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PRECAMBRIAN ORGANISMS AND THE ISOTOPIC COMPOSITION OF ORGANIC REMAINS IN THE KETILIDIAN OF SOUTH-WEST GREENLAND

BY

E. BONDESEN
K. RAUNSGAARD PEDERSEN
AND
O. JØRGENSEN

WITH 8 FIGURES AND 5 TABLES IN THE TEXT
AND 13 PLATES

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

The geological setting of organic remnants from well preserved Ketilidian rocks of SW Greenland is presented. The absolute age (2000 ? m.y.) of the rocks is discussed and compared to that of other regions.

Many types of organic remnants have been found in these low-metamorphic rocks. Most of the organic remnants are microscopic globules and fragments with cell-like structures.

The type which is best preserved is a complex globular structure on about $^1/_2$ mm in diameter. This structure is established as a new monotypic form genus *Vallenia erlingi* RAUNSGAARD PEDERSEN n. gen. et sp.

Stromatolithes and other macro-structures of possible organic origin are also found.

A coal-graphite layer indicates that large-scale accumulation of organic matter has taken place.

The organic remnants are so well preserved that it has been possible to extract small amounts of paraffines (n-C_{11} to n-C_{31} with maximum about n-C_{18} to n-C_{20}) and other organic compounds.

The carbon-isotope composition from carbonaceous matter and carbonates from a number of samples has been determined. The analytical procedure is described.

The result of this investigation shows δ C^{13}-values which indicate that the carbonaceous material is probably of organic origin.

CONTENTS

INTRODUCTION

This paper contributes to the discoveries of organisms and traces of life in the "middle Precambrian" (2500–1700 m. y.) (GOLDICH *et al.* 1961) which have been recorded in the last few years (TYLER and BARGHOORN 1954, BARGHOORN and TYLER 1965). The aim of the paper is to present the geological setting of organic remnants found in the Ketilidian rocks of SW Greenland together with a provisional description and investigation of the organic matter. The paper falls in three parts concerning:

1) the geological conditions (E. B.)
2) the palaeontological relations (K. R. P.) and
3) an investigation of the abundance of carbon isotopes (O. J.).

Further work on the material collected is in progress.

During the mapping by the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse = GGU) in the Ivigtut region in South-West Greenland (61°–62° N, 48°–49° W) in the years 1955 to 1960, extensive areas of low-metamorphic sediments and volcanics were discovered, in addition to the already known occurrences of the Arsuk and Sermilik groups (WEGMANN 1938). These remnants of old supracrustals are regarded as representing the geosynclinal deposits of the Precambrian Ketilidian fold belt. One of the areas discovered in a provisional photo-geological survey is situated along the border of the Inland Ice between Sermiligârssuk fjord and Arsuk Fjord (fig. 1). This area was designated "Eastern Belt" in the general synthesis of the geology of the Ivigtut region (BERTHELSEN 1960); it was later named Grænseland (= border land) when it became the object of mapping by one of the authors (BONDESEN 1962, and in prep.). In 1964 the neighbouring area to the north, the Midternæs area, was mapped by A. K. HIGGINS. In 1965 he collected new material from Grænseland and found additional organic material in the Midternæs area.

The Grænseland area, which is difficult to reach without the use of helicopters, is situated at an altitude of 700 to 1000 m, traversed by strong melt-water torrents and bounded by glaciers. The area proved to consist of unusually well preserved sediments and volcanics; in some areas these were moderately to strongly folded and thrusted, in other areas autochthonous and hardly deformed. The metamorphism is as a whole very feeble in the lower greenschist facies. The sediments rest unconformably on basement gneisses.

During the mapping several observations pointing towards the possible existence of organic remnants were made. Later examinations of thin sections showed structures which, in addition to the megascopic observations, confirmed that life had existed at the time of deposition of the Ketilidian sediments.

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To mag. scient. Ole Larsen thanks are due for great help and advice in the isotopic work and also for assistance in the field together with mag. scient. John Hansen, mag. scient. Niels Abrahamsen and Mrs Kirsten Bondesen. Mr P. Nielsen, Mineralogisk-Geologisk Institut, University of Copenhagen, who prepared some of the photographs, Mr G. Ritnagel, GGU, who made the numerous thin sections, Mrs B. Larsen, Geologisk Institut, University of Aarhus, who undertook a large proportion of the laboratory work, and Mrs E. Bækgaard, who typed the manuscript, are heartily thanked.

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I. GEOLOGICAL SETTING

Outline of regional geology

The general geological development of the whole of South-West Greenland has for the last decade been the object of extensive research by the members of the GGU staff. Reviews of the general geology have been given by BERTHELSEN (1960, 1961) and ALLAART (1964). The broad chronological development is well established although some discussion continues. A discussion of the isotopic age determinations and their geological setting, and comparisons with other Precambrian areas, has recently been presented by BRIDGWATER (1965).

The position of the Grænseland area is shown in fig. 1. It forms a part of the belt of supracrustal rocks which can be followed from Sermiligârssuk fjord to Kobberminebugt and the Arsuk Ø region. On Midternæs in Sermiligârssuk fjord and in Grænseland the supracrustals rest unconformably on the basement gneisses, whereas the border elsewhere is tectonic or obscured by granitisation or migmatisation (WINDLEY *et al.* 1966). Along Sermiligârssuk fjord a belt of older supracrustals—the Tartoq Group (HIGGINS and BONDESEN 1966)—can be followed from east to west.

Further south in the area shown in fig. 1, Ketilidian supracrustals are found in the southern part of Kobberminebugt (WATTERSON 1965). In the areas of "the Julianehaab granite" inclusions of metasediments which are probably derived from Ketilidian supracrustals are found (ALLAART 1964). In the Sermilik area 225 km south-south-east of Grænseland thick well preserved sediments of the Ketilidian Sermilik group are again found (WEGMANN 1938, ESCHER 1966).

The general chronology of the geological development of South Greenland as employed by GGU members is given in table I. The absolute ages are taken from BRIDGWATER (1965) to which the reader is referred for discussion.

Of all the occurrences of Ketilidian supracrustals the Grænseland and the Midternæs areas are the best preserved and show the most complete sequence, and it is only in these areas that definite organic remnants have been found. However, graphitic schists and gneisses have been observed in several other regions.

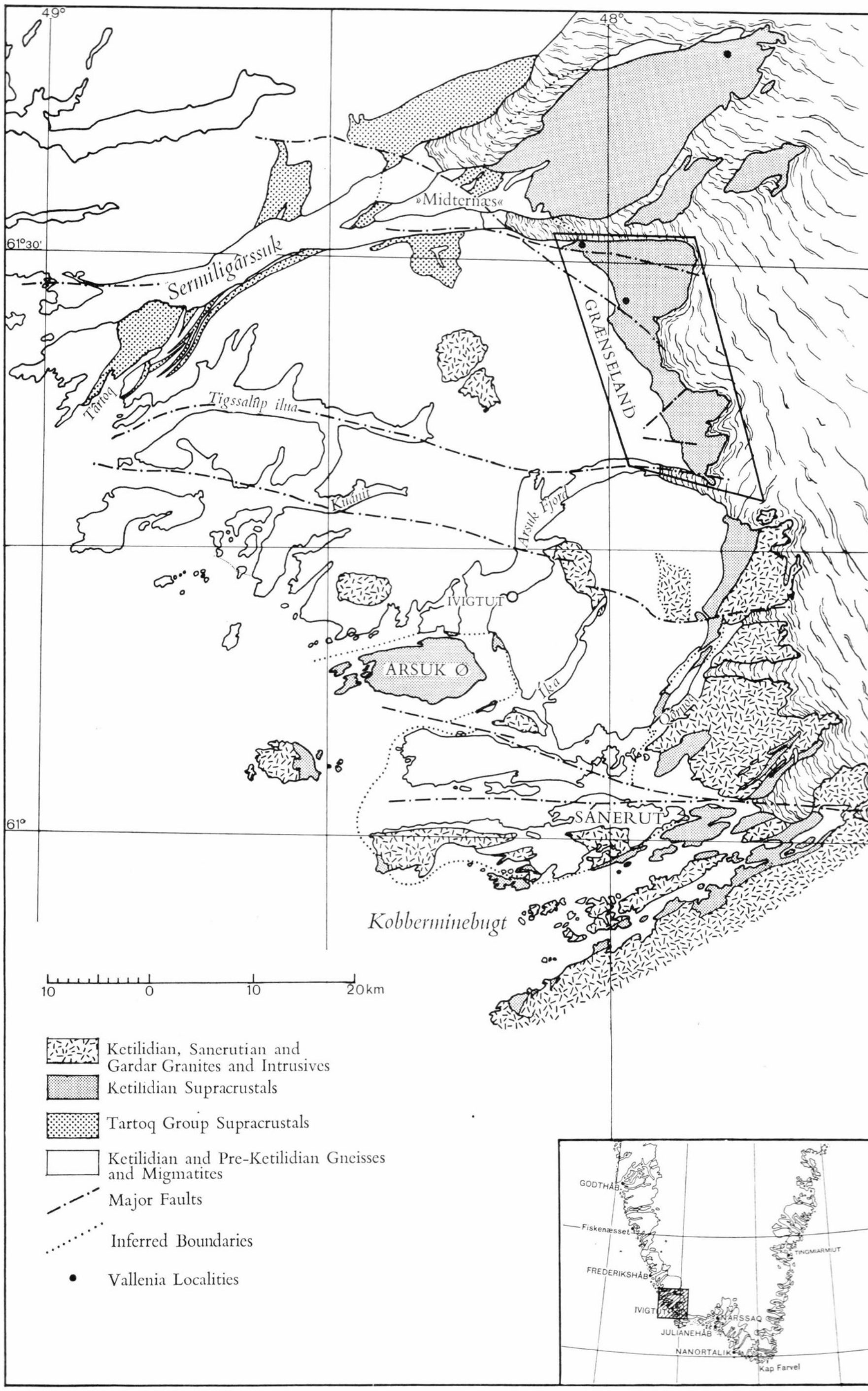
49°
48°
61°30'
61°
»Midternæs«
Sermiligârssuk
GRÆNSELAND
Tartoq
Tigssalûp ilua
Kuânit
Arsuk Fjord
IVIGTUT
ARSUK Ø
Ika
SÂNERUT
Kobberminebugt
10 0 10 20km
Ketilidian, Sanerutian and Gardar Granites and Intrusives
Ketilidian Supracrustals
Tartoq Group Supracrustals
Ketilidian and Pre-Ketilidian Gneisses and Migmatites
Major Faults
Inferred Boundaries
Vallenia Localities
GODTHÅB
Fiskenæsset
FREDERIKSHÅB
IVIGTUT
NARSSAQ
JULIANEHÅB
NANORTALIK
TINGMIARMIUT
Kap Farvel

Fig. 1.

Table I.

Cretaceous–Tertiary	dykes
	dykes and faulting
Gardar (1020–1450 m.y.)	major alkaline intrusions
	continental sandstones and lavas
	basic dykes
Sanerutian (1650–1500 m.y.)	reactivation, faulting
	plutonic activity
	basic dykes
Ketilidian (? 1700 m.y.?)	folding, metamorphism, granitisation
(? 2000 m.y.?)	sedimentation and lava extrusion
	basic dykes
	folding, granitisation, migmatisation.
	sedimentation and lava extrusion (Tartoq Group).

No fossiliferous beds older than Quaternary have been found in South-West Greenland except that Bøgvad (1936) has reported an erratic with cryptozoon-like structures.

Local stratigraphy and geology

The varied stratigraphical sequence preserved in Grænseland has been outlined by Berthelsen (*in* Rankama 1965) and described in detail by Bondesen (1962 and in prep.). The stratigraphical sequence including approximate thicknesses is shown in table II.

The Ketilidian is here divided into a lower sedimentary group—the Vallen Group—and an upper, mainly volcanic, group—the Sortis Group. The distribution of the different stratigraphical units is shown in fig. 2.

The Vallen Group

The sedimentation began in small scattered basins and in small depressions on a probably peneplained surface in which residual arkosic gravel and conglomerates of badly sorted, although well rounded, material accumulated.

The Lower Zig Zag Land Formation is developed south of lake Vallen in a sedimentary basin; here deposition of calcareous dolomites led to a deep carbonatisation of the gneiss surface and the residual deposits. Large chert lenses are believed to have formed as a result of the carbonatisation. Varved shales and more dolomites follow and the formation

Table II. *Stratigraphy of the Ketilidian supracrustal rocks of Grænseland.*

Group	Formation		Unit	m
(top undefined)				
Sortis Group (>2500 m)	Rendesten Formation (>1500 m)	upper	Undivided sequence of varved slates, dark brown slates, quartzitic slabs and bedded greywackes with abundant sills and intrusions of leuco- and melanogabbro	~1000
		lower	Pyroclastics and dark brown slates including gabbro sills	> 500
			Black and dark brown slates including dolomite and tectonites	0–50
	— structural discordance —			
	Foselv Formation (1000 m)		Upper Pillow Member (pillow lavas with gabbro sills and pyroclastics)	~ 700
			Carbonaceous Member (coal and graphite, carbonaceous shales)	~ 1
			Lower Pillow Member (pillow lavas with gabbro sills)	~ 300
Vallen Group (~1700 m)	Grænsesø Formation (150–600 m)		Pyrite schists	1–20
			(persistent sills)	20–500
			Black and whitish chert	2–8
			Dolomite with *Vallenia*	~ 2
			Dolomites and carbonaceous shales	20–60
			Black carbonaceous shales	10–30
	— structural discordance —			
	Blåis Formation (>800 m)		Graded greywackes (>400 m)	
			Banded greywackes (0–300 m)	
			Mixed greywacke, semipelites (~200 m)	
			Black pelites (including "wild flysch" unit (0–30 m)) (100–400 m)	
			Lower greywackes (including bands of dolomites at the top (0–250 m)	
	Zig Zag Land Formation (100–275 m)	upper	Dolomite Shale Member (including two dolomite bands at the base)	50–150
			Banded Quartzite Member	10–140
			Ore Conglomerate Member	1–12
		lower	Rusty Dolomite Member	0–8
			Varved Shale Member	~20
			Lower Dolomite Member (including talc quartzite and chert lenses)	0–30
			Residual gravel, conglomerates and arkose carbonatised with chert lenses	0–10
	unconformity			
	pre-Ketilidian basement (nebulitic gneisses, banded biotite gneisses and banded amphibolites)			

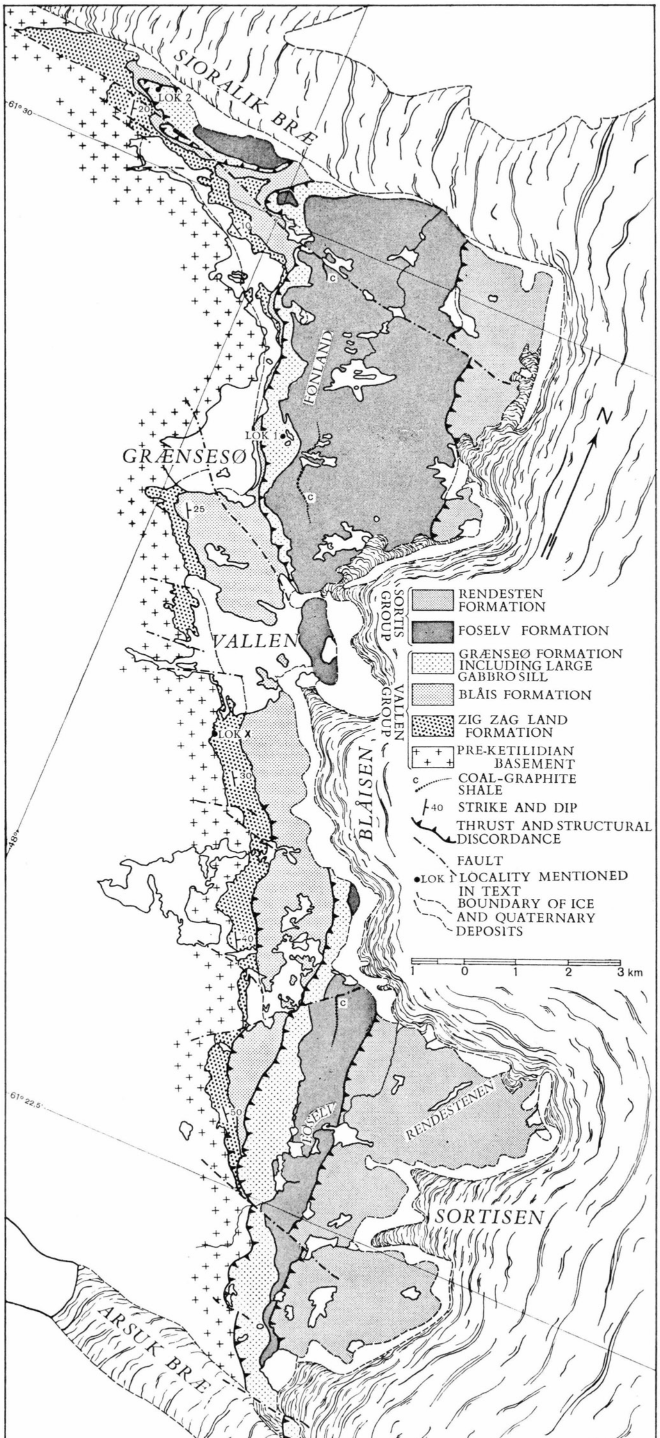
SIORALIK BRÆ
LOK 2
61° 30'
FONLAND
LOK 1
GRÆNSESØ
VALLEN
BLÅISEN
N
SORTIS GROUP
VALLEN GROUP
RENDESTEN FORMATION
FOSELV FORMATION
GRÆNSEØ FORMATION INCLUDING LARGE GABBRO SILL
BLÅIS FORMATION
ZIG ZAG LAND FORMATION
PRE-KETILIDIAN BASEMENT
COAL-GRAPHITE SHALE
STRIKE AND DIP
THRUST AND STRUCTURAL DISCORDANCE
FAULT
LOCALITY MENTIONED IN TEXT
BOUNDARY OF ICE AND QUATERNARY DEPOSITS
1 0 1 2 3 km
LOK X
48°
61° 22.5'
FOSELV
RENDESTENEN
SORTISEN
ARSUK BRÆ

Fig. 2.

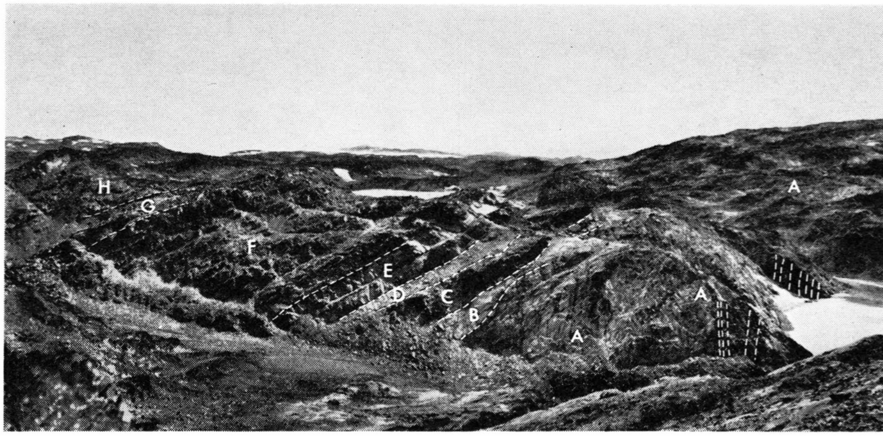

Fig. 3. Pre-Ketilidian gneisses (A) unconformably overlain by the Zig Zag Land Formation with dolomites (B), varved shales (C), dolomites (D), conglomerate (E), quartzites (F), dolomitic shales (G) and greywackes (H). The succession shown in the photograph is practically unaffected by tectonisation. The pre-Ketilidian structure is marked by a subvertical amphibolite band at the lake shore to the right in the photograph.

terminates in coarse clastic material and black sand deposits. Sun cracks in the varved shales show that the basin was very shallow and temporarily dry. The carbonatisation of the basement gneisses, the varved shales, and the further stratigraphic development on top of the Lower Zig Zag Land Formation, suggest that the basin was shallow, closed and probably also relatively limited, perhaps a lake. In the Lower Zig Zag Land Formation some macro-spherical structures (p. 28) of possible organic origin have been found (pl. 12, fig. 2).

The Upper Zig Zag Land Formation has at its base a 1–12 m thick conglomerate of quartzite boulders and cobbles in a matrix of black sand, mainly magnetite and quartz. The conglomerate transgresses the gneisses north of lake Vallen where the Lower Zig Zag Land Formation is lacking. On top of this conglomerate a varied sequence of quartzites with small graded conglomerates, slumps, current bedding, sun cracks and ripple marks occurs. The succession shows fine banding and laminae with considerable variation in grain-size from silt to coarse sand. The basin structure is well demonstrated by this member which, from a thickness of 10 m on the newly transgressed basement area north of lake Vallen, increases southwards to a thickness of more than 100 m. In the northern part of the area another basin structure with more than 140 m of quartzite is found, and in the Midternæs area the same basin again appears to shallow (Higgins and Bondesen 1966). These basin structures seem to persist far up in the Vallen Group and possibly also into the Sortis Group.

In their upper part the quartzites are sometimes black, and owe their colour to black chert grains and pebbles, which contain carbonaceous material with organic microstructures.

On top of the Zig Zag Land quartzites banded dolomites in two distinct layers form excellent marker horizons throughout the whole area. These are succeeded by an up to 140 m thick sequence of greenish-grey dolomitic shales, which shows more even sedimentation throughout the area. In these shales remnants of micro-organisms have been found.

The Blåis Formation forms a considerable series of deposits characterized by pelites and coarse greywackes. The fine clastic sedimentation characteristic of the Upper Zig Zag Land Formation continues through the major part of the region, except for the southern part where a thick series of graded greywackes with thin dolomite bands is found. In the Midternæs area a similar development is found. The pelitic sediments, which may have fine laminae and a variety of sedimentary structures, are in their upper part intermingled with coarse clastic material, and they are overlain by a thick series of rhythmically graded greywackes in units up to three metres thick, with pebbly bases and pelitic tops. Boulder conglomerates occur in addition to scattered pebbles and fragments of shales. The graded greywackes are thought to be turbidites deposited in connection with fault movements in the near vicinity.

Evidence of tectonic movements during sedimentation has been found in the lower pelitic part of the Blåis Formation in the form of a "wild flysch" unit just south of Grænsesø. This unit, which thins out towards the south, contains boulders and fragments of all the sedimentary members which underlie it, and the basement gneisses. The movement of a major fault appears to have been in the order of at least 200 m vertically prior to the deposition of the unit. The fault, which possibly has been responsible for the "wild flysch" unit, can be mapped throughout the basement and later displaced the sediments and Gardar dykes up to 1500 m sinistrally.

Traces of definite organic material have not been found in the Blåis Formation. However, carbonaceous material is present in the pelitic part. Pebbles of a black cherty quartzite containing carbonaceous matter have been observed.

The Grænsesø Formation forms the lower part of an extensive thrust sheet, mainly containing the volcanics of the Sortis Group. Conditions in the southern part of Grænsesø suggest continued deposition from the graded greywackes to the dark graphitic pelites of the Lower Grænsesø Formation.

The sedimentation of the Grænsesø Formation is characterized by a rapid change from black pelites to dolomites and dark cherty quartzites.

This cycle seems to be repeated in large as well as small units. However, the tectonic conditions in the lower part of the thrust sheet are such that establishment of a detailed stratigraphy is difficult.

The Grænsesø Formation is intruded by a large basic sill on top of which, in the southern part of the area, pyritic schists occur. In the northern part the upper part of the formation is characterized by cherty quartzites. The thickness of the formation varies considerably (see table II). The general appearance of the Grænsesø Formation is shown in pl. 13.

It is in the Grænsesø Formation that most of the organic remnants have been found. Globular structures (*Vallenia* p. 20) are found in the northern part of the area in a greyish-black dolomite near the top of the formation. The same rock at a similar stratigraphic position, and therefore possibly the same level, has been found north of Grænsesø and in the Midternæs region. Stromatolithic calcareous rocks (p. 28) are probably in situ in this formation, and graphitic and strongly carbonaceous shales have also been found. All the best samples described are from south-east of Grænsesø, where the formation reaches its greatest thickness.

The Sortis Group

This group is dominated by volcanics, mainly pillow lavas and pyroclastic deposits, and is intruded by numerous sills. Sediments are found, especially in the upper part of the group. The group is made up of two formations separated by a large thrust.

The Foselv Formation consists mainly of pillow lavas. Pyroclastics occur locally. Two important features are a coal layer in the Fønland region and a thin layer of graphitic schists in the southern part of the area which together form the Carbonaceous Member. They are found at what is thought to be the same stratigraphic level and may be the same horizon. The coal layer in the Fønland region varies in thickness from a few cm to about 1 m and can be followed for about 2 km. Locally the coal has been thickened tectonically or by the influence of load from the overlying pillow lavas. Migration also took place under the regional tectonic movements and the coal has been encountered concentrated in a vertical fault zone.

Black carbonates and quartzitic nodules (probably chert) have been found associated with the coal.

The coal has been subjected to later pyrometamorphism in contact with a large Gardar dolerite dyke which has resulted in strong graphitisation.

The coal has been analysed by statsgeolog W. Christensen of the Geological Survey of Denmark. The coal was not flammable without addition of easily flammable material. The results of the analysis are set out in table III.

Table III. *Analysis and heating values of coal from Foselv Formation.*

GGU Sample No.	20909	20910	20911	20912
H_2O % wgt.	0.74	1.03	1.02	1.11
ash – –	27.3	10.7	15.1	11.3
S – –	–	0.38	0.28	0.27
ash % of dry material	27.5	10.8	15.3	11.4
S – – – –	–	0.38	0.28	0.27
K-cal/kg	5521	6713	6436	6602
K-cal/kg dry	5562	6783	6502	6676
K-cal/kg ($\div H_2O$ and ash)	7668	7602	7671	7536

The Rendesten Formation differs from the Foselv Formation in its lack of pillow lavas. It consists of thick piles of pyroclastics interbedded with pelites and graded greywackes, and intruded by large intrusive masses. The pyroclastic deposits range from fine tuffs to coarse scoriae with volcanic bombs. No certain sub-aerial lava flows have been observed, but large conformable bodies occur, some of which are very fine-grained and thus might be lavas; but as no structures indicating flow have been found, and several of these units display intrusive relations, most of them are regarded as sills.

The greywackes differ from those of the Blåis Formation in that grading is less pronounced. However, strongly banded successions occur as well as finely laminated pelites. The upper part, which is without pyroclastics, contains fine varved shales with interbedded pebble layers, and pelitic shales with quartzitic slabs also occur. Dolomites are found only at the base of the Rendesten Formation.

As the Rendesten Formation is comparatively strongly deformed and disturbed by gabbro intrusions and numerous smaller thrusts, the detailed stratigraphy is unknown. Several of the pelitic rocks are carbonaceous, but as yet they have not yielded any definite organic structures.

State of preservation of the rocks

As previously mentioned the Grænseland and Midternæs supracrustals are the best preserved and most complete Ketilidian succession known in South-West Greenland, although they have been subjected to mild metamorphism and exhibit evidence of at least two phases of deformation. However, the deformations are restricted to certain zones and stratigraphical levels, and several parts of the succession, to judge from preserved sedimentary structures and textures, are virtually undisturbed.

The first deformation caused folding and thrusting in restricted stratigraphic levels. Thus the dolomitic shales of the Upper Zig Zag Land Formation were folded and a main thrust was initiated at the base of the Grænsesø Formation; possibly some of the thrusts at higher levels were also produced during this phase of deformation. The axial planes of the overturned to isoclinal folds dip NE, and the fold axes plunge in general to the SE.

The second deformation led to the formation of asymmetric to overturned folds with NNW dipping axial planes and ENE plunging axes which deform the first folds. The size of the folds and the intensity of the deformation varies with the lithology and the location with respect to the major basin structures.

The metamorphism corresponds to greenschist facies of Barrovian facies series (Winkler 1965). The sediments show microscopially the development of muscovite, chlorites and in the southern part of the region biotite. All the igneous rocks have been reconstituted as greenstones of actinolite and chlorite, but usually, where deformation is lacking, their original texture is preserved. Generally the metamorphism is strongest towards the south, where the deformation also is strongest (Windley *et al.* 1966).

The deformations and the metamorphism are thought to be of Ketilidian age; late dyking as well as faulting is also present, but may include what corresponds to the Sanerutian plutonic episode. Further intrusion of dolerite, trachyte and lamprophyre dykes as well as faulting, occurred during the Gardar period.

Absolute age of the Grænseland rocks

No isotopic age dates are at present available from Grænseland rocks or from other Ketilidian supracrustals, nor has the Ketilidian metamorphism been dated from South Greenland. The nearest isotopically dated rock, which is also one of the oldest dates known from South Greenland, is the Tigssaluk granite situated 18 km west of Vallen. This has been dated at 1615 ± 40 m.y., a Rb/Sr age of biotite (Bridgwater 1965). This age is related to the Sanerutian (Berthelsen 1960), which is a period of reactivation, metamorphism and some deformation, which also affected Ketilidian rocks. The oldest Sanerutian age is 1645 ± 50 m.y.

BRIDGWATER suggested that Ketilidian plutonism took place from about 2000 to 1700 m.y. ago in a comparison of isotopic ages from other parts of Greenland and he compared the Ketilidian-Sanerutian and Gardar of South Greenland to the large scale chelogenic cycles of other continents (Svecofennidian of the Baltic shield and similar development in the Canadian shield). The Ketilidian sedimentation which in Greenland began this cycle may thus have had an age as old as 2000 m.y.

The relationships between Sanerutian and Ketilidian are still under discussion, and there is no evidence as to the importance of the gap between these two episodes of plutonism. One of the authors (BONDESEN 1962, and in prep.) has suggested a close relationship in time, as the activities are closely connected in space, and the age of the Ketilidian might therefore be younger than that suggested by BRIDGWATER. However, future isotopic age datings in progress at the Geological Institute in Copenhagen may yield ages which will better define the age of the Grænseland Ketilidian rocks.

The sediments of Grænseland are of geosynclinal type, as are all other Ketilidian sediments in South Greenland. Although on a world-wide scale geosynclinal sedimentation may have been diachronous, it nevertheless presumably took place in the same broad time intervals, just as orogenic activity and plutonism are also grouped round time intervals (GASTIL 1960). A comparison with similar sediments of similar ages on other continents therefore seems of value, from the point of view that similar physico-chemical and biological conditions might have existed.

Organic remnants of a supposed age similar to the Ketilidian have been found on the Canadian shield in the Labrador trough (Hudsonian 1800–1600 m.y.) in regions showing a similar sedimentological development (STINCHCOMB *et al.* 1965). In the Michigan—Superior region (Pinokean 1750–1650 m.y.) a variety of organisms have been found in the Gunflint iron formation (TYLER and BARGHOORN 1954, BARGHOORN and TYLER 1965) and an anthracite coal which occurs in the Michigamme formation (Upper Huronian) (TYLER *et al.* 1957). The sedimentological development here differs from the Ketilidian in that thick iron formations are widespread (JAMES 1958). However, Grænseland is until now the only area of Ketilidian supracrustals where "iron formations" of the Superior type (LEPP and GOLDICH 1964) have been found. While chert is an important feature in connection with the iron formations of the Superior region, chert in Grænseland seems to be restricted to the Lower Zig Zag Land and Grænsesø Formations as a primary sediment, but is widespread as a detrital component in greywackes and conglomerates.

Attention is drawn to the Jatulian of the Karelidian fold belt (1800 m.y.) on the Baltic shield (Simonen 1960, Kharitonov 1963) where organic remnants have been found and the Onega schists contain "Shungite", which is a carbonaceous sediment comparable to the Grænseland coal.

From the Transvaal system (2100–1800 m.y.) (Nicolaysen 1962) coal and massive graphites have been reported in addition to widely destributed organic remnants (Schweigart 1965). The South American Minas Gerais province (Rio das Belhas Series) provides similar ages and conditions (Herz *et al.* 1961).

II. THE ORGANIC REMNANTS

Method of preparation

In the Ketilidian supracrustal sediments of Grænseland many types of organic structures have been discovered. Most of the structures are microscopic, but some macro-structures are also found.

In this paper some of the most characteristic types of organic structures are described. In addition to those described many very small structures, most of them under 10 micron in diameter, occur in the sediments. The investigation of these, which involves practical difficulties, is not yet complete.

The structures have been studied in thin sections and in preparations of isolated fragments.

The organic material from many samples of dolomite, quartzite and carbonaceous rocks from different stratigraphic levels in the Grænseland sequence was isolated by treatment with hydrochloric acid ($10\,^0/_0$) for 1 to 3 hours and in hydrofluoric acid ($40\,^0/_0$) for two to three days. The residuum was then mounted in silicone oil ($n = 1.403$). The coaly and graphitic samples have been slightly oxidized in Schultze solution ($HNO_3 + KClO_3$).

In some samples the organic material has been separated from the disintegrated rock by means of heavy liquid separation ($Zn\,Br_2$ with a sp. gr. about 2.0).

It is difficult, or impossible, to avoid a little dust contamination from the laboratory. Examination of the structures *in situ* in thin sections will of course avoid the problem of contamination. But the small structures are best analysed when isolated from the rock and the fact that it is possible to isolate the structures by dissolving the minerals of the rocks is further evidence for their organic origin.

To check on possible contamination, laboratory dust may be allowed to collect and be analysed.

The organic-like structures distinguisted are grouped and described in the following sections:

Globular structures,
carbonaceous fragments with cell-like structures,
microscopic globules (spore-like bodies),
stromatolithic structures, and
macro-spherical structures.

Globular structures

The most distinctive of the organic remains are globular structures with a diameter of about $^1/_2$ mm. These structures were found in the Vallen Group in the upper part of the Grænsesø Formation (p. 13).

The globular structures occur in large numbers in a dark grey dolomite about 1 m thick and with an orange to red weathering colour.

The rock consists dominantly of twinned carbonate minerals in a homogranoblastic saccharoidal texture. Average grain-size is 1 mm. The carbonate minerals are dolomite and calcite in the proportions 10 to 2 (shown by X-ray diffraction) and possibly a little $FeCO_3$. Most of the carbonate grains are pure and have recrystallized across the borders of the globular organic structures (pl. 1–3). Some carbonate grains contain a dusty pigmentation of opaque material. Small quartz grains occur locally in between the carbonate and also in a concentric arrangement in the organic structures (pl. 3, fig. 1). A few larger 0.5 mm rounded quartz grains are possibly of clastic origin. Scattered laths of colourless mica (muscovite?) are found and a little non-pleochroic chlorite of brownish anomalous interference colours also occurs. Some plagioclase (albite) and rounded zircon crystals have been recorded.

The opaque material is idiomorphic pyrite, and carbonaceous material in the globular structures.

This dolomite bed has been found at two localities in Grænseland and one in Midternæs. The distance between the localities is 7 km, 20 km and 25 km (map, fig. 1) respectively. The layer occurs at the same stratigraphic position in the sequence at each of the three localities (stratigraphical sequence see table II).

The complex and uniform nature of the globular structures make it almost certain that they have an organic origin. Therefore it has been prefered to name the structures after the normal taxonomic practice, as has been done with other Precambrian fossils in recent years (BARGHOORN and TYLER 1965, PFLUG 1965 and 1966). The fossils are placed in a new form genus:

Genus *Vallenia* RAUNSGAARD PEDERSEN, nov. gen.

Genus-diagnosis:

Globular complex structure about 1 mm in diameter distinctly delimited by a relatively thin outer layer: the outer spherical layer. Inside this another thin spherical layer conforms with the outer layer. Between the two spherical layers there are sometimes small indistinct radial connections. The inner part of the globule is dark-coloured to opaque carbonaceous and normally without structures.

Type of genus: *Vallenia erlingi* nov. sp. (pl. 1, fig. 2) (monotypic).

The name *Vallenia* is derived from the lake Vallen, near which the first fossils were found (map, fig. 2).

Vallenia erlingi RAUNSGAARD PEDERSEN, nov. sp.

Pl. 1, fig. 1, 2, 3; pl. 2, fig. 1, 2, 3; pl. 3, fig. 1, 2, 3; pl. 4, fig. 1, 2, 3, 4; pl. 5, fig. 1, 2, 3, and pl. 6, fig. 1, 2.

Diagnosis:

Globular structures with a distinct relatively thin outer spherical layer, and inside this another thin spherical layer conforms with the outer. The spherical layers are sometimes connected by small indistinct radial connections. In the inner part of the globule is a dark-coloured to opaque carbonaceous core.

Holotype: Pl. 1, fig. 2.

Thin section no. 52970/00, 120.0—30.6

Type locality:

600 m east of southern Grænsesø.

Occurrence:

Precambrian (Ketilidian), Vallen Group, Grænsesø Formation, South-West Greenland.

Species name derivation: after ERLING BONDESEN, who first collected the rocks with *Vallenia.*

Description:

Globular structure with a variation in diameter from 0.25 mm to 1.5 mm.

The shape as seen in thin sections varies from regular circular to flat elliptical. The outer limitation is distinct and is in the thin sections indicated by a regular black layer about 3–5 micron thick: the outer spherical layer (pl. 1, 2, 3, and pl. 4). About 30–120 micron inside the outer layer is a corresponding inner layer: the inner spherical layer, which is also about 3–5 micron thick. The spherical layers are in some cases connected by small indistinct radial "pillars" (pl. 2, fig. 1; pl. 6, fig. 2). Inside these two layers are a dark black-brown to opaque core with an irregular outer limitation.

The dark core is carbonaceous. The carbon isotope composition determined on carbonaceous material from the spheres is δ C^{13}: –22.5 (see p. 34). This value is within the range for biogenic carbon produced by photosynthesis (BARGHOORN and TYLER 1965, CRAIG 1953).

In the outer part of the dark core there occurs in a few specimens a very special cellular structure (pl. 4, fig. 4; pl. 5, fig. 1–3) with irregular radiating narrow sectors, which are devided by relatively strong transverse walls or thickenings. Studied by fine-focusing on the microscope the sectors have the appearance of radiating tubes with annular thickenings, but in reality they are probably a special type of cellular structure. The diameter of the "tubes" is about 8 micron and the thickenings are about 1 micron in cross-section. As far as could be seen on the available material the structures do not seem to be a result of crystallization, but are an original structure a little disturbed by later crystallization. This structure is only seen in a few specimens where the core has been ground relatively thin (but without destroying the carbonaceous material). This construction with a very strong inner cellular structure is very curious, especially in relation to the dimension of the globular structure, but it helps to explain the relatively great content of carbonaceous material in the inner core of *Vallenia erlingi* nov. gen. et sp.

The outer form and the variation in size of *Vallenia erlingi* nov. gen. et sp. have been determined by measurements of a large number of specimens. The measurements were carried out on rock-slices under the microscope, measurements on one sample being made on three planes cut at right-angles to each other. The variation in size is shown in fig. 4. The measurements also indicate that the outer shape of *Vallenia erlingi* nov. gen. et sp. is an irregular sphere.

The single specimens of *Vallenia erlingi* nov. gen. et sp. occur scattered in a grey dolomite with generally a distance of a few mm between each other (pl. 12, fig. 1). Only in very few cases has a direct contact between the globules been observed (pl. 6, fig. 1).

Vallenia erlingi nov. gen et sp. is preserved in large numbers. The dolomite with the specimens has been found at three localities. The state of preservation is a little different at the three localitites:

Locality 1: 600 m east of southern Grænsesø (see maps, fig. 1 and 2). Pl. 1, fig. 1–3, pl. 2, fig. 1–3.

Most of the specimens of *Vallenia erlingi* nov. gen. et sp. are a little deformed in outer form. In almost all specimens black cores are preserved. The cores are very often cracked and the fissures are filled in with carbonate and quartz. In the opaque core-mass flakes of colourless mica, and sometimes small quartz grains, are scattered. The outer and the inner spherical layers are usually distinct. In a few specimens radiating connections between the spherical layers are observed (pl. 2, fig. 1). The carbonate crystals in the groundmass of the dolomite continue to the core through the two spherical layers without disturbing the thin layers. In specimens from this locality quartz is rare between the spherical layers.

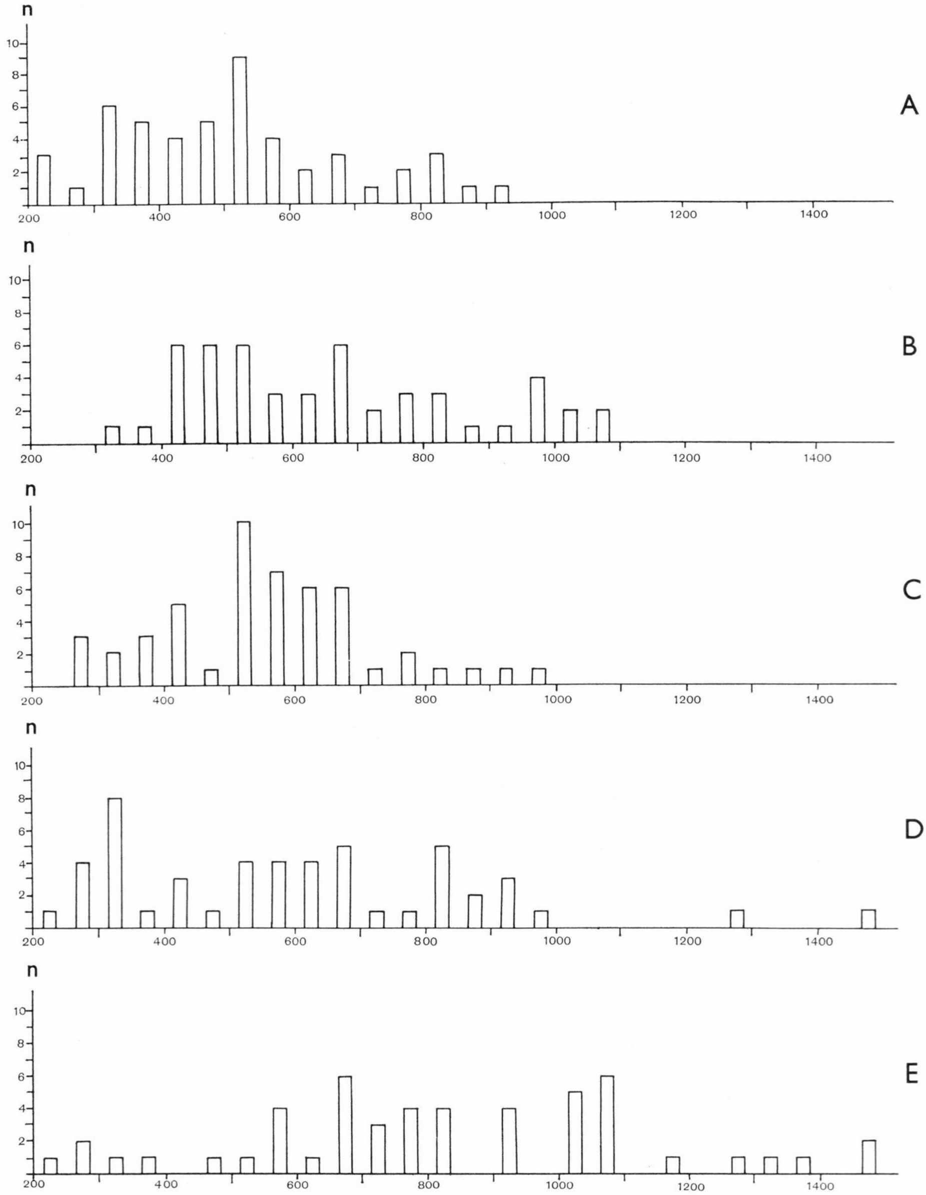

Fig. 4. Histogram showing diameter (in micron) of specimens of *Vallenia erlingi* nov. gen. et sp. n = number of specimen. A, B, C: Measurements on three planes at right-angles to each other on sample from loc. 1. D: Sample from loc. 2. E: Sample from loc. 3. See p. 22.

Locality 2: north of Grænsesø near Sioralik Bræ (see maps, fig. 1 and 2). Pl. 4, fig. 1–4; pl. 5 and pl. 6, fig. 2.

The specimens of *Vallenia erlingi* nov. gen. et sp. from this locality are only weakly deformed in their outer parts, but they are rather altered in their inner parts. The opaque cores in a large number of specimens are compressed and the central part is filled in by carbonate crystals, or fine-grained colourless mica. The two spherical layers are usually well preserved and distinct. The surrounding carbonate crystals pass, in most of the specimens, only through the outer spherical layer. Between the spherical layers occur normally uniform quartz grains. In a few specimens a characteristic cellular structure occurs in the outer part of the core (see p. 21, pl. 4, fig. 4; pl. 5, fig. 1–3).

Locality 3: NE Midternæs, HIGGINS's locality (see map, fig. 1). Pl. 3, fig. 1–3; pl. 6, fig. 1.

Most of the specimens of *Vallenia erlingi* nov. gen. et sp. are almost perfect spheres. The opaque material of the core is often strongly compressed (pl. 6, fig. 1), and the central part is filled up with fine-grained quartz. The outer spherical layer is generally distinct, but the inner is very often destroyed by recrystallization. A number of specimens have an outer row of uniform quartz grains just inside the outer spherical layer (pl. 3, fig. 1). In a few cases a connection between a large and a small sphere is found (pl. 6, fig. 1).

Remarks:

It has not been possible to classify *Vallenia erlingi* nov. gen. et sp. in any fossil or living group. The phylogenetic affinity of *Vallenia erlingi* nov. gen. et sp. is thus uncertain. With respect to Precambrian fossils where there are no very clear relationships to other organisms it seems preferable not to guess as to the affinity to recent organisms until further information becomes available.

The carbon isotope composition of *Vallenia erlingi* nov. gen. et sp. suggests, as mentioned, that it was photosyntetic. The δ C^{13}-value on -22.5 shows that the composition of *Vallenia erlingi* nov. gen. et sp. is lighter than modern marine algae and very near the value from a freshwater green algae (-22.7) (CRAIG 1953). But the data on recent algae are too little to allow any conclusion.

The mode of occurrence in the sediments without contact between the single specimens could be a result of a planktonic mode of life.

This distribution also clearly shows the difference between *Vallenia erlingi* nov. gen. et sp. and oolitic structures, as does the regular and uniform structure of the single specimens of *Vallenia erlingi* nov. gen. et sp.

On account of the state of preservation of *Vallenia erlingi* nov. gen. et sp. chemical investigations were carried out to find whether complex organic compounds were present. The work has been carried out by cand. pharm. J. LAM, Kemisk Institut, University of Aarhus.

The investigation of the rock with *Vallenia erlingi* nov. gen. et sp. was carried out on 1998 g of the rock from Loc. 1 (p. 22) (GGU sample no. 52970 (3)). The rock was crushed down in a mortar to pass a sieve 230 mesh. The material was extracted three times with a mixture of benzene and methanol (3 :1 volume) for respectively 170, 190 and 120 hours.

From the extraction liquid was isolated about 100 mg organic compound. In this matter were indentified alkanes, ketones, and possibly esters of fatty acids. Gas-chromatographic examination on the alkane fraction has shown that all the paraffines from n-C_{10} to n-C_{31} are represented with a maximum about n-C_{18}, n-C_{19}, n-C_{20}.

The paraffines found agree with extracts from Precambrian sediments with organic structures from North America (Barghoorn *et al.* 1965, Meinschen *et al.* 1964, Meinschen 1965, and Oro *et al.* 1965).

The organic matter extracted from the rock with *Vallenia erlingi* nov. gen. et sp. and other rocks from the Ketilidian is under further examination and the results will soon be published.

It seems that the same organic compounds are represented in most of the suitable rocks. The greatest amount was extracted from the coal samples.

The presence of the paraffines together with the other organic compounds is a further proof of the organic origin of *Vallenia erlingi* nov. gen. et sp. and together with the carbon isotope composition it seems to indicate that *Vallenia erlingi* nov. gen. et sp. was a plant.

Precambrian fossils perhaps related to *Vallenia erlingi* nov. gen. et sp. are graphitic bodies reported from the Huronian Michigamme shales. The small graphitic bodies are of elliptical or sub-spherical form with average dimension about 2 mm (Tyler *et al.* 1957). On this material it was concluded that the graphitic bodies most probably represent compressed remains of organisms and that among recent primitive plants free-floating blue-green algae could be analogous to the graphitic bodies. Graphitic bodies almost identical to these are reported from the Labrador trough (Stinchcomb *et al.* 1965) and have been similarly interpreted.

As none of the graphitic bodies show internal structures like *Vallenia erlingi* nov. gen. et sp. it is impossible to decide anything about the relationship.

Carbonaceous fragments

Together with *Vallenia erlingi* nov. gen. et sp. there occur small irregular lumps of dark and opaque carbonaceous material. Most of this material is rather homogeneous but a few of the lumps show an irregular cellular structure.

One of these lumps is illustrated in pl. 6 fig. 3. It is from dolomite, Grænsesø Formation, locality: north of Grænsesø near Sioralik Bræ (GGU sample no. 53061/2). This fragment is built up by threads about 2 micron thick. The threads are oriented in the same direction and form anastomosing bundles of threads. The carbonate crystals of the dolomite do not cross the limit of the cellular fragment. The cavities in the cellular structures are filled in by quartz. Many of the cellular fragments are partly destroyed by the growth of the quartz. It has not been possible to determine the origin of these fragments, but they could have been part of larger organic entities.

In the preparations made by dissolving the dolomite with *Vallenia erlingi* nov. gen. et sp. there are many similar fragments of carbonaceous material, but normally these fragments broke down to small pieces during the disolving of the rock in acid.

Many of the other rock-specimens from Grænseland have yielded carbonaceous fragments similar to the above mentioned. Well preserved and relatively large fragments occur in the cherty black quartzite layers of the Grænsesø Formation.

Most of the fragments are small and are built up in an irregular manner by thin threads or filaments very often together with more compact fragments (pl. 7 fig. 1–2). The shape of many of the fragments has been affected by compression of the rocks. In thin section the fragments are seen in between the crystals making up the rocks but also in the interior of the crystals. The diameter of the threads varies from about 0.1 micron to 2 micron.

Pl. 7 fig. 1–2 show large fragments and filaments from black quartzites with limestone from the Grænsesø Formation, locality: at Sioralik Bræ north of Grænsesø (GGU sample no. 53060).

The filaments shown in pl. 7 fig. 3 are from a black quartzite from Upper Zig Zag Land Formation, locality: south of Vallen (GGU sample no. 53025).

Similar cellular tissue-like fragments have been found in Precambrian sediment series together with other organic structures (Barghoorn *et al.* 1965, Barghoorn and Schopf 1965, and Cloud *et al.* 1965).

In the thin sections of some of the rocks very small short filaments occur, which in form and dimension are similar to some modern bacteria (pl. 8 fig. 1–2). The diameter of the filaments is up to 1 micron and their lenght about 2–4 micron. They are of a brownish colour and often occur together in small "colonies". From the available characters it does not seem possible to identify the structures with living groups of bacteria. In fact it is not possible to prove that they are bacteria remains. The best that can be said is perhaps that the structures are similar in morphology to some modern bacteria.

Bacteria-like structures have been reported from other Precambrian series (Cloud *et al.* 1965, Cloud 1965, Kuznetsov *et al.* 1963, and Schopf *et al.* 1965). The figured examples are from Foselv Formation, locality: north Fønland (GGU sample no. 53063). (δ C^{13} for this sample see table V).

Microscopic spheres

In many of the preparations made on the carbonaceous residuum from the acid treatment of the rocks microscopic spheres are found, most of them below 20 micron in diameter. These bodies, which have the appearence of spores, are often not very distinct, but several types can be distinguished. Similar "spores" have been reported from other Precambrian sediments (Timofeev 1959, Roblot 1963, Barghoorn *et al.* 1965, Barghoorn and Schopf 1965, Barghoorn and Tyler 1965, Pflug 1965, Cloud 1965, and Love and Zimmerman 1961). Interpretations of these "spores" have been very different, ranging from the spores of higher land plants to more primitive types of tallophytae. In relation to the state of preservation and the available characters of the fossils, some of these interpretations seem rather hazardous. However, the rather distinct outer limitation together with the resistance of these bodies makes it possible that they are organic remnants.

The spore-like bodies from Grænseland are not described in detail in this paper; only a few types are figured to show a little of the variations in form.

Type 1: Pl. 9 fig. 1–3 and pl. 8 fig. 3.

Spheroidal body with distinct hyalin outer layer and possibly a perforation. Diameter 3–5 micron. Specimens figured in pl. 9 derived from a preparation of black quartzite from the Zig Zag Land Formation. Locality: north of northern Grænsesø (GGU sample no. 53073). The specimens on pl. 8 fig. 3 are from the Grænsesø Formation from thin section of the *Vallenia*-bearing rocks from loc. 2. (p. 23) (GGU sample no. 53061–2).

Type 2: Pl. 9 fig. 4–6 and pl. 10 fig. 4–5.

Dark thick-walled sphere with non-regular reticulum. Diameter about 16 micron. The sphere figured on pl. 9 derives from a preparation of black quartzite from the Upper Zig Zag Land Formation. Locality: north of northern Grænsesø (GGU sample no. 53073). The specimens pl. 10 fig. 5–6 are from a thin section from Zig Zag Land Formation (GGU sample no. 53073–1).

Type 3: Pl. 10 fig. 1–4.

Sphere with thick hyaline outer layer. In the outer layer are lens shaped thickenings which form a characteristic pattern. Diameter: 18 micron and 12 micron. The small specimen was found in a preparation of the coal layer from the Foselv Formation. Locality: Fønland (GGU sample no.

20908). The large specimen was isolated from a black quartzite from the Upper Zig Zag Land Formation. Locality: north of northern Grænsesø (GGU sample no. 53073).

Stromatolithic structures

Near one of the localities of *Vallenia erlingi* nov. gen. et sp. (locality 1; fig. 2) several pieces of a calcareous rock with stromatolithic structures have been found (pl. 11) (GGU sample no. 52973). It is not quite certain from where in the stratigraphical sequence it has been derived, but the outer appearance of the stromatolithic rock suggest that it has not been transported, and makes it probable that it is very close to its "*in situ*" position. To judge from where it was found it is probably derived from the Grænsesø Formation.

The largest fragment of the stromatolithic rock found measures 15 cm in cross-section.

The structures as seen in the sectioned surface of the stromatolithe (pl. 11 fig. 1–2) are irregular, rounded, sub-circular to strongly lobed bodies, which look like fused spheres. These bodies have a dark outer zone and are normally lighter in the central part. A light grey homogeneous matrix occurs between the closely packed bodies. The bodies are up to 20 mm in length and 8 mm in cross-section. The structure appears to be growing up from a plane substratum and not from single points on it. The original outer shape of the stromatolithic structures is not preserved.

In modern works on stromatolithes (REZAK 1954 and 1957, GINZBURG 1960) it is stressed that the outer shape of the colony is very important in classification, together with the orientation and appearance of the laminae. Stromatolithes are now usually interpreted as a result of algae activity.

In thin sections and preparations made by dissolving the stromatolithic rock from Grænseland, no distinct algae-like filaments have been observed.

Because of the fragmentary preservation of the finds from Grænseland it seems best to classify these specimens simply as stromatolithes.

Macro-spherical structures

Close to the basal conglomerate in the Lower Zig Zag Land Formation about 1 km south of lake Vallen (fig. 2, lok x) was found a small piece of disintegrated quartzitic rock in dolomite with some macro-spherical structures (pl. 12 fig. 2). The spheres have a diameter of about 1 cm and lie in contact with each other forming rows; some of them are perfectly spherical, but others are fused together. The single spheres seem to have a double outer layer of which the outermost is common for several spheres and connects the single spheres of the rows.

The best preserved specimens, illustrated in pl. 12 fig. 2 (GGU sample no. 53140), have a small central cavity encircled by an indistinct layer. This layer is in one specimen regular and in another strongly lobed. No organic matter has been found with the structures, so it is difficult to decide definitely whether the structures are of organic origin.

III. THE CARBON-13 ABUNDANCE IN THE CARBONACEOUS MATTER

The scope and the material

The purpose of this investigation is to determine whether the isotopic composition of the Precambrian carbonaceous matter described in the previous section could contribute to the elucidation of genetic problems.

Investigations of the stable carbon isotopes have been performed in many parts of the world since NIER and GULBRANSEN (1939) first demonstrated the existence of a considerable variation in the isotopic composition of carbonaceous matter of various origins. However, certain differences of opinion still exist between various authors concerning the use of the isotopic composition as an indicator of the origin of carbonaceous matter.

In this paper the author will not attempt to discuss the fundamental causes of fractionation (as the material analysed in the present investigation is too little), but the results will be considered from a geological point of view and compared with those of previous investigators.

Table IV. *Samples examined for the C^{13}/C^{12} ration*

GGU No.		
20909	graphitised coal	
20910	graphitised coal	
20911	weakly graphitised coal	
20912	graphitised coal	Coal layer in the Foselv Formation, Fønland
52972	graphitised coal	
52993	coal	
52971	black bituminous shale	
52996	black bituminous shale	Grænsesø Formation, Fønland
53061	dolomite with *Vallenia erlingi* nov. gen. et sp.	
53063	carbonaceous dolomite	Foselv Formation, Fønland

Table IV lists the samples examined. For their location and stratigraphic position see fig. 2 and table II.

The samples can be divided into two groups. The first group comprises coal, graphitised coal and black bituminous shales. The graphitisation is the result of contact metamorphism adjacent to a large doleritic dyke intersecting the coal layer. The second group consists of two dolomites containing carbonaceous matter. The carbonate and the carbonaceous matter were analysed separately.

The experimental procedure

Before conversion to carbon dioxide, the samples were crushed in a porcelain mortar. The coal and graphite samples were all treated with hydrochloric acid prior to cumbustion, in order to reduce contamination from carbonates.

The conversion of the samples to carbon dioxide was carried out at the Carbon-14 laboratory of the National Museum. The method and apparatus—constructed by civ.ing. H. TAUBER—are those of DE VRIES (VRIES and BARENDSEN 1953, VRIES 1955), with minor modifications. This method differs slightly from that described by CRAIG (1953) and is briefly outline below.

Preparation of the carbon and graphite samples

Carbon and graphite samples were treated in the apparatus which is sketched in fig. 5. Before the combustion was commenced, the apparatus was cleaned of atmospheric carbon dioxide by a strong blow-out with oxygen.

The samples were treated in a furnace (A) with tank oxygen, and the carbon dioxide was cleaned of NH_3, SO_2, halogens and carbon products by a system of filters (B, D, E). Lastly the clean CO_2 gas was absorbed in a strong NH_3-solution as ammonium carbonate (F). After final cumbustion the NH_3-solutions from the two wash bottles were brought together, the solution was heated to 60°–70° C, a strong solution of $CaCl_2$ was added and the absorbed carbon dioxide was precipitated as $CaCO_3$. After filtering, the whole precipitate was washed and brought the reaction vessel of the regeneration system (fig. 6). The system was evacuated to 50 mm Hg and orthophosphoric acid was added to the calcium carbonate.

Before the carbon dioxide released was trapped with liquid nitrogen, the sytem was blown clean of atmospheric air by pumping out the first developed gas. The connection to the pump was then broken at stopcock H_2. The gas passed through two water traps (cooled with dry ice) where the aqueous vapour was collected. The carbon dioxide gas was then trapped with liquid nitrogen in the sample trap (T_3).

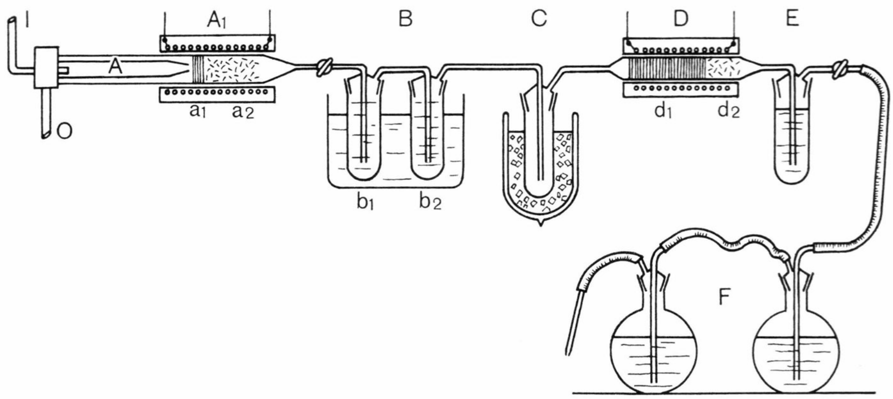

Fig. 5. A: Furnace for combustion of sample in pure oxygen. A_1: Electric furnace (700–750° C) with Pt-catalyser (a_1) and CuO (a_2) for conversion of organic gas and CO to CO_2. B: Thermostat (60° C) with two wash bottles; one with a $K_2Cr_2O_7$ acid solution (b_1) and one with a $KMnO_4$-solution in acid (b_2). C: Freezing trap with dry ice and acetone. D: Electric furnace (450° C) with $PbCrO_4$ (d_1) and Ag (d_2 silver wool) trapping halogens. E: SO_2 trap with $KMnO_4$-acid solution. F: Two wash bottles with a NH_4-solution in which the cleaned CO_2-gas is absorbed.

When all the calcium carbonate has been dissolved the stop-cock (H_2) between the CO_2-trap and the water-traps were closed and high vacuum was applied on the CO_2-trap for 10–15 minutes in order to clean the carbon dioxide of oxygen contamination. After a final cleaning the carbon dioxide was collected to the sample tube (T_6), by transferring the liquid nitrogen bath to this tube and freezing out the CO_2.

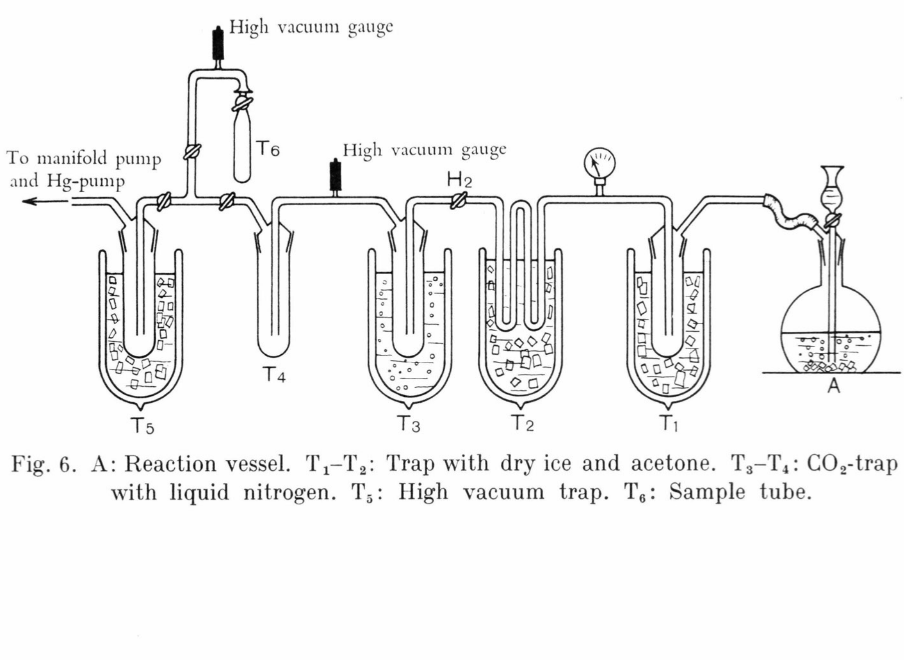

Fig. 6. A: Reaction vessel. T_1–T_2: Trap with dry ice and acetone. T_3–T_4: CO_2-trap with liquid nitrogen. T_5: High vacuum trap. T_6: Sample tube.

Preparation of the carbonate samples

The conversion of the carbonate in the dolomite samples (no. 53061 and no. 53063) to carbon dioxide was carried out in the system sketched in fig. 7. The two wash bottles contained a strong NH_3-solution. The dolomite sample was placed in the reaction vessel with some water, and a HCl-solution added very slowly through the dropping funnel so that the gas stream passed through the wash bottles at about 3 to 4 bubbles per minute.

When all the carbonate had been disolved, the carbonate ions were precipitated and later washed and reconverted to CO_2 as already described.

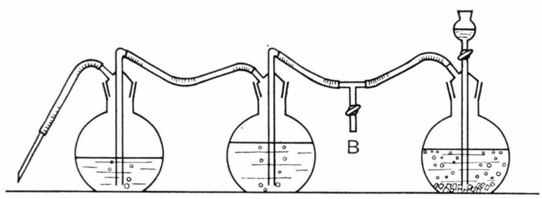

Fig. 7. A: Reaction vessel with HCl-solution. B: Stop-cock for outlet of contained gas. C_1–C_2: Wash bottles with NH_3-solution.

All the carbonate matter of the samples was disolved by the HCl treatment, and after drying the residual carbon was converted to carbon dioxide by the same method used for conversion of the pure carbon and graphite samples.

The mass spectrometric measurements

The mass spectrometric measurements were performed at the Department of Physics at H. C. Ørsteds Institut, Copenhagen. The mass spectrometer used in the work is one with a double collector. With this instrument it is possible to a measure directly the isotopic ratio in a mixture of isotopes.

The figures recorded are the differences in the ratio of the mass 45 to mass 44 ion beams of the samples and that of the standard gas, expressed in parts per 1000 of the ratio of the standard gas i. e.

$$\delta C^{13}_{(x\text{-std.})} = \frac{R_{sample} - R_{standard}}{R_{standard}} 10^3 \ ^0/_{00}$$

where R is the ratio of the abundance of the ions of mass 45 to ions of mass 44.

In order to render the results directly comparable with the values published earlier (Craig 1953, Jeffery *et al.* 1955), the values obtained in the present investigation were converted to δ-values by reference to the Chicago scale.

The standard used in this work was carbon dioxide made from oxalic acid provided by the National Bureau of Standards and the preparation method was that described above for coal and graphitised coal. Three samples of standard gas have been measured against Craig's PDB-standard and the average value δ C^{13} (std.-PDB) = — 19.62 $^0/_{00}$ is used in this work (Craig 1961).

The accuracy of the measurements is within the limits ± 0.25 $^0/_{00}$, although under the most favourable conditions a lower margin of error could be expected.

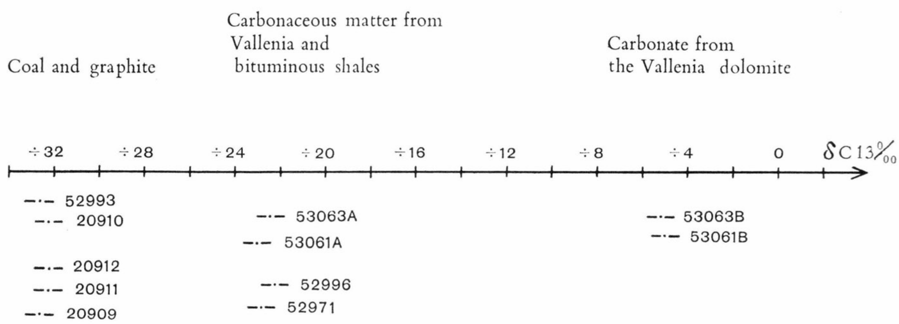

Fig. 8. Diagram showing the distribution of carbon isotopes δ C^{13} $^0/_{00}$ referred Craigs Chicago scale. Dot shows measured value, line on each side indicate zone of experimental error. Ciffers refer to sample number (Table V).

The results of the investigation

The general results of the investigation are presented in fig. 8 and table V. As seen from fig. 8 there is a well marked division into three groups:

1) the coal and the graphitised coal,
2) the bituminous shales and carbon from the dolomite with *Vallenia* and
3) the carbonates from these rocks.

In the first group the isotopic compositions of the light graphites (samples no. 20909, 20910, 20912, 52972) are about the same as the Precambrian graphite schists recorded (Craig 1953, Jeffery *et al.* 1955) which have a δ-value between -32 $^0/_{00}$ and -35 $^0/_{00}$.

The very small difference in isotopic composition between the coal and the graphitised coal (samples no. 53993 and 20910), seen in connection with the geological evidence of contact metamorphism, is in agreement with previous investigations (Rankama 1954, Wickman 1953, and Wickman *et al.* 1951) which show that thermal metamorphism and graphitisation cause no change in the isotopic composition and that

Table V.

GGU Sample No.		$\delta C^{13}_{(x-PDB)}$
20909	graphitised coal	-32.6 ‰
20910	– –	-32.3 –
20911	weakly graphitised coal	-32.3 –
20912	graphitised coal	-32.1 –
52972	– –	-32.3 –
52993	coal	-32.5 –
52971	black bituminous shale	-23.0 –
52996	– – –	-22.3 –
53061 A	carbonaceous matter from dolomite with *Vallenia erlingi* nov. gen. et sp.	-22.5 –
53061 B	carbonate from dolomite with *Vallenia erlingi* nov. gen. et sp.	-5.2 –
53063 A	carbonaceous matter from dolomite	-23.0 –
53063 B	carbonate from carbonaceous dolomite	-5.3 –

if graphitisation causes any change, it is to render the carbon a little heavier.

The high values of about -32 ‰ for the samples no. 20909, 20910, 20911, 20912, 52972, 52993, suggest the accumulation of organic material under extreme reducing conditions (Jeffery *et al.* 1955).

The second group includes two bituminous shales (no. 52971 and 52996) and the carbonaceous material from two dolomites (no. 53061 A and 53063 A). The most interesting sample in this group is no. 53061 A. As described p. 24 the carbonaceous matter is found in structures of organic origin, *Vallenia erlingi* nov. gen. et sp.

A comparison with the isotopic composition of the organic carbon in modern marine algae (recorded by Craig 1953, table 4) shows that the composition of *Vallenia erlingi* nov. gen. et sp. is lighter than the modern marine algae which have a composition from -8 to -17 ‰. The isotopic composition of *Vallenia erlingi* nov. gen. et sp. is closer to the values of coal and fossil wood of various ages (Craig 1953, table 9 and table 10) which have an average δ-value at -24 ‰. One of the few recent freshwater plants—a green algae—analysed by Craig (1953, p. 71) shows a composition on $\delta = -22.7$ ‰. The close agreement of the composition of the carbonaceous material from *Vallenia erlingi* nov. gen. et sp. with the freshwater green algae analysed does not permit any conclusion because material for comparison is still too limited. As discussed by Craig (1953) and Jeffery *et al.* (1955), the accumulation and decomposition of organic compounds under the formation of oil and bituminous matter generally lead to enrichment with C^{12} in the residual substances. It is therefore not impossible that *Vallenia erlingi* nov. gen. et sp. had a heavier composition prior to decomposition.

Sample no. 53063 A is of the same type as no. 53061 A but without clear organic structures in the carbonaceous matter. The isotopic composition is very close to the value of the sample with *Vallenia erlingi* nov. gen. et sp.

The remaining samples of the second group are two bituminous shales (nos. 52971 and 52996) also from the Grænsesø Formation. With an average $\delta = -22.7\ ^0/_{00}$ the shales are heavier than the shales recorded by Craig (1953, table 11) most of which have a δ-value about $-23\ ^0/_{00}$ to $-30\ ^0/_{00}$.

The third group comprises the carbonate from two dolomite samples (nos. 53061 B and 53063 B). The isotopic composition is lighter (with $\delta = -5.3\ ^0/_{00}$ and $\delta = -5.2\ ^0/_{00}$) than the dolomites (with $\delta = +1.2 \rightarrow +2.7$) recorded by Craig (1953, table 5), but the data agree with the dolomite of Jeffery *et al.* (1955, table 1) and the bituminous limestones investigated by Landergreen (1954).

IV. CONCLUSION

The Ketilidian rocks of Grænseland, SW Greenland, comprise a series of low metamorphic sediments and volcanics as described in section I.

In the sediments many types of organic structures have been found. These relatively well preserved structures—some of which are described in section II—indicate that organic life in Greenland had started when the sediments were laid down. The age of the sediments seems to be about 2000 million years.

It is remarkable that both macro- and micro-organic structures are represented. The organic origin of the structures is shown by their complex structure, the isotopic composition of the carbonaceous matter and by the presence of small amounts of paraffines and other organic compounds.

The best preserved macro-structures are from the least deformed parts of the respective formations they are found in. Judging by the state of preservation of sedimentary structures, the organic structures are undeformed.

The micro-structures are derived from both undeformed and moderately deformed sediments. They are well preserved but may in some cases suffer from recrystallization of the mineral components. It is the general impression that the majority of the sediments in Grænseland would preserve traces of organisms. Of rock types which normally are regarded as suitable for preservation e. g. shales and calcareous rocks, many of the specimens collected for purely sedimentological and petrological purpose yielded organic material. Also rocks less able to preserve fossils e. g. quartzites and greywackes, have been shown to contain organic material.

That the organic remnants also have a relatively large horizontal distribution is shown from the three *Vallenia* localities (see p. 22). Judging from stratigraphical relations it should be possible to trace the dolomite with *Vallenia* for more than 50 km in Grænseland and Midternæs, and possibly also in the better preserved Ketilidian rocks elsewhere, for example on Arsuk Ø (fig. 1).

The Carbonaceous Member of the Foselv Formation including the coal also shows that a large scale accumulation of organic material has taken place. A layer of coal of 1 m may be derived from an original deposit of considerable thickness.

From the relations mentioned above it is concluded that organic remnants, especially in microscale but also in macro, are likely to be found over all the area where conditions, i. e. rock type, tectonic relations and metamorphic grade allow. In this respect this Precambrian complex does not seem to differ from many post-Cambrian sequences.

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Færdig fra trykkeriet den 7. februar 1967.

PLATES

Plate 1.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1: 50×. Locality: 600 m east of southern Grænsesø
(Loc. 1, see p. 22).
Thin section no. 52970/00.

Fig. 2: 50×. Holotype. Locality: 600 m east of southern Grænsesø
(Loc. 1, see p. 22).
Thin section no. 52970/00.

Fig. 3: 50×. Locality: 600 m east of southern Grænsesø
(Loc. 1, see p. 22).
Thin section no. 52970/00.

Fig. 1.

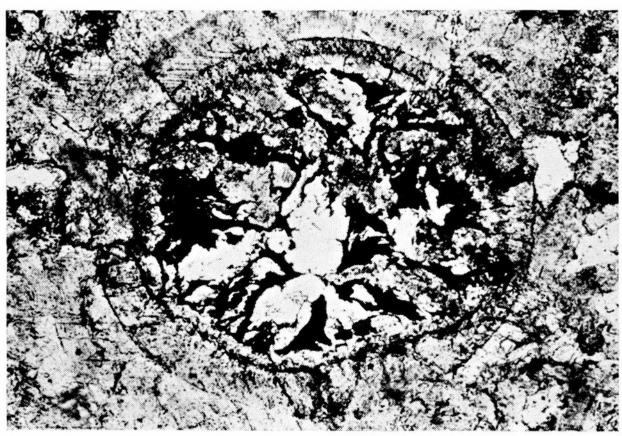

Fig. 2.

Fig. 3.

Plate 2.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1: 50×. Locality: 600 m east of southern Grænsesø (Loc. 1, see p. 22).
Thin section no. 52970/0.

Fig. 2: 50×. Locality: 600 m east of southern Grænsesø (Loc. 1, see p. 22).
Thin section no. 52970/1.

Fig. 3: 50×. Locality: 600 m east of southern Grænsesø (Loc. 1, see p. 22).
Thin section no. 52970/2.

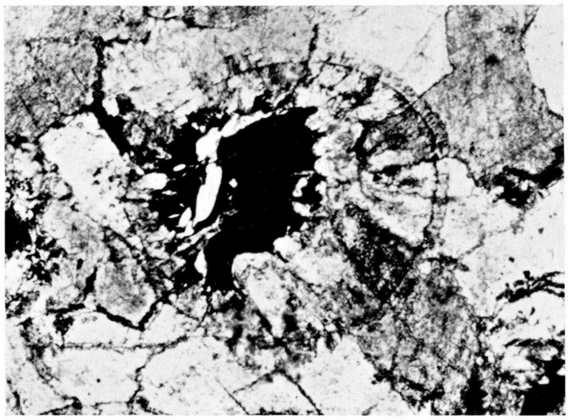

Fig. 1.

Fig. 2.

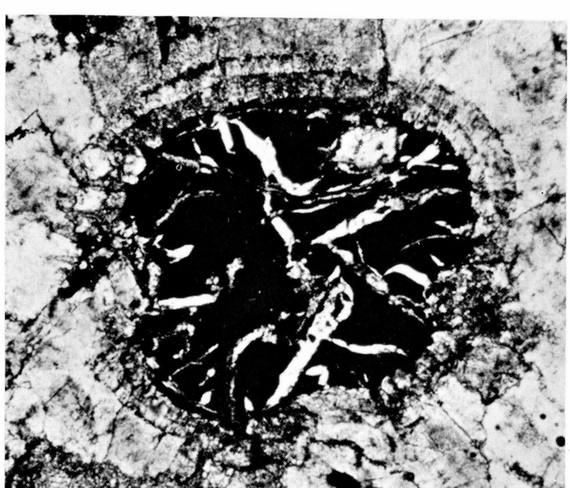

Fig. 3.

Plate 3.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1: 50×. Locality: NE Midternæs, HIGGINS locality (Loc. 3, see p. 24).
Thin section no. 71380–1.

Fig. 2: 50×. Locality: NE Midternæs, HIGGINS locality (Loc. 3, see p. 24).
Thin section no. 71380–u.

Fig. 3: 50×. Locality: NE Midternæs, HIGGINS locality (Loc. 3, see p. 24).
Thin section no. 71380–u.

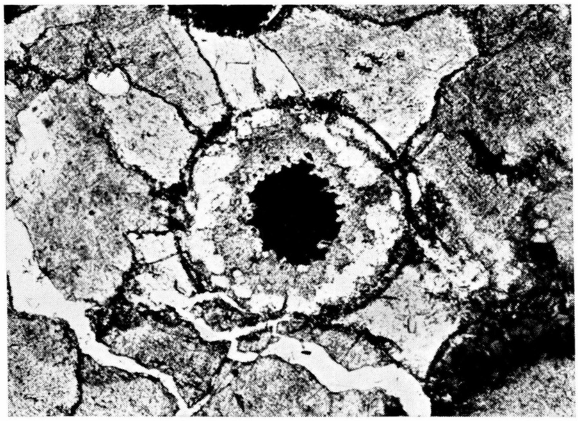

Fig. 1.

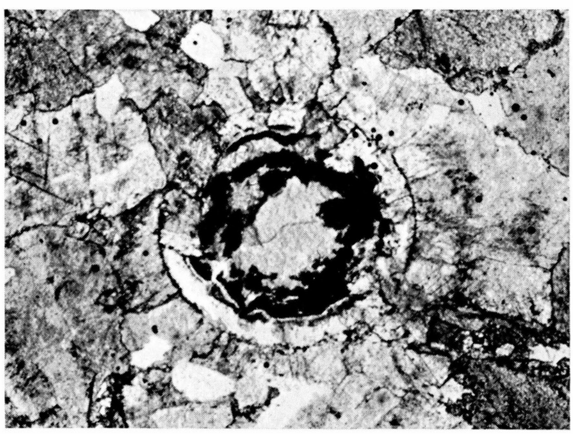

Fig. 2.

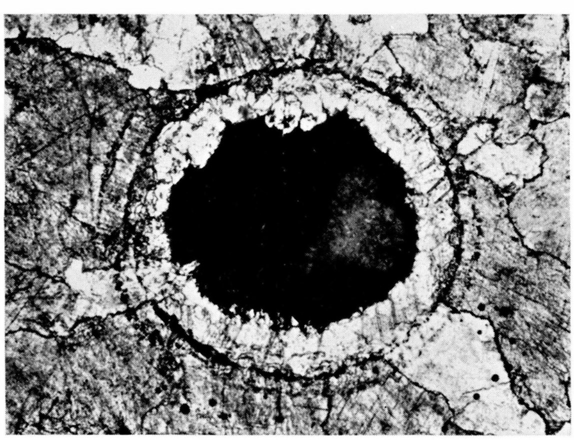

Fig. 3.

Plate 4.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1–4: The same specimen in different magnifications.
Locality: North of Grænsesø near Sioralik Bræ (loc. 2, see p. 23).
Thin section no. 53061–0

Fig. 1: 50×.

Fig. 2: 250×. The two spherical layers with quartz crystals between. The inner spherical layer a little disturbed by the quartz.

Fig. 3: 100×. The carbonaceous core with crystals of mica.

Fig. 4: 1000×. Detail of thin ground part of the outer of the carbonaceous core.


Fig. 1.


Fig. 2.


Fig. 3.


Fig. 4.

Plate 5.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1, 2, 3: 1500×.
Detail of thin ground part of carbonaceous core (see p. 21–22).

Fig. 1 and fig. 2 show an upper and a lower focus of the same part of the core.

Locality: North of Grænsesø near Sioralik Bræ (Loc. 2, see p. 23).
Thin section no. 53061–2.

PLATE 5.

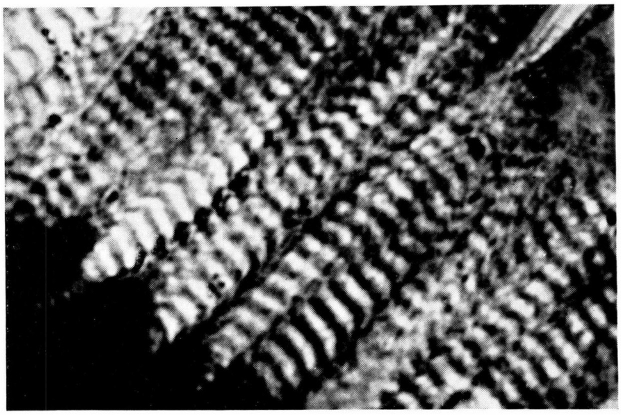

Fig. 1.

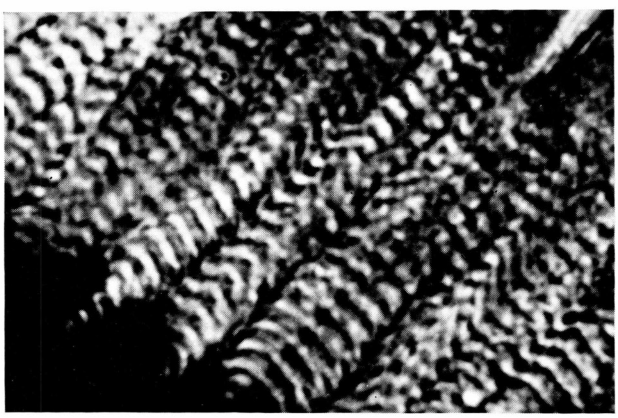

Fig. 2.

Fig. 3.

Plate 6.

Vallenia erlingi RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20).

Fig. 1: 25×. Locality: NE Midternæs, HIGGINS locality
(Loc. 3, see p. 24).
Thin section no. 71380–1.

Fig. 2: 100×. Locality: North of Grænsesø near Sioralik Bræ,
(Loc. 2, see p. 23).
Thin section no. 53061–2.
Carbonaceous fragment (p. 25).

Fig. 3: 250×. Locality: North of Grænsesø near Sioralik Bræ,
(Loc. 2, see p. 23).
Thin section no. 53061–2.

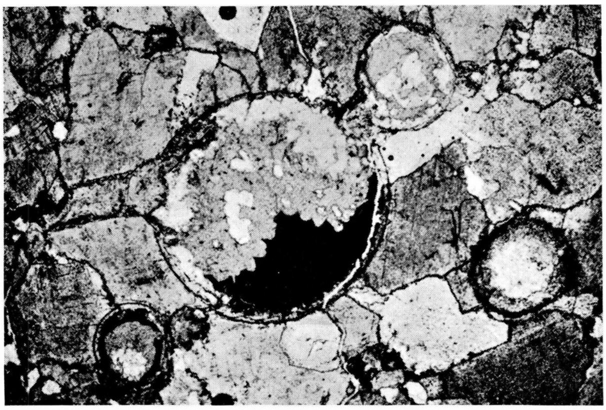

Fig. 1.

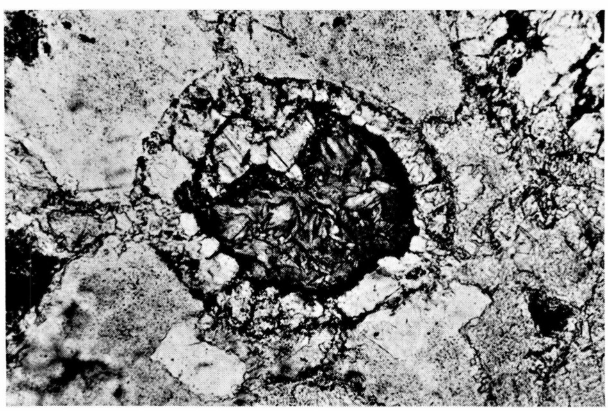

Fig. 2.

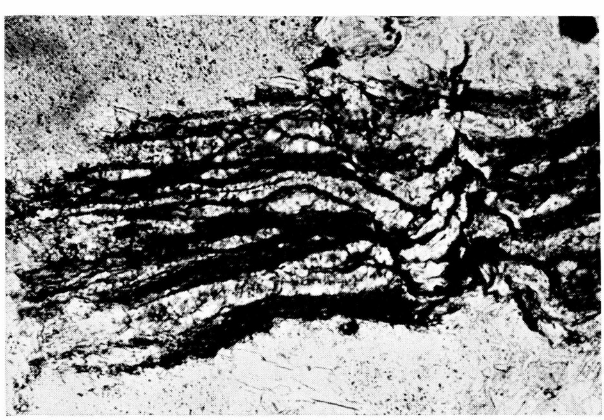

Fig. 3.

Plate 7.

Fig. 1, 2: 1500×. Carbonaceous fragment from preparation.
Upper and lower focus. See p. 26.
Locality: At Sioralik Bræ, north of Grænsesø, (Grænsesø Formation).
Preparat no. 53060–1–1.

Fig. 3: 2000×. Filamentary carbonaceous fragments from thin section. See p. 26.
Locality: South of Vallen, (Upper Zig Zag Land Formation).
Thin section no. 53025–1.

Plate 7.

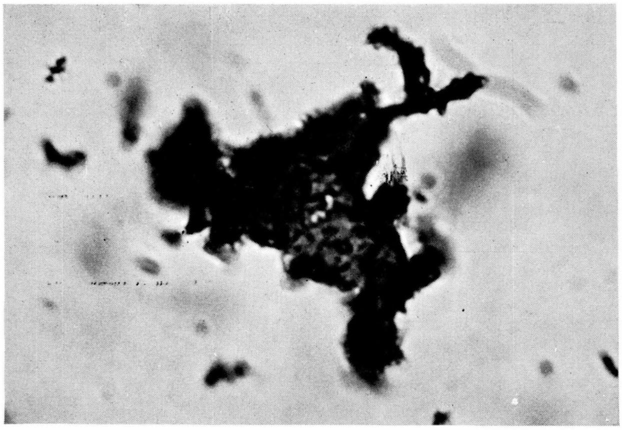

Fig. 1.

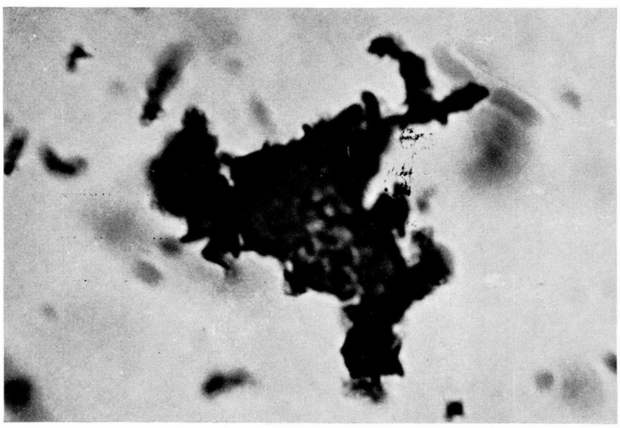

Fig. 2.

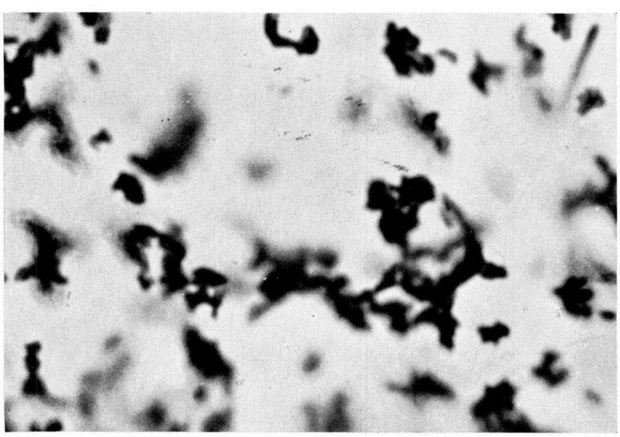

Fig. 3.

Plate 8.

Fig. 1, 2: 1500×. Micro-filaments in quartz grain in thin section. See p. 26.
Locality: North Fønland (Foselv Formation).
Thin section no. 53073–1.

Fig. 3: 2000×. Microscopic sphere (type 1) in thin section. See p. 27.
Locality: North of Grænsesø near Sioralik Bræ (Grænsesø Formation).
Thin section no. 53061–2.

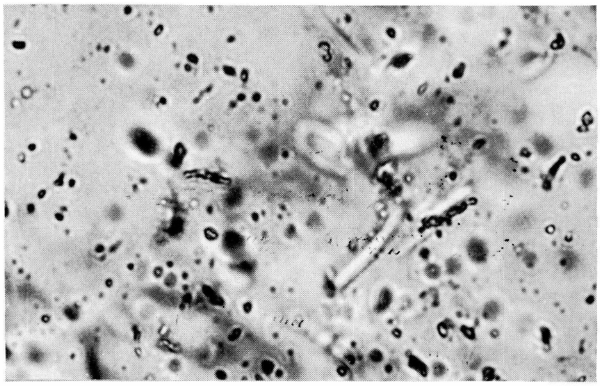

Fig. 1.

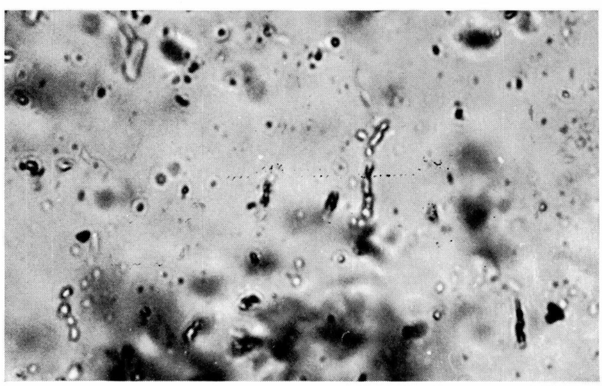

Fig. 2.

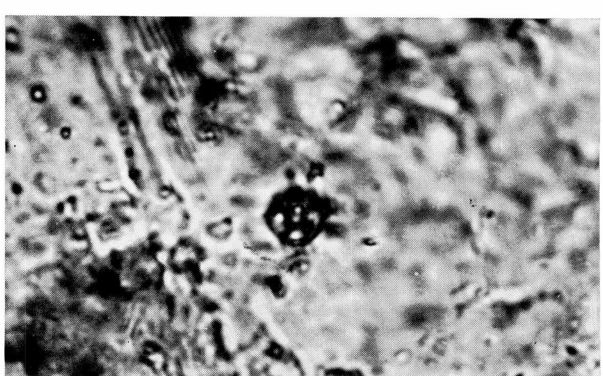

Fig. 3.

Plate 9.

Fig. 1, 2, 3: 2000×.	Microscopic sphere (type 1) from a preparation. See p. 27. Upper, middle and lower focus. Locality: North of northern Grænsesø (Upper Zig Zag Land Formation). Preparat no. 53073–1–1.
Fig. 4, 5, 6: 1500×.	Microscopic sphere (type 2) from a preparation. See p. 27. Upper, middle and lower focus. Locality: North of northern Grænsesø (Upper Zig Zag Land Formation). Preparat no. 53073–1–1.

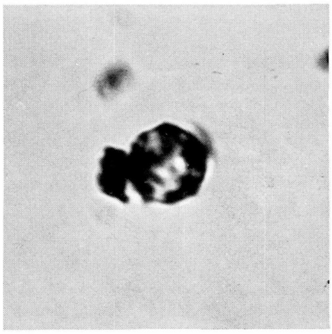

Fig. 1.

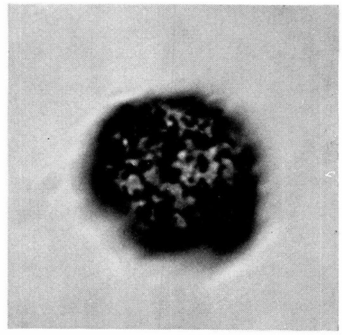

Fig. 4.

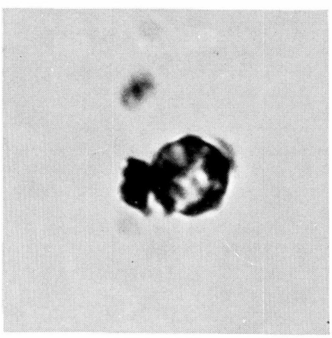

Fig. 2.

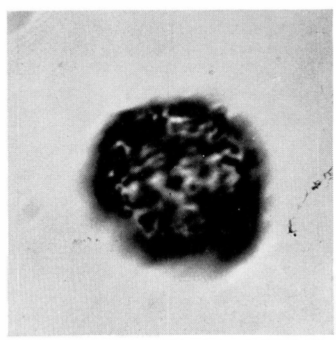

Fig. 5.

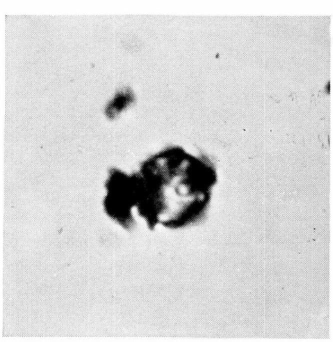

Fig. 3.

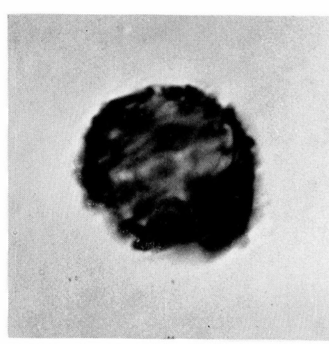

Fig. 6.

Plate 10.

Fig. 1, 2, 3: 1500×.	Microscopic sphere (type 3) from a preparation. See p. 27. Upper, middle and lower focus. Locality: North of northern Grænsesø (Zig Zag Land Formation). Preparat no. 53073–1–1.
Fig. 4: 1500×.	Microscopic sphere (type 3) from a preparation. See p. 27. Locality: Fønland (Foselv Formation). Preparat no. 20908–1–1.
Fig. 5, 6: 1500×.	Microscopic sphere (type 2) from a thin section. See p. 27. Upper and lower focus. Locality: North of northern Grænsesø (Zig Zag Land Formation). Thin section no. 53073–1.

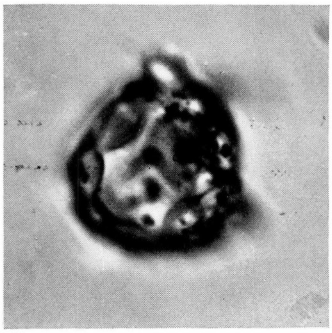

Fig. 1.

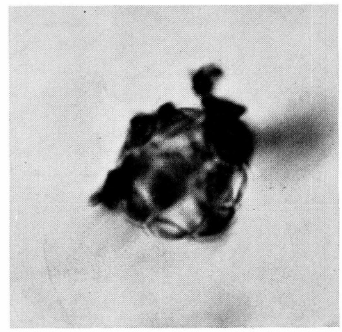

Fig. 4.

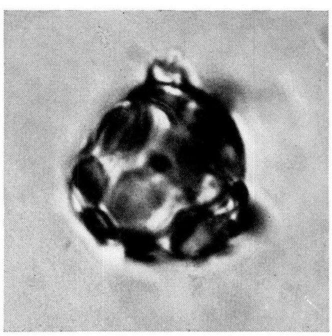

Fig. 2.

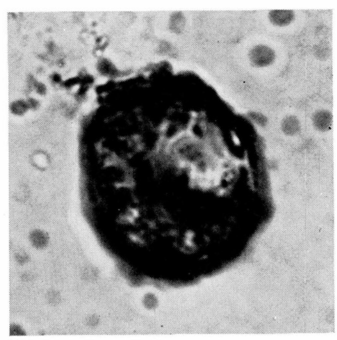

Fig. 5.

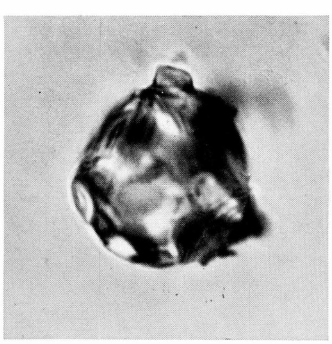

Fig. 3.

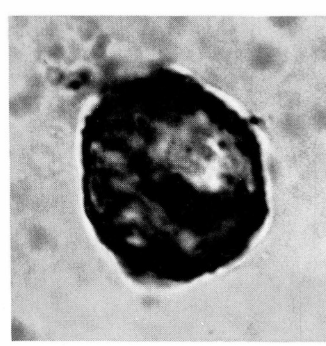

Fig. 6.

Plate 11.

Fig. 1, 2: 1,25×. Stromatolithic structure.
See p. 28.
Locality: 600 m east of southern Grænsesø.
P. Nielsen phot.

Fig. 1.

Fig. 2.

Plate 12.

Fig. 1: 1,1×. Sectioned surface of the rock with *Vallenia erlingi* RAUNSGAARD PEDERSEN nov. gen. et sp. (p. 20 and 24).
Locality: North of Grænsesø near Sioralik Bræ (Loc. 2).
P. NIELSEN phot.

Fig. 2: 1,75×. Macro-spherical structures. See p. 28–29.
Locality: 1 km south of Vallen
(Zig Zag Land Formation).
P. NIELSEN phot.

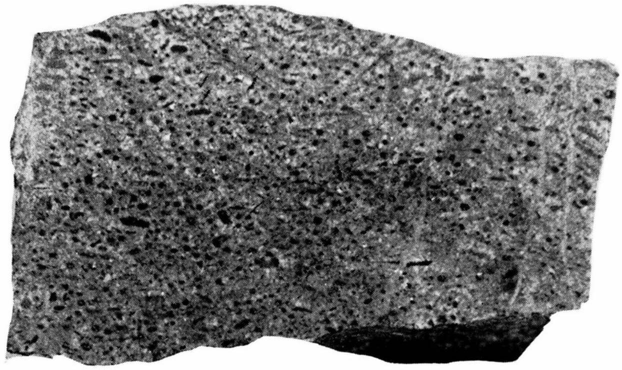

Fig. 1.

Fig. 2

Plate 13.

Grænsesø Formation exposed in a cliff face along the east shore of Grænsesø. In the foreground the dolomitic shales of the Zig Zag Land Formation (A) and above the scree lensoid bodies of dolomite in black carbonaceous shales. Large basic sills are indicated (γ) and on top of the hills pillow lavas of the Foselv Formation (π).

Plate 13.