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RAPPORT Nr. 76

The Geological Survey of Greenland
Report No. 76

Radiometric survey between Scoresby Sund and Hold with Hope, central East Greenland

by

Bjarne Leth Nielsen and Leif Løvborg

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Abstract

Airborne gamma-spectrometry and subsequent radiometric field investigations in central East Greenland have revealed a number of areas of above average radioactivity and a number of radioactive anomalies within these areas. These areas can be divided geologically into: pre-Caledonian crystalline basement, late and post-Caledonian plutonic rocks, Tertiary plutons and areas of intensive faulting and shearing. Areas bordering continental sedimentary formations are envisaged as potential host rocks for epigenetic uranium mineralization.

The spectrometer system applied, with a detector volume of 3.7 litres, does not completely satisfy a quantitative evaluation of the spectrometric data recorded and a distinction between major rock units is only possible from the gross channel count rates.

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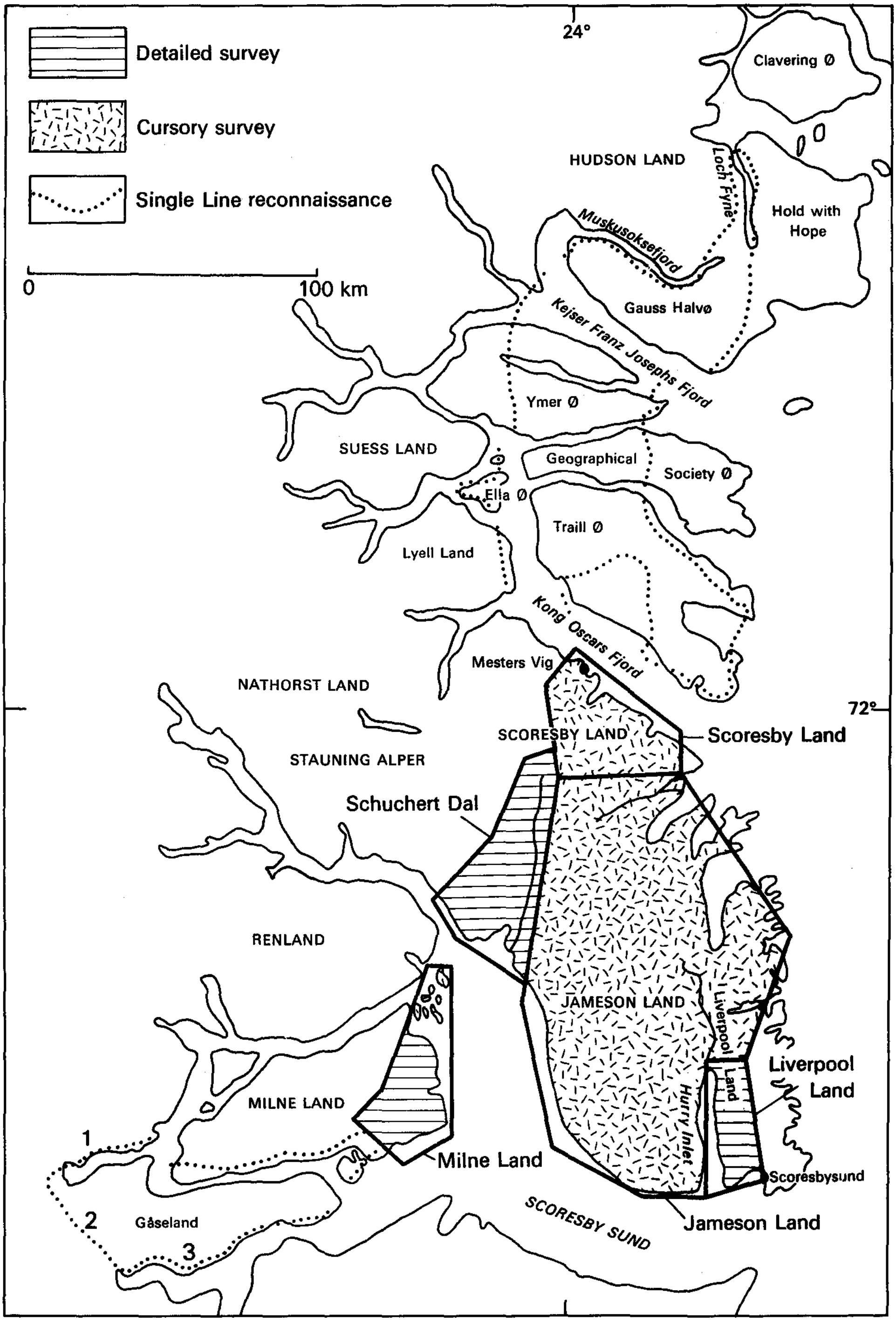

Fig. 1. Radiometrically surveyed areas in central East Greenland. The various categories of accuracy are marked.

INTRODUCTION

In July and August of 1971 an aerial gamma-spectrometric survey was carried out in central East Greenland from Scoresby Sund (70°N) to Hold with Hope (74°N) (fig. 1). The airborne instrumentation was installed and serviced by personel from the Research Establishment Risø of the Danish Atomic Energy Commission while the programme was planned and executed by staff of the Geological Survey of Greenland. The airborne work was followed by ground investigations in the summers of 1971 and 1972. The radiometric data were processed on computer installations at Risø. A laboratory gamma-ray spectrometer at the Electronic Department (Løvborg, 1972) was used for radioelement analysis of sample material.

The airborne gamma-ray spectrometer was flown in a Dornier 28 twin engine aircraft with short take-off and landing capabilities. The aircraft was chartered from A/S Aerokort, Denmark, and operated from the airstrip at Mesters Vig on the southern side of Kong Oscars Fjord. Most of the data were recorded during contour flying maintaining an average terrain clearance of 50 m (*c* 150 ft). Navigation was purely visual. Data were recorded over approximately 7000 line kilometres corresponding to 60 flying hours of data recording at an average speed of 115 kilometres an hour.

In 1973 a new and more detailed survey was initiated over the same area and extended further north to 76°N (Nielsen & Larsen, 1974) using an improved airborne instrument. The combined surveys are expected to furnish a distribution pattern of radioelements in central East Greenland.

The survey of the data presented here is divided into three categories: (1) areas of detailed survey, characterized by flight line spacing of 200 to 500 metres, (2) areas of cursory survey in which the flight lines are several kilometres apart, and (3) areas with only a single reconnaissance flight. The three categories are shown on figure 1.

Topography and geology

The topography within the area is extremely varied and largely controlled by the major geological features. In the central fjord zone and westwards gneisses, granites and metasediments of Precambrian to late Caledonian age give a rugged mountainous region with summits exceeding 2000 m and glaciers in the valleys. In the eastern part of the area Palaeozoic and Mesozoic sedimentary formations give gently rolling topographic features. Tertiary intrusions cutting through the sediments produce local mountainous regions. To the north the average elevation increases and the high plateaux are partly covered by permanent snow fields.

The wide range of geological units represents an almost complete stratigraphic succession from the Precambrian to the Tertiary. The Caledonian orogen and the succeeding tectonic movements followed by continental and marine sedimentary incursions are controlling factors for the distribution of the radioelements.

INSTRUMENTATION AND DATA PROCESSING

Airborne gamma-ray spectrometer

The airborne gamma-ray spectrometer was a Nuclear Enterprises type NE 8424, Mark 15, equipped with two standard detector units and an ABEM model DS-1195 five channel strip chart recorder. A radio altimeter, CSF type AM 220, was installed in the aircraft for continuous recording of the terrain clearance.

Each of the two detector units contains a 6″ diameter × 4″ NaI (T1) crystal optically coupled to a 5″ photomultiplier tube (figs 2, 3). The pulses from the photomultiplier pass, via preamplifiers, to a summing amplifier in which the two pulse-height distributions are matched and combined. The five counting channels in the pulse-height analyser are read-out on ratemeters with adjustable ranges and time constants. Channel 1 registers the total (gross) gamma ray intensity of the terrain beneath the aircraft, whereas channels 2, 3, and 4 register gamma-rays with energies 2.62, 1.76, and 1.46 MeV, characteristic of Tl^{208} in the Th^{232} decay series, Bi^{214} in the U^{238} decay series and K^{40}. Channel 5 is used for monitoring the overall gain of the spectrometer. The count rate from this channel is produced mainly by 0.662 MeV gamma-rays emitted by a weak Cs^{137} source placed between the detector units. A possible gain drift shown by one or the other of the photomultipliers would be observed as a decrease in the deflection of the ratemeter in channel 5. The proper gain-control potentiometer in the summing amplifier is then adjusted until a maximum deflection has been re-

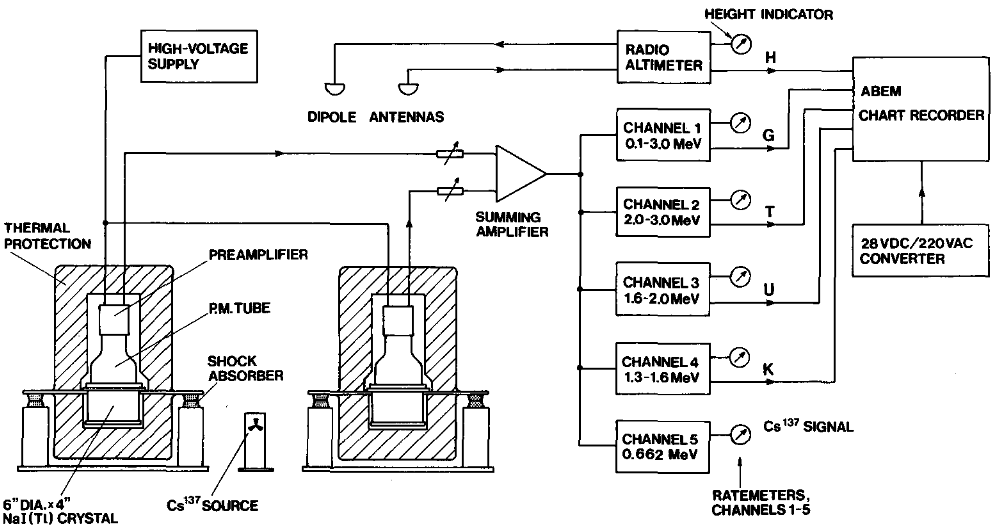

Fig. 2. Schematic representation of the airborne gamma-ray spectrometer, Nuclear Enterprises type NE 8424, Mark 15.

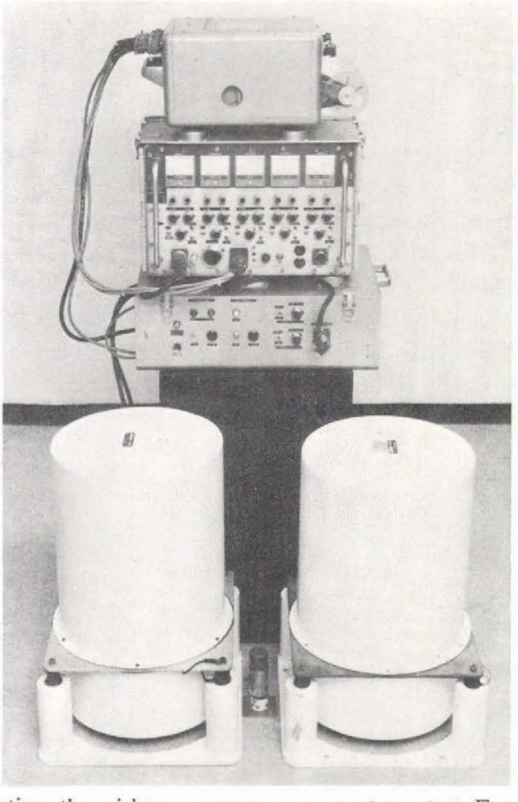

Fig. 3. Units constituting the airborne gamma-ray spectrometer. From above downwards: analogue strip chart recorder, pulse-height analyser, converter and voltage supply, and detector units. The reference Cs^{137} source is placed between the detector units.

established. The contribution of the Cs^{137} gamma-radiation to the measured total gamma-ray intensity is neutralized by means of the zero suppression control of the ratemeter in channel 1. The strip-chart recorder produces a permanent paper record of the signal H from the radio altimeter and the signals G, U, T, and K from the ratemeters in channels 1, 2, 3 and 4. The five curves are drawn on a wax-lined paper chart by means of electrically heated stylus arms giving maximum deflections of 2.5 cm on the chart.

Data processing

The record on the paper charts produced by the ABEM recorder were digitized by means of an optical curve follower which was controlled and read-out by an EAI-680/PDP-8 hybrid computer. The record was digitized once every 100 m of aircraft flying distance and stored on a magnetic tape file. The record representing the signal H was converted to feet. The numbers representing the signals G, U, T and K were converted to counts per second based on a knowledge of (1) the average zero position of the stylus arms on the paper charts, (2) the signals required to deflect the stylus arms fully from their zero positions, and (3) the settings of the ratemeter range selectors which were adjusted many times during flight in order to utilize the maximum deflection of the stylus arms. The resulting data were stored on a magnetic tape file called GGUFLIGHT 71 which is permanently stored at Risø.

The general evaluation of the survey data was done from an inspection and manual processing of the radiometric profiles in relation to the geological formations traversed during the flights. For this purpose a computer programme was used by means of which data on the GGUFLIGHT 71 file were presented graphically (fig. 4).

A radiometric profile shows the signals H, G, U, T and K, and the ratios U/T, U/K and T/K (e.g. fig. 4). The signals G, U, T and K are normally corrected for background. The background used in this survey was that recorded daily over Kong Oscars Fjord. The background was very constant consistent with the fact that radon-retaining inversion layers never developed during the season. The following average

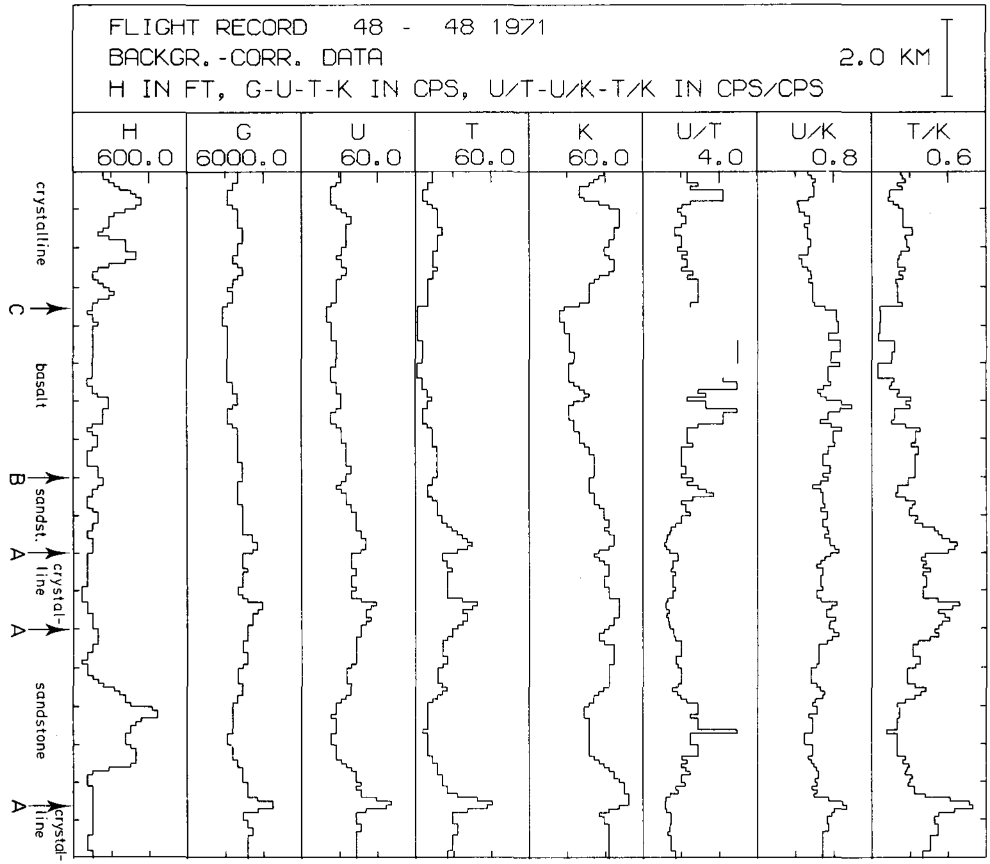

Fig. 4. Radiometric profiles of record 48, from Milne Land south of Charcot Gletscher. The profiles have only been corrected for background radiation. Note how the lithological contacts are reflected in the channels. The anomalies at A are thorium-rich placer deposits at the base of Jurassic Charcot Bugt Sandstones overlying the crystalline rocks.

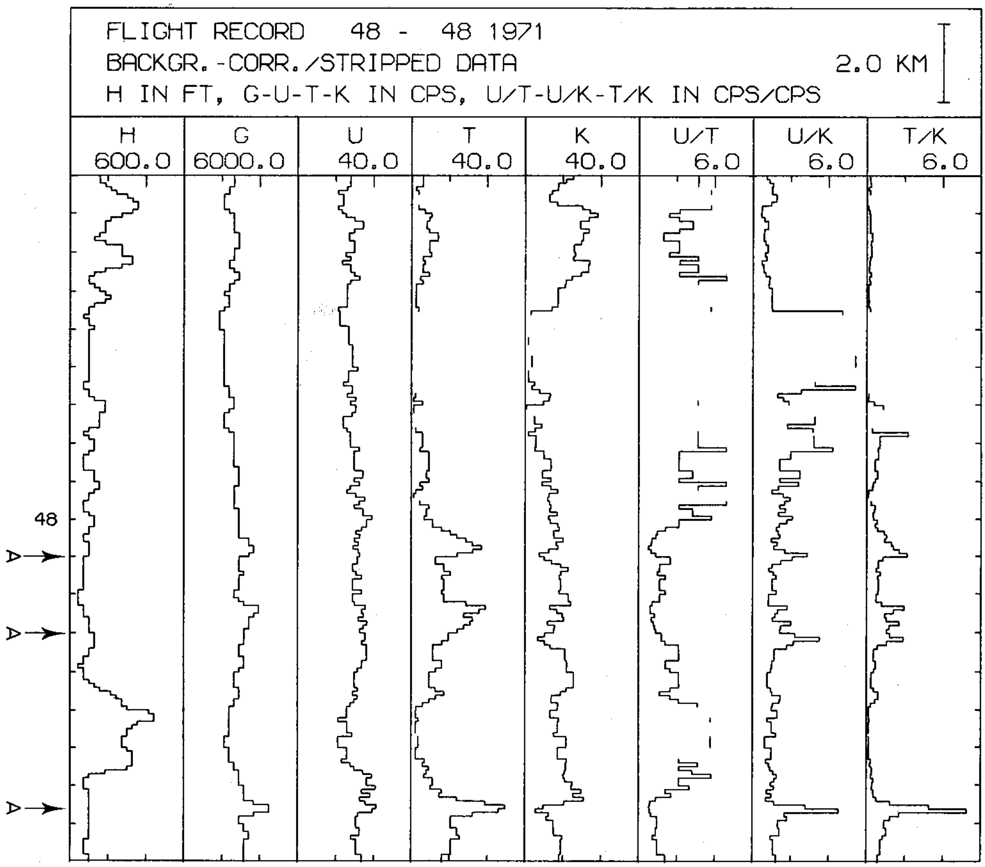

Fig. 5. The same radiometric profiles as in fig. 4 after spectrum correction, 'stripped' data. Note how the peaks at A are diminished in the U channel.

background count rates were determined and subtracted in the computer runs: G 270 cps, U 2.86 cps, T 3.25 cps, and K 4.43 cps.

A typical radiometric profile is shown in fig. 4. This is part of the detailed survey across the contact where Caledonian crystalline rocks are overlain by Upper Jurassic Charcot Bugt Sandstone. The contacts marked A, B and C are manifested by different intensities in the various channels. Ground investigations have shown that the anomalies marked A reflect placer deposits containing thorium-rich minerals along the contact zones. However, the peaks cannot be ascribed solely to an increased concentration of thorium as the peaks are also dependent on the U and K content. The spectrum interdependence of the ratemeter signals U, T and K must therefore be removed by a 'stripping' procedure.

A set of 'stripping' equations were derived from calibration measurements with the airborne gamma-ray spectrometer placed on four concrete standards. These standards were constructed at the Atomic Energy Research Establishment at Risø with the purpose of being able to make absolute calibration of portable radiometric equipment (Løvborg *et al.*, 1972).

The concrete standards are slabs 3 m in diameter and 50 cm thick, and are characterized by a predominant content of either uranium, thorium or potassium. The equations arrived at were:

$$T' = 1.19T - 0.32U$$
$$U' = 1.19U - 0.70T$$
$$K' = K - 0.46T' - 1.11U'$$

where T′, U′ and K′ are count rates which can be supposed to be proportional to the contents of thorium, uranium and potassium in a terrain producing the ratemeter signals U, T and K.

The profile shown in fig. 5 was drawn after the 'stripping' equations had been applied to the U, T and K data of fig. 4. The count rate T′ is characterized by distinct peaks at A, whereas there is no increase in the count rates of U′ and K′ at A. It is therefore concluded that the ratioactivity of the location A (the contact zone between sandstone and crystalline rocks) is mainly due to thorium. This agrees with the ground observations.

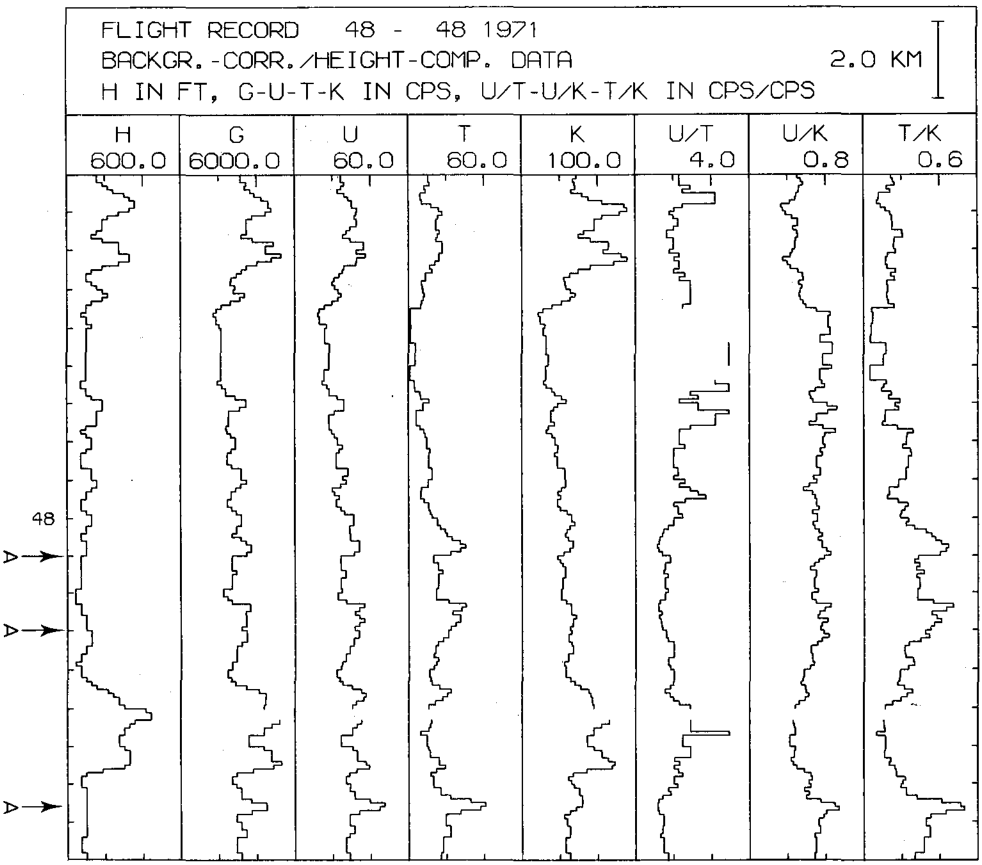

Fig. 6. Same radiometric profiles as in fig. 4 after height compensations. In the rugged terrain this compensation is inapplicable as the original negative correlation between height and count rate is now turned into a positive correlation, especially in the K channel in the sandstone area.

The weak negative profile shown by the count rate K′ at A indicates that the constants in the stripping equation relating K and K′ are overestimated in the calibration of the instrument. Because of this overcorrection and because of the wide statistical fluctuations often shown by the count rates U′, T′ and K′, the 'stripping' procedure was only used as an aid in distinguishing the radioactive intensities, particularly in areas with high anomalies (see also figs 11, 12).

Since the flight line crossed several broad valleys with a resultant departure from the standard clearance of 150 ft the count rates, G, U, T and K were multiplied by a factor F to compensate for the decrease in the ratemeter signal.

The factor F is given by:

$$F = \exp\ (\mu[H\text{-}150])$$

were the linear attenuation coefficient (μ) assigned to the individual spectrometer channels were taken from Darnley (1972). They are: G 0.0020 ft^{-1}; U 0.0017 ft^{-1}; T 0.0017ft^{-1}; K 0.0023 ft^{-1}.

The height compensation factor has been applied to the profiles in fig. 6, but has clearly been insufficient compensation. It is concluded that the height compensation factor is inapplicable in this type of steep terrain. Instead of making the ratemeter signals independent of the terrain clearance the formula introduces a positive correlation between the height above the surface and the ratemeter signals. This can be explained by the fact that while the radio altimeter measured the distance to the ground below the aircraft, a significant part of the gamma-radiation measured by the detector units was not direction controlled and came from steep sloping surface. Since a variable detector-to-source geometry was a characteristic of the entire survey, no further attempts were made to eliminate or reduce the height effect.

RESULTS

In the area of the detailed survey the profiles obtained from the spectrometer were drawn both with and without the 'stripping' correction applied to the U, T and K signals. No 'stripping' correction was applied to the areas of the cursory survey and the single line reconnaissance survey. The full set of profiles are kept in the open files of The Geological Survey of Greenland.

The average values and ranges of the G, U, T and K signals in this report are stated in counts per second (cps) with the ranges given in parentheses.

Areas of detailed survey

Three areas, where potential granitic source rocks border a sedimentary basin, were chosen for detailed survey (fig. 1).

(1) The western part of the Schuchert Dal area where a major fault zone separates late kinematic Caledonian granites and migmatites to the west from Carboniferous and Permian clastic sediments to the east. The faulting was active throughout the Upper Palaeozoic and Mesozoic.

(2) The eastern part of Milne Land where Mesozoic sediments in the south-eastern corner of the island rest upon the eroded surface of Caledonian gneisses and granites.

(3) The western part of southern Liverpool Land around Hurry Inlet. This area consists of Caledonian gneisses and granites covered to the south and west by Mesozoic sediments.

An almost complete flight coverage was attempted in these areas. Flight line spacings are of the order of 100 to 200 metres, leaving out the most inaccessible parts. The flight lines were drawn on aerial photographs at a scale of 1:50 000. An example of the flight line pattern can be seen in fig. 7, which shows the surveyed area west of Schuchert Dal with closely spaced flight lines and fiducials.

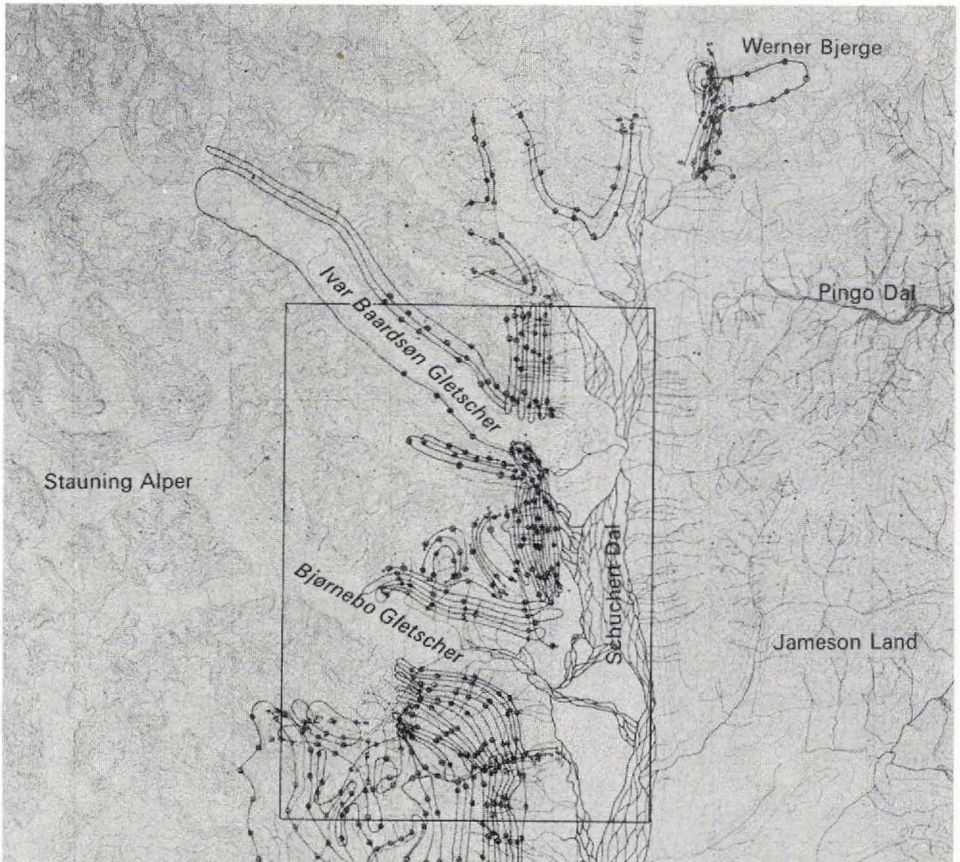

Fig. 7. Flight line pattern in the Schuchert Dal area and Werner Bjerge with the flight lines to a large extent following the topographic contours.

Schuchert Dal

Detailed radiometric investigations were carried out west of Schuchert Dal in the area around Ivar Baardsøn Gletscher and Bjørnebo Gletscher (figs 7, 8). The closely spaced flight lines were followed by ground investigations. To the south of the Gurreholm Dal area and to the north of Holger Danskes Briller the flight lines were spread further apart. The results of the airborne survey are listed in Table 1.

A general geological description of the area has been given by Kempter (1961). Henriksen & Higgins (1970), Collinson (1972) and Perch-Nielsen *et al.* (1972). A geological map comprising the main part of the investigated area is shown in fig. 8. The following geological units are distinguished:

(1) Caledonian and late Caledonian crystalline rocks
 Migmatites *sensu lato* – may indicate reactivated pre-Caledonian rocks
 Muscovite-biotite granite
 Quartz-hornblende syenite
(2) Carboniferous and Lower Permian sediments
 Carboniferous and Lower Permian arkoses and sandstones
 Upper Permian reef carbonates
(3) Tertiary stills and dykes, and intrusive syenites at Werner Bjerge.

Table 1. Count rates from rock formations in the Schuchert Dal area recorded during airborne gamma-spectrometric survey

	G	U	T	K
Muscovite-biotite granite Stauning Alper	3000(2500-3500)	40(25-55)	36(25-40)	81(70- 95)
Quartz-hornblende syenite Stauning Alper	3300(3000-3500)	39(25-50)	40(30-45)	95(65- 95)
Migmatites s.l. Stauning Alper	3250(2500-4000)	49(25-60)	48(35-60)	91(70-100)
Migmatite north of Holger Danskes Briller	1900(1600-2200)	20	35	65
Minor anomaly Holger Danskes Briller	2200	32	50	65
Permian sandstone Gurreholm Dal area	2230(2000-2600)	22(20-25)	33(27-36)	65(60- 70)
Permian sandstone east of Stauning Alper	3270(2200-4000)	35(18-60)	41(23-50)	77(50-100)
Limestone, arkoses Karstryggen area	2040(2000-2200)	20(18-20)	20	40(30- 50)
Minor anomaly Karstryggen area	3500	30	40	70
Tertiary syenite Werner Bjerge	3500(2000-5000)	45(20-70)	40(20-55)	95(70-110)
Anomalies in main fault zone	4350(4000-5000)	51(40-65)	61(50-70)	98(95-110)

Average values, and range (in parentheses) of G, T, U and K are in counts per second

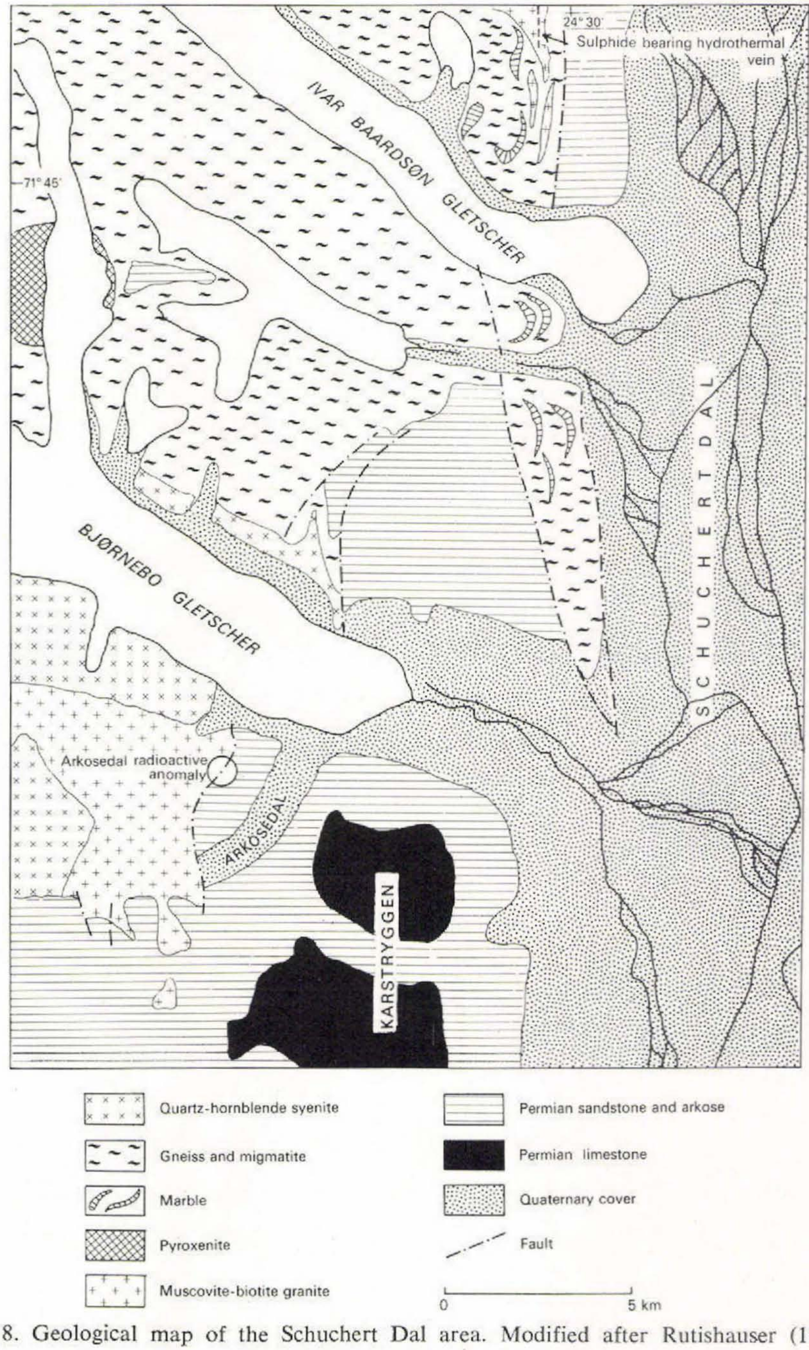

Fig. 8. Geological map of the Schuchert Dal area. Modified after Rutishauser (1971).

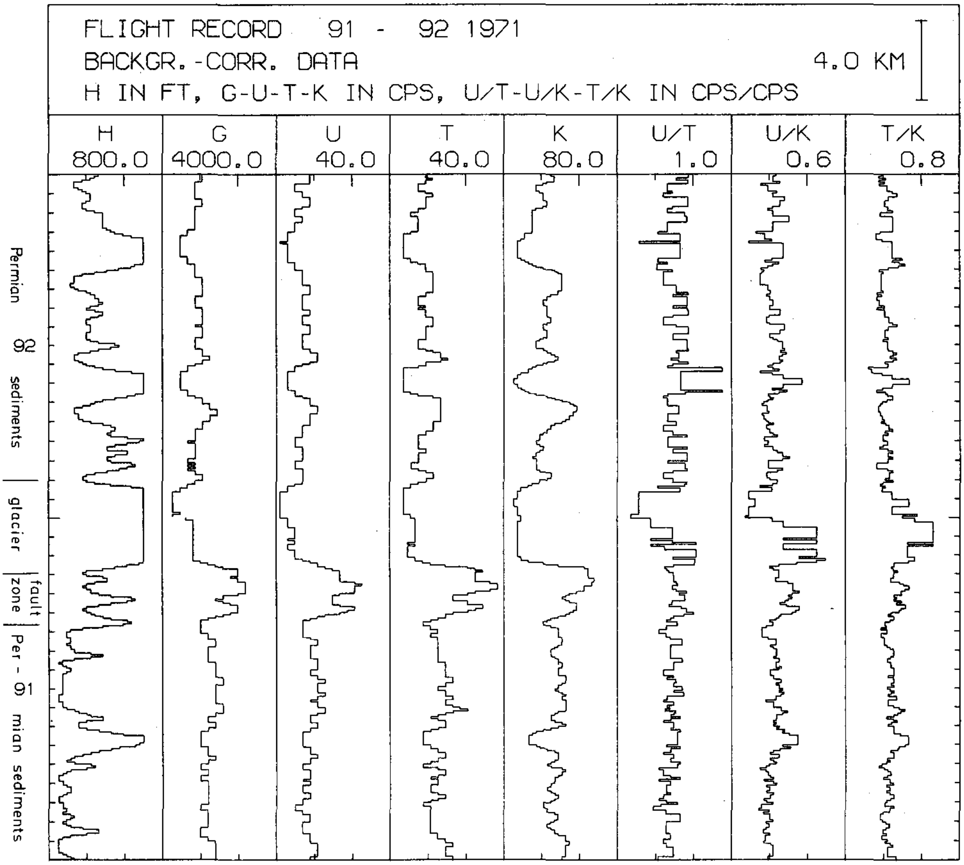

Fig. 9. Radiometric profiles of the fault zone cutting Permian sediments in the western Schuchert Dal. Note the enrichment with radioactive materials in the faulted zone.

A major fault zone, active during post-Devonian time, separates Upper Palaeozoic sediments to the east from Caledonian migmatites and late kinematic granites and syenites to the west. Muscovite-biotite granites of homogeneous composition make up a considerable part of the Stauning Alper, usually with sharp boundaries to the surrounding migmatites. Only a few aplites and pegmatites rich in muscovite are found in the granites. A weak foliation occurs locally. Towards the fault zone large flat-lying sheets of granite and migmatite alternate. Marble layers a few hundred metres wide striking north–south and dipping steeply to the west are enclosed in a few places within the migmatites.

The eastern part of the Stauning Alper around Bjørnebo Gletscher and Ivar Baardsøn Gletscher seems to constitute a radioactive culmination with high count rates not only in the late kinematic granites and syenites but also in the Caledonian migmatites. To the south, in the migmatites around Holger Danskes Briller, the general count rate level is only two thirds of that to the north.

It is noteworthy that the Permian clastic sediments to the east of the fault have the same order of magnitude of count rates as the adjacent crystalline rocks to the west.

Field scintillometer measurements in the eastern Stauning Alper, and the adjacent sediments, have shown fairly constant radiation levels of 25-30 μR/h on the granites, sandstones and arkoses, with those from the arkoses (35 μR/h) usually slightly higher than from the sandstones. The radioelement distribution in the migmatites is more heterogeneous with readings from 11 to 27 μR/h, and on average a little lower than in the granites. This difference between the granites and migmatites was not confirmed by the airborne survey. All fault zones, both major and minor, show a marked increase in radioactivity over that of the general level (fig. 9). In the main fault zone the scintillometer readings increase to 40-50 μR/h in the arkoses and 35-40 μR/h in the granites. A rusty shear zone in migmatites south of Ivar Baardsøn Gletscher gave scintillometer readings of 40 to 100 μR/h. Assays of hand samples showed a high thorium content (Table 2).

Table 2 lists the field scintillometer readings of various samples and their radioelement analyses by gamma-spectrometry undertaken in laboratory.

During the faulting of the area in post-Devonian time the Stauning Alper area was uplifted relative to the Palaeozoic and Mesozoic sediments in Jameson Land and Scoresby Land. The main north–south trending fault zone in the southern Arkosedal area is split up into a series of faults with east–west displacements interconnected by minor faults with associated tilting of the adjacent sediments. Close to the main fault a gradual change over about 50 m is observed from coarse-grained arkoses into breccia rocks with angular fragments of granite. In shear zones the colour of the arkose changes from grey-red to purple. Hydrothermal calcite and fluorite veins may be seen in the fault zone as well as fluorite on joint surfaces in the granite.

East of the fault zone sandstones and siltstones with intercalations of arkoses

Table 2. Radioelement contents and exposure rates from rock types of the Schuchert Dal area

Rock type	GGU No.	Exposure rate* μR/h	Radioelement content† U(ppm)	Th(ppm)	K(%)	Th/U
Grey granite	148209	23	2.4	26	4.5	10.1
Red biotite granite	148219	28	5.0	35	5.3	7.0
Muscovite granite	148225	45	2.8	18	5.6	6.4
Migmatite, shear zone	148230	110	-	340	4.3	-
Granite, rusty zone	148224	40	24	40	5.3	1.7
Gneiss	148220	24	2.8	9.3	2.9	3.3
Gneiss	148226	22	1.0	11	1.9	11.0
Sandstone, Blyklippen Member	148211	17	9.1	51	1.76	5.6

* Exposure rates measured by field scintillometry

† Radioelement content measured by laboratory gamma-spectrometry

and conglomerates predominate. They belong to the Blyklippen Member of Westphalian age (Perch-Nielsen *et al.*, 1972). The general dip of the bedding planes is 10-15° SW towards the crystalline foreland which was probably the source area for the sedimentary debris. In the Arkosedal area the sediments are considerably coarser than in the northern Schuchert Dal. Ripple marks together with frequent alternation of arkoses, sandstones and conglomerates suggests a fluctuating near-shore depositional environment. The sandstones and siltstones are white to greenish in colour whereas the arkoses and conglomerates are red due to a high content of feldspathic debris.

In the Karstryggen area (fig. 8) Upper Permian reef carbonates were deposited on top of the arkoses. Limestone displaying karst phenomena constitute the major part of the surface of the ridge.

The Marine Upper Permian limestones in the Karstryggen area are of low radioactivity compared with the clastic facies at lower stratigraphic levels. A minor increase in the count rates was recorded in the southern part of the Karstryggen area (Table 1).

Radiometric flight data from the syenites in the westernmost part of the Tertiary Werner Bjerge intrusion (Table 1) are similar to the data from granites and syenites in the Stauning Alper. The high count rates from syenites in the two areas are similar. The highest radioactivity in this part of Werner Bjerge was recorded in the moraines at the front of Sirius Gletscher. The source area for the moraine boulders awaits detailed investigation.

Arkosedal

Uranium mineralization was discovered by Nordisk Mineselskab A/S in 1970 in the main fault zone on the western slope of Arkosedal at an altitude of 1100 m (figs 8, 10). The main fault zone, which trends north–south, is irregular altered

Fig. 10. Stauning Alper massif with Arkosedal in the foreground. The dotted line marks the main fault zone separating late Caledonian granites and Permian arkoses. The uranium mineralization is seen as a light staining along a small part of the fault above the arrow.

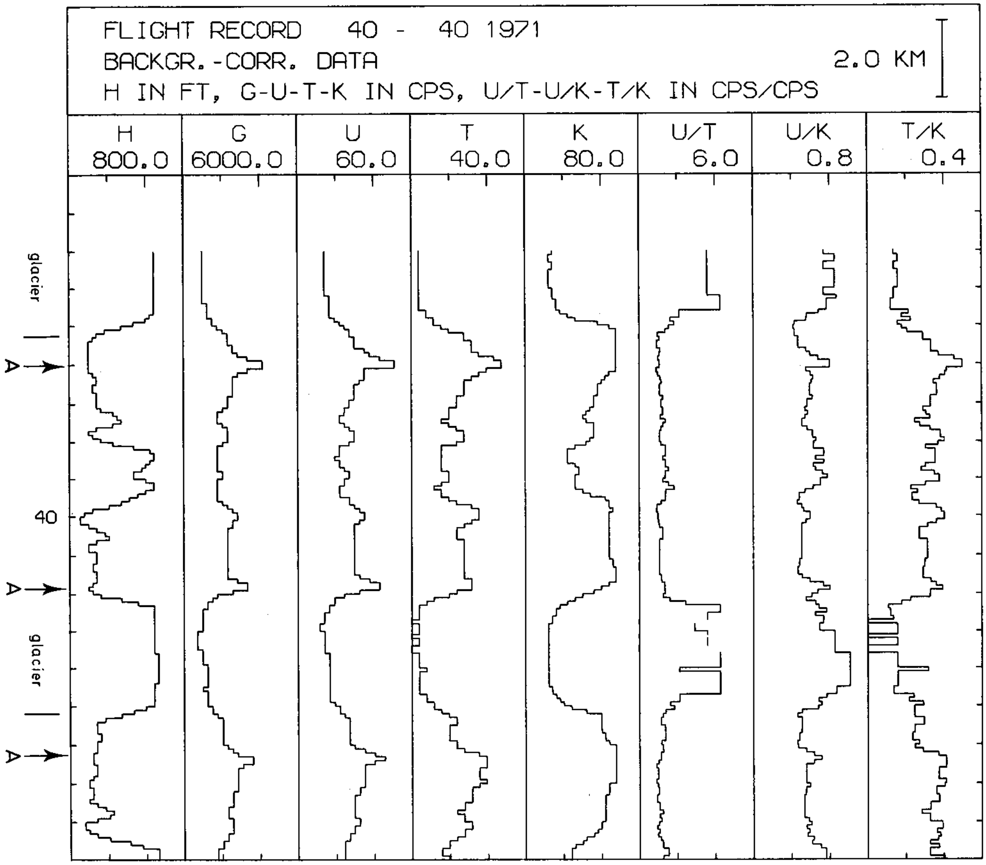

Fig. 11. Radiometric profiles of the uranium anomaly in Arkosedal. The mineralized fault zone has been traversed three times (marked with A). No corrections except background have been applied to the profiles.

and oxidized for about 200 m by hydrothermal processes giving an intense yellow staining in a zone with a maximum width of 5 m.

The airborne scintillometer record of uncorrected (fig. 11) and 'stripped' (fig. 12) data demonstrates the relative uranium enrichment. Field scintillometer measurements in the fluorite-bearing part of the fault zone showed maximum exposure rates of about 2000 μR/h.

Gamma-spectrometer analyses indicate that the uranium content is proportional to the amount of fluorite. The uranium generally occurs in brown limonitic material either intergranular in the fluorite matrix of lining the fluorite veins (Wollenberg, 1971); in some samples no direct association with the fluorite could be found. Whole rock gamma-spectrometric analyses show that the uranium content varies from a few to 3000 ppm; the Th/U ratio is generally less than 0.4. The average uranium content, based on 300 samples, is 240 ppm (Wollenberg, personal communication).

No primary uranium minerals have been identified, but grains with a yellowish

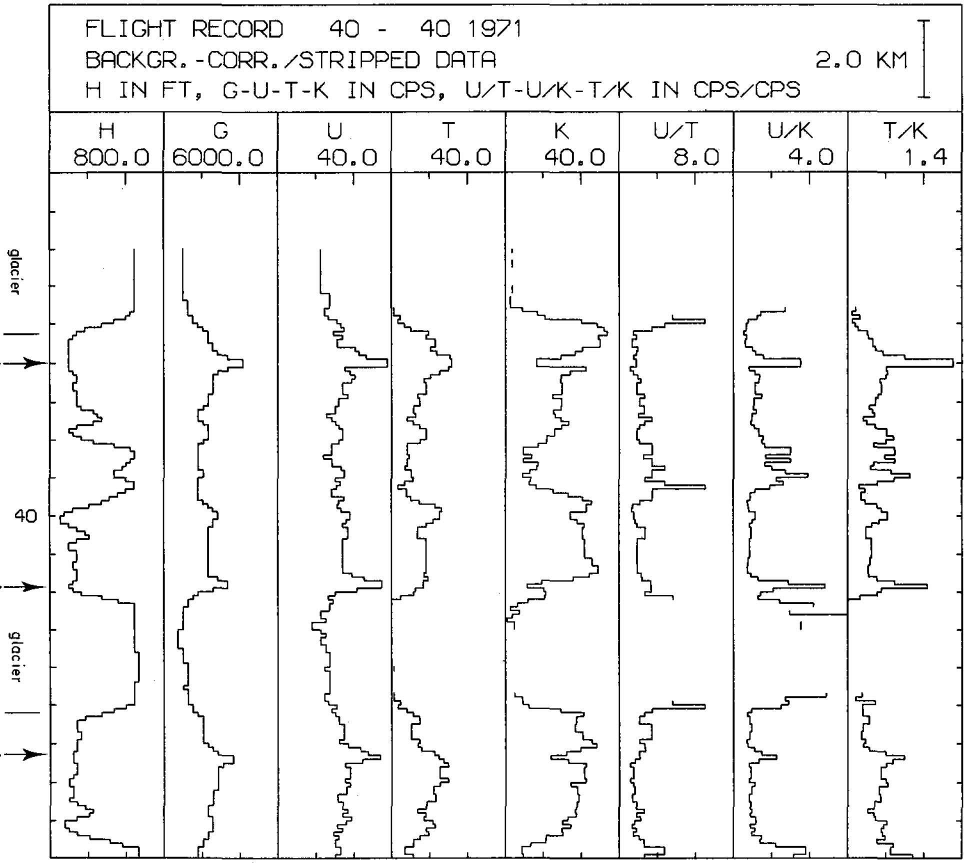

Fig. 12. The same radiometric profiles as in fig. 11 after 'stripping'. In this plot the anomaly can be classified as a uranium enrichment.

green fluorescence on exposure to ultra-violet light are ubiquitous. Fission track analyses (Wollenberg, 1971) showed that uranium is present in varying amounts in the different minerals. Wollenberg tabulates the following associations.

(1) Transparent hexagonal grains, possibly apatite. Uranium content 2300 ppm.

(2) Limonitic material. Uranium content 950-2500 ppm.

(3) Transparent to opaque amorphous minerals. Uranium content several per cent.

(4) Anhedral transparent grains. Uranium content several tens of per cent.

No minor elements except for barium, strontium and lead explained by the presence of baryte and a small amount of galena, occur in anomalous quantities in the ore. Semi-quantitative spectrographic analyses of 19 elements based on 10 samples are listed in Table 3.

The occurrence belongs genetically to hydrothermal pitchblende-fluorite vein-type deposits. At the present erosion level the occurrence has been oxidized and the original uranium minerals altered and perhaps leached to a certain extent.

Table 3. Optical spectrographic analyses on ten samples from the Arkosedal uranium mineralization

Oxides	%	Elements	ppm
MgO	0.27 (0.17-0.46)	V	27 (20-38)
CaO	16.88 (0.69-49.55)	Co	10 (7-18)
TiO_2	0.45 (0.22-0.68)	Ni	19 (12-23)
MnO	< 0.05	Cu^{+1}	90 (58-215)
Fe_2O_3	2.0 (1.2-4.5)	Cu^{+2}	13 (7-17)
SrO	0.13 (0.07-0.20)	Zn	101 (35-181)
BaO	1.61 (0.83-2.03)	As	74 (47-102)
		Mo	79 (20-207)
		Ag	< 3
		Sn	< 5
		W	< 50
		Pb	398 (173-846)
		Bi	< 5

The average values are given in per cent and parts per million; ranges are shown in brackets. The samples were collected by Nordisk Mineselskab A/S and analysed at Sveriges Geologiska Undersökning, Stockholm

The age of the mineralization is at present unknown. It might be controlled by the late to post-Caledonian intrusive events with deposition from ore-bearing solutions in a low temperature environment. However, no occurrences of metalliferous ore deposits related to the granitic intrusives are known from the area, and the controlling factor of the uranium mineralization is most likely to be the late to post-Caledonian faulting. Frictional heat is believed to have mobilized available ground fluids followed by deposition of uranium and fluorite in the final stage of cooling near the limits of migration (Gabelman, 1970). Alternatively the mineralization might be genetically associated with the Tertiary intrusions, mainly the complex of Werner Bjerge. Although the ore parageneses of the molybdenum deposit at Malmbjerg and of the contemporaneous lead-zinc bearing quartz veins outside the intrusion are different, this does not exclude a relationship between the Arkosedal mineralization and the intrusive events.

The occurrence has been trenched by Nordisk Mineselskab A/S.

Milne Land

A detailed radiometric survey was made over the late and post-kinematic rocks of eastern Milne Land bounded to the west by the major north–south fault zone

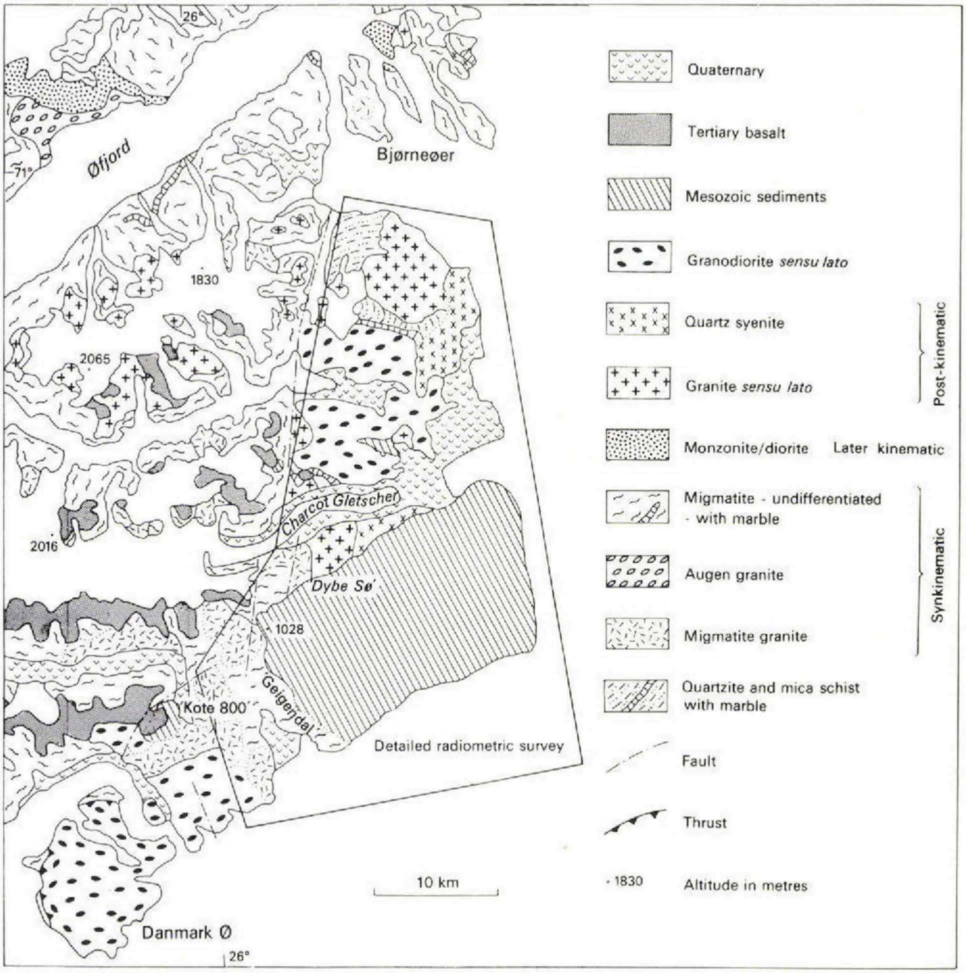

Fig. 13. Geological map of eastern Milne Land.

(fig. 13). To the south of the Charcot Gletscher flight line spacings are in the order of 200 m; to the north of the glacier the line spacings are wider and irregular. The Mesozoic rocks were covered in less detail. The crystalline and sedimentary rocks south of Charcot Gletscher were visited during the field work in 1971 and 1972. The main results of the flight line data are presented in Table 4.

Geological reviews of the area have been presented by Funder (1970), Håkansson *et al.* (1971) and Henriksen & Higgins (1971, 1973) who recognize the following major geological formations:

6. Quaternary
5. Tertiary basalts
4. Upper Jurassic and Lower Cretaceous sandstones, siltstones and shales

3. Late and post-kinematic intrusive rocks of granite, quartz syenite and granodiorite
2. Migmatites
1. Metasediments (quartzites, mica schists and marbles).

North of Charcot Gletscher the area is comprised of quartzites and mica schists with considerable thicknesses of marbles surrounded by a series of post-kinematic granodiorites as large conformable sheets of uniform composition (Henriksen & Higgins, 1971). The granodiorite is cut by a quartz syenite and by various granite bodies.

The quartz syenite which is emplaced to the north-east of the granodiorite contains inclusions of the granodiorite and remnants of marble. Inhomogeneous biotite granites and quartz syenites show considerable range of radioactivity values (Table 4).

The lowest radioactivity occurs over the quartzites and certain parts of the inhomogeneous post-kinematic granites and quartz syenites while minor inclaves within the metasediments, and the granite in the north-east of the area have a higher radioactivity, a reflection of the inhomogeneous nature of the granite.

The southern area covered by the detailed survey consists of migmatites with considerable variation in the proportions of granitic neosome, while locally there is a high proportion of amphibolite remnants. These amphibolite enclaves are frequently enclosed by a 10 cm wide zone of coarse grained granitic neosome rich in biotite. Monazite grains are common in association with the biotite crystals. Both migmatites and granites may locally be rich in garnet. These migmatites are of unusually high radioactivity; the highest radioactivity being found around the lake just south of Charcot Gletscher and around 'Kote 800'. Southwards towards Danmarks Ø the gross count level decreases to half that of the high values.

The high radioactivity of the migmatites appears to be controlled by the proportion of neosome present in the migmatite. Monazite-bearing neosome surrounding remnants of amphibolite was observed south-west of the lake south of Charcot Gletscher. Further west the Milne Land granite corresponding to the neosome surrounding the amphibolite enclaves in the migmatites also contains highly radioactive accessories, probably monazite (J. Escher, personal communication). Field scintillometer measurements around the area of the lake gave the following radioactive levels: paleosome 12μR/h; neosome 25–30μR/h and amphibolite 7μR/h. Locally the radioactivity of the neosome may reach 50 to 100 μR/h.

The distribution of high radioactivity of placer deposits at the border zone of the Jurassic sediments appears to be controlled by the high radioactivity of the adjacent migmatite indicating that the source area for the placers was the adjacent local crystalline foreland.

The post-kinematic granites and quartz syenites on both sides of Charcot Gletscher have an average gross count level of about 3000 cps, a level comparable to the granites of Stauning Alper. This seems to be a characteristic count level for the acid intrusive rocks within the Scoresby Sund region. However, in the Milne Land area several radioactive anomalies were found with higher values in restricted units consisting of either a coarse grained, red granite or a dark, garnet-bearing syenite. Fission track analyses on samples showed that the garnets contain about 85 ppm uranium and accessory zircon about 1050 ppm uranium.

Table 4. Count rates from rock formations in eastern Milne Land recorded during airborne gamma-spectrometric survey

	G	U	T	K
Quartzite, mica schist	1625(1200-2000)	16(11-24)	17(10-25)	49(40-55)
Anomaly close to contact to granite	3000	27	35	70
Migmatite south of Charcot Gletscher	5250(5000-5500)	38(25-45)	29(26-35)	62(50-75)
Migmatite north of Danmark Ø	2200	25	30	60
Granite, north-east Milne Land	1620(1200-2000)	18(14-23)	20(15-26)	52(30-70)
Anomaly in the east end of granite area	3500	25	25	85
Granite area north-west of Charcot Bugt	3000	25	32	60
Granite south of Charcot Gletscher	3000	28(25-30)	30	65(60-70)
Quartz syenite north of Charcot Gletscher	1900(1300-2500)	22(14-30)	26(18-35)	63(55-70)
Quartz syenite south of Charcot Gletscher	3000	30	40	60
Anomalies in quartz syenite south of Charcot Gletscher	4350(4000-5000)	55(50-60)	72(60-70)	85(75-100)
Granodiorite north of Charcot Gletscher	2250(1600-2500)	23(17-30)	28(18-35)	59(55-65)
Anomalies along border of Charcot Bugt Sandstone	3500(3000-4000)	38	50	75(70-80)
Charcot Bugt Sandstone south of crystalline front	4600(4200-5000)	43(35-50)	24(16-35)	63(55-70)
Charcot Bugt Sandstone, 'Geigendal'	2050(1500-3000)	25(15-35)	29(15-45)	51(30-65)
Charcot Bugt Sandstone remnants north of Charcot Gletscher	2500(1000-3500)	33(10-50)	42(15-60)	58(40-70)
Anomaly, 'Kote 800'	9500	95	95	95
Anomalies, 'Geigendal'	4750(4500-5000)	60	85(80-90)	73(65-80)
Anomalies south of 'Dybe Sø'	6000(5000-7000)	65(50-75)	55(45-60)	75(70-80)
Silt and shale, south-east Milne Land	4200	40	16	55

The granodiorite in the north gave a rather uniform count rate level with a mean of 2250 cps, though in a zone surrounding erosion outliers of Jurassic sandstone the radioactivity in the grandiorite is substantially higher. This could be due to scattered radioactive debris from the sandstone area.

A large number of Geiger-Müller countings made by A. K. Higgins during the mapping of the crystalline rocks largely corroborate the aeroradiometric data.

The Mesozoic rocks of the area are sandstones of the Charcot Bugt Sandstone. They were deposited on a ruggedly eroded surface of crystalline rocks with the latter now appearing as 'windows' within the sandstone area, and isolated outliers of sandstone now separated from the main outcrop. The base of the sandstone is sometimes an organic or calcareous shell fragment conglomerate (Håkansson *et al.*, 1971). Coarse grained pebble conglomerates are common in the lower part of the sandstone sequence and layers of organic material form intraformational horizons. The sandstones are normally white but may be red or yellow due to oxidation. Heavy mineral concentrations, with zircon and monazite as the main constituents, are known at several places along the boundary zone between the sandstones and the crystalline rocks. These placers were easily detectable on the airborne spectrometer (figs 6, 14).

Redistribution processes, e. g. solifluction and glaciation effects, are additional factors in the present distribution of the radioactivity. A characteristic count rate level

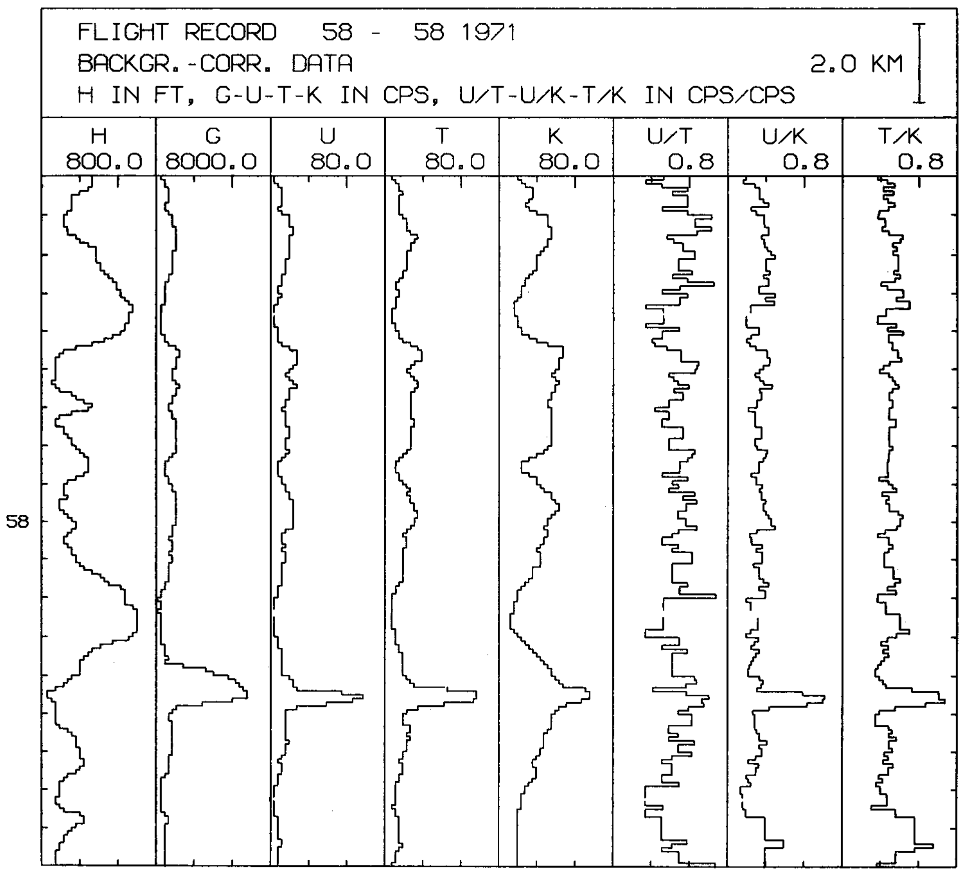

Fig. 14. Radiometric profiles over 'Kote 800', Milne Land. The thorium-rich placer deposits make up a distinctive anomaly. No corrections except background have been applied to the profiles.

is difficult to obtain from the area, but it is thought that the lower range of figures for the sandstones on Table 4 is representative of the sandstones. Field scintillometer readings showed an increase in the radioactivity of the placer deposits by factors of 5 to 15 over that of the sandstone, while at 'Kote 800' (fig. 13) there is an increase by a factor of 50 over that characteristic for the sandstone.

In the richest horizons at 'Kote 800' zircon amounts to 20 per cent of the rock. Gamma-spectrometric analyses of 18 samples in the laboratory have given the following average radioelement contents:

U ppm	143 (8–577)
Th ppm	1331 (47–5996)
Th/U	9 (6–10)

with ranges shown in brackets.

The Jurassic Charcot Bugt Sandstone is followed stratigraphically by a 'shale and glauconite' series and the Hartz Fjeld Sandstone which reaches up into the Lower Cretaceous. Over the 'shale and glauconite' series the count rates are rather high, especially in the U channel, reflecting an absorption of uranium on organic and argillaceous matter in a marine environment.

Tertiary plateau basalts overlie the crystalline and Mesozoic rocks; these were not investigated radiometrically.

Extensive areas are covered by moraine and superficial deposits up to an altitude of about 500 m (Funder, 1970) which have a masking effect on the gamma-radiation from the underlying rocks.

Liverpool Land

Over Liverpool Land the aeroradiometric survey was confined to the Storefjord area in central Liverpool Land and to the western half of southern Liverpool Land (fig. 15). The density of the flight lines is only shown for a restricted part of the area in fig. 19. On the east side of Hurry Inlet the line spacing is at about 200 m. Throughout Liverpool Land the navigation was based on aerial photographs. The proportion of rock exposure is high throughout most of the area with only the coastal fringe along the eastern side of Hurry Inlet covered by Quaternary deposits. The count rate levels are listed in Table 5 which are given in stratigraphic order.

The crystalline complexes of Liverpool Land are divisible into three metamorphic areas separated by a series of plutonic rocks mainly of granitic composition (fig. 15). These make an independent block which cannot be correlated with the pre-Caledonian or Caledonian complexes elsewhere in East Greenland. Recent descriptions of the geology have been given by Coe & Cheeney (1972).

The metamorphic rocks display a considerable variation in radiometric properties. In southern Liverpool Land the garnetiferous hornblende-biotite gneiss shows distinctly lower count rate levels than the younger granodioritic gneiss, though a number of minor thorium anomalies were detected in the former. These lie in a north–south belt approximately two kilometres east of Hurry Inlet. There is a gradual increase in radioactivity from east to west which might be controlled by the relative abundance

Table 5. Count rates from rock formations in Liverpool Land recorded during airborne gamma-spectrometric survey

	G	U	T	K
Mesozoic sediments (Klitdal)	2000	40	20	80
Biotite granite (Klitdal)	2450(1200-3000)	40(20-58)	37(18-55)	89(70-100)
Biotite granite (Hurry Inlet)	1850(1400-3000)	26(18-45)	27(12-40)	83(60-100)
Hbl.-biotite granite (Storefjord)	2450(1200-3000)	45(20-55)	38(18-45)	90(80-100)
Quartz monzodiorite (west of Istorvet)	970(800-1300)	9(8-10)	6(5- 8)	46(40-50)
Migmatitic gneiss (Storefjord)	1000	20	18	60
Banded hbl.-biotite gneiss (Storefjord)	2500	50	40	100
Granodioritic gneiss	1850(1200-2688)	32(15-60)	26(20-50)	78(40-90)
Veined garnetiferous hbl.-biotite gneiss	1470(1100-1800)	18(12-25)	18(9-27)	69(60-90)

of garnet in the gneiss. The granodioritic gneiss was traversed in several places and showed the greatest radioactivity around Kæmpehøjen. Compared to the granetiferous gneiss the increased radioactivity appears to be largely due to a higher uranium content.

The highest count rates among the metamorphic rocks were recorded in the banded hornblende-biolite gneiss south of Storefjord while some of the lowest count rate levels in Liverpool Land are over the migmatitic gneiss with marble layers south of Storefjord.

The plutonic rocks of western Liverpool Land are comprised of a variety of rock types some of which were investigated in detail. The biotite granites immediately east of Hurry Inlet and Klitdal are the most extensive of the post-kinematic plutons. To the east of Hurry Inlet the Hurry Inlet granite (Coe, 1975) contains abundant xenoliths in the marginal zone whereas the granite in the Klitdal area is more leucocratic and homogeneous. The Klitdal biotite granite has a consistently high level of radioactivity of 2500–3000 cps in the G channel, while the Hurry Inlet biotite granite has a general, rather low radioactivity especially in the U channel, and only in its northern area are the count rates similar to those of the Klitdal granite (Table 5). A minor uranium anomaly of 50 cps was located in Kalkdal.

Two general features characterize the distribution of radioactive elements in the Hurry Inlet granite; (1) the radioactivity increases from east to west, and (2) the radioactivity of the biotite granite increases abruptly along the rims of the east–west valleys. (1) A possible explanation for the westward increase in radioactivity might be the distribution of the weathered debris from the granite giving a higher proportion of fine grained material in the south, and hence greater absorption capabilities for radioelements in the low-lying western areas. The same tendency has been seen in Jameson

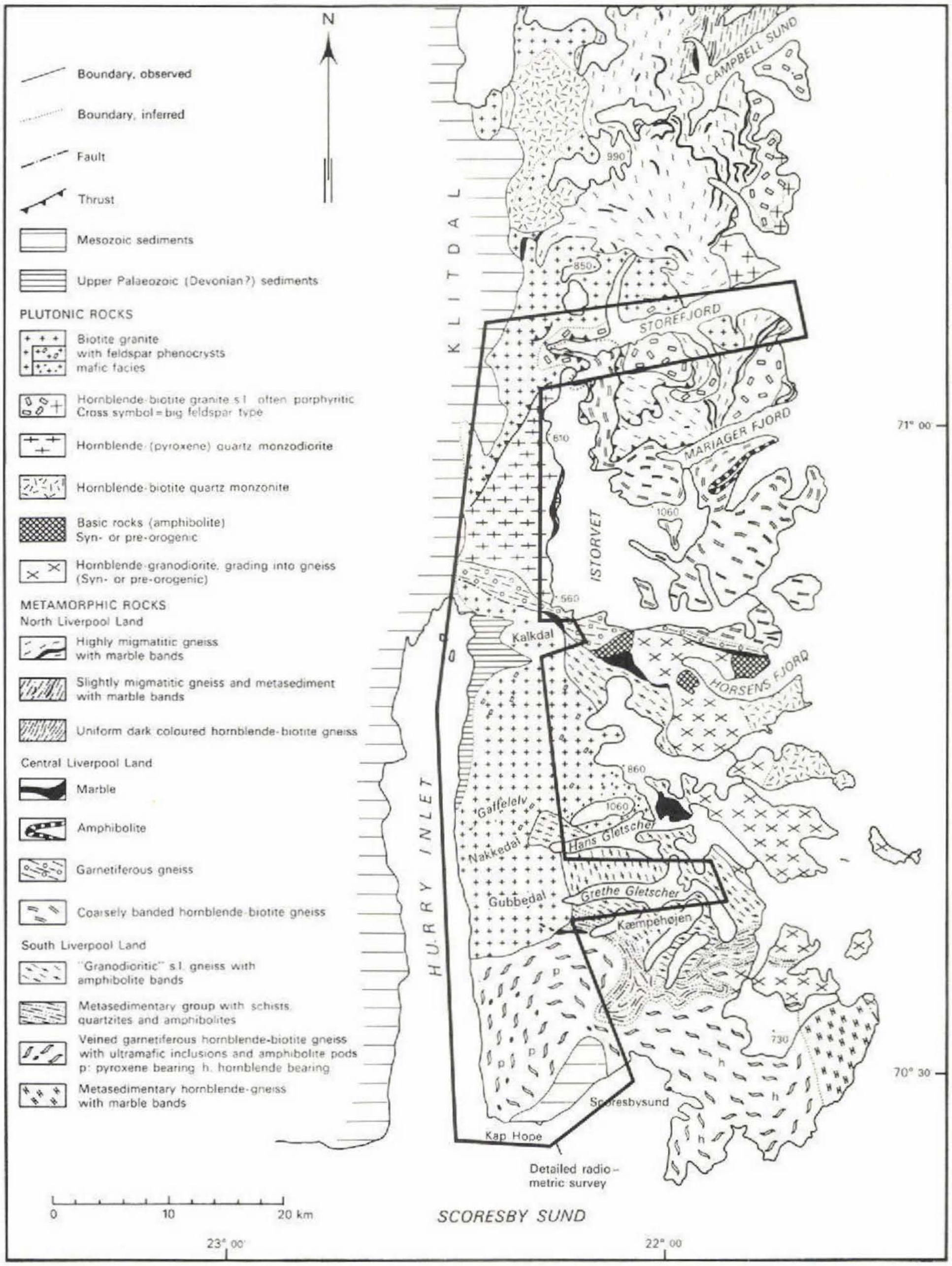

Fig. 15. Geological map of Liverpool Land. After Coe & Cheeney, 1972.

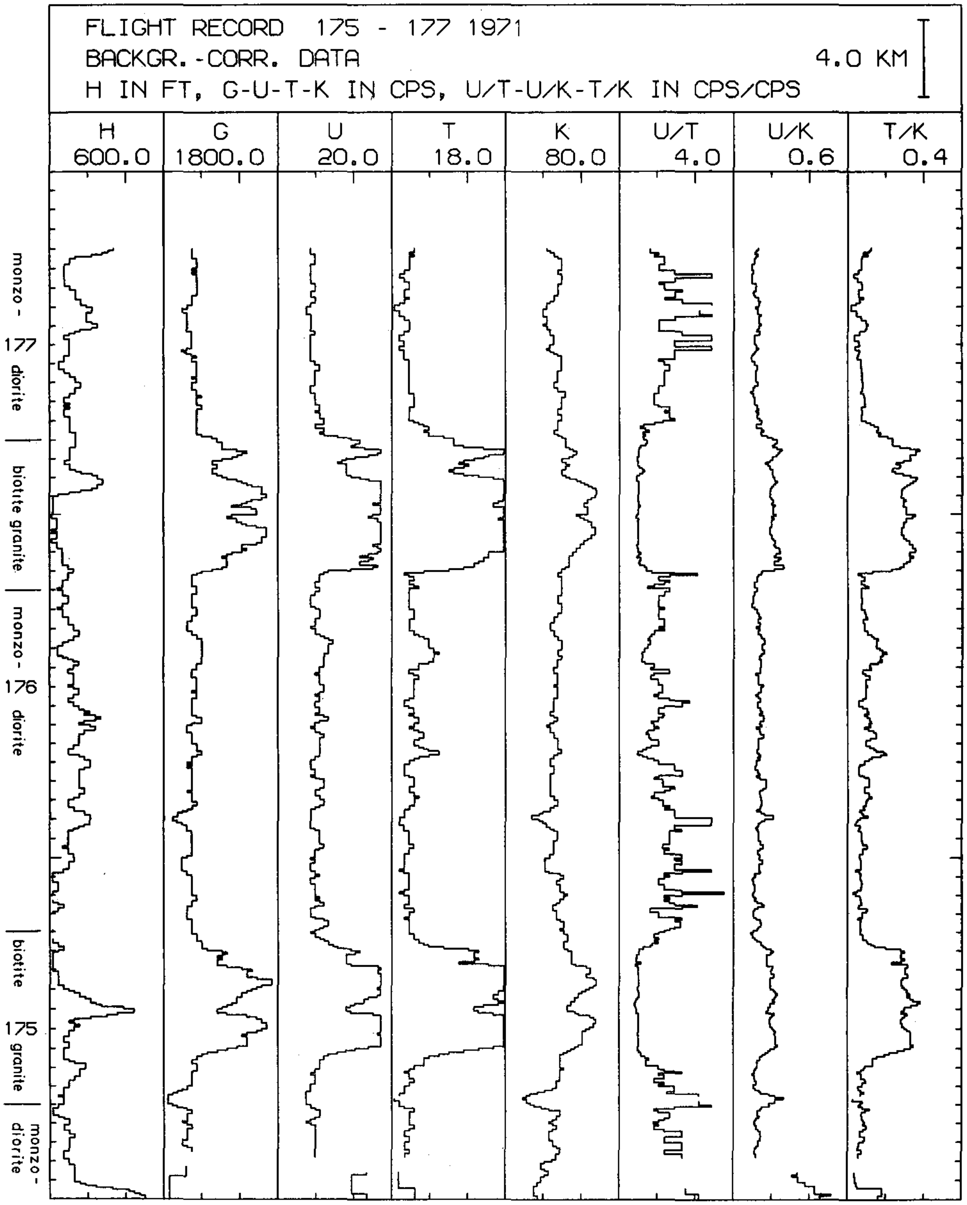

Fig. 16. Radiometric profiles over monzodiorite and biotite granite in Liverpool Land. The area of biotite granite having the highest count rates has been traversed two times. The plot clearly shows the contrasting values of the generated radioelement ratios

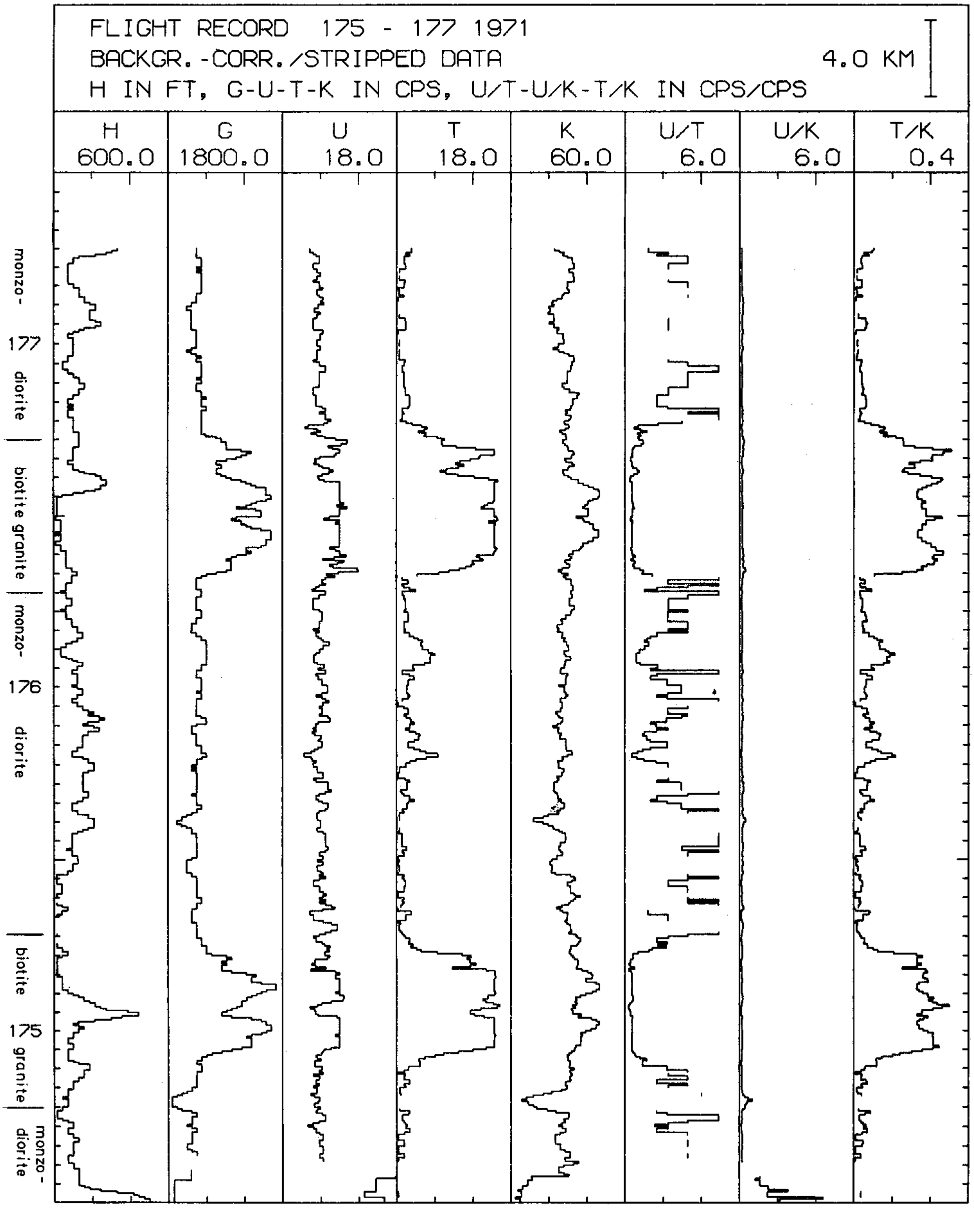

Fig. 17. The same radiometric profiles as in fig. 16 after 'stripping'. After correction it is seen that the biotite granite is characterized by a strong thorium enrichment compared with the monzodiorite.

Table 6. Radioelement content of samples from Kalkdal, Liverpool Land

Rock type	GGU No.	U (ppm)	Th (ppm)	K (%)
Biotite granite	148206	10	40	4.1
Porphyritic biotite granite	148205	9	33	4.0
Granodioritic biotite gneiss	148207	2	14	2.1

Land where soils covering low-lying coastal areas had a higher count rate in all channels. A similar increase in count rate levels was observed in the garnetiferous hornblende-biotite gneiss to the south where the proportions between exposed and soil-covered rock follow the same trend as in the north, but in addition, there is a compositional change with an increase in the garnet content to the west. From late to post-kinematic granites on Milne Land it was shown that garnet contained 85 ppm uranium. (2) The explanation for the increase in radioactivity along the sides of the valley is still speculative. The highest rate of increase is found at the southern rim of Gubbedal west of Grethe Gletscher, an increase most distinct in the T channel. It is suggested that the distribution of the radioelements is tectonically controlled with enrichment in shear and crust zones. Such zones have been observed along the rims of Nøkkedal and Gaffelelv (K. Coe, personal communication). The trends of these valleys and rivers may originally have been defined by crush zones.

The hornblende-quartz monzodiorite west of Istorvet is separated from the Klitdal granite by a thrust. The monzodiorite possesses the lowest radioactivity recorded within the surveyed part of Liverpool Land. The count rate levels increase abruptly in the thrust zone and remain high over the granite (figs 16, 17). The difference in count rates is due to a higher thorium content in the biotite granite (Table 6 and cf. difference in the rations U/K and T/K in figs 16, 17).

The hornblende-biotite granite in Storefjord has a relatively high count rate similar to that from the banded hornblende-biotite gneiss in the same area.

Upper Palaeozoic and Mesozoic sediments overlie the crystalline rocks at Klitdal and Kap Hope. These are conglomerates, sandstones, siltstones and arkoses generally dipping gently to the west. All are poorly exposed preventing a detailed survey. Average values from the sediments in Klitdal are given in Table 5.

Dolerites, lamprophyres and feldspathic basalts of probably Tertiary age which cut the sediments and crystalline rocks on Liverpool Land are of small areal extent and hence play only a minor rôle in the interpretation of the radiometric results.

Areas of cursory survey

Jameson Land and Scoresby Land (fig. 18) were covered by cursory surveys with flight line spacings ranging from a few hundred metres to tens of kilometres depending upon the topography. The flight lines tended to follow the contours in the valleys, avoiding snow covered plateaux and local glaciers. Over southern Jameson Land the flight lines were straight (fig. 19).

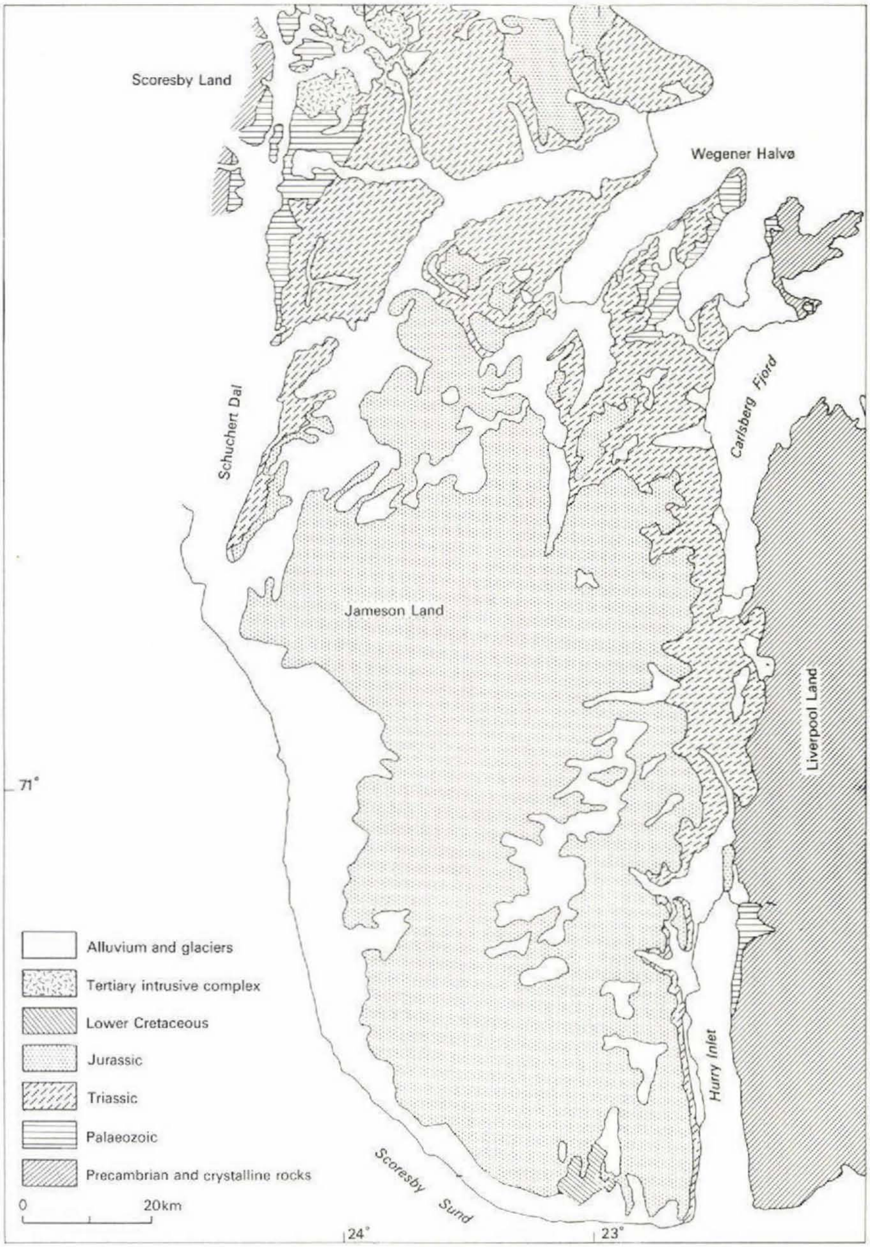

Fig. 18. Simplified geological map of Jameson Land and Scoresby Land.

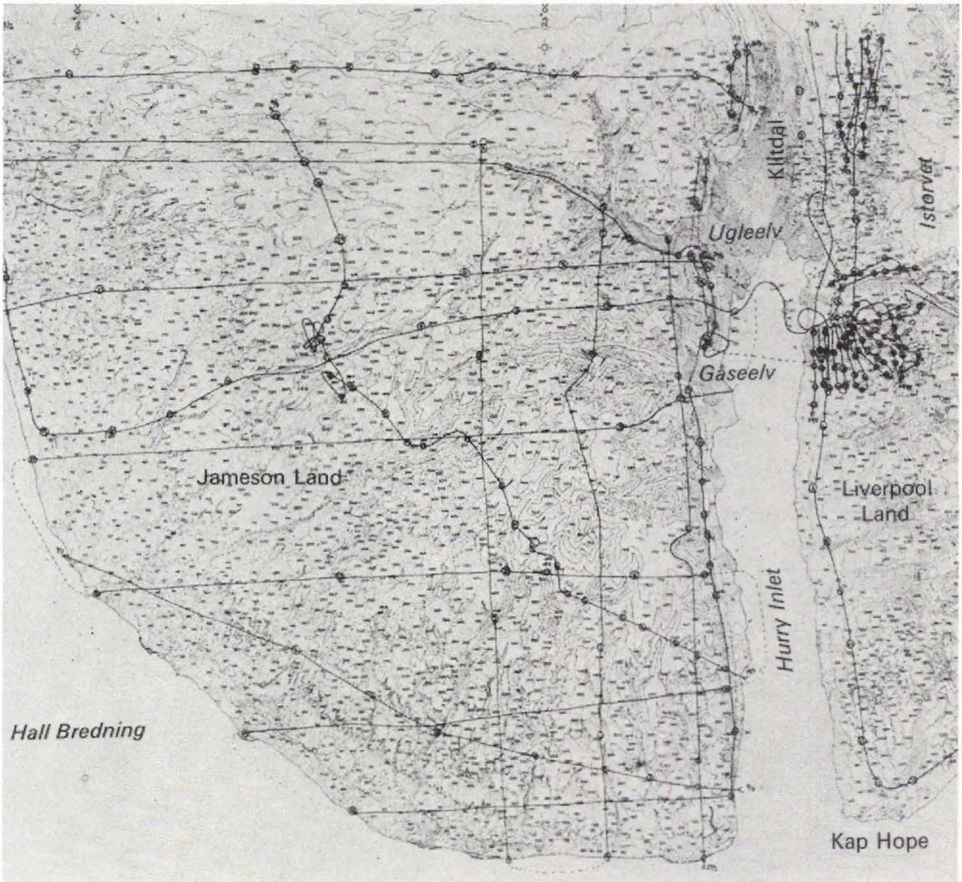

Fig. 19. Flight line distribution patterns in south Jameson Land. The high density of the flight lines east of the head of Hurry Inlet is representative for the flight line distribution in the remaining part of south Liverpool Land where flight lines are not shown on the figure.

Superficial deposits cover a large part of southern Jameson Land masking the count rate differences between the lithological units. Swampy areas and waterlogged soils are widespread throughout western Jameson Land absorbing gamma-radiation to varying extents. The large range of count rates are therefore largely due to these terrain factors.

The stratigraphy of the Upper Palaeozoic and Mesozoic formations has been described by Perch-Nielsen *et al.* (1972) and Surlyk *et al.* (1973); a simplified sequence is given in Table 7. The airborne spectrometer survey is divided according to the stratigraphy and the results are presented in Tables 8 and 9.

There is an overall very general decrease of radioactivity southwards (Tables 8 & 9).

Table 7. Upper Palaeozoic and Mesozoic sequence of Jameson Land and Scoresby Land

System	Formations	Members
Lower Cretaceous	Hesteelv	Muslingeelv Crinoid Bjerg
Jurassic	Raukelv	Fynselv Salix Dal Sjællandselv
	Hareelv	
	Olympen	
	Vardekløft	Fossilbjerget Pelion Sortehat
	Neill Klinter	Ostreaelv Gule Horn Rævekløft
	Kap Stewart	
Triassic	Fleming Fjord	Ørsted Dal Malmros Klint Edderfugledal
	Gipsdalen	Kap Seaforth Solfaldsdal
	Pingo Dal	Sydkronen Paradigmabjerg Rødstaken
	Wordie Creek	
Permian and Carboniferous	Foldvik Creek	
	Mesters Vig	Aggersborg Domkirken Profilbjerg Blyklippen Skeldal

Formations and members investigated radiometrically are underlined.

Carboniferous and Permian

Arkoses and conglomerates of the Domkirken Member south of Werner Bjerge gave notably higher count rates compared with sandstones and arkoses of the Blyklippen Member near Mesters Vig. The gamma survey showed that the radioactivity increases towards the intrusive syenites of Werner Bjerge implying that radioelements have migrated into the sediments from the alkaline intrusion.

Conglomerates with a high proportion of gneiss and granite pebbles have a relatively high radioactivity and thin silty layers in the arkoses are enriched in radioelements compared to the coarser sandstones.

Triassic, Jurassic and Lower Cretaceous

The Wordie Creek and Pingo Dal Formations are exposed in Jægerdalen (Pictet Bjerge) in Scoresby Land and in Pingo Dal east of Werner Bjerge. Cross-bedded, red sandstones dominate the sequence with conglomerates and intercalations of arkoses and silty layers. Count rates are characteristically lower than in the Carboniferous and Permian continental sediments, and are slightly lower in the Pingo Dal Formation than in the underlying Wordie Creek Formation. In the Pingo Dal Formation a minor increase in the T channel count rate was found west of Gipsdalen, and another anomaly in which the count rates were highest in the U channel, occurs in Jægerdalen.*

In the overlying Fleming Fjord Formation there is uranium enrichment by a factor of seven in two places on the north slope of Pingo Dal, near its junction with Ørsted Dal. The uranium and thorium contents in the yellow part of a 10 m thick silty layer in a red sandstone is 14.6 ppm and 6.3 ppm respectively compared with 2.0 ppm and 8.6 ppm in the surrounding sandstone.

Scintillometer readings on outcrops of the Kap Stewart and Neill Klinter Formations have shown count rates comparable to the underlying formations. Only in the overlying Vardekløft Formation can differences be seen in the count rates. Here there is a general increase in count rate levels from south to north (Table 8 shows a large variation in the count rates in the G channel), a reflection of a change in lithology from mainly sandstones of the Pelion Member in the south to the Fossilbjerget Member in the north consisting of shales with subordinate horizons of sandstones and concretions of glauconitic and phosphatic nodules. The shaly facies of this member possesses the highest count rate levels recorded in Jameson Land.

In the overlying Hareelv Formation of shales with irregular sandstone lenses the count rate level rises towards the west. The low count levels in the east are attributed to topographic effects combined with intense solifluction together with a relatively higher proportion of sandstone lenses of low radioactivity. Several minor anomalies can be explained as shale outcrops. Assays of the uranium and thorium content of the shales (Table 11) show an enrichment by factors of four to five over the average in the sandstones. An anomaly near Jyllandselv seems to be enriched mainly in uranium.

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* Field observations by J. Engell in 1974 indicate that the anomaly in Jægerdalen coincides with a trachyte dyke of Tertiary age.

Table 8. Count rates from rock formations in Jameson Land recorded during airborne gamma-spectrometric survey

	G	U	T	K
Hesteelv Formation sandstones, shales	950(800-1200)	9(6-12)	10(8-16)	32(25-50)
Raukelv Formation sandstones	900(600-1200)	10(5-18)	12(6-20)	33(25-40)
Anomaly north-west of Crinoidbjerg	1400	14	15	45
Hareelv Formation sandstones, shales	1250(700-1600)	16(7-21)	17(10-23)	50(30-65)
Anomaly near Jyllandselv	2000	55	26	70
Vardekløft Formation Pelion Member sandstones	1190(750-1800)	11(7-15)	15(8-18)	38(35-40)
Anomalies	1300-1600	15-20	21-25	40-60
Vardekløft Formation Fossilbjerget Member shales	1400(1200-1600)	19(16-23)	21(18-24)	61(45-75)
Neill Klinter Formation mainly sandstones	1100(1000-1200)	12(10-14)	15(13-18)	42(40-45)
Kap Stewart Formation sandstones, shales	1050(900-1300)	10(8-12)	12(10-15)	35(30-40)
Fleming Fjord Formation sandstones, siltstones	1100(900-1600)	16(14-22)	15(12-17)	52(35-60)
Two anomalies, Pingo Dal	1500, 2000	20, 27	18, 18	40, 60
Pingo Dal Formation sandstones	1350(1200-1500)	10	8	50
Wordie Creek Formation sandstones	1400	12	16	50
Carboniferous and Lower Permian sandstones, arkoses	1700	17	20	60

The lowest count rates on Jameson Land were recorded over the sandstones and shales of the two youngest formations – Raukelv and Hesteelv – of uppermost Jurassic and Lower Cretaceous age respectively.

Tertiary

Tertiary intrusive syenites are easily distinguished from the surrounding sediments on the airborne spectrometer by their higher count rates. The intrusive centres in Pictet Bjerge, including Kap Syenit, seem to be less radioactive than the Werner Bjerge syenites exposed in Schuchert Dal. Two anomalies were found on opposite sides of Mellem Gletscher to the north of Werner Bjerge which are assumed to be connected with intrusive syenites .

Table 9. Count rates from rock formations in Scoresby Land recorded during airborne gamma-spectrometric survey

	G	U	T	K
Tertiary syenite Kolossen, Delta Dal	2700	25	30	70
Tertiary syenite Pictet Bjerge	2300(2000-2700)	23(20-27)	22(18-27)	60(50-70)
Lower Jurassic Kap Stewart Formation Horsedal	1200(1000-1400)	12(10-15)	16(12-20)	45(30-60)
Triassic and Jurassic sediments Pictet Bjerge	1000(800-1200)	10(8-12)	12(10-15)	40(30-50)
Carboniferous and Permian sediments Blydal and Delta Dal	1250(1000-1500)	12(10-15)	13(8-18)	35(20-50)

Single line reconnaissance flights

Single line reconnaissance flights were made to the north of Mesters Vig as far as Loch Fyne, and over southern Milne Land and Gåseland (fig. 1). The results are summarized in Table 10. A survey of the regional geology north of Mesters Vig is given by Haller (1971), and Milne Land and Gåseland are described by Henriksen & Higgins (1973).

The routes across the Devonian basin have distinctly higher count rates than elsewhere. The highest count rates were recorded over late Devonian granites and rhyolites on the eastern slopes of Giesecke Bjerge. Increases in gamma activity appear also to be connected with the north–south faults on the borders between the Devonian sandstones and sediments of the Eocambrian Eleonore Bay Group to the west. Within the Carboniferous sandstone there appears to be a general decrease in radioactivity to the north.

In the Milne Land and Gåseland areas the highest count rates were recorded over the granodiorites north-east of Danmark Ø, and are lowest over areas of marbles, amphibolites and gneisses of the Krummedal supracrustal series between the heads of Gåsefjord and Vestfjord.

Geiger-Müller measurements and radiation dosimetry

During the regional mapping by the Geological Survey of Greenland of the entire Scoresby Sund region about 2000 *Geiger-Müller measurements* were taken. In general the results of the measurements follow the main conclusions of the airborne gamma-spectrometric survey. The Geiger-Müller counters have to a large extent been used in examining shear zones, faults, hydrothermal impregnations and rusty horizons. Compared to a general count rate level from 15 to 45 counts per minute (cpm) the following categories can be distinguished:

Table 10. Count rates from rock formations in central East Greenland recorded during airborne gamma-spectrometric single line reconnaissance flights

	G	U	T	K
Lyell Land Eleonore Bay Group sediments	300- 600	8-12	4- 8	30-40
Ella Ø Cambro-Ordovician sediments	300- 400	10	2- 3	20-30
Ella Ø Devonian sandstones	500- 700	12	8	40
Ella Ø (Maria Ø) Eleonore Bay Group sediments	400	10	2- 3	20-30
Ymer Ø Eleonore Bay Group and Devonian sediments	1000-1400	14-16	9-17	40-55
Ymer Ø, eastern end Carboniferous sandstones	1400	15	15	50
Ymer Ø, eastern end Tertiary basalt	900	10	7	45
Moskusoksefjord Devonian sandstones	1000	18	15-20	40-60
Moskusoksefjord Devonian granites	1500-2000	25-50	25	80
Loch Fyne Caledonian crystalline rocks	1000	30-40	20-40	40-70
Loch Fyne Devonian granite/rhyolite	2000-2500	40-60	35-45	100
Loch Fyne Carboniferous sandstones	800-1600	20-30	10-20	50-80
Loch Fyne Tertiary basalt	400- 500	10-12	6- 8	40
Geographical Society Ø Devonian and Carboniferous sandstones	600-1200	10-20	8-16	30-60
Milne Land, south coast Caledonian crystalline rocks	1200-1500	12-18	15-20	30-50
Milne Land, north-east of Danmark Ø, granodiorites	1700	20	22	50
Gåseland Area 1	1000	12	16	40
Gåseland Area 2	200- 700	3- 7	5-10	15-30
Gåseland Area 3	600-1100	6-13	8-18	20-40

1. Pegmatites at various localities. 60–75 cpm.
2. Granites and syenites in the Stauning Alper and south of Charcot Gletscher on Milne Land. 65–240 cpm.
3. Mylonite and marble in the Stauning Alper. 65–75 cpm.
4. Biotite dioritic dyke in a large marble layer in Nordvestfjord with a count rate of 200 cpm.
5. Carboniferous-Permian sandstone with dark impregnations in Schuchert Dal. 140–250 cpm.

The natural radiation levels of the major rock formations of the region were also investigated by means of *thermoluminiscence dosimetry* (Nielsen & Bøtter-Jensen, 1973). In histograms representing the frequency distribution of dose rates the deviation in the group of crystalline rocks is small compared with the deviation in the group of sedimentary rocks.

DISCUSSION

General evaluation

A large number of field scintillometer readings were taken during the field work in addition to the aerial radiometric measurements. An attempt was made to correlate the average values of the aerial count rates G, U, T and K with the field scintillometer readings and the estimated abundances of uranium, thorium and potassium (Table 11).

The exposure rates measured in the field were corrected for an observed background exposure rate of 1.5 μR/h, and then compared with exposure rates (F) calculated according to the formula (Løvborg & Kirkegaard, 1974).

$$F\ (\mu\text{R/h}) = 0.63\ \text{ppm U} + 0.31\ \text{ppm Th} + 1.54\ \%\ \text{K}.$$

In areas with rugged topography, in particular in the Stauning Alper, the field measurements were generally higher (up to 1.7 times) than predicted by the formula while in comparatively flat terrain, such as over Jameson Land, there was agreement within $\pm$ 10 %. From this it is concluded that the samples of shale and sandstone collected in Jameson Land are representative of the lithologies.

A comparison between the aerial gross count rates and the field scintillometer measurements indicate a strong terrain influence. This can be seen, for example, in the values from shales in Jameson Land and the gneisses and migmatites in the Stauning Alper (Table 11). Both environments have ground exposure rates of *c.* 17 μR/h, but while the average count rate G over the shales was only 1400 cps that over the gneisses and migmatites varied from 2500 to 4000 cps. This terrain dependence is ascribed to the fact that the solid angle of gamma-ray detection is higher in a mountainous area (Stauning Alper) than over a relatively flat area (Jameson Land). Also in the mountainous area the steep slopes are generally better exposed than the formations in areas without relief. The outcropping shales do not usually form an infinite source.

Table 11. Outlines of airborne radiometric count rate levels, laboratory gammaspectrometric assays of radioelements, and exposure rates from field scintillometer measurements of major stratigraphic and lithological units in central East Greenland

Age and locality	Rock types	G	U	T	K	U ppm	Th ppm	K %	N	Field measurement μ R/h
<u>Jurassic</u> Jameson Land and Scoresby Land	shales	1400	19	21	61	8.3	15	2.4	7	17.5
	sandstones	1050	11	14	37	1.7	4.8	1.4	15	7.5
<u>Jurassic</u> Milne Land	sandstones	3325 (1500-5000)	34 (15-50)	27 (15-45)	57 (30-70)	0.8-570	8.0-5900	0.9-2.8	27	7-1700
<u>Triassic</u> Scoresby Land	sandstones and siltstones	1000	10	12	40	3.4	6.0	1.7	27	8
<u>Permian</u> Scoresby Land	shales sandstones siltstones arkoses	1250	12	13	35	0.9-9.9	4.2-51	1.2-5.3	10	5-35
<u>Carboniferous</u> Scoresby Land	sandstones and arkoses					1.9	9.1	2.5	12	15
<u>Late Caledonian</u> Hurry Inlet	granites	1850 (1400-3000)	26 (18-45)	27 (12-40)	83 (60-100)	6.4	29	3.7	4	-
<u>Late Caledonian</u> Milne Land	granites	3000	28	30	65	1.9	11	3.3	6	17.5
<u>Late Caledonian</u> Stauning Alper	granites	3000 (2500-3500)	40 (25-55)	36 (25-40)	81 (70-95)	3.6	29	5.2	14	35
<u>Caledonian</u> Stauning Alper	gneisses and migmatites	3250 (2500-4000)	20	35	65	1.8	9.5	3.3	4	17
<u>Caledonian</u> Gåseland	Metasediments and gneisses	950	11	14	35	2.3	11	2.0	15	10

G, U, T and K in cps

N number of determinations

The amounts by which the count rates G, U, T and K are influenced by variations in the radioelement abundances in the rock formations were estimated as:

G	80–180	cps/μR/h
U	$\sim$ 0.5	cps/ppm U
T	1.3–3	cps/ppm Th
K	$\sim$ 20	cps/% K

The sensitivity of U and T to uranium and thorium is very low compared to the sensitivity of G. This indicates that a spectrometric aerial survey based on a detector volume of 3.7 litres of NaI/(Tl) can only be justified in that it permits a distinction between uranium and thorium anomalies. This is clearly seen in the anomaly at Jyllandselv in Jameson Land (Table 8) where the threefold increase in the count rate in the U channel over comparative average values elsewhere indicates an enrichment in uranium (*c.* 80 ppm U).

On the assumption that the Th/U ratio is almost constant, the variation in the combined uranium–thorium content of the formation under investigation can be taken from the variation of the count rates in the T channel where the effects of 'stripping' are minimal. Throughout the whole area the count rates in the T channel vary from about 10 cps to 50 cps. This is divisible into simplified groupings of the various lithologies. (Data from the single line reconnaissance flights are not included).

10–20 cps	Sandstones, silt and shale in Jameson Land and Scoresby Land. Metamorphic rocks in Liverpool Land.
20–30 cps	Plutonic rocks in Milne Land. Anomalies in Jameson Land.
30–40 cps	Plutonic rocks in Liverpool Land and the Stauning Alper. Sandstones in Milne Land and east of the Stauning Alper.
40–50 cps	Migmatites in the Stauning Alper. Anomalies in the Stauning Alper and Milne Land.

Radioactive anomalies

Radioactive anomalies have been encountered in a number of different geological environments covering a large geological time span (Table 12). The anomalies in the marine and epicontinental sedimentary formations of Jameson Land are small and so are the general radiation levels of these formations. Possibilities of finding concordant sedimentary radioactive deposits within this area are regarded as limited. The Caledonian formations including the late kinematic plutonic rocks and the pre-Caledonian basement appear to be more attractive for further prospecting work. Magmatic uranium mineralization in pegmatitic and hydrothermal deposits may occur in the late Caledonian granites and syenites, in fault and shear zones, and in the adjacent clastic sediments. The anomalies at Milne Land and in the eastern part of the Stauning Alper are of the latter type. The Tertiary plutons require detailed investigation.

Table 12. Main radioactive anomalies encountered during the airborne radiometric survey in the Scoresby Sund region

Locality	Geological environment	cf. Table/Fig.
Mellem Gletscher	Tertiary Werner Bjerge complex	
Sirius Gletscher	Tertiary Werner Bjerge complex	
Crinoidbjerg south Jameson Land	Sandstone, Raukelv Formation	Table 8
South-east Milne Land	Jurassic sandstone	Table 4
Jyllandselv Jameson Land	Sandstone, shale Hareelv Formation	Table 8
South Jameson Land	Sandstone, shale Vardekløft Formation	Table 8
Pingo Dal Scoresby Land	Sandstone, siltstone Fleming Fjord Formation	Table 8
Jægerdalen Scoresby Land	Sandstone, Lower Trias	
Karstryggen Schuchert Dal	Upper Permian carbonate rocks and arkoses	Table 1
Kalkdal Liverpool Land	Biotite granite late Caledonian	Table 5
Kæmpehøjen Liverpool Land	Granodioritic gneiss Caledonian	Table 5
East Stauning Alper	Fault zone in late Caledonian granite	Table 1
Arkosedal Stauning Alper	Fault zone between late Caledonian granite and Upper Permian arkose	Figs 9-11
South-east Milne Land	Late Caledonian quartz syenite	Table 4
South-east Milne Land	Late Caledonian granodiorite	Table 4
North-east Milne Land	Late Caledonian granite	Table 4
Holger Danskes Briller	Migmatite, pre-Caledonian, Caledonian	Table 1

Comparative mineralization areas in Sweden and Scotland

Uranium mineralization occurs within the area of the Caledonian fold belt and bordering regions in Sweden and Scotland in similar situations to that in East Greenland.

In Sweden uranium mineralization is known east of the fold belt close to the Caledonian front. In the northern part of Sweden nappes were thrust eastwards over Precambrian crystalline rocks and Eocambrian, Cambrian and Ordovician sediments are to some extent preserved in a narrow rim on the eroded basement close to the Caledonian front. Pitchblende veins occur in the granitic gneiss of the basement and the same mineral occurs disseminated in Eocambrian quartzitic sandstones in the Arjeplog area near the Polar Circle (Lundberg, 1973). Some of the mineralization in the basement is accompanied by a sodium-calcium alteration.

Uraniferous sandstones and siltstones of Lower Ordovician age occur in the Tåsjö area (64° N) close to the Caledonian nappes (Gee, 1972). In the marine sediments the uranium is associated with phosphatic horizons. A similar geological environment is found in the Vardekløft Formation in Jameson Land where the Fossilbjerget Member may constitute a similar regime.

The source and age of the uranium mineralization in the two Swedish areas is unknown. In the sedimentary deposits the uranium can be followed by base metals such as lead and molybdenum. There is no evidence that the uranium in the veins cutting the granitic gneiss basement has its origin in the basement. The proximity of the Caledonian front and a recent discovery of uranium mineralization within Caledonian nappes (Lundberg, personal communication) suggests that mineralizing solutions were active during the Caledonian thrusting possibly indicating a migration and tectonic transport from the west.

In Scotland uranium mineralization is known in Caledonian granitic rocks of the Northern Highlands and in the Old Red Sandstone derived from them (Michie *et al.*, 1973).

Uranium enrichment is known in the Helmsdale and Grudie granites in eastern Sutherland. In the Grudie granite uranium follows both disseminated pyrite–fluorite–molybdenite mineralization and vein type mineralization with galena, fluorite and baryte on both sides of the interface between the granite and the underlying Moinian metamorphic rocks. In the poorly exposed Helmsdale granite a linear radioactive structure has been defined where anomalous uranium values are accompanied by anomalous contents of lead (Michie *et al.*, 1973).

There are thus general similarities between the late Caledonian granites in Scotland and in East Greenland. In both regions granitic rocks are found with radioactivity values above the average, e.g. the disseminated mineralization in the quartz syenite and granodiorite on Milne Land and in the Grudie granite. In both regions radioactive fluorite and baryte-bearing vein type deposits occur in a Caledonian regime, e.g. the fault zones in Arkosedal and the eastern Stauning Alper as well as in the Scottish Caledonian granites and the adjacent metamorphic basement.

Uranium mineralization in the Devonian molasse sediments in northern Scotland is found in various environments. The Lower Old Red Sandstone consists mainly of arkoses, and the Middle Devonian sequence of phosphatic and shaly rocks may be enriched in uranium (Gallagher *et al.*, 1971). The mineralization is found in the sediments overlying the Helmsdale granite and further north in Caithness and Orkney. The source of the uranium in the Old Red Sandstone could well be deeply eroded Caledonian granites.

In East Greenland Devonian molasse sediments were deposited in closed sedimentary basins under differing environmental conditions. Devonian rhyolites and tuffs are intercalated in the sandstone sequence, and late Caledonian granitic rocks are exposed within the molasse area.

During prospecting in 1973-75 uranium mineralization in Middle Devonian acid volcanic rocks was discovered and examined.

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