical detection limits of the elements considered relevant to present in this report.

Water

The water samples (unfiltered and unacidified) were sent by ship to Denmark. At GGU they were stored for 2 months before analysis. The conductivity and fluoride concentration were measured by means of conductivity-meter and ion-sensitive electrode. The remaining 60 ml of each sample was analysed for uranium by laser-induced scintillometry (Table 1).

DATA PRESENTATION

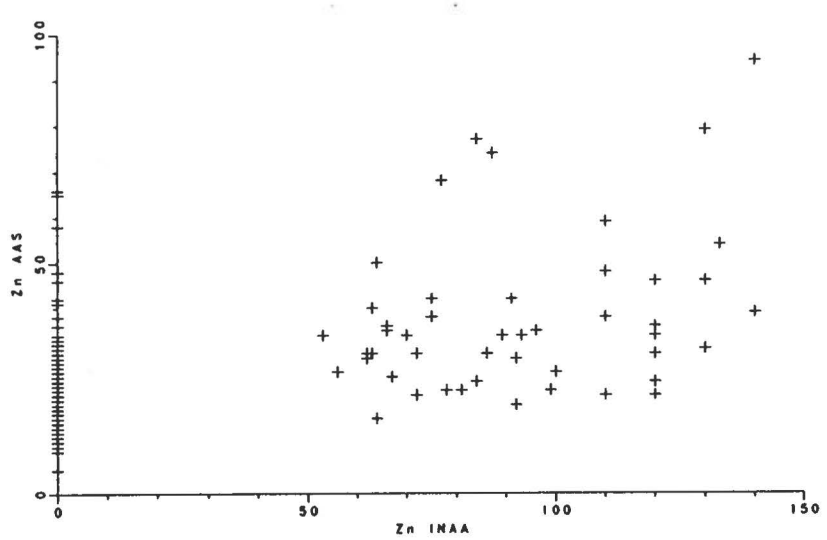
The analytical results are presented in this report as element distribution maps at 1:1 000 000 scale together with summary statistical parameters and histograms of the frequency distribution for each element, Fig. 2 to 29. The size of a dot is related to the element concentration of the sample as indicated below the histogram. In cases where the frequency distribution approximates log-normal the maximum dot size corresponds to the 98th percentile of the distribution, otherwise the scaling is chosen so as to

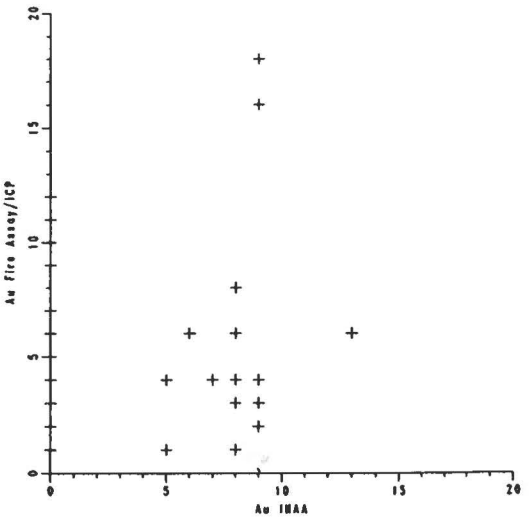
reflect variations in the geochemical background as clearly as possible. Maximum values are shown in the statistical parameters in the figures, and values regarded as geochemical anomalies are shown on the interpretation map, Fig. 30.

The detection limits for the elements Zn (by INAA), Ni, As, Au, Pt and Pd are high in relation to the general abundance of the elements in the samples. In the data files concentrations below detection limits are registered as zero and this truncates the frequency distributions. Hence, the medians and means as they are given in the Figs for the above elements are not representative.

The analytical results for Zn determined by INAA and AAS, respectively, in 136 samples, are poorly correlated (see left diagram below). The INAA values are significantly higher than the corresponding AAS values. As AAS-analysis for Zn is generally regarded as very reliable, it is concluded that the INAA determinations are generally too high and inaccurate.

There is also a poor correlation between the values for Au determined by INAA and Fire Assay/ICP, respectively (see right diagram below). However, this is expected because the analytical results at the ppb-level is influenced by the presence or absence of individual gold grains in the samples. When the samples are split before analysis the limited number of gold grains are not likely to be evenly distributed between the two aliquots submitted to the two different types of analysis. Altogether, Au analysis of small amounts of material can only be regarded as semiquantitative, and the geographical distribution of gold-containing samples is more significant as an indicator of mineralisation than small differences in the actual analytical values.





DISCUSSION AND PRELIMINARY INTERPRETATION

Elements indicating mineralisation

The location of samples with high contents of metals considered to be indicative of mineralisation is shown on Fig. 30.

Gold (Figs. 2 & 3). The majority of the gold values are below 5 ppb. Most of the gold values above 12 ppb (Fig. 30) can be related to outcropping metavolcanic rocks. A few raised Au values are associated with the Fiskenæsset complex, possibly ultramafic units, and the two highest values (the northern representing 200 ppb, the southern 42 ppb) are apparently associated with gneisses. However, the 200 ppb sample was taken from a stream that runs through gneisses with thin (200 m) bands of mafic and leucocratic amphibolite. The 42 ppb sample is from faulted gneiss with amphibolitic enclaves.

Arsenic (Fig. 4). In general, As may be an indicator of gold mineralisation. However, in this survey the values obtained are generally below the detection limit (2 ppm), and the few samples with slightly higher values (up to 7 ppm) are not regarded to be significant. They may be related to amphibolites or mafic enclaves in gneisses.

Zinc, copper, lead (Figs. 5,6,7 & 8). The higher Zn and Cu values indicate mineralisation in the Bjørnesund and Ravns Storø supracrustal belts. In ultramafic rocks of the Fiskenæsset complex, and in associated amphibolites, weak sphalerite and chalcopyrite mineralisation occurs (Ghisler, 1976). This possibly accounts for the raised levels of Zn and Cu in some areas underlain by these rocks. Values of Pb are low and do not indicate significant mineralisation. The highest values appear to be derived from supracrustal rocks. As shown above caution is advised regarding the INAA Zn analyses.

Chrome (Fig. 9). High values of Cr are encountered in samples from streams draining the southwestern part of the Fiskenæsset complex, thus reflecting the known chromite mineralisation (Ghisler, 1976). The lower Cr values in the northeastern part of the complex suggest less intense mineralisation in that area.

Nickel (Fig. 10). Scattered high Ni values are derived from ultramafic rocks in the Fiskenæsset complex as well as from ultramafic enclaves in gabbroic amphibolites elsewhere.

Platinum & Palladium (Figs. 11 & 12). These elements have very low concentrations in the samples, and the few values of Pt above the detection limit (up to 8 ppb) are mainly derived from the northeastern part of the

Fiskenæsset complex, whereas samples with Pd up to 10 ppb are scattered over both the Fiskenæsset complex and the supracrustal rocks.

Uranium (Figs 19 and 27). Most samples have low U values, but in the southern part of the study region a number of samples with very high U values (30-200 ppm in stream sediments 0.15 - 0.25 ppb in stream water) indicate mineralisation possibly in the form of uraninite or other (soluble) U-bearing minerals associated with pegmatites which occur in amphibolite layers and lenses in the gneisses.

A single sample in the northernmost part of the study region (64°00'N, 49°43'W) has very high concentrations of Ba, REE (see maximum values in corresponding Figs.), fairly high Ta, Th and U, and also contains Au, As, and Sb. The conductivity and fluoride concentration of the corresponding stream water is also high. The element association suggests that the sampled stream drains a carbonatitic rock unit. The relatively high REE contents and the U anomaly (78 ppm in sediment and 0.13 ppb in water) in samples to the west may likewise reflect the presence of carbonatitic or alkaline rocks.

Element distribution reflecting lithological association

Some of the element distribution patterns reflect and characterise known lithological units of the study region and other provide information on regional geochemical variation which appear unrelated to mapped rock units.

The distribution of elevated Co and Sc reflects the occurrences of amphibolites of both volcanic and plutonic origin in the entire area. Supracrustal rocks, in general, are reflected by high levels of stream water conductivity (Fig. 29), possibly because their permeability is higher than it is in the gneisses. The anorthosites of the Fiskenæsset intrusive complex, as mentioned, are reflected by high Cr (and Pt).

The distribution of Na, Th, U, and REE is not readily related to a particular rock unit or association and is believed to mainly reflect variations in the gneisses. High concentrations of Na characterise the region southeast of Bjørnesund and possibly indicate increased proportions of albite in the samples derived from the supracrustal rocks as well as from the surrounding gneisses. Outside the uranium anomalous districts (probably pegmatites or late granites) the geochemical background variation for U and Th can be related to the metamorphic grade according to previous investigations using stream sediment (Kalsbeek, 1974; Steenfelt and Dam, 1991) and general ideas about crustal differentiation of incompatible elements. The generally low contents of U and Th in the western and northern part of the region agree with the predominance of high metamorphic grades, up to granulite

facies (Kalsbeek & Garde, 1989). The eastern part of the area between 63°10'N and 63°30'N is characterised by elevated Th and LREE (La, Ce, Nd) including Eu, scattered slightly elevated U values, and low level of HREE (Yb, Lu). This suggests a change upwards in crustal level from west to east. The higher crustal level in the east is also supported by the presence of fluoride (believed to be derived from high-level granites) in some of the streams.

CONCLUSION

The geochemical survey of the region between 62°30'N and 64°00'N has delineated areas of interest regarding mineralisation potential: Indications of gold and base metal mineralisation are mostly found in the Bjørnesund and Ravns Storø supracrustal belts, although the largest single Au values seem associated with smaller supracrustal rock outcrops within gneisses north of Fiskenæsset. Raised values of noble metals together with high Cr and Ni also relate to rocks of the Fiskenæsset complex.

High values of particularly REE, Ba, U and Th suggests the presence of carbonatite or alkaline rocks in the extreme northern part of the study region. In the central part of the region, the variations in lithophile elements indicate a westward change from higher to lower crustal level.

ACKNOWLEDGEMENTS

The authors thank I. Rytved for sample processing, J. Halskov for drafting, M.S. Jørgensen for sample site digitalisation and P. Dawes and P. Appel for making helpful suggestions improving the manuscript.

REFERENCES

Andersen, L.S. & Friend, C.R.L. 1973: Structure of the Ravns Storø amphibolite belt in the Fiskenæsset region. Rapp. Grønlands Unders. 85, 50-54.

Appel, P.W.U. 1989: Investigations of heavy mineral concentrates from stream sediment samples collected during the period 1982 to 1986 in the Nuuk area, West Greenland. Open File Ser. Grønlands geol. Unders. 89/1, 17 pp.

Appel, P.W.U. 1990: Tungsten mineralization in the Nuuk region, West Greenland. Open File Ser. Grønlands geol. Unders. 90/4 51 pp.

Ashwal, L.D., Jacobsen, S.B., Myers, J.S., Kalsbeek, F. & Goldstein, S.J. 1989: Sm-Nd age of the Fiskenæsset anorthosite complex, West Greenland. Earth and Planet. Sci. Lett. 91, 261-270.

Beeson, R. 1988: Identification of cordierite-anthophyllite rock types associated with sulphide deposits of copper, lead and zinc. Trans. Instn Min. Metall. (Sect. B: Appl. Earth Sci.) 97, B108-B115.

Braithwaite, R.J. 1991: Temperature and precipitation climate between Paamiut and Nuuk, West Greenland. Internal Note, Grønlands geol. Unders.

Chadwick, B. & Coe, K. 1983: Descriptive text to Geological map of Greenland 1:000 000 Buksefjorden 63 V.1 Nord. The regional geology of a segment of the Archaean block of southern West Greenland. Grønlands geol. Unders., 70 pp.

Friend, C.R.L. 1975: The geology and geochemistry of the pre-Ketilidian basement complex in the Ravns Storø area, Fiskenæsset region, Southern West Greenland. Unpublished Ph.D thesis, Univ. London, 245 pp.

Friend, C.R.L., Hall, R.P. & Hughes, D.J. 1981: The geochemistry of the Malene (Mid-Archean) ultramafic-mafic amphibolite suite, southern West Greenland. Spec. Publs geol. Soc. Aust. 7, 301-312.

Friend, C.R.L., Nutman, A.P. & McGregor, V.R. 1988: Late Archean terrane accretion in the Godthåb region, southern West Greenland. Nature 335, 535-538.

Friend, C.R.L., McGregor, V.R. & Nutman, A.P. 1990: Late Archean crustal evolution in the Nuuk region of southern West Greenland. In Glover, J.E. and Ho, S.E. (ed.): Third International Arhaean symposium, Perth 1990, Extended abstr. vol., 253-255.

Friend, C.R.L. & Nutman, A.P. 1991: Refolded nappes formed during late Archean terrane assembly, Godthåbsfjord, southern West Greenland. J. Geol. Soc. Lond. 148, 507-519.

Ghisler, M. 1976: The Geology, Mineralogy and Geochemistry of the Pre-Orogenic Archaean Stratiform Chromite Deposits at Fiskenæsset, West Greenland. Monogr. Series miner. Deposits 14, 156 pp.

Kalsbeek, F. 1974: U, Th and K contents and metamorphism of the Archaean rocks from South-West Greenland. Bull. Geol. Soc. Denmark 23, 124-129.

Kalsbeek, F. & Myers, J.S. 1973: The geology of the Fiskenæsset region. Rapp. Grønlands geol. Unders. 51, 5-18.

Kalsbeek, F. & Garde, A. 1989: Geological map of Greenland 1:500 000, sheet 2, Frederikshåb Isblink - Søndre Strømfjord, descriptive text. 36 pp, Copenhagen: Geological Survey of Greenland.

Larsen, L.M. 1991: Occurrence of kimberlite, lamproite and ultramafic lamprophyre in Greenland. Open File Ser. Grønlands geol. Unders. 91/2, 36 pp.

McGregor, V.R. 1969: Early Precambrian geology of the Godthåb area. Rapp. Grønlands geol Unders. 19, 28-30.

Myers, J.S. 1974: Acid and intermediate intrusions, deformation and gneiss formation, north-east of Fiskenæsset. Rapp. Grønlands geol. Unders. 73, 7-15.

Myers, J.S. 1985: Stratigraphy and structure of the Fiskenæsset complex, southern West Greenland. Bull. Grønlands geol. Unders. 150, 72 pp.

Page, N.J., Myers, J.S., Haffty, J., Simon, F.O. & Aruscavage, P.J. 1980: Platinum, Palladium and Rhodium in the Fiskenæsset complex, southwestern Greenland. Econ. Geol. 75, 907-915

Pidgeon, R.T. & Kalsbeek, F. 1978: Dating of igneous and metamorphic events in the Fiskenæsset region of southern West Greenland. Can. J. Earth Sci. 15, 2021-2025.

Steenfelt, A. & Dam, E. 1991: Reconnaissance geochemical exploration of map sheet 67 V 2 (67° to 68°N, 49°30' to 52°W), West Greenland. Open File Ser. Grønlands geol. Unders. 91/8, 13 pp.

Weaver, B.L., Tarney, J. & Windley, B.F. 1981: Geochemistry and petrogenesis of the Fiskenaesset anorthosite complex, southern West Greenland: nature of parental magma. Geochim. cosmochim. Acta 45, 711-725.

Windley, B.F. 1984: The evolving continents, 2nd Edition. New York: John Wiley & Sons, 399 pp.

Company reports available for inspection at GGU:

Brunet, J.E.: Report on the investigation of Western Greenland 1977. Charter Consolidated Limited internal report, 12 pp, 3 appendices, 16 maps.

Christensen, K.: Greenex' Prospecting 1985. Rapport nr. 4-85. Internal report, Greenex A/S, 21 pp.

Table 1. Instrumentation at the Geological Survey of Greenland.

Field measurement of gamma radiation: Saphymo-Srat SPP-2 scintillometer.
Water samples:
Conductivity: Chemotest JK 8800
Fluoride concentration: Orion EA 920 pH/ion analyzer
Uranium concentration: Scintrex UA-3 Uranium Analyzer

Table 2. Analyses and detection limits. All analyses by Activation Laboratories Ltd.

All samples were analysed for the following elements:
Au Ag As Ba Br Ca Co Cr Cs Fe Hf Hg Ir Mo Na Ni Rb Sb
Sc Se Sn Sr Ta Th U W Zn La Ce Nd Sm Eu Tb Yb Lu
104 samples related to rocks of the Fiskenæsset complex and supracrustal rocks were separately analysed for Au, Pt and Pd, and 48 samples related to supracrustal rocks for Pb, Zn and Cu. The following elements had analyses below detection limits, or were elements of little mineral resources/regional geological importance having uniformly low concentrations:
Ag Cs Hg Ir Mo Se Sn Sr Sb W Tb Sm Ta Br Hf Rb
These are not considered further, the analyses are available at GGU.
Detection limits:
INAA
Au 1ppb As 2ppm Ba 100ppm Ca 1% Co 5ppm Cr 10 ppm Fe 0.02%
Na 500ppm Ni 50ppm Sc 0.1ppm Th 0.5ppm U 0.5ppm Zn 50ppm
La 1ppm Ce 3ppm Nd 5ppm Eu 0.2ppm Lu 0.05ppm Yb 0.05ppm
ICP-ES
Au 1ppb Pt 5ppb Pd 2ppb
AAS
Pb 1ppm Zn 1ppm Cu 1ppm

LIST OF FIGURES

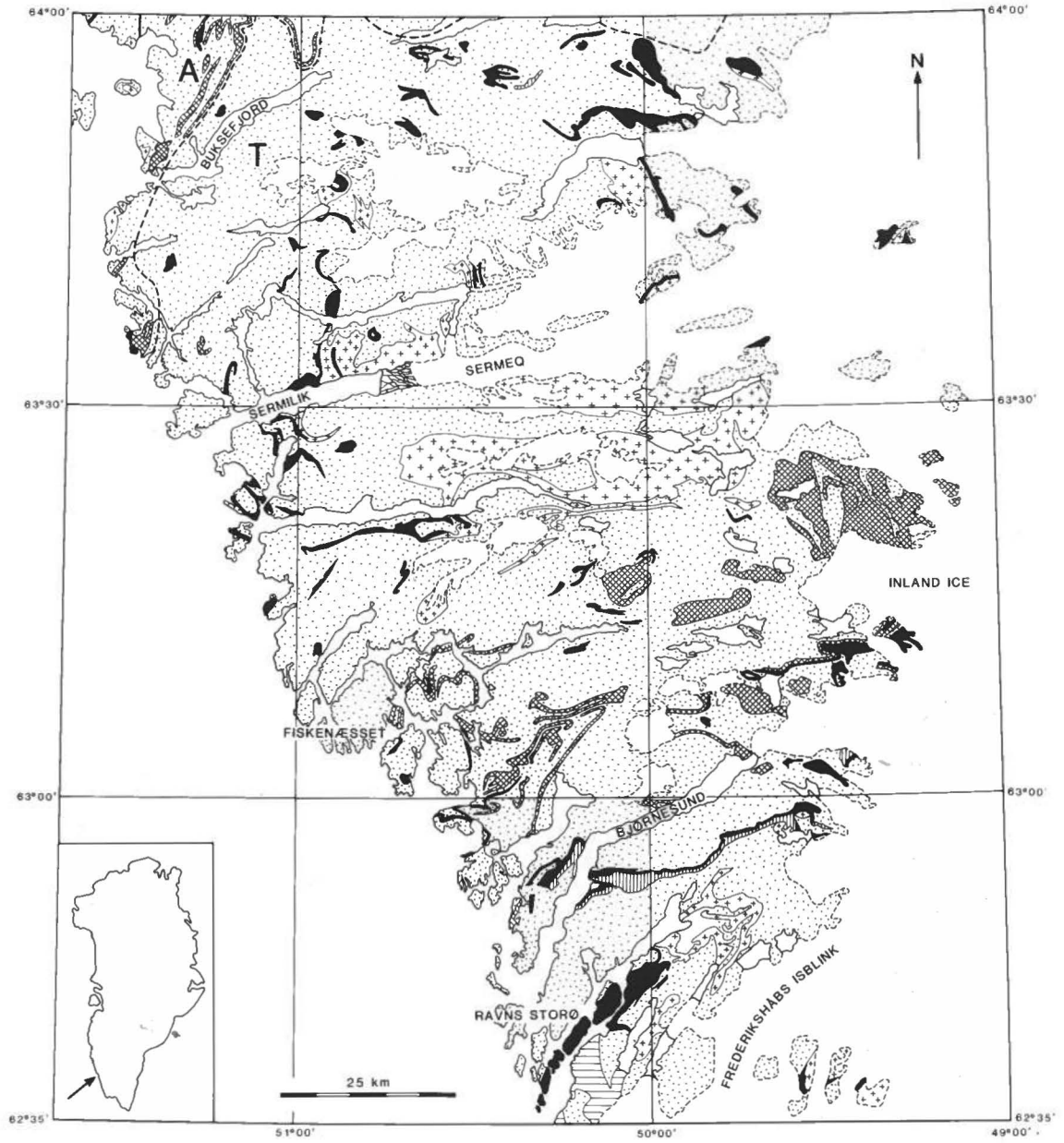
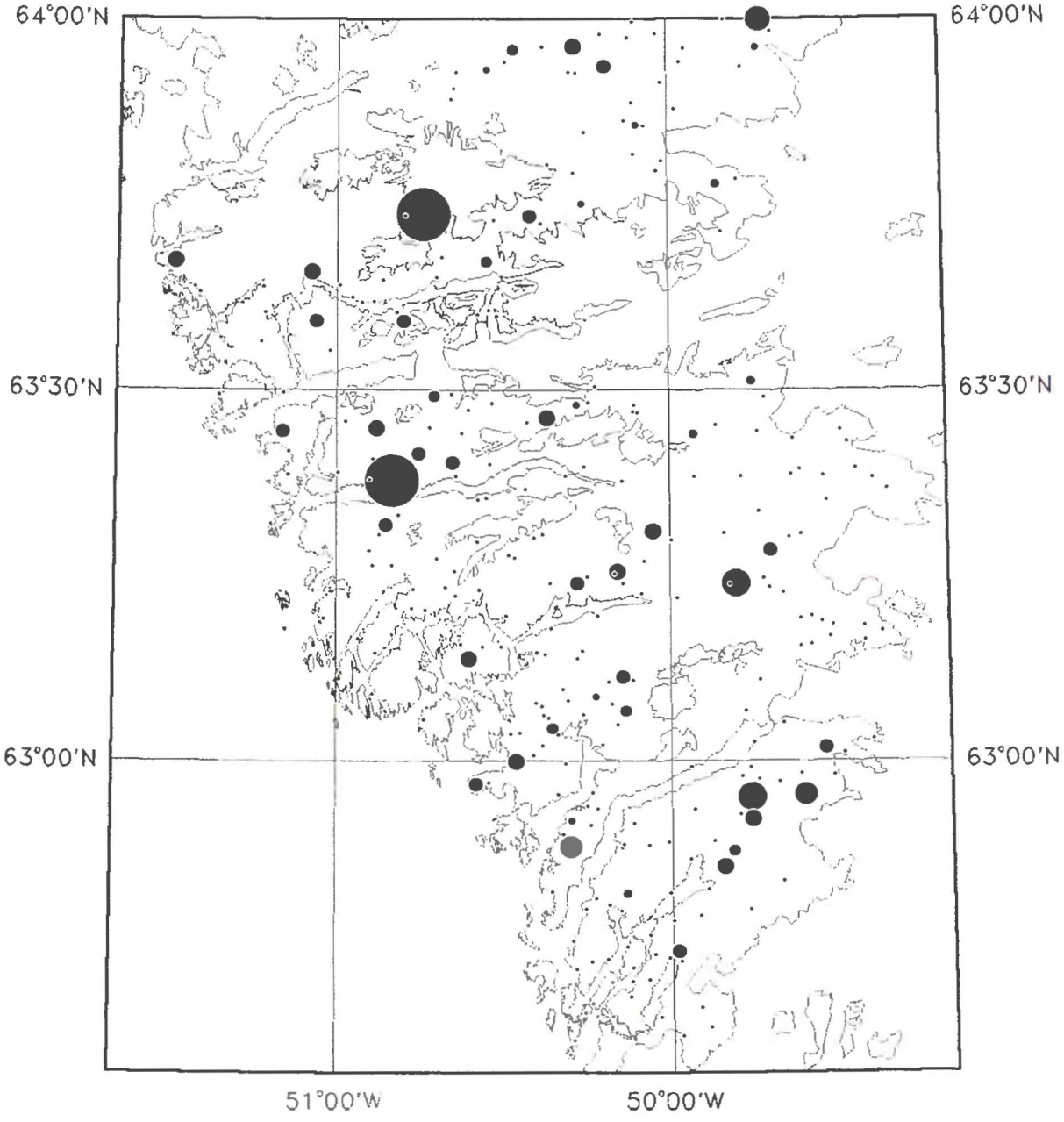
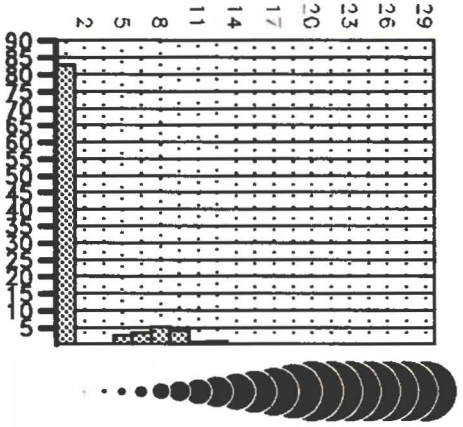


Fig. 1. Simplified geological map of the area from Frederikshåbs isblink to latitude 64°N
Based on the GGU 1:500 000 geological map of Greenland, Sheet 2, Frederikshåbs Isblink - Sondre Strømfjord.

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Au in stream sediment





Au ppb

Instrumental Neutron Activation Analysis

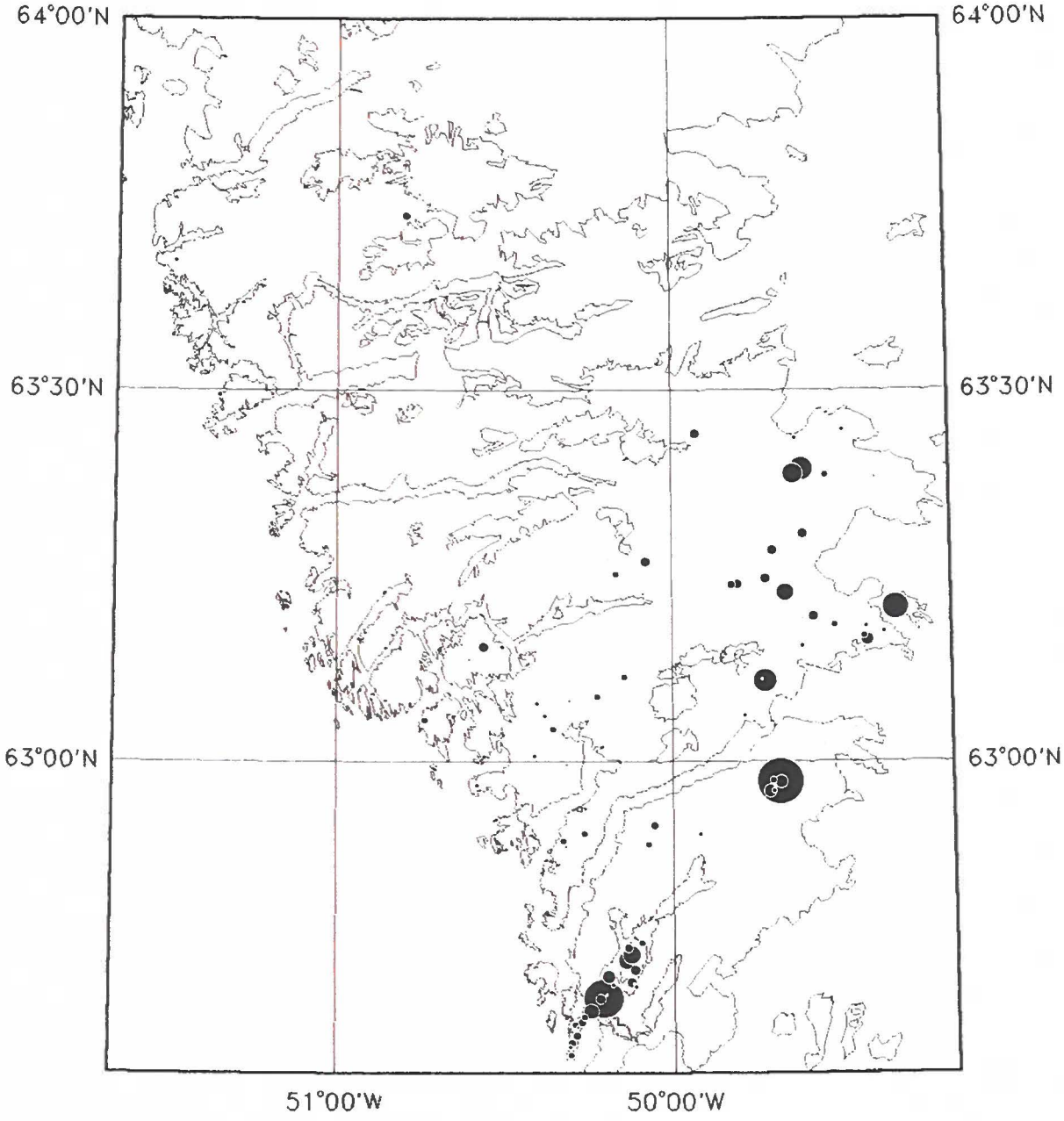
Number of samples:	277
Min. value:	0
Max. value:	200
Mean:	2
Median:	0
Variance:	158
Std. Dev.:	13

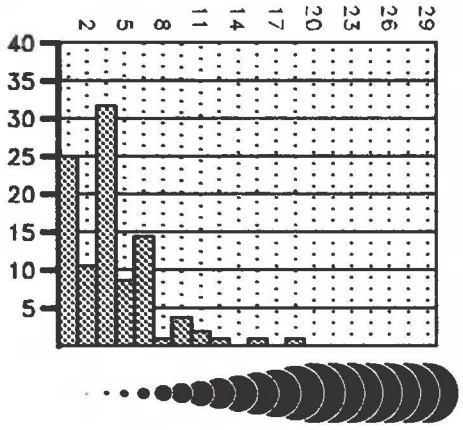
50 km

Fig. 2

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Au in stream sediment





Au ppb

Fire Assay + ICP-ES

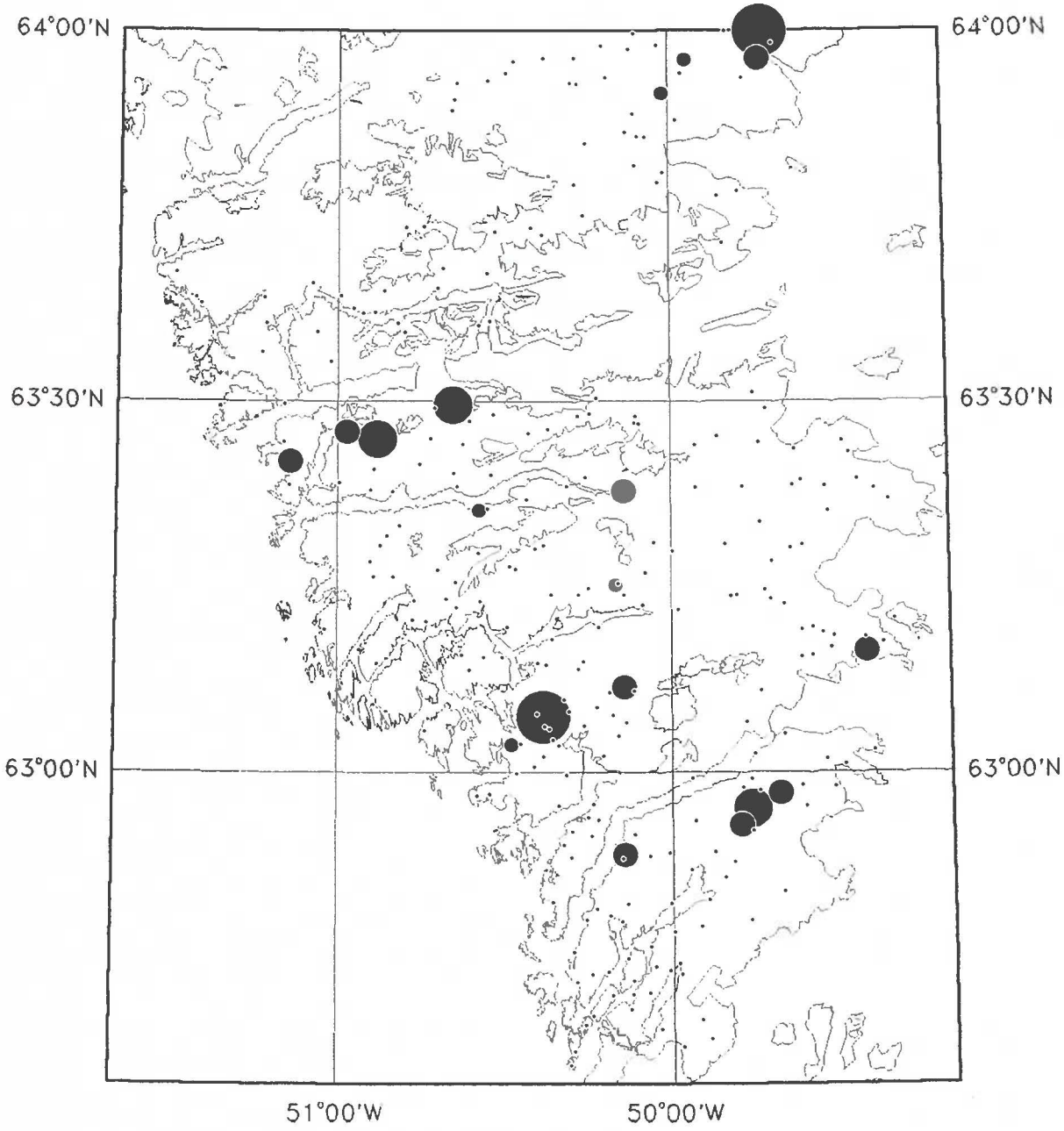
Number of samples:	104
Min. value:	1
Max. value:	18
Mean:	4
Median:	3
Variance:	10
Std. Dev.:	3

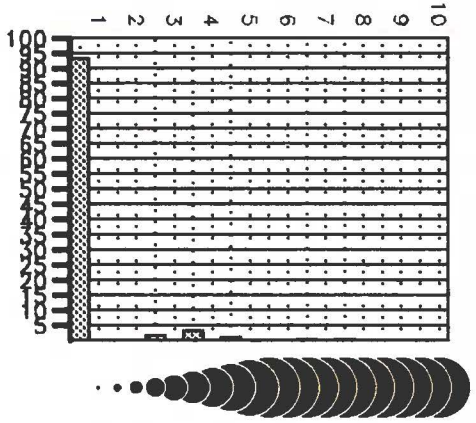
50 km

Fig. 3

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: As in stream sediment





As ppm

Instrumental Neutron Activation Analysis

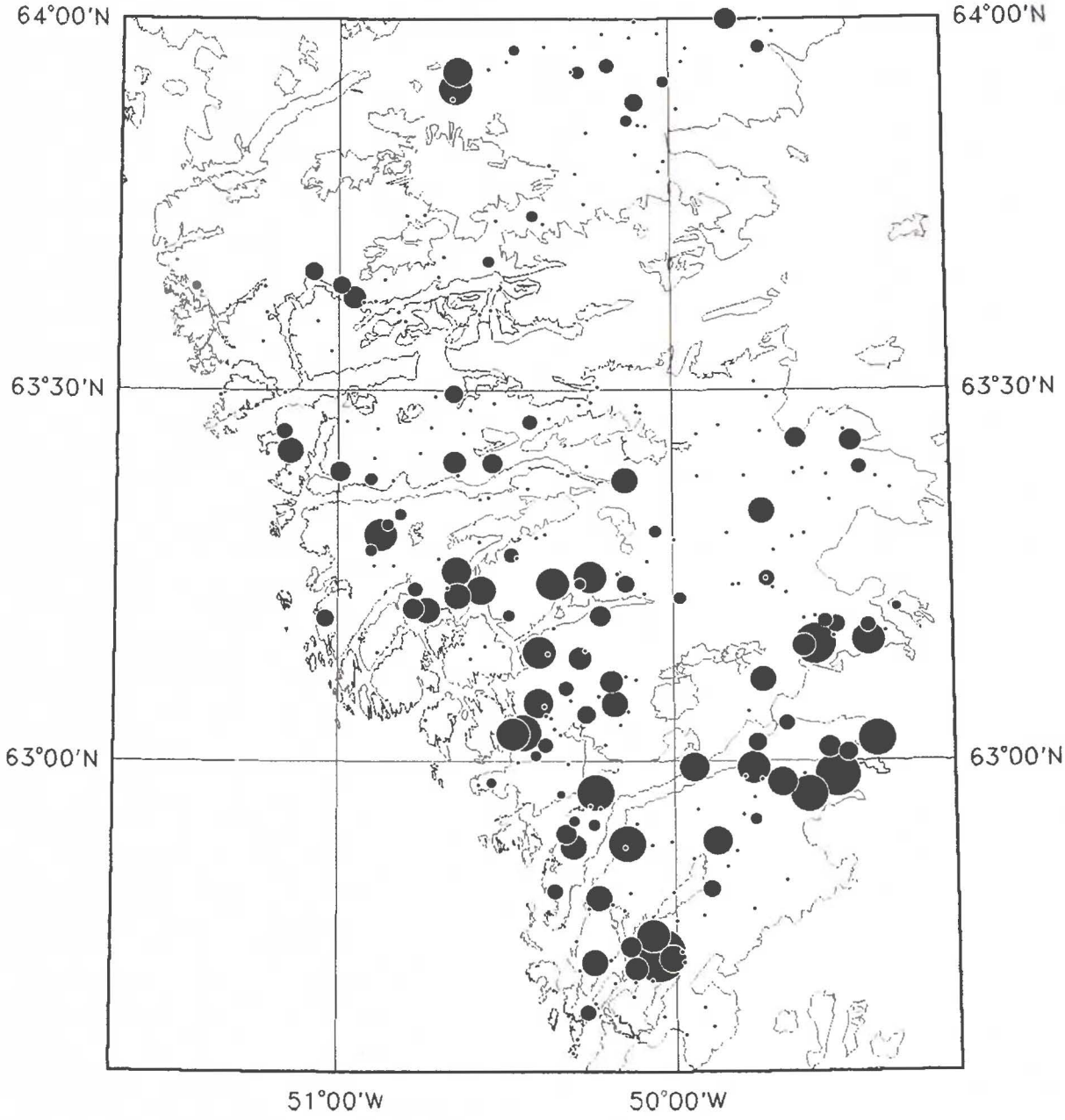
Number of samples:	277
Min. value:	0
Max. value:	7
Mean:	0
Median:	0
Variance:	1
Std. Dev.:	1

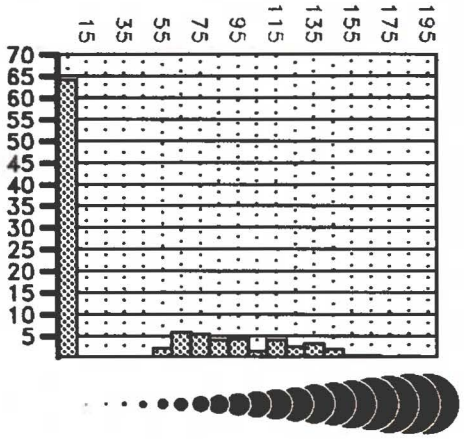
50 km

Fig. 4

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Zn in stream sediment





Zn ppm

Instrumental Neutron Activation Analysis

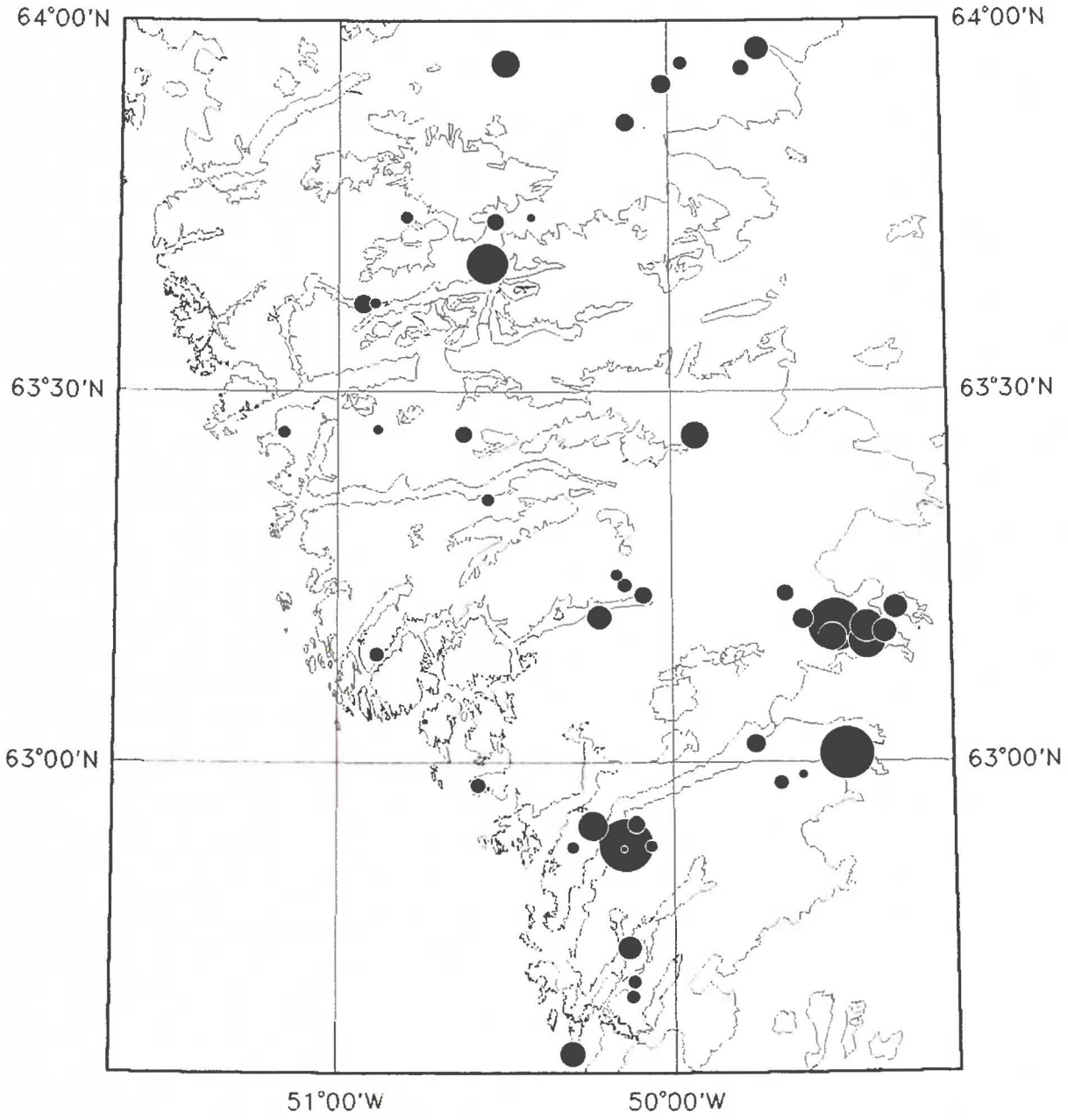
Number of samples:	277
Min. value:	0
Max. value:	180
Mean:	34
Median:	0
Variance:	2337
Std. Dev.:	48

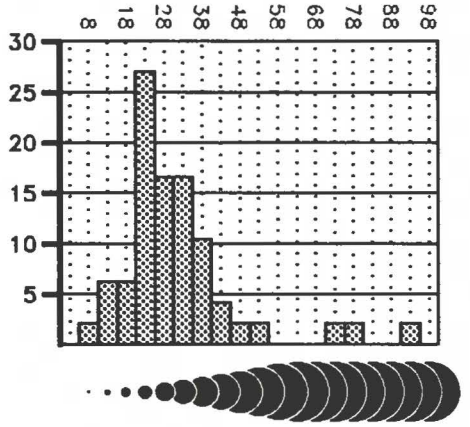
50 km

Fig. 5

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Zn in stream sediment





Zn ppm

Aqua Regia – AAS

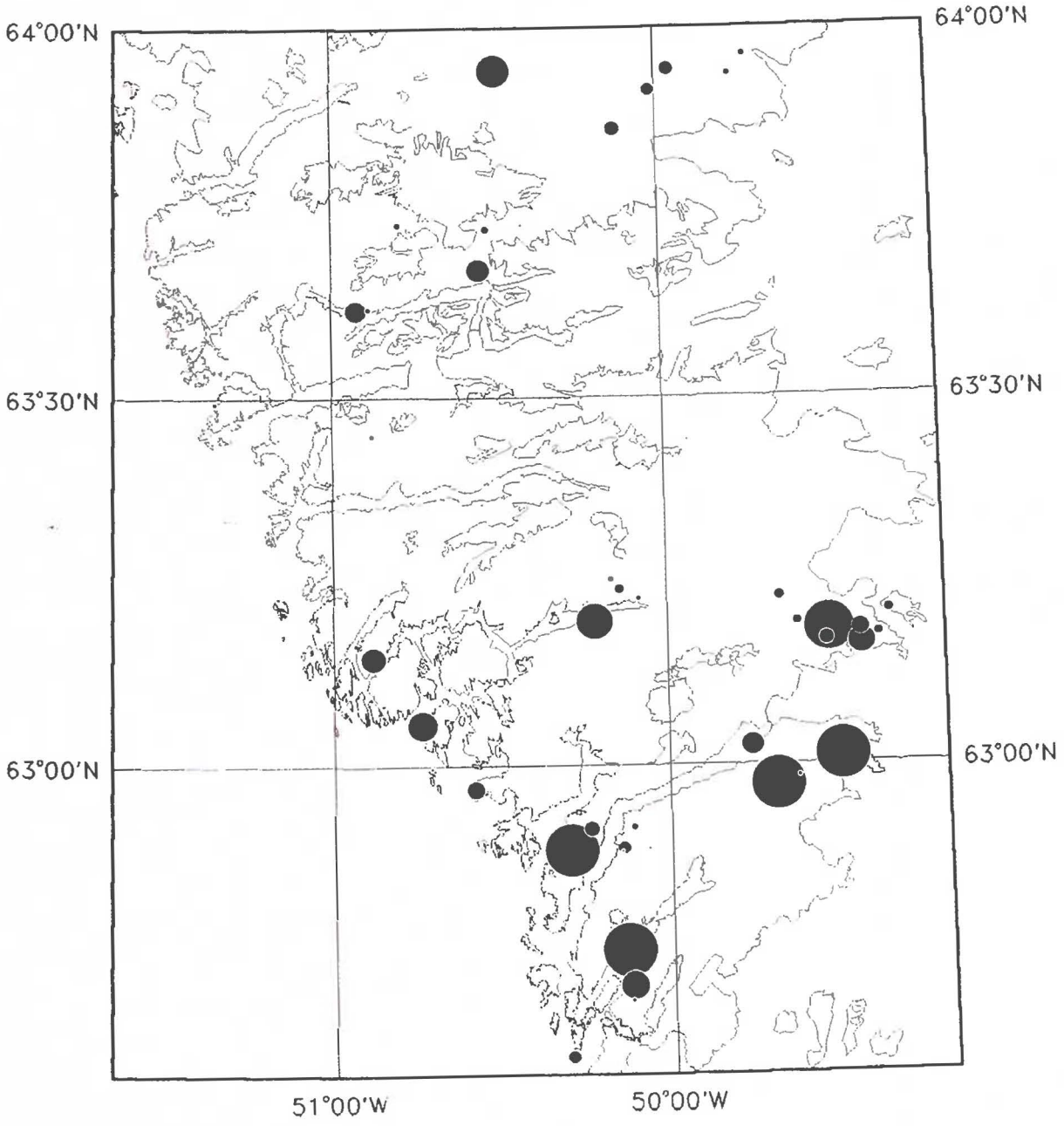
Number of samples:	48
Min. value:	5
Max. value:	94
Mean:	30
Median:	27
Variance:	265
Std. Dev.:	16

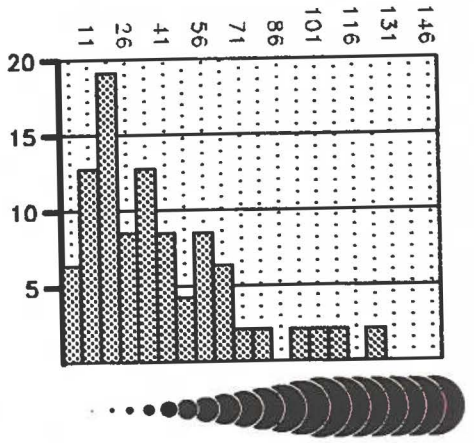
50 km

Fig. 6

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Cu in stream sediment





Cu ppm

Aqua Regia – AAS

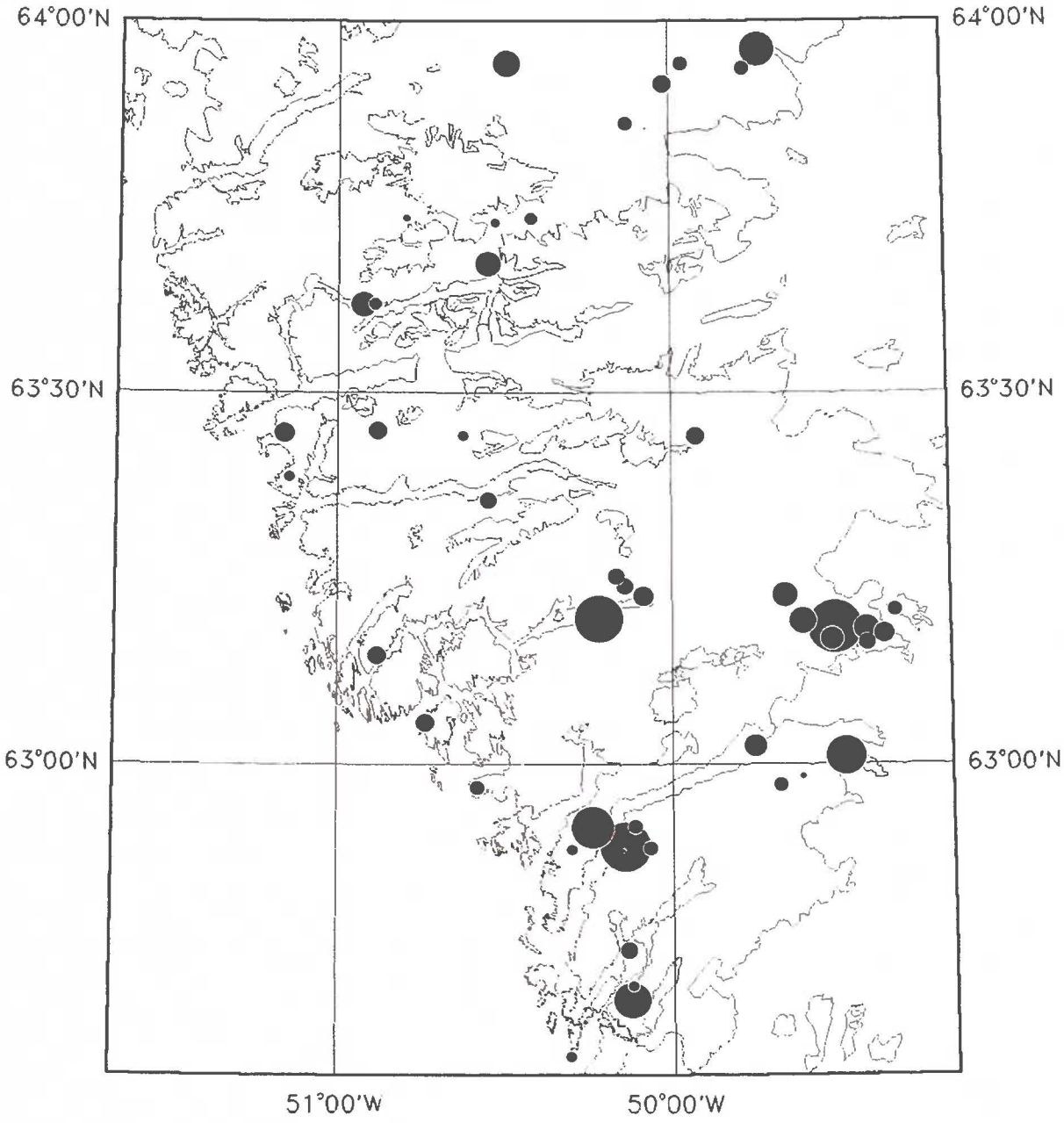
Number of samples:	48
Min. value:	4
Max. value:	151
Mean:	41
Median:	30
Variance:	1075
Std. Dev.:	33

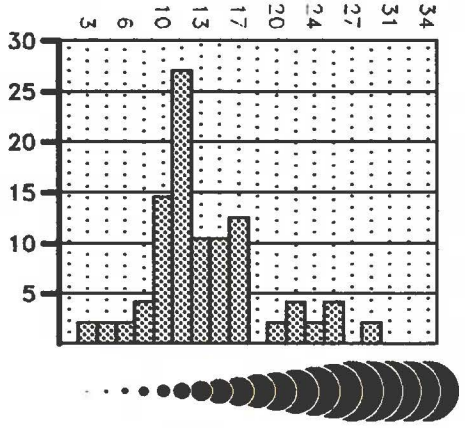
50 km

Fig. 7

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Pb in stream sediment





Pb ppm

Aqua Regia – AAS

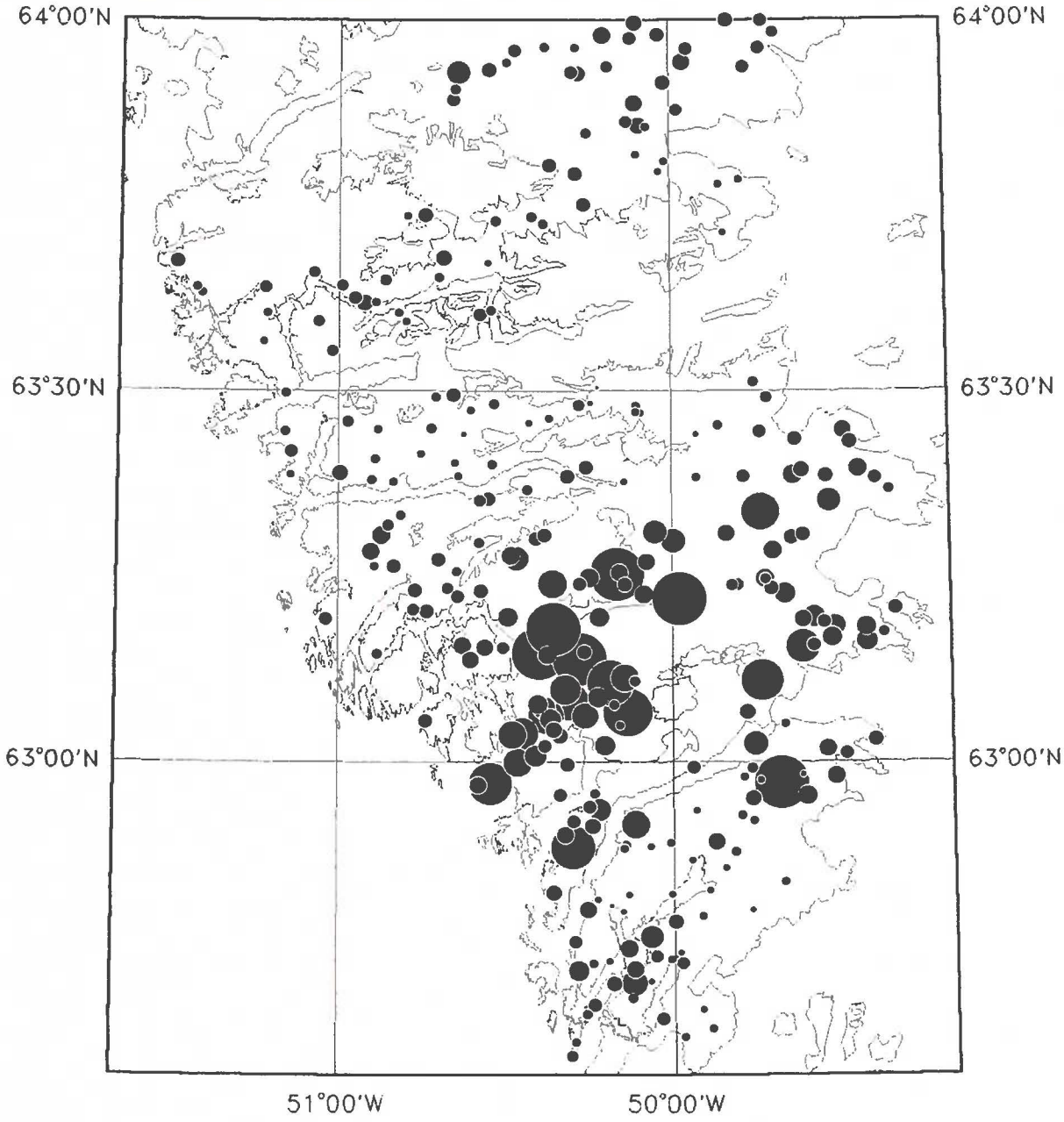
Number of samples:	48
Min. value:	3
Max. value:	28
Mean:	13
Median:	12
Variance:	28
Std. Dev.:	5

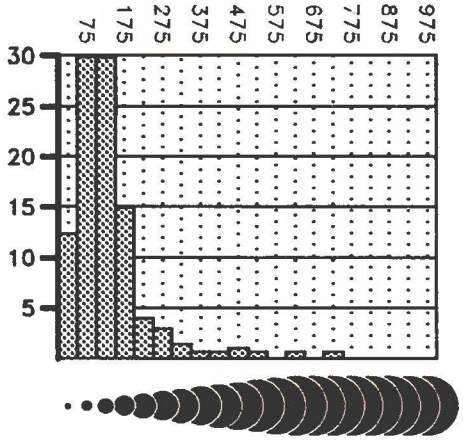
50 km

Fig. 8

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Cr in stream sediment





Cr ppm

Instrumental Neutron Activation Analysis

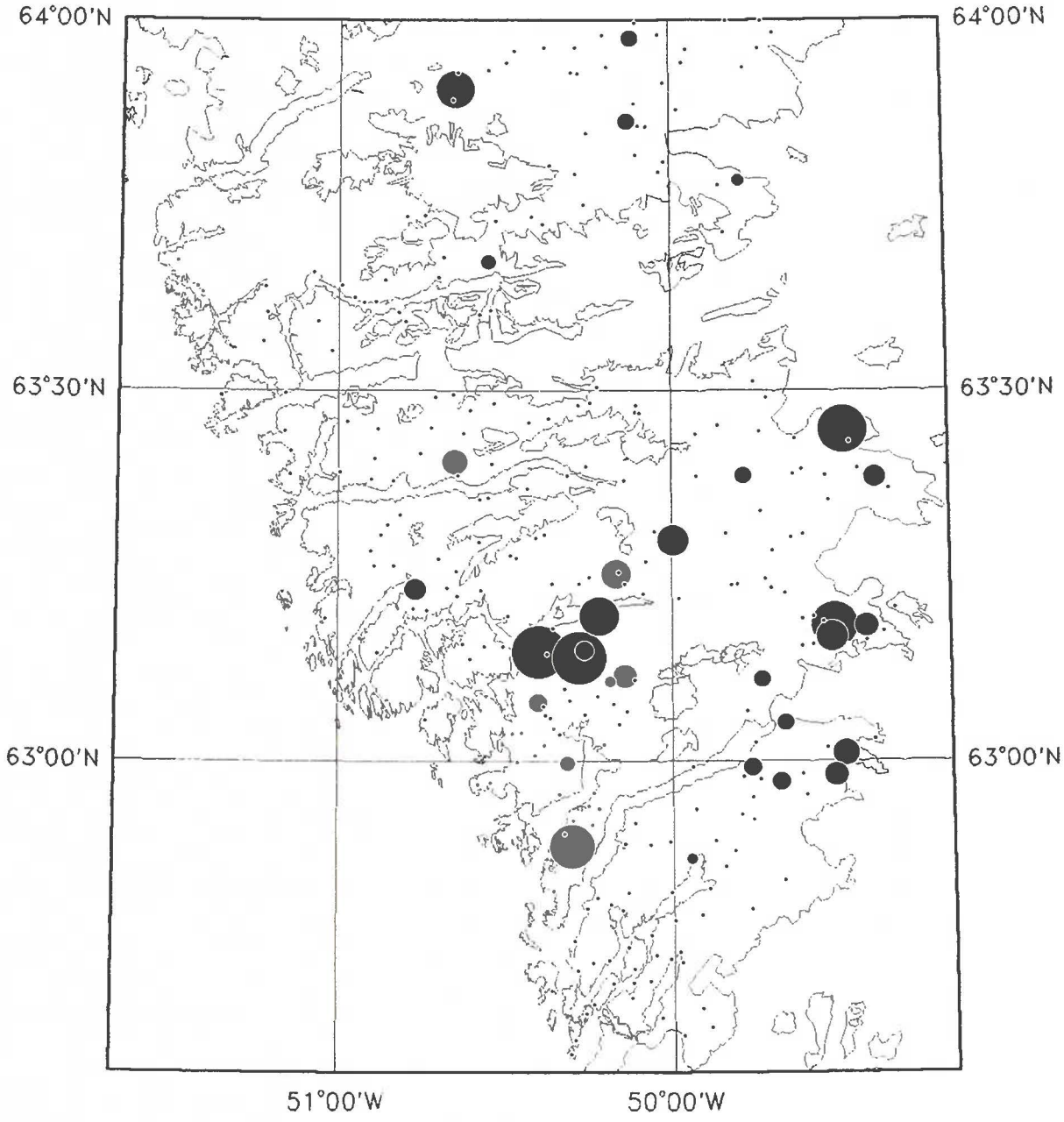
Number of samples:	277
Min. value:	0
Max. value:	2300
Mean:	143
Median:	110
Variance:	32331
Std. Dev.:	180

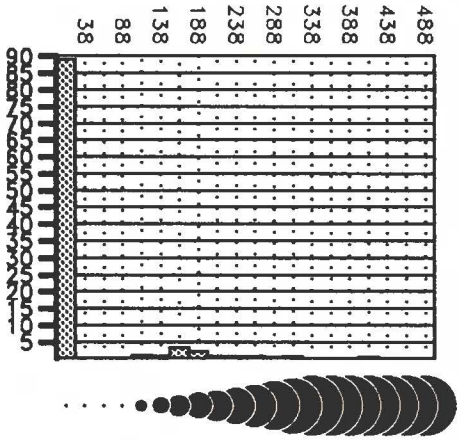
50 km

Fig. 9

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Ni in stream sediment





Ni ppm

Instrumental Neutron Activation Analysis

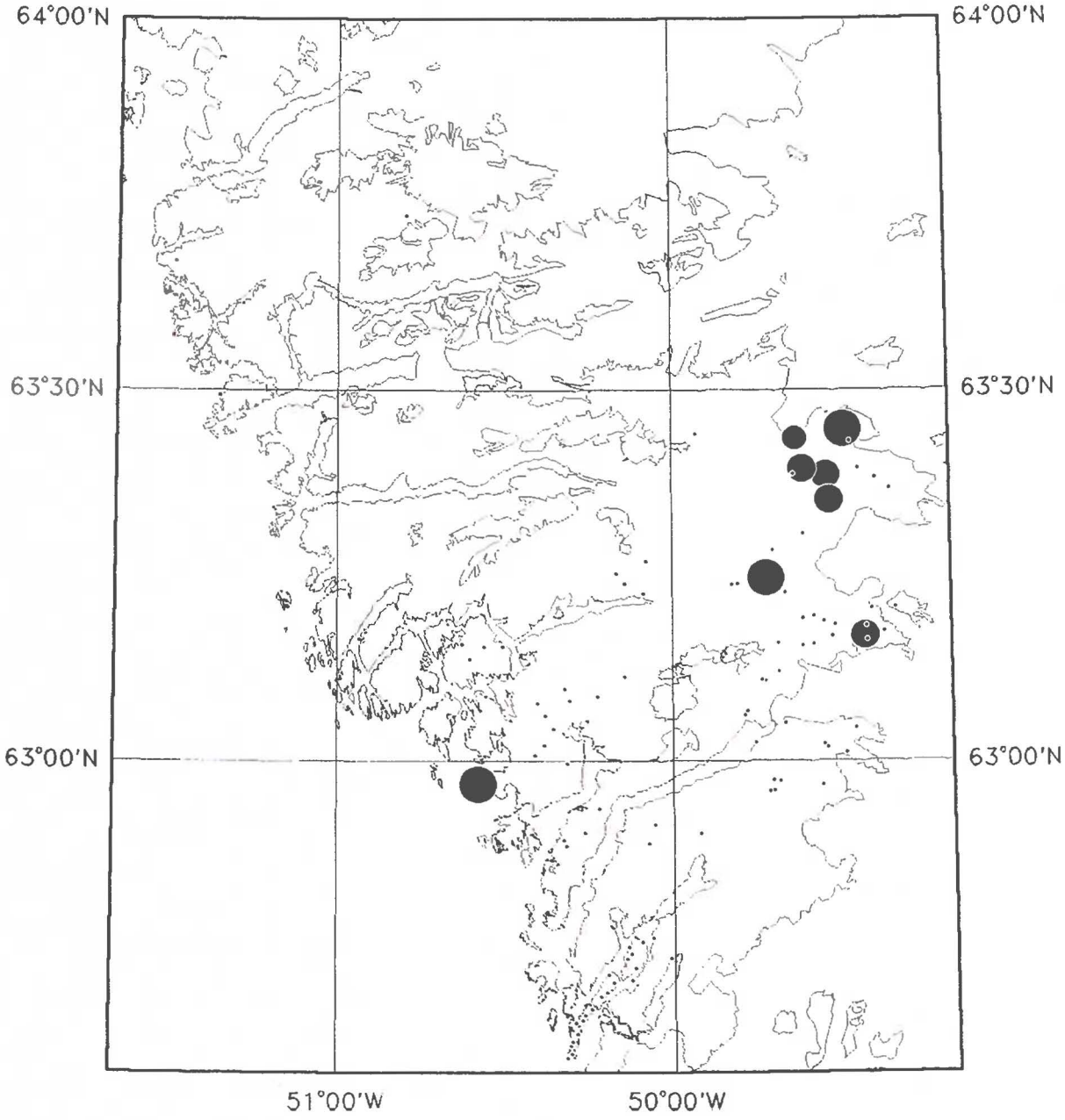
Number of samples:	277
Min. value:	0
Max. value:	610
Mean:	23
Median:	0
Variance:	5404
Std. Dev.:	74

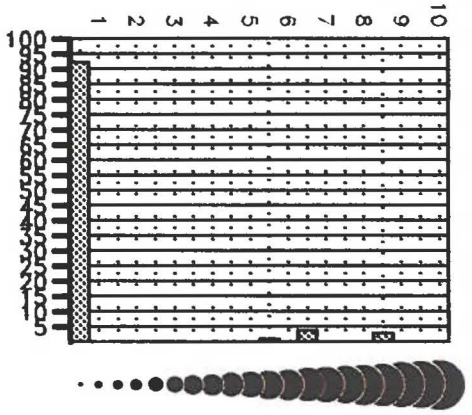
50 km

Fig. 10

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Pt in stream sediment





Pt ppb

Fire Assay + ICP–ES

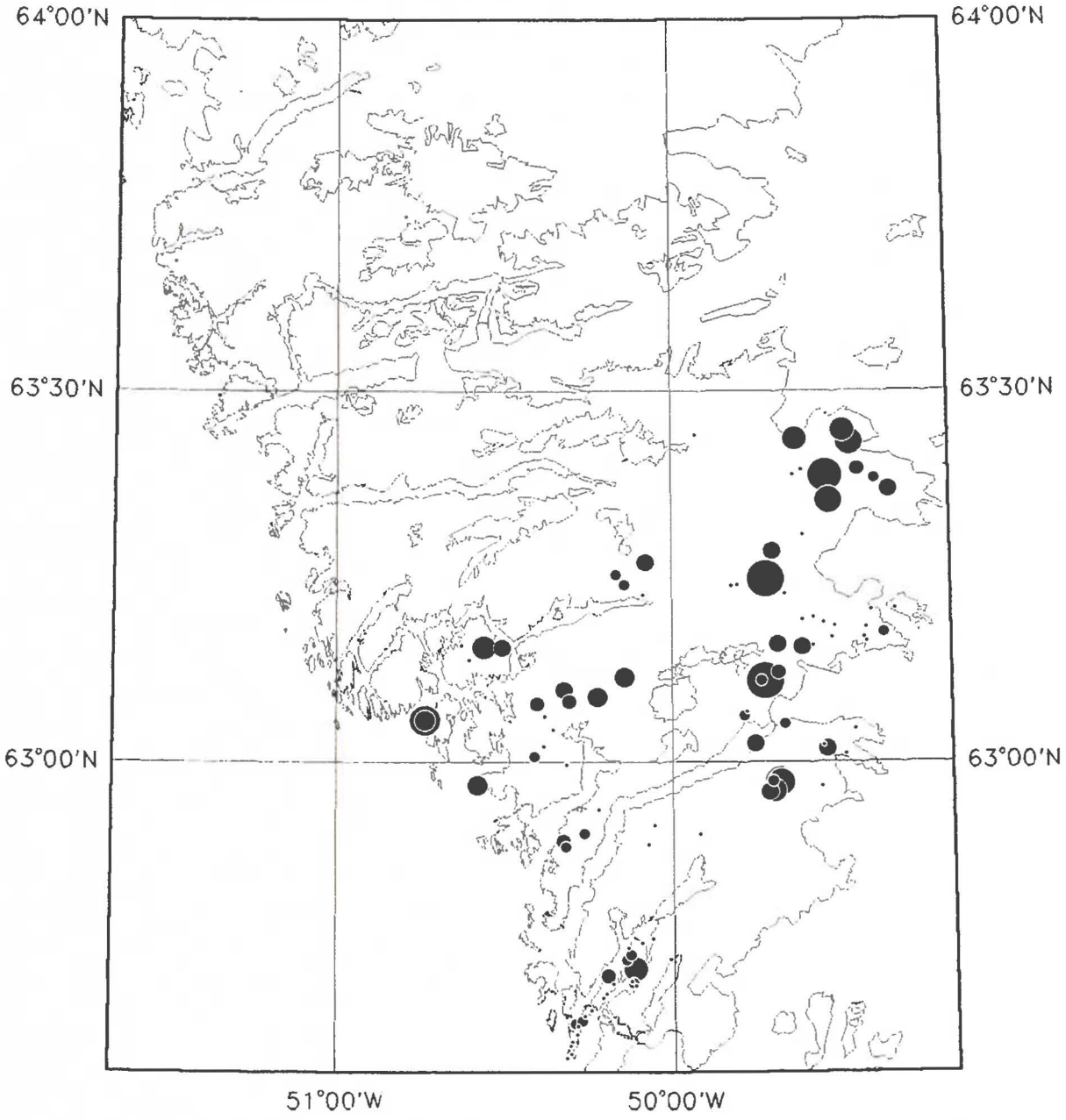
Number of samples:	104
Min. value:	0
Max. value:	8
Mean:	1
Median:	0
Variance:	3
Std. Dev.:	2

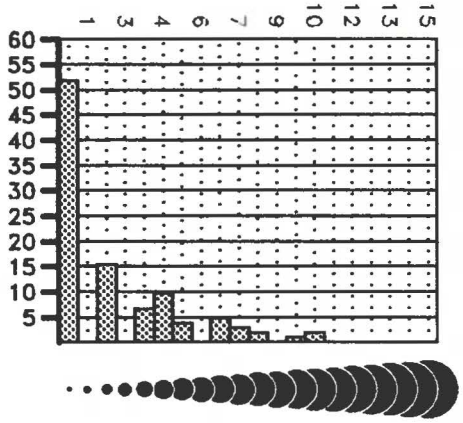
50 km

Fig. 11

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Pd in stream sediment





Pd ppb

Fire Assay + ICP–ES

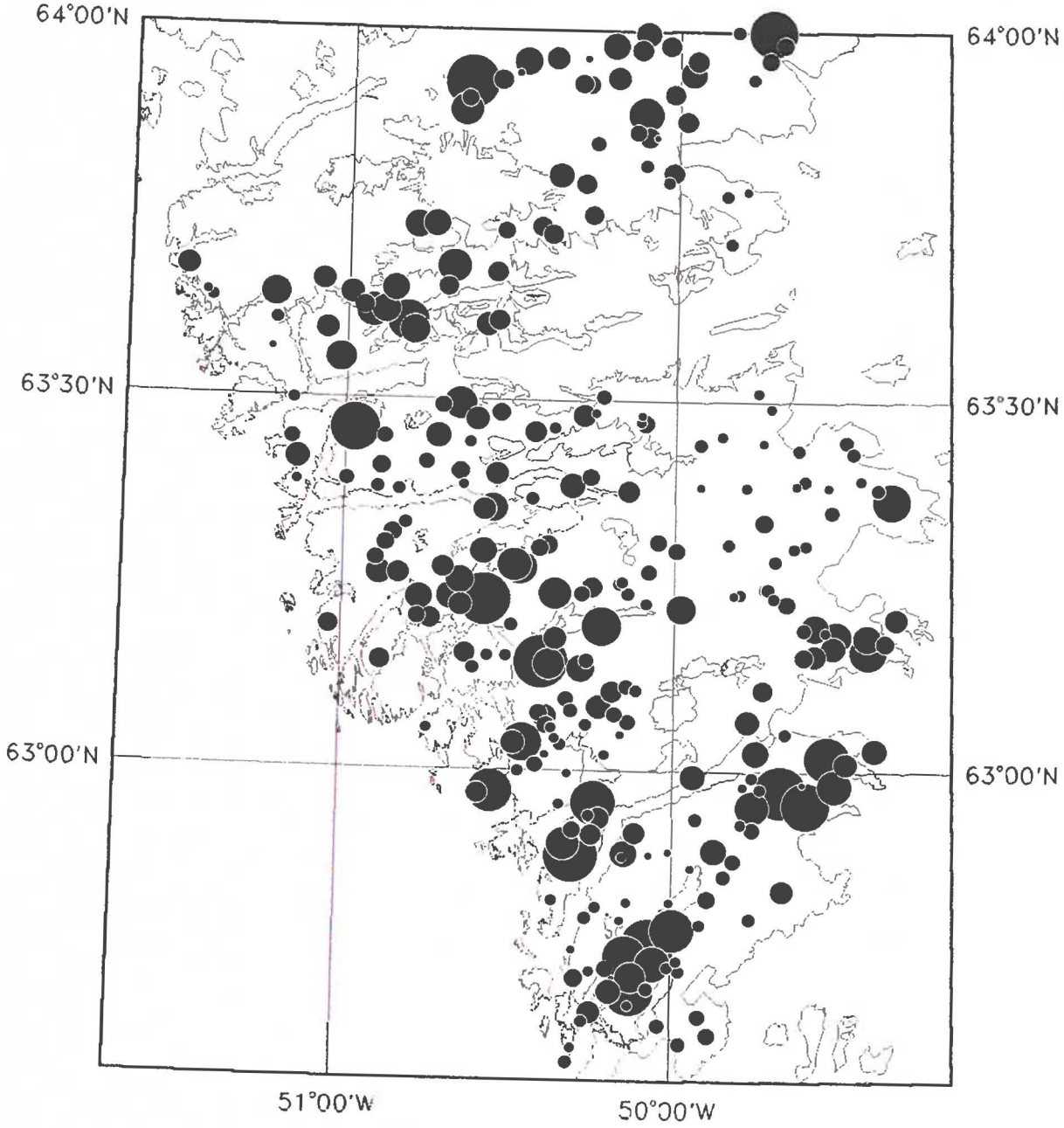
Number of samples:	104
Min. value:	0
Max. value:	10
Mean:	2
Median:	0
Variance:	7
Std. Dev.:	3

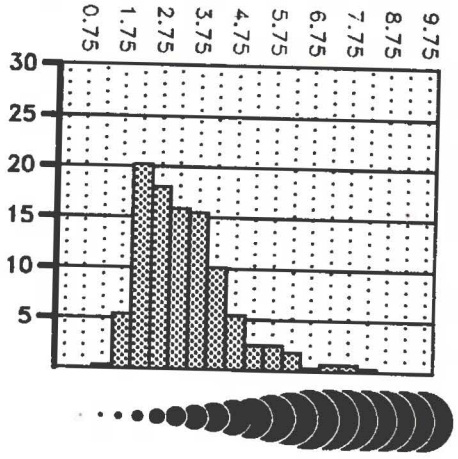
50 km

Fig. 12

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Fe in stream sediment





Fe pct

Instrumental Neutron Activation Analysis

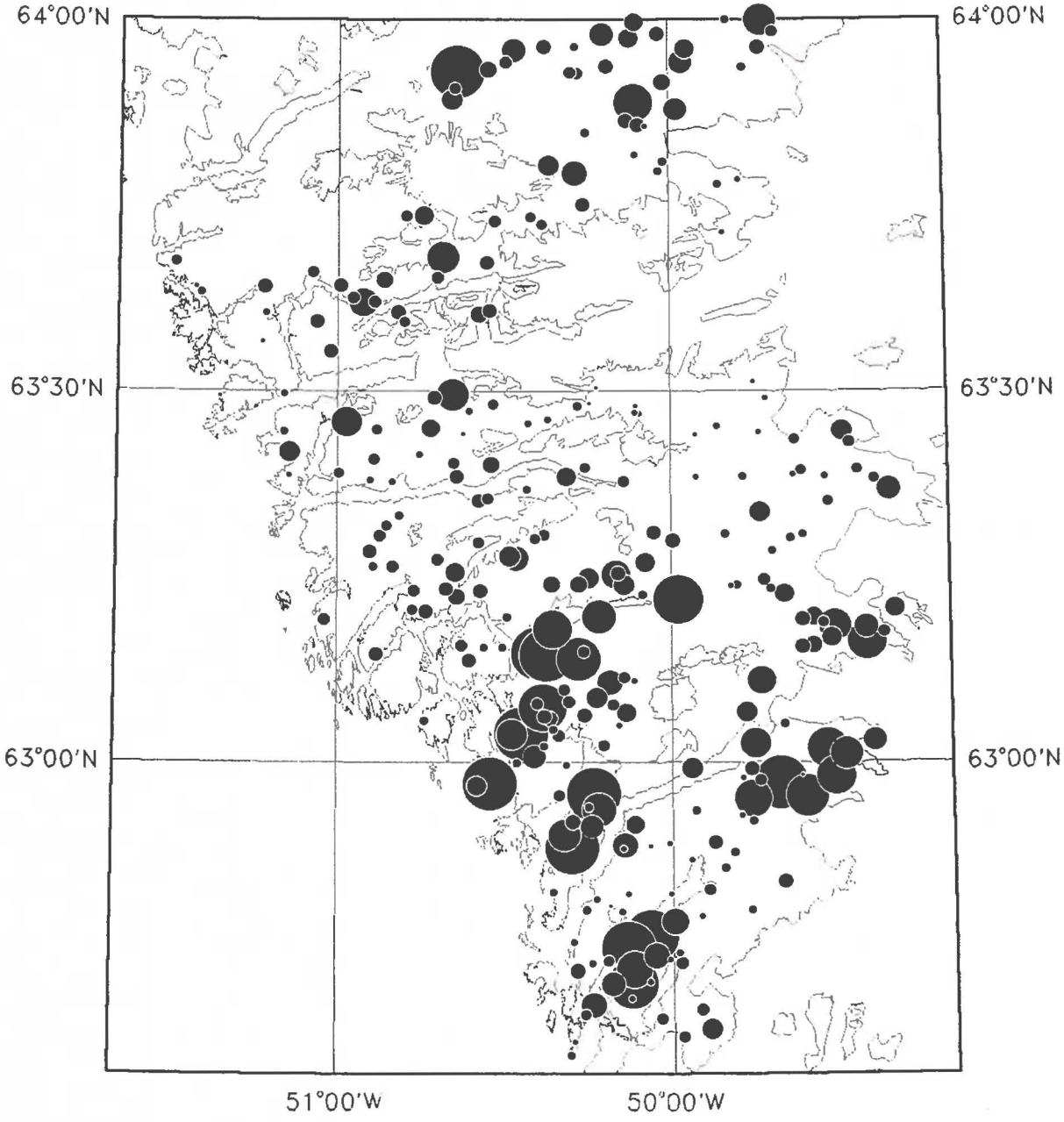
Number of samples:	277
Min. value:	1.10
Max. value:	8.24
Mean:	3.37
Median:	3.14
Variance:	1.44
Std. Dev.:	1.20

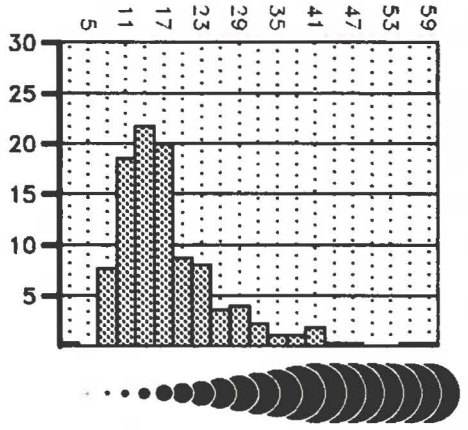
50 km

Fig. 13

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Co in stream sediment





Co ppm

Instrumental Neutron Activation Analysis

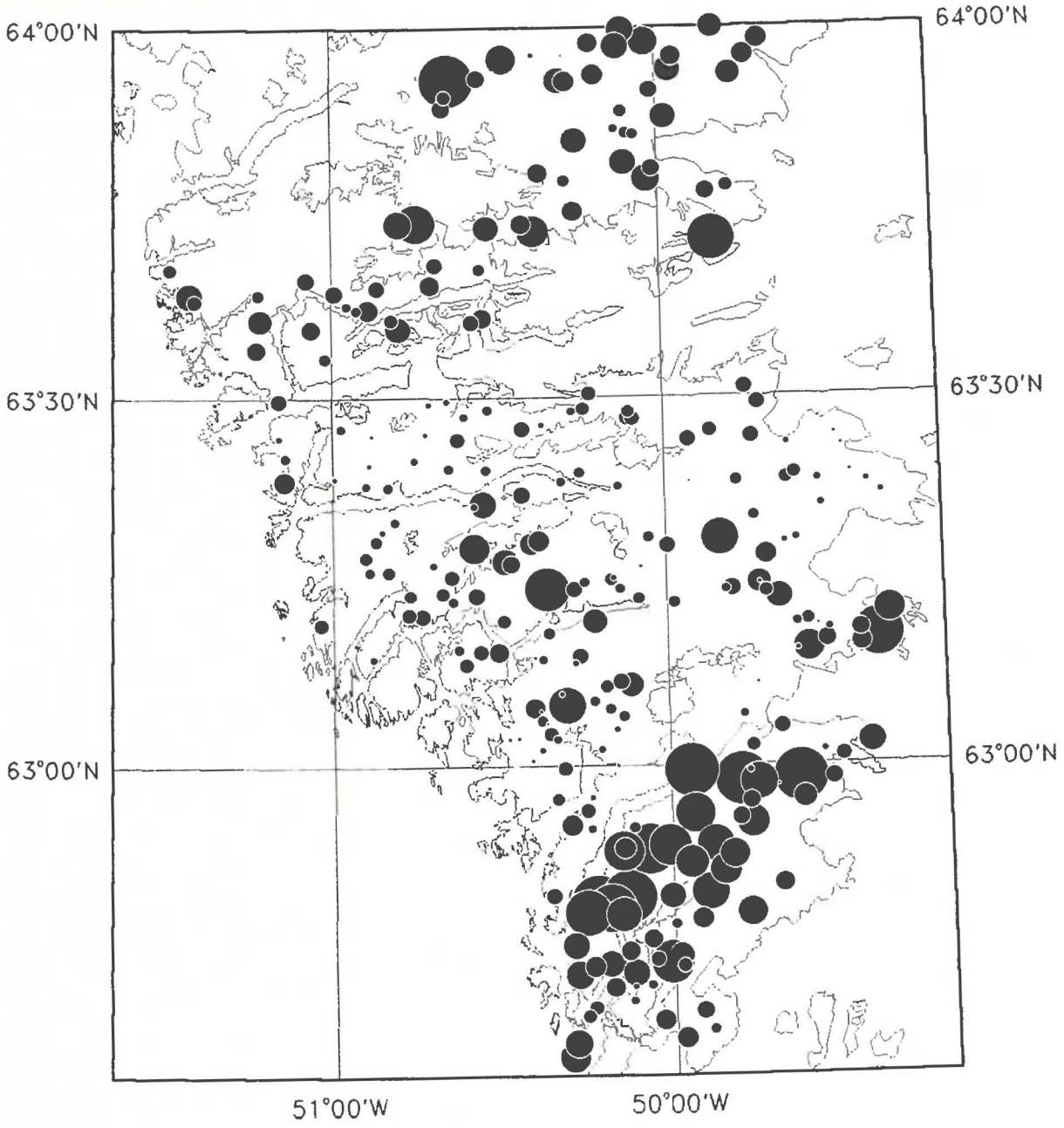
Number of samples:	277
Min. value:	0
Max. value:	67
Mean:	17
Median:	15
Variance:	78
Std. Dev.:	9

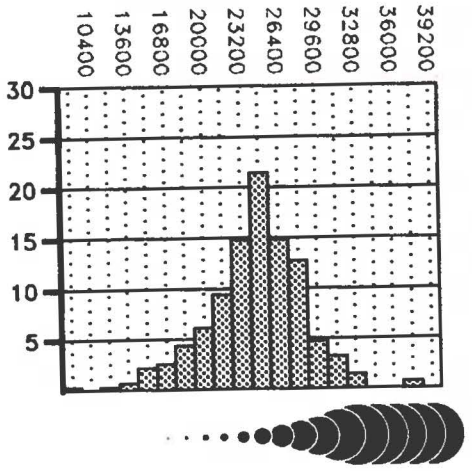
50 km

Fig. 14

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Na in stream sediment





Na ppm

Instrumental Neutron Activation Analysis

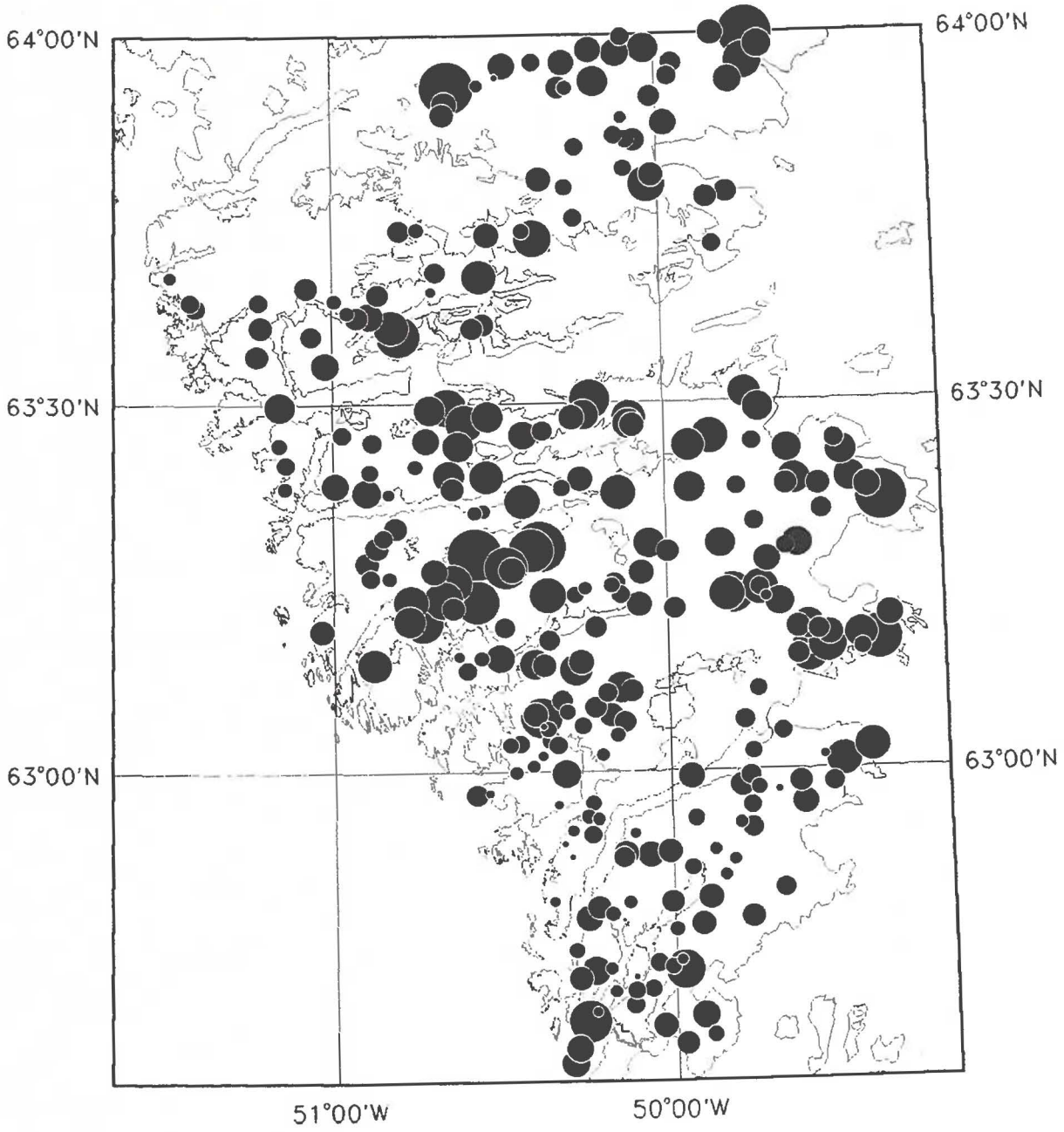
Number of samples:	277
Min. value:	9350
Max. value:	69800
Mean:	24486
Median:	24700
Variance:	23921850
Std. Dev.:	4891

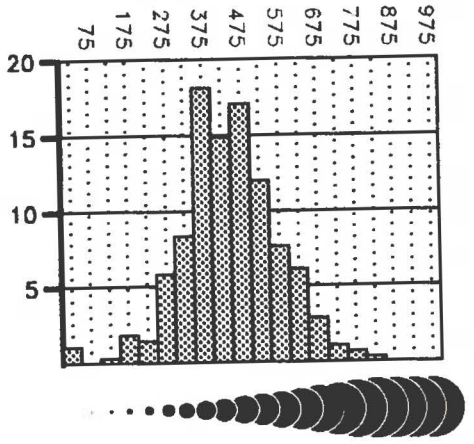
50 km

Fig. 15

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Ba in stream sediment





Ba ppm

Instrumental Neutron Activation Analysis

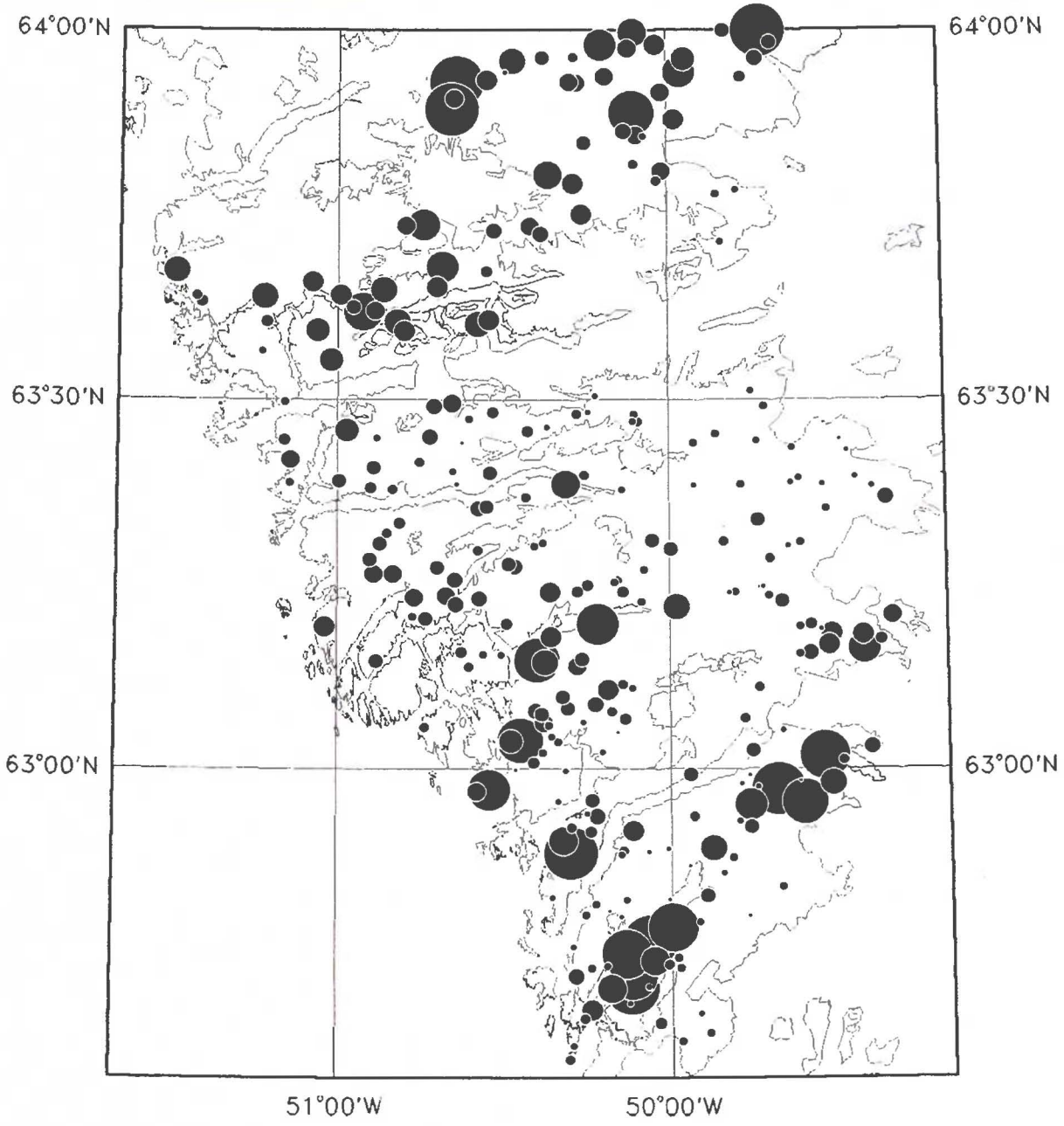
Number of samples:	277
Min. value:	0
Max. value:	4400
Mean:	458
Median:	440
Variance:	76082
Std. Dev.:	276

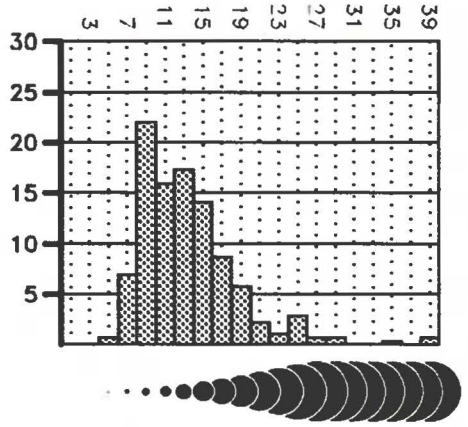
50 km

Fig. 16

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Sc in stream sediment





Sc ppm

Instrumental Neutron Activation Analysis

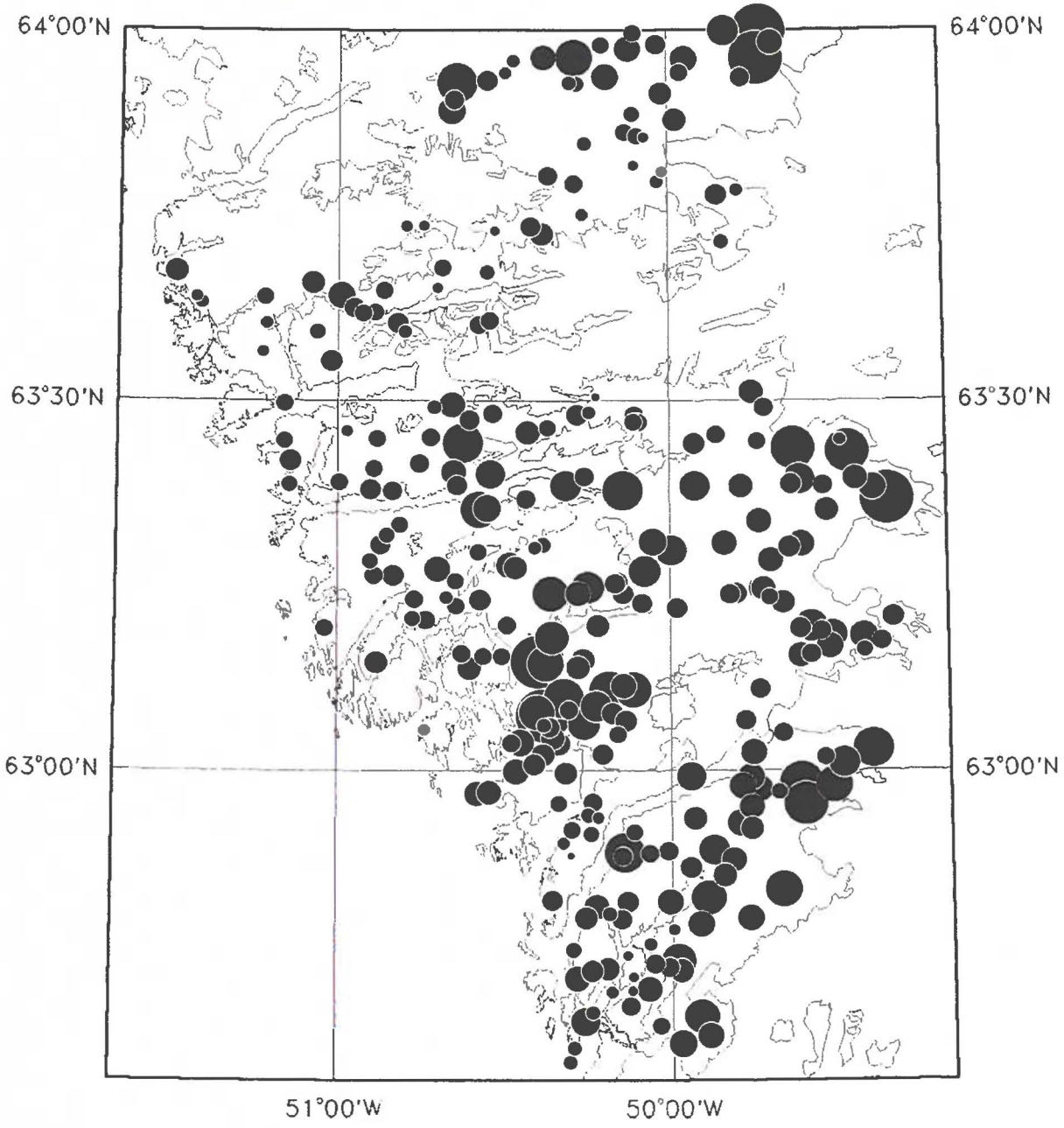
Number of samples:	277
Min. value:	6
Max. value:	39
Mean:	13
Median:	12
Variance:	26
Std. Dev.:	5

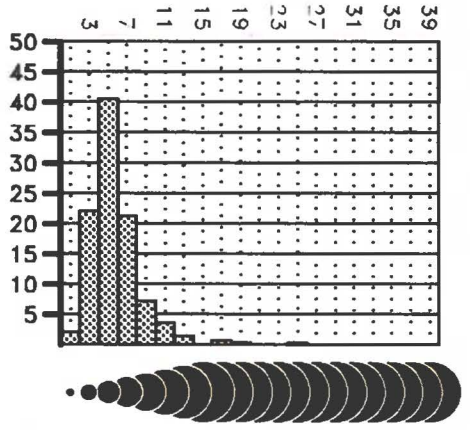
50 km

Fig. 17

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Th in stream sediment





Th ppm

Instrumental Neutron Activation Analysis

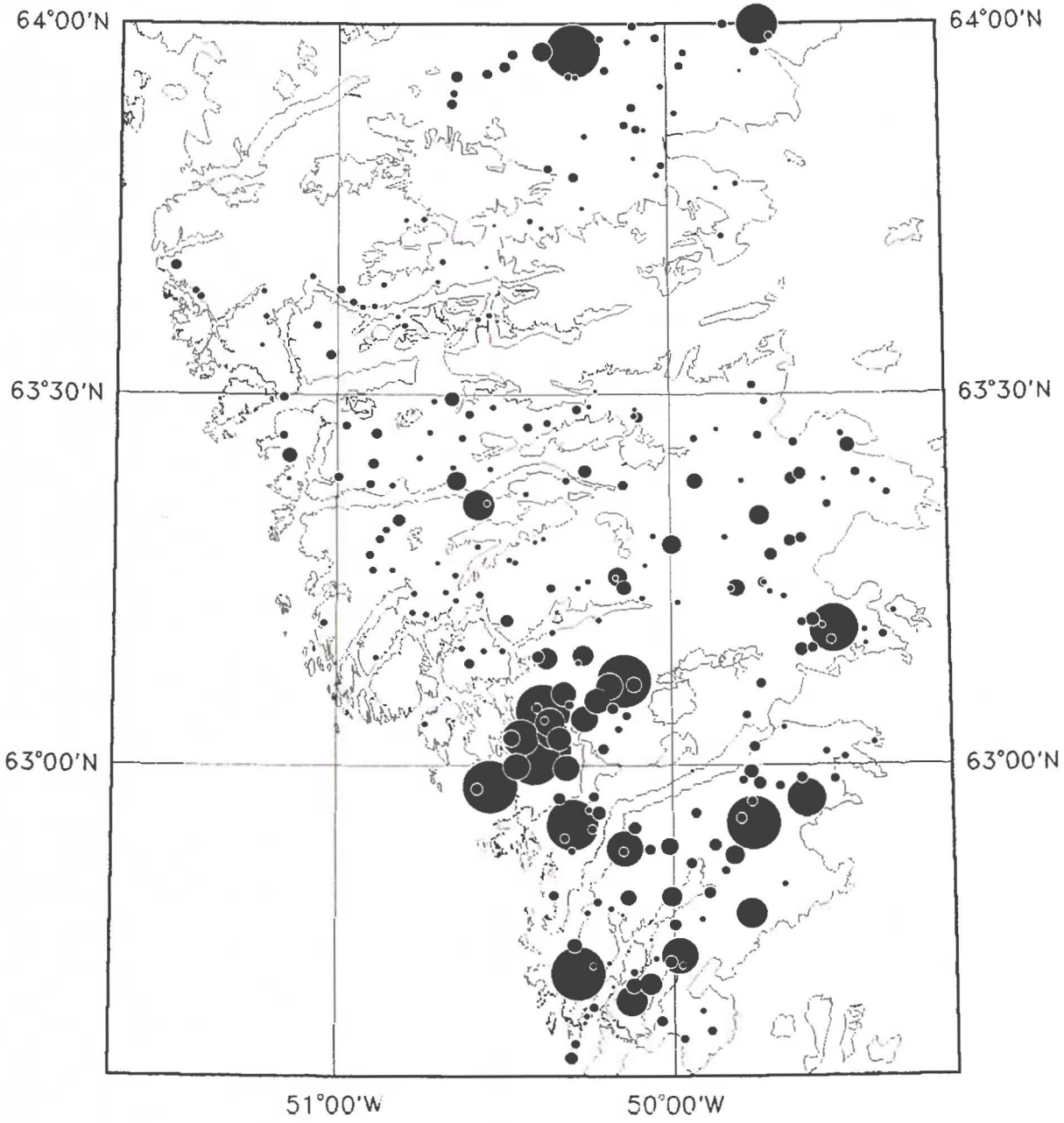
Number of samples:	277
Min. value:	1
Max. value:	130
Mean:	6
Median:	5
Variance:	63
Std. Dev.:	8

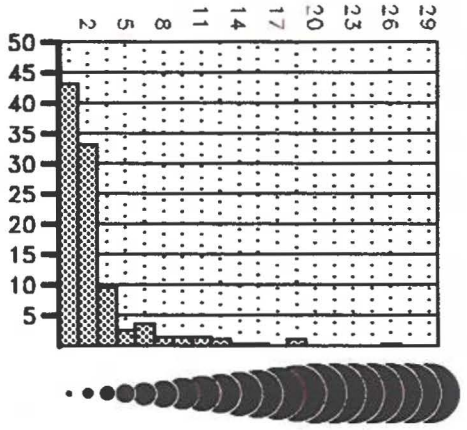
50 km

Fig. 18

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: U in stream sediment





U ppm

Instrumental Neutron Activation Analysis

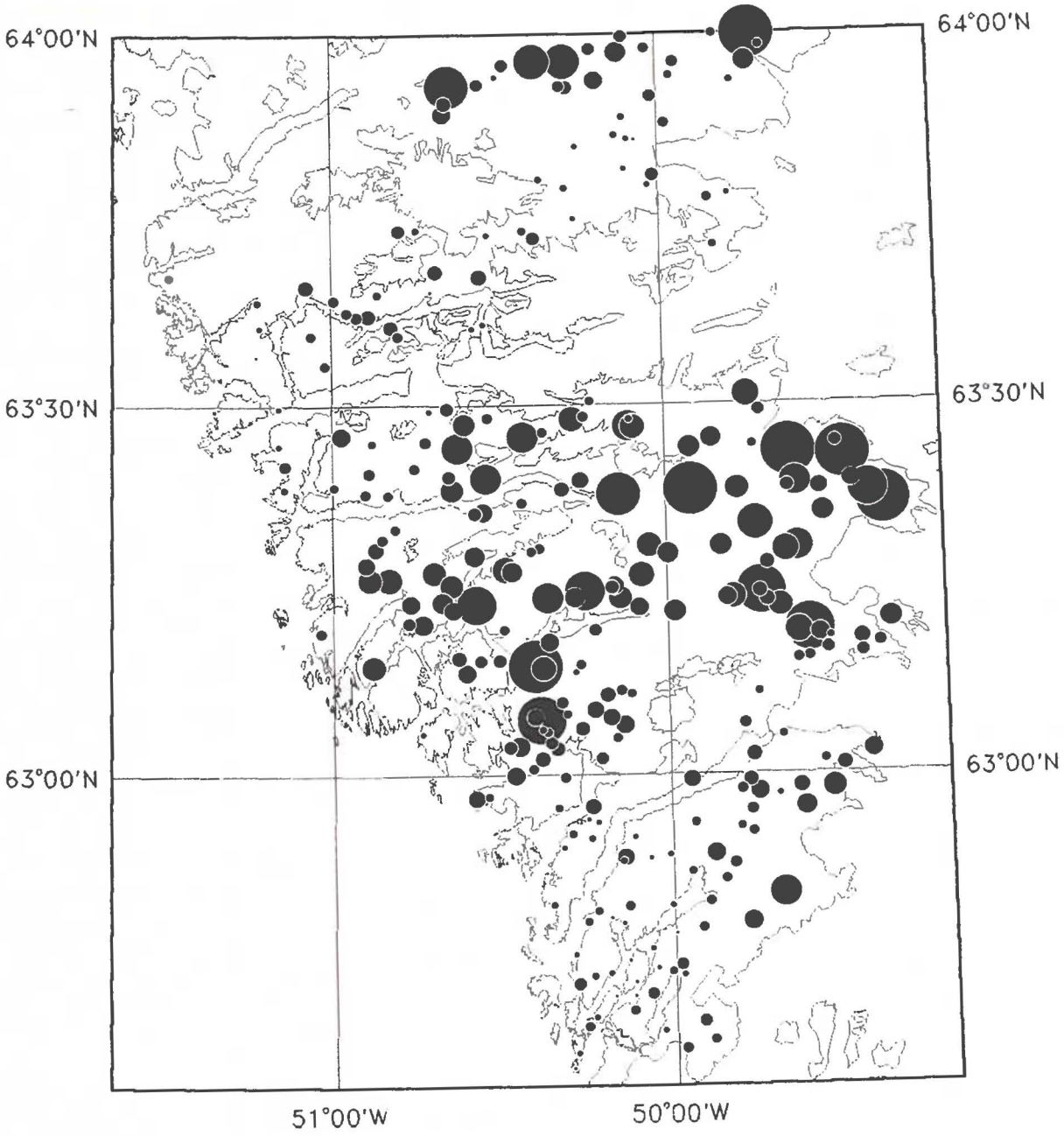
Number of samples:	277
Min. value:	0
Max. value:	200
Mean:	4
Median:	2
Variance:	190
Std. Dev.:	14

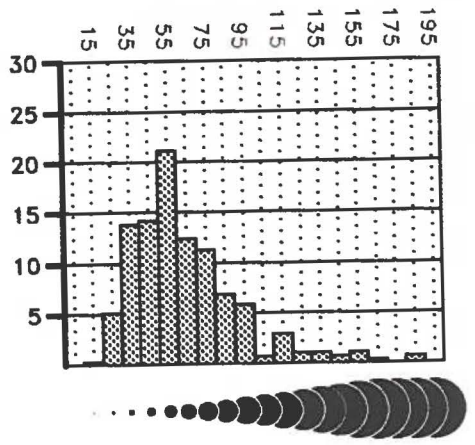
50 km

Fig. 19

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Ce in stream sediment





Ce ppm

Instrumental Neutron Activation Analysis

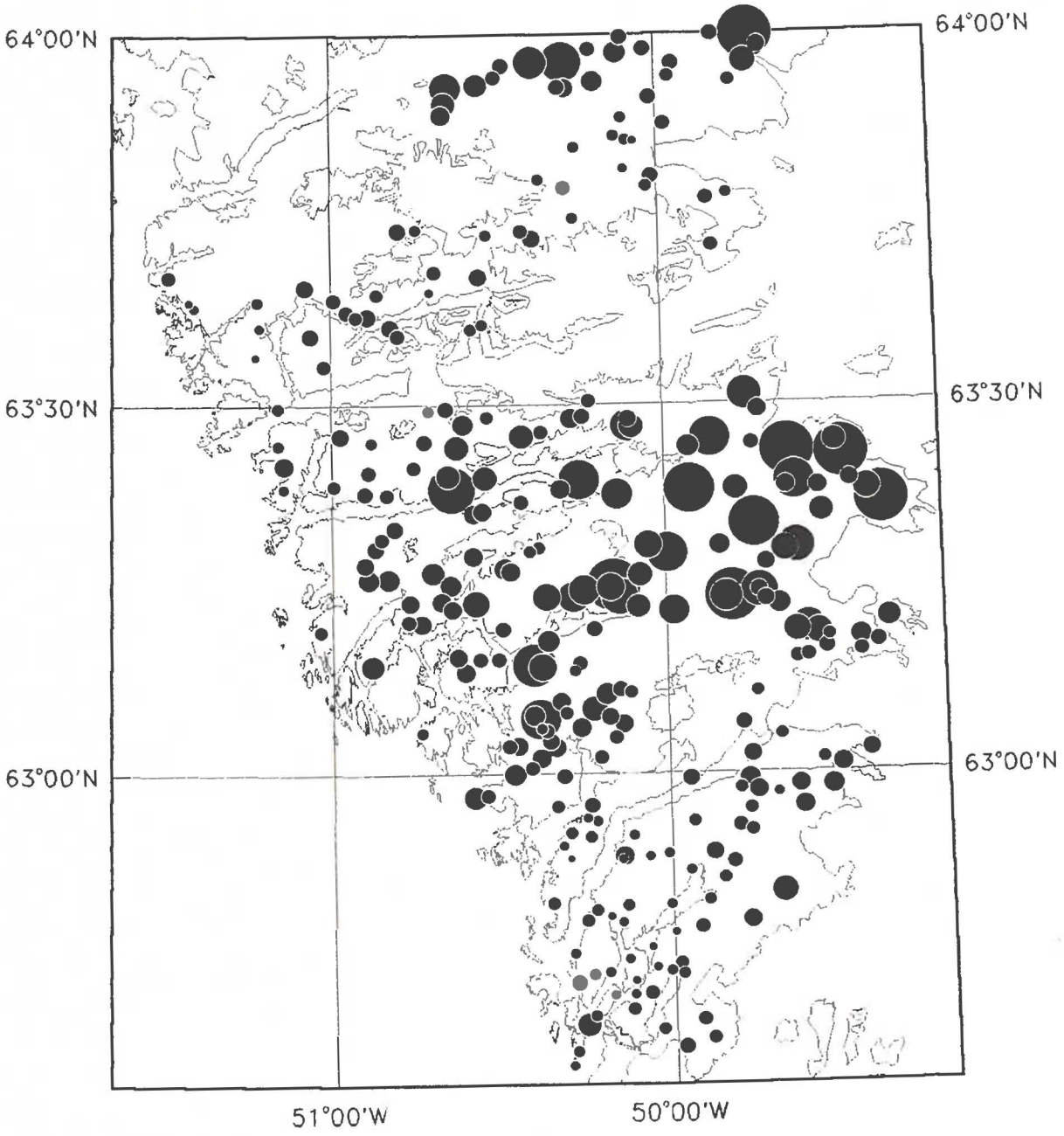
Number of samples:	277
Min. value:	13
Max. value:	630
Mean:	67
Median:	57
Variance:	2549
Std. Dev.:	50

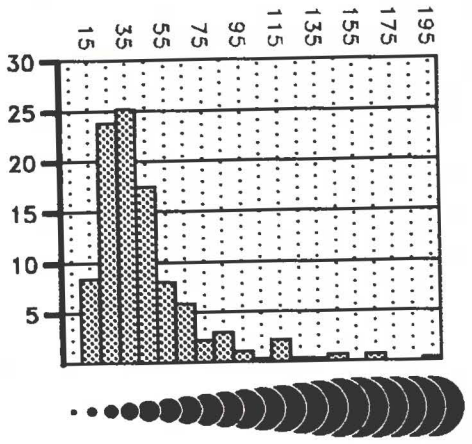
50 km

Fig. 20

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: La in stream sediment





La ppm

Instrumental Neutron Activation Analysis

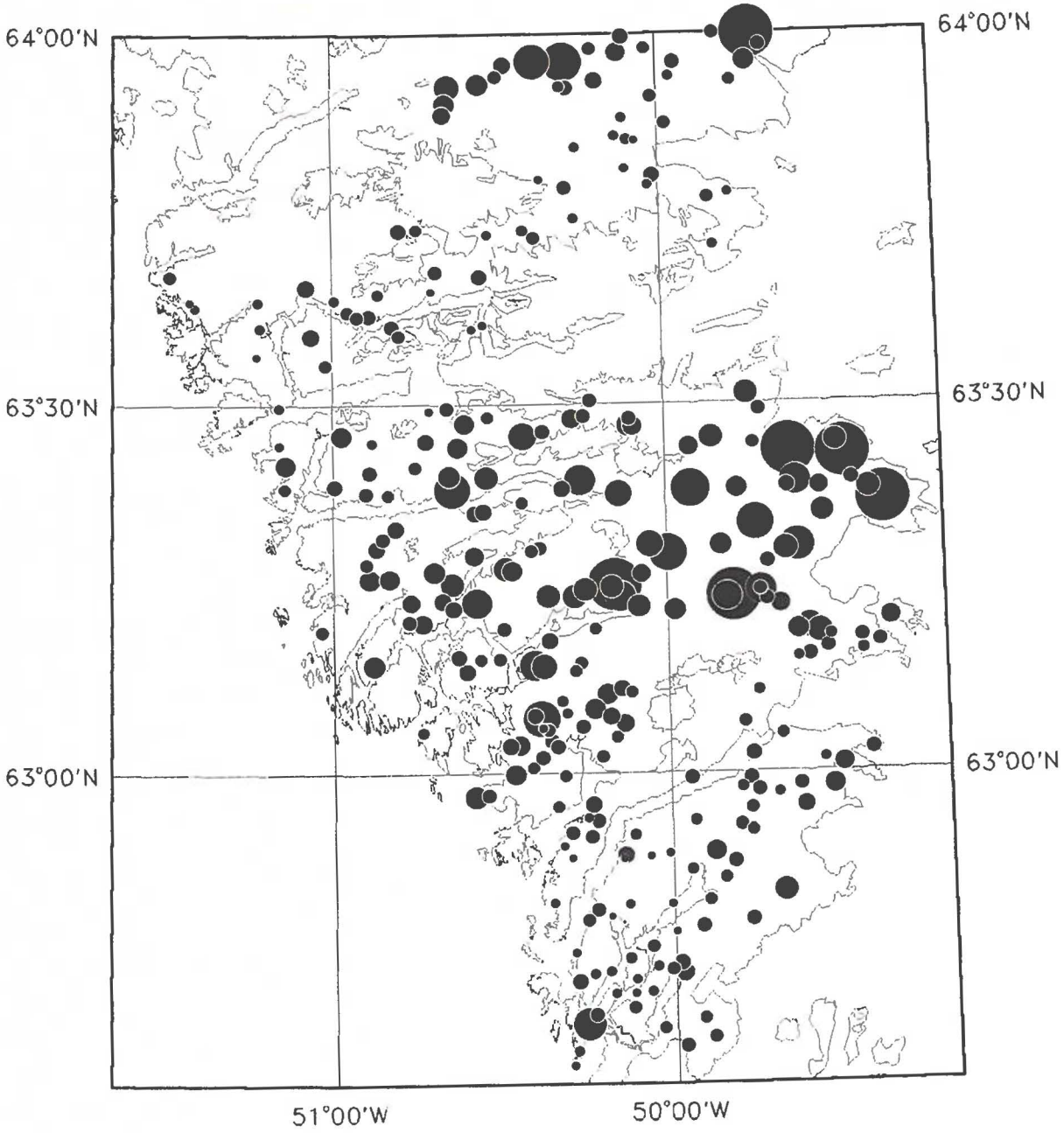
Number of samples:	277
Min. value:	10
Max. value:	370
Mean:	46
Median:	36
Variance:	1357
Std. Dev.:	37

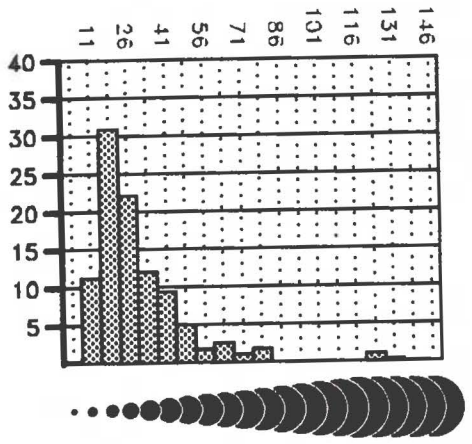
50 km

Fig. 21

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Nd in stream sediment





Nd ppm

Instrumental Neutron Activation Analysis

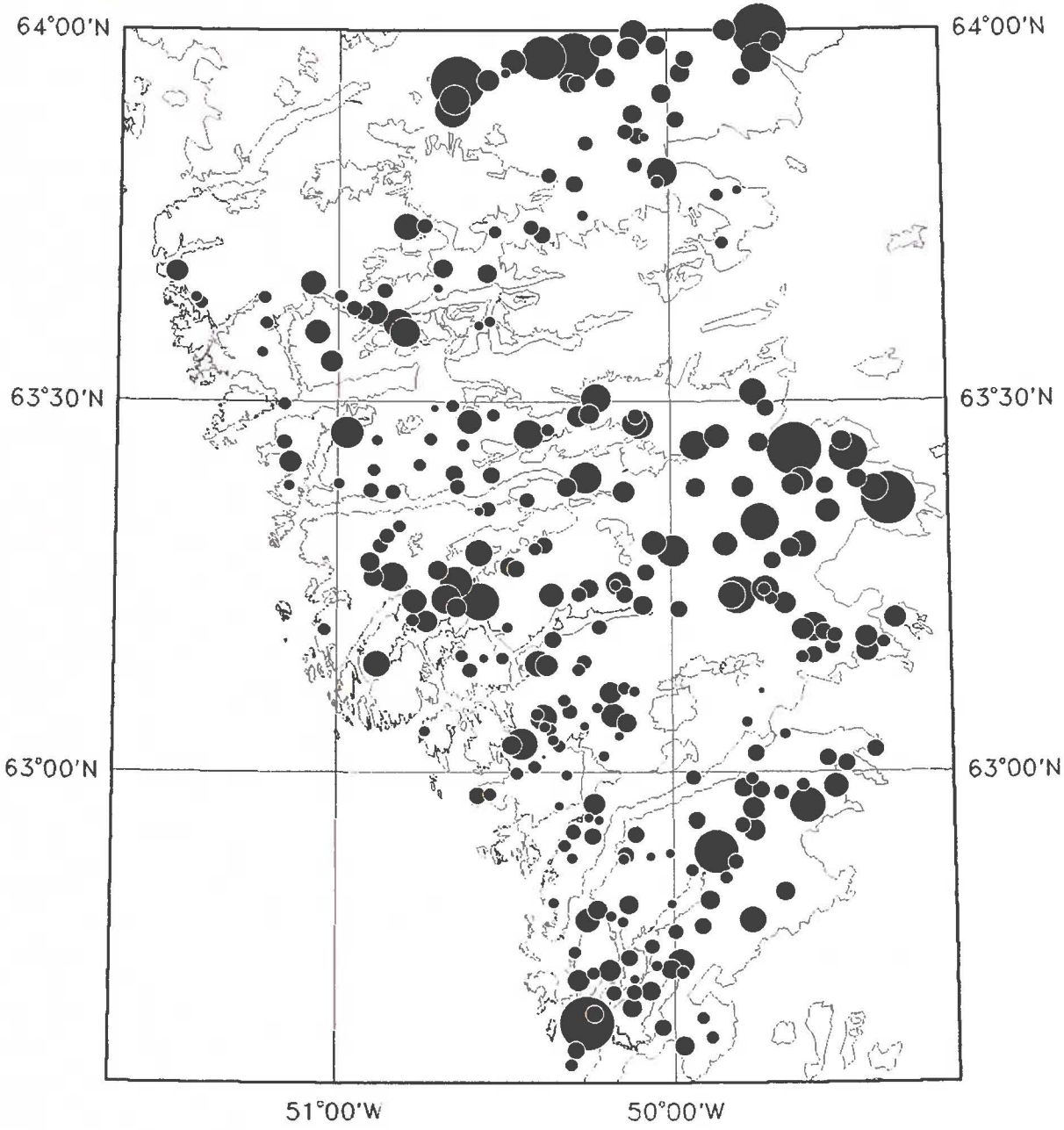
Number of samples:	277
Min. value:	0
Max. value:	280
Mean:	31
Median:	24
Variance:	635
Std. Dev.:	25

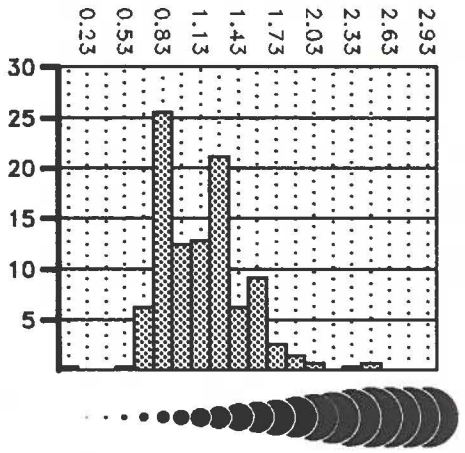
50 km

Fig. 22

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Eu in stream sediment





Eu ppm

Instrumental Neutron Activation Analysis

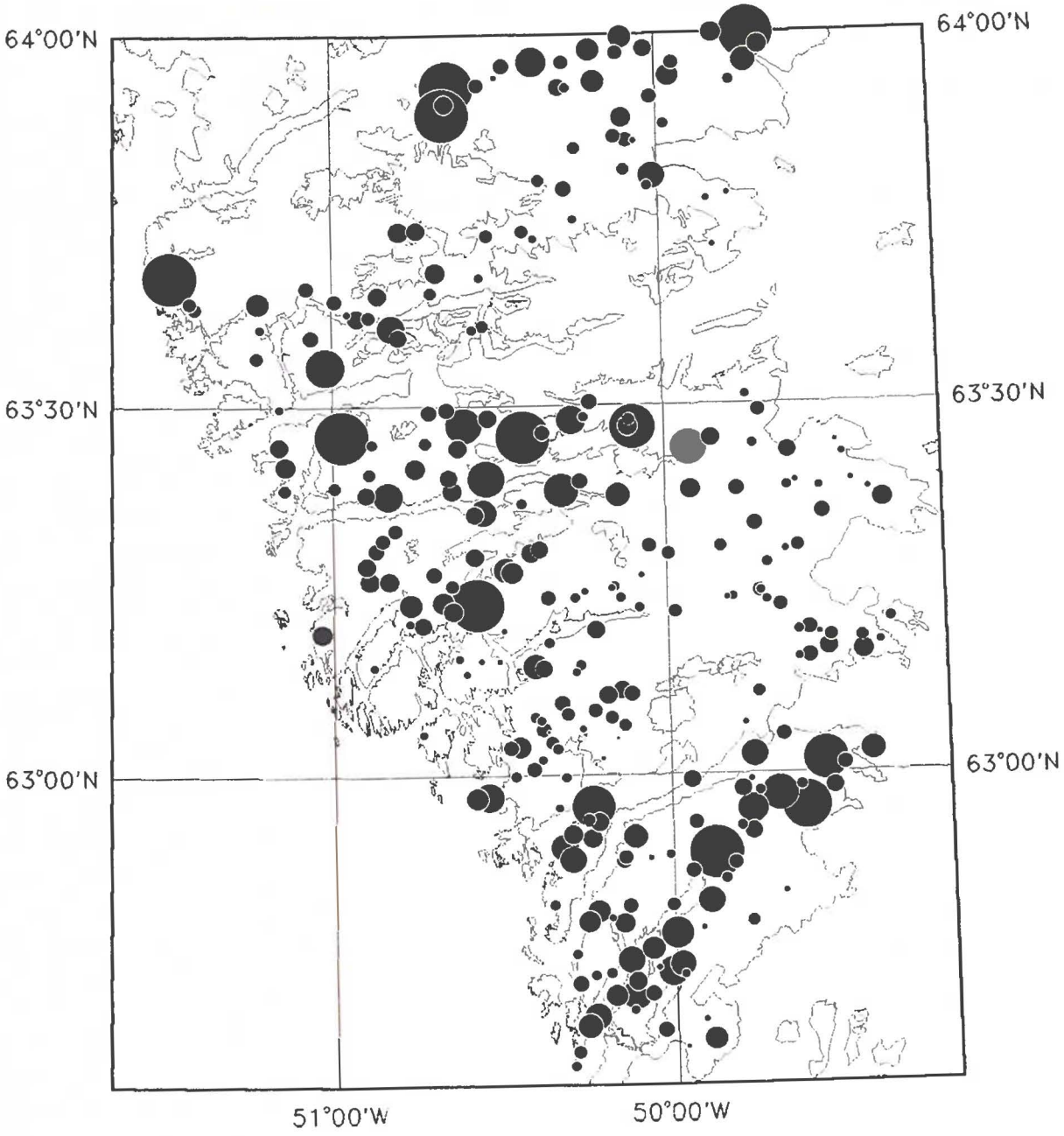
Number of samples:	277
Min. value:	0.00
Max. value:	21.00
Mean:	1.23
Median:	1.10
Variance:	1.58
Std. Dev.:	1.26

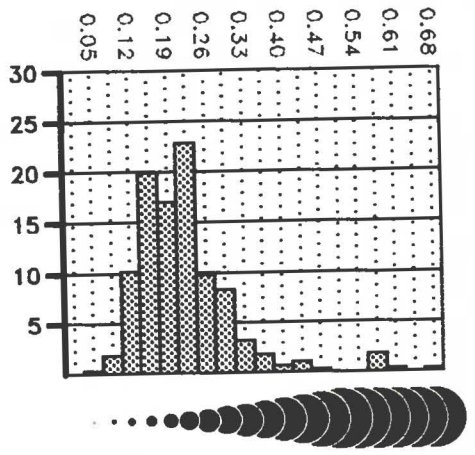
50 km

Fig. 23

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Lu in stream sediment





Lu ppm

Instrumental Neutron Activation Analysis

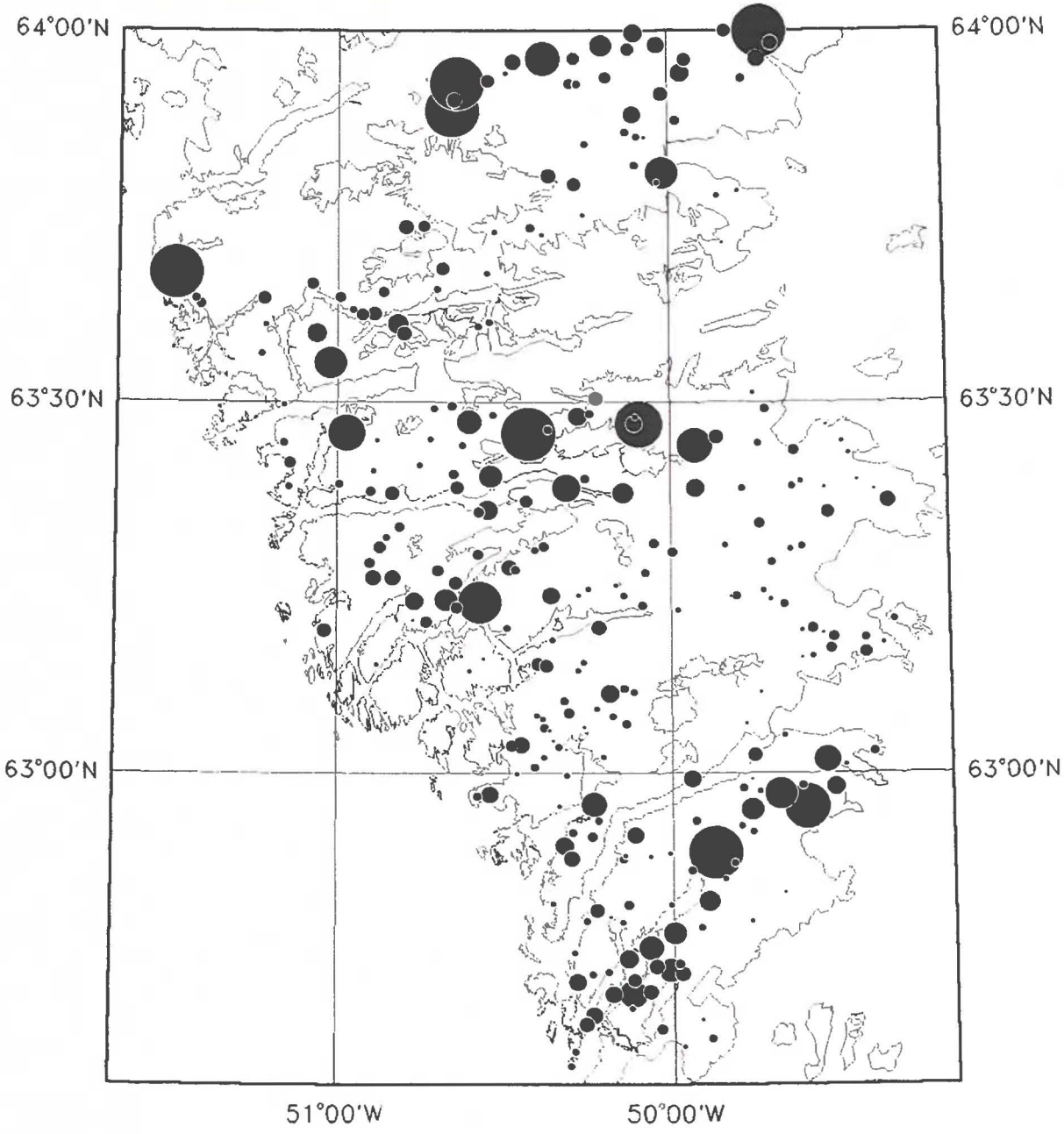
Number of samples:	277
Min. value:	0.06
Max. value:	0.70
Mean:	0.22
Median:	0.21
Variance:	0.01
Std. Dev.:	0.10

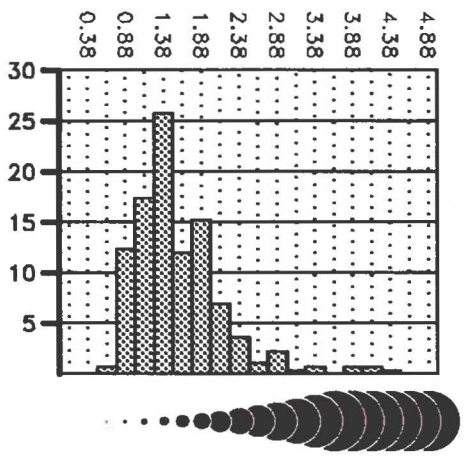
50 km

Fig. 24

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Yb in stream sediment





Yb ppm

Instrumental Neutron Activation Analysis

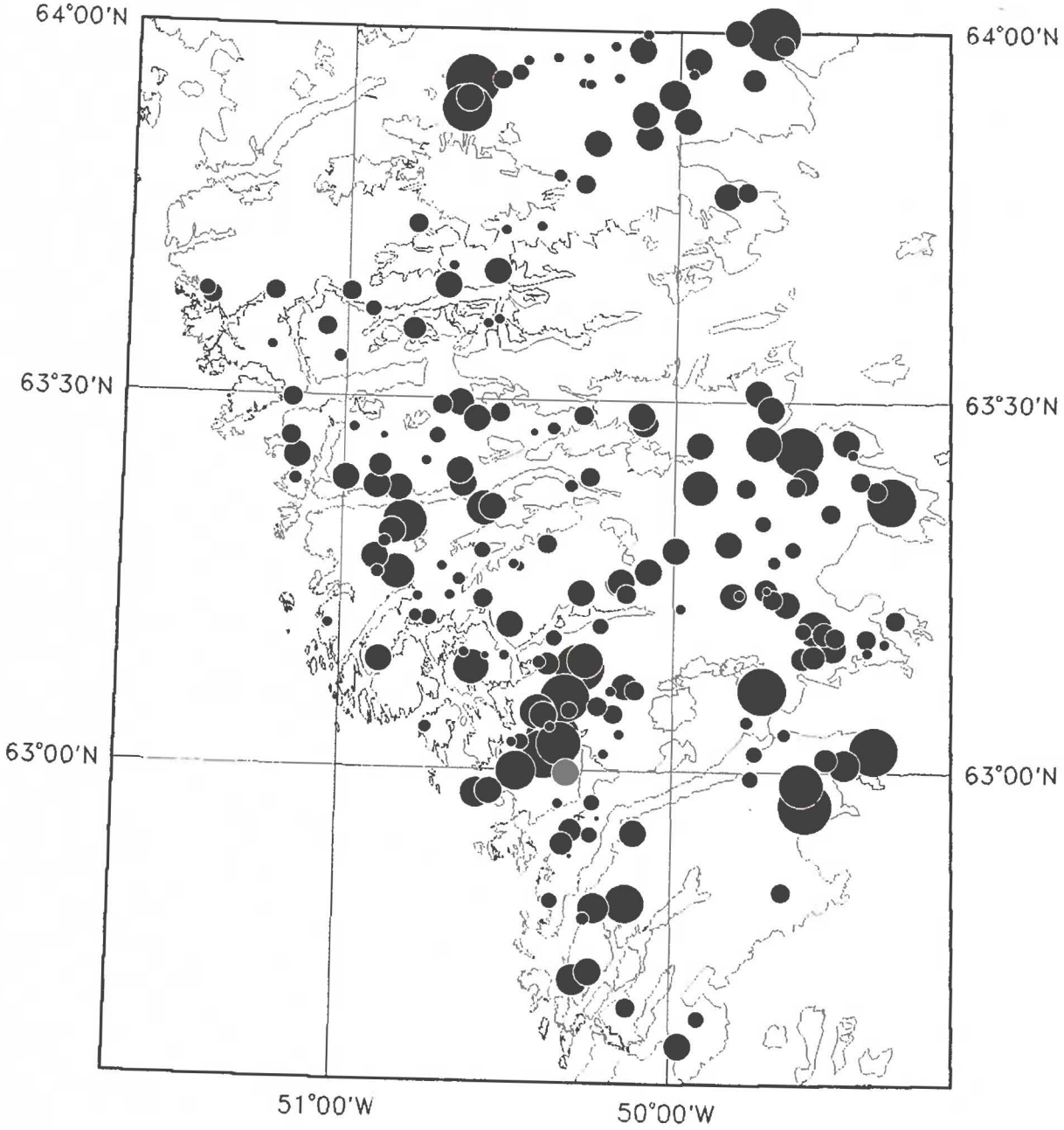
Number of samples:	277
Min. value:	0.54
Max. value:	6.30
Mean:	1.58
Median:	1.40
Variance:	0.44
Std. Dev.:	0.66

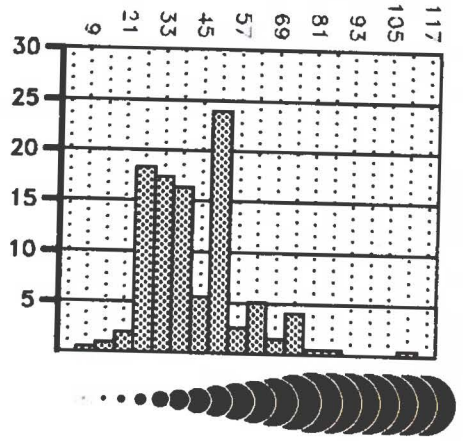
50 km

Fig. 25

Grønlands Geologiske Undersøgelse

GAMMA–RADIATION MAP: Total radiation





Counts per sec.

Scintillometry

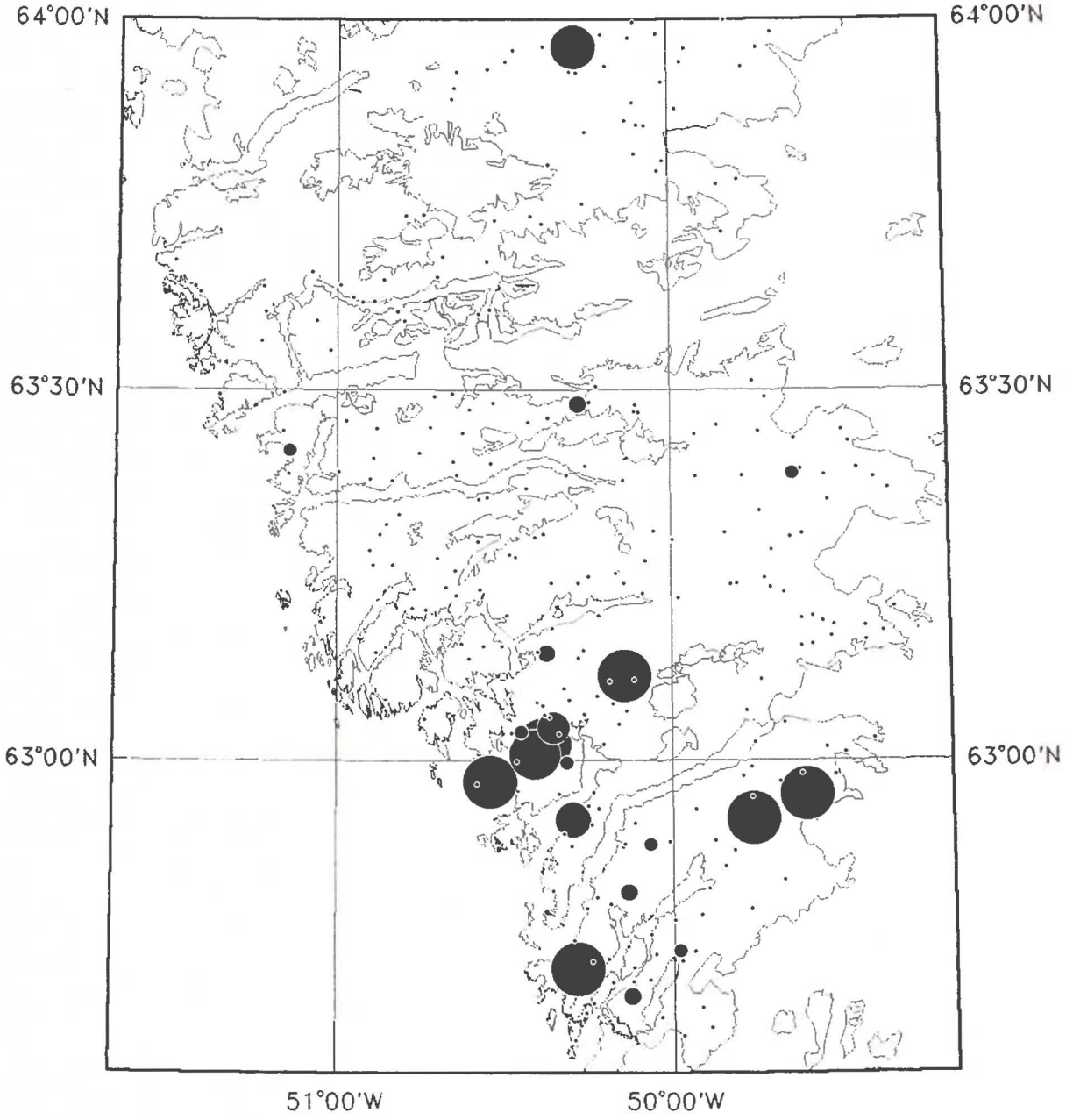
Number of samples:	197
Min. value:	8
Max. value:	200
Mean:	43
Median:	40
Variance:	355
Std. Dev.:	19

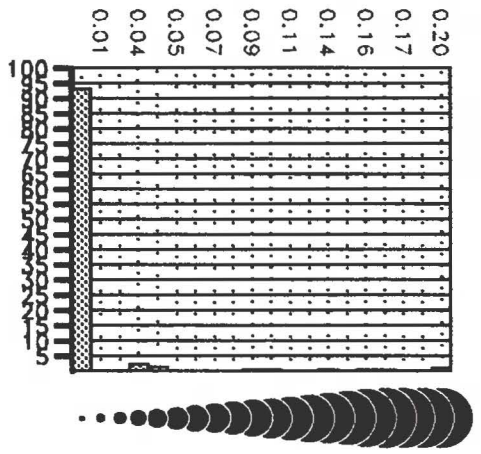
50 km

Fig. 26

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: U in stream water





U ppb

Laserinduced scintillometry

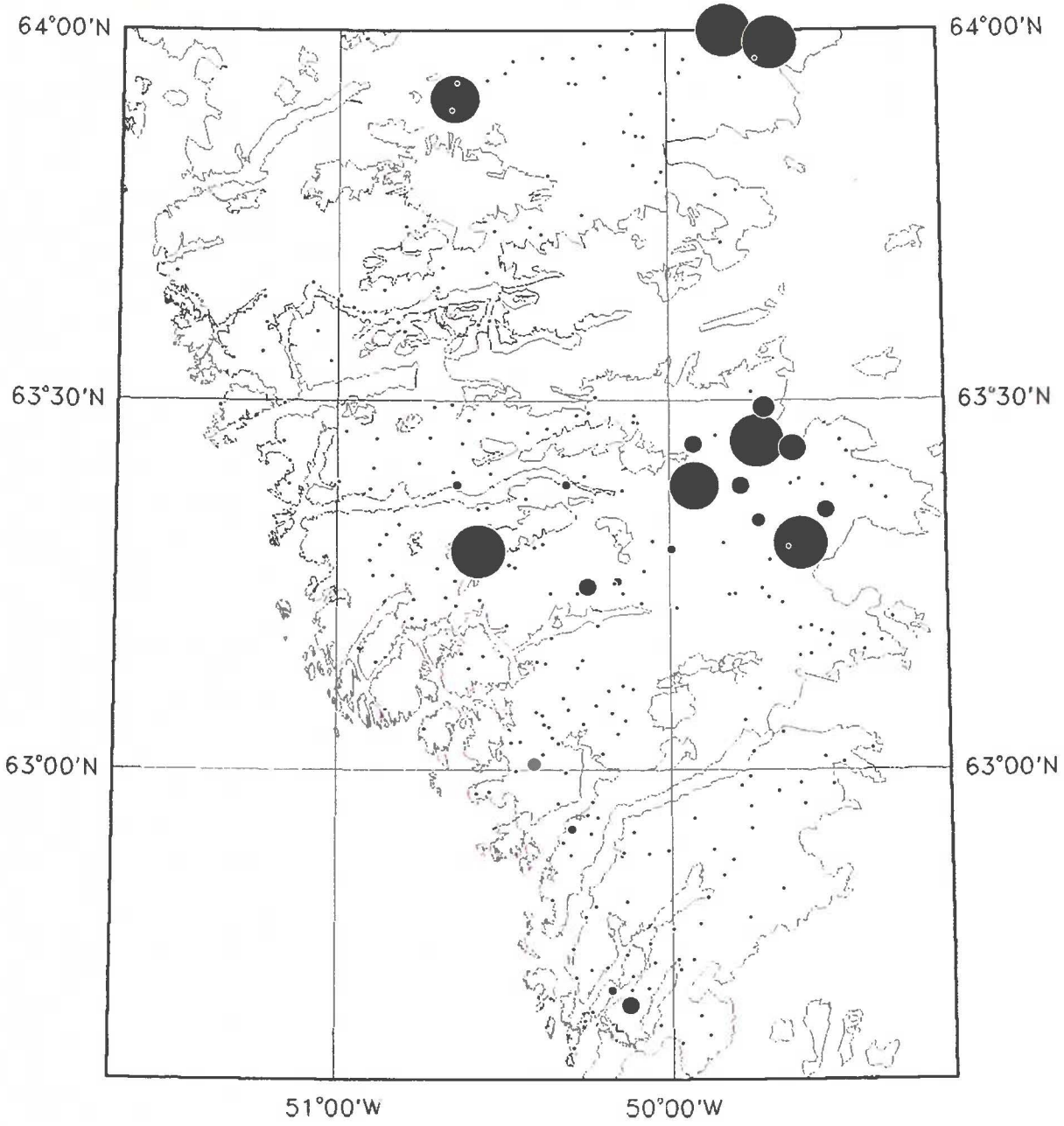
Number of samples:	268
Min. value:	0.00
Max. value:	0.25
Mean:	0.01
Median:	0.00
Variance:	0.00
Std. Dev.:	0.03

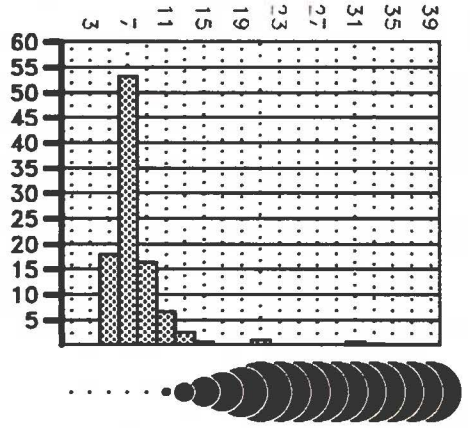
50 km

Fig. 27

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: F in stream water





F ppb

Ion sensitive electrode

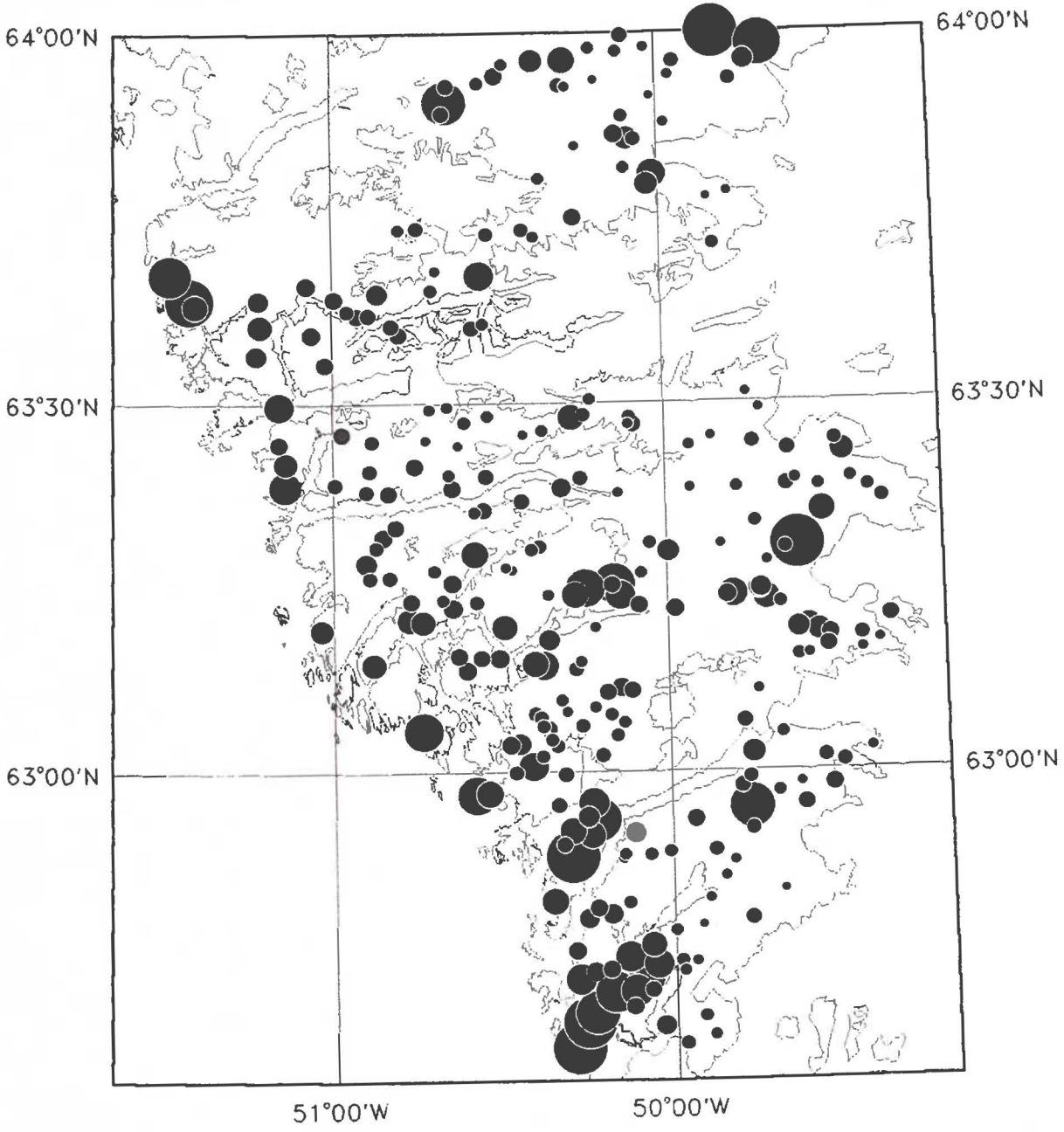
Number of samples:	268
Min. value:	4
Max. value:	45
Mean:	8
Median:	7
Variance:	17
Std. Dev.:	4

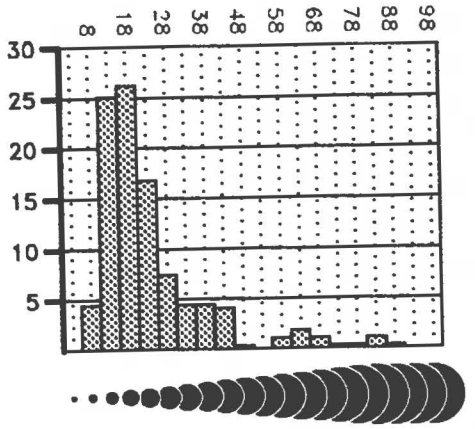
50 km

Fig. 28

Grønlands Geologiske Undersøgelse

GEOCHEMICAL MAP: Conductivity of stream water



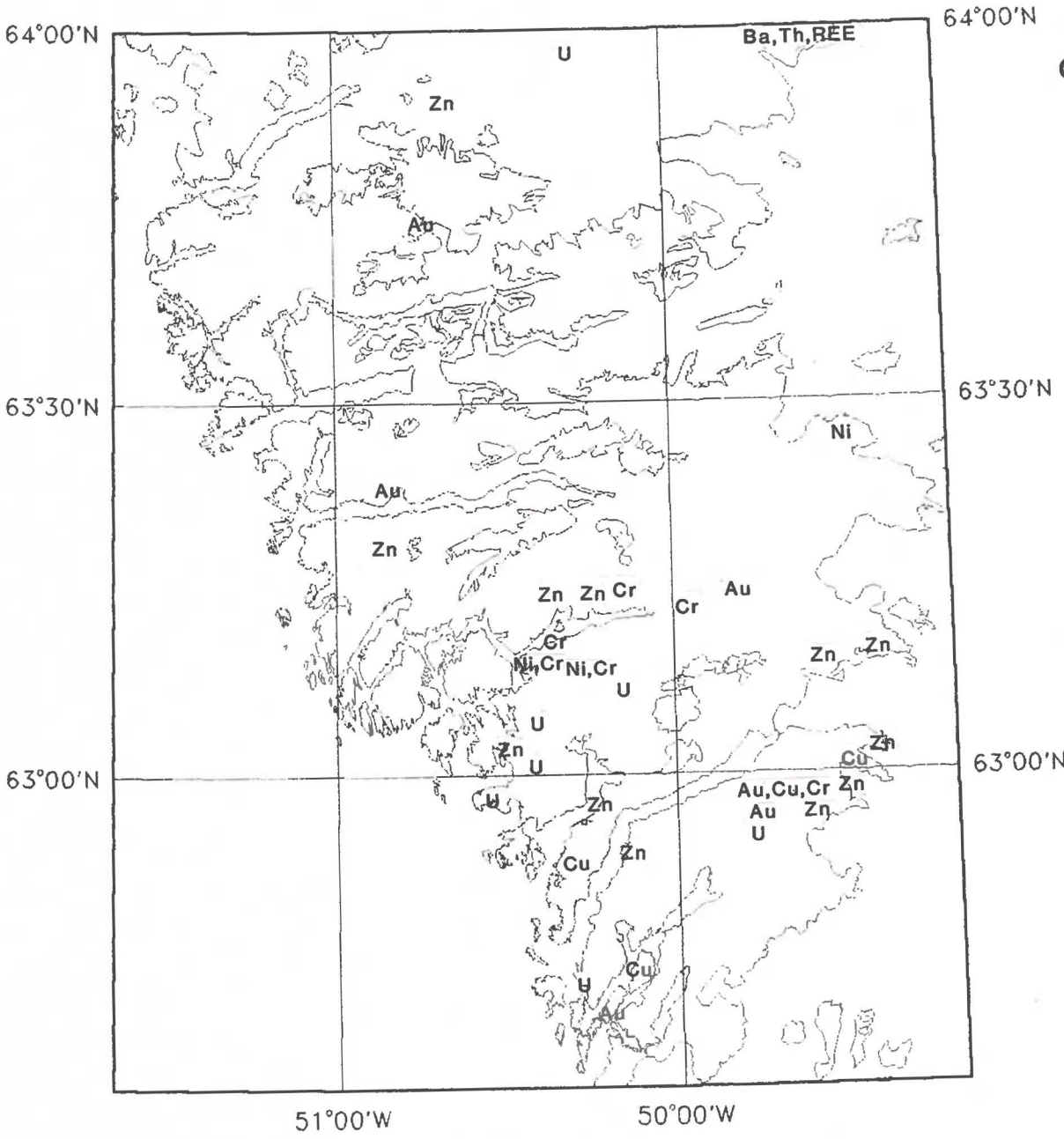


Micro Sievert

Number of samples:	268
Min. value:	8
Max. value:	132
Mean:	24
Median:	19
Variance:	261
Std. Dev.:	16

50 km

Fig. 29



GEOCHEMICAL ANOMALY MAP

Au		>	12 ppb
Zn	INAA	>	120 ppm
	AAS	>	90 ppm
Cu		>	100 ppm
Cr		>	600 ppm
Ni		>	300 ppm
U		>	25 ppm

Ba,Th,REE:

Sample having the max. attained values of Ba,Th,Ce,La,Nd,Eu,Yb.

50 km

Fig. 30

ISSN 0903-7322