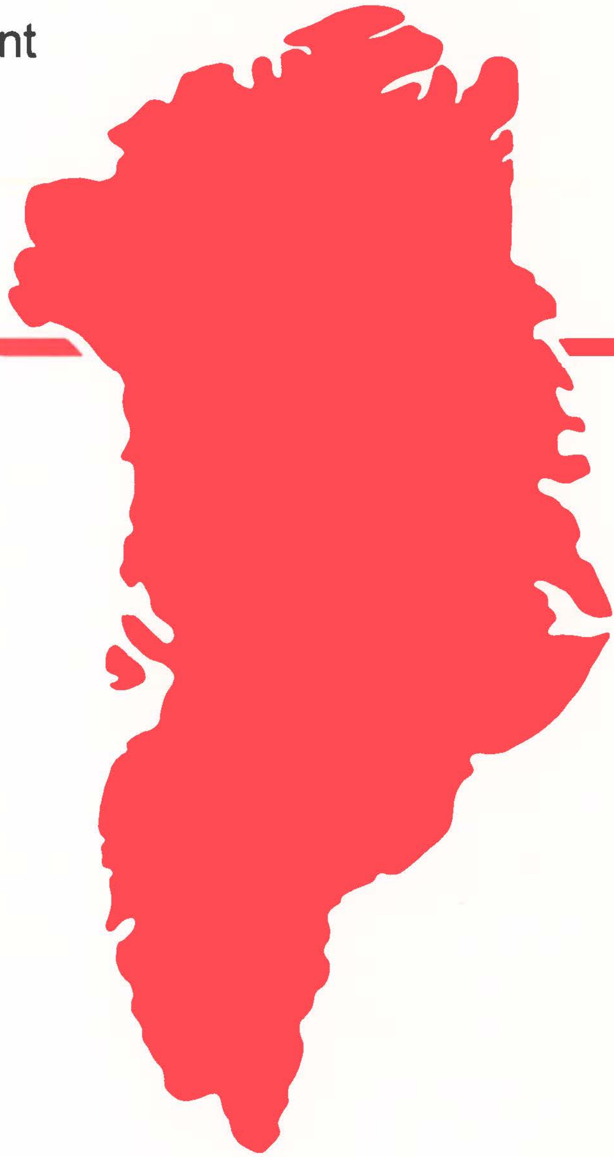
The Grønnedal–Ika alkaline complex in south Greenland

Review of geoscientific data relevant to exploration



Jan Bondam

Open File Series 92/2

January 1992

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Ujarassiortut Kalaallit Nunaanni Misissuisoqarfiat
GEOLOGICAL SURVEY OF GREENLAND

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Abstract

A condensed review is presented of available data of geochemical and geophysical nature, extracted from unpublished reports and studies, and from other sources in the files of the Geological Survey of Greenland, that are relevant to exploration within the Grønnedal-Ika alkaline complex.

The majority of these data are analytical results obtained during drilling and by further scattered observations with respect to the centrally emplaced magnetite and apatite bearing carbonatite plug within the complex.

Some mineral chemistry data are included.

Geological setting

The Grønnedal-Ika nepheline syenite complex, situated at 61°14'N, 48°03'W on the Ivigtut peninsula, is the earliest known alkaline intrusion of the mid-Proterozoic Gardar Province of South Greenland. The province is reviewed by Upton (1974), Emeleus & Upton (1976) and Upton & Emeleus (1987).

The Gardar province encompasses a period of continental rifting with subsequent deposition of sandstones and lavas, named the Eriksfjord Formation, followed by the emplacement of central intrusions and several generations of dykes over an extended period ranging from 1300 Ma to 1120 Ma. For further information reference is made to the geological map of Greenland 1:500 000, sheet 1, Sydgrønland and to the descriptive text by Kalsbeek et al. (1990).

The Grønnedal-Ika complex is intruded into regional Archaean gneisses that on the Ivigtut peninsula include characteristically deformed anorthosite and gabbro-anorthositic units. Other gneisses in the vicinity of the intrusion carry abundant inclusions of amphibolite, greenschists and metasediment that have been mapped as a single unit, named the Ika gneiss series (Berthelsen & Henriksen, 1975).

The following brief summary description of the intrusion is extracted from Emeleus (1964) who comprehensively described the structure and the geological history of the Grønnedal-Ika complex accompanied with a geological map, scale 1:15 000. The map is included in this report.

Four successive rock series are recognised in an originally ovoid shaped intrusive complex of steeply dipping ring structures of nepheline syenites, with centrally emplaced plugs of xenolithic syenites and carbonatite.

The different nepheline syenite series include a range of laminated rock types, such as foyaite, a nepheline-poor variety of pulaskite, ijolite, malignite and ditroite.

The late intrusion of the carbonatite phase has been viewed as a single event that includes carbonate impregnated and brecciated nepheline syenitic rocks at the margin of the centrally emplaced Ca- and Fe-carbonatite plug.

In a post-igneous phase the whole complex was cut by dykes of several different generations and composition such as dolerites, lamprophyres, phonolites and trachytes, and by irregular sheets of porphyritic basalt.

The dyke rocks extend into the surrounding basement. Subsequently, later faulting distorted the oval shape of the intrusive complex.

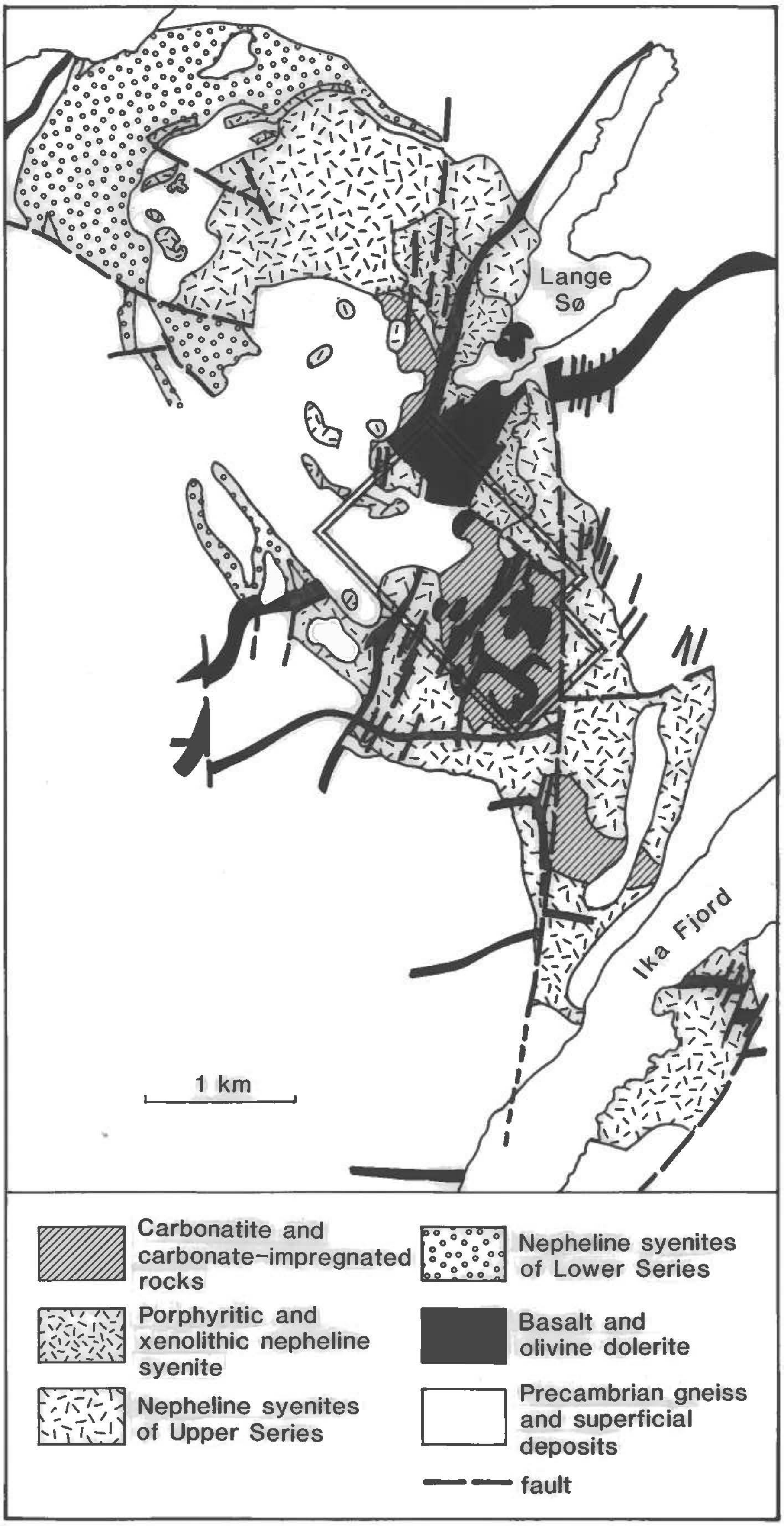


Fig. 1. Geological sketch map of the Grønnedal-Ika complex after Woolley (1987). The position of the included magnetic anomaly map is indicated by a polygon that encircles carbonatite.

The radiometric (Rb-Sr) age of the central intrusion is 1299 $\pm$ 17 Ma (Blaxland et al. 1978), the post-igneous dykes belong to the mid-Gardar intrusive period with radiometric ages in the range between 1250 and 1200 Ma.

A short review of the Grønnedal-Ika complex is given by Woolley (1987). The review includes a simplified geological map of the alkaline complex that is reproduced in fig. 1. On this map the position of the magnetic anomaly map, included in this report, is outlined.

The geochemistry of the Grønnedal-Ika complex and associated rock types has been treated by Gill (1972, a, b). These papers are mainly concerned with magma associations both of the major rock units and of the dyke rocks. Morteani et al. (1986) studied elemental distribution patterns as related to the relative enrichment or depletion of the chemical elements under discussion, compared to the element concentration of the earth's primitive mantle, as proposed by Sun (1982) and others.

Melting experiments including nepheline syenites from the Grønnedal-Ika complex have been reported by Sood & Edgar (1970).

Economic geology

Introductory remarks

Already at the end of the last century mention was made of the occurrence in the area of ore-grade magnetite, embedded in "limestone" (Holst, 1886), i.e. carbonatite. This indication led to exploration activity from 1948 to 1950, which encompassed a magnetic ground survey, trenching and drilling in the main anomalies.

The field exploration was carried out by Kryolitselskabet Øresund A/S on behalf of the State authority. The report includes drilling logs and chemical analyses of drill core and grab samples from the trenches. It is accompanied by a map in the scale of 1:2 000 of the vertical magnetic intensities over a part of the carbonatite intrusion (Bøgvad, 1951a). The drill cores are stored at the Geological Survey of Greenland and are open for inspection. Some of the results of this exploration activity are briefly referred to by Emeleus (1964) and by Nielsen (1976).

An account for this operation, intended for the general reader, has been published by Bøgvad (1951b).

In 1956 a reconnaissance radiometric survey of the carbonatite was carried out by the Geological Survey of Greenland covering the area close to and around the drilling site.

Willmers (1971) investigated the nepheline syenites of the complex as a possible raw material for the glass and ceramic industries.

From 1983 to 1986 the Grønnedal-Ika complex was once more in the focus of attention as part of an EEC-funded project, as reported by Morteani et al. (1986). The goal of this project was to assess the niobium and phosphorus content of the intrusive series, as an indicator for subsequent enrichment of these elements in late carbonatite.

A regional airborne geophysical survey of the whole Ivigtut peninsula was carried out by Finnprospecting (1985) on behalf of Kryolitselskabet Øresund A/S, which also covers the Grønnedal-Ika complex. This survey includes magnetic, electromagnetic and VLF measurements.

In the following chapters the available data relevant to aspects of economic geology are presented separately for both the nepheline syenites and the carbonitites.

The Grønnedal-Ika complex is situated close to the partly depleted cryolite deposit at Ivigtut and easily accessible from the nearby township Grønnedal, a naval base with good harbour facilities and infrastructure.

The nepheline syenites

Willmers (1971) made a comprehensive, well-documented laboratory study of a preliminary nature of the major nepheline syenite members found in the complex, on the viability to obtain ceramic and glass grade concentrates by magnetic separation alone no froth flotation or chemical treatment being employed.

The study was based on a collection of large hand specimens of the rock types as described by Emeleus (1964). In all 46 samples were investigated.

The designation of nepheline syenite used by Willmers (1971), is as follows:

Upper series:

Foyaite (Fo, U)

Pyroxene-rich syenite (Ps, U)

Lower series:

Granular syenite (Gs, L)

Foyaite (Fo, L)

Coarse-grained brown syenite (Bs, L)

Table 1. Chemical analyses of rock samples of nepheline syenites, both before and after magnetic separation.

Rock Unit		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	S	P_2O_5	Total
Gs, L	Rock	55.37	18.89	7.75	0.72	2.58	8.75	4.96	0.57	0.24	0.01	0.17	100.07
	Product	60.84	21.21	0.67	0.16	1.09	8.96	7.00	0.00	0.00	0.04	0.00	100.06
	Residue	50.39	6.91	23.43	2.09	5.30	9.35	1.13	1.31	0.00	0.00	0.05	100.00
Bs, L	Rock	57.07	25.61	5.62	0.44	0.26	3.97	6.63	0.20	0.08	0.01	0.11	100.00
	Product	63.56	21.28	1.65	0.21	0.16	6.99	6.09	0.00	0.00	0.04	0.00	100.00
	Residue	43.13	27.50	17.86	2.89	0.07	1.12	6.92	0.48	0.00	0.00	0.05	100.00
Fo, L	Rock	56.10	20.13	6.93	0.32	1.75	7.92	6.37	0.14	0.21	0.01	0.08	99.96
	Product	61.22	20.86	0.48	0.03	0.97	9.15	7.37	0.00	0.00	0.04	0.01	100.13
	Residue	48.57	15.32	19.42	0.95	3.64	7.17	4.30	0.39	0.00	0.00	0.06	99.82
Ps, U	Rock	50.47	17.02	13.22	0.98	6.26	5.74	4.45	0.37	0.43	0.01	1.08	100.03
	Product	57.84	21.62	1.04	0.09	4.29	6.83	6.88	0.00	0.00	0.04	0.88	99.81
	Residue	47.51	8.31	24.38	2.57	9.57	5.27	1.67	0.63	0.00	0.00	0.11	100.02
Fo, U	Rock	56.14	21.38	6.09	0.35	1.35	7.78	6.45	0.15	0.17	0.01	0.09	99.96
	Product	60.85	21.89	0.64	0.03	0.19	8.69	7.65	0.00	0.00	0.04	0.00	99.98
	Residue	48.07	11.52	23.13	1.56	5.45	6.73	2.89	0.56	0.00	0.00	0.07	99.98

Table 2. Yield weight percentages after magnetic separation of crushed rock samples of nepheline syenite in the grain size range -90 to +108 mesh.

	Tests	Non-magnetic fraction			Magnetic fraction			Ferromagnetic fraction		
	N	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Gs, L	1	66.47	-	-	33.16	-	-	0.39	-	-
Bs, L	1	80.34	-	-	19.59	-	-	0.03	-	-
Fo, L	7	73.52	87.44	60.20	20.66	35.72	11.72	5.81	12.07	0.85
Ps, U	2	50.13	60.56	39.70	49.63	60.13	39.13	0.23	0.33	0.13
Fo, U	3	77.00	85.58	65.20	20.80	30.74	13.60	2.19	4.08	1.16

The abbrevations added in brackets, are used in the following tables for the rock units in question.

Table 1 shows the result of chemical analyses, expressed as a mean of several determinations of the initial rock types, and of the non-magnetic fraction and the residue after magnetic separation.

A Frantz Isodynamic Magnetic Separator model L-1 was used under the following test conditions: sample size 10 g, dip 30^{o}, side slope 20^{o}, flow rate 4-5 g/h; 3 runs were made for each sample, with varying magnetic field strength.

	in Amp	Mass susceptibility (cgs) x 10^{-6}
Run 1	0.05	1000
Run 2	0.60	20
Run 3	1.20	5

The yield of the employed separation process is given in Table 2.

Table 3 summarises the chemical analyses of some of the glasses which were prepared from the non-magnetic fraction.

Table 3. Microprobe analyses of clear glasses: mean of 4 determinations of each sample

	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	(Na_2O+K_2O)	$\frac{Na_2O}{(Na_2O+K_2O)}$	Total
Bs, L	63.46	17.75	1.41	6.57	5.99	12.56	52.3	97.18
Fo, L	59.00	23.55	0.31	8.72	6.52	15.24	57.2	98.10

Minor inclusions of iron containing minerals, mainly of aegirine, are observed both in nepheline and in the feldspars.

No further efforts have been made, neither in the field nor in the laboratory, to search for more suitable primary raw material and to elaborate the processing.

Morteani et al. (1986) have studied the distribution of Nb and P_2O_5 in the rock suites of the Grønnedal-Ika complex on the basis of whole-rock chemical analyses. A deversity of minerals found in the different rock types were analysed by microprobe. The minerals included in this study are pyroxenes (aegirine, aegirine-augite), amphiboles (kataphorite, richterite, actinolite), biotite, carbonates (calcite, dolomite, ankerite, siderite, strontianite, synchisite), phosphates (apatite, monazite), pyrochlore and related Nb-Ta minerals like columbite and fersmite.

No microprobe analyses of nepheline and feldspars are available.

The carbonatites

The centrally placed intrusion of carbonatite in the nepheline-syenite complex is severely affected by later intrusions of Gardar dykes and sills and by faulting.

Emeleus (1964) distinguishes between an outer rim of carbonate-impregnated syenitic rocks and carbonatite proper.

The carbonate-impregnated rocks form an intrusive breccia surrounding a central plug of predominantly Ca-carbonatite, with minor off-shoots both into the brecciated rim and along the contact with the main foyaite of the Upper Series. Flow banding is frequently observed.

Due to later intrusions of doleritic and alkaline dyke rocks and sills, and subsequent faulting the field relations are rather complicated as apparent from the enclosed geological map.

Emeleus (1964) pointed out that the surrounding nepheline syenites do not clearly show fenitic alteration, neither at the contact with the carbonatites, nor in the inclusions of nepheline syenite found in the intrusive breccia.

The lack of clear signs of fenitisation is ascribed to the occurrence of an adjacent body of syenitic rocks designated "xenolithic porphyritic syenite". This irregular plug bears clear signes of having been emplaced under explosive conditions. Accordingly it may have paved the way for a less forcefull injection of carbonatite in a hot environment.

Besides Ca-carbonatite, irregularly distributed layers of Fe-carbonatite occur, carrying siderite as the main carbonate. A magnetite-rich variety of carbonatite has attracted attention as a possible ore.

Exploration

As previously mentioned exploration effort was carried out by Kryolitselskabet Øresund A/S on behalf of the State authority in the period from 1948 to 1950.

The analytical results and the detailed map of the ground magnetic survey have never been published.

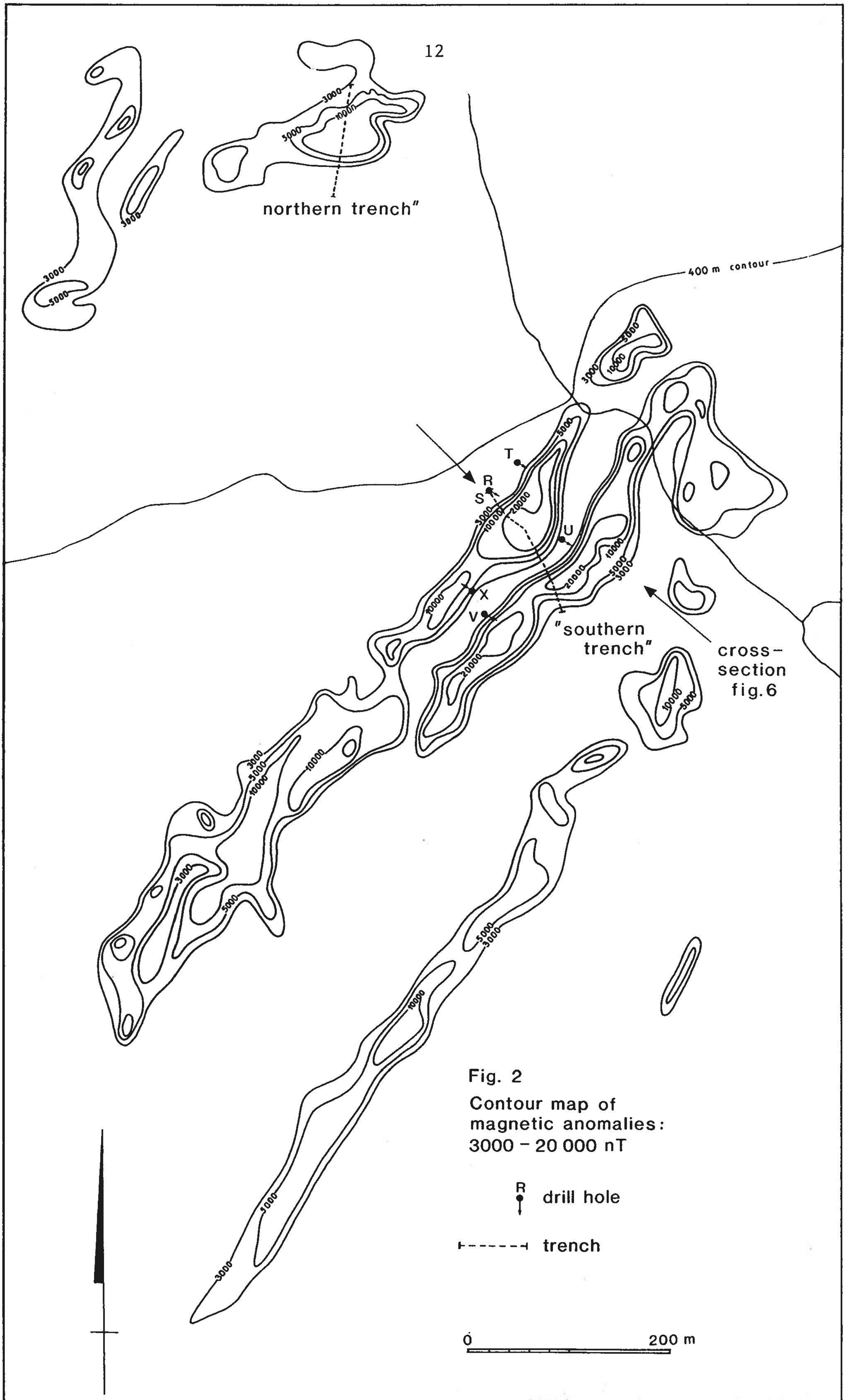


Fig. 2
Contour map of magnetic anomalies: 3000 - 20 000 nT

A simplified version of the magnetic map is found in Emeleus (1964) together with a few semi-quantitative data for some trace elements present in the carbonatites and taken from drill cores.

The results of the exploration did not encourage further investigation, and no additional studies have been undertaken except for scattered observations on the mode of occurrence of apatite and magnetite.

Later work by Morteani et al. (1986) is concerned with the distribution of P_2O_5 and Nb in the whole complex, including the carbonatites.

In the following sections the different aspects of the exploration activities are presented in more detail.

Geophysical surveys

The ground magnetic survey in 1949 was carried out by the Meteorological Institute in Copenhagen.

The instrument that was used was a magnetometer (BMZ 19) that measures the vertical intensity only. Measurements were carried out along a grid with a rectangular distance of 40 metres between the measuring points. A residual magnetic anomaly map in scale 1:2 000, relative to a natural vertical field intensity of 53,000 nT was ultimately produced in one handcoloured copy.

The field data obtained have recently been digitalised and recompiled in scale 1:5 000 at the Geological Survey of Greenland. The map is included in this report. Its position is indicated in Fig. 1.

The anomaly pattern seems closely connected to later intrusions of olivine dolerite and microporphyritic basalt. In a number of cases magnetite has been observed being psedoumorphic after siderite. It was therefore suggested that magnetite to some extent was formed due to contact metamorphism (Nielsen, 1976).

On the basis of the magnetic anomalies found during the survey two trenches were dug in high anomalous areas and the position of 6 drill holes delineated.

The position of both trenches and diamond drill holes with respect to the magnetic anomalies is given in Figure 2.

A reconnaissance radiometric survey of the exploration area was carried out in 1956 with the aid of a Berkeley Scaler. An arbitrary counts/minute unit was employed as the instrument that was used was not calibrated. As shown in Figure 3 a radiometric high anomaly was found close to the drilling sites. The anomaly pattern seems to indicate a connection with a

Fig. 3

Contour map
of radiometric
anomalies in
arbitrary units

Values between
60 and 90
in the surrounding
terrain

0 200 m

Fig. 4. Bottom profile of the northern trench.

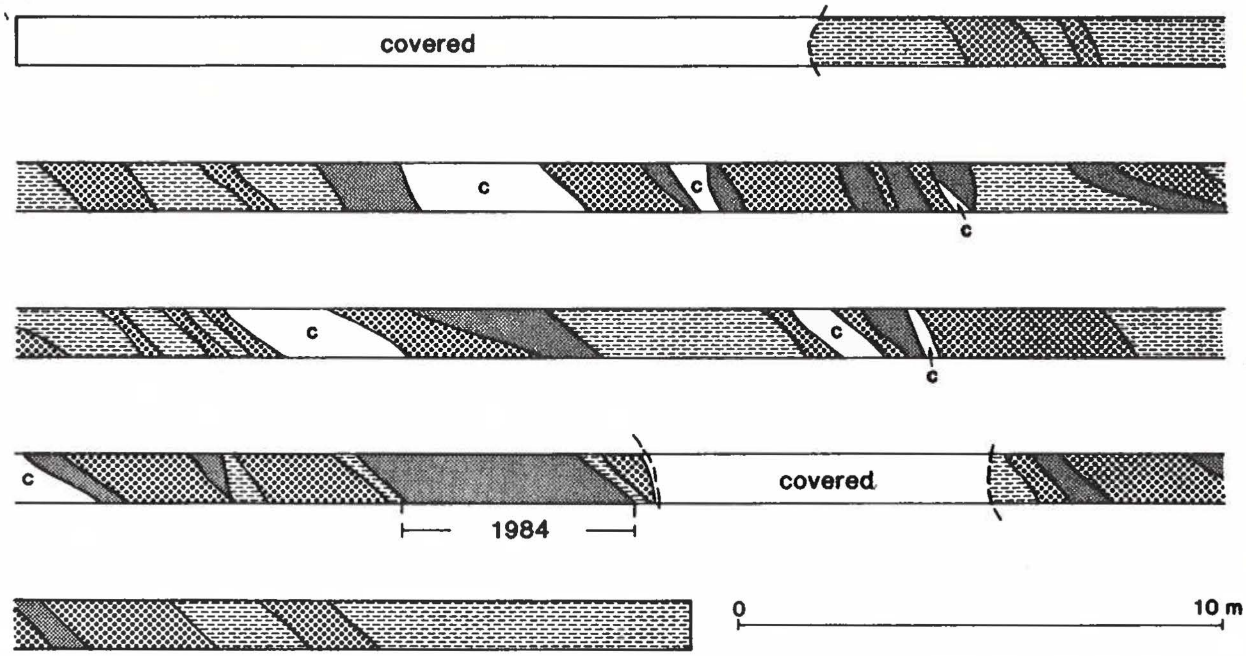
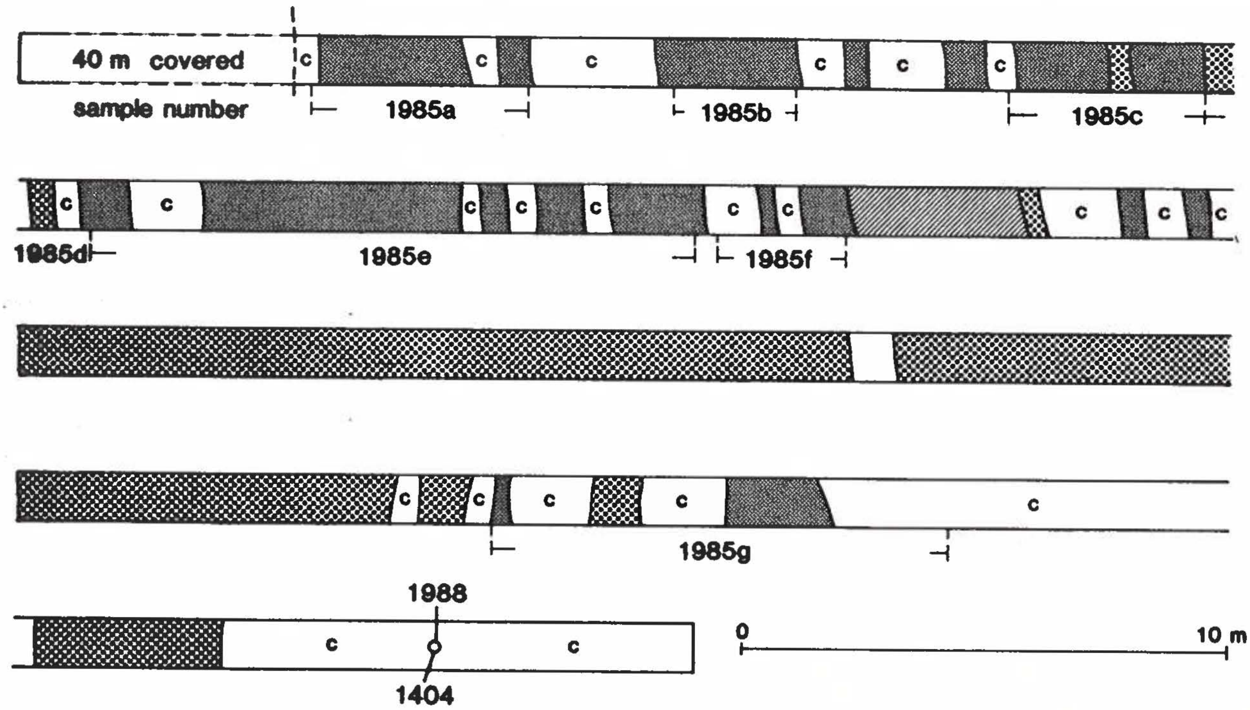


Fig. 5. Bottom profile of the southern trench.



Legend

cross-cutting fault, apparent from the geological map prepared by Emeleus (1964). No further study of the distribution of radioactivity have been undertaken. Morteani et al. (1986) analysed a number of pyrochlore samples from the deposit, which on average contained 1.3% UO_2 (max. 13.9% UO_2). ThO_2 was not analysed for.

Trenching

On the basis of the magnetic ground survey trenching was carried out on two separate magnetic anomalies, about 350 m apart. The northern trench measures about 110 metres, the southernmost one measures close to 140 metres in length.

The profiles of the succession of rock types found in the trenches is reproduced in Figures 4 and 5 respectively. A total of 8 chip samples (sample nos 1984, 1985 a-g) of magnetite-rich carbonatite were taken and analysed for the content of acid soluble total iron and phosphorus, as given in Table 4.

Table 4. The content of total iron and phosphorus of grab samples taken during trenching cf. figures 4 and 5

	Sample no.	% Fe	% P
Northern trench:	1984	46.7	0.07
Southern trench:	1985a	24.0	1.42
	1985b	44.0	1.54
	1985c	35.8	0.35
	1985d	36.7	0.40
	1985e	44.0	0.33
	1985f	42.5	0.44
	1985g	30.1	1.2

A sample of rather pure magnetite (sample no. 1404) was taken in the southern trench, cf. Fig. 5.

The result of chemical analyses of this sample and of a hand specimen of magnetite previously sent to the laboratories of the Swedish company, LKAB, is given in Table 5. Ba, Cr, Ni, Cu, Pb, Mo, F and Cl were under the detection limit in the wet chemical analysis methods used at that time in the laboratory of Kryolitselskabet Øresund.

Table 5. Chemical analyses of two different samples of magnetite, analysed at the laboratories of Kryolitselskabet Øresund (KØ) and of LKAB

	KØ 1404	LKAB
Fe_3O_4	83.89	80.35
Fe_2O_3	11.10	12.01
MnO	0.62	0.55
CaO	tr.	0.24
MgO	tr.	0.12
Al_2O_3	n.d.	0.94
SiO_2	1.19	1.95
TiO_2	0.89	0.94
V_2O_3	nil	tr.
P_2O_5	0.107	0.105
S	0.01	0.011
Loss on ignition	0.90	3.15
	98.707%	99.916%

Additionally a sample of carbonatite gangue (sample no. 1988) was taken in the southern trench. This sample was analysed only for total iron, Fe^{2+} and P with the following result: 8.2% total Fe, 0.77% Fe^{2+}, 0.43% P . It has been reported that this sample contains 1.5% barytes.

Drilling

In total 6 diamond drillings were carried out with a combined length of 750 metres. The position of the these inclined drill holes is shown in Figure 2.

A profile, perpendicular to the main strike of the magnetic anomaly alongside the olivine dolerite dyke, includes the diamond drill holes R, S and U.

Figure 6 shows a generalised cross-section of rock types observed along this profile. The same succession of rocks is found in drill hole T, as apparent from Fig. 10. The inclined drill holes X and V are positioned on the olivine dolerite dyke and intersect only magnetite carrying carbonatite.

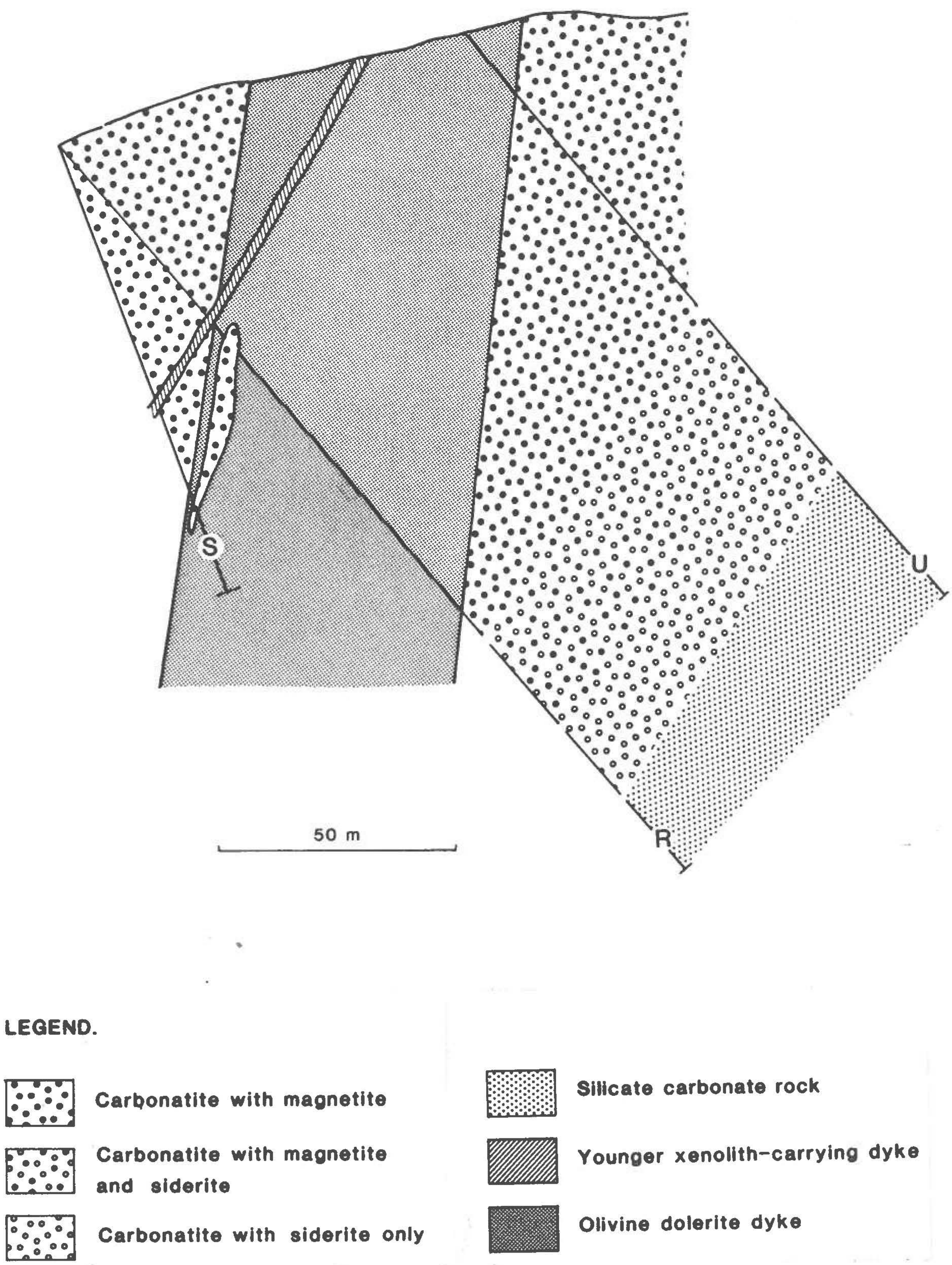


Fig. 6. Generalised representation of the intersected rock suite as observed in the diamond drill holes R, S, U. The orientation of this vertical profile is 123^{o} west of N.

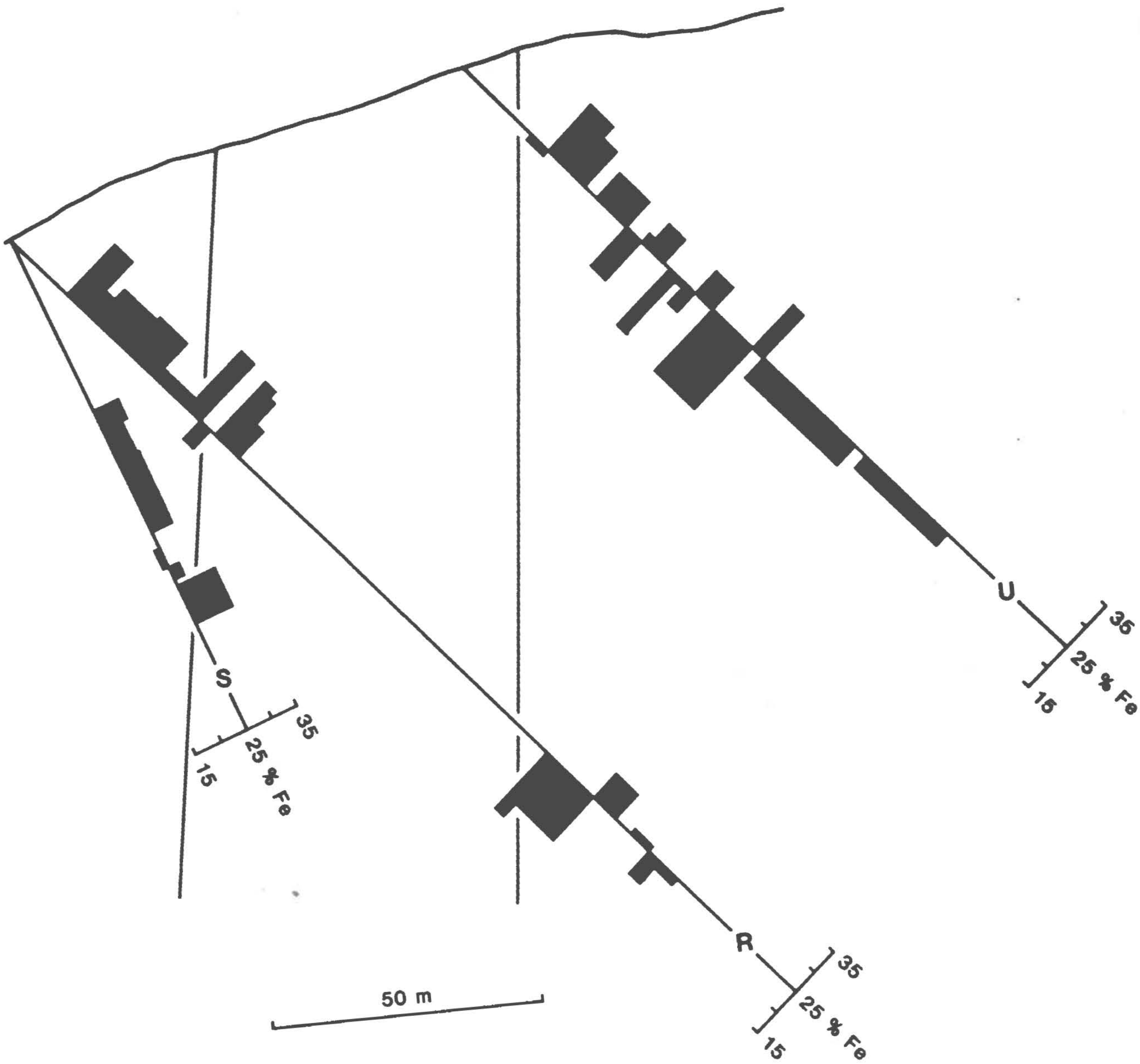


Fig. 7. The distribution of the total iron content in the diamond drill holes R, S and U.

In Table 6 the content of iron soluble in hydrochloric acid is given. The distribution of the total iron content is illustrated in Fig. 7 for the profile along the drill holes R, S, U, showing a pattern indicative of zonation.

Table 6. The content of iron in the diamond drill holes R, S, T, U, V, X

drill hole	depth in m from - to	% Fe	drill hole	depth in m from - to	% Fe
R	13.55- 17.73	37.1	U	16.94- 22.45	23.7
	17.73- 19.83	29.8		22.45- 27.26	35.7
	19.83- 27.82	32.8		27.39- 30.58	33.6
	27.82- 35.00	32.9		33.05- 41.32	31.2
	35.00- 42.71	27.3		41.32- 44.07	15.3
	42.71- 46.46	39.1		44.07- 46.22	27.1
	46.46- 48.64	19.4		46.56- 50.04	30.5
	50.28- 51.71	37.6		52.27- 53.70	11.1
	52.11- 52.90	36.3		54.09- 55.10	24.9
	54.10- 55.50	30.1		55.19- 58.29	20.5
	131.90-134.23	11.5		58.43- 61.56	29.6
	134.23-135.18	14.4		61.56- 72.36	10.2
	137.85-145.62	14.0		72.36- 74.00	35.3
	145.62-149.90	30.6		74.00- 97.82	19.6
	154.31-158.88	25.0		99.46-120.48	22.1
	158.88-160.47	19.2			
	160.47-166.14	23.3	V	15.23- 21.37	10.4
				21.37- 22.98	28.0
S	33.50- 37.36	30.0		23.22- 36.84	34.0
	37.36- 43.70	29.0		37.43- 38.75	26.9
	43.70- 57.27	29.3		38.75- 39.43	45.7
	60.48- 63.69	24.5		41.37- 44.45	34.0
	63.95- 67.23	27.2		45.31- 46.02	32.8
	68.27- 76.67	31.8		46.51- 47.13	26.5
				47.91- 59.36	27.2
T	10.25- 35.37	24.9		60.05- 61.04	29.9
	120.97-123.54	14.1			
	128.91-132.36	9.6	X	20.78- 28.66	11.0
	138.13-142.46	9.6		30.90- 36.66	13.5
	147.54-148.66	16.2		37.47- 42.33	17.0
	155.33-157.86	12.3			
	158.34-161.96	15.8			
	172.25-175.55	13.1			

The result of chemical analysis of the phosphorous content of a number of drill core samples is given in Table 7.

Table 7. The phosphorous content of selected samples from the diamond drill holes R, S, T, U, V, X

drill hole	depth in m from - to	% P
R	13.55- 17.73	0.50
	54.10- 55.50	0.58
	137.85-145.62	1.10
	200.62-200.68	0.82
S	33.50- 37.36	0.60
	68.27- 76.67	0.94
T	10.25- 35.37	1.15
	175.36-175.47	1.38
U	61.65- 72.36	0.98
	99.46-120.48	1.64
V	15.23- 21.37	1.13
	47.91- 59.36	0.51
X	37.47- 42.33	0.42

The distribution of apatite in diamond drill hole T is discussed in the following chapter on the mineral assemblage of the carbonatites.

Four drill core samples were selected for partial chemical analysis. The result is given in Table 8.

Table 8. Partial chemical analyses of a restricted number of samples from diamond drill holes R and S

drill hole	depth in m from - to	Fe	CaO	MnO %	TiO_2	S	P
R	13.55-17.73	37.1	11.5	2.8	0	0.60	0.50
	54.10-55.50	30.1	24.0	2.1	tr.	0.37	0.58
S	33.50-37.36	30.0	16.8	2.3	0	0.35	0.60
	68.27-76.67	31.8	20.4	2.7	tr.	0.63	0.94

From diamond drill hole T, two core samples were analysed for Mg, Sr, Ba, Y and La with the result given in Table 9 (see also Emeleus, 1964).

Table 9. Partial chemical analysis for Mg, Sr, B, Y and La: diamond drill hole T

depth m	Mg %	Sr %	Ba ppm	Y %	La %
121.8	0.15	2.63	500	0.06	0.2
127.7	0.40	2.63	200	0.03	0.1

No further chemical analytical data of core samples are available. However, the distribution of phosphorous and niobium in the rock suites of the Grønnedal-Ika complex has been specifically treated by Morteani et al. (1986). From this study the distribution frequency of niobium in the carbonatites has been derived, as illustrated in Fig. 8.

Further chemical and mineralogical data are discussed in the following chapter.

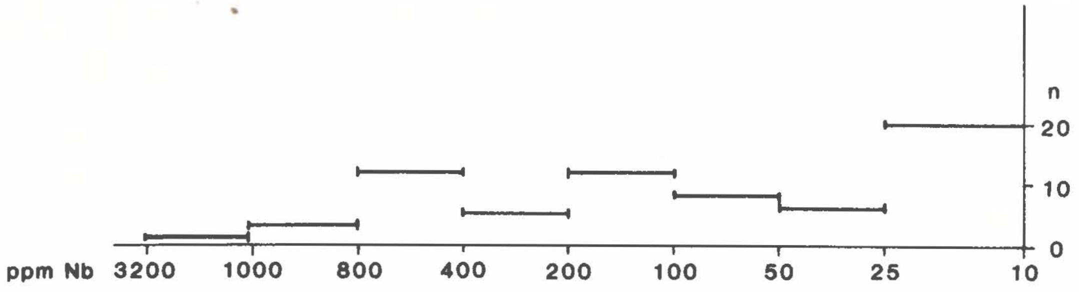


Fig. 8. The frequency distribution of niobium in 67 samples of carbonatite on a logarithmic scale for the indicated intervals in ppm, after Morteani et al. (1986).

Mineral assemblage of the carbonatites

The mineral composition of successive layers found within the carbonatite intrusive body may vary considerably. For that reason no reliable figures are available on the mineral distribution. A study has been made of the distribution of apatite versus that of magnetite in the carbonatites, without conclusive results, as discussed later.

Besides calcite and ferrodolomite, siderite is often a main constituent of the rocks. Other carbonates, found in subordinate amounts are strontianite and synchisite.

The compositional position of coexisting major carbonates in a triangular diagram with end members $CaCO_3$, $MgCO_3$ and $FeCO_3$ is reproduced in Figure 9. The results of two microprobe analyses of synchisite and one strontianite is given in Table 10.

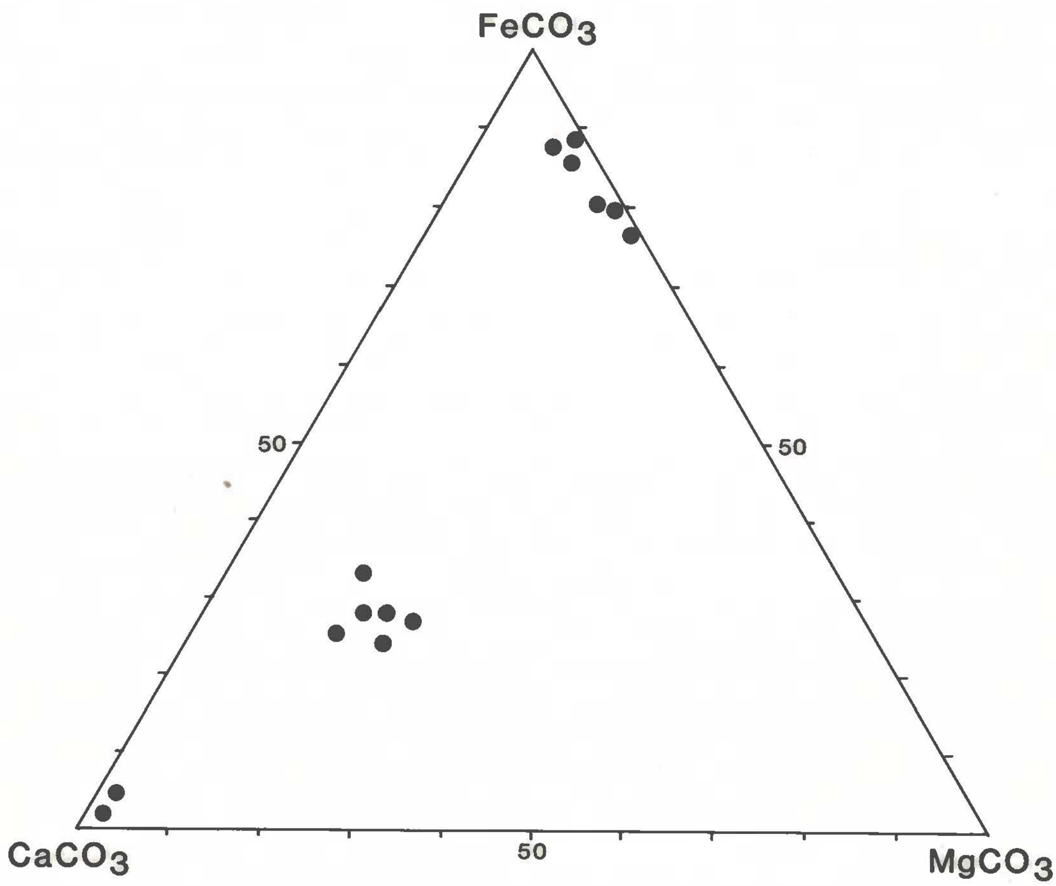


Fig. 9. Coexisting (Ca, Mg, Fe) carbonates in a number of selected samples of carbonatite.

Table 10. The composition of synchisite and strontianite after Morteani et al. (1986)

Mineral	synchisite	synchisite	strontianite
Sample no.	283413	283475	283402-1
		%	
La_2O_3	10.7	9.5	-
Ce_2O_3	22.7	28.1	0.1
Nd_2O_3	13.3	15.1	-
Fe_2O_3	-	0.1	-
SrO	-	0.3	61.3
CaO	16.8	12.8	9.6
P_2O_5	0.5	0.4	-
Sum	64.0	66.3	71.0
Rest CO_2	36.0	33.7	29.0

Magnetite is concentrated in massive layers and in stringers in Ca-carbonate. The chemical composition of magnetite is given in Table 5.

Magnetite-containing Ca-carbonatite merges into Fe-carbonatite, carrying siderite in the eastern extension of the prospected area.

Apatite is present in both Ca- and in Fe-carbonatite. The phosphorus content in drill hole samples has been given in Table 7. The distribution of apatite has been studied in diamond drill hole T, together with the distribution of magnetite by modal analysis in thin sections. In all 29 thin sections of rock samples taken at intervals of about 3 m have been studied. The result of this determination is given in Figure 10. It is obvious that apatite is not evenly distributed, neither in Ca-carbonatite, nor in Fe-carbonatite. Occasionally it is found in stringers.

Besides apatite, monazite has been observed. Microprobe analyses of two samples of apatite and two of monazite are presented in Table 11.

Fig. 10. The distribution of magnetite and apatite in diamond drill hole T, based on point counter determinations. Compare Fig. 6 for the lithology and Tables 6 and 7 for the content of total Fe and P.

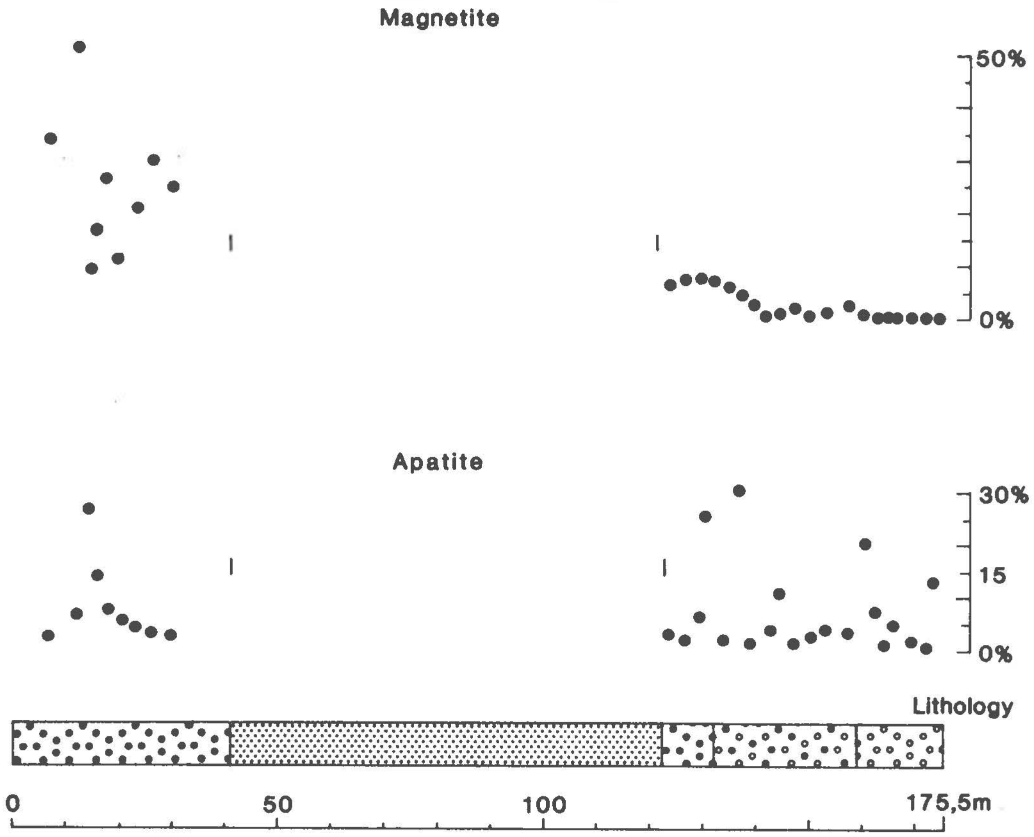


Table 11. The composition of apatite and monazite after Morteani et al. (1986)

Sample no.	apatite 283407	apatite 305737	monazite 283402(1)	monazite 283402(2)
% La_2O_3	0.2	0.1	15.2	12.5
Ce_2O_3	0.4	0.1	32.8	31.4
Nd_2O_3	0.3	0.1	14.1	16.5
Fe_2O_3	0.2	-	-	-
SrO	2.2	0.9	0.2	0.3
CaO	53.1	55.4	0.4	0.2
Na_2O	0.2	0.1	-	-
P_2O_5	43.1	45.0	32.7	33.8
Sum	99.7	101.7	95.4	94.6

The main carrier of the niobium content of the carbonatites is pyrochlore. Apart from pyrochlore, grains of fersmite and columbite have been identified, normally in contact with pyrochlore. On the basis of 90 microprobe analyses of pyrochlore Morteani et al. (1986) determined the average composition of pyrochlore to be as follows:

	TiO_2	Fe_2O_3	CaO	Na_2O	SrO	Ce_2O_3	Nb_2O_5	Ta_2O_5	others*	sum
%	1.9	1.3	13.9	4.9	2.2	1.0	62.8	3.0	0.8	93.0

* Others: P_2O_5, ZrO_2, La_2O_3, Nd_2O_3

Besides the main typical minerals mentioned above, the carbonatite contains subordinate quantities of sphalerite and pyrite.

Pyroxene, amphibole and mica may occur in neglible quantity. Further mineralogical and petrological details are given in Emeleus (1964) and Morteani et al. (1986).

Final remarks

Besides the carbonatite intrusion of the Grønnedal-Ika alkaline complex, a number of scattered carbonatite occurrences have been observed in Greenland, that vary widely in age and mode of occurrence. The main occurrences are listed below.

Name	Location	Age
Tupertalik	65.49°N, 51.84°W	2650 Ma
Singertât	63.25°N, 42.00°W	2680 Ma
Grønnedal-Ika	61.23°N, 48.07°W	1299 Ma
Sarfartôq	66.50°N, 51.25°W	600 Ma
Qaqarssuk	65.38°N, 51.68°W	173 Ma

The two last named, Sarfartôq and Qaqarssuk, have been extensively explored.

In a number of cases the carbonatites are related to the widespread occurrences of kimberlite, lamproite and ultramafic lamprophyre in Greenland, as compiled by Larsen (1991).

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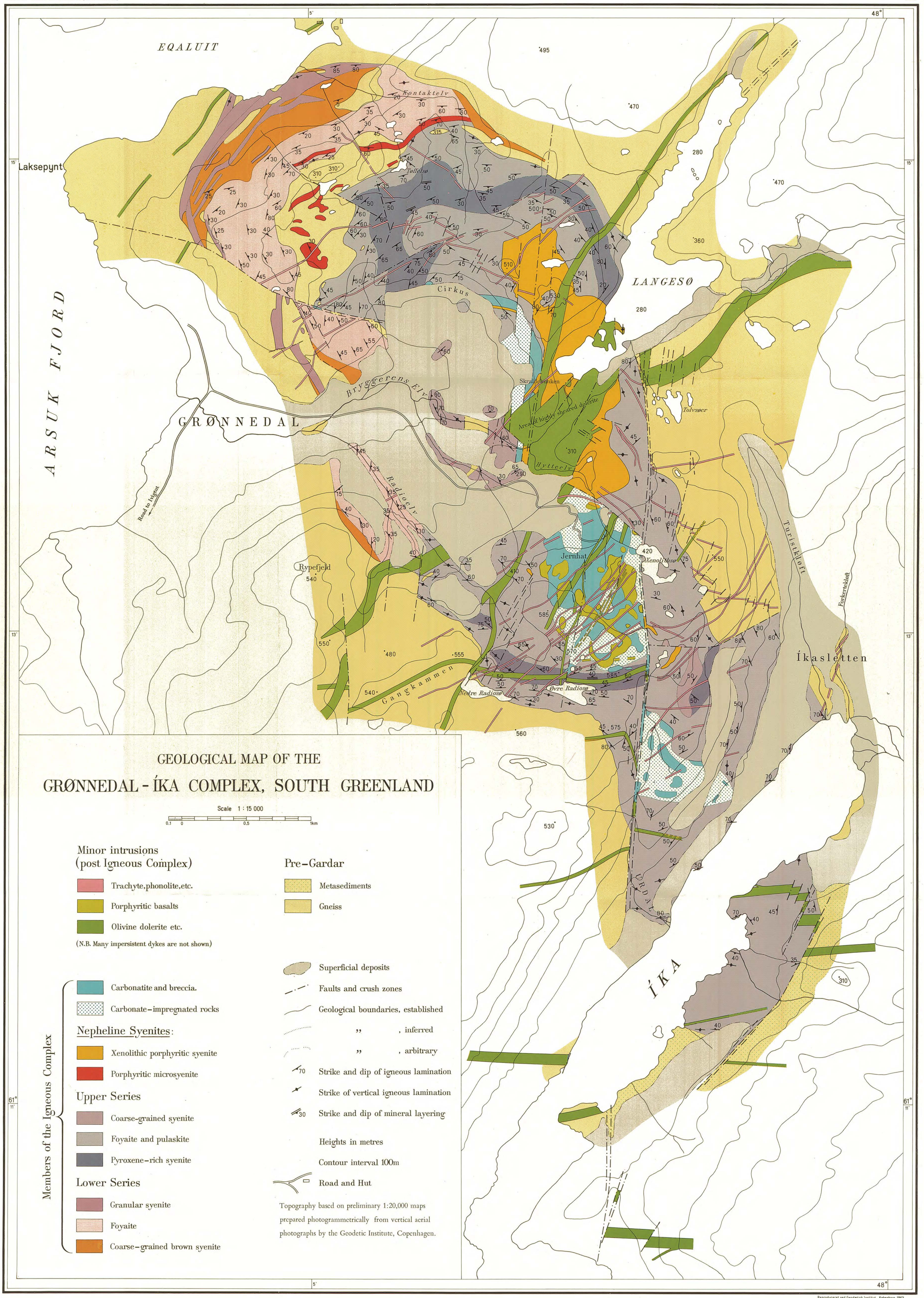

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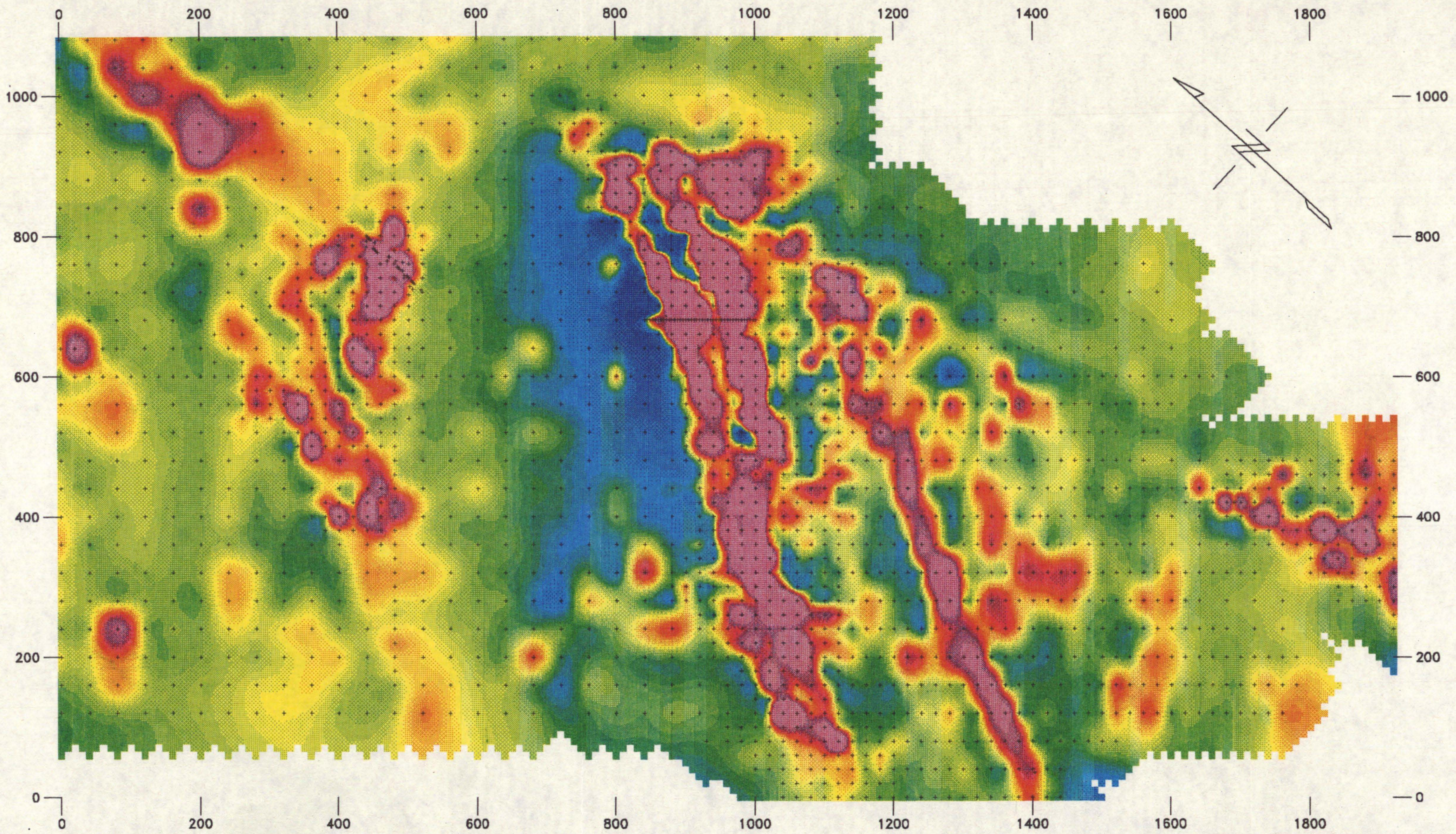

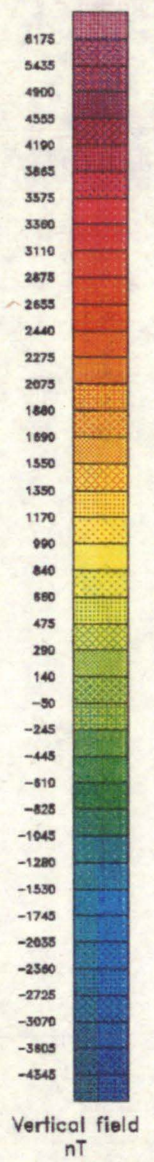

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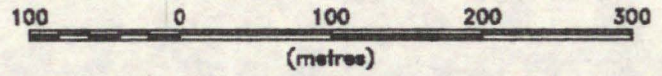

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