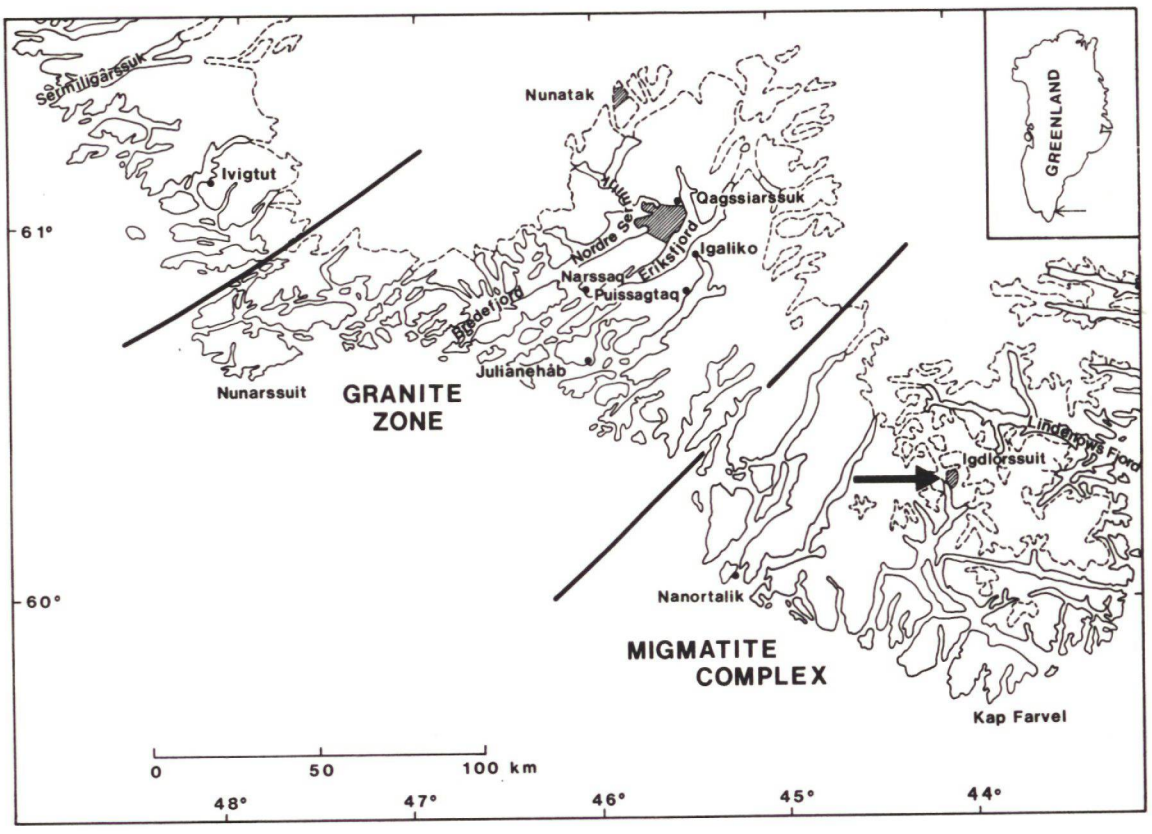
GEOLOGY AND EVALUATION OF THE URANIUM MINERAL OCCURRENCE AT IGDLORSSUIT, SOUTH GREENLAND



REPORT NO. 2
THE SOUTH GREENLAND EXPLORATION PROGRAMME 1984-1986

GRØNLANDS GEOLOGISKE UNDERSØGELSE
The Geological Survey of Greenland
ØSTER VOLDGADE 10, 1350 KØBENHAVN K, DANMARK

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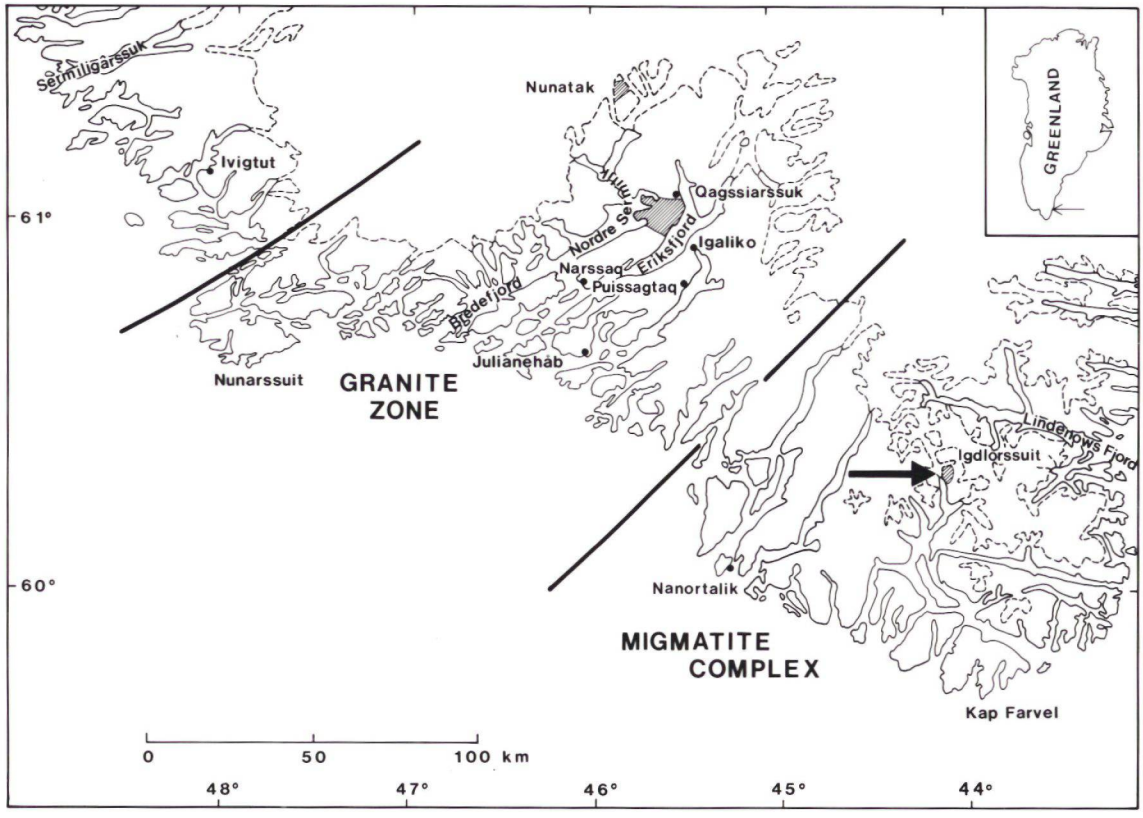

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GEOLOGY AND EVALUATION OF THE URANIUM MINERAL OCCURRENCE

AT

IGDLORSSUIT, SOUTH GREENLAND

The South Greenland Exploration Programme 1984-1986
Report No. 2

Ashlyn Armour-Brown

Plane table mapping at Igdlorssuit, view looking north

The Geological Survey of Greenland
May 1986

ABSTRACT

Geological and radiometric mapping, and petrological and mineralogical investigations were made of a uranium mineral occurrence at Igdlorssuit, South Greenland during 1984 and 1985. The results have been evaluated in terms of the uranium potential and genesis the showing. The work was part of the South Greenland Exploration Programme (Sydex) carried out by the Geological Survey of Greenland (GGU) in cooperation with Risø National Laboratory (Risø). It was financed by the Danish Ministry of Energy.

Igdlorssuit is located at the northerly limit of the fjord system about 60 km north of Kap Farvel (60° 23´; 46° 06´). The main uranium mineral showing is on a small alp on the eastern side, 500 m vertically above the fjord. Detailed plane table mapping (1:1000), and radiometric measurements with a lead collimated scintillometer calibrated for uranium delineated this occurrence. Regional mapping (1:10 000), however, showed that it was only one of many similar uranium occurrences in the area albeit the largest and richest.

The area contains a series of rafts or pendants of metasedimentary and metavolcanic supracrustal rocks dipping gently to the north-east in rapakivi granite. The uranium minerals are either disseminated along the layering in the supracrustal rafts, or more usually concentrated in small fractures which are themselves stratabound.

Isoclinal folds and sedimentary features indicate that the beds have been overturned and that the present layering does not represent the original bedding sequence. The rapakivi granite appears to have been controlled by this earlier structural fabric.

The supracrustal units have been mapped on the basis of their texture and composition and divided into five units. The metasediments include a polymictic metaconglomerate with well rounded felsic cobbles and boulders, and a meta-arkose probably with a volcanic rock component but sedimentary structures prove demonstrates its waterlain origin. The metavolcanic rocks include an intermediate lithic and crystal tuff of massive grey felsic texture and a basic to ultramafic pyroxenite unit. Associated with the latter two is a narrow sulphide and graphite rich siliceous bed. The metamorphic grade has been determined from coexisting ortho and clinopyroxene to be high granulite facies with a temperature of up to 900°C.

Over 35 uranium mineral occurrences have been found scattered over the hillside. They are stratabound to certain members of the meta-arkose and intermediate metavolcanic units. The uranium bearing mineral is uraninite which is disseminated as fine grains through the strata or concentrated as medium sized grains along the pre-rapakivi fractures and associated breccias. This mineralisation, therefore, can be classified as stratiform but locally controlled by folds and veins where it has been concentrated by structural and metamorphic events.

Textural and paragenetic relationships, and isotopic data show that the uranium was present in the supracrustal units before the folding, metamorphism and intrusion of the granite. Isotopic and chemical ages of strictly stratabound uraninite indicate an age of 1740 Ma which corresponds to the U-Pb isotopic ages of the zircons in the rapakivi granite. An uraninite occurrence in a vein on the other hand returned an age of 1704 Ma suggesting a later remobilisation.

The largest, highest grade uranium mineralised zone is about 50m long and up to 5m wide with an average grade of 0.31% with highs up to 7%. If the surface dimension is projected 60m down dip to based on the distribution of the supracrustal units this would give a atonnage of about 17 000 tons of ore or about 50 tons of uranium.

The results of the mapping and sampling has established that this type of mineral occurrence can reach economic grades, and its surface expression suggests a size which could approach economic proportions. The wide

distribution of occurrences suggests that uranium was present over larger area than just Igdlorssuit. The stratabound distribution of the minerals suggests that the uranium was already present in the supracrustal units but was mobilised by the regional metamorphism and concentrated in zones of lower pressure such as on the crests of folds, an abstract should be able to start above, or in the fractures.

This type of mineral occurrence probably accounts for the many uranium anomalies identified in the Migmatite Complex, both by the airborne gamma-spectrometer and geochemical sampling, and should constitute the type of target to be sought in future exploration in the area.

GEOLOGY AND EVALUATION OF THE URANIUM MINERAL OCCURRENCE AT IGDLORSSUIT, SOUTH GREENLAND

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1 INTRODUCTION

1.1 Backgrounds, aims and personnel

One of the main aims of the South Greenland Exploration Programme (SYDEX) was the detailed evaluation of the uranium showing found previously by the SYDURAN project at Igdlorssuit, South Greenland. This report describes the results of the field work carried out in 1984 and the subsequent evaluation of the petrographic, mineralogical, and analytical studies and the conclusions that can be drawn from them.

The Igdlorssuit uranium showing is situated at the northerly limit of the fjord system about 60 km north of Kap Farvel (60°23´N, 44°06´W) (fig. 1.1). The showing is on a small alp on the eastern side of the fjord, about 500 m vertically above the sea. Access to the alp is only possible by helicopter or a steep mountainous route to the south down to the fjord which is not practical for transportation of heavy equipment.

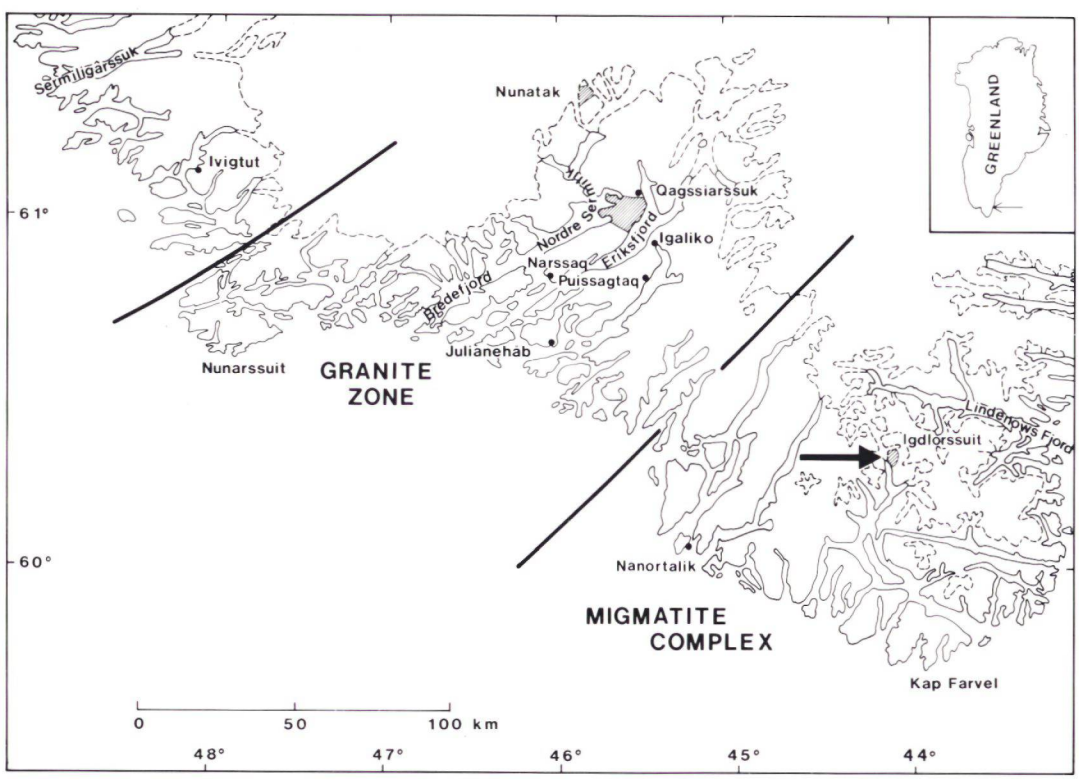


Fig. 1.1. Location map of Igdlorssuit, South Greenland.

The showing was originally found by Bjarne Wallin using helicopter-borne scintillometry during the 1982 field season when investigating a uranium gamma-spectrometer anomaly from the reconnaissance survey. It was briefly described in the final report of The SYDURAN programme (Armour-Brown et al., 1983).

The project was financed by the Danish Ministry of Energy under its Energy Research Programme 1984 (EFP ´84) the Geological Survey of Greenland (GGU) in collaboration with Risø National Laboratory (Risø) were responsible for the project and it was under the direction of Agnete Steenfelt at GGU and Leif Løvborg at Risø.

A. Armour-Brown of GGU made the regional geological map and Bjarne Wallin of Risø the detailed geological map. They were assisted in the field by Poul Sørensen (Risø) who carried out the detailed radiometric survey along with the associated calculations and plotting of results, Jens P. Nielsen who made the plane table topographic map, and Hans Christiansen who prospected the hillside with a scintillometer and found many of the radioactive occurrences. Much of the laboratory work was carried out by Eva Nørringgaard and later by Morten Heegaard of GGU.

1.2 Methods

The field mapping, sampling and radiometric grid measurements were made during a three week field period from 22nd July to 12th August, 1984. The five man field team and 1200 kg of equipment were flown in one trip from Narssarssuaq with a Sikorski S-61 helicopter, chartered from Grønlandsfly A/S. Although the pilot was concerned about the weight he took two extra passengers on the outward flight and had no difficulty landing. The camp site was adequate if a little exposed. The view is dramatic in all directions. The weather was changeable and 6 days were lost due to bad weather but there were sufficient dry and sunny days to carry out the planned work on schedule.

1.3 Topographic mapping

The geological mapping was prepared at a regional scale of 1:5000 and a detailed scale of 1:1000. The topographic base map for the regional map was made from a set poor quality aerial photographs taken in 1947 (flight GRE-6, photo nos. 4302, 4304 & 4306). Control points supplied by the Geodetic Institute and the fjord level allowed control of the altitude and the geographic position. The contours were mapped using the photogrammetric equipment (PG-2) available at GGU by Olav Winding. Parallax problems because of the poor quality of the photographs, which had incomplete overlap and shadows along the steep slopes, makes the final map of dubious accuracy, but it was adequate at the scale of observation and the illustrative purposes for which it has been used.

The topographic base map for the detailed map was made in the field using a plane table and alidade. The topography was drawn directly onto the map by the surveyor (Jens P. Nielsen). The geology could then be sketched in with

relatively good accuracy. Providing there was no rain and wind to shake the plane table, mapping at this scale was rapid at 1:2500 scale or less. If the surveyor had had previous experience with the method a larger area could have been mapped.

Two maps were made at 1:500 scale, one to the north and one to the south of a stream which forms a steep canyon (map 3) and by joining control points surveyed at 1:2500. These maps were digitised at Risø and combined using a computer graphics system.

The horizontal error on the resulting 1:1000 scale map (map 2) is of the order of +/- 1 m. The relative error between contoured heights is of the same order of magnitude but the altitude above sea level had to be approximated from the contours on the photogrammetrically prepared regional map. Three control points common to both maps were compared with a control measurement from sea level using a paulin altimeter. On the basis of the best fit of these criteria the 0 m contour on the plane table map was selected as corresponding to an altitude of 478 m. There is an uncertainty in this altitude of at least +/- 5 m. The geographic grid has been added to the plane tabled, detailed map on the basis of the three common control points. The relative positions of the three control points, identified on the aerial photographs, and compared with those mapped by the plane table were within +/- 1 m. The scale was reduced, however, by 4.4%. This discrepancy is presumed to be due to the poor quality of the aerial photographs. The geographic grid was, therefore, positioned on the detailed map by using the closest fit between the three control points and enlarging the grid by 4.4%. The control points can be identified in the field and they have also been marked with paint which should remain visible for a few years and on the aerial photographs used in the field.

1.4 Acknowledgements

The author is indebted to a great number of people, without whose assistance this work would not have been possible. He would like to thank all those at Risø, Elektronik Afdeling who have been involved with this study. The section describing the radiometric survey equipment and results were contributed by Leif Løvborg. Many of the uranium and other trace element analyses were carried out at Risø by Per Jensen and under the direction of Helmar Kunzendorf.

I would also like to thank my colleagues, Per Nyegaard and Tapani Tukiainen for many helpful discussions, Adam Garde for his contributions to establishing the grade of metamorphism, and Jørn Rønsbo for his assistance with the elektron-microprobe analysis. Isotopic analyses have been carried out by Ian Swainbank at the British Geological Survey.

2 GEOLOGY

2.1 Regional geology

Previous geological work in the Igdlorssuit area has been restricted to coastal surveys by Bridgwater et al. (1966) and Sutton & Watterson (1968). The area has been classified as pelitic to semipelitic gneisses on the 1:500 000 scale geological map (Allaart, 1975).

From our more detailed survey at Igdlorssuit it is clear that rapakivi granite is the main rock unit from sea level up to the higher peaks with only minor components of metamorphic rock. These are mainly metavolcanic, and meta-arkosic units. The rock units and their metamorphic grade are similar to those described elsewhere in the Migmatite Complex (Dawes 1970, Escher 1966). In particular Wallis (1966) has described very similar units in the area some 20 km to the west of Igdlorssuit. The only unit present at Igdlorssuit which has not been described by other workers in the complex is the intermediate metavolcanic unit. There is only one reference in Sutton & Watterson (1968), to agglomerate found in the fjord system north of Augpilagtoq. It is the writers belief that this is a problem of field identification, because much of the intermediate metavolcanic unit is a massive structureless rock and could have been classified as a meta-arkose. All workers in the the complex have referred to metaconglomerate and meta-arkose (also referred to as a quartzite by Escher (1966)) with preserved sedimentary structures. They have also referred to a narrow sulphide rich unit with graphite. The general stratiform nature of this sulphidic unit is well illustrated in Wallis´ sketch map showing the location of the subhorizontal rusty bands along both walls of a large valley (Wallis, 1966). Dawes (1970) has identified the main sulphide minerals in these bands as pyrrhotite with lesser amounts of chalcopyrite, pyrite and marcasite.

Earlier workers have tended to minimise the importance of isoclinal folding and emphasise the flat-lying structure and widespread development of a flattening-type of fabric with no stretching or linear element (Escher & Watt, 1976). All previous workers, however, describe synmetamorphic isoclinal folding with relatively low angle to horizontal plunges albeit in rather different directions. This inconsistency of axial directions could presumably be due to the younger more open folding with NW axial direction which has been described by Escher (1966).

The metamorphic grade for most of the complex has been described as high amphibolite facies (Escher & Watt, 1976). Wallis (1966) and Dawes (1970), however, both point to widespread granulite facies metamorphism with limited areas of retrograde metamorphism to the amphibolite facies. Wallis also maintains that it increases in grade towards the east of his area. That is to say towards Igdlorssuit.

The Ketilidian (mid-Proterozoic) age of the rocks in the complex is well established by isotopic studies. These are summarised in fig. 4.3. (Gulson & Krogh, 1975). More recent isotopic studies including Nd-Sm and Pb-Pb whole rock data have shown that there is either a very low (10%) component of Archaean crust (Patchett & Bridwater, 1984) or otherwise none at all (Kalsbeek & Taylor, 1985).

2.2 Geology at Igdlorssuit

2.2.1 Lithological units

The supracrustal units occur as a series of rafts, elongated in the NNW-SSE direction dipping gently to the ENE. Their distribution and density are best illustrated on an uncontrolled section taken from an oblique photo because of the steep slope of the area which averages 50^{o} below the alp, and 30^{o} above it (fig. 2.1). They have been divided on the basis of their texture and mineralogical composition into five units. It has not been possible to establish a stratigraphy, but by assuming that a conglomerate is the the basal unit and was a reclining anticline, an apparant stratigraphy evolves which is indicated by the order of the units in the legend.

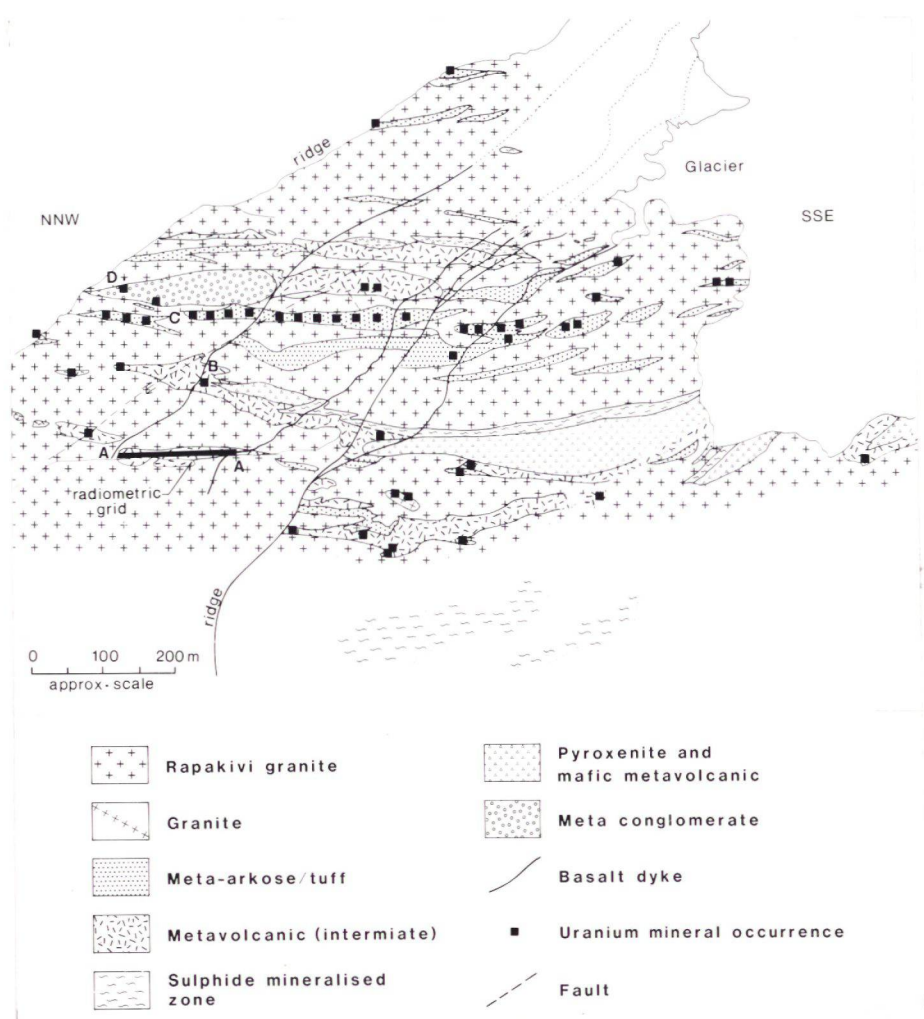


Fig. 2.1. Geology of Igdlorssuit illustrated on oblique photo.

Metaconglomerate

The most distinctive unit is a metaconglomerate. It is composed of pebbles and cobbles of felsic composition in a calc-silicate matrix. The cobbles have been deformed by tectonism (fig. 2.2.). The unit outcrops over a horizontal distance of 250 m and has a maximum width of 50 m with its southern limit formed by the crest of a reclining antiform with a horizontal NNW-SSE axis. It

Fig. 2.2. Photograph illustrating texture of the metaconglomerate.

is pinched out by the rapakivi granite to the north. It contains only one very rich (1.0-15% U) uraniferous fracture which strikes approximately NNE-SSW and can be traced over some 50 m (map 1, loc. A). The fracture and the mineral rich zone is narrow (5-20 cm), and the uranium minerals can only be found at either end of the fracture and not continuously along it.

Metavolcanic unit

A metavolcanic unit of intermediate composition apparently overlies stratigraphically the conglomerate. This is a medium-grained, massive brittle rock which is green when fresh and weathers white, and in some places the weathered surfaces have a lithic or crystal tuff texture (fig. 2.3). It is the most common supracrustal rock type in the area and a common host rock for the uranium minerals. It is usually broken up into large angular blocks within the rapakivi granite, which suggests that it was a relatively brittle rock type at the time of the intrusion of the granite.

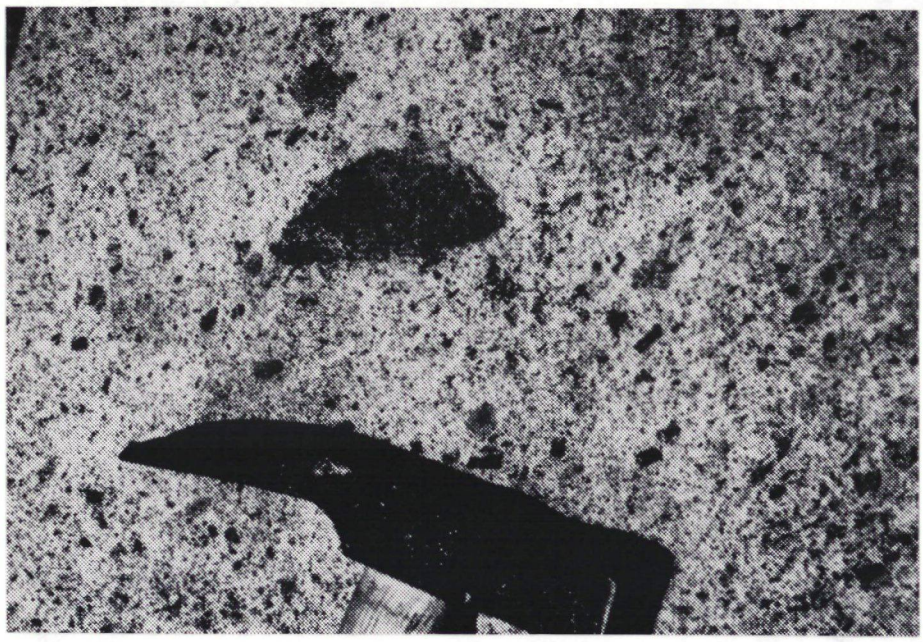


Fig. 2.3. Photograph of lithic tuff texture of the metavolcanic unit.

Meta-arkose

A meta-arkose apparently overlies the stratigraphically metavolcanic unit. It was originally differentiated in the field from the metavolcanic unit on the basis of its granular texture and contained sedimentary structures, and it may well contain a volcanic component in the form of waterlain tuffs as well as purely sedimentary material. It is a fine-grained, grey granular rock with sedimentary layering. It varies from 5 to 20 m in thickness and can be traced along strike for considerable distances.

One horizon, structurally just below the conglomerate is particularly uraniferous, hosting numerous uranium occurrences, ranging between 0.01 and 0.3% U over a horizontal distance of some 750 m. These are mostly in minor cross-fractures but also occur along the layering which may be bedding (fig. 2.4). At the southern margin of the mapped area (map 1) an iron rich pelitic gneiss occurs which is also uraniferous.

Pyroxenite

A pyroxenite unit composed mostly of medium to fine grained dark green pyroxene, which in places forms more than 90% of the rock (fig. 2.5), with coarse biotite and hornblende in a grey plagioclase matrix.

It occurs as lens-shaped boudin-like bodies ranging up to 200 m by 50 m which have a general stratiform distribution associated with the metavolcanic unit. Because of these features and a lithic-tuff texture, which can be seen on weathered surfaces in less structurally disturbed areas, it is suggested

that this rock unit was derived from a mafic rich basic volcanic flow similar to those described by Dawes (1970). Its lower competence compared to the other units has lead to a greater degree of recrystallisation and metamorphic segregation forming the pyroxenite and its lens shape.

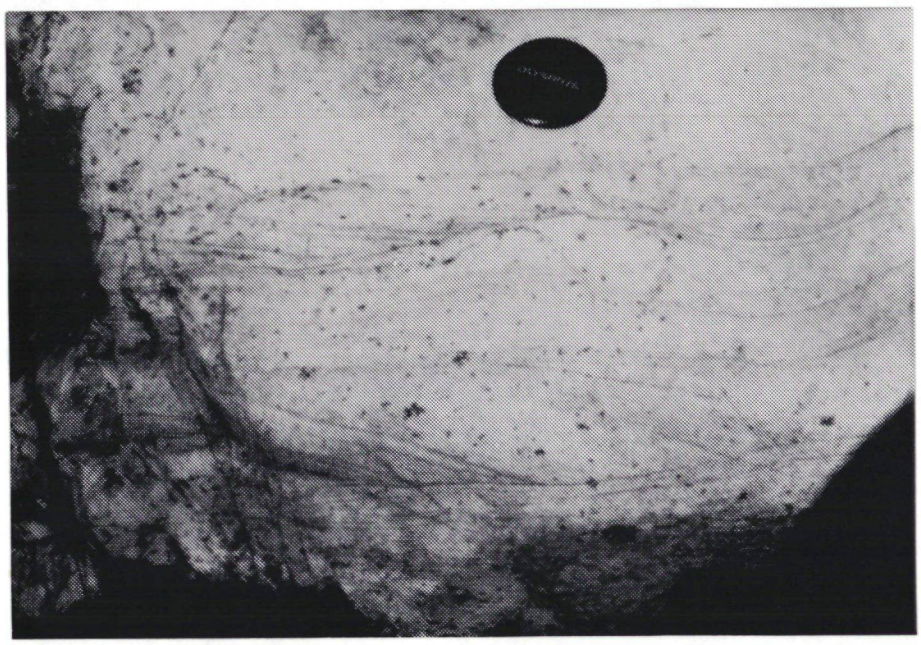


Fig. 2.4. Photograph of sedimentary structures in the meta-arkose.

Sulphide rich metasediment

The sulphide-rich metasedimentary unit is intimately associated with the mafic volcanic unit and usually outcrops immediately above or below it. It is usually not more than 3 m thick and rarely outcrops along strike for more than

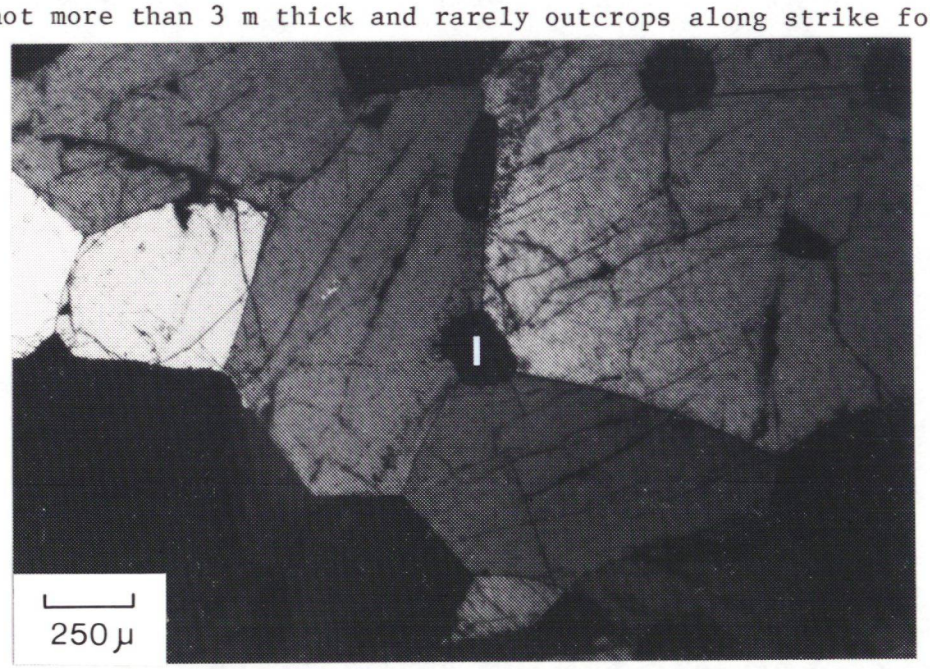


Fig. 2.5. Photomicrograph of pyoxenite illustrating ilmenite (opaque I) at triple junctions of granular augite under X-nicols (sample 325289).

200 m. It is a grey rock, when fresh, of medium to fine grain size with a granular texture and disseminated sulphide minerals in a quartz-feldspar matrix, but it is usually friable, graphitic, rusty and deeply weathered. The sulphide often include appreciable amounts of molybdenite. Uranium is not usually present.

Granite

The supracrustal rocks are intruded by two granite units. The older granite outcrops only in a relatively small raft in the rapakivi granite in the mapped area. It is medium-grained biotite granite with a rather high radioactivity of up to 280* ur in small enclaves of a few square metres. Analysis of this granite (Table 2.1, sample 325271) showed that the radioactivity is due to thorium and an autoradiograph showed that it was contained in zoned monazite which occurs in small aggregates sometimes as inclusions in biotite (fig. 2.6) If this granite is a product of anatexis of the supracrustal rocks then its present U/Th ratio of 0.09 is an indication that partitioning of uranium and thorium, with an increase in uranium content over thorium, did not take place at this stage.

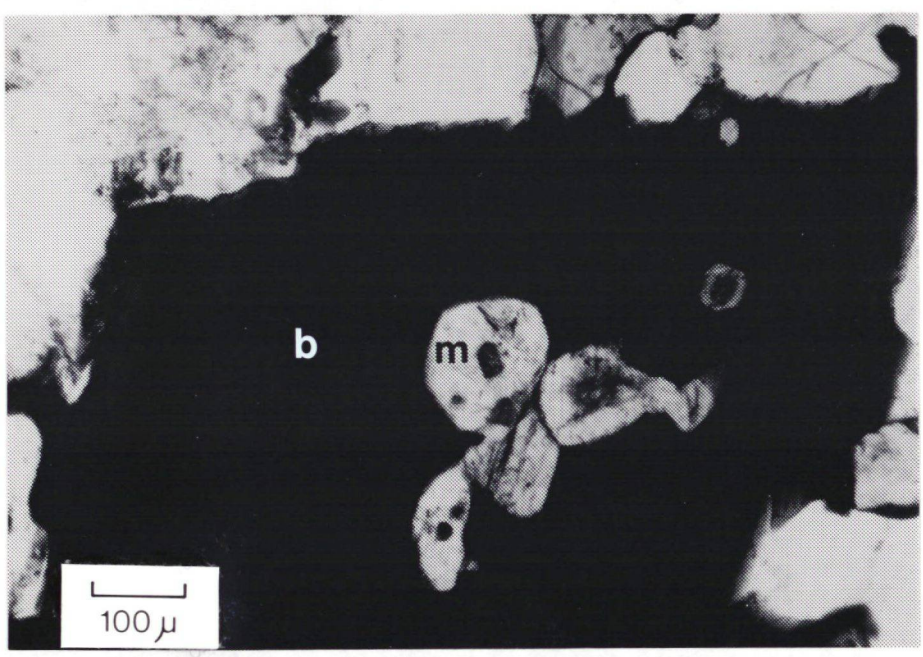


Fig. 2.6 Photomicrograph of the two generations of monazite (m) in biotite (b) in the leucocratic granite (sample 325271).

Rapakivi granite

Rapakivi granite is the major rock unit in the area and is uniform in both composition and texture. It is very coarse grained with large ovoids of orthoclase feldspar, blue quartz, acessory biotite, and occasionally hornblende. It is a ´biotite pyterlite´ in the Finnish classification system

* ´ur´ is a unit of gamma-radiation which is proportional to the radiation derived from the equiavlent quantity of uranium in ppm.

for rapakivi granite because the feldspar ovoids do not have any well developed plagioclase rims (Vorma, 1976). In contrast to the older granite it has a remarkably constant and relatively low radioactivity (25-28 ur) even when adjacent to uraniferous radioactive supracrustal units. This is interpreted as reflecting its largely intrusive allochthonous nature. On a broad scale it appears to have intruded preferentially along the planar structures in the supracrustal units such as the compositional layering and axial planes of the folding, but on a smaller scale it is often seen to cut across these features, particularly the more brittle and competent, intermediate metavolcanic unit.

Basalt dykes

Basalt (dolerite) dykes cut all the above units. They are mostly rather narrow (0.5-2.0 m) but they are consistent along strike for many kilometres. They strike in two dominant directions, E-W and NNW-SSE. They are mentioned by all the previous workers and seem to be a widely distributed feature in the Migmatite Complex. They are composed of fine-grained to aphanitic, dark green to black rock which is occasionally vesicular. They have been classified as Gardar dykes by previous workers (Sutton & Watterson, 1968) but this has never been established with certainty, and they could possibly be yonger.

2.2.2 Structure and distribution of geological units

Prior to the intrusion of the rapakivi granite, the supracrustal units have been isoclinally folded and fractured. The isoclinal folding was presumably a synmetamorphic feature when the rocks were relatively hot and plastic. One period of isoclinal folding has been recognised so far, but this could well prove to be an oversimplification. The axis of the folding trends more or less NNW-SSE with a horizontal plunge, and the axial plane dips gently (10^{o} to 30^{o}) to the ENE. Fig. 2.7 illustrates something of the sharpness of this folding.

At locality B (fig. 2.8 & 2.9) the mafic volcanic unit is terminated in a sharp antiform which is overlain by intermediate metavolcanic rocks which at this point are highly uraniferous (>1,5% U). This suggests that the folding was one of the episodes that helped to mobilise and concentrate uranium. A schematic cross section has been drawn which illustrates some of these features (fig. 2.10) and the down dip extension of the units.

Pre-rapakivi fracturing is characterised by a narrow (0.5-1.0 cm) irregular fractures without a preferred orientation, which are often curved in ptygmatic-like folds, but also tend to be enechelon and/or to horsetail into small breccia zones (fig. 2.11). Their form suggests relatively brittle

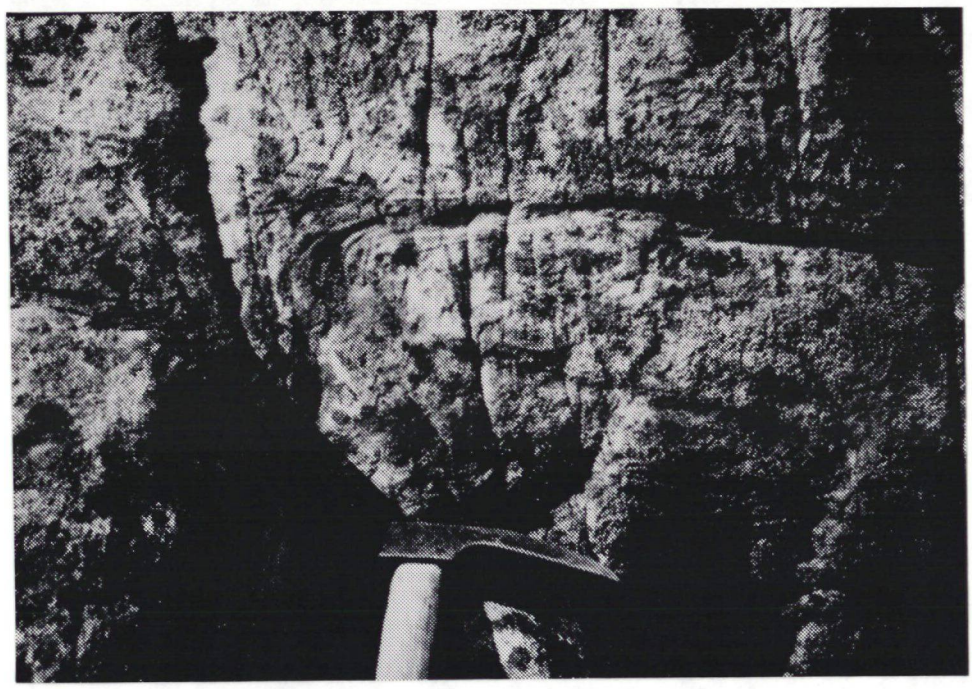


Fig. 2.7. Photograph of isoclinal fold in meta-arkose.

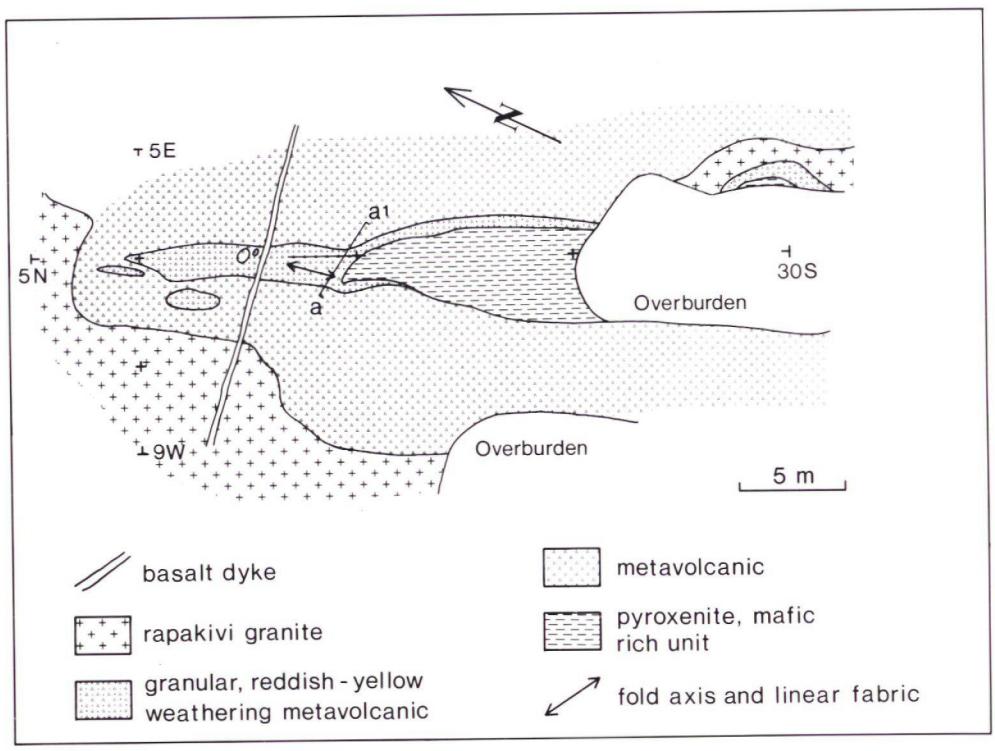


Fig. 2.8. Sketch map of geology at locality B, see fig. 2.1.

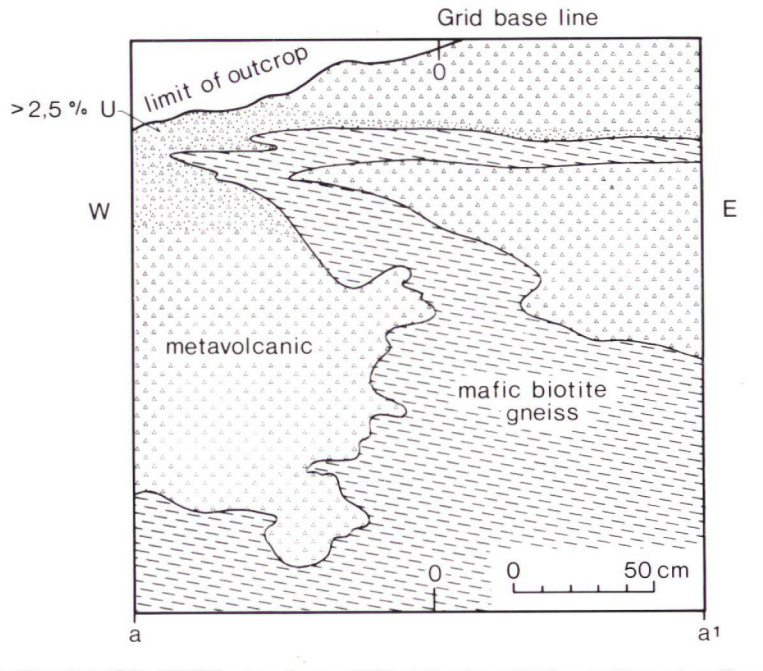


Fig. 2.9. Drawing illustrating isoclinal folding and the distribution of uraninite at locality B, cross section aa´ (see fig. 2.8).

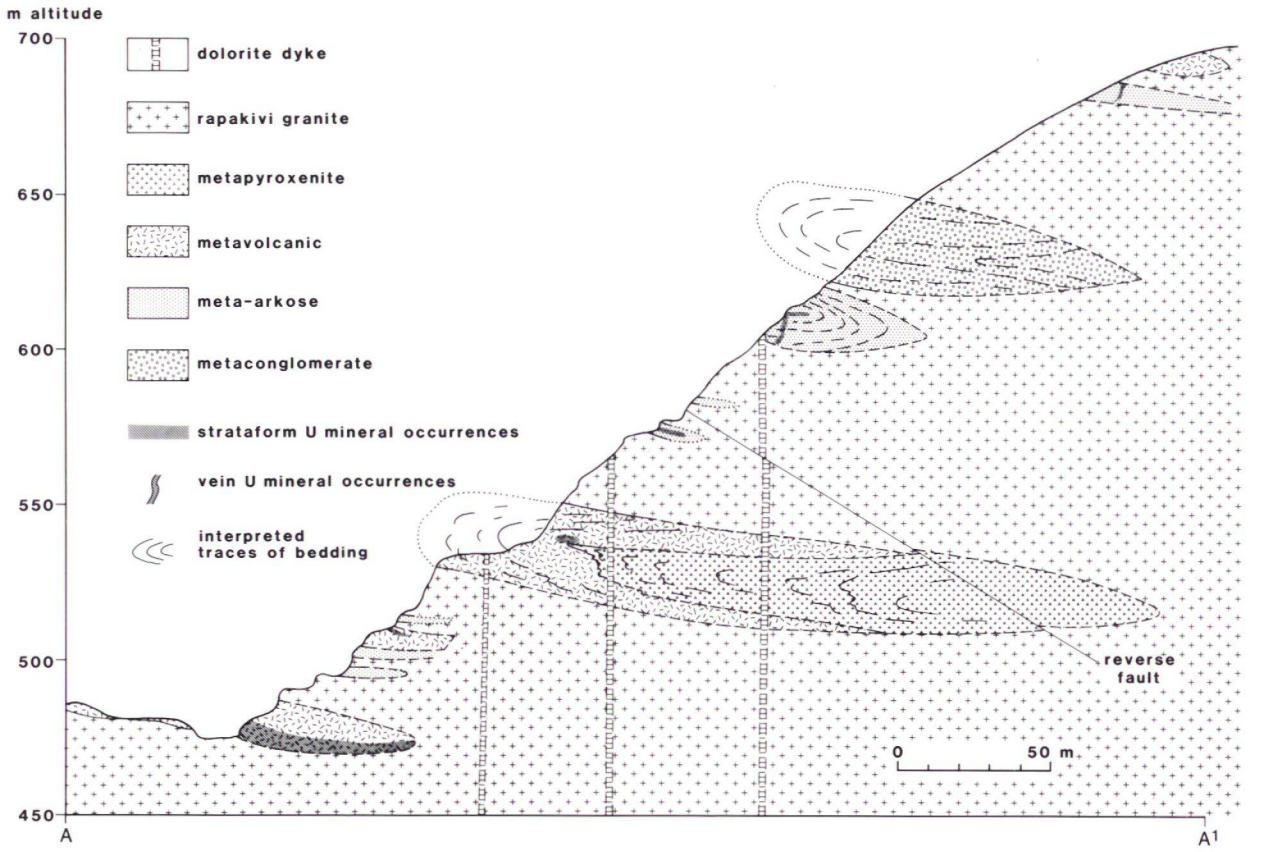
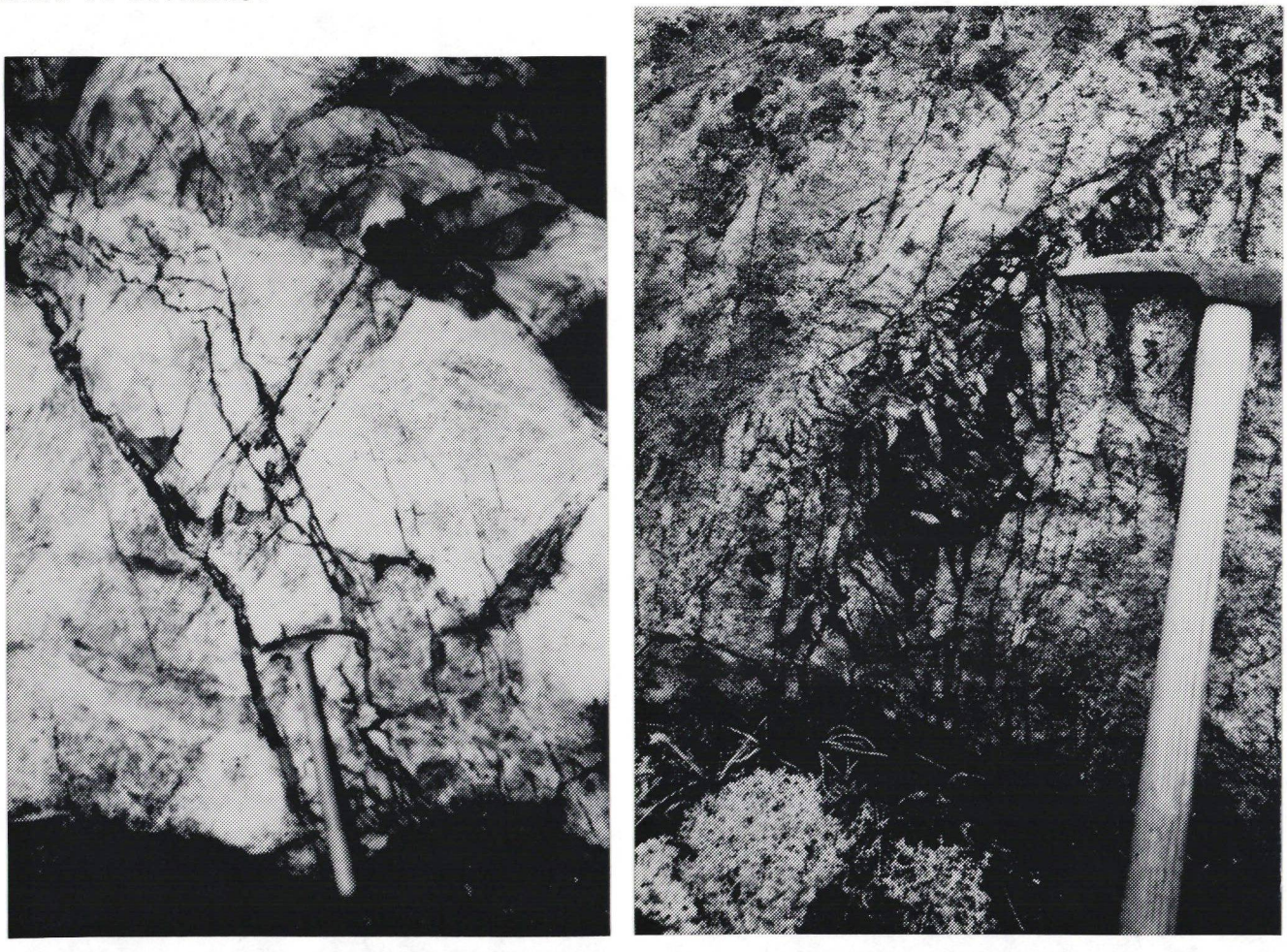


Fig. 2.10. Geological cross section AA´ (see map 1).

deformation compared to the isoclinal folding. They are usually filled with mafic minerals, magnetite, and commonly but not always, host uranium minerals. They have not been observed cutting the older granite and are always terminated by the rapakivi granite. They are, therefore, older than the rapakivi granite and possibly older than the older granite. Their mode of formation is uncertain but their appearance and relative age to the folding and the rapakivi granite suggest that they are late stage deformation of features formed by the migration and accumulation of intraformational volatiles.

Post-magmatic faulting is only of minor significance within the field area where E-W faults have a minor dextral sense of movement of a few metres, and two inclined faults dipping 40^{o}-50^{o} to the NE have a small (2-3 m) reverse sense of movement.



A B

Fig. 2.11. Photographs of minor fractures and associated brecciation. A: is in meta-arkose and B: illustrates the horsetail fracturing and breccation in the metavolcanic unit.

2.2.3 Major element geochemistry

The major element geochemistry of the metavolcanic and the meta-arkose units confirm, from a chemical point of view, the classification of these rocks into two units. The most indicative component is silica (table 2.1). All the

meta-arkose samples contain over 64% SiO_2 with an average of 68% and all the metavolcanic samples are below 59% SiO_2 with an average of 57%. The MgO and CaO values tend to be slightly higher in the metavolcanic rocks than the meta-arkose but the differences are not large.

When the chemical compositions are compared to other rocks they fall close to the fields of composition to which they have been ascribed (fig. 2.12).

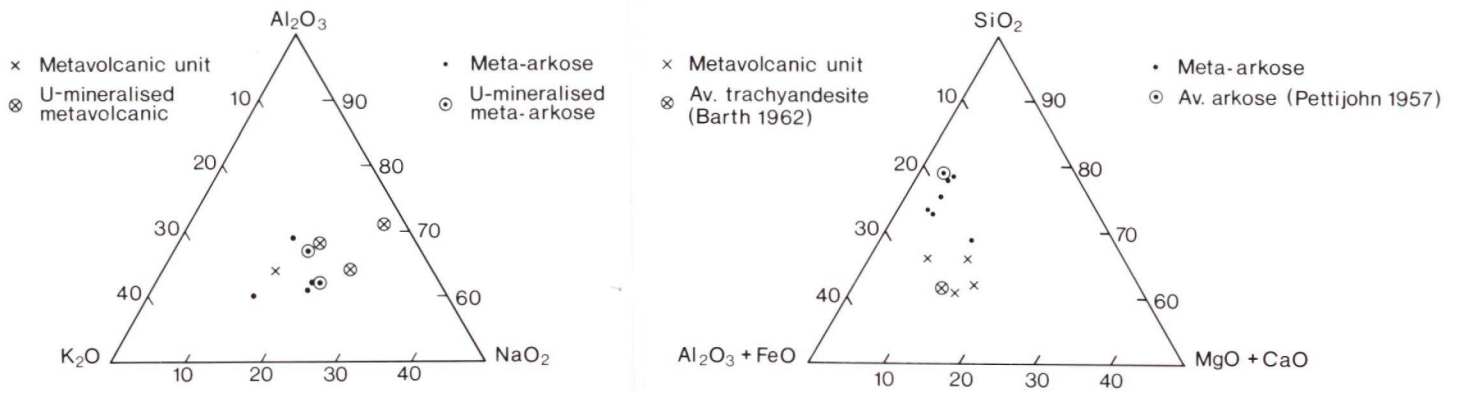


Fig. 2.12. Triangular diagrams showing composition of meta-arkose and metavolcanic units in comparison with accepted values.

The meta-arkose does tend to be slightly less siliceous than an average meta-arkose and have a higher iron content. This suggests that it probably contains a component of volcanic material; however, the sedimentary structures, which include cross bedding and cut and fill channels indicate its waterlain origin. The metavolcanic unit is of intermediate composition.

2.2.4 Detailed geology of main uranium occurrence

The geological map (map 3) illustrates the distribution of the rock units which contain the largest and richest uranium occurrences. The uranium bearing rock in this area belongs to the metavolcanic unit. It has been divided on the basis of its colour and its grain size into the finer grained greenish unit (V2) which is believed to be derived from a crystal tuff and the coarser grained brownish metavolcanic unit (V1) which is thought to be derived from a lithic tuff, but these differnces may prove to be due to later metamorphic effect rather than primary compositional feautures.

As noted earlier the metavolcanic unit appears to have broken up into rather large angular blocks. This is reflected in the irregular outline of these metamorphic units. From the general distribution of the units they appear to dip approximately 5-15° SE, which would also account for the irregular outline of the rock units on the alp. The result of this dip is that if the highly uraniferous units continue to the southeast then they will have plunged below the general surface level of the alp south of the stream. Their continuation

Table 2.1. Major and minor element analyses of rock samples from Igdlorssuit

	Metaarkose (MA)						
	unmineralised				mineralised		average
	304337	305032	325264	325288	305029	325268	of 6
	Major elements in %						
SiO_2	64.29	64.75	71.65	66.08	68.06	72.63	67.91
TiO_2	0.48	0.51	0.42	0.59	0.37	0.38	0.45
Al_2O_3	15.52	11.17	12.78	16.07	12.65	11.09	13.21
Fe_2O_3	0.59	0.60	0.44	0.63	2.33	0.65	0.87
FeO	3.65	5.40	2.55	2.90	3.05	3.41	3.49
MnO	0.06	0.19	0.03	0.03	0.03	0.04	.06
MgO	1.87	3.65	1.03	1.17	1.39	1.37	1.74
CaO	1.66	7.53	2.68	2.12	2.75	3.24	3.33
NaO_2	3.44	2.31	4.43	5.51	4.46	2.92	3.84
K_2O	6.81	2.61	3.83	4.46	3.26	2.55	3.92
P_2O_5	0.16	0.16	0.07	0.19	0.18	0.08	0.14
Trace elements in ppm							of 4
U	<20.00	<20.00	2.90	3.05	1670.00	346.00	117.30
eU			-1.00	3.82	-1.00	230.00	116.40
eTh			-1.00	6.43	50.00	5.96	5.65
Pb			0.00	25.00	237.00	53.00	39.00
Rb			86.00	80.00	3.00	37.00	67.66
Sr			292.00	355.00	365.00	206.00	284.33
Zr			192.00	261.00	526.00	473.00	308.66
Mo			0.00	0.00	1412.00	16.00	16.00
Y			12.00	21.00	64.00	42.00	25.00
V			20.00	0.00	14.00	61.00	27.00
Ni			30.00	3.00	169.00	17.00	16.66
Cu			0.00	0.00	119.00	23.00	23.00
Zn			18.00	73.00	106.00	23.00	38.00
Cr			0.00	0.00	287.00	0.00	0.00

	intermediate Metavolcanic (MV)			
unmineralised	mineralised			average
	325263	304328	304845	305030	4 samples
SiO_2	59.09	55.64	55.42	58.17	57.08
TiO_2	0.97	0.41	0.91	0.46	0.68
Al_2O_3	16.10	15.74	14.74	13.09	14.91
Fe_2O_3	0.87	1.79	1.02	1.36	1.26
FeO	5.37	2.80	7.16	4.59	4.98
MnO	0.11	0.06	0.12	0.08	0.09
MgO	2.39	3.96	4.21	3.24	3.45
CaO	4.61	10.36	8.10	8.43	7.87
NaO_2	3.64	5.75	4.01	5.10	4.62
K_2O	5.32	0.59	2.82	2.25	2.75
P_2O_5	0.29	0.22	0.38	0.24	0.28
Trace elements in ppm					
U	25.10	-1.00	>2000.0	4700.00	
eU	15.60	9201.00		-1.00	
eTh	3.35	247.00		107.00	
Pb	0.00	1106.00		727.00	
Rb	164.00	0.00		0.00	
Sr	486.00	731.00		514.00	
Zr	353.00	1603.00		821.00	

Table 2.1 cont.

	intermediate Metavolcanic (MV)			
	unmineralised	mineralised		average
	325263	304328	304845 305030	4 samples
Mo	7.00	313.00	243.00	
Y	44.00	193.00	138.00	
V	72.00	203.00	113.00	
Ni	38.00	214.00	198.00	
Cu	54.00	125.00	111.00	
Zn	76.00	107.00	326.00	
Cr	0.00	351.00	423.00	

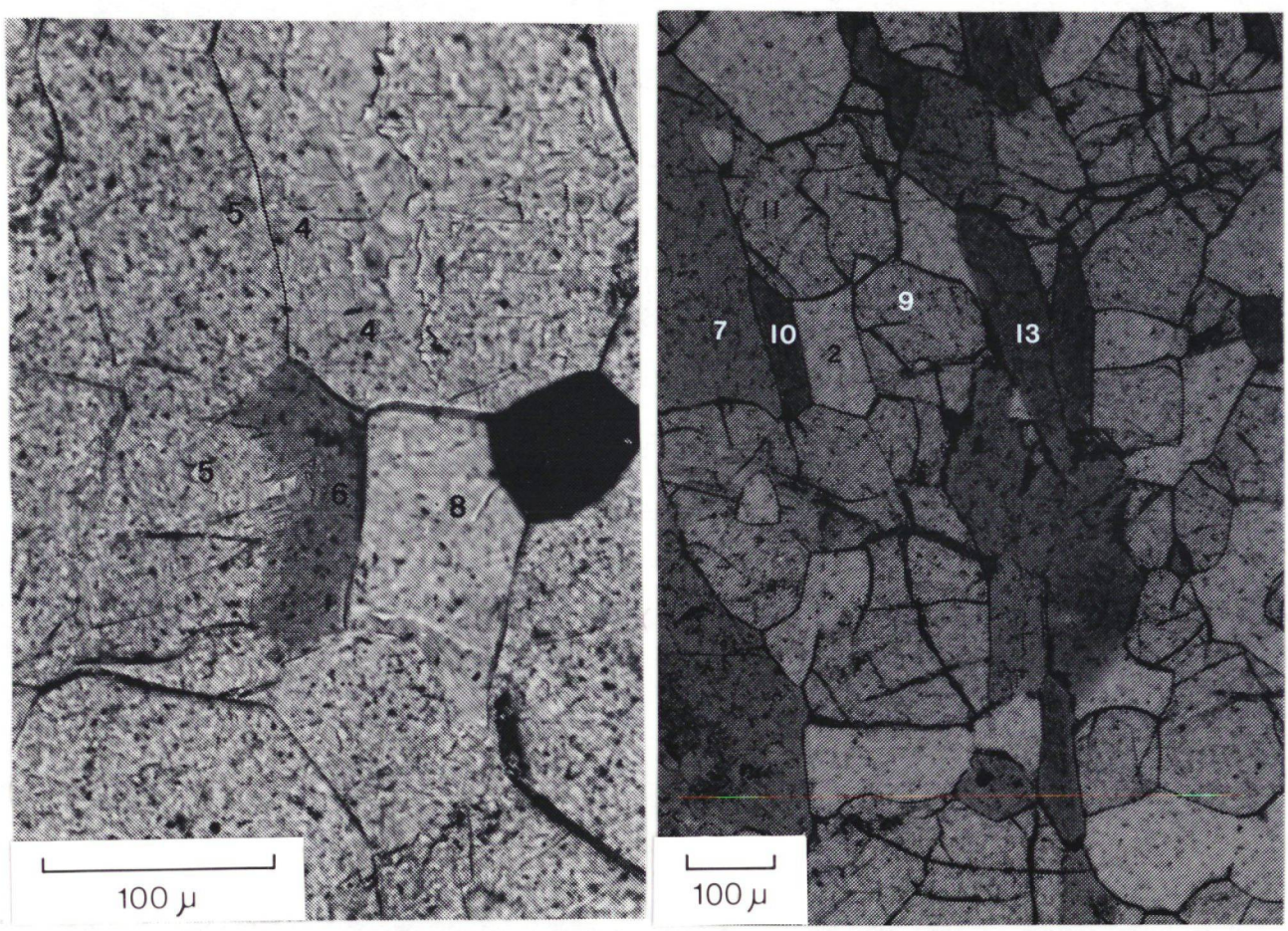
	MV dyke	MV dyke mafic	granite leuco-	granite rapakivi	Ca-Fe MA
	325249	325248	325271	325287	325273
SiO_2	64.13	43.62	70.98	62.28	51.89
TiO_2	0.56	0.12	0.17	0.89	0.58
Al_2O_3	14.56	8.21	14.28	16.25	14.08
Fe_2O_3	1.28	11.23	0.22	0.95	2.40
FeO	2.78	16.70	1.21	5.55	14.52
MnO	0.08	0.38	0.01	0.09	0.24
MgO	0.89	1.10	0.32	1.17	3.49
CaO	3.68	17.11	0.80	3.23	6.21
NaO_2	3.64	2.06	3.01	3.53	3.28
K_2O	7.76	0.17	5.87	4.45	0.43
P_2O_5	0.14	0.00	0.65	0.22	0.19
Trace elements in ppm					
U	6.69	1.43	124.00	8.07	922.00
eU	-1.00	-1.00	126.00	6.97	850.00
eTh	-1.00	-1.00	1440.00	7.19	22.40
Pb	13.00	25.00	68.00	25.00	169.00
Rb	246.00	57.00	236.00	166.00	52.00
Sr	224.00	123.00	101.00	310.00	393.00
Zr	315.00	35.00	210.00	456.00	4448.00
Mo	4.00	7.00	7.00	1.00	87.00
Y	29.00	53.00	300.00	24.00	93.00
V	7.00	0.00	0.00	45.00	42.00
Ni	16.00	116.00	10.00	23.00	15.00
Cu	75.00	147.00	0.00	27.00	74.00
Zn	36.00	152.00	51.00	86.00	121.00
Cr	0.00	912.00	0.00	0.00	515.00

N.B. -1.00 or blank = not analysed
0.00 = not detectable
eU, eTh = gamma-spectrometer analyses based on the radioactivity derived from their respective daughter isotopes ^{214}Bi and ^{208}Tl. Implication is that there is not necessarily equilibrium betwen parent and daughter isotope.
Major element analyses have been carried out by XRF glass disc with an accuracy and precision of better than +/- 1%.
U analyses have been carried out by delayed neutron counting with an accuracy and precision of +/- 1%.
The minor elements analyses were carried out by energy dispersive x-ray fluorescence techniques and are semi-quantitative with an accuracy and
precision between +/- 5-20% depending on the element and its level

has not been found on the walls of the canyon on either side of the stream; however, some of the critical zones are covered with overburden or are inaccessible.

2.2.5 Metamorphism

The high grade of the metamorphism at Igdlorssuit is indicated firstly by the complete absence of muscovite, and secondly by the presence of cordierite, spinel, orthopyroxene and olivine and its granular texture. Garnet has not been found and the low aluminium contents (table 2.1) presumably predicates its formation. Hornblende and biotite are present and are formed at the expense of pyroxene (fig. 2.13) and therefore products of retrograde metamorphism. Both the well developed granoblastic texture and the purity of the minerals which have been analysed by the microprobe (Table 2.2) suggest that the minerals have had time to equilibrate.



A B

Fig. 2.13. Photomicrograph of pyroxenite unit A: showing amphibole (6) growing from bronzite (5) in contact with diopside (4) opague mineral is chalcopyrite. B: showing amphibole (7) bordered biotite (10 & 13) and bronzite (11), anorthite (8) and olivine (9). The numbers refer to the same grains analysed by microprobe and referred to in table 2.2 (sample 325290).

Microprobe analyses of the silicate phases of minerals from the pyroxenite unit have revealed a mineral assemblage of Mg-rich orthopyroxene (bronzite), clinopyroxene (diopside), olivine (Fo70) and anorthite (An90). Three different methods for estimating the temperature of metamorphism have been made using the relationship between the composition of the coexisting ortho and clinopyroxene (Wood & Banno, 1973, Wells, 1977 and Lindsley, 1983). These gave results varying from 933° to 925° and 875° C respectively. A reasonable estimate would seem to be about 900°C. This temperature establishes that metamorphic conditions were well up in the granulite facies and corroborates Wallis' (1966) results which showed that the rocks about 20 km to the west were of granulite facies and tended to increase in grade eastwards, that is towards Igdlorssuit.

2.2.6 Uranium mineral occurrences

Over 35 uranium mineral occurrences have been found scattered over the hillside (fig. 2.1, map 2). With the exception of two occurrences they tend to be restricted to certain members of the meta-arkose and intermediate metavolcanic units. One of the two exceptions is a uraniferous sulphide rich vein which cross cuts the metaconglomerate at locality D (map 2). This appears to be one of the late stage ptygmatic fractures and is described more fully in chapter 4. The second exception is a uranium occurrence at the boundary between the pyroxenite and metavolcanic unit at the extreme north of the mapped area (loc. E map 2).

The uranium bearing mineral is uraninite which is disseminated as fine grains through the strata or concentrated as medium sized grains along the pre-rapakivi fractures and associated breccias. This mineralisation, therefore, can be classified as stratabound but locally controlled by folds and veins where it has been concentrated by structural and metamorphic events.

The largest, highest grade uranium mineral zone remains the area that was found by B. Wallin in 1982 (Armour-Brown et al, 1984) and was mapped with the plane table. This zone of uraniferous metavolcanic unit can be traced continuously for 150 m along strike. To the north it is broken up into a series of rafts in the rapakivi granite some of which contain radioactive anomalies. To the south the same unit is similarly broken up and dips below the accessible outcrop level. Because of the massive, structureless nature of the host rock it has not been possible to relate the uranium minerals in this showing to any particular feature within the rock, but it seems likely that its brittle nature contributed to its fracturing, which would give more ready access to the uranium-rich volatiles and form traps for the uranium minerals. It could also represent a concentration of uraninite in the crest of a fold in

the metavolcanic unit which has not yet been recognised. If this is the case then the form of the potential ore body would be pipe like in form plunging to the SE rather than a sheet dipping to the NE.

An important group of uranium occurrences, from the point of view of establishing a genetic model for this mineralisation, are those that occur in the meta-arkose immediately below the metaconglomerate (fig 2.1 and map 2, loc C). These can be traced, discontinuously along an overall strike length of 750 m. The uraninite is mainly concentrated in the small synmetamorphic cross fractures, but at one locality it is stratabound and radioactivity has been traced for 50 m continuously along the bedding. Another important occurrence is at locality B where uraniferous metavolcanic rocks have been folded into an isoclinal fold (fig. 2.8). These occurrences demonstrate that uranium is stratabound and was present before the folding (see also chap. 4.2 on microscopic textures).

Table 2.2. Microprobe analyses and their calculated chemical formulas of the minerals from two samples from the pyroxenite unit

mineral	--clinopyroxene--		--orthopyroxene--		----------amphibole--------		
sample	augite	diopside	bronzite En74		horneblende		
no.	325289	3225290	3225290	3225290	3225290	3225290	3225290
grain no.	1	4	5	12	1	3	6
SiO_2	44.74	52.30	53.01	53.17	43.34	42.43	43.08
TiO_2	1.35	0.45	0.20	0.17	2.69	2.42	2.30
Al_2O_3	8.75	1.64	1.32	1.38	11.31	12.08	12.15
FeO	6.17	5.93	15.64	15.75	8.36	7.58	7.57
MnO	0.13	0.16	0.35	0.33	0.10	0.11	0.06
MgO	11.51	15.47	26.08	25.82	14.68	14.27	14.82
CaO	24.75	22.29	0.83	0.87	11.76	12.01	11.91
NaO_2	0.02	0.13	0.00	0.00	1.68	1.62	1.65
K_2O	0.00	0.00	0.00	0.00	0.93	0.92	1.03
CrO	0.31	0.10	0.06	0.06	0.49	0.32	0.32
NiO	0.02	0.02	0.04	0.00	0.08	0.08	0.07
sum	97.75	98.49	97.53	97.55	95.42	93.84	94.96
no. of ana.	6	3	4	3	3	3	2
cations	4	4	4	4	15.5	15.5	15.5
oxygen	6	6	6	6	23	23	23
Si	1.70	1.96	1.97	1.97	6.38	6.30	6.35
Ti	0.04	0.01	0.01	0.01	0.30	0.30	0.26
Al_{3+}	0.39	0.07	0.06	0.06	1.96	2.11	2.11
Fe_{2+}	0.12	0.00	0.00	0.00	0.30	0.26	0.32
Fe	0.07	0.19	0.49	0.49	0.73	0.69	0.62
Mn	0.00	0.01	0.01	0.01	0.01	0.00	0.01
Mg	0.65	0.86	1.41	1.43	3.22	3.18	3.26
Ca	1.01	0.89	0.03	0.03	1.86	1.92	1.88
Na	0.00	0.01	0.00	0.00	0.48	0.47	0.47
K	0.00	0.00	0.00	0.00	0.17	0.18	0.19
Cr	0.01	0.00	0.00	0.00	0.06	0.04	0.04
Ni	0.00	0.00	0.00	0.00	0.01	0.01	0.01
sum	3.99	4.00	3.98	4.00	15.48	15.46	15.52

Table 2.2. cont.

	amphibole	-----olivine----		anorthite	biotite
sample	hornebl.	Fo69	Fo70		
no.	3225290	3225290	3225290	3225290	3225290
grain no.	7	9	11	2&8	10
SiO_2	42.40	37.54	37.72	42.99	36.91
TiO_2	2.56	0.02	0.03	0.00	3.79
Al_2O_3	11.95	0.03	0.02	34.43	15.22
FeO	7.72	26.97	26.64	0.11	7.92
MnO	0.09	0.37	0.35	0.03	0.02
MgO	14.45	34.36	34.47	0.03	18.40
CaO	11.93	0.02	0.02	19.23	0.07
NaO_2	1.68	0.00	0.00	0.39	0.16
K_2O	1.02	0.00	0.00	0.01	9.43
CrO	0.46	0.00	0.00	0.00	0.49
NiO	0.07	0.23	0.22	0.00	0.17
sum	94.33	99.54	99.47	97.22	92.58
no. of ana.	5	5	4	8	3
cations	15.5	3	3	5	
oxygen	23	4	4	4	
Si	6.31	1.01	1.01	2.05	
Ti	0.28	0.00	0.00	0.00	
Al_{3+}	2.10	0.00	0.00	1.93	
Fe_{3+}	0.33	0.00	0.00	0.00	
Fe^{2+}	0.64	0.61	0.60	0.00	
Mn	0.01	0.01	0.01	0.00	
Mg	3.20	1.37	1.38	0.00	
Ca	1.90	0.00	0.00	0.98	
Na	0.49	0.00	0.00	0.04	
K	0.19	0.00	0.00	0.00	
Cr	0.05	0.00	0.00	0.00	
Ni	0.01	0.01	0.01	0.00	
sum	15.51	3.01	3.01	5.00	

N.B. Microprobe analyses were made with an analytical and sampling precision of approximately +/-2% at the 1 std. dev. level, based on repeat analyses of the same grain. The accuracy was measured with standards.

3 RADIOMETRIC SURVEY

Radiometric grid surveys over four of the most interesting uranium mineral occurrences at Igdlorssuit were performed in July and August 1984 using a portable scintillation counter calibrated in units of ppm eU (parts per million of equivalent uranium). The readings were controlled by measurements with integrating thermoluminescence dosimeters (TLD) taped to selected spots on the rock surface and rock samples for sealed-can gamma-ray analysis. This chapter describes the equipment used and how the survey data were processed and their results.

3.1 Equipment and procedures

3.1.1 Scintillometer measurements

The portable counter used was a Saphymo-Stel type S.P.P.2NF "scintillometre de prospection". To determine the associated calibration factor, the instrument was placecd on concrete calibration pads with known equivalent uranium concentrations. These pads, 3 m in diameter and 50 cm thick, are situated at Risø National Laboratory and were described by Løvborg et al. (1981).

From the recorded calibration factor of 4.5 counts/s per ppm eU it was concluded that the counter would go off-scale on rock containing more than about 0.3 percent uranium. To make the instrument usable on Uranium contents of up to a few percent, a lead collar for the probe crystal was added. The probe with the collar attached is illustrated in fig. 3.1. The reduced calibration factor was 0.60 counts/s per ppm eU, corresponding to an attenuation of the original sensitivity by a factor of 7.5.

The survey at Igdlorssuit was carried out on a 1 metre grid and included 1186 uranium assays in the main profile of the mineralisation. Each assay was based on the average of 5 ratemeter readings in succession at the measurement position with the instrument held against the rock. The result was multiplied by the calibration factor to give the content of equivalent uranium (eU).

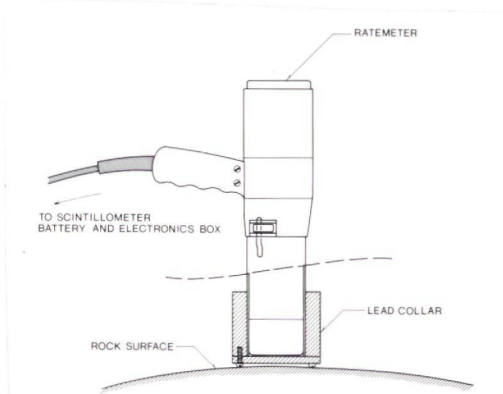


Fig. 3.1. Gamma-ray scintillometer probe with attached lead collar for reducing the count rate generated by high levels of uranium.

3.1.2 Dosimeter measurements

A thermoluminescence dosimeter (TLD) is a small passive device capable of integrating radiation doses. Its function is to emit light upon heating, the light emission being a function of the radiation energy stored in the TLD material. TLDs prepared from hot-pressed lithium fluoride (LiF) are commonly used for monitoring environmental exposure rates because they produce a uniform light output over a wide range of radiation energies. Since there exists a proportional relation between gamma-ray exposure rate and radioelement concentration in the ground, it is theoretically possible to assay uranium ore grades from the surface doses recorded over a known time interval.

In the exploration reported here 52 LiF TLD´s, supplied by the Health Physics Department at Risø, were taped onto the rock surface in grid points of widely differing U grades. Each dosimeter contained 3 LiF pellets in a plastic housing carrying a binary hole-code identification (Bøtter-Jensen et al., 1974). Five additional dosimeters were distributed among the field crew for monitoring personal radiation doses involved with the survey task. The TLDs placed on the rock surface were exposed for 15 to 17 days in their respective positions. All dosimeters were kept together during the travel to and from Greenland. An extra TLD stored at Narssarssuaq airport, while the field work was done, provided the dose contributed by cosmic rays between the departure from Denmark and the arrival of the TLD´s in the lab about 3 weeks later. This contribution was subtracted from the field readings.

A graph of net TLD exposure rates against the eU concentrations recorded in identical grid points on the rock surface shows a good correlation with a regression slope of 0.53 microR/h per ppm eU (fig. 3.2, appendix). This is consistent with a similar test which was carried out on the Kvanefjeld uranium-thorium deposit in 1977 and yielded a regression slope of 0.50 microR/h per ppm eU (Løvborg et al., 1980). The abscissa axis terminates at 4000 ppm eU because the few dosimeters placed on rock with percent concentrations of uranium would be expected to receive their doses from very confined and perhaps unevenly dispersed grains of uraninite. The offset of the regression line in fig. 3.2 by some 60 ppm eU with respect to the point of zero uranium concentration probably represents scintillometer counts contributed by gamma-ray "skyshine" over the mineral occurrence. "Skyshine" is radiation reflected from the air. This component of a terrestrial radiation field carries little dose, but its energy of 50 to 200 keV coincides with the range of energies to which a scintillometer is mostly sensitive. It would perhaps have been pertinent to reduce the eU readings by 60 ppm.

The total doses received by the 5 persons of the field team are shown in

Table 3.1. Radiation doses received by the five members of the Igdlorssuit field team and the control dosimeter kept at Narssarssuaq airport

Dosimeter no.	Use of dosimeter	Integrated dose in millirem (mrem)
1	Control monitoring	8
2	Personal monitoring	43
3	do	23
4	do	14
5	do	19
6	do	14

table 3.1 which also shows the dose recorded by the control dosimeter kept at Narssarssuaq airport.

It can be seen that the expected radiation dose from staying in the Igdlorssuit area for 3 weeks amounts to between 2 and 5 times the dose received in an area of normal background radiation. The maximum personal dose of 43 mrem recorded by dosimeter No 2 should be compared with the maximum permissible weekly dose of 100 mrem per week recommended by the International

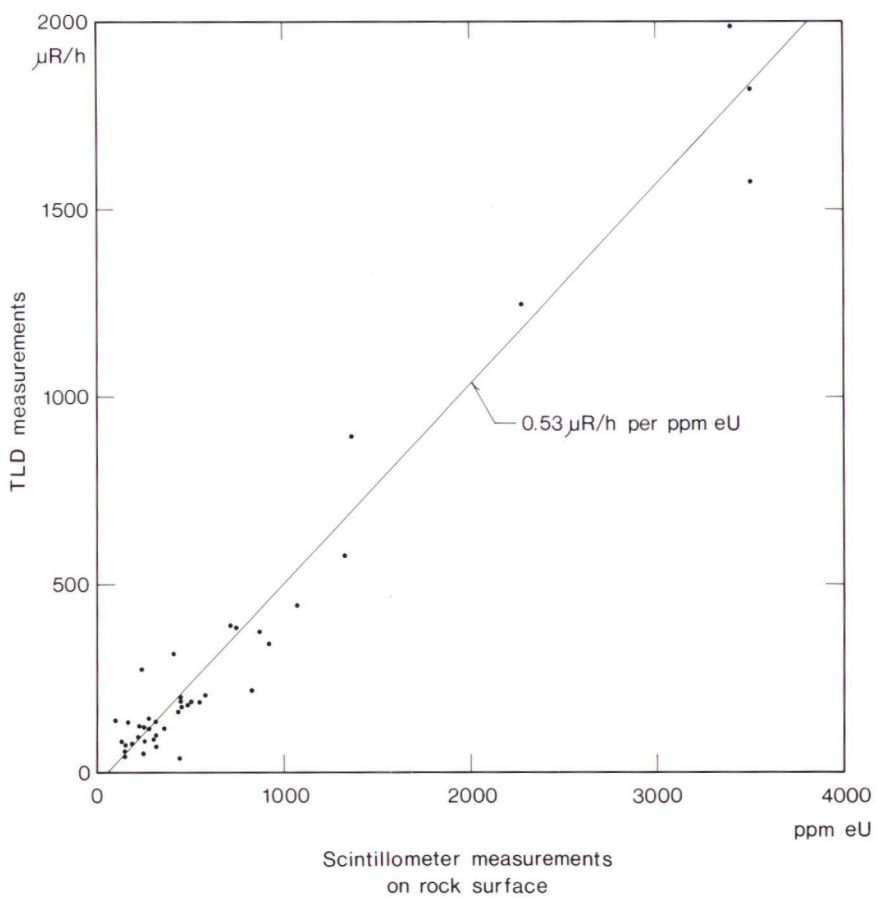


Fig. 3.2. Correlation of uranium content measured by gamma-ray scintillometer and LiF thermoluminescent dosimeters.

Commission on Radiological Protection (IAEA, 1973). This dosimeter was worn by Poul Sørensen who made the grid measurements and spent an average of 4-5 hours a day in the most radioactive areas for three weeks.

3.1.3 Rock sampling

As a further test of the scintillometer eU assays, rock sample were collected from 33 grid points. The samples were crushed with a jaw crusher at Risø, after which the resulting particles and dust were packed into cylindrical metal cans of 170 ml volume. Each can was then sealed with an impressed lid and stored to await the build-up of radioactive equilibrium between Rn226 and Rn222 (radon) in the U238 decay chain. Analysis for equivalent uranium and thorium concentrations was done by gamma-ray counting using energy windows centered on the 1.76-MeV emission from Bi214 (for uranium) and the 2.61-MeV emission from Tl208 (for thorium). Samples with U contents of less than few thousand ppm were analysed with a high-sensitivity, automated gamma-ray spectrometer. Samples with more than a few thousand ppm U were analysed with a Geometrics GR-410A portable spectrometer whose detector probe was placed within a tower of lead rings. Both pieces of equipment were calibrated using sample cans packed with U and Th reference materials originating from the New Brunswick Laboratory of the U.S. Department of Energy.

Thorium could not be detected in any of the samples with high uranium contents because of interference in the Tl208 energy window by energy derived from uranium isotopes. Low thorium values were recorded for samples with low uranium contents (appendix 3.1). Three samples with high uranium contents were analysed by wet chemical methods in 1983 (table 3.2).

Table 3.2. Uranium and thorium content of three samples analysed by wet chemical methods at the chemical laboratory, Risø

sample no.	U ppm	Th ppm	U/Th
260939	20200	825	24
260943	1130	530	2
260944	30900	800	39

As the radiation from thorium is about 40% that from uranium it can be seen that it is of only minor significance at the highly uraniferous locations, accounting for less than 2% of the measured total radiation. In the less uraniferous areas (about 1000 ppm U) it could be appreciably more significant, rising to some 20% of the total measured radiation. In a future evaluation of similar occurrences the thorium content should be measured systematically. An evaluation of the U/Th ratios may help to elucidate the metamorphic processes

as well as avoiding incorrect estimates of the total uranium content.

A plot of uranium values measured by scintillometer against rock sample values is highly scattered (fig. 3.3). The correlation coefficient is, however, still significant (r=0.90). The slope of the regression line is 1.01 and the intercept on the eU measurements is 50 ppm. In fact the slope of the line changes around the 100 ppm mark (fig. 3.3). This suggests that the variations above 100 ppm U are random whereas below this value there is a systematic component which raises the scintillometer assays. Perhaps it marks

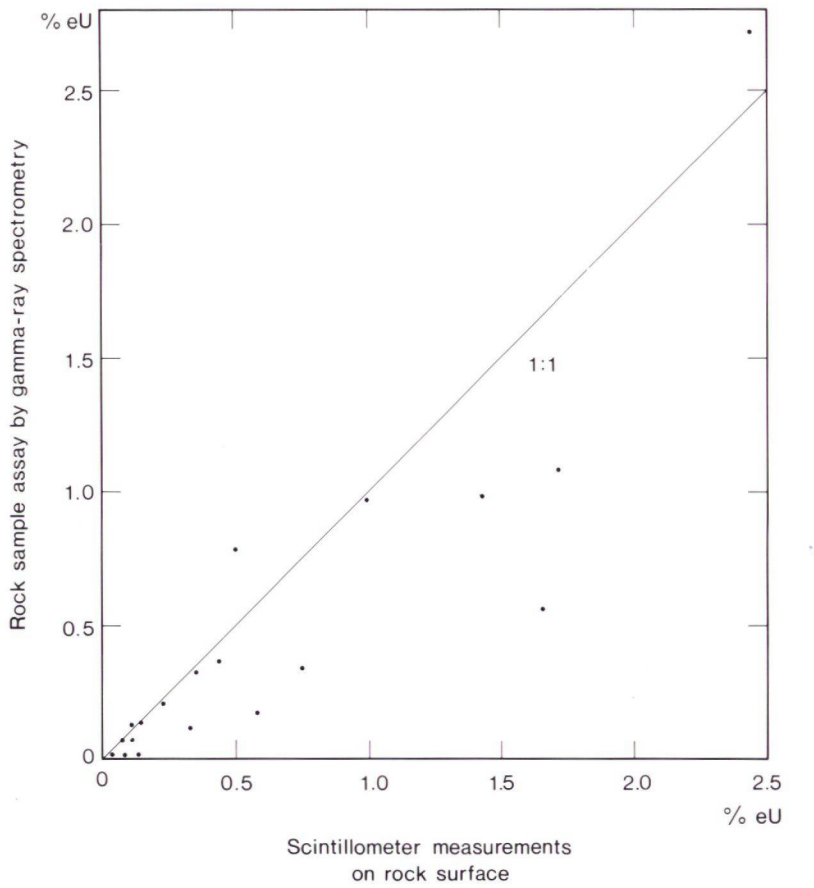


Fig. 3.3. Correlation of uranium measured by gamma-ray scintillometer and rock assay by gamma-ray spectrometry.

the point where skyshine and the thorium contents contribute a significant proportion of radiation to the readings. It also may reflect the different analytical methods as samples with below about 100 ppm U were analysed by the sensitive gamma spectrometer at Risø whereas those above were measured by the less sensitive GM-410. It would seem reasonable to assume that the high variability is due to sampling problems. In general the scintillometer measurements will assay a wider area than the rock samples, but will be affected more by the very high radiation from adjacent points in addition to mass effect from uneven topography.

3.2 Calibration and accuracy of scintillometric measurements

It must be concluded from a comparison of the scintillometer assays with those from the rock samples and the TLDs that the former tend be slightly higher than they should be and that this becomes more significant at the lower uranium levels. This discrepancy, however, is more than offset by the speed and, therefore, the coverage that is possible with the scintillometer. In addition only the areas with relatively high contents of uranium (over 250 ppm U) have been evaluated by this method. With these qualifications the scintillometer assays have been accepted as representative of the uranium content of the rock.

3.3 Uranium content, distribution and ore estimation

Four radioactive occurrences at Igdlorssuit were assayed on a grid basis with the lead collimated scintillometer. Three of them lie within the area mapped in detail (map 3) and the fourth locality B, is shown on map 2 and fig. 2.1.

The largest area surveyed, was 110 m long and 12-5 m wide (fig. 3.7). The other three grids (figs 3.4, 3.5, & 3.8) are in the order of a few tens of metres. The histogramme of all the 1186 eU assays from grid AA illustrates a log-normal distribution with a geometric mean of 349 ppm eU (fig. 3.6). The maximum value is 2.5% because the instrument was off scale when the uranium content was over this level. The maximum TLD analyses is up to 7.5%.

The scintillometer assays have been made at 1x1 m intervals and the values contoured by hand. The results from grid A (fig. 3.7) demonstrates that the uraniferous zone is continuous for 60 m with further zones occurring intermittently along strike to the northwest for a total of 110 m. Further to the northwest of the grid, unmineralised rapakivi granite is the dominant rock type with only occasional inclusions of metavolcanic rocks with or without associated radioactivity (map 2). No continuation to the southeast has been found and if there is one then it should plunge below the surface level of the alp to the south of Dyke Canyon.

The uraniferous zone is restricted to the metavolcanic unit, and is always cut by the rapakivi granite. In general it follows the NW-SE trend of the unit. This general trend tends to be broken up by narrow but distinct WNW-ESE trending discontinuities in the uranium level. These are parallel to the jointing and minor fracturing related to younger faulting and basalt dyke emplacement in this direction. Presumably the uraniferous discontinuities are related to these later structural features whose development allowed the remobilisation and removal of uranium away from them.

One of the main purposes of carrying out the radiometric grid survey was to

assess the possible economic potential. An estimation of the ore grade and volume has been made by summing the area under each contour interval and projecting it down to a depth of 60 m. The depth of 60 m was chosen on the basis of the regional mapping (see cross section fig. 2.9) which showed that units of the thickness of the metavolcanic unit could be traced down dip along the valley walls into the rapakivi granite for approximately that distance before pinching out. The tonnage and the tons of uranium under each contour interval was then calculated using a specific gravity of 2.8 for the rocks and the median between the contour intervals (appendix). The result gave an ore tonnage of 17000 tons of uranium ore with a grade of about 0.31%U, which corresponds to about 50 tons of uranium.

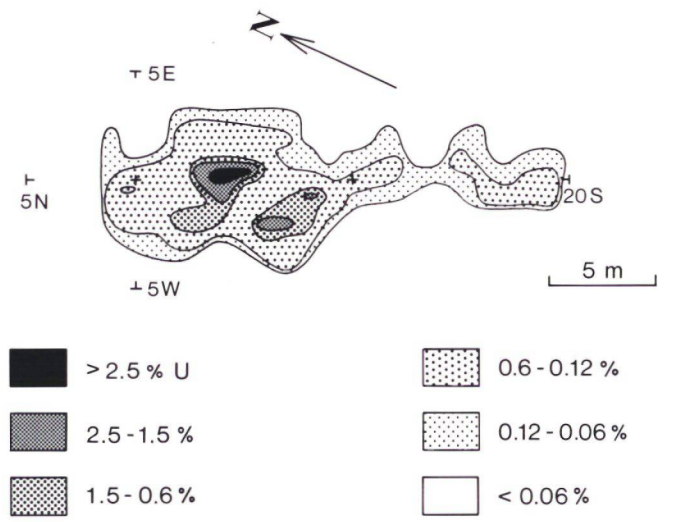


Fig. 3.4. Radiometric map of grid B.

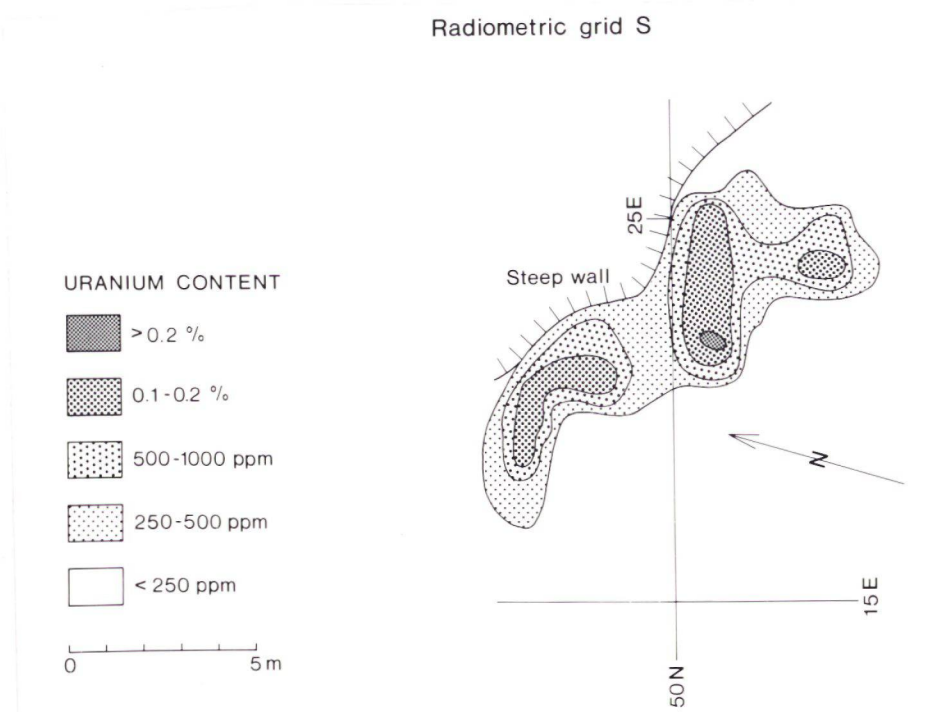


Fig. 3.5. Radiometric map of grid S.

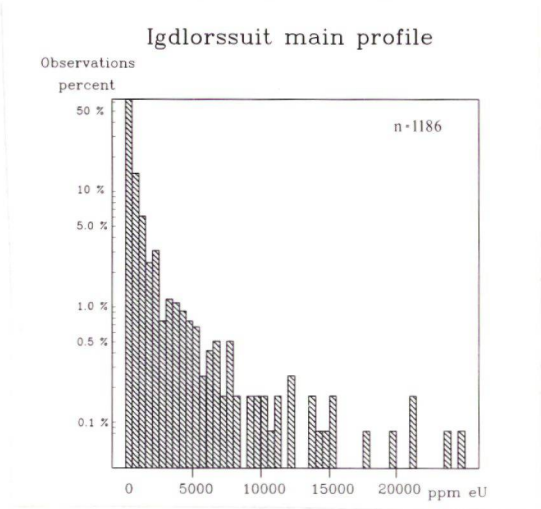
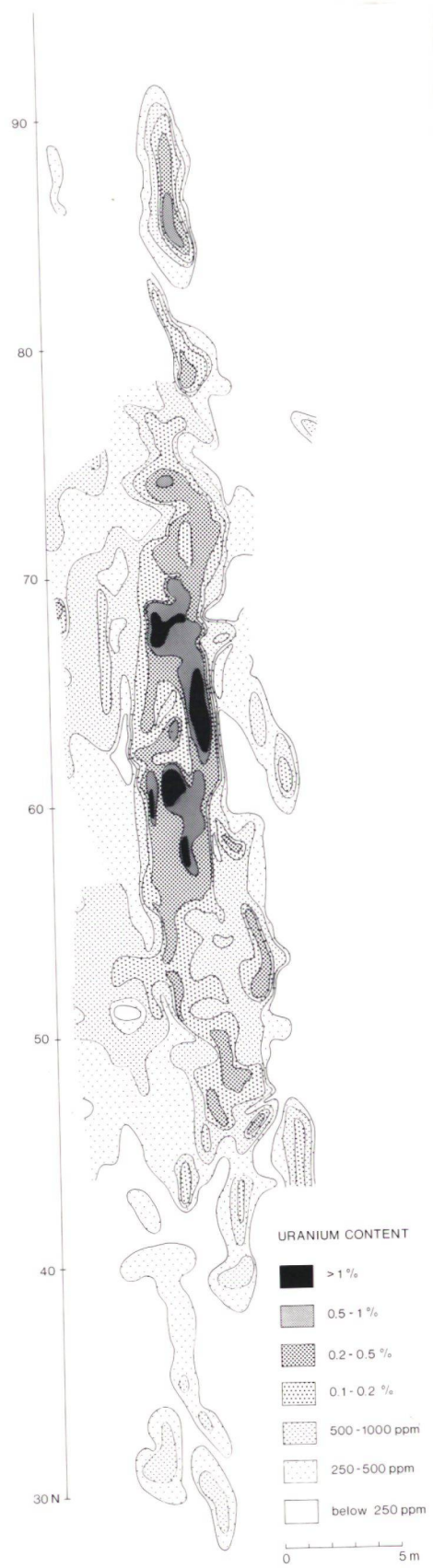


Fig. 3.6 Histogram of 1186 gamma-ray readings taken from the main uranium mineral locality, grid A.



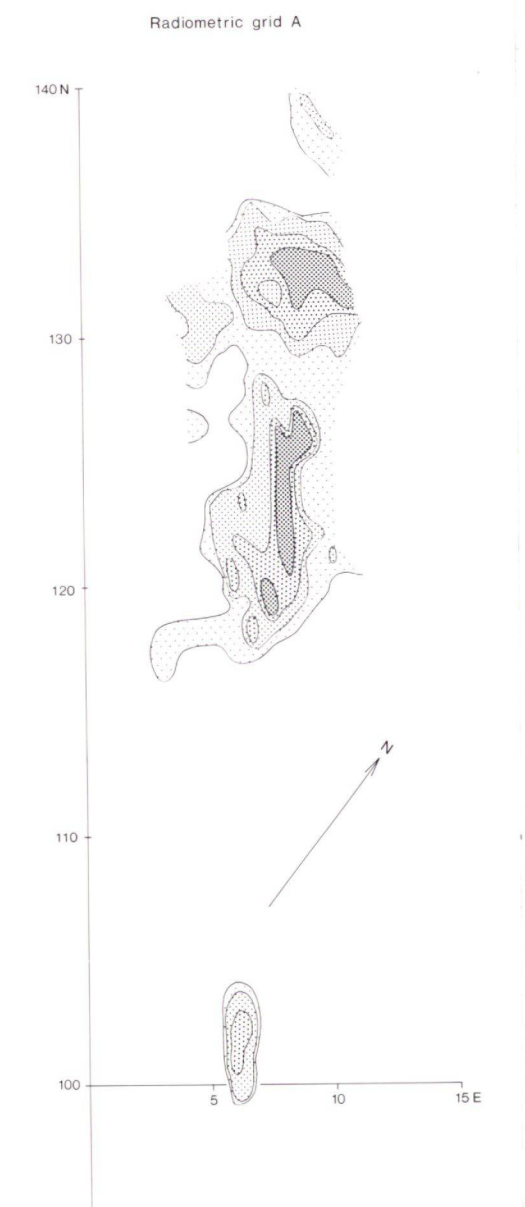


Fig. 3.7. Radiometric map of grid A.

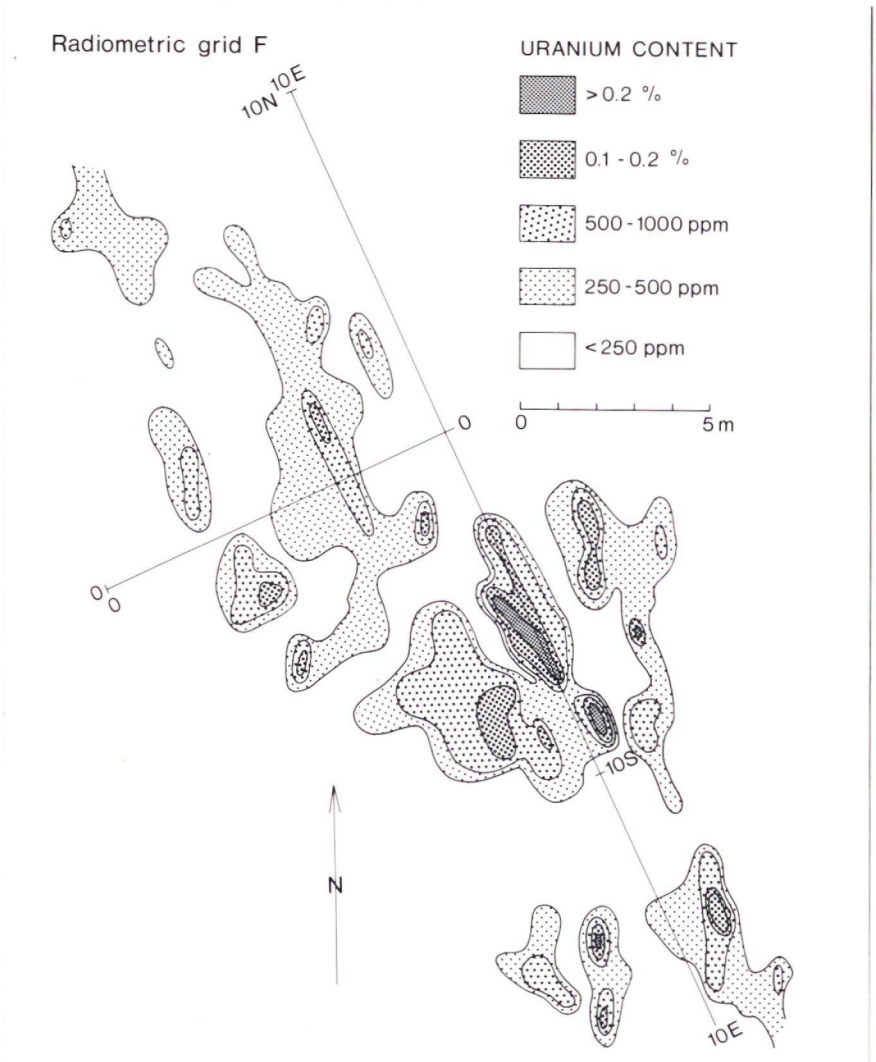


Fig. 3.8. Radiometric map of grid F.

4 DESCRIPTION OF URANIUM MINERALS AND ISOTOPE AND MICROPROBE ANALYSES

The distribution of the uraniferous minerals have been studied in 23 hand specimens with the use of autoradiographs. The textural and paragenetic sequence has been studied in 15 polished thin sections and autoradiographs have been used to locate the uraniferous minerals.

The main purpose of this work was to find microscopic, and compositional evidence, both chemical and isotopic, to corroborate the field observations. These suggested firstly, that the uranium was present in the supracrustal rocks before the rapakivi granite and their regional metamorphism, and secondly that uranium was present in the supracrustal rocks before they were regionally metamorphosed and intruded by the rapakivi granite, and thirdly that there may be more than one generation of uraninite: older stratiform uraninite disseminated along the bedding, and younger uraninite in the synmetamorphic veinlets.

4.1 Texture and paragenesis of uraninite

Autoradiographs of both the hand specimens and the thin sections confirm the fine grained disseminated nature of the uraninite. It is practically always finer than 100 micron and usually in the 20-70 micron range. It is always anhedral and tends to form subcircular grains as inclusions in silicate minerals, and along the grain boundaries. It has a particularly strong affinity for pyroxene with which it is commonly associated in the syn-metamorphic veinlets and in which it also occurs as inclusions (fig. 4.1).

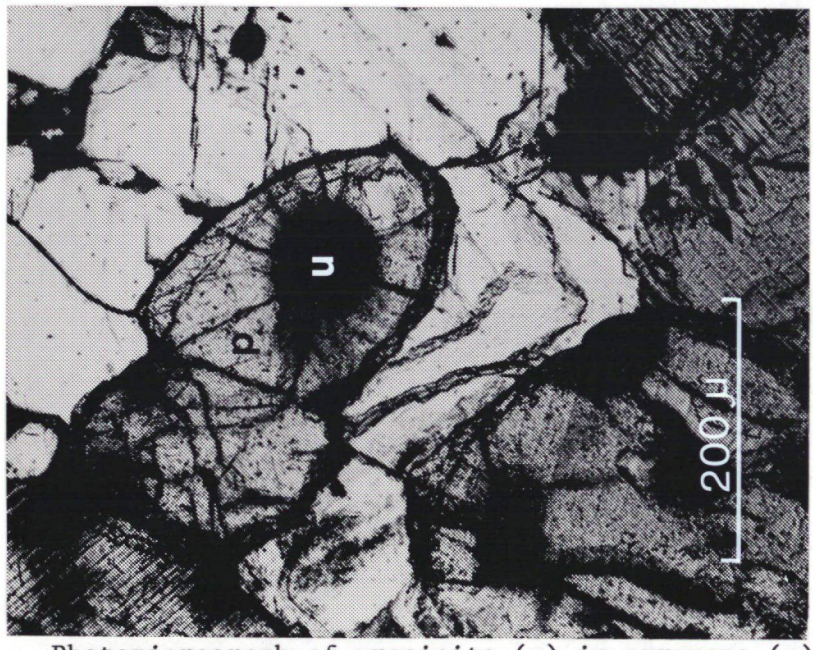


Fig. 4.1. Photomicrograph of uraninite (u) in pyroxene (p) in (sample 304339).

An example of the stratabound uraninite was taken from the meta-arkose where the radioactivity could be traced along the layering of the bedding for 50m. An autoradiograph of the hand specimen cut at right angles to the bedding

(fig. 4.2) illustrates the planar distribution of the uranium minerals with small lens shaped aggregates. Microscopic examination revealed a fine grained granoblastic texture of pyroxene (diopside), quartz and calcic plagioclase (fig. 4.3). Uraninite is distributed as very fine grains (from 15 to 70 microns) usually associated with pyroxene. Sample 325269 is taken from the folded stratabound uraninite from location B (map 2, fig. 2.1) already discussed (fig. 2.8). An autoradiograph of a hand specimen cut at right angles to the fold axis revealed how the uraniferous rich band has been folded (fig. 4.4). This is an extremely important finding since it establishes that uranium was present before the folding and the regional metamorphism. The uraninite at this locality is also fine grained except where it has been concentrated in the crests and cusps of the folds into coarser grained aggregates along with pyroxene. The pyroxene tends to be brownish and discoloured and maybe converted to amphibole in the proximity of the uraninite. The chemical and isotopic composition of this sample will be discussed further in the following sections.

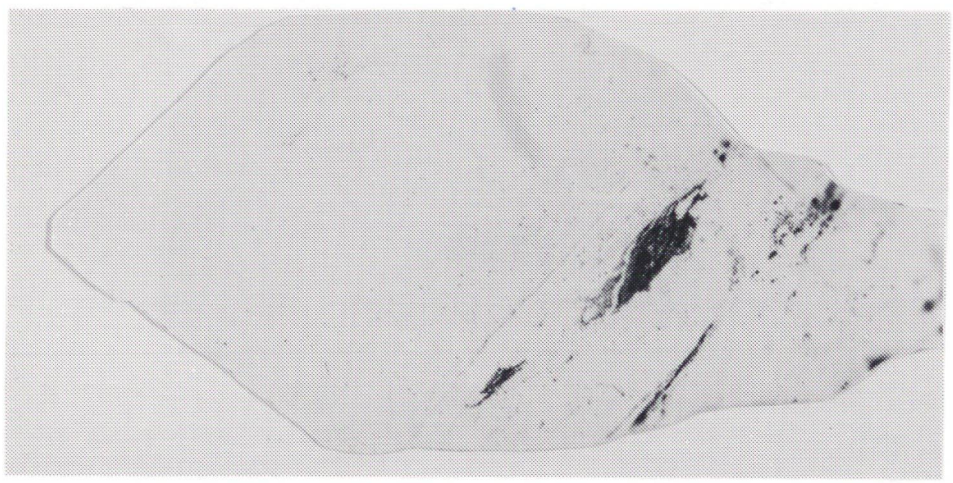


Fig. 4.2. Autoradiograph of uraniferous meta-arkose cut perpendicular to bedding (sample 325268).

The uraninite which occurs in the fractures is exemplified in samples 325247 and 325250. The first sample is from a fracture in the meta-arkose (fig. 2.1, loc. C) just below the metaconglomerate and the second sample was from the fracture which cuts across the metaconglomerate. Autoradiographs of the hand specimens show how similar the shape of the fractures are both at macroscopic and hand specimen scale (compare figs. 2.10 and 4.5). At the microscopic scale their shape is also similar (fig. 4.6) and the affinity for uraninite for diopside can be demonstrated.

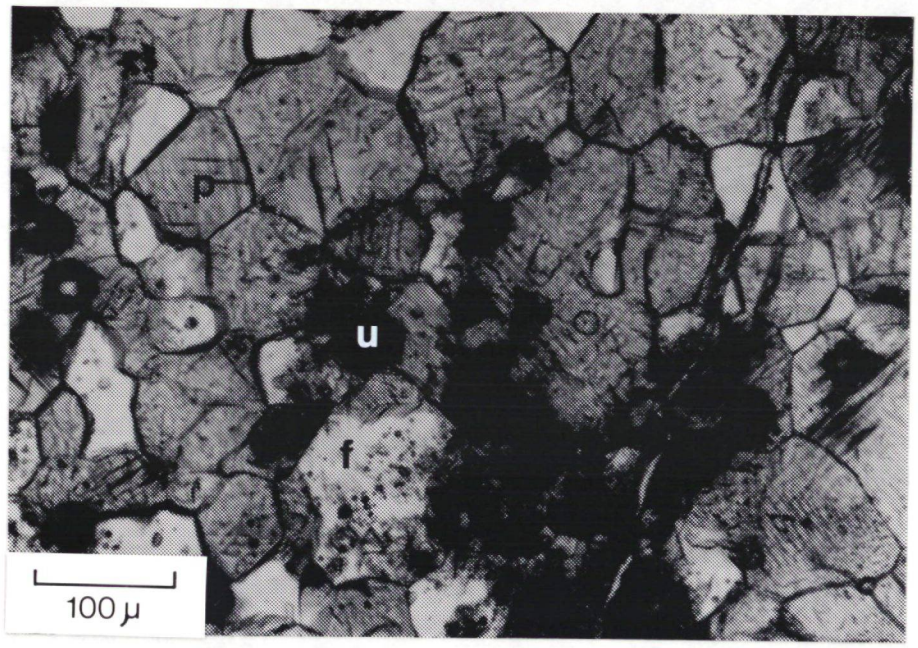


Fig. 4.3. Photomicrograph of uraninite (opaque) associated pyroxene (p) and feldspar (f) (sample 325268).

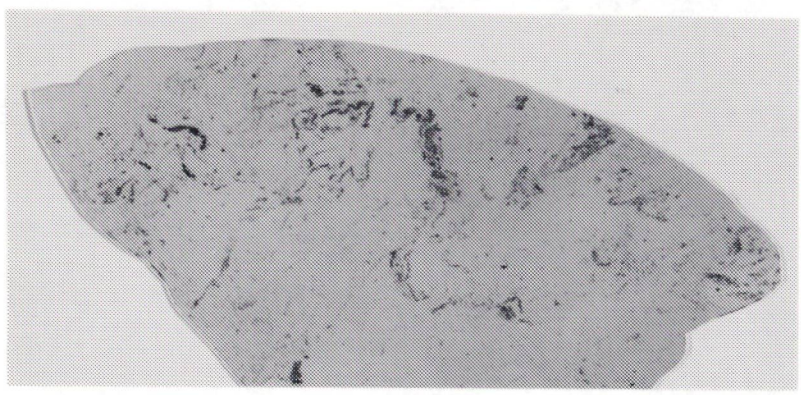


Fig. 4.4. Autoradiograph illustrating folded uraniferous band cut perpendicular to fold axis (sample 325269).

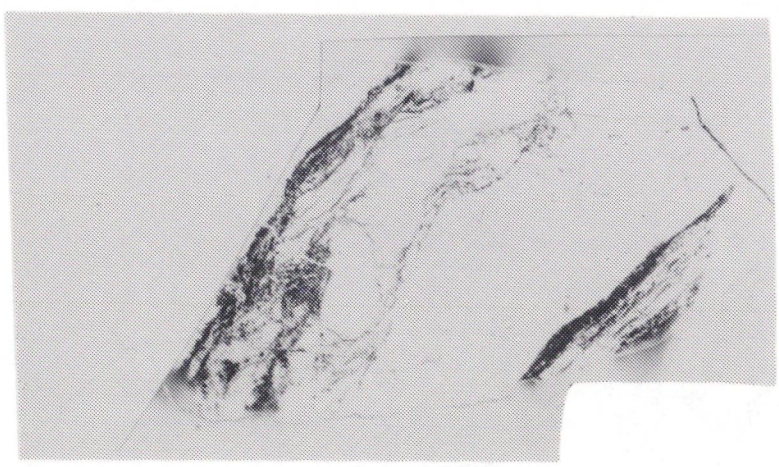


Fig. 4.5. Autoradiograph illustrating distribution of uraninite in fractures (sample 325247).

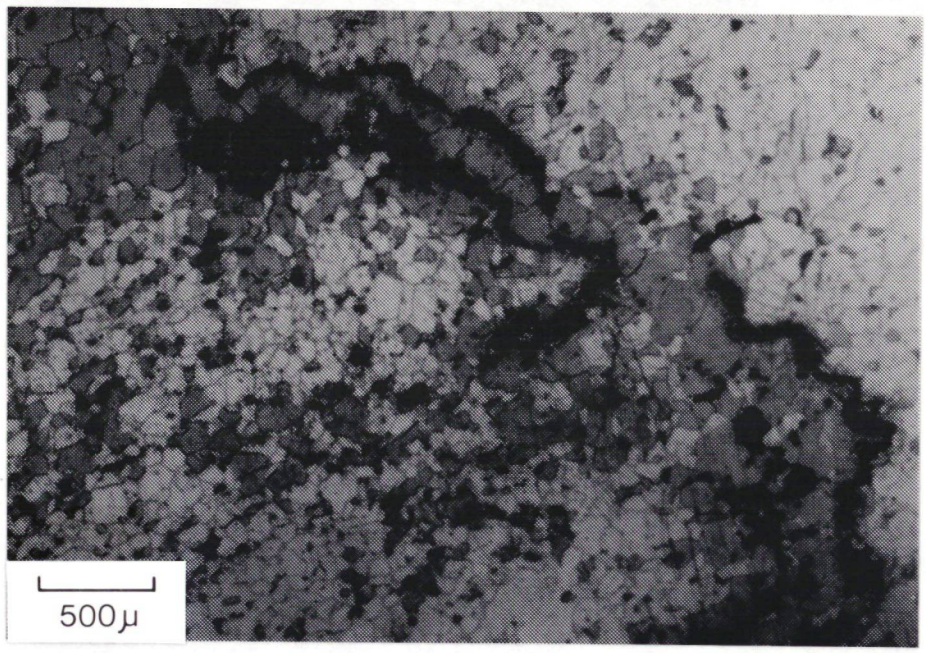


Fig. 4.6. Photomicrograph of uraninite (opaque) in fracture with pyroxene (dark grey) in meta-arkose (sample 325252).

4.2 Results of microprobe analyses of uraninite

Microprobe analyses have been made with the crystal spectrometer on the microprobe at the Mineralogical Institute of the University of Copenhagen, with the assistance of Jørn Rønsbo. Twelve elements were analysed, including U, Pb, Th, Ti, Fe, Ca, Mo, Nb, Ce, Y, Si and Nd. The instrument was calibrated and the precision measured by a number of mineral standards. A uraninite standard described by Smellie (1978) was used for uranium, and a wulfenite standard was used for lead and molybdenum calibration. A thorite standard was used for thorium. The precision of the other elements were not measured as they proved to be present in bearly detectable quantities. All points were checked for compositional homogeneity with the back-scatter electron image.

The results of the analysis of the standards indicate that the uranium can be analysed with a precision of better than +/- 1% and lead with a reproducibility of better than +/- 3.6% at the single standard deviation level (table 4.1). The average value of the standards were slightly lower than the accepted values but uncertainties such as those due to grain inhomogeneities seem to outway the usefulness of making corrections. The thorium standard was only measured once because thorium was not detected in any significant amounts. None of the analyses have been corrected on the basis of the standards because it was felt that the assumptions that have to be made concerning the homogeneity of the standards and the measured differences does not seem to warrant the calculation.

A summary of the microprobe data is shown in table 4.2. The analyses of the uraninite show that the mineral is relatively pure with the exception of lead. This is taken to reflect the high temperature to which they have been subjected and the long time they had to equilibrate. The high lead value was assumed to be radiogenic lead and to reflect their age. Isotopic studies, which will be discussed below, have shown that this was a valid assumption.

Table 4.1. Mean and standard deviation of repeat analyses of standards on the microprobe in December 1985

Standard no.	value	measured value	std.dev.	% std.dev	no.of ana.	date	element
SU---6	87.75%	87.13%	0.49	0.57%	17	June '85	U
SU---6		7.52%	0.27	3.55%	17	June '85	Pb
SU---6		0.57%	0.18	31.00%	17	June '85	Ca
SMo---	60.79%	59.06%	1.34	2.20%	6	June '85	Pb
SMo---	39.21%	37.64%	1.90	5.1%	6	June '85	Mo
SMo---		0.31%	0.07	21.6%	6	June '85	Nd
STh---	14.97%	14.65%		-2.14%	1	June '85	Th
SU---6	87.75%	88.65%	1.34	1.5%	12	Dec.'85	U
SU---6		7.77%	0.69	8.9%	12	Dec.'85	Pb
SU---6		0.67%	0.14	21.10%	12	Dec.'85	Ca

The chemical ages have, therefore, been calculated for all the analyses and averaged for each sample. Thorium has also been taken into account in this calculation but only one sample (304339) has had significant amounts of thorium. This sample was taken from a particularly small (1-2 sq m) inclusion in the rapakivi and in addition contains an appreciable amount of cerium. This is believed to reflect some contamination from the rapakivi. If this is the case then it shows that the final crystallisation of the uraninite did not take place until after the emplacement of the rapakivi.

There is only one other sample with consistently higher trace values of another element and that is from one of the veins (325246) and contains calcium. Its higher calcium content suggests in this instance that the uranium was mobilised into a cross fracture with help of the carbonate complexing.

The most important result from microprobe data was the chemical ages. They are ages calculated on the assumption that all the lead contained in the uraninite is derived from the radioactive decay of U and Th (Delaloyle, 1979). The radioactive decay constants recommended by Steiger & Jager (1977) were used for these calculations. The histogram of all 75 determinations gave an arithmetic average and a median of 1730 Ma with a standard deviation of +/-50 Ma (fig. 4.4, & table 4.2). The percentage mean standard deviation of this distribution is 2.87%. This is less than the combined standard errors of the lead and uranium analysis which is about 4.6%. The spread of values at the 2

standard deviation level of +/-100 Ma can be accounted for by the analytical variation and almost accounts for the total observed variation between a minimum of 1641 Ma and a maximum of 1896 Ma.

It was attempted to separate the disseminated uraninite from the vein uraninite on the basis of their chemical ages and composition. But no statistically significant difference could be found. This is probably mostly due to the poorer precision of the lead analysis.

Table 4.2. Summary of microprobe analyses on uraninite from different rock samples and average chemical ages

Sample no.	304339	325247	325268	325246	325273	325254	325258	325269
UO2	67.128	71.157	71.673	71.189	71.866	72.879	71.623	72.265
ThO2	4.875	0.031	0.224	0.000	0.413	0.022	0.127	0.012
PbO	18.551	20.403	20.013	19.867	19.609	19.972	19.546	20.360
FeO	0.314	0.129	0.700	0.391	0.909	0.232	0.787	0.071
CaO	0.279	0.479	0.325	1.745	0.373	0.472	0.727	0.644
Ce	0.923	0.477	0.425	0.155	0.614	0.407	0.423	0.196
Y2O3	0.370	0.178	0.416	0.452	0.452	0.119	0.043	0.246
Nd	0.954	0.232	0.332	0.164	0.670	0.331	0.216	0.129
Chemical ages								
Ma	1690	1769	1730	1731	1697	1705	1699	1744
no.of ana.	3	16	14	14	14	4	4	9

	304328	304328
UO2	68.135	57.834
ThO2	0.020	0.138
PbO	18.452	24.180
FeO	0.048	0.049
CaO	3.384	0.552
Ce	0.574	0.379
Y2O3	0.000	0.126
Nd	0.098	0.055
Chemical ages		
Ma	1689	2363
no.of ana.	3	3

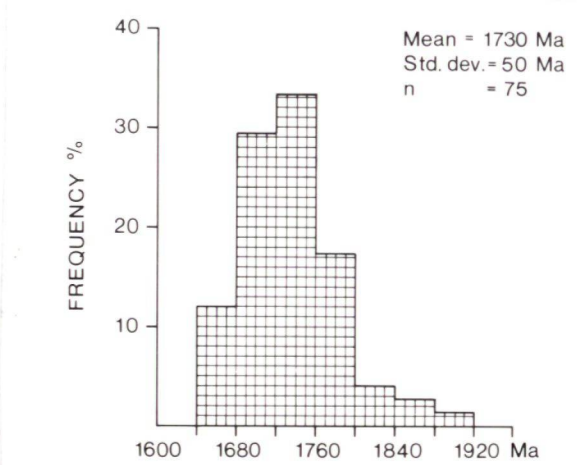


Fig. 4.7. Histogramme of chemical ages calculated from microprobe analyses of uraninite.

This 1730 Ma age for the crystallisation of the uraninite agrees with the suggested cooling age of the rapakivi granite which was intruded some 20-14 Ma years earlier (c. 1740 Ma, from Gulson and Krogh, 1975). It also corresponds with the isotopic ages discussed below.

4.3 Results of isotopic analyses

U/Pb isotopic analysis has been made on 6 samples. Three analyses were made on uraninite concentrates, and three analyses on whole rock samples which contained some uraninite. The samples were chosen from both locations where the uraninite was stratabound (325410 & 325269) and in a vein (325250). The whole rock Pb isotope analyses were done on the rational that if uranium was present in the supracrustal rocks before its final crystallisation either after regional metamorphism or the emplacement of the rapakivi then radiogenic lead from this period would have migrated into the surrounding rocks and their isotopic composition should reflect this by giving an older age than the uraninite.

Table 4.3. U-Pb isotopic analyses of uraninite and whole rock from six samples from Igdlorssuit. Analyses were made by the isotope dilution method by Ian Swainbank at the British Geological Survey

	---Isotopic composition in atom %----				concentration in ----weight %------	
Sample no	Pb204	Pb206	Pb207	Pb208	U%	Pb%
325250	0.00199	90.46	9.47	0.068	73.81	20.90
325269	0.00081	90.32	9.64	0.041	68.33	20.32
325410	0.00585	90.01	9.65	0.335	68.85	20.79
	-----isotopic ratios------			---------ages in Ma----------		
	206/238	207/235	207/206	206/238	207/235	207/206
325250	0.2979	4.2926	0.1044	1681.1	1691.9	1704.4
325269	0.3124	4.5955	0.1066	1752.6	1748.5	1742.5
325410	0.3159	4.6333	0.1063	1769.4	1755.3	1737.5

whole rock analyses

	206/204	207/204	208/204	
325258	2092.00	238.30	37.96	plot gives 1759 +/-5Ma
325273	263.90	41.93	36.36	
325282	17.38	15.35	34.95	

Chemical ages calculated from the above U & Pb analyses

	UO2	ThO2	PbO	age in Ma	age in Ma from microprobe
325250	83.710	0.000	22.510	1679.5	analyses of uraninite
325269	77.520	0.000	21.890	1747.7	1744.6 av. of 9 analyses with
325410	78.110	0.000	22.400	1769.7	std.dev.= 45.8 Ma

The sample preparation of the mineral concentrates were made by disc milling and wet sieving the resulting fine sand through 250, 100, 80 & 40 micron stainless steel sieves. Mineral separates were made mostly on the 100-80 micron fraction but also on the 80-40 micron fraction if there was not sufficient material in the coarser fraction. Both the strongly and the weakly magnetic fractions were then separated and the remaining non-magnetic fraction was split using methylene iodide with a specific gravity of 3.31. A final panning in water of the heavy fraction in a small pan helped to concentrate the uraninite before hand picking.

Isotopic analyses were carried out by the isotope dilution method at the British Geological Survey by Dr Ian Swainbank.

The results are shown in table 4.3 and plotted on the concordia diagram (fig. 4.8) and the Pb/Pb plot (fig. 4.9). All of them have an extremely low common lead content indicating that the assumptions that were made for calculating the chemical ages were valid.

Only one sample (325269) plots on the concordia within the analytical reproducability and gives a reasonable age of 1742 +/-4Ma. The uranite in sample 325410 has suffered small uranium loss. Presumably this is due to leaching of the uranium during weathering as these are surface samples. Sample 325250 on the other hand has suffered a lead loss. As this is also a surface sample which has undergone the same weathering conditions it can only be assumed that the associated sulphides have restricted the relative mobility of uranium compared to lead.

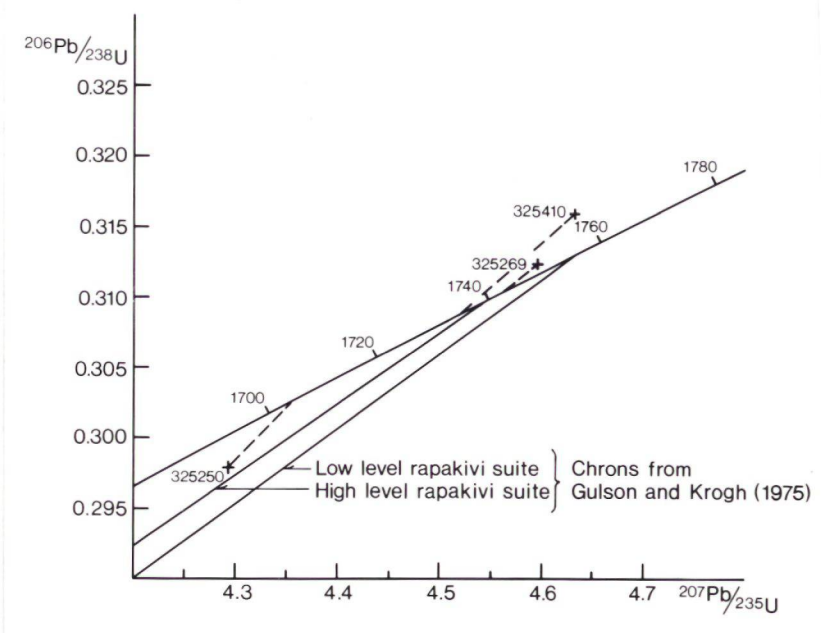


Fig. 4.8. Concordia diagramme showing the isotopic ratios of the uraninite samples. Dashed lines join sample to Pb 207/206 isotopic age.

In any case the 206Pb/207Pb ratios are consistent with the hypothesis that the stratabound uraninite (325269 & 325410) is older than the vein type uraninite (325250). The age of 1740 +/- 4 Ma for stratiform uraninite corresponds with the U/Pb zircon ages of 1740 Ma of the higher level rapakivi suite (fig. 4.10) (Gulson & Krogh, 1975). This supports the hypothesis already proposed from the chemical ages that the uraninite isotope ratios have been reset at the time of the emplacement of the rapakivi granite.

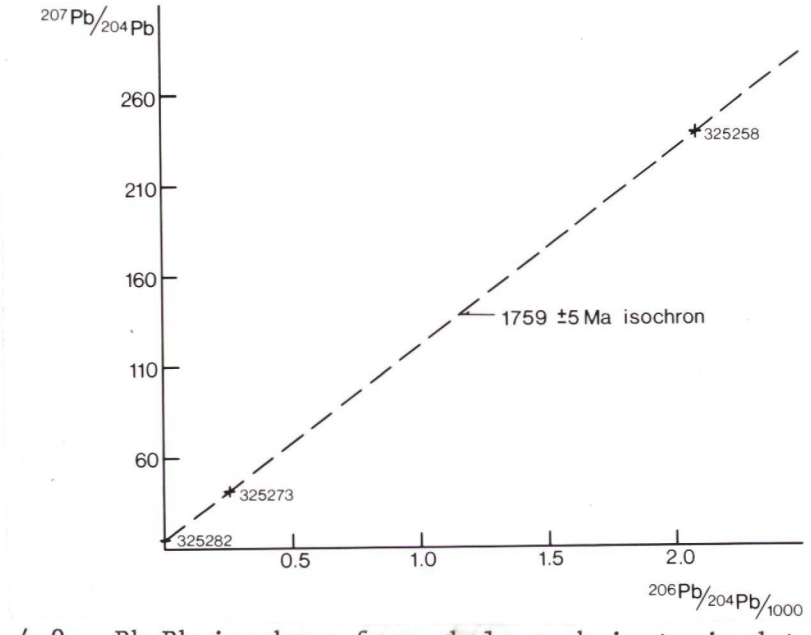


Fig. 4.9. Pb-Pb isochron from whole rock isotopic data.

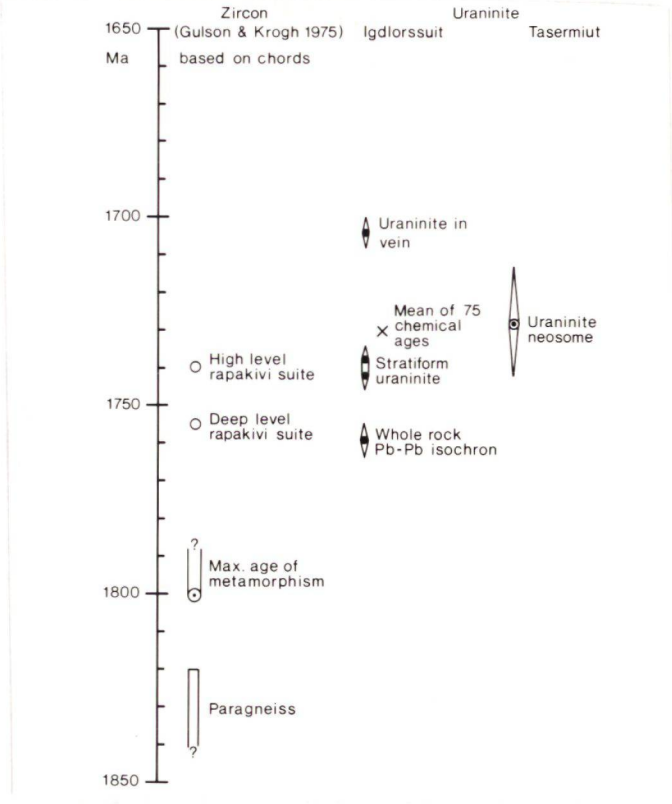


Fig. 4.10. Summary of known isotopic ages in the Migmatite Complex.

The age of vein uraninite (325250) is difficult to explain because the field evidence suggests that the veins were formed prior to the emplacement of the rapakivi granite and its isotopic age appears to have been set about 36 Ma later at 1704 +/- 4 Ma. A possible explanation could be that the veins were formed after the intrusion of the rapakivi granite and were due to a release in pressure in supracrustal rafts which were rising in the granitic magma and a migration of intraformational volatiles along planes of weakness which did not affect the surrounding mostly crystalline impermeable granite. The acceptance of such a hypothesis must await confirmation of the 1704 Ma isotopic age.

The whole rock Pb-Pb isochron suggests an age of 1759 +/-5 Ma. Again, as expected, this is older than the uraninite and indicates that the uranium was present in the supracrustal rocks at least before the intrusion of the rapakivi granite. It unfortunately says nothing about the presence of the uraninite before the regional metamorphism. Obviously more samples should be analysed to confirm this isochron, but at this stage it is at least possible to speculate that 1760 Ma was the minimum age for the presence of the uranium in the supracrustal rocks. It corresponds with the youngest age of zircon in neosome measured by Gulson and Krogh (1975).

5 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion of genesis

From the foregoing descriptions there emerges a number of relevant points which have a bearing on the genesis of this uranium occurrence. They can be summarised as follows:

1) The stratiform distribution of uranium occurrences both on a regional and a local scale suggests an early association of uranium with particular horizons.

2) The folded uraniferous bands demonstrate that the uranium was present before the folding. Since the folding was contemporaneous with the regional metamorphism, which preceeded the intrusion of the granite, it was, therefore present before these events as well. The inclusion of the uraninite grains in the metamorphic minerals corroborates this point.

3) The older isotopic age of uraninite in stratiform occurrences (1743 +/-4Ma) compared to uraninite from a cross fracture (1704 +/-4Ma) suggests that there was some later remobilisation of uraninite.

4) Similarly, the older whole-rock Pb-Pb isotopic age (1759 +/-5Ma) shows that radiogenic lead disseminated into the surrounding rock before the crystallisation of the uraninite and demonstrates a minimum age for the presence of uranium in the supracrustal rocks.

5) The presence of sulphide minerals and graphite suggest that a low oxygen fugacity gave rise to a reducing environment which could have played a role in the retention of the uranium during metamorphism.

The first two points demonstrate that the uranium was present in the supracrustal rocks before the regional metamorphism. Textural and isotopic results either confirm or does not contradict this conclusion.

A number of uranium occurrences in metamorphic rocks with similarly high U/Th ratios have been described from elsewhere in the world. These are notably in the Precambrian shield areas such as Canada, Sweden, and southern Africa but the writer has not found any that occur in granulite facies rocks with such a high temperature. There are occurrences of urano-thorianite reported in pyroxenite in the granulite facies in Madagascar (Moine et al., 1985). But their metamorphic temperature was in the order of 700^{o} to 780^{o}C not 900^{o}C and their U/Th ratio is always below 1 and is, therefore not comparable to the Igdlorssuit occurrence. There is no concensus as to the genesis of this category of uranium mineral showing mainly because the regional metamorphism has obliterated much of the evidence. Some workers prefer a syngenetic and/or epigenetic introduction of uranium along particular permeable strata, and some agree, usually for textural reasons, that the uranium was present before the regional metamorphism. Isotopic ages tend to show that the uraninite crystallised during the last thermal event and is, therefore, of limited help

in establishing its age of deposition.

Both in Labrador (Gower et al., 1982) and north Sweden (Smellie & Laurikko, 1984 & Smellie, 1984) similar stratiform uranium deposits have been reported. Their geneses have been interpreted in various different ways but final proofs are lacking. In both areas acid volcanic rocks occur and are presumed to have been the source of the uranium. Both in Labrador and at Skuppesavon in north Sweden (Smellie & Laurikko, 1984) some form of alkali metasomatism is favoured because uranium minerals are associated with sodium enriched halos. The stratabound distribution of the uranium minerals are explained by the channelling of the U-bearing solutions along permeable strata. Igdlorssuit differs from these areas in not having acid volcanic rocks. The metavolcanic rocks are of intermediate composition. Their high Sr and Zr levels, however, suggest a calc-alkaline province, which could just as well be a source of uranium. Again this may not be such an important point for the development of syn-sedimentary types of deposit. What is important is the porosity of the rocks, the oxidation-reduction front and through-flowing uraniferous solutions. Due to lack of evidence it is not worth speculating on the source or character of the U bearing solutions. It is clear from the reconnaissance data (Armour-Brown et al., 1983) that South Greenland is part of a U province and, therefore, there must be a number of possibilities for the source of the uranium if not the solutions.

One of the more comparable showings occurs at Karpinka Lake in Aphebian gneiss in the vicinity of the Athabasca basin in Saskatchewan, Canada (William-Jones & Sawiuk, 1985). The writers there describe fine disseminated stratabound uraninite and brannerite in meta-arkose between marble and pelite metamorphosed up to the amphibolite facies. The uraniferous minerals are, in particular, associated with sillimanite. The U/Th ratio is high with an average of 35 and tends to increase with increasing U content where there is more than 100 ppm U present. The authors propose that the host rocks were a poorly lithified continental arkosic sandstone rich in Fe and Ti minerals and that by a combination first of a sulphidication of the the host rocks followed by an introduction of uranium in the ground water or other circulating waters that uranium was concentrated by a process of absorption on kaolinite and titania ´sponges´ which had already been produced by earlier alteration. During the metamorphism associated with the Hudsonian orogeny about 1800 Ma the uranium absorbed by the kaolinite became transformed into the fine grained uraninite associated with sillimanite and the uranium absorbed by the titinia ´sponges´ became brannerite.

At Igdlorssuit there is no brannerite. Brannerite, however, has been shown to break down during further anatexis (Ruhlmann, 1981) to form uraninite and

ilmenite. These are common minerals at Igdlorssuit. There is little evidence of pelitic minerals at Igdlorssuit and this is reflected in the low aluminium contents of the supracrustal rocks (table KEMIGD). But clay minerals are not essential for the deposition of uranium in a sedimentary rock unit. All that is required is an oxidation and reduction interface and a through-flow of uraniferous water.

Although the early mechanisms for concentrating uranium in the supracrustal rocks is obscure for the time being and must await further studies, the important conclusion from the point of view of the uranium potential of the Migmatite Complex is that uranium can remain despite the very high grade of metamorphism of their host rocks. The uraniferous nature of the supracrustal rocks in the Migmatite Complex is confirmed indirectly by zircons with uraniferous overgrowths which were noted to occur in '...subconcordant granitic sheets...' (i.e. neosome) by Gulson & Krogh (1975), and also by the uraninite concentration found in neosome in the Tasermiut area with a U/Th ratio of 10 (Nielsen & Tukiainen, 1981). These features can be easily explained if the neosome were derived from the anatexis of uraniferous supracrustal rocks.

5.2 Significance of results

The small tonnage and grade would not be a negative aspect in itself if it was combined with geological features which indicated a down dip extension of the ore. The intrusion of the rapakivi granite has, however, disrupted the continuity of the uraniferous units. If they continue down dip they would be extremely difficult to find and the costs of exploration and mining at this location would probably outway the benefits because of this uncertainty of locating more ore.

The main significance of the uranium showing at Igdlorssuit is that it represents a model of the type of mineralisation which can be expected in the Migmatite Complex of South Greenland. Similar supracrustal rocks are distributed over wide areas of the complex, on the west coast around Tasermiut and on the east coast north and south of Lindenows Fjord. In the final report of the SYDURAN project (Armour-Brown et al., 1984) nine areas were outlined where reconnaissance uranium anomalies remain to be explained. The chances, therefore, of finding the same type of uranium mineral occurrence must be rated extremely high. If similar grades were found in a place where the supracrustal rocks were not so dissected by intruding granite the exploration for the lateral and down dip extensions of the uraniferous horizons would be greatly facilitated, and tonnages could quickly reach economic levels.

It is important to emphasise that the the Migmatite Complex has only been explored at the reconnaissance density of observation and there may be other

anomalous areas outside the original 9 which have not been located. The only way to prove this is to increase the density of observation by at least ten times over the Migmatite Complex. This recommended figure is based on the reconnaissance coverage which on average covered about 10% of the total area. A tenfold increase should, therefore, cover the remaining area with a high chance of finding every reasonable sized uranium mineral occurrence which was not covered by overburden. Stream sediment geochemistry should be used to supplement the helicopter borne gamma-spectrometer survey especially in covered areas.

5.3 Summary of conclusions

There are estimated to be about 17 000 tons of uranium ore at Igdlorssuit with a grade of 0.31%. This would give about 50 tons of uranium metal. Although the grades are promising, reaching up to 4%, the volume of ore is clearly too low to suggest any mineral exploitation at this relatively inaccessible locality. From the disposition of the supracrustal rafts in the granite it is possible that the uraniferous unit may project to about 60 m depth. Any continuation down dip into the granite of the same uraniferous raft would be difficult to find. For these reasons the economic potential of this occurrence must be rated low.

The uranium showing at Igdlorssuit is probably of syn-sedimentary or epigenetic origin. In any case the uranium was present in the supracrustal rocks prior to their metamorphism and the intrusion of the granite. They are not, therefore, related directly to the genesis of the granite.

Isotopic data show that stratiform uraninite crystallised at the time of the high-level rapakivi granite at 1740 Ma. Limited whole rock data, which requires confirmation, indicates a minimum age of 1759 Ma for the presence of the uranium in the suprcrustal rocks and that radiogenic lead was being lost to the surrounding country rocks. A relatively young age of 1704 +/-4 Ma for uraninite in a cross cutting vein shows that there was mobilisation of uranium from the stratiform locations. The fact that it is considerably younger than the rapakivi granite calls into question either the accuracy of the isotopic analyses or the interpretation that this veinlet was of pre-rapakivi origin. These require resolving.

Microprobe analyses of the uraninite has confirmed the isotopic ages with chemical ages with a mean of 75 determinations of 1740 Ma. The method was not sufficiently accurate to detect different ages of the different types of uraninite and no significant compositional differences were found between uraninite which was classified as stratiform and that occurring in cross cutting fractures.

Regional mapping suggests that isoclinal folding of the supracrustal rocks is an important structural feature which will have to be resolved in local situations in order to find the extensions and additional ore bodies. The concentration of uranium in zones of brecciation and in the cusps of folds are probably very important structural features which lead to increased uranium grades.

The texture and composition of the country rocks have confirmed that they were metamorphosed up to the granulite facies. Microprobe analyses of clinopyroxene and orthopyroxene in equilibrium with each other have established that these rocks reached a temperature of around 900°C which is high in the granulite facies. A limited review of the literature suggests that these are the highest grade metamorphic rocks which are known to contain so much uranium with such a high U/Th ratio.

Limited petrographic and geochemical analyses have confirmed that the metavolcanic rocks are of calc-alkaline composition and that meta-arkose probably contained a volcanic component.

Radiometric measurements with a scintillometer are adequate for the surface appraisal of the uranium showings especially if the grid measurements are made with calibrated instruments. The speed with which radiometric readings can be made offsets the disadvantages and lack of accuracy of individual measurements can be compensated for by the large number of measurements that can be made.

5.4 Recommendations for future work

Recommendations for future work in this area can be divided into two categories: firstly the relatively academic studies to elucidate further the petrogenesis of this unique occurrence and secondly mineral exploration.

5.4.1 Petrological studies

The petrography should be studied further to both confirm the preliminary findings which have been made during this work and extend the knowledge about this showing. These should include studies to resolve the original composition of the metamorphic rocks and their origin before the regional metamorphism, the temperature to which they have been subjected during metamorphism and the chemical changes they have undergone during metamorphism and the intrusion of the granites and how these might relate to the concentration mechanisms of uranium before and after metamorphism. Very little work has been done on the sulphide and graphite components in the rocks and the presumed influence that they have had on the oxygen fugacity and uranium mobility.

Fluid inclusion studies would be particularly invaluable at this stage to establish the composition and the temperature conditions of the fluid phases

at the time of crystallisation of the metamorphic rocks and the uraninite and help explain the geochemical conditions which have led to the retention of uranium during the regional metamorphism.

Further isotopic studies should be made especially whole-rock analyses of the uraniferous horizons as these have a possibility of measuring at least a proportion of the radiogenic lead which was derived from the uranium before the uraninite crystallised and compared with ages from uraninite in the same horizons. Uranium and lead isotopic studies should be extended to include strontium and oxygen isotopic measurements in order to determine the origin of the country rocks and the sulphide minerals.

5.4.2 Future exploration

The Igdlorssuit uranium occurrence is a model for the type of uranium that is to be expected in the Migmatite Complex. The gamma-spectrometer survey which has been used effectively in the reconnaissance surveys and in the more detailed survey on the Motzfeldt Centre has shown its ability to detect uranium mineral showings where there is good exposure. The exposure is relatively good throughout the Migmatite Complex. Therefore, an initial gamma-spectrometer survey, with the instrumentation installed in a helicopter, should be carried out over the Migmatite Complex as a whole at 10 times the density of the reconnaissance survey. Such a survey should locate every exposed sizeable mineral occurrence. Exploration geochemical methods should be used in areas of poor exposure as a supplement to the gamma-spectrometer survey. A radiometric survey could be accomplished with 12 000 km of contour flying and would take about one month to complete. The flying could be made from Prins Christianssund radio station and would not require any base camp facilties or expensive fuel depots. The results could be plotted and evaluated during the course of the next year and anomalies worth following up identified. Such a survey would also be helpful in the next phase of geological mapping in the Migmatite Complex much of which has been mapped only at a preliminary reconnaissance scale.

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APPENDIX

Appendix 3.1 Assays from in situ scintillometer measurements and thermo-luminescent dosimeters, and gamma-spectrometer measurements on rock samples from the same locations

	U		U			eU		eTh
NR	DOS. PPM	STD	SCINT. PPM	STD	GGU NR	LAB. PPM	STD	PPM
1	218.3	9.2	230.0	20.0				
2	211.2	9.1	360.0	19.0	325442	158.0	7.9	7.1
3	292.5	12.0	440.0	27.0				
4	2250.2	40.5	2280.0	70.0	325441	2084.8	108.8	13.0
5	28648.3	1289.2	24300.0	650.0	325424	27141.3	1409.5	615.0
6	619.0	28.5	920.0	30.0				
7	3272.6	140.7	3500.0	140.0				
8	677.0	17.6	870.0	33.0	325448	120.0	2.7	4.4
9	157.1	6.8	300.0	23.0				
10	338.7	19.6	450.0	32.0	325445	73.4	8.1	7.5
11	1033.3	15.5	1330.0	55.0	325444	160.3	14.5	6.6
12	753.9	19.6	830.0	29.0				
13	168.3	4.2	220.0	20.0				
14	493.1	24.2	240.0	15.0				
15	257.8	7.5	280.0	17.0	325443	127.3	12.7	6.8
16	79.9	2.6	150.0	13.0	325439	7.9	0.4	0.7
17	213.0	3.2	280.0	17.0				
18	1619.0	29.1	1360.0	49.0				
19	4835.4	106.4	4360.0	94.0	325426	3623.0	198.5	16.0
20	20059.6	942.8	14300.0	500.0	325425	9839.8	510.0	30.0
21	9765.8	39.1	7700.0	310.0				
22	211.2	7.2	320.0	20.0				
23	694.5	7.6	750.0	47.0	325447	717.7	35.4	7.5
24	307.6	10.2	490.0	23.0				
25	81.0	1.7	250.0	16.0	325451	13.4	0.4	2.4
26	178.6	6.3	310.0	22.0				
27	570.1	20.5	410.0	20.0				
28	135.5	3.5	190.0	15.0				
29	102.1	3.8	150.0	12.0				
30	331.0	4.6	500.0	22.0				
31	363.1	5.4	580.0	24.0				
32	243.7	13.2	170.0	13.0				
33	305.4	6.7	450.0	22.0				
34	145.9	9.5	250.0	16.0	325449	62.6	4.2	7.4
35	2834.4	65.2	3500.0	130.0	325440	3236.2	370.8	22.0
36	704.7	19.7	710.0	27.0	325450	372.0	34.9	4.4
37	129.1	2.1	150.0	13.0				
38	104.6	3.1	140.0	13.0				
39	361.0	27.8	450.0	21.0				
40	238.5	3.6	310.0	18.0				
41	147.5	1.0	140.0	12.0	325446	252.3	2.5	4.3
42	216.8	2.6	250.0	18.0				
43	806.4	35.5	1070.0	49.0	325438	1270.0	43.6	30.3
44	250.3	12.8	100.0	10.0				
45	67.5	1.5	450.0	28.0				
46	3578.8	139.6	3200.0	110.0				
47	48438.4	775.0	25100.0	999.0				
48	13227.0	383.6	12900.0	220.0				
49	515.7	12.9	550.0	25.0				
51	18047.0	162.4	25100.0	999.0				
52	74807.0	3590.7	25100.0	999.0				

APPENDIX 3.1 cont.

NR	U DOS. PPM	STD	U SCINT. PPM	STD	GGU NR	eU LAB. PPM	STD	eTh PPM
0	0.0	0.0	5000.0	110.0	325405	7883.2	362.2	29.0
0	0.0	0.0	3260.0	95.0	325403	1174.8	76.1	10.0
0	0.0	0.0	7500.0	150.0	325404	3481.5	262.0	16.0
0	0.0	0.0	9900.0	180.0	325408	9702.3	522.9	42.0
0	0.0	0.0	25100.0	999.0	325420	30705.2	1273.7	261.0
0	0.0	0.0	150.0	13.0	325421	5.0	0.3	5.4
0	0.0	0.0	76.0	10.0	325422	2.2	0.4	2.5
0	0.0	0.0	40.0	6.0	325423	3.1	0.6	5.4
0	0.0	0.0	1100.0	45.0	325432	739.7	31.0	9.6
0	0.0	0.0	1400.0	37.0	325433	1391.3	89.5	17.0
0	0.0	0.0	5800.0	210.0	325452	1753.8	77.1	16.0
0	0.0	0.0	17100.0	130.0	325454	10834.7	487.6	110.0
0	0.0	0.0	25100.0	999.0	325456	14670.2	642.6	127.0
0	0.0	0.0	16500.0	140.0	325455	5615.3	448.9	39.0
					325424	27681.0		801.0
					325453	18474.0		306.0
					325458	1013.0		20.0
					325468	689.0		52.9

Appendix 3.2 Ore calculations over radiometric grid A

U % grade range	median	area in sq m	vol in cu m x 60	ore tonnage SG = 2.8	tons of U
2-1 %	1.5 %	.76	45.6	128	2
1-0.5 %	0.75 %	11.6	696	1950	15
0.5-0.2 %	0.35 %	38.55	2313	6476	23
0.2-0.1 %	0.15 %	49.06	2943	8240	12
			Total	16794	52

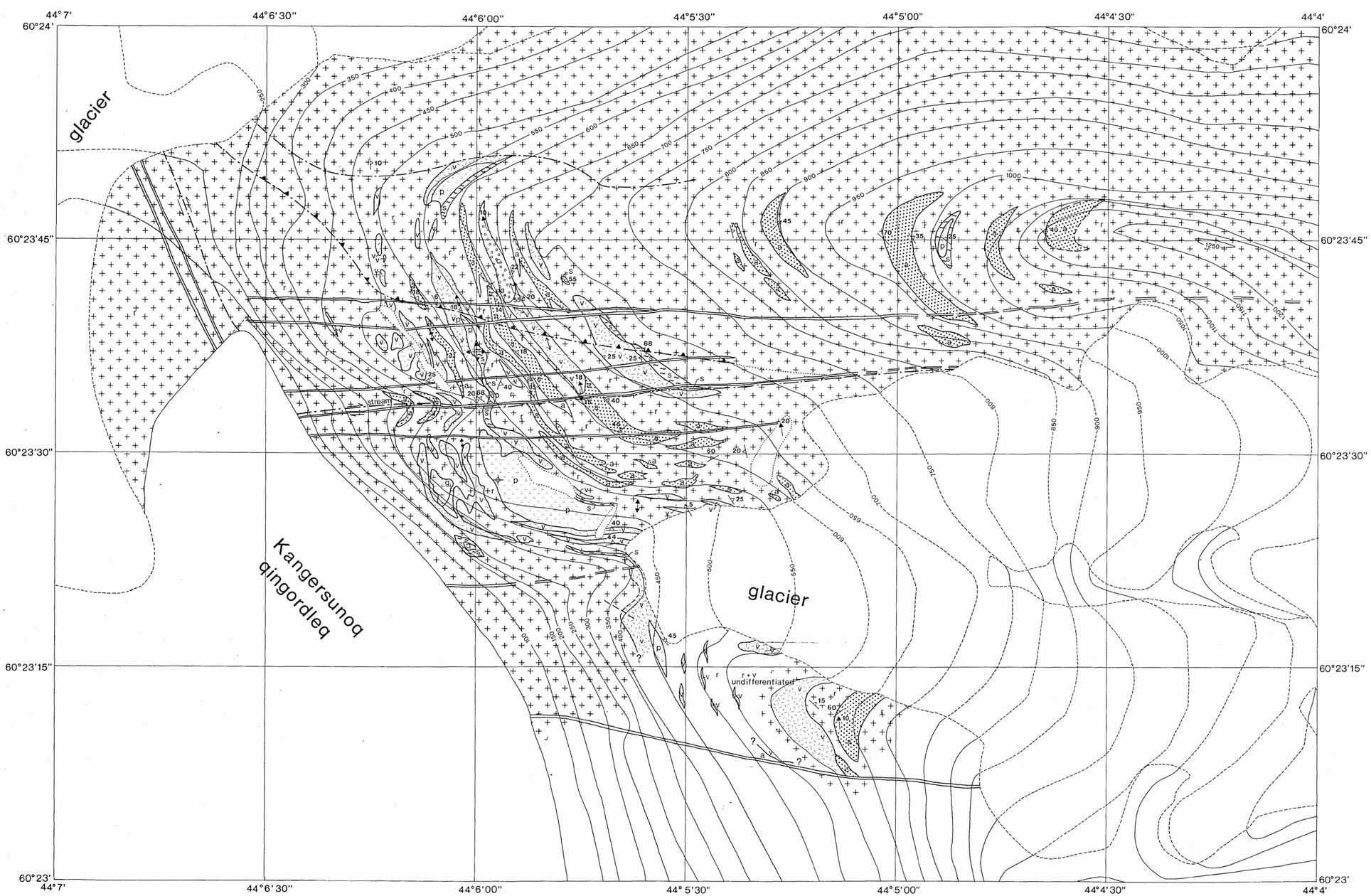
average grade of ore 0.31% U

N.B. The surface areas have been calculated for each range of grades by summing the area under each contour range. This has been multiplied by 60 m which is the possible down dip extension to give the total volume of ore. See geological cross section fig. 2.9.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MAP 1
GEOLOGICAL MAP OF

IGDLORSSUIT, SOUTH GREENLAND



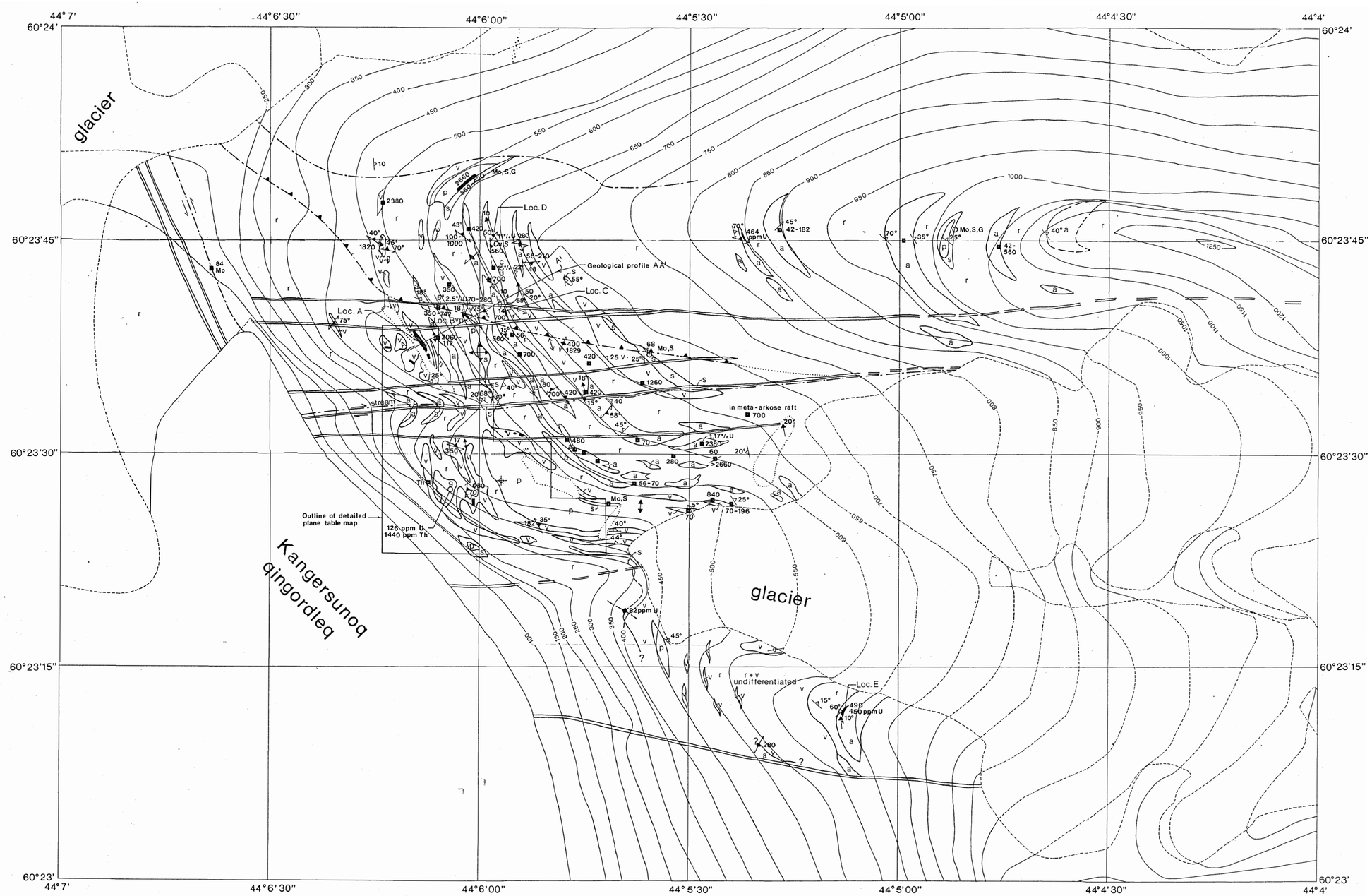
Overburden
Basalt dyke
Rapakavi granite
Granite
Meta-arkose/tuff
Intermediate metavolcanic unit
Sulphide rich metasediment
Pyroxenite and mafic metavolcanic unit
Metaconglomerate
Reverse fault
Fault
Contact between metasediment and rapakivi granite
Fold axis
Linear fabric

Topography drawn photogrammetrically by the Geological Survey of Greenland, June 1984
Trigonometric points from the Geodetic Institute, Denmark.
SYDEX Rep. no. 2 1986

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MAP 2
GEOLOGICAL MAP OF

IGDLORSSUIT, SOUTH GREENLAND
LOCATION OF URANIUM MINERAL OCCURRENCES



Overburden
Basalt dyke
r Rapakavi granite
g Granite
a Meta-arkose/tuff
v Intermediate metavolcanic unit
s Sulphide rich metasediment
p Pyroxenite and mafic metavolcanic unit
c Metaconglomerate
50 Reverse fault
Fault
20° Contact between metasediment and rapakivi granite
10° Fold axis
60° Linear fabric
75 Radioactive fractures dip
280 Radioactive mineral occurrence radioactive measurement in ur
O Other mineral localities
Th Thorium dominated radioactivity
Cu Copper minerals
Mo Molybdenite
S Sulphide minerals
G Graphite
Loc. A Localities referred to in text of report

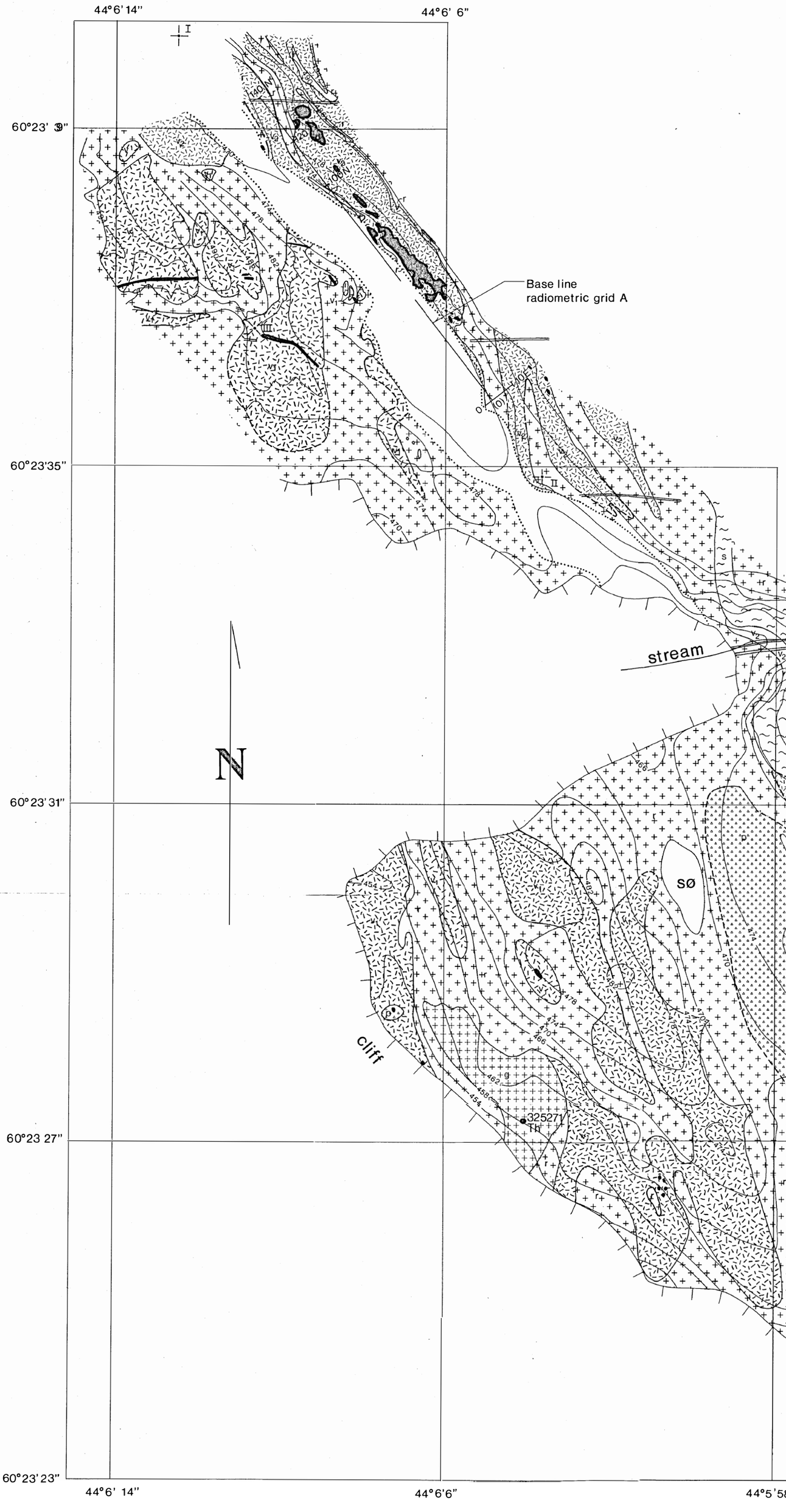
Topography drawn photogrammetrically by the Geological Survey of Greenland, June 1984
Trigonometric points from the Geodetic Institute, Denmark.
SYDEX Rep. no. 2 1986

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MAP 3

DETAILED GEOLOGICAL MAP OF

IGDLORSSUIT, SOUTH GREENLAND



- Mapped boundary
- Inferred boundary
- Overburden
- Basalt dyke
- Rapakivi granite
- Granite
- Intermediate metavolcanic unit
- Intermediate metavolcanic unit fine grained tuff
- Sulphide rich metasediment
- Pyroxenite
- Radioactive mineral occurrences
  U-uranium >500 ppm
  Th - thorium dominated
- Planetable photogrammetric control points

0 20 40 60 80 100 m

Contour interval 4 m

Topography drawn by Jens P. Nielsen using plane table and alidade July, August 1984. Ground control established photogrammetrically at the Geological Survey of Greenland in 1985, with 4-5‰ error in the position of the geographical grid and ±4 m error in altitude. Relative positions ±1 m error.

SYDEX Rep. no. 2 1986