## Conclusions

The ornamental stone project has revealed that West Greenland has only a limited potential for ornamental stones, mainly due to persistent regional joint systems. There are not many varieties of rocks which are sufficiently attractive to fetch a high price on the European market. However, a few types of rock deserve further consideration, notably anorthosite as a substitute for marble in gravestones, large deposits of grey rapakivi granite for building purposes, and the Igaliko sandstone. Further field studies are needed before samples from the Ammassalik district can be fully evaluated.

*Acknowledgements.* The authors are grateful to many people in Greenland who aided us during the field work especially at sea, and not least to N. C. Nielsen, Danstein A/S, for indispensable technical assistance and evaluation in Denmark. Published with permission from Grønlands Hjemmestyre.

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*A. A. G., Geological Survey of Greenland, Copenhagen.*
*C. B., CH-1410 Thierrens, Switzerland.*
*J. G., Mikkelborg Park 18, DK-2980 Kokkedal, Denmark.*

# Geochemical mapping: distribution of gold, arsenic, antimony and tantalum in South Greenland

*Agnete Steenfelt and Tapani Tukiainen*

New graphics software utilising raster techniques has been developed at the Geological Survey of Greenland (GGU) during 1989 and 1990 for presentation of geochemical and geophysical areal data. The software is very suitable for the display of the regional variation of chemical elements as contoured colour maps of interpolated data. In this paper we show the distribution patterns for a few selected elements of economic interest, which have been determined in stream sediment samples collected in South Greenland in 1979. The implications of the new information for the mineral potential of the region are briefly discussed.

## Data acquisition

The stream sediment samples were collected during a regional reconnaissance geochemical uranium exploration programme (Syduran) covering most of South Greenland (Fig. 1a; Armour-Brown *et al.*, 1982). About 2300 samples were collected at an average density of 1 sample per 6 $km^2$, and the $< 0.1$ mm grain size fraction was analysed at Risø National Laboratory, Denmark, for uranium by delayed neutron counting, and for 17 major and trace elements by radio-isotope energy dispersive X-ray fluorescence (Kunzendorf, 1979).

The uranium exploration and geological aspects of the results have been treated by Armour-Brown *et al.* (1983) and Steenfelt & Armour-Brown (1988). The multi-element data were presented as geochemical maps by Armour-Brown *et al.* (1982) and by Olesen (1984), and they were treated statistically by Armour-Brown & Olesen (1984). Steenfelt (in press) has dealt with the significance of the niobium, yttrium and uranium distributions.

Early in 1990 the stream sediment samples were reanalysed at Actlabs, Canada, for 34 elements by instrumental neutron activation. Only the gold and arsenic results of the new analyses have previously been published (Steenfelt, 1990). Remaining stream sediment sample material is currently being analysed at GGU for major and trace elements by X-ray fluorescence.

## Data processing and presentation

Regional geochemical data based on analysis of stream sediment samples essentially provides point information, and the conventional way of presenting results is to use symbol maps in which the size, shape or colour of the symbol illustrates the concentration of a particular element at the sample locality. This type of data presentation benefits the recognition and precise location of anomalous element concentrations.

However, the recognition of *geochemical provinces* requires display of the elemental background variation in a large area with even coverage of sample localities. In such background maps some kind of data-interpolation or gridding is necessary so that the local variation is suppressed and the large scale trends are more easily identified. Weighted and unweighted static or moving average methods are the most widely used (e.g. Cameron, 1986; Koljonen *et al.*, 1989).

In this report (Figs 1b, c & d) we have used the kriging technique, which is often referred to as 'the best linear unbiased estimator'. The kriging technique differs from other gridding methods in that it takes into account the directional changes in the behaviour of the sample medium.

The distribution of anomalies or of scarce and erratically occurring elements is best displayed by means of point symbols. Here we have chosen to show the distribution of anomalously high values of gold (Figs 3 & 4) as circles superimposed on the geochemical background maps which are relevant for the interpretation of the anomaly patterns. The size of the circles is proportional to the element concentration.

## Geological setting

The major lithotectonic units of South Greenland are shown in Fig. 1a. A comprehensive list of references to previous geological investigations in the area can be found in the description of the 1:500 000 geological map of South Greenland (Kalsbeek *et al.*, 1990).

The Archaean domain (3.0–2.8 Ga old) is dominated by basement gneisses and granitic rocks, and flanked to the east by Proterozoic supracrustal rocks, mainly basic volcanics (Fig. 1a).

The Early Proterozoic domain (Fig. 1a), divided into a granite and a migmatite province, was formed 1.85–1.75 Ga ago by accretion on to the southern margin of the Archaean continent (Patchett & Bridgwater, 1984; Kalsbeek & Taylor, 1985). The granite province is dominated by batholiths, while the migmatite province includes a variety of sediments and felsic volcanics which were deformed, metamorphosed, and intruded by acid to basic magmas during Proterozoic orogenic episodes (Allaart, 1976; Kalsbeek *et al.*, 1990). Late to post-tectonic granitic intrusions are represented by the so-called rapakivi suite (Fig. 1a).

Middle Proterozoic alkaline magmatism (1.3–1.1 Ga) associated with continental rifting affected both the Archaean and Proterozoic domains. In addition to the major intrusive complexes shown in Fig. 1a, the entire region is cut by basic dyke swarms, while downfaulted deposits of sediments, basic lavas and volcaniclastic rocks have a restricted distribution.

## Trace element background distribution

Previous studies have shown that the chemical composition of stream sediment in Greenland is very close to the composition of the bedrock surrounding the stream (Kalsbeek *et al.*, 1974; Steenfelt & Kunzendorf, 1978; Steenfelt, 1988). The stream sediment analytical data may therefore be used to display the presence of regional lithogeochemical variations.

The elements tantalum (Ta), arsenic (As), and antimony (Sb) presented here generally have very low concentrations in the samples, which is in agreement with the estimate for average abundances in the upper continental crust (Table 1). However, the maps (Figs 1b, c & d) show that the elements are not regularly distributed, but are enriched in certain districts.

Figure 1b shows that Ta is typically associated with the alkaline rocks. The highest values are related to the major alkaline intrusive complexes (cf. Fig. 1a) whereas the entire area affected by alkaline magmatism is outlined by high background for Ta (> 90th percentile). On

*Table 1. Estimated element contents*

| | Upper crust | South Greenland |
|---|---|---|
| As | 1.5 ppm | 8.9 ppm |
| Sb | 0.2 ppm | 0.38 ppm |
| Ta | 2.2 ppm | 1.8 ppm |

Upper crust: Upper continental crust (Taylor & McLennan, 1985).
South Greenland: Averages for stream sediment from South Greenland.

*Table 2. Abundance of arsenic in geochemical surveys*

| | 50% | 95% | 99% | Max. |
|---|---|---|---|---|
| South Greenland, percentiles of actual values⋆ | 3 | 33 | 110 | 1100 |
| Other geochemical surveys, percentile values | | | | |
| West Greenland, 64°–70°N, stream sediment | 0 | 5 | 19 | 717 |
| East Greenland, 74°–79°N, stream sediment | 1 | 14 | 30 | 270 |
| Baffin Island, lake sediments (Cameron, 1986) . | 4 | 90 | 250 | 999 |
| Nordkalott, till, fine fraction (Bølviken *et al.*, 1986) | 1.3 | 8.5 | | 74 |
| Scotland, stream sediment (Plant *et al.*, 1989) | 5 | | 46 | |

⋆The percentile values in Figs 2–4 are based on grid values.

the other hand the migmatite province appears to be deficient in Ta as compared to the estimated upper crustal average (Table 1). The Ta map suggests that the two alkaline intrusive complexes in the centre of the granite province have the highest potential for Ta mineralisation, and in fact a large low grade deposit is known in the north-eastern of the Ta-rich complexes (Tukiainen, 1988). This late to post-magmatic hydrothermal Nb-Ta deposit has been investigated in detail and resource estimates have been calculated (Thomassen, 1989).

Arsenic (As) and antimony (Sb) are associated with hydrothermal mineralising processes and the distribution maps of these two elements indicate where mineralisation has occurred. The high background district, outlined in the migmatite province, represents a significant enrichment in As and Sb which has not previously been recognised. The concentration levels are very high here compared to crustal abundance (Table 1), and As is also high compared to other geochemically surveyed areas (Table 2). The high backgrounds for the two elements partly coincide in this district, but elsewhere the distribution patterns are different; elevated levels of As are generally located near outcrops of basic volcanics, whereas the high levels of Sb occur in the vicinity of granitic or felsic supracrustal rocks. The origin or mode of the As and Sb enrichment is not known, and invites investigation as it is of importance for any modelling of gold mineralisation.

## Significance of the gold distribution

Arsenic (As) and antimony (Sb) are enriched in almost all types of gold deposits and they are widely used as indicators of gold mineralisation (Boyle, 1986; Davenport & Nolan, 1989; Plant *et al.*, 1989; Smith *et al.*, 1989). For this reason the gold anomalies have been plotted on the background maps for As and Sb (Figs 1c & d). The abundance and clustering of gold-bearing samples is considered significant in relation to the distribution of other elements and the geological setting. However, because the instrumental neutron activation analyses were conducted on the very small amounts of material that remained of the samples after the first round of analyses, (7 or 1 gram aliquots), the measured gold values of individual samples cannot be regarded as representative (Nichol, 1989).

The occurrence of Au-bearing samples in the As-Sb-rich district of the migmatite province is strongly indicative of gold mineralisation. Anomalous Au values for stream sediment samples have previously been recorded in this area (Steenfelt, 1987), and gold was obtained by panning at several localities (Christensen, 1989); the source of this gold has not yet been located. In view of the differences in the lithological affinities of As and Sb as displayed by the background maps, it is possible that there are at least two different types of gold mineralisation: one associated with As enrichment and hosted by basic volcanics, and one associated with Sb and hosted by felsic sediments and volcanics. In this context it should be noted that the area has a complex history of

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Fig. 1. (a) Major lithotectonical units of South Greenland based on Allaart (1975). (b) Geochemical map of Ta. (c) Geochemicalmap of Sb with suprerimposed anomalies of Au. Minimum circle size equals 20 ppb, maximum size equals 200 ppb and above. (d) Geochemical map of As with superimposed anomalies of Au. Circles as above.

The contoured element distribution maps based on panel kriging with a circular search area of 8 km and panel size of 5.5 km. The semi-variograms display raw data while the percentiles represent grid values. The circles mark the location of anomalies. The circle size is proportional to the element concentration in the intervals specified.

Fig. 1a.

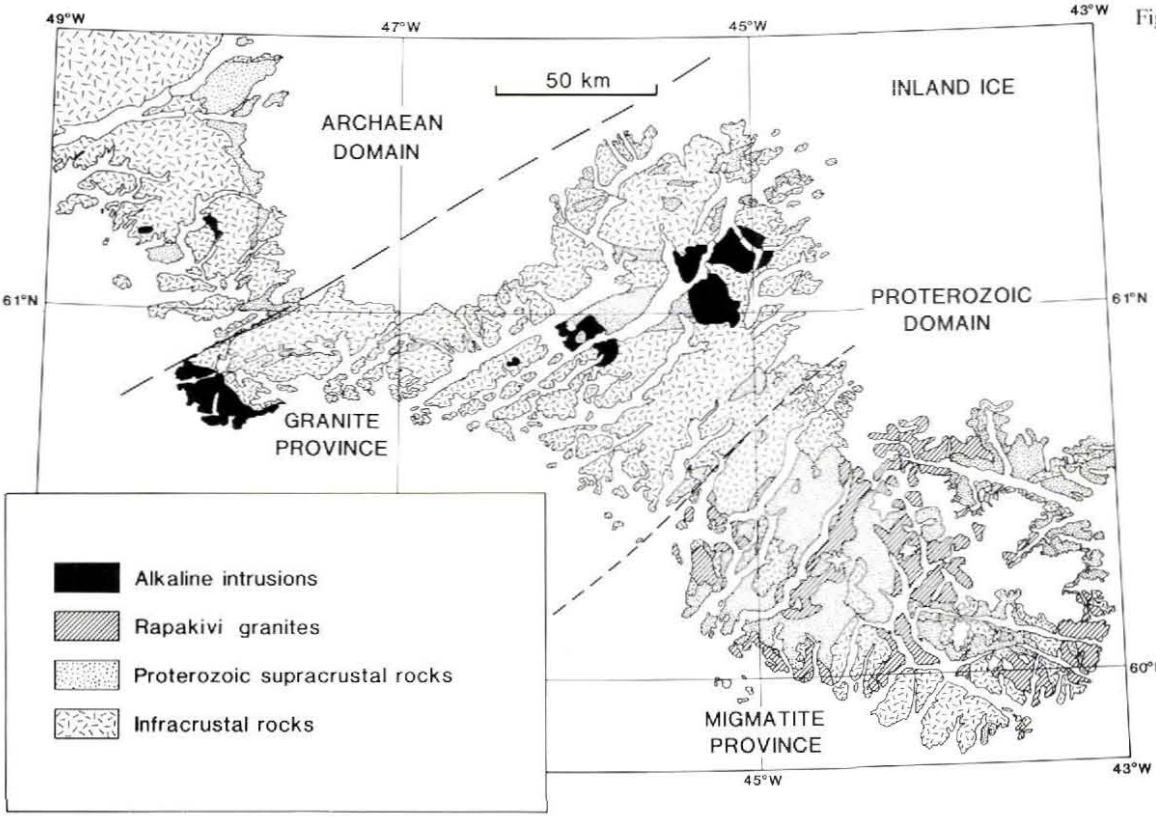
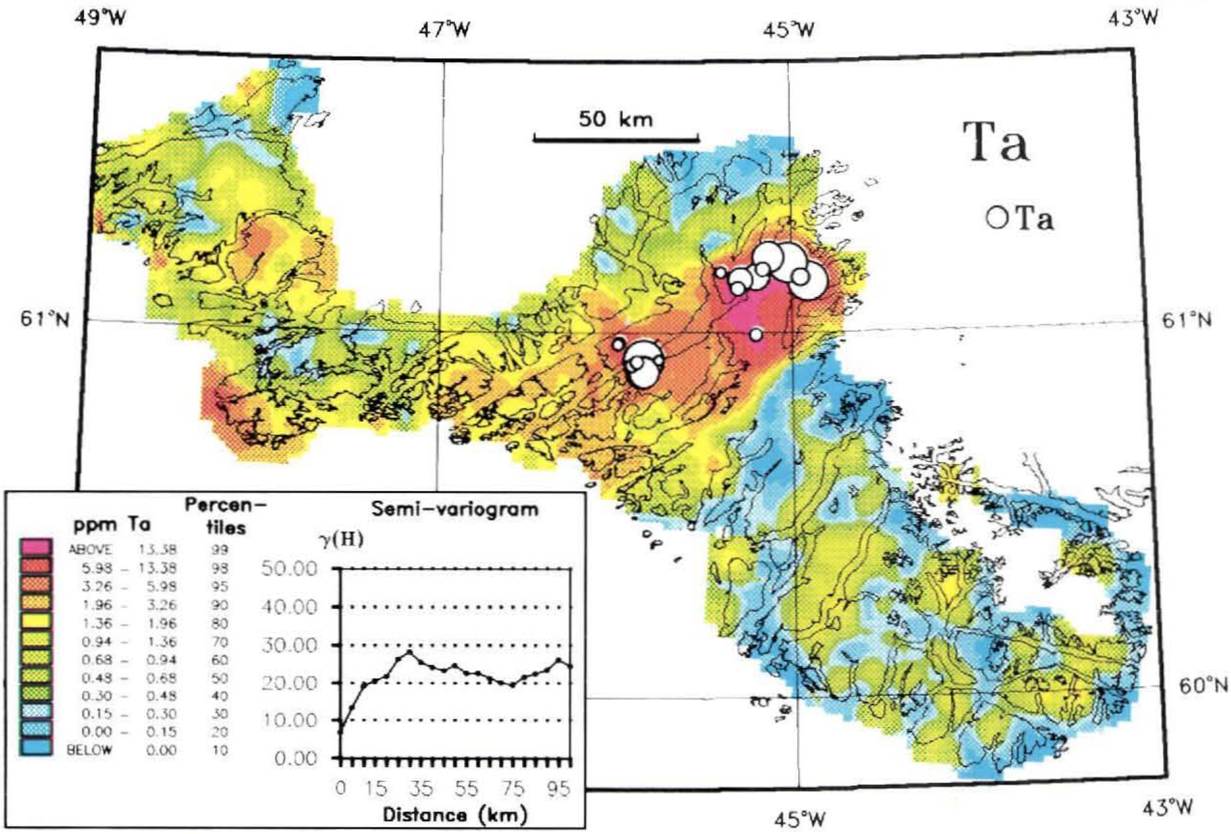
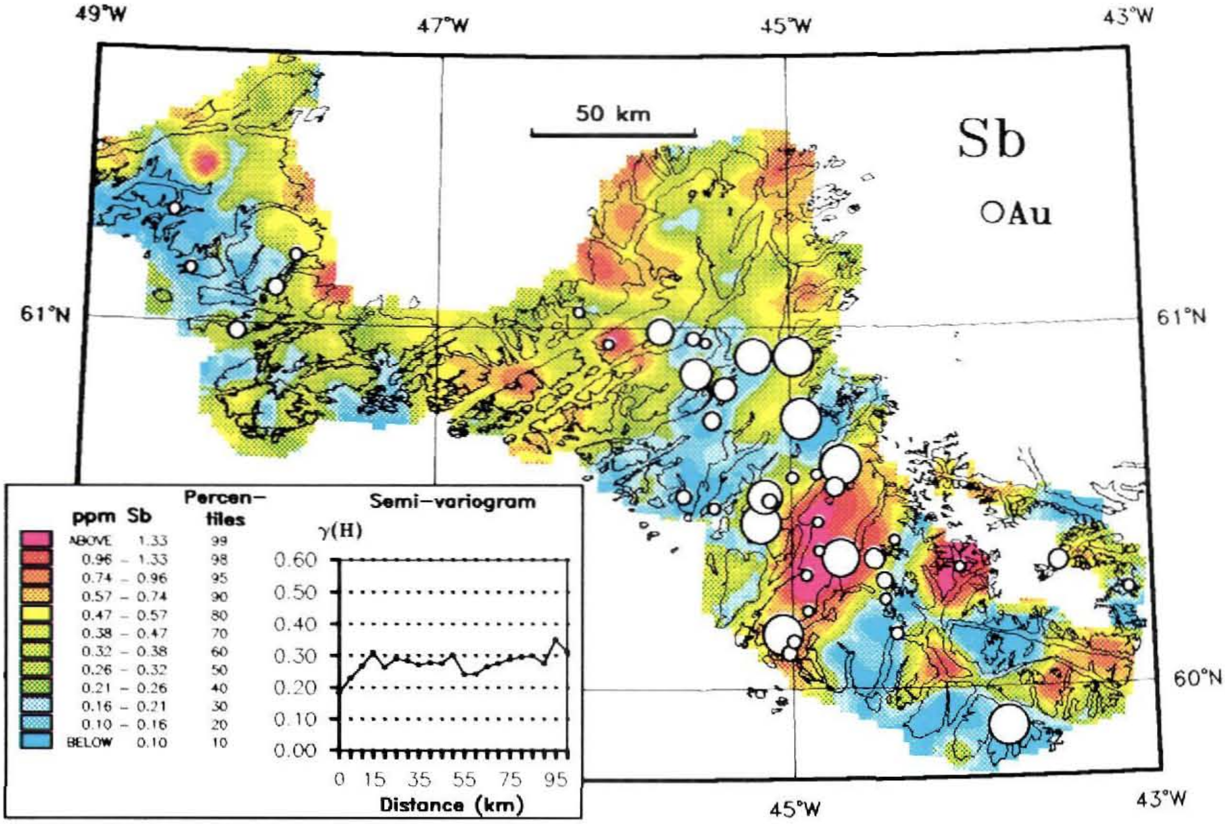
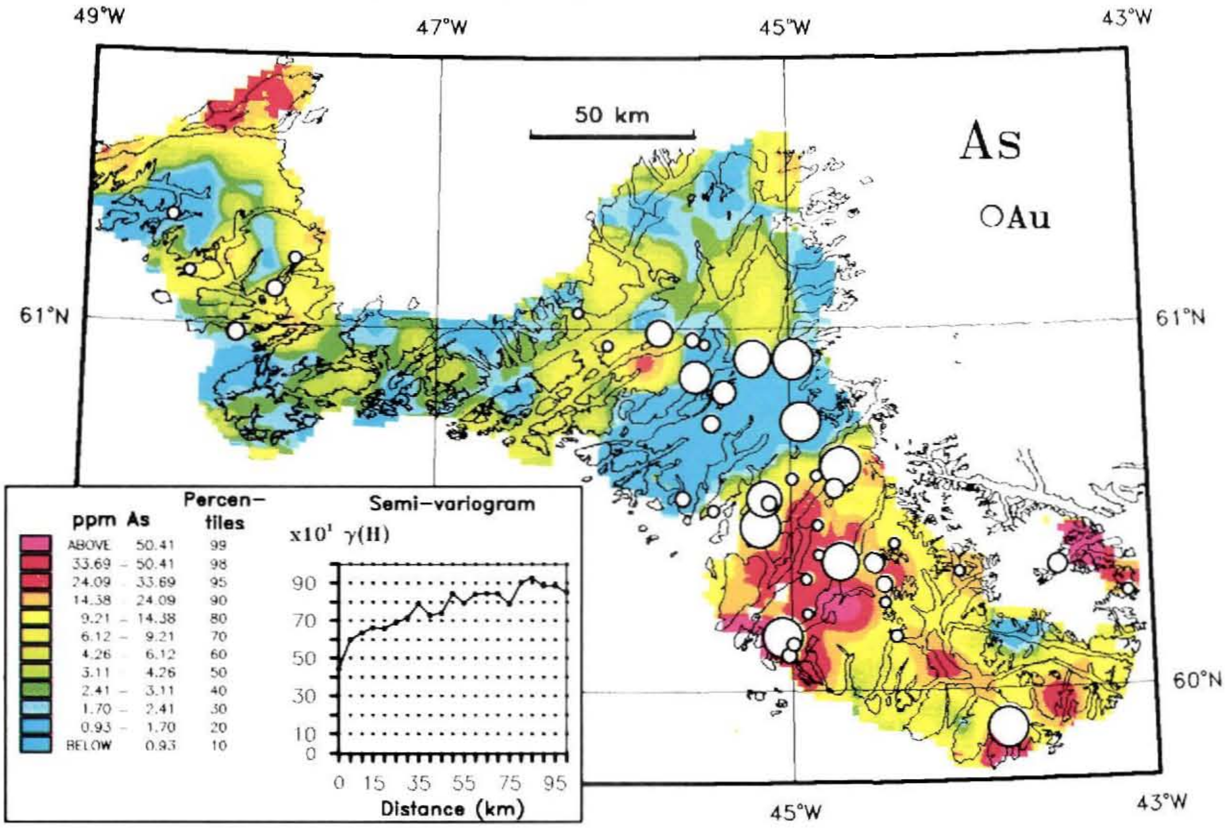

49°W
47°W
45°W
43°W
50 km
INLAND ICE
ARCHAEAN
DOMAIN
61°N
PROTEROZOIC
DOMAIN
GRANITE
PROVINCE
Alkaline intrusions
Rapakivi granites
Proterozoic supracrustal rocks
Infracrustal rocks
60°N
MIGMATITE
PROVINCE
45°W
43°W

Fig. 1b.


49°W
47°W
45°W
43°W
50 km
Ta
○Ta
61°N
61°N
60°N
ppm Ta
Percen-
tiles
ABOVE 13.38 99
5.98 – 13.38 98
3.26 – 5.98 95
1.96 – 3.26 90
1.36 – 1.96 80
0.94 – 1.36 70
0.68 – 0.94 60
0.48 – 0.68 50
0.30 – 0.48 40
0.15 – 0.30 30
0.00 – 0.15 20
BELOW 0.00 10
Semi-variogram
γ(H)
50.00
40.00
30.00
20.00
10.00
0.00
0 15 35 55 75 95
Distance (km)
45°W
43°W


49°W
47°W
45°W
43°W
61°N
60°N
50 km
Sb
○Au
ppm Sb
Percen-tiles
ABOVE 1.33 99
0.96 - 1.33 98
0.74 - 0.96 95
0.57 - 0.74 90
0.47 - 0.57 80
0.38 - 0.47 70
0.32 - 0.38 60
0.26 - 0.32 50
0.21 - 0.26 40
0.16 - 0.21 30
0.10 - 0.16 20
BELOW 0.10 10
Semi-variogram
γ(H)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 15 35 55 75 95
Distance (km)


49°W
47°W
45°W
43°W
61°N
60°N
50 km
As
○Au
ppm As
Percen-tiles
ABOVE 50.41 99
33.69 - 50.41 98
24.09 - 33.69 95
14.38 - 24.09 90
9.21 - 14.38 80
6.12 - 9.21 70
4.26 - 6.12 60
3.11 - 4.26 50
2.41 - 3.11 40
1.70 - 2.41 30
0.93 - 1.70 20
BELOW 0.93 10
Semi-variogram
x10¹ γ(H)
90
70
50
30
10
0
0 15 35 55 75 95
Distance (km)

deformation, metamorphism and magmatism which will also have affected any primary mineralisation containing Au, As, and Sb.

Some of the high gold values in the granite province (Figs 1c & d) are not associated with elevated backgrounds for As and Sb, and their significance is more difficult to evaluate. They occur mostly in the part of the province which is affected by alkaline magmatism. An eventual gold mineralisation in this area is likely to be of hydrothermal origin and related to shear or fracture zones (Steenfelt, 1990).

## Conclusion

The element distribution maps based on recently acquired neutron activation analyses of stream sediments provide new information of relevance for the evaluation of the mineral resource potential of South Greenland. The background maps of As and Sb outline major areas critical for gold mineralisation. Anomalously high Au concentrations in stream sediments confirm that such mineralisation has taken place. The display of anomalous values on relevant geochemical back-ground maps facilitates interpretation of their significance.

*Acknowledgment.* The neutron activation analyses were financed by Nunaoil A/S, Denmark.

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*A. S. & T. T., Geological Survey of Greenland, Copenhagen.*

# Registration of kimberlites and other potentially diamond-bearing rocks in Greenland

*Lotte Melchior Larsen*

Kimberlites are potentially diamondiferous rocks. They have been found at a number of localities in Greenland (Fig. 1), notably in the Holsteinsborg–Sarfartôq region and south of Frederikshåb (Andrews & Emeleus, 1971, 1975, 1976; Larsen, 1980; Scott, 1977, 1979, 1981; Thy *et al.*, 1987). Prospecting for diamonds and kimberlites was carried out by several mining companies in West Greenland in the years 1970–1988.

In recent years it has been realised that other rocks than kimberlites may carry diamonds. Some lamproites are now known to carry significant amounts of diamonds (Scott-Smith & Skinner, 1984; review by Bergman, 1987), and also ultramafic lamprophyres sometimes contain a few diamonds (Rock, 1986; Hamilton & Rock, 1990). Such rocks are also known from various localities in Greenland.

The potentially diamondiferous rocks kimberlite, lamproite and ultramafic lamprophyre are all of very deep-seated origin, hence the diamonds which are only stable at more than 150 km depth. They are all volatile-rich and strongly potassic, and distinction between the three groups involves a complex set of mineralogical and geochemical criteria. They occur mostly as thin dykes and sometimes as narrow volcanic pipes. The rocks weather easily and tend to be covered by soil and vegetation. Because of this they are very elusive rocks, and it is difficult to establish a true picture of their distribution in a region.

Some information about occurrences of kimberlites and related rocks in Greenland is published, as cited above. However, much unpublished information resides in the Geological Survey of Greenland (GGU) in a variety of forms ranging from Ph.D. and other theses through internal reports from scientists and mining companies to scattered field notes and samples from many mapping teams. All mining company reports relevant in this connection are now available to the public. In order to provide interested parties with more easy access to this very heterogeneous information source, a computer-based registration system has been established at GGU, covering all the currently known occurrences of kimberlite, lamproite and ultramafic lamprophyre.

## Registration

Each known locality has been given a number. The first part of the number is that of the Kort- og Matrikelstyrelsen (KMS, formerly Geodetic Institute) 1:250 000 topographical map sheet on which the locality is situated, while the second part is a consecutive number. This allows the number of localities within a given map sheet to increase with time as necessary. For each locality existing information is compiled in a standard form, as shown by the example in Table 1. In some instances the information available amounts only to a locality and