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DEVONIAN SEDIMENTS OF EAST GREENLAND V

THE CENTRAL SEQUENCE, KAP GRAAH GROUP AND MOUNT CELSIUS SUPERGROUP

BY

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WITH 57 FIGURES, 13 TABLES AND 20 PLATES

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Abstract

The first phase of deposition of the Upper Devonian Kap Graah Group consisted mainly of braided river sands, with minor lacustrine and probable aeolian sediments. These deposits are broadly similar to those of the underlying Kap Kolthoff Supergroup, and the boundary is generally conformable, rather arbitrary and probably diachronous. In the centre of the outcrop, the first phase accumulated over 1000 m of sediments and the palaeoccurrents flowed southwards. There is a small amount of evidence for a margin of this basin some way to the west, and much stronger evidence for an eastern margin traversing Gauss Halvø and continuing southwards. In various parts of this eastern marginal zone 1) the lower Kap Graah Group rests unconformably on folded Kap Kolthoff Supergroup, 2) major volcanism occurred, and 3) coarse sediment was derived from the east.

The second phase of deposition of the Kap Graah Group accumulated up to 900 m of sediment which was marked by a change to northwards of the basinal palaeoccurrent direction. Deposition extended farther eastwards overlying folded sediments that range from Vilddal Supergroup to lower Kap Graah Group. This reflects an eastern migration of the eastern margin of the basin, but palaeocurrents and coarsening both show that material was still being derived from an eastern source area. Vertebrate fossils are more abundant in this second phase of the Group.

The Remigolepis Group of the Mount Celsius Supergroup reaches a thickness of about 800 m and follows conformably on the upper Kap Graah Group. Siltstones are the dominant lithology, and appear to have accumulated in low gradient rivers, which both preceded, and followed, a distinctive phase of dominantly lacustrine sedimentation. The low-gradient rivers contained a diverse assemblage of fish and amphibians.

The final episode reflected in the succession is a return to more coarse-grained sandstone accumulation. This formed the Grönlandaspis Group, which may be partly Lower Carboniferous in age, and is up to 600 m thick.

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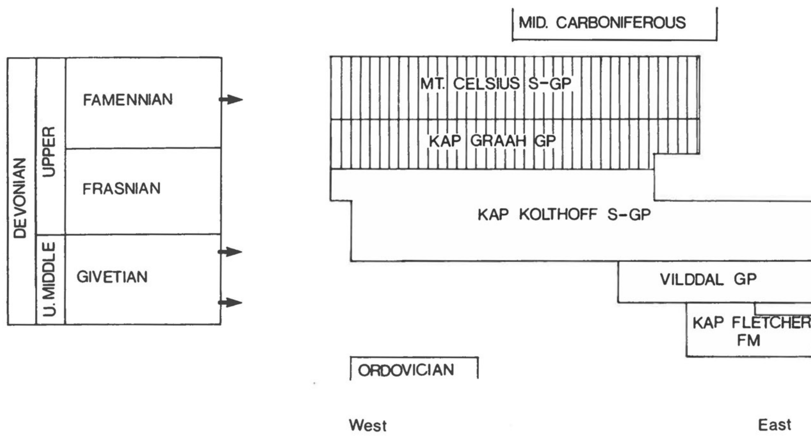

Fig. 1. Chart showing simplified stratigraphical scheme and age correlation of Devonian rocks of East Greenland. Vertical ruling indicates the two units that are the subject of this paper. Vilddal Gp should be Vilddal S-Gp (Supergroup).

INTRODUCTION

The Kap Graah Group and the Mt. Celsius Supergroup are the youngest stratigraphic units of the Devonian succession in East Greenland (Figure 1). They occur in the central parts of the Devonian outcrop area (Figure 2). The formal stratigraphic terms used in this paper are listed in an Appendix (Table 13).

This paper results from field-work carried out between summer 1968 and summer 1970 by members of the Cambridge Greenland Expeditions (Friend, 1969, 1970, 1971). These expeditions, and the general features of the sediments, have been described by Friend, Alexander-Marrack, Nicholson & Yeats, in the earlier numbers of this volume of *Meddelelser om Grønland.*

In Number 1 (Friend and others, 1976), we have also explained our development and use of a classification system for intervals of standard thickness (usually 10 m) of our sedimentary logs. The classification consists of 'sample groups', each indicated by a label (e.g. 4C), and a short description (e.g. grey-co. slst.-flat). The sample groups resulted from computer analysis, fully described in Number 1, of data from the Vilddal Supergroup and Kap Kolthoff Supergroup. In the youngest sediments, which are the subject of this paper, a classification has been used that, although identical in concept, is different in some matters of detail.

The main differences are that 1) the number of sample groups used is smaller (25 compared with 31), because some groups were found to be absent in the youngest sediments, and others were taken, arbitrarily, to be so similar that they were amalgamated; (2) the standard brief

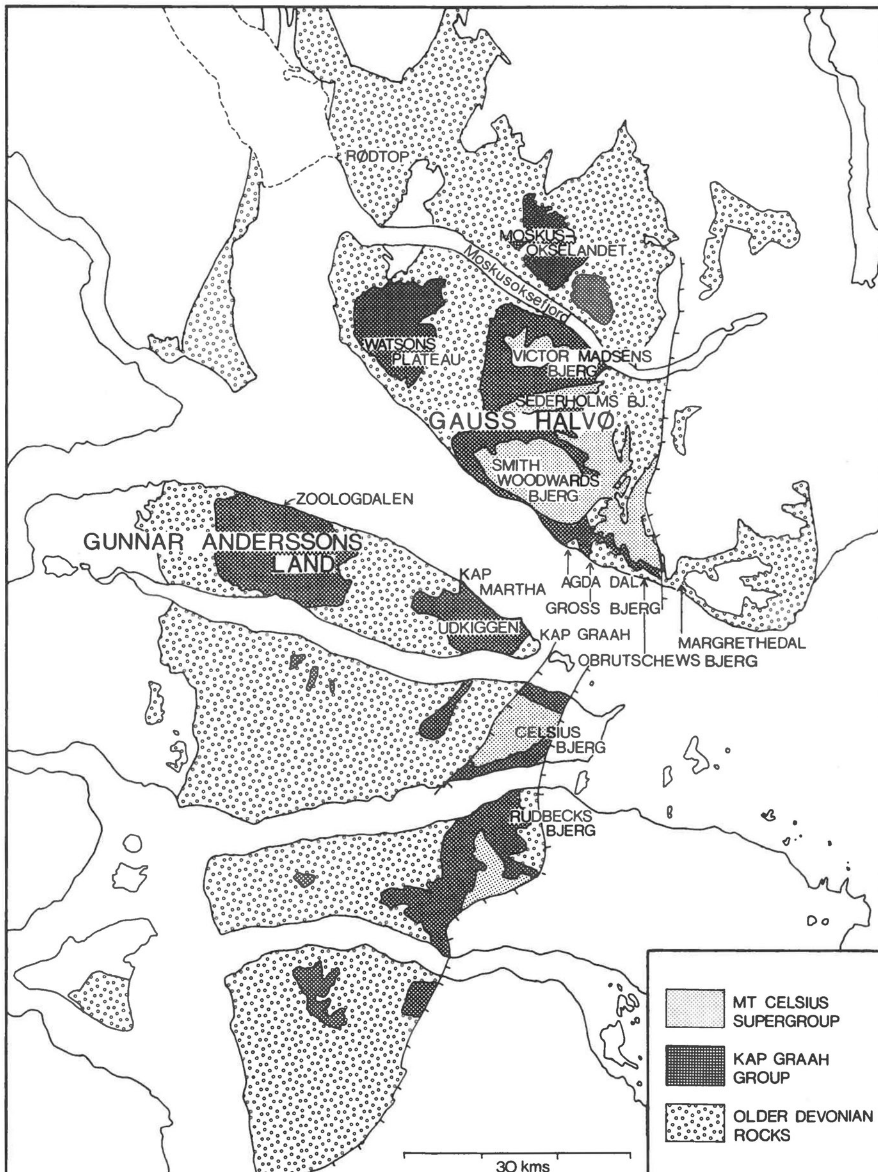

Fig. 2. Simplified geological map, showing outcrop areas of Kap Graah Group, Mt. Celsius Supergroup and older Devonian rocks.

descriptions of each sample group are summaries of a "mean sample" arithmetically defined after classification of the samples. They may not be identical to the standard descriptions used in the earlier numbers of this volume. The full list of sample groups used in this paper, with the standard brief descriptions, grain size and structure content of the mean samples, is given in Figure 3.

1A	red–f.,m.sst.–flat, trough X
1B	red–f.sst.–trough X
1C	red–f., m.sst.– trough X, flat
1D	red–f.sst.– trough X, flat
2A	red – f., m.sst.– trough X, flat
2B	red – m., f. sst.– trough X, flat
2C	red – m., co. sst.– trough X
2E	red – m., co. sst.– trough X
2F	red – m., co. sst.– trough X
2G	red – m., f. sst.– planar X, flat
3A	grey– f., m. sst.– trough X
(3B	red – f., m. sst.– flat, trough X)
3C	grey– m., f. sst.– flat, trough X
3D	grey– m., co. sst.– trough X
4C	grey– co. slst.– flat
4E	grey– co. slst., f. sst. – flat, trough X
5A	red – v. f. sst., co. slst.– trough X, flat
5C	red – co. slst., v. f. sst.– flat, asym. rip.
5D	red – m. slst.– flat, asym. rip.
6	congl.
7B	grey– f. sst.– planar X, flat
7C	grey– v. f., f. sst.– flat
7D	grey– f., v. f. sst.– trough X, flat
7E	grey– f. sst.– trough X, flat
8	red – v. f., f. sst.– flat, asym. rip.

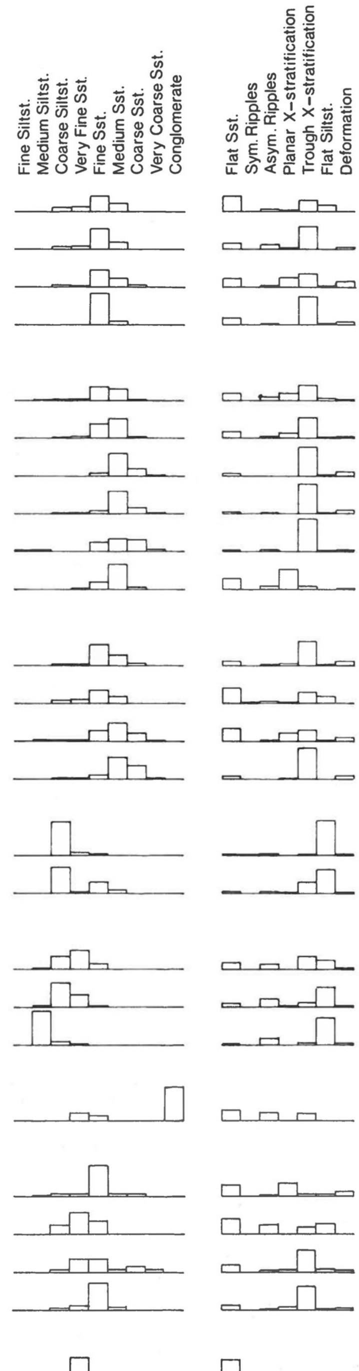

Fig. 3. List of sample groups used in the classification of the sediments. After each label (eg. 1A), is the short standard description (eg. red-f., m. sst.-flat, trough X), and histograms showing relative thicknesses of various grain-sizes and structures in a 10 m sample with the mean properties of the group.

CLASSIFICATION AND DESCRIPTION OF SEDIMENTS

In this section the properties of the most important sedimentary associations (classified, see above, as 'sample groups') are described. Some comments are made on their probable environments of deposition.

Medium and Coarse Sandstone Sample Groups
(3D, 2F, 2E, 2C, 3C, 2G)

Sample Group 3D (grey-m., co. sst.-trough X)

This consists of grey, medium cross-stratified sandstones, with subsidiary fine and coarse sandstone (Figure 4). Samples in this group have the greatest mean same-structure thicknesses of all the sample groups. The dominant structure involved is cross-stratification, though its mean set height is less in this group than in some of the finer sandstone sample groups. 3D samples tend to be more pebbly than samples from the coarser 2F sample group (red-m., co. sst.-trough X), and they have a rather higher incidence of soft sediment deformation and flat bedded sandstone. Although the content of siltstone is low in general, siltstone lenses occur in sample group 3D (grey-m., co. sst.-trough X) that are considerably thicker than those of 2F (red-m., co. sst.-trough X). It is the most common sample group in the Kap Kolthoff Supergroup, and is predominant in some parts of the Kap Graah Group also. It has three modes of occurrence (i) it forms stable monotonous successions of over 100 m, with occasional finer intervals of sample group 3C (grey-m., f. sst.-flat, trough X), or 3A (grey-f., m. sst.-trough X); (ii) it may separate conglomerates (6, congl.) from a long sequence of sandstones of sample group 2C (red-m., co. sst.-trough X) and 2E (red-m., co. sst.-trough X); (iii) rarely, it precedes a long sequence of sample group 4C (grey-co. slst.-flat).

In the first mode noted above, the palaeocurrent variance exhibited both in 10 m samples and by entire sequences of 10 m samples may be very low. Such low variance accumulations represent the deposits of a train of large-scale, medium sand bodies, most probably in a braided complex of low sinuosity channels. The pebble content is usually high, and vertebrate bones are occasionally present.

Sample Group 2F (red-m., co. sst.-trough X)

This is the coarsest sample group, with the exception of 6 (congl.). It contains more or less equal amounts of medium and coarse sandstone, with subsidiary fine sandstone (Figure 5). Almost the only structure

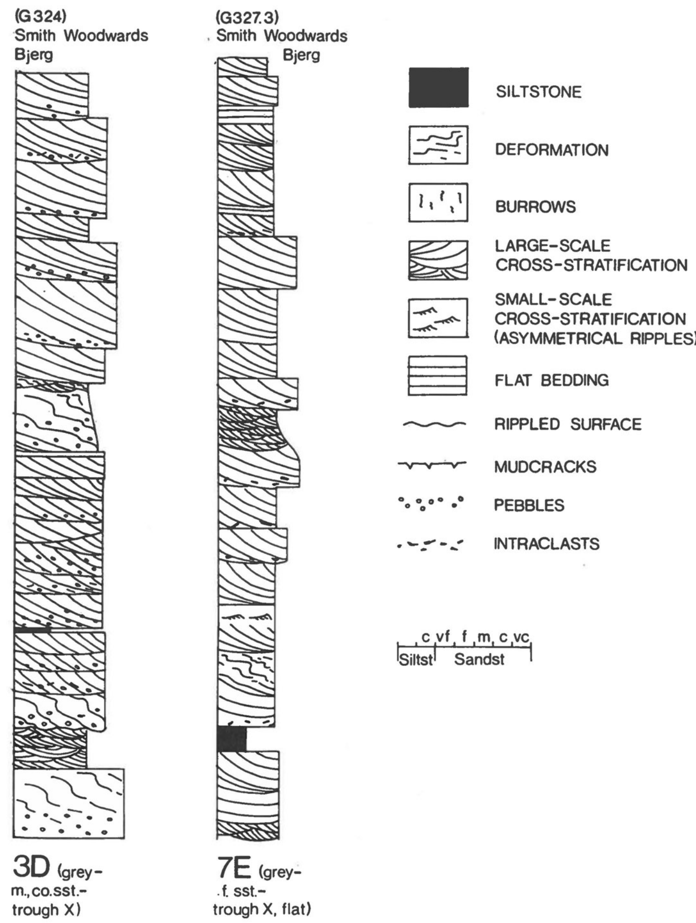

Fig. 4. Two 10 m samples chosen to illustrate sample groups 3D and 7E.
1 m represented by 1 cm.

present is cross-stratification, on various scales and almost invariably of curved foreset type. The proportion of flat bedded sandstone is the lowest of any of the sandstone sample groups. Samples from this group form short red and grey-red successions, often highly pebbly, in association with sample group 2B (red-m., f. sst.-trough X, flat), and with 2E (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X). There is only a limited association with sample group 3D (grey-m., co.sst.-trough X).

Samples of this group form a wedge of pebbly sandstones on Kap Graah, the fluvial origin of which is suggested by an abundance of scour surfaces, occasional vertebrate bones, and by a relatively low-variance unidirectional palaeocurrent distribution. This wedge was probably built up by low sinuosity, braided streams of relatively high power.

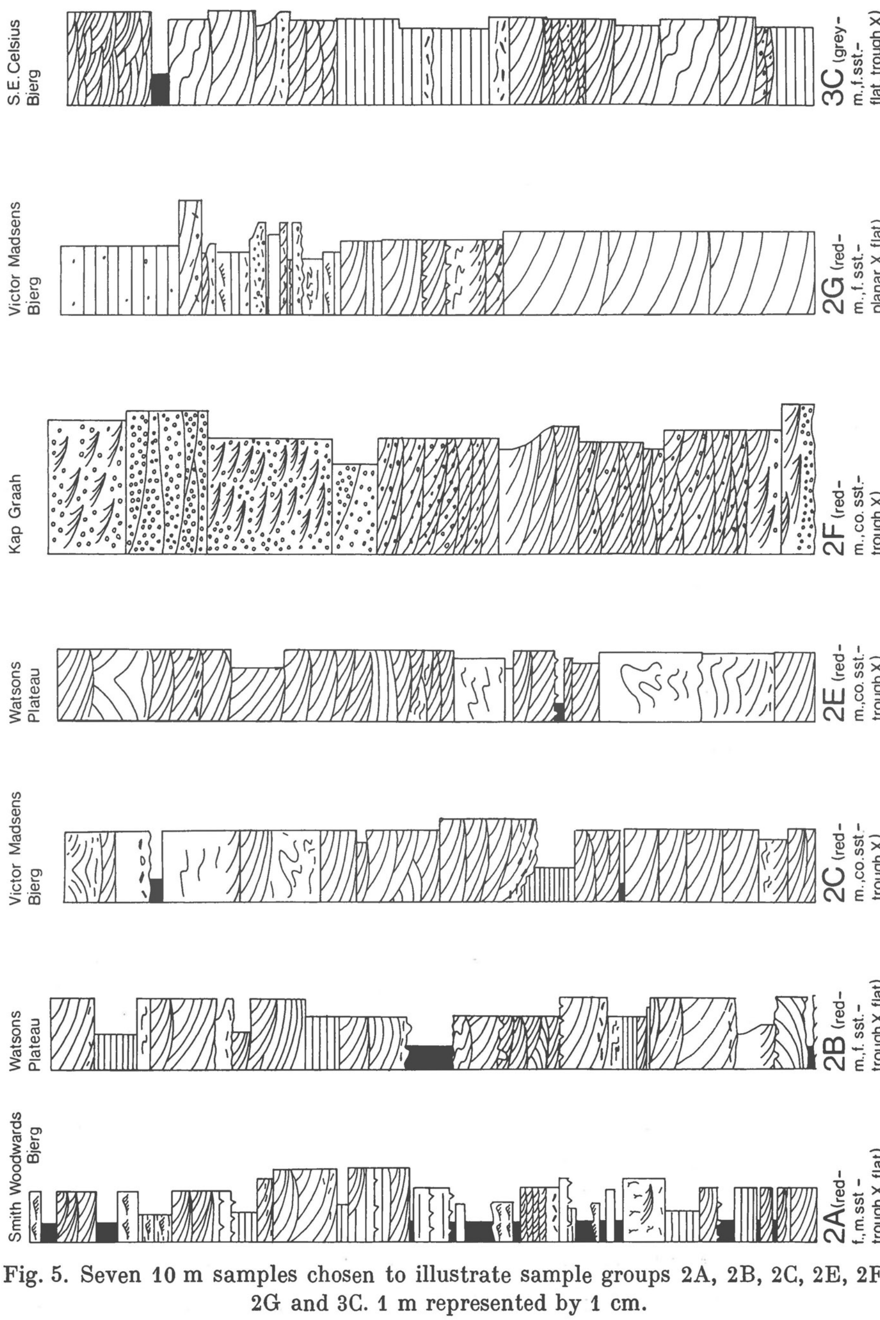

Fig. 5. Seven 10 m samples chosen to illustrate sample groups 2A, 2B, 2C, 2E, 2F, 2G and 3C. 1 m represented by 1 cm.

Sample Group 2E (red-m., co. sst.-trough X)

This may be regarded as the red equivalent of 3D (grey-m., co. sst.-trough X), to which it is very similar in its sedimentary structure and grain size distributions (Figure 5). The transition probabilities between structures are almost identical for these two sample groups. It is slightly finer grained than 3D (grey-m., co. sst.-trough X), overall, with slightly more cross-stratification and soft sediment deformation. Its mean same-structure thickness is lower than that of 3D (grey-m., co. sst.-trough X).

It is a highly self-associative sample group, i.e. it forms 'stable' successions. A sequence of up to 120 m of 2E (red-m., co. sst.-trough X) occurs on Watsons Plateau, almost wholly cross-stratified and probably of aeolian origin. In fluviatile successions it forms thinner sequences, of the order of 30 m, alternating with 2C (red-m., co. sst.-trough X). These may be pebbly, and contain siltstones. It may also overlie medium and fine sandstone intervals of sample group 2B (red-m., f. sst.-trough X, flat), and can be followed by red intervals of medium 'planar' cross-stratified sandstones of sample group 2G (red-m., f. sst.-planar X, flat). Although it is the second most important sample group, there is only a limited association with the grey medium sandstone 3D (grey-m., co. sst.-trough X).

Sample Group 2C (red-m., co. sst.-trough X)

This group (Figure 5) resembles 2E (red-m., co. sst.-trough X) and 2G (red-m., f. sst.-planar X, flat) in its grain size distribution, containing rather more medium sandstone than does 2E (red-m., co. sst.-trough X). It includes slightly more flat bedded sandstone than 2E (red-m., co. sst.-trough X), and slightly less cross-stratification. Its mean same-structure thickness is greater than that of 2E (red-m., co. sst.-trough X), and close to that of 3D (grey-m., co. sst.-trough X). Its mixed red and green-grey colouration is a point of distinction from 2E (red-m., co. sst.-trough X) and 3D (grey-m., co. sst.-trough X). With 3D (grey-m., co. sst.-trough X) it shows the highest mean siltstone lens thickness.

It is not as common as 2E (red-m., co. sst.-trough X) or 3D (grey-m., co. sst.-trough X), the longest measured succession of it being 30 m. It mainly occurs with the red medium sandstones of 2E (red-m., co. sst.-trough X), and to a lesser extent with 3D (grey-m., co. sst.-trough X), with the fine and medium grey sandstones of 3A (grey-f., m. sst.-trough X), and with 2F (red-m., co. sst.-trough X). The example of the sample group illustrated in Figure 5 is no doubt of fluvial origin, containing siltstones, clasts, and many angular and irregular scour surfaces. However, an interval of 2C (red-m., co. sst.-trough X) on S. Udkiggen may be of aeolian origin: its cross-strata were of planar foreset type.

Sample Group 3C (grey-m., f. sst.-flat, trough X)

This group (Figure 5) differs from the fine and medium sandstone 2B (red-m., f. sst.-trough X, flat) in its content of coarse sandstone, and from the other medium sandstone groups in its higher content of flat bedded sandstone and in the development of planar foreset cross-stratification. It contains a higher proportion of flat bedded sandstone than any other sample group (Figure 3), and shows a markedly low content of cross-lamination.

Sample group 3C (grey-m., f. sst.-flat, trough X) has a strong association with the grey medium sandstone 3D (grey-m., co. sst.-trough X) and it may perhaps be regarded as a slightly finer variant of the latter. In addition to this mode of occurrence, it may overlie grey fine sandstone sample groups 7C (grey-v. f., flsst.-flat), 7B (grey-f. sst.-planar X, flat), 7E (grey-f. sst.-trough X, flat); or the slightly coarser red-grey 2A (red-f., m. sst.-trough X, flat) and 2C (red-m., co. sst.-trough X), as a passage into 3D (grey-m., co. sst.-trough X) or 2E (red-m., co. sst.-trough X); and, rarely, it may separate 3D (grey-m., co. sst.-trough X) from 7D (grey-f., v. f. sst.-trough X, flat) in a fining sequence. Its association with major successions of 3D (grey-m., co. sst.-trough X), the combination of flat bedded sets (probably originating in upper flow regime conditions) and cross-stratification, and the presence of occasional fish fragments, suggest that 10 m intervals of the sample group represent fluvial sediments.

Sample Group 2G (red-m., f. sst.-planar X, flat)

This group (Figure 5) contains subsidiary fine sandstone. Among the medium sandstone sample groups its characteristic feature is its content of planar foreset and bottomset cross-stratification, with only minor development of curved foreset cross-stratification. It also contains a notable amount of flat bedded sandstone.

The greatest thickness of this sample group observed was 20 m. It occurs in red fine and medium sandstone successions, with 2A (red-f., m. sst.-trough X, flat) and 1C (red-f., m. sst.-trough X, flat), or in slightly coarser red intervals of 2C (red-m., co. sst.-trough X), 2E (red-m., co. sst.-trough X) and 2F (red-m., co. sst.-trough X). It is not a relatively common sample group.

The Fine and Medium Sandstone Sample Groups
(3A, 2B, 2A, 1C, 1B)

These five sample groups are distinguished from each other primarily by their grain size distributions, rather than by particular development of sedimentary structures. All of them exhibit curved foreset cross-stratification, and minor bottomset type. As will be shown below, their spatial distribution is systematic in the Kap Graah Group.

Sample Group 3A (grey-f., m. sst.-trough X)

In this sample group medium sandstone is subsidiary to fine sandstone. It exhibits the greatest mean cross-stratification thickness of the five sample groups and its content of flatbedded sandstone is minor. Soft-sediment deformation is relatively common, for the fine-medium sandstone sample groups, as are extraformational clasts.

3A (grey-f., m. sst.-trough X) occurs primarily as short, finer intervals within thicker successions of grey medium sandstones (3D, grey-m., co. sst.-trough X). A second, subsidiary mode of occurrence is with 7E (grey-f. sst.-trough X, flat), 7D (grey-f., v. f. sst.-trough X, flat), and 7B (grey-f. sst.-planar X, flat), when it forms slightly coarser intervals in predominantly fine sandstone fluvial units.

Sample Group 2B (red-m., f. sst.-trough X, flat)

In this group (Figure 5) medium sandstones (mainly red) predominate slightly over fine sandstones, and slightly less siltstone is present than in the other fine and medium sandstone sample groups. The cross-stratification mean samestructure thickness is less than that of 3A (grey-f., m. sst.-trough X), and similar to those of 2A (red-f., m. sst.-trough X, flat) and 1C (red-f., m. sst.-trough X, flat). In its other properties it is intergradational with the other sample groups in this category.

It is a poorly documented sample group. A succession of 30 m is the maximum recorded, overlain by red medium sandstones of 2E (red-m., co. sst.-trough X). The irregular scour surfaces seen in the example of Figure 5 are suggestive of a fluviatile origin for that 10 m interval. No same-structure thicknesses greater than 2 m are present in the section.

Sample Group 2A (red-f., m. sst.-trough X, flat)

This group (Figure 5) resembles 2B (red-m., f. sst.-trough X, flat) overall, except that fine and medium sandstones are of equal importance. Its siltstone content is relatively high. It forms thin bedded successions containing mudcracks, ripple cross-laminae, and fish fragments. Indications of bioturbation have been observed.

The sample group occurs in grey-red 10–20 m units, within larger intervals of coarser sandstones. It may follow 3D (grey-m., co. sst.-trough X), 3A (grey-f., m. sst.-trough X) or 3C (grey-m., f. sst.-flat, trough X), and is usually succeeded by 1B (red-f. sst.-trough X) or 2C (red-m., co. sst.-trough X).

Sample Group 1C (red-f., m. sst.-trough X, flat)

This group consists predominantly of red fine sandstones, and is characterised by its development of cross-stratification of planar and curved foreset types. The mean same-structure thickness is low. Flat-bedded sandstones are important, and soft-sediment deformations are numerous. It contains few clasts. No vertebrates were observed in the sample group.

It has been recorded in successions of up to 30 m, usually following 2G (red-m., f. sst.-planar X, flat) or 1B (red-f. sst.-trough X) and overlain by 2E (red-m., co. sst.-trough X). In its association with the red medium sandstones of 2E (red-m., co. sst.-trough X) it may represent a relatively finer aeolian interval. In other associations it may represent a finer fluviatile sequence.

Sample Group 1B (red-f. sst.-trough X)

This group includes little medium sandstone. In common with 7D (grey-f., v. f. sst.-trough X, flat) it contains an abundance of small sets and therefore exhibits very low mean set and same-structure thickness. Planar type cross-stratification is not present. Ripple cross-lamination is relatively well-developed, and the occasional siltstones which occur tend to be thicker than in the other fine and medium sample groups. Intraformational conglomerates are common, but extraformational clasts are absent.

It was recorded infrequently, in association with fine-medium sandstones of 2A (red-f., m. sst.-trough X, flat), and with the red siltstones and fine sandstones of 5A (red-v. f. sst., co. slst.-trough X, flat), in units of up to 20 m.

Fine Grained Sandstone Sample Groups
(7E, 7D, 7B)

Sample Group 7E (grey-f. sst.-trough X, flat)

This group (Figure 4) exhibits greater development of cross-stratification than the other fine sandstone sample groups, with a relatively low content of flat-bedded sandstone. It is characterised by its mean cross-stratification same-structure thickness, which is considerably greater than those of the other fine sandstone sample groups.

It commonly succeeds intervals of the fine and medium sandstone sample group 3A (grey-f., m. sst.-trough X), and to a lesser extent those of 3C (grey-m., f. sst.-flat, trough X). It may form successions of up to 50 m; alternatively it may initiate a unit of predominantly fine sandstone, including 1B (red-f. sst.-trough X) or 7B (grey-f. sst.-planar X, flat).

10 m intervals of this sample group, consisting almost entirely of cross-strata, represent the deposits of large scale ripple trains. These might be aeolian, but the prevalence of clasts and scour surfaces, of soft-sediment deformations, and the occasional presence of vertebrate bones, suggest that they originated in fluvial channels.

Sample Group 7B (grey-f. sst.-planar X, flat)

This group shows the strongest fine sandstone mode. In contrast with 7E (grey-f. sst.-trough X, flat) it contains a high proportion of flat bedded sandstones, and accordingly exhibits the least development of cross-stratification of any sandstone sample group. A feature of the sample group is its development of soft-sediment deformations.

As with 7D (grey-f., v. f. sst.-trough X, flat) there are few section data to indicate its associations. It occurs with 3A (grey-f., m. sst.-trough X) at several localities, and to a lesser extent with 3C (grey-m., f. sst.-flat, trough X). All the intervals classified in this sample group are thought to be of fluvial origin.

Sample Group 7D (grey-f., v. f. sst.-trough X, flat)

This group is characterised by its development of fine and very fine sandstone, more or less in equal proportions, and by its relatively high siltstone content. Its mean same structure thickness and set heights are relatively inconsiderable. Its siltstone content is the highest seen in the sandstone sample groups, and there is a high probability of it containing intraformational clasts, and vertebrate remains. It resembles the red siltstone/fine sandstone sample group 5A (red-v. f. sst., co. slst.-trough X, flat) in many respects, and may be preceded or succeeded by it; or may be succeeded by 3A (grey-f., m. sst.-trough X).

Distribution of Siltstone amongst the Sandstone Sample Groups

Lenticular Siltstones

Siltstones show predominantly lenticular geometry (Plate 1) in the sandstone sample groups, commonly reaching 2 m in thickness. They rest on scour surfaces, and are also sharply bounded above by erosion surfaces. Table 1 lists the sedimentary structures present in five lenses from a measured section classified in sample group 2C (red-m.,

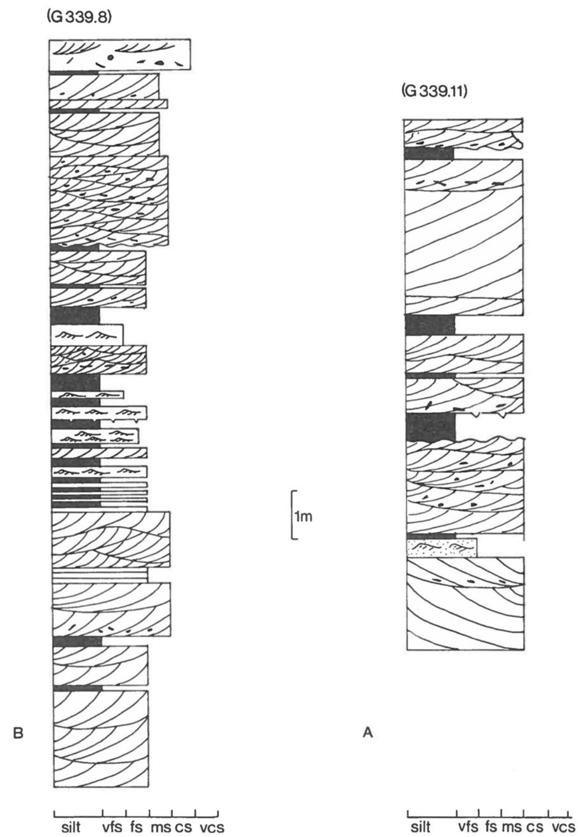

Fig. 6. Two types of Kap Graah Group siltstone bodies:
A) lenses bounded by scour surfaces, 870 m, Gross Bjerg,
B) laterally extensive siltstones not bounded by scour surfaces, 890 m, Gross Bjerg.

co. sst.-trough X) and Figure 6 shows a measured section containing two typical siltstone lenses.

Lenticular siltstones frequently contain sandstone horizons with ripple forms and small-scale cross-laminae; occasionally their basal layers contain intraformational clasts; rarely do they fine upwards. Table 2 details lens mean thicknesses and their carbonate and cross-lamination content, for the sandstone sample groups. The mean thicknesses are based on observed maxima, which may vary considerably within a sample group.

Lenticular siltstone bodies very similar to those of Figure 6 have been described by SELLEY (1969, p. 336–7) who considers them to be the deposits of abandoned channels. ALLEN (1965a) presented a braided river model in which such siltstones were included; and in a modern braided river complex RUST & WILLIAMS (1969) noted that many channels and troughs associated with large bed forms were being filled by fine sediments. DOEGLAS (1962, p. 179) described the accumulation of silt and clay in braided stream channels whose upstream ends had been closed by bar migration.

Thin-bedded Sandstone-Siltstone Successions

These successions in the sandstone sample groups, exemplified by Figure 6, are comparatively rare. Their characteristic features are the absence of a basal scour surface, and their considerable lateral extent. Intervals of this type may be up to 5 m thick. For a very similar

Table 1. *Properties of five lenticular siltstone deposits from interval of sample group 2C, Victor Madsens Bjerg.*

Thickness metres)	mudcracks	lithology	asym-metrical ripples	in situ carbonate nodules
2.0	×	siltstone sandstone	×	×
0.2	–	siltstone	×	×
0.5	–	siltstone	–	–
0.4	×	siltstone sandstone	×	×
1.5	–	siltstone	×	×

Table 2. *Data on lenticular siltstone bodies in the sandstone sample groups: 270 records.*

Sample Group	Mean lens thickness (m)	% with cross-laminae	% with in situ carbonate nodules
7D	0.15	5 %	–
1B	0.40	33 %	33 %
7B	0.19	6 %	–
1C	0.15	–	–
2A	0.35	7 %	–
2B	0.26	33 %	–
3A	0.22	–	16 %
3C	0.18	–	–
2G	0.10	–	–
2E	0.07	25 %	14 %
7E	0.17	20 %	10 %
2F	0.15	33 %	–
2C	0.40	14 %	21 %
3D	0.43	7 %	7 %

Table 3. *Approximate number of siltstone partings per 10 metre interval, sandstone sample groups. 320 records.*

Number of siltstone partings	7 D	1 B	7 B	1 C	2 A	2 B	3 A	3 C	2 G	2 E	7 E	2 F	2 C	3 D
	5	4	3	1	3	2	2	2	4	2	2	1	2	1

siltstone-sandstone complex to that illustrated, SELLEY (1969, p. 335–336) favoured a floodplain origin, primarily because of the absence of a basal scour surface.

McGOWAN & GARNER (1970, p. 86) have described modern chute deposits which resemble them. These were up to 2 m thick and 10 m in width, containing an infill of sands and structureless muds. The sedimentary structures of the sands varied from parallel lamination on the margin, through climbing ripple cross-laminae, to small-scale cross-laminae in the chute axis. It is not clear whether or not the base of the unit was a scour surface.

Isolated Siltstone Partings in the Sandstone Sample Groups

These usually separate cosets of cross-strata. They are very variable in their lateral extent, and are commonly between 2–10 cm in thickness. They consist usually of sandy siltstone, often micaceous and poorly-bedded; some contain ripple cross-laminae. Their abundance in the sandstone sample groups is shown in Table 3.

From the Rio Grande, HARMS & FAHNESTOCK (1965, p. 97) described silt deposits up to 10 cm thick, extending over large areas of the channel floor and presumed to be deposits from suspension at low stage. A similar origin for the partings seems likely.

In contrast with the isolated partings in the sandstone sample groups, complexes of siltstone and sandstone laminae and beds are very common in sample groups 5A red-v. f. sst., co. slst.-trough X, flat) and 5C red-co. slst., v. f. sst.-flat, asym. rip). An overbank origin may be attributed to many of these.

Siltstone Sample Groups

Sample groups 4C (grey-co. slst.-flat) and 5D (red-v. f. sst., co. slst.-trough X, flat) consist almost entirely of siltstone and silty mudstone, grey and red respectively. These lithologies also form an important proportion of sample groups 5A (red-v. f. sst., co. slst.-trough X, flat), 5C (red-co. slst., v. f. sst.-flat, asym. rip.) and 4E (grey-co. slst., f.sst.-flat, trough X).

Sample Group 5A (red-v. f. sst., co. slst.-trough X, flat)

Plates 2 and 3 illustrate the highly distinctive appearance of this sample group. It consists of red flatbedded siltstones and red, cross-

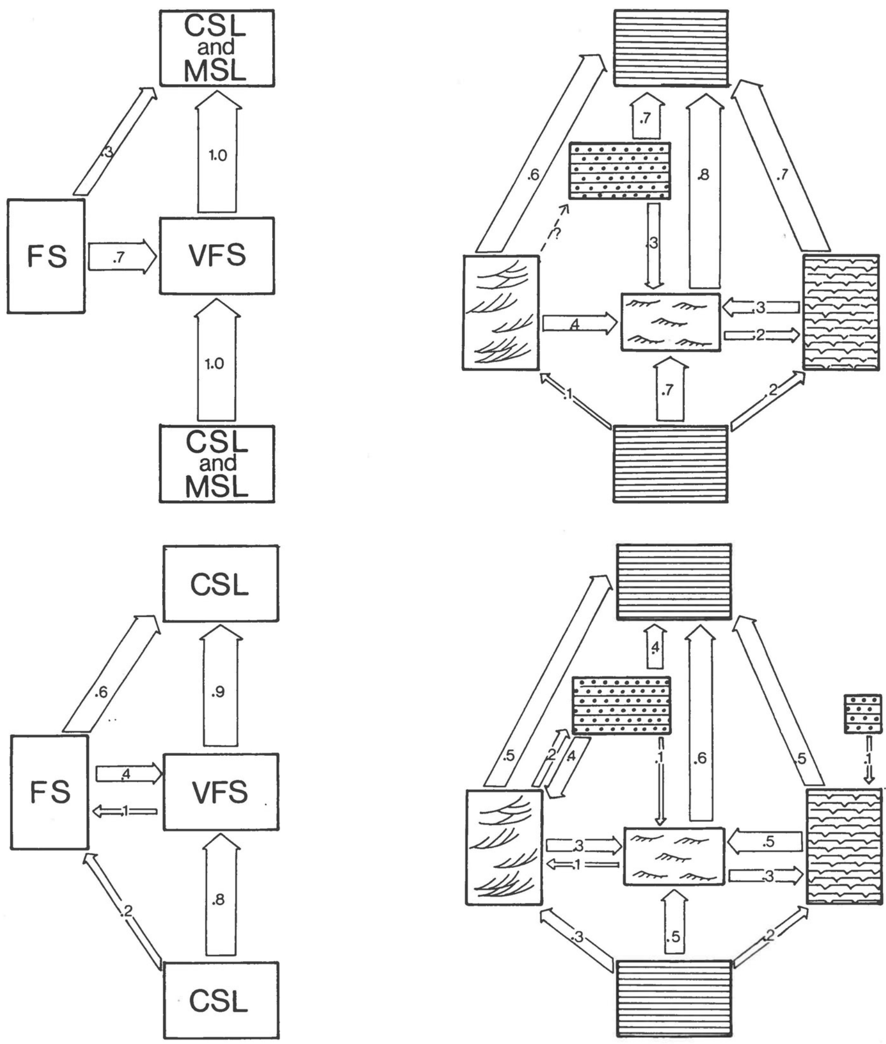

Fig. 7. Transition probability plots for grain-size and structure. Upper diagrams based on 190 m of 10 m samples classified in group 5 C. Lower diagrams based on 120 m of 10 m samples classified in group 5A. MSL—medium siltstone, CSL—coarse siltstone, VFS—very fine sandstone, FS—fine sandstone, Structures indicated are large cross-bedding, small (ripple) cross-stratification, flat bedded siltstone (with and without desiccation cracks), flat bedded sandstone.

stratified and flat-bedded very fine sandstones. Fine sandstones are also present.

The mean cross-stratification coset height is slightly greater than that of sample group 5C (red-co. slst., v. f. sst.-flat, asym. rip.), but the mean set height is relatively less. The cross-stratification is of type 3 (low angle) with no representatives of types 1 and 2 (planar and curved). Foreset dips of 5–10° are usually observed, and their dip direction in a particular exposure may be strongly oblique to the palaeocurrent vector mean as determined from the surrounding sediments. Occasional irregular soft-sediment deformation of foresets is present.

The bases of the cosets are commonly scour surfaces, often irregular, and they bear more flute and tool marks than do those of sample group 5C (red-co. slst., v. f. sst.-flat, asym. rip.). Above the scour surfaces intraformational conglomerates are usually present, in which vertebrate remains are commonly found. Extraformational clasts are only present where the 10 m interval immediately overlies an unconformity surface, or a conglomerate division.

Flat-bedded sandstones occur in the upper parts of the sandstone units or succeeding the main cross-stratified cosets, as Figure 7 indicates. They are of approximately the same thickness as in sample group 5C (red-co. slst., v. f. sst.-flat, asym. rip.), modally of very fine sandstone, and frequently contain primary current lineation. The probability of occurrence of this latter structure is higher in sample group 5A (red-v. f. sst., co. slst.-trough X, flat) than in 5C (red-co. slst., v. f. sst.-flat, asym. rip.).

Asymmetrical ripples and cross-laminae usually directly succeed cross-stratified beds, but they may follow very fine flat-bedded sandstones They also appear within siltstone units (Figure 7).

The flat-bedded siltstones may be up to 1.7 m thick, extending laterally until cut out by the basal scour surface of an overlying sandstone unit. They frequently contain cross-laminae, and often exhibit concretionary carbonate development. Comparative data on typical siltstone sheet development in the siltstone sample groups are given in Table 4.

Bioturbation structures are commonly well-developed in sample group 5A (red-v. f. sst., co. slst.-trough X, flat), and typical structures are illustrated in Number 2 of this volume. Details of the vertebrates recorded in this sample group are given in the same Number.

Sample Group 5D (red-m. slst.-flat, asym. rip.)

This group consists of red medium and coarse sandy siltstones, with high content of clay and only a minor proportion of very fine sandstone.

The shoreline cliffs of Aina Dal, illustrated in Plates 4 and 5, consist in their upper part of sample group 5D (red-m. slst.-flat, asym. rip.). The shoreline is more or less at right-angles to the palaeoslope determined for the Aina Dal Formation at this locality. No very fine sandstones are present in the 5D (red-m. slst.-flat, asym. rip.) succession, which consists of sheets of siltstone exhibiting cross-cutting relations. In the walls of the Aina Dal waterfall (Plate 5), which provide cliff sections approximately parallel to the palaeoslope, greater lateral continuity of the sheets is evident and their mutual relationships are less discordant.

Table 4. *Data on siltstone sheets, from 460 records. Siltstone intervals in 4E are frequently only partially exposed.*

	4C	5D	5C	5A	4E
Colour.................	Grey > Red	Red	Red	Red	Grey
Mean thickness (metres)..	1.2	1.6	0.7	0.7	1.8
% with crosslaminae.....	< 5 %	31 %	15 %	22 %	?
% with in situ carbonate nodules................	(granules)	12 %	5 %	4 %	?7 %

The siltstone sheets may be up to 4.5 m thick, but are more usually between 1–1.5 m (Table 4). Their bases are smooth, plane or slightly undulose. Inclined bedding surfaces can be discerned within the sheets (Plate 4), dipping at angles of less than 15°. Asymmetrical ripple cross-laminae indicate palaeocurrent flow approximately parallel to the strike of the inclined surfaces, and it is possible that they represent successive depositional surfaces formed during infilling of large channels.

Intraformational conglomerates are frequent, with siltstone clasts attaining 5 cm; some contain only carbonate nodules. No extraformational clasts have been collected from sample group 5D (red-m. slst.-flat, asym. rip.). In almost all instances there is a high mica content.

In successions in which this sample group alternates with 5C (red-co. slst., v. f. sst.-flat, asym. rip.), or is adjacent to it, beds of very fine sandstone are present in limited numbers. This situation is mainly seen on Celsius Bjerg. In such beds asymmetrical cross-laminae are very common, and ripple forms are preserved on their upper surfaces. Interference patterns and low symmetrical ripple forms have been observed.

As Figure 8 shows, transitions from siltstones to fine sandstones may occur. These sandstones show cross-stratification of type 3 (low angle) and tend to be more irregular in geometry than those of 5A (red-v. f. sst., co. slst.-trough X, flat). The base is usually scoured, with intraformational conglomerate; and the coset usually passes upwards to siltstone, perhaps via an interval of cross-lamination. Flat-bedded sandstones with primary current lineation are very rare indeed.

Mudcrack surfaces are very common, with up to 13 extensive horizons present in a 10 m interval. They occur within siltstone successions, or may be present on the upper bedding surfaces of very fine sandstone beds (Figure 7).

Poorly-developed concretionary carbonate nodule horizons are occasionally present. Other evidence of the development of carbonates after deposition of the siltstones was afforded by examination of thin sections, in which rhombs of dolomite (some possibly reworked) were common.

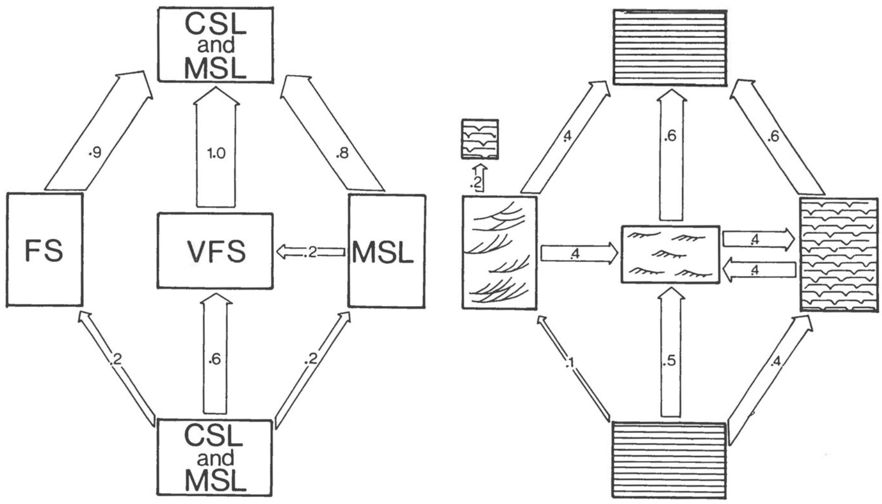

Fig. 8. Transition probability plots for grain-size and structure in 150 m of 10 m samples classified in group 5D. Symbols as for Fig. 7.

The vertebrate fauna is prolific in sample group 5D (red-m. slst.-flat, asym. rip.) at Aina Dal, the bones almost all single. *Ichthyostega* and *Soederberghia* crania were found here, in addition to the ubiquitous *Remigolepis* and *Holoptychius*. Trace fossils are rarely observed in the siltstones, but bioturbation indications are common in cross-laminated sandstones. Plant remains in these red rocks are very uncommon.

Sample Group 5C (red-co. slst., v. f. sst.-flat, asym. rip.)

In some respects sample group 5C (red-co. slst., v. f. sst.-flat, asym. rip.) is intermediate in its properties between 5A (red-v. f. sst., co. slst.-trough X, flat) and 5D (red-m. slst.-flat, asym. rip.). It consists of red, coarse flat-bedded siltstones with subsidiary red, cross-laminated and cross-bedded very fine sandstones. A typical example of the sample group is shown by Figure 9. Its sandstone bodies are of three types:

(1) Very fine sandstone cosets, of slightly-reduced mean height relative to those of 5A (red-v. f. sst., co. slst.-trough X, flat). They usually rest on a scoured surface, invariably on siltstone beds. They are composed of sets of type 3 (low angle), of irregular geometry such that palaeocurrent data are difficult to obtain from the cross-stratification. Flat-bedded sandstones with primary current lineation are present sparingly, above the cosets. Soft-sediment deformations occur within the cosets, usually irregular warps, but cuspate deformations have been recorded. Over half of the cosets are directly succeeded by flat-bedded siltstones, the remainder by cross-laminated horizons.

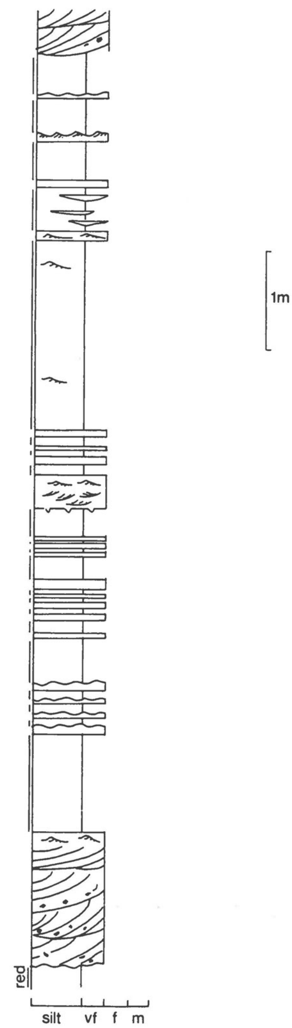

Fig. 9. 10 m sample chosen as typical of group 5C.

Intraformational conglomerates are slightly less likely to occur than in 5A (red-v. f. sst., co. slst.-trough X, flat). They tend to contain smaller clasts, and carbonate fragments often predominate.

(2) Extensive lenticular very fine sandstones occur, which are entirely cross-laminated. Linguoid and straight-crested ripples are associated with them, frequently preserved on the upper bedding surfaces. The mean thickness of these units is 0.45 m. Unlike the cosets they may be superimposed on each other.

Their bases are sharp and smooth, but rarely show evidence of scouring. Some exhibit mudcrack polygon infillings. Figure 8 shows that a transition from siltstones to one of these units is a more probable event than to a coset. They are most unlikely to be succeeded directly by a coset.

They contain abundant indications of bioturbation, and occasional fish fragments. Irregular soft-sediment deformations disturb the cross-laminae.

(3) Cross-laminated sandstone beds, generally about 5 cm thick, frequently occur within siltstone sheets. They may occur singly or in groups, with or without rippled top surfaces. Thinner units of this type are often broken into plates, during compaction, as a result of the ductility contrast between them and the containing siltstones; these may be developed into pseudo-nodules.

The siltstones of this sample group are thinner than those of 5D (red-m. slst.-flat, asym. rip.), and are of more or less the same thickness as those of 5A (red-v. f. sst., co. slst.-trough X, flat). One channel infilling of sandy siltstone has been observed in this sample group, with a concentration of bones at the base.

Sample Group 4C (grey-co. slst.-flat)

Sample group 4C (grey-co. slst.-flat) is volumetrically the most important sample group of the Mt. Celsius Supergroup. It consists of grey, and subsidiary red, flat-bedded siltstones which contain a variable but usually high clay content. Discrete groups of thin-bedded siltstones are present, and these contain most of the small-scale sedimentary structures: cross-laminae; convolute laminae; and desiccation cracks.

The description given here of the typical development of the sample group is based on sections measured in the Wimans Bjerg Formation, (Figure 51) at Stensiøs Bjerg. This Formation consists entirely of sample group 4C (grey-co. slst.-flat). Minor amounts of very fine sandstone are present in 10 m intervals of the sample group at other stratigraphic levels.

Figure 10A and Plate 6 illustrate the transition at Aina Dal between sample group 5D (red-m. slst.-flat, asym. rip.) and the Wimans Bjerg Formation. Figure 10B represents a typical interval from the upper half of the Formation. The transition is 20 m thick, with a gradational top and base. It consists of red-grey muddy siltstones, alternating with sandy siltstone beds up to 12 cm thick; these contain symmetrical and asymmetrical cross-laminae, and convolute laminae. Towards the upper part of the transition these thinner siltstones begin to occur in groups, separated by 1–1.5 m intervals of more or less structureless siltstone.

With reddening of the lower part of the siltstone bed which separates the groups (hereafter termed "complexes"), a characteristic unit

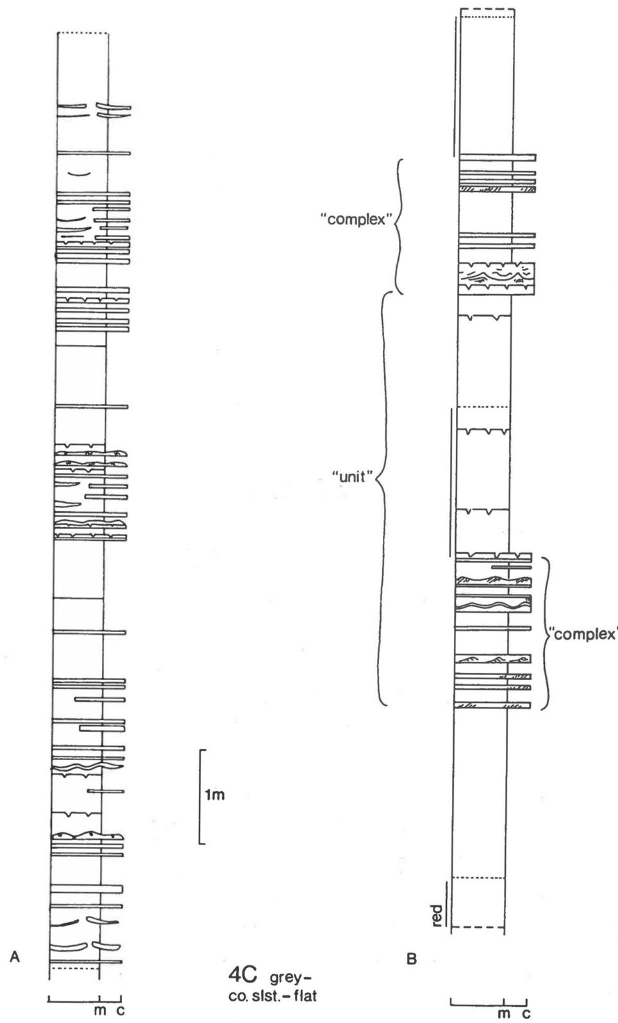

Fig. 10. A) Log of transition, at Aina Dal, between sample group 5D (red-m. slst.-flat, asym. rip.) and 4C (grey-co. slst.-flat). The latter forms the base of the Wimans Bjerg Formation.
B) 10 m sample classified in group 4C, typical of upper Wimans Bjerg Formation.

is developed which dominates the following succession. Figure 10B shows two of these units, which occur in sequence with remarkable regularity in the upper part of the Wimans Bjerg Formation. In the lower half of the 200 m Formation they tend to be less-uniformly developed.

No sandstone beds or vertebrate remains are found in the entire succession of the Formation, on Stensiøs Bjerg or elsewhere on Gauss Halvø. The unit is made up by the following components:

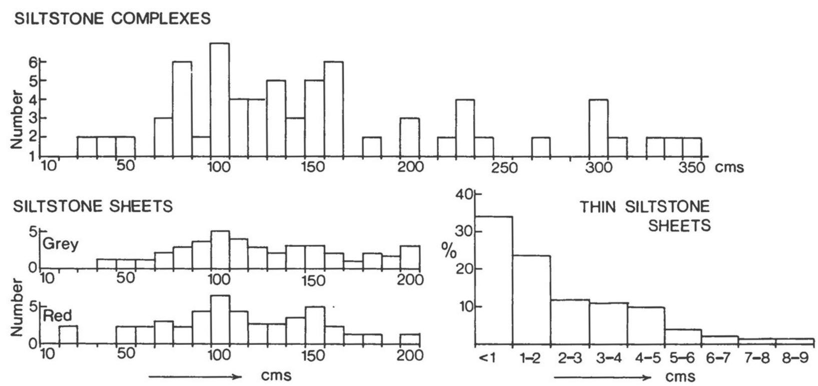

Fig. 11. Thickness distribution of siltstone complexes and sheets in sample group 4C.

(1) Flat-bedded Siltstone Sheets, grey or red, are usually about 1 m thick (Table 4). Their thickness distribution is given in Figure 11. The grey siltstones may reach 3.5 m in thickness, the red siltstones rarely exceed 2 m. Neither type is flat-laminated, both are poorly-sorted.

Most of the red siltstones contain scattered, pink calcium carbonate granules, but development of definite nodular horizons is atypical and has only been recorded at one locality. Grey siltstone beds do not contain these carbonate granules.

The grey and red siltstone sheets both contain desiccation-cracked surfaces. In slightly coarser siltstone asymmetrical ripple cross-laminae are occasionally present, but they do not occur in well-defined horizons. No scour surfaces, tool marks, or soft-sediment deformations are observed in the siltstones, and no clast concentrations are present.

As Figure 12 indicates, the red siltstones may pass gradationally into grey siltstones, but transitions from grey to red siltstones are rare. Grey siltstones are highly likely to pass into a "complex", but red siltstones rarely do so.

(2) Thin-bedded Cross-laminated Siltstones composed mainly of medium-grained siltstone but also showing a high content of fine siltstone, and minor amounts of very fine sandstone. Their clay content is considerably less than that of the flat-bedded siltstones, and their grains may exhibit a high degree of size-sorting. They are cemented by calcium carbonate, and also contain dolomite rhombs which have grown in situ. The thickness distribution of the complexes in which they occur is detailed in Figure 11. For descriptive purposes two categories are distinguished: those beds less than 10 cm thick, and those over 10 cm. The thickness distribution of thin-bedded siltstones less than 10 cm thick is given in Figure 11. They are typically no more than 0.5–1 cm

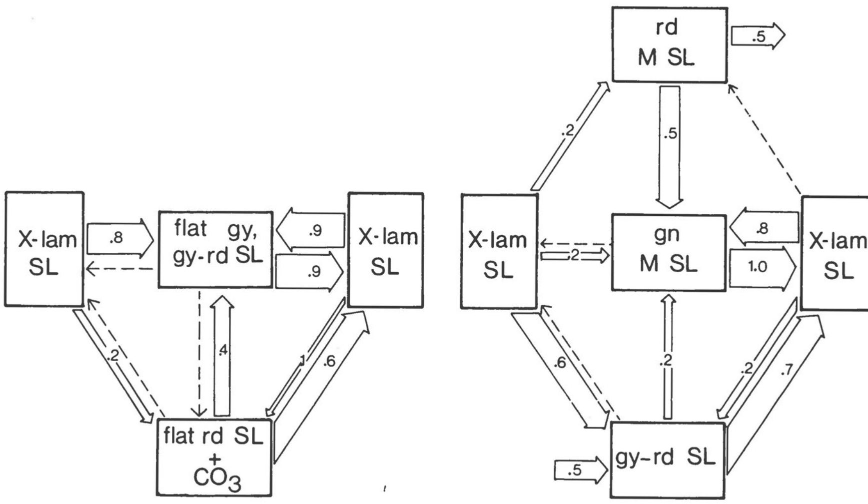

Fig. 12. Transition probability plots for distinctive lithologies in samples classified as 4C. left—normal, right—green variant.

thick, but they are laterally extensive and even those only 0.5 cm thick may extend for 4.5 metres. The thicker beds frequently extend beyond the confines of the outcrops; Plate 7 gives an impression of their geometry.

Units thicker than 10 cm comprise approximately 7 % of the total of thin-bedded siltstones measured on Stensiøs Bjerg, and a much lower proportion of those observed on Obrutschews Bjerg. They may be composite (formed of several thinner beds), as seen in Plate 8, but over two thirds of them are singly-constituted (Plate 9). The thicker units, which may attain 30 cm at maximum, are usually sharply-defined by a planar lower surface.

The most characteristic internal structure of the thin-bedded siltstones is cross-lamination. Asymmetrical cross-laminae at the base of a bed are frequently followed by symmetrical draping of laminae, and then, particularly in beds over 10 cm thick, by flat-laminated or structureless siltstone which fills the ripple-troughs, resulting in a plane upper bedding surface. Only approximately 11 % of the thicker siltstones exhibit ripple-marked upper surfaces. In most of the thinner units such ripple-form infillings are not developed. Ripples exposed on upper bedding surfaces are usually symmetrical, with wavelengths of up to 20 cm. They yield consistent palaeocurrent directions within one bedding surface area, and interference patterns are rather rare.

Ripple-marked surfaces are often associated with desiccation cracks, particularly when they bear a veneer of fine silt or clay laminae. 30 % of the thin-bedded siltstones have desiccation cracks on their upper sur-

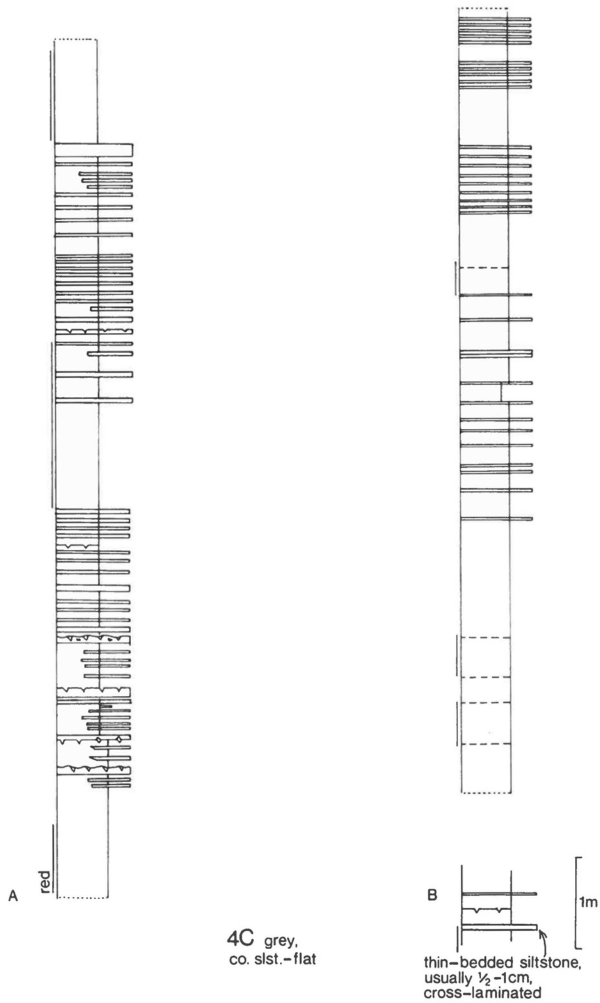

Fig. 13. A) Log of succession typical of green variant of sample group 4C.
B) Log of succession typical of fine-grained variant of sample group 4C.

faces; these usually form polygons (up to 30 cm in diameter and 20 cm in depth) but concentric patterns have been observed, with radial cracks from the centre.

Soft-sediment deformation within the thin-bedded siltstones is common, and may be of considerable complexity. The thicker beds tend to contain more deformations, with internal convolutions and pseudonodules. An illustration of one of these convolute deformations is given in Number 2 of this volume, and they can be seen in Plate 8.

Two deviations from the general development of the sample group outlined above will be noted here.

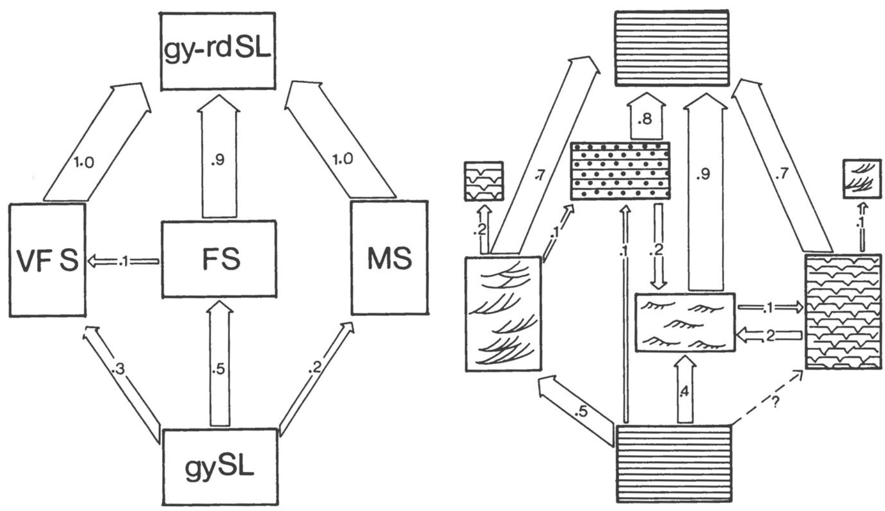

Fig. 14. Transition probability plots for samples classified in group 4E. Symbols as in Fig. 7 with addition of MS—medium sandstone.

In the upper 30 m of the Wimans Bjerg Formation an interesting series of green, finer siltstone divisions is present, classifying into sample group 4C (grey-co. slst.-flat). Figure 13A illustrates one of these intervals. They differ from the usual unit in these respects:

(1) The number of thin-bedded siltstones per complex is increased, and they tend to be thinner, with fewer rippled upper surfaces;

(2) they are separated by medium siltstones, in which red coloration is rather more important; and, most obviously,

(3) the siltstones separating the units of the complex are green. Thin-section examination has shown that they are almost entirely altered to chlorite, obliterating earlier textures. Figure 12, right is a transition probability matrix for this variant of the sample group; it is evident that the relationships between the lithologies are similar to those of the standard succession.

On Obrutschews Bjerg and Gross Bjerg the sample group is distinguished by its finer grain size, relatively lower content of red siltstones, and less-marked development of the discrete complex. An interval of measured section from Obrutschews Bjerg is shown in Figure 13B. The thin-bedded siltstones are finer, closer-spaced and more numerous per complex: and they are thinner, with less thickness variation. Rippled surfaces are few, and palaeocurrent data indicate much greater variation of flow directions than was evident on Stensiøs Bjerg.

Sample Group 4E (grey-co. slst., f. sst.-flat, trough X)

Sample group 4E (grey-co. slst., f. sst.-flat, trough X) is a composite of grey siltstones resembling the sheets of sample group 4C (though lacking the thin-bedded siltstones), and of fine-medium grained sandstone units up to 4 m thick. Plate 10 illustrates one of the sandstone units.

The cross-stratification is of type 4, and the cosets rest on scour surfaces. Foreset deformations are minor, or irregular type. Intraformational conglomerates of siltstone and carbonate concretions are present containing occasional holoptychiid scales and plant fragments up to 1 m in length; no extraformational clasts are present. Flat-bedded sandstones with primary current lineations occur mainly in the upper parts of the sandstone units (Figure 14). The lineation is abundant, present also on low-angled cross-stratification bedding surfaces. Rippled surfaces are rare, though "rib and furrow" structures are common. Palaeocurrent direction data obtained from various levels in a single sandstone complex were sometimes widely divergent.

Flat-bedded siltstones between the sandstone cosets, mainly grey with red horizons, tend to be obscured by scree on the Stensiøs Bjerg ridge, from which most of the records of the sample group were obtained. They are generally between 2–3 m thick, but may reach 5 m. Carbonate concretions have been observed in situ, and 15 cm units of very fine sandstone are sporadically present.

THE KAP GRAAH GROUP ON YMER Ø

Figure 2 indicates the areas of the Kap Graah Group to be described in the next three sections. This section deals with the Group on Gunnar Anderssons Land and on Celsius Bjerg, the main areas on Ymer Ø.

The nomenclature used here for the stratigraphic divisions recognised in the Kap Graah Group is informal; there are over 30 of the divisions, almost all of only local development and usually intergradational.

The Kap Graah Syncline Area

Numerous investigators have visited Kap Graah. NATHORST (1901) found here the first fish remains to be recovered from East Greenland, described by SMITH WOODWARD (1900). KOCH (1929, p. 79) noted the synclinal structure of the area. ORVIN (1930), KULLING (1930), and SÄVE-SÖDERBERGH (1932a, 1933) made further palaeontological collections, described by HEINTZ (1932; and in KULLING, 1930), and STENSIØ (1931, 1934, 1936, 1939, 1948).

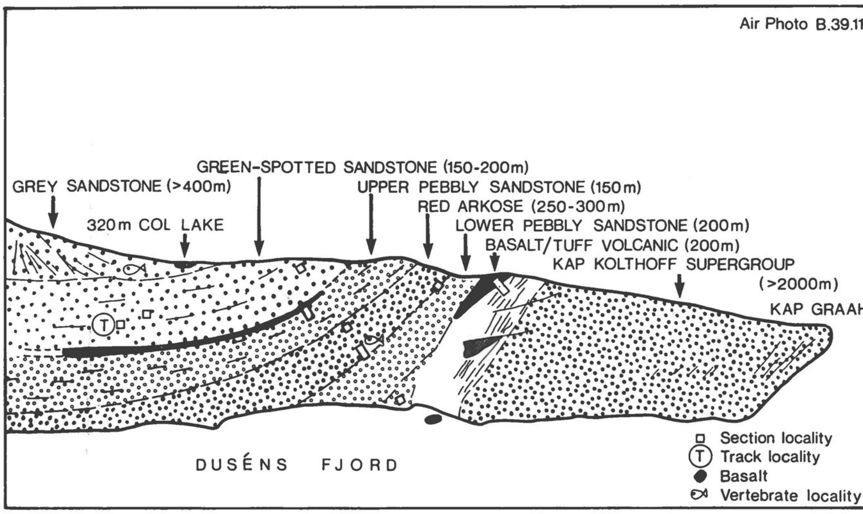

Fig. 15. Sketch, based on an oblique aerial photograph, showing the local divisions of the Kap Graah Group, and the Kap Kolthoff Supergroup in the Kap Graah peninsula.

BÜTLER (1935) made stratigraphic studies and established his "Kap Graah Series" here; in 1955 he described the succession in more detail. The volcanic components have been discussed by DALVESCO (1954, p. 30), RITTMAN (1940), and BACKLUND & MALMQVIST (1932, p. 39).

The succession of the syncline area is shown diagrammatically by Figure 15.

The volcanic division

The first low hill west of the Kap consists of a succession of tuffs and basalt lava flows, showing considerable lateral variation and reaching a maximum thickness of approximately 200 m. DALVESCO (1954, p. 30) and BÜTLER (1955, p. 24) have briefly described the locality.

In a section measured on the southeast side of the hill two stratigraphic units were recognised:

The pyroclastic subdivision

Within the grey (sample group 3D (grey-m., co. sst.-trough X)) sandstones of the Kap Kolthoff Supergroup, below the hill on the east side, bright-green "sandstones" with basalt and quartz clasts are present. Previous workers have termed these tuffites (RITTMAN, 1940), and the name is retained here. Their appearance marks the onset of volcanic activity, and a few metres higher in the succession the pyroclastic division of the Kap Graah Group is established.

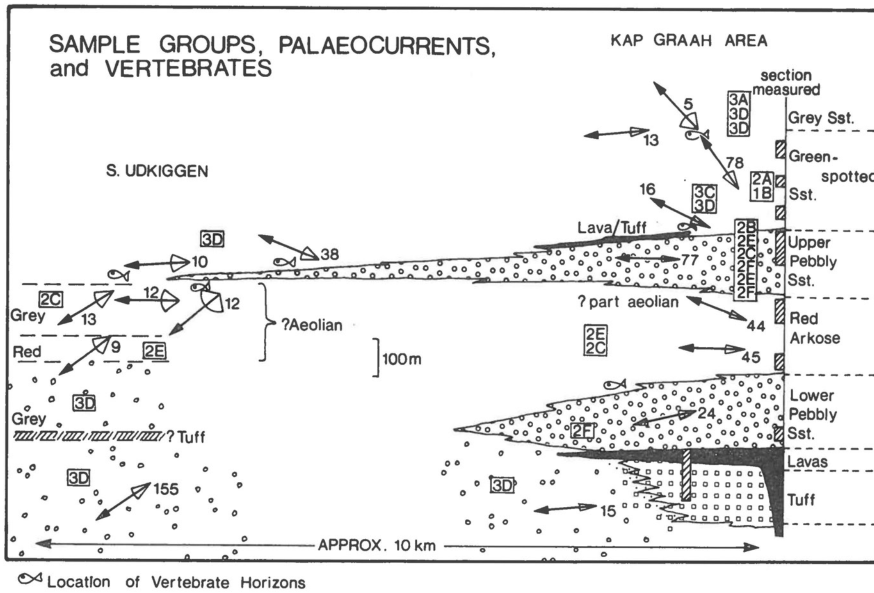

Fig. 16. Diagrams representing successions on Kap Graah, and S. Udkiggen, Gunnar Anderssons Land. Parts of succession logged in detail, in the Kap Graah area, are shown by oblique-lined boxes to left of vertical line.

Because the 'tuffite' sandstones are highly altered it is difficult to specify their original composition. They contain angular and fractured grains of quartz and cloudy feldspar, with heavily-chloritised basalt fragments and granules, in an indeterminable matrix (up to 50 $^0/_0$ of the rock) of chlorite and clays. No glass shards were observed in the thin sections prepared.

In common with the underlying sandstones they were deposited by westward-flowing currents (Figure 16), and contain pebbles of quartz and pale pink rhyolite. The contacts between adjacent tuffites and sandstones are frequently complex, and isolated pods of sandstone up to 6 m thick occur within tuffite beds, either with sharp and carious boundaries or with diffuse margins. Sandstone bodies may grade laterally into tuffite; some pinch and swell or neck-out completely.

The first major tuffite of the division outcrops higher on the southeast side of the hill, a 20 m unit of dark-green tuff containing sand and blocks of basalt. It contains synsedimentary faults, internal erosion surfaces, and steepsided scour channels (Plate 11). Above this follow several metres of greyer tuffaceous sandstones with quartz pebbles, and then a second unit of dark olive-green tuffite, which is up to 50 m thick and contains more numerous and larger basalt blocks (reaching half a metre in diameter) and pebbles of sandstone and quartz. After several metres of chaotic bedding the blocks of this unit become crudely sorted into

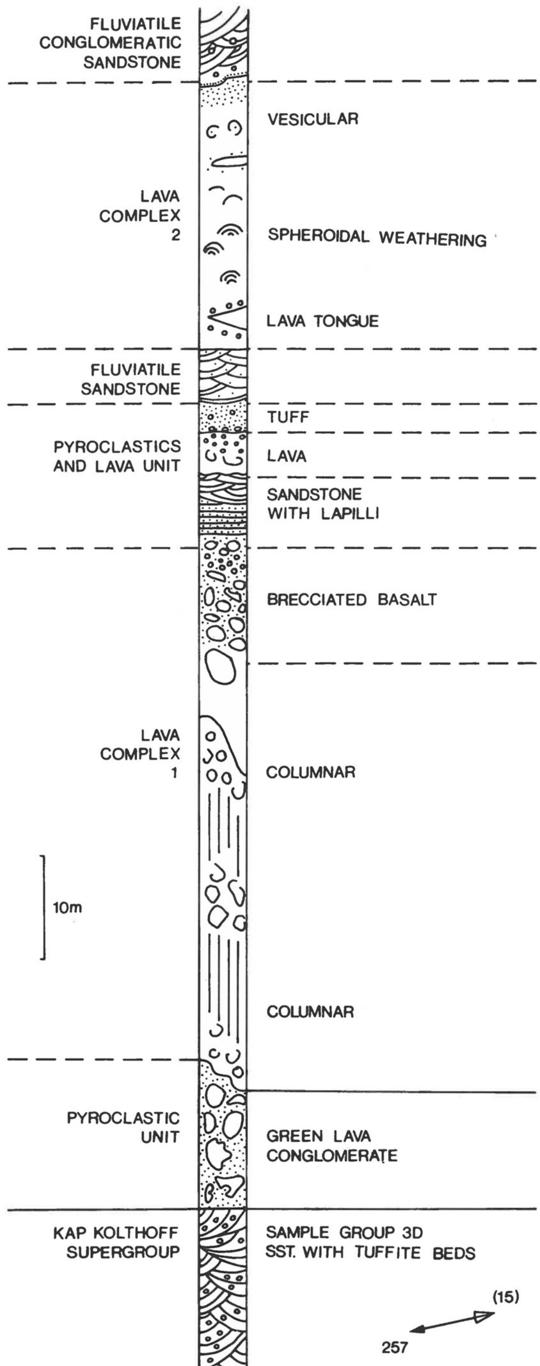

Fig. 17. Detailed sections measured on E. side of volcanic hill, Kap Graah. (see Fig. 15).

Table 5. *Modal roundness data (in situ), lower and upper pebbly sandstone divisions, Kap Graah Group.*

Clast type	Modal roundness Lower pebbly sst 54 clasts	 Upper pebbly sst 86 clasts
Quartz	0.7–0.9	0.7–0.9
Quartzite and sandstone	0.5–0.7	0.5–0.7
Rhyolite, tuff	0.3–0.5	0.3

layers, alternating with less pebbly dark-green tuffite beds. Most of these are irregularly flat-bedded in units up to 1.5 m, the remainder are cross-stratified.

Basal Lavas and associated deposits

On the upper part of the eastern side of the hill the thickness of the pyroclastic division is as little as 5 m. This much-reduced succession is immediately followed by lavas, as shown in Figure 17. Dalvesco's account recorded a similar sequence, but quoted markedly different thicknesses for some of the units.

The lower pebbly sandstone division

This division follows the volcanic rocks, its basal beds resting on an eroded surface of basalt and incorporating occasional basalt clasts. The lack of large numbers of basalt fragments may suggest that the site of volcanism was rapidly buried, possibly subsiding after extrusion of the lavas.

The division consists, at most, of approximately 200 m of purple-white and red, cross-stratified coarse pebbly arkoses and feldspathic sandstones. A typical interval classified in sample group 2F (red-m., co. sst.-trough X). The quartz content of the sandstones is about 70–75 %, with the grains showing strain extinction and welded together by pressure solution. Orthoclase is the dominant feldspar, at 10–15 %; poly-crystalline quartz grains and granules form up to 15 % of the rock.

The sediments remain coarse and poorly-sorted throughout the division. Extraformational clasts occur profusely, comprising white quartz, brown and green tuff, quartzite and sandstone, and ubiquitous pink rhyolite of porphyritic and flow-banded types. Green calcareous siltstones are occasionally found, possibly derived from the Vilddal Group (Middle Devonian) of the Kap Franklin area. Basalt pebbles occasionally appear in the upper parts of the division, as well as in the basal beds. Metamorphic schists are very rarely present.

The rhyolite blocks are particularly abundant in the lower 100 m of the division. Near the base they may reach 50 cm in diameter, ac-

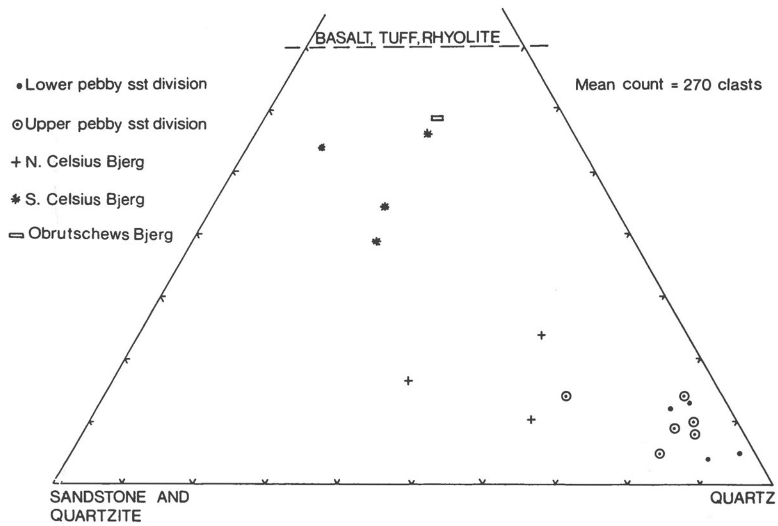

Fig. 18. Diagram illustrating proportions of pebbles of various compositions in Kap Graah Group sediments from different localities.

cording to Bütler (1955, p. 26); 15 cm is a common size. They are usually angular, commonly flow-banded, of brown or orange colour. Approximate dimensional estimates made at four stations in the lower 100 m of the succession of the division demonstrate the general upward size reduction trend of each of the main clast types. Modal roundness data are given in Table 5, also estimated in situ. Four clast composition counts were made (Figure 18); it is noteworthy that counts from the upper pebbly division (q. v.) gave very similar ratios.

The division is not represented in the western limb of the Kap Graah syncline, and is presumed to wedge out westwards. Palaeocurrent data (Figure 16) indicate that transportation of the sediment was to the southwest.

The red arkose division

In the eastern limb of the syncline a brick-red arkose division attains approximately 250 m in thickness. Its basal beds are intercalated with pebbly units, and its upper part is also transitional, marked by a major influx of extraformational pebbles.

The division consists of large-scale cross-stratified, red medium-grained arkoses, 10 m intervals of which classified in sample groups 2E (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X). A typical example of the large sets (of curved foreset, type 2) is shown in Plate 12, and mean set height data are given in Table 6.

Other than at the base, where it is slightly coarser and contains clasts of the same types as were present in the underlying division, it

Table 6. *Cross bedding and clast data for Kap Graah and S. Udkiggen areas, (see Figure 8).*

Kap Graah Area (divisions)	(1) mean set height m.	(2) mean height of top 10 % of sets	(3) % sets with extra-clasts	(4) % sets with intra-clasts
grey sst	0.35	0.65	6	23
green spotted sst	0.40	1.00	5	9
	0.40	1.00	–	6
upper pebbly sst	0.55–0.80	–	32–68	–
red arkose	1.10	2.00	3	–
lower pebbly sst	0.35	0.75	95	–

lacks extraformational pebbles. About 3 % of the sets contain intraformational clasts, chiefly of red siltstone with subsidiary carbonate clasts. Towards the top of the division, with slight fining, there is a greater incidence of ripple cross-lamination, and mudcrack surfaces become more common. Several bone fragments were found, and burrow structures are occasionally preserved.

Westerly palaeocurrent vector means were obtained from the division, the data derived mainly from the large cross-stratification sets with additional readings from ripple marks and primary current lineation. The overall variance is low, with the orientation of foresets in close agreement with the minor sedimentary structures.

The upper pebbly sandstone division

The second, upper pebbly division of the Group on Kap Graah is approximately 150 m thick in the eastern limb of the syncline, thinning westwards to less than 10 m on the south slopes of Mt. "Luncke"*-Udkiggen (Figure 16). Its base is gradational, represented by the first major extraformational pebble influx following the red arkose division. Its top is partly marked by basalt lava and tuff horizons, which are not completely developed across the division; elsewhere it is recognised by a sharp decrease in the extraformational pebble content.

Red medium and coarse-grained, poorly-sorted pebbly and non-pebbly cross-stratified sandstones form approximately 80 % of the succession, with subsidiary very coarse sandstones. Siltstone beds are very rarely preserved. Sample groups 2E (red-m., co. sst.-trough X) and 2F (red-m., co. sst.-trough X) are well represented in this division.

The clast types present are these: white and yellow quartz; pink porphyritic and flow-banded rhyolite, and brown rhyolite tuff; basalt;

* This name has not been officially recognized, but has been used in earlier publications (eg. SÄVE-SÖDERBERGH, 1933, plate 2). It is located on fig. 19 of this paper.

purple and grey quartzites; white and pink coarse sandstones (which were probably derived from the Kap Kolthoff Supergroup); mica-schist, very rarely; and ubiquitous intraformational red siltstone clasts. As in the lower pebbly sandstone division, feldspars form over 15 $^0/_0$ of the rocks. Very worn fish fragments were found near the top of the division, and in its upper levels trace fossils were also observed.

Rhyolite and tuff fragments are initially present in limited numbers but from about 50 m above the base of the division rhyolite clasts up to 30 cm in diameter are present. Basalt clasts appear at about 70 m below the basalt-tuff horizon covering the division. The ternary plot of the clast compositions (Figure 18) is based on estimates made at six levels in the division, and demonstrates the close accordance of clast types in the upper and lower pebbly sandstone divisions. Size estimates at these stations indicate the tendency for upward size increase. Modal roundness estimates (Table 5) are almost identical with those for the lower pebbly sandstone division.

The grand vector mean of the palaeocurrent data from the division (Figure 16) agrees closely with that obtained from the lower pebbly sandstone division. Whether the source area was the same for the clasts of both divisions, or whether the clasts of the upper division were derived by erosion of more easterly deposits of the lower division, is uncertain. The latter possibility is favoured by two observations: rhyolite and tuff clasts occur predominantly in the lower part of the lower pebbly sandstone division, but are mainly present in the upper part of the upper pebbly sandstone division; and the upward clast size reduction trend seen in the lower pebbly sandstone division is the reverse of the trend evident in the upper pebbly sandstone division.

The volcanic division succeeding the upper pebbly sandstone division consists, on the south side of the cape, of 1–2 m of basalt, partly vesicular, overlain by a tuff layer and a second basalt lava. The horizon is usually about 0.5 m thick, lying on grey coarse pebbly sandstones which contain basalt fragments. Some of these are vesicular, and BÜTLER (1955, p. 27–28) has noted blocks up to head-size which he termed bombs. Basalt lava flows are also present at approximately this stratigraphic level on the north side of the Cape.

The green-spotted and grey sandstone division

The remaining 600 m of the Group, seen only in the western limb of the syncline, become progressively less well-exposed. Extensive vegetated terraces, backed by low rock walls, give way at 300 m to scree-covered slopes descending from the eastern ridge of Udkiggen and "Mount Luncke" (Plate 12), and the final 300 m of the succession are very poorly exposed. The younger Remigolepis Group does not occur on Gunnar Anderssons Land.

The measured 10 m intervals of the sandstones of this division classified mainly into sample group 3D (grey-m., co. sst.-trough), with subsidiary 3A (grey-f., m. sst.-trough X), 1B (red-f. sst.-trough X), 3C (grey-m., f. sst.-flat, trough X) and 2A (red-f., m. sst.-trough X, flat). Extraformational clasts are markedly reduced in number, consisting mainly of quartz. The development of green spots, 1–2 mm in diameter, is an interesting phenomenon; they also occur on Gauss Halvø. They begin to appear in the grey-pink sandstones almost immediately above the upper pebbly sandstone division, and are present intermittently in the following 200 m of the succession.

They are mainly concentrated at the bases of sets of cross-strata, with lesser development at the tops of the sets, and tend to be more discrete and of deeper colour in very fine and fine sandstones rather than in medium sandstones, in which they are usually larger and paler with diffuse margins. They may be absent from some of the sets of a coset.

Thin-section examination has shown that the spots are chlorite patches, originating around basalt lithic grains. None of the chlorite spots is of detrital origin. Their development may be traced from peripheral growths, through more advanced stages of alteration in which the fabric of the basalt grain can still be discerned, to total replacement. Opaque iron oxide grains within the basalt chips are unaffected, and may be seen enclosed within chlorite patches.

Authigenic overgrowths of quartz seem to pre-date the chlorite development in some instances, whereas calcite-infilling of the pore-spaces between chlorite-coated grains indicates that final cementation post-dated its formation. Partial calcite replacement of chlorite patches occurs with pseudomorphing of the original basalt chips. Chlorite rims, sometimes fibrous, tend to be present around quartz and feldspar grains adjacent to a basalt chip undergoing alteration and some fine and medium-grained sandstones are rendered pale green by chlorite which has disseminated throughout the matrix. In such instances associations between chlorite and basalt chips or iron-oxide grains are not seen, and it is suggested that the dissemination, which pre-dated calcite cementation, was caused by expulsion of pore fluids on lithification. Such redistribution would be facilitated by the greater permeability of coarser sandstones.

The division is the most fossiliferous of the Group on Kap Graah, with several well-known vertebrate localities. The most notable is that of ORVIN, at 280 metres, below and slightly westward of the small lake in the col (Figure 15). From this locality *Phyllolepis*, *Bothriolepis*, and *Holoptychius* have been described by STENSIØ (1934, 1937) and HEINTZ (1932). KULLING's locality 6 (1931, p. 12) is on the small ridge east of the col, slightly above ORVIN's locality stratigraphically. SÄVE-SÖDER-

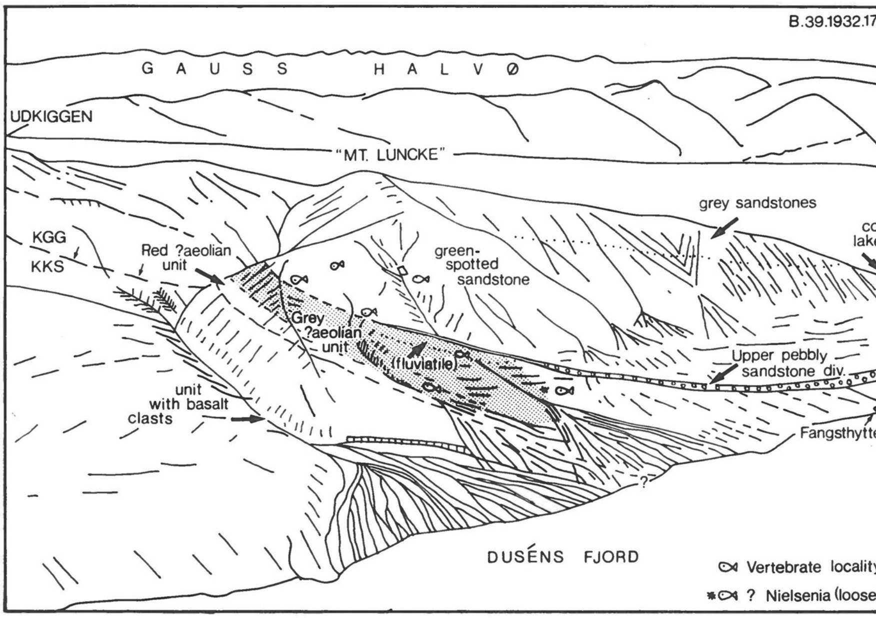

Fig. 19. Sketch, based on an oblique aerial photograph, showing main features of outcrops on South Udkiggen, Eastern Gunnar Anderssons Land.

BERGH (1932a, pp. 19–20) found several localities near to ORVIN's; and we collected crossopterygian bones at 320 metres on the west side of the col.

The Kap Graah Group on S. Udkiggen, 10 km west of Kap Graah in Dusėns Fjord

On the east side of the first major valley west of Kap Graah, on the south side of Gunnar Anderssons Land, the succession exposed differs markedly (Figure 19) from that described above. Unfortunately the outcrops between this valley and Kap Graah are small and occur intermittently due to scree and moraine cover, but it is clear that considerable lateral facies variations exist in the lower half of the Group.

The base of the Group near Kap Graah was defined at the base of the volcanic divisions recognised there. No development of lavas is present to the west, but at 230 metres in the east side of the valley an unusual very poorly sorted dark grey and purple fluvial unit of at least 15 m contains fragments of basalt. Limited palaeocurrent data suggest that the volcanic material in this unit was derived from source rocks to the east. Figure 16 suggests that its stratigraphic level corresponds approximately with that of the Kap Graah volcanic division.

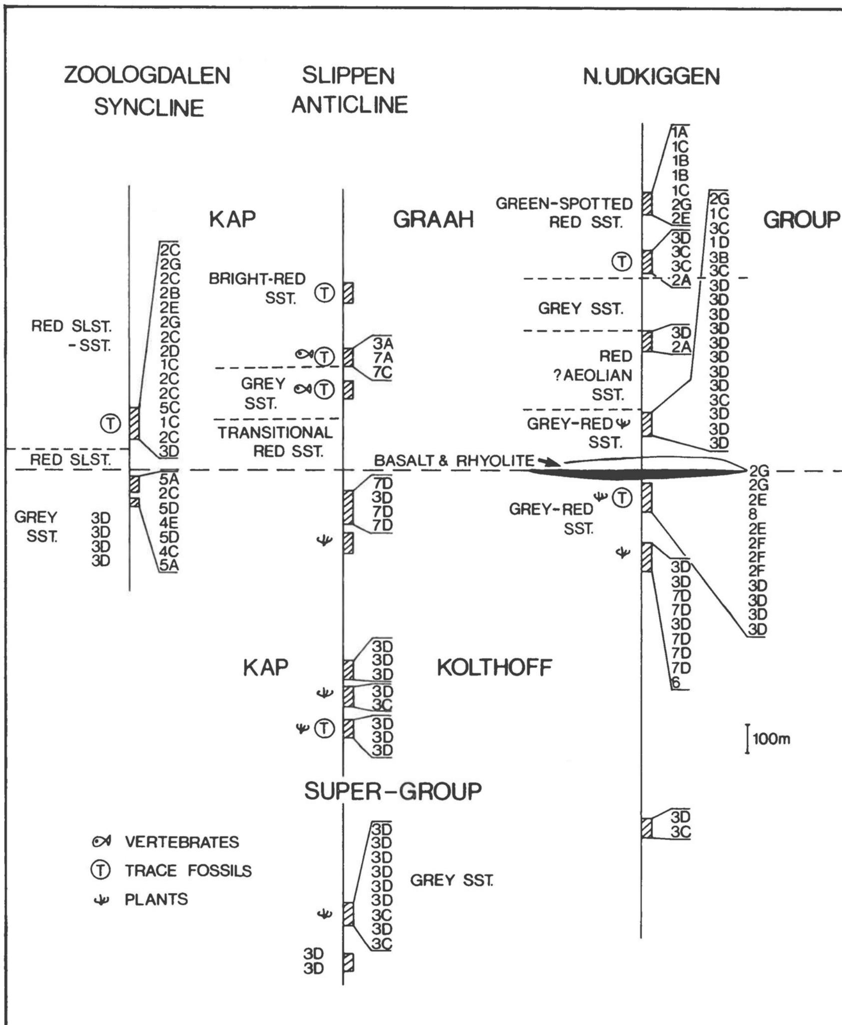

Fig. 20. Diagram summarising successions on N. Udkiggen, the Slippen anticline, and the Zoologdalen syncline, all localities on the north side of Gunnar Anderssons Land. Logged intervals with sample group classification of 10 m samples are shown.

The succeeding rocks are typical of the Kap Kolthoff Supergroup, consisting of approximately 250 m of sample group 3D (grey-m., co. sst.-trough X) sandstones containing clasts of porphyritic rhyolite, white and grey quartz, rare basalt, and grey siltstone and plant (or carbonaceous) remains.

At least 50 m of red medium-grained sandstones of sample group 2E (red-m., co. sst.-trough X) succeed these rocks. They are cross-stratified on a large-scale, with sets up to 3 m thick containing no other sedimentary structures than rare soft-sediment deformations. No fish

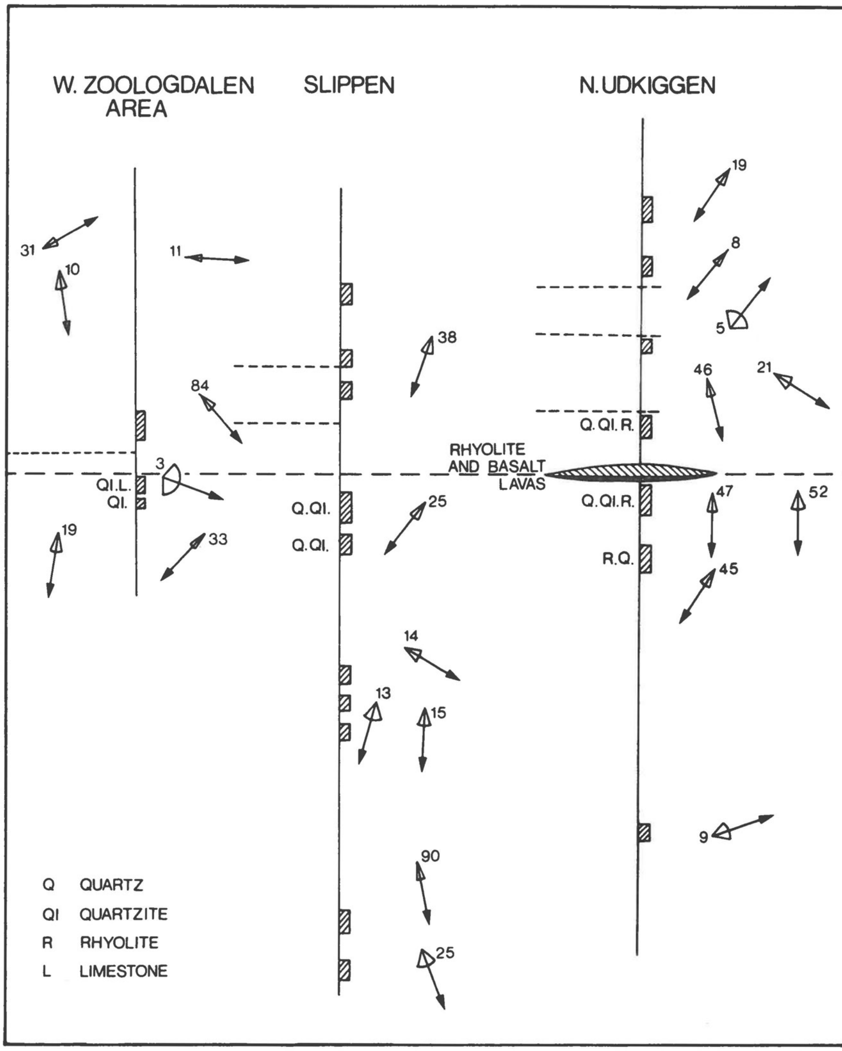

Fig. 21. Diagram showing palaeocurrent data for same successions as Fig. 20. Palaeocurrents were measured W. (left) and E. (right) of Zoologdalen. Pebble types are also shown.

remains or pebbles were seen. With a colour change to grey, a very similar lithology continues for a further 150 m, containing no ripple or mud-crack horizons and bedded in large sets which occasionally are disturbed by undulose soft-sediment deformation structures or micro-faults. It is possible that this division was wind-deposited.

At the top of this unit the sandstones become less well-sorted, with more variable and reduced set heights. Ripple marks and cross-lamination are now present, and plant stems appear together with bones of *Bothriolepis*. Here we found an almost complete *Bothriolepis* carapace with pectoral fins attached. Green spots then develop in the sandstones and the following succession can be shown to be laterally-equivalent to the green-spotted division described in the col area (measured section classifications are given in Figure 16).

No conglomeratic sandstones are encountered in the valley sections. The most-westerly outcrops of the upper pebbly sandstone division, consisting of several metres of conglomerate, can be observed in a gully 1 km east of the main valley (Figure 19), where they separate the lowest grey sandstone with *Bothriolepis* from the green-spotted sandstones.

The lithostratigraphic correlation diagram, Figure 16, is based on this horizon. It suggests that the uppermost part of the Kap Kolthoff Supergroup in eastern Dusén's Fjord, as recognised by BÜTLER, may be at least in part laterally equivalent to divisions defined as part of the Kap Graah Group.

The Succession of N. Gunnar Anderssons Land

We examined the succession between N. Udkiggen and the west side of Zoologdalen (Figure 2), with the results summarised in Figures 20 and 21.

The Kap Kolthoff Supergroup forms a monotonous succession consisting of sample group 3D (grey-m., co. sst.-trough X) with subsidiary 3C (grey-m., f. sst.-flat, trough X), and the palaeocurrent data collected show little variation from a general southerly direction. In the lower part of the exposed succession the clasts present are of intraformational siltstone and carbonate, whereas in the upper 400 m extraformational pebbles become numerous. They include quartz, quartzite, and volcanic material, introduced mainly by southerly-flowing streams (although some strongly westerly local trends were noted). On the west side of Zoologdalen there is evidence of more-easterly stream flow, and the sandstones in the upper part of the Supergroup contain pebbles of quartzite and "metamorphic limestones". No vertebrate remains were found in the Supergroup, but plant fragments are common and rare trace fossils were recorded.

Definition of the base of the Kap Graah Group is not facilitated by the presence of an unconformity, or a distinct petrographic change. At Kap Martha, 15 km from Kap Graah, a local succession of 100 m of rhyolitic ash, tuff and tuffite followed by over 100 m of alkali-rhyolite lavas (DALVESCO, 1954, p. 26) occurs above a reddened interval of sample groups 2E (red-m., co. sst.-trough X), 2F (red-m., co. sst.-trough X) and 2G (red-m., f. sst.-planar X, flat).

A basaltic horizon is also present on the north slope of Udkiggen, at the same stratigraphic level as the rhyolite, consisting of 10–15 m amygdaloidal lava flows with ropy top surfaces, separated by thin siltstone containing basalt fragments.

At Udkiggen the succeeding 250 m of pebbly grey and red sandstones consist mainly of sandstones classified in sample group 3D (grey-m., co. sst.-trough X), with subsidiary 3C (grey-m., f. sst.-flat, trough X), containing a pebble suite similar to that of the underlying Kap Kolthoff Supergroup: quartz, quartzite, rhyolite, and intraformational clasts. Rhyolite clasts occurring in the succession up to 70 m above the lavas are flow-banded (as is common at Kap Graah) but thereafter they are homogeneous.

Following this fluviatile unit is a 300 m sequence of red, probably aeolian cross-stratified sandstones which exhibit wellrounded grains and contain no clasts or faunas. The few current directions which were obtained in this interval deviate considerably from the general south or southwesterly trends shown by the Group on Udkiggen. Above this probably aeolian interval follows a 200 m grey division, from which no measured section was obtained.

The uppermost division of the Group recognised here is at least 400 m thick, consisting of fine and medium-grained red sandstones of sample groups 2E (red-m., co. sst.-trough X), 2G (red-m., f. sst.-planar X, flat), 1C (red-f., m. sst.-trough X, flat) and 1B (red-f. sst.-trough X), in which only intraformational clasts are present. Some green spots were recorded in this unit (the most westerly observation of spots on Gunnar Anderssons Land), which was deposited by south-westerly flowing streams.

East of Zoologdalen the base of the Group can only be defined arbitrarily, as there are numerous red-grey alternations and no contemporaneous volcanics are developed. A transitional interval between the Group and the Kap Kolthoff Supergroup contains sandstones of mixed fluviatile and "aeolian" types, with quartz and quartzite pebbles, and is succeeded by a 150 m red, probably aeolian unit. Above this, grey sandstones form a 200 m unit, with occasional fish remains and intraformational pebbles. Southerly palaeocurrent directions were obtained.

West of Zoologdalen, the Kap Graah Group succession is radically different from those described previously, and from those of Watsons Plateau and Smith Woodwards Bjerg to the north. Easterly and southeasterly palaeocurrent directions are predominant, and fragments of quartzite and "metamorphic limestone" are present in the lowest part of the Group. A measured section near the base contained a variety of sample groups, mainly 2C (red-m., co. sst.-trough X) and 2G (red-m., f. sst.-planar X, flat) with subsidiary 2B (red-m., f. sst.-trough X, flat), 2E (red-m., co. sst.-trough X) and 1C (red-f., m. sst.-trough X, flat).

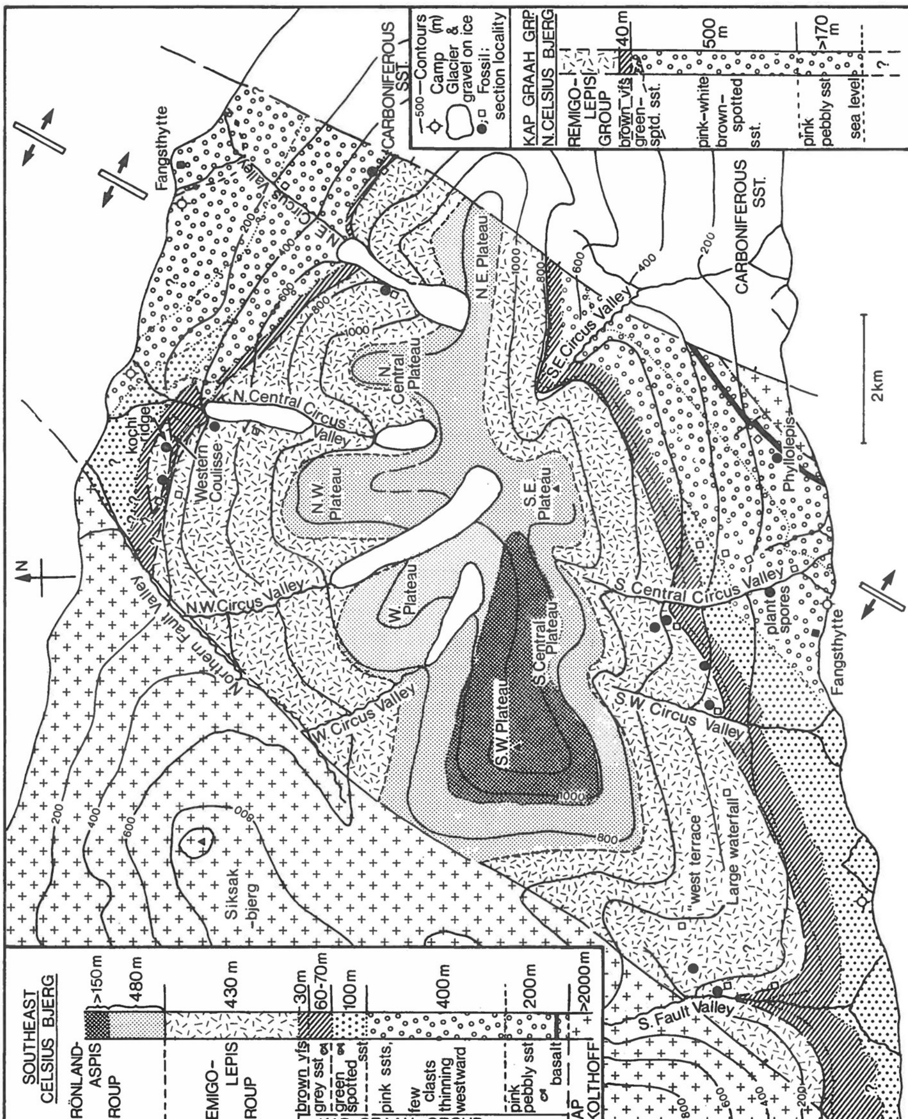

Fig. 22. Geological sketch map, and summary sections, of the Mt. Celsius area, eastern Ymer Ø. An open anticline is shown trending N.E.–S.W.

Higher in the succession no measured sections were made; as siltstone becomes more important so the exposures deteriorate. At least 300 m of coarse micaceous siltstone and very fine sandstone are developed, containing occasional 40–60 cm grey medium-grained sandstones which provide consistent easterly palaeocurrent data. No vertebrates were collected; however, SÄVE-SÖDERBERGH (unpublished ms) examined the Kap Graah Group succession west of Zoologdalen and found a locality with abundant *Bothriolepis* plates just above the contact with the Kap Kolthoff Supergroup. Slightly higher, a plate of *Phyllolepis* was collected.

The Kap Graah Group on North Celsius Bjerg, Ymer Ø

On N. Celsius Bjerg the Group is at least 700 m thick, its base below sea level. Much of its outcrop area is covered by moraine and scree, and only in the N. E. Circus valley area (Figure 22), and between the two Circus valley deltas, are sizeable exposures present. Figure 23 summarises the sedimentological and palaeocurrent data obtained during a brief examination of the Group.

Its lower part consists mainly of pink pebbly arkoses of sample group 2E (red-m., co. sst.-trough X), with subsidiary 2F (red-m., co. sst.-trough X). Two pebbly divisions cannot be distinguished here. There is no evidence of contemporaneous volcanism in the exposed part of the succession, and none of the sandstones was thought to be of aeolian origin. Palaeocurrent data obtained (Figure 23) indicate that, as was the case for the two pebbly divisions on Kap Graah, current flow and clast transportation were to the west.

The lowest-exposed pebbly sandstones are not as coarse as the Kap Graah lower pebbly sandstone division, and do not contain rhyolite clasts of comparable size. Clast composition data (plotted together with data from Kap Graah in Figure 18) and size estimates for the pebbles from these beds indicate their general similarity to those of the Kap Graah upper and lower pebbly sandstone divisions. The clast types of both areas include white quartz, grey quartzite, pink porphyritic rhyolite, and grey coarse sandstones typical of the Kap Kolthoff Supergroup. Red siltstone clasts are present, but siltstone beds do not occur in the lower pebbly parts of the succession. The N. Celsius Bjerg pebble assemblages are relatively richer in clasts of sedimentary rocks and in tuff fragments.

Gradationally the pink pebbly arkose succession passes upwards into white and grey arkoses of sample groups 3D (grey-m., co. sst.-trough X) and 2E (red-m., co. sst.-trough X), containing occasional intervals of finer sandstones. These beds form a division approximately 500 m thick, the thickness impossible to estimate with precision because of

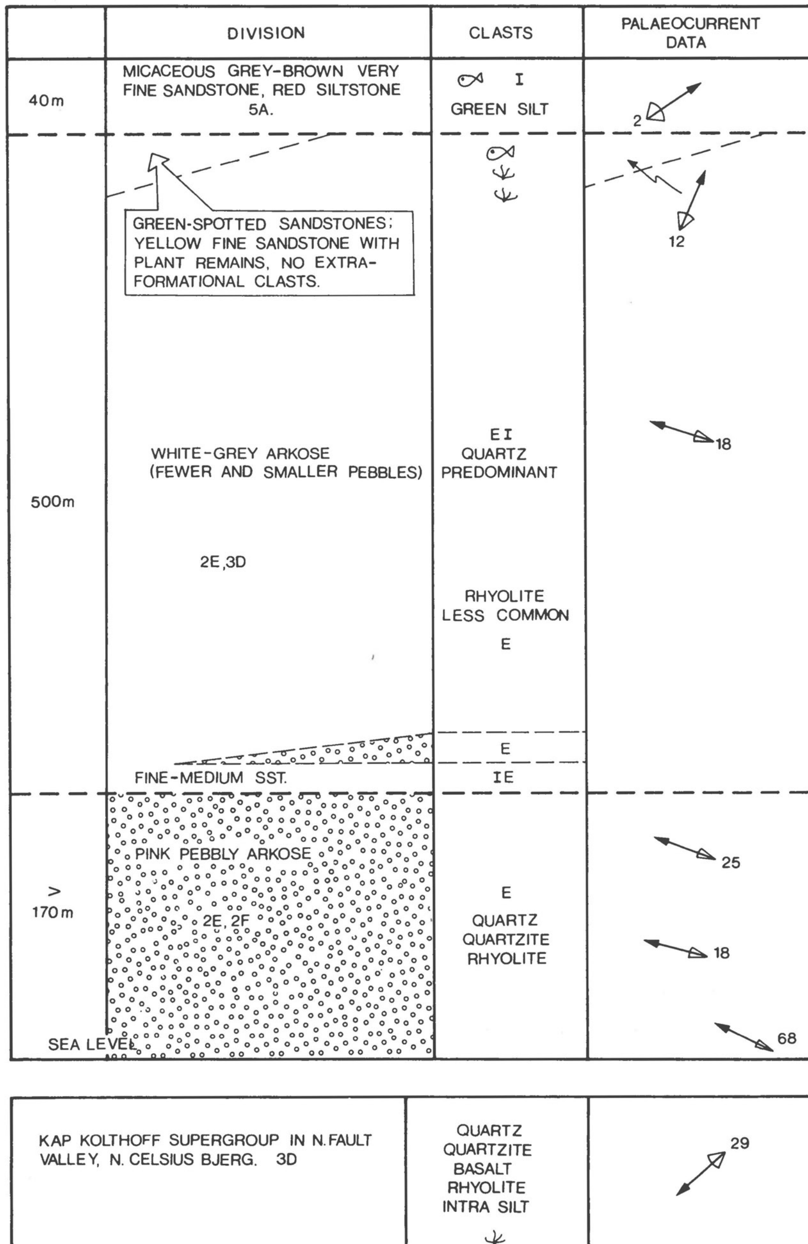

Fig. 23. Summary succession, showing palaeocurrent and clast data for Kap Graah Group divisions on North Celsius Bjerg. I—intraformational, E—extraformational.

extensive gravel cover and the presence of numerous faults. Higher in the succession the clasts become smaller and fewer, with rhyolite less abundant and quartz dominant. Intraformational pebbles only become important in the uppermost 100 m of the Group. No fish fossils have been found in this succession.

Seen only at the west end of the mountain, green-spotted sandstones are feebly-developed in the final 60 m of the Group, passing into a 40 m division of micaceous very fine sandstones and red siltstones. These beds are succeeded by sample group 5A (red-v. f. sst., co. slst.-trough X, flat) sediments at the base of the Remigolepis Group. They exhibit more-northerly directed palaeocurrents (Figure 23).

Data obtained from the Kap Kolthoff Supergroup west of the large fault in N. Fault Valley (Figure 22) are given in Figure 23. 70 m of measured section were obtained here, classifying in sample group 3D (grey-m., co. sst.-trough X), providing westerly-directed palaeocurrent indicators.

The Kap Graah Group on South Celsius Bjerg

The outcrop area of the Group on S. Celsius Bjerg is shown by Figure 22. The Group is best-exposed in deep ravines on the southeast part of the mountain; elsewhere exposures are intermittent, and westwards they become increasingly poor. The uppermost part of the Group is never well-exposed. Bütler (1955, pp. 35–38) and Säve-Söderbergh (1933, pp. 16–21) have briefly described the succession. The thickness of the Group is about 850 m here, and its development is summarised in Figure 24.

The Group's base, seen only at the southeast corner of the outcrop area, is marked by a strong colour change from Kap Kolthoff Supergroup grey sandstones of sample group 3D (grey-m., co. sst.-trough X) to the red sample group 2E (red-m., co. sst.-trough X) succession. There is no angular unconformity and no change in the clast content or palaeocurrent directions between the two major stratigraphic divisions.

A volcanic horizon is present 30 m above the base of the Group, consisting of 5 m of basalt resting on a blackened, indurated sandstone surface. It incorporates sandstone blocks, and is succeeded at several localities by dark tuff.

The lower 200 m of the pink arkoses at the base of the Group are highly pebbly, classifying in sample groups 2E (red-m., co. sst.-trough X), 2F (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X). Conglomeratic lenses are present near the base of the Group, containing basalt, pink rhyolite, rhyolitic tuff, quartz, sandstone and quartzite clasts, and

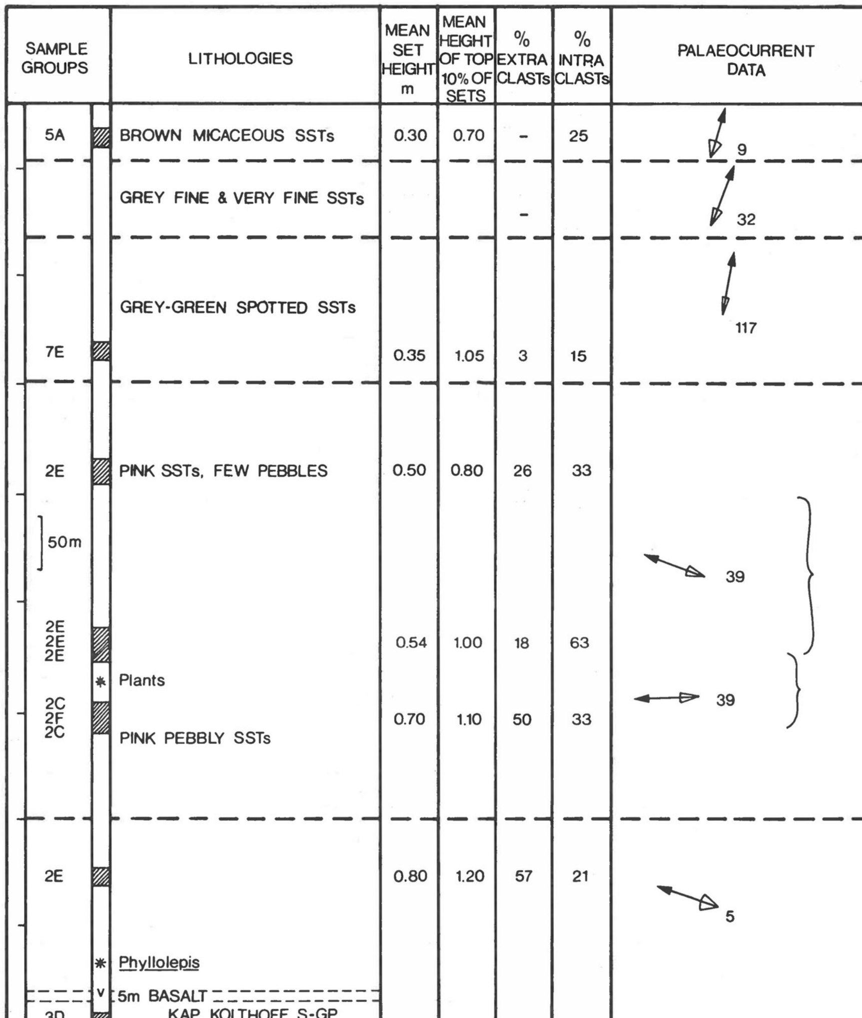

Fig. 24. Data collected in Kap Graah Group succession on South Celsius Bjerg. Positions of logged parts of succession indicated by oblique-ruled blocks.

fragments of intraformational red siltstone. The clasts reach 3–4 cm in length, with the quartz rounded to the greatest extent and the volcanic material subangular or angular. Clast composition data collected from a conglomeratic bed near the Group's base are plotted in Figure 18, with other Kap Graah Group data.

Most of the following 400 m of the succession are of sample group 2E (red-m., co. sst.-trough X), less pebbly and slightly finer-grained, with a higher content of intraformational clasts. Siltstone lenses are not common; but plant remains have been recovered from lenticular sandy siltstones at 145 m above sea level in the South-Central Circus Valley.

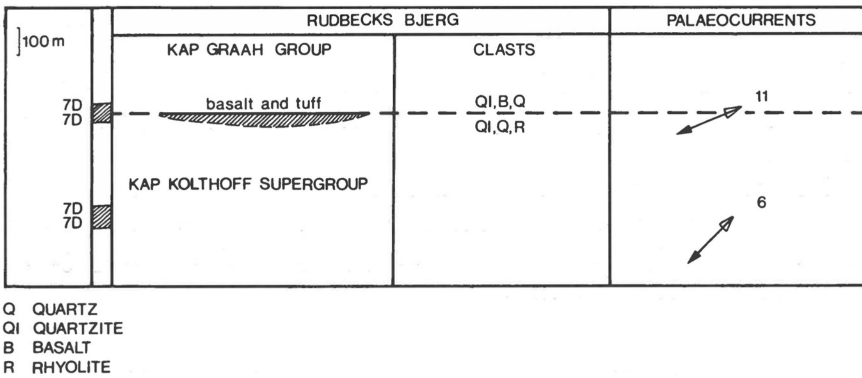

Fig. 25. Palaeocurrent and clast data collected from Kap Kolthoff/Kap Graah junction on Rudbecks Bjerg.

From material collected at this locality K. C. Allen has obtained well preserved megaspores (personal communication), which he considers indicative of an Upper Frasnian or Famennian age.

The green-spotted sandstones which succeed the pink arkoses classify in sample group 7E (grey-f. sst.-trough X, flat), thickening westwards from about 100 m on the southeastern part of the mountain to almost 200 m, 1.5 km further west. *Bothriolepis* bones occur occasionally in the grey, fine and medium-grained sandstones, often in intraformational conglomerates together with plant remains. The pronounced northerly trend of the palaeocurrent vector mean is noteworthy.

A sequence of grey, non-spotted sandstones up to 100 m thick follows the green-spotted division, very poorly exposed. No measured section data were obtained, but these sediments would probably classify in sample groups 7E (grey-f. sst.-trough X: flat) and 7B (grey-f. sst.-planar X, flat). They are finer, flaggy, and more micaceous than the green-spotted sandstones. They exhibit the northerly palaeocurrent trend evident in the underlying division.

A transitional division of sample groups 5A (red-v. f. sst., co. slst.-trough X, flat) and probably 7D (grey-f., v. f. sst.-trough X, flat) occurs at the top of the Group, composed of dark-brown, highly micaceous, very fine sandstones which contain few vertebrates but very numerous bioturbation structures. There is no stratigraphic break between the Kap Graah and Remigolepis Groups on Celsius Bjerg.

Rudbecks Bjerg

About 5 km south of Celsius Bjerg, across Sophia Sund, is Rudbecks Bjerg (Fig 2).

The base of the Group is very sharply-defined there, with no angular unconformity. As on S. Celsius Bjerg a basalt and tuff unit is present at this level (Figure 25), consisting of two basalt lava flows of irregular thickness, resting in places on cherry-red tuff and (according to DALVESCO, 1954) containing glassy lapilli. BÜTLER (1955, p. 50) states that the basalts are represented several km to the south by green and violet tuffs.

BÜTLER (1955, p. 52) observes that the red lower part of the Group forms a lesser thickness on Rudbecks Bjerg than on S. Celsius Bjerg, with similar clast types, and that in the upper part of the Group green-spotted sandstones are present.

Correlation of the Kap Graah Group Successions on Ymer Ø

In this section a review is made of the Kap Graah Group successions described from Ymer Ø, and a lithostratigraphic correlation between them is suggested.

Nowhere on Ymer Ø is the base of the Group defined by an unconformity. On S. Celsius Bjerg and Rudbecks Bjerg it is marked by minor basalt lava and tuff development and by a petrographic change from grey carbonate-cemented Kap Kolthoff Supergroup sandstones of sample group 3D (grey-m., co. sst.-trough X) to quartz-cemented, hard red sandstones of 2E (red-m., co. sst.-trough X). There is no apparent change in the palaeoslope direction or clast composition, as is also the case on Gunnar Anderssons Land. On N. Celsius Bjerg the base is below sea level.

On Kap Graah the Group's base was defined beneath the 200 m basaltic lava and tuff division. Basalt lavas are absent from the S. Udkiggen area, but a dark tuffaceous unit is present which contains basalt clasts, and this may be laterally equivalent to the Kap Graah volcanics. It occurs at a stratigraphically comparable level in both areas, beneath the upper pebbly sandstone division, but a direct connection can not be demonstrated because the synclinal fold carries the beds below sea level. The base of the Group is marked on N. Udkiggen by means of the rhyolitic and basalt development there; it is difficult to establish how closely this stratigraphic level approximates to that of the volcanism at Kap Graah.

In Figure 26 an interpretation is given of the relationship between the successions described from eastern Ymer Ø. The correlation between S. Udkiggen and Kap Graah is largely based on the observed field relations (Figure 16), and a clearly defined correlation between N. Udkiggen and Kap Graah would be uncertain without the control of this intermediate S. Udkiggen column. It appears that intervals of over 10 km without exposure render comparisons between successions very difficult.

The variation of the sedimentary successions over short distances

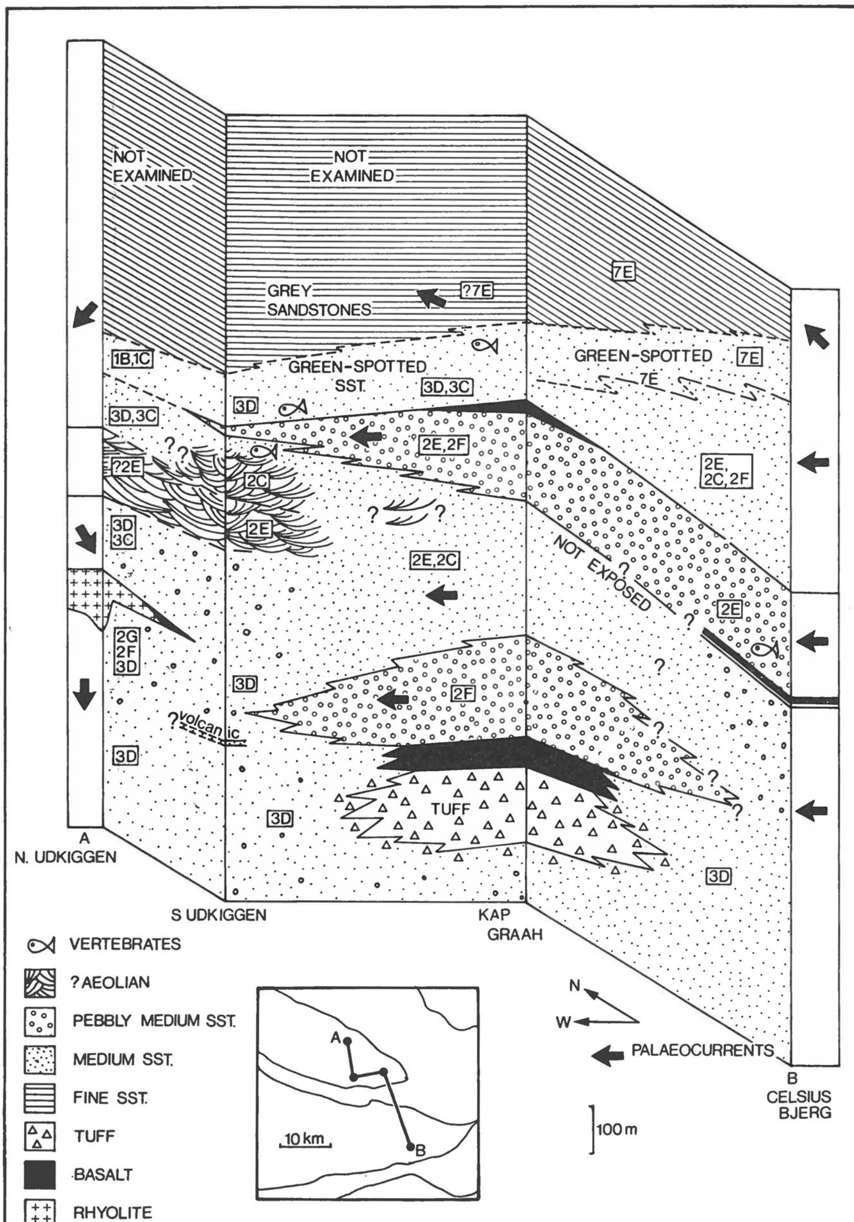

Fig. 26. Fence diagram showing possible lithological correlation in the upper Kap Koltwhoff Supergroup and Kap Graah Group of eastern Ymer Ø. Time relations are discussed in the text.

and the localised nature of the volcanic rocks are striking, and from the great dissimilarity which exists between the Kap Graah and S. Udkiggen sequences (separated only by 8 km) it can be inferred that the stratigraphic relations between Celsius Bjerg and Kap Graah may also be complex. The N. Celsius Bjerg succession shows greater similarity to that of S. Celsius Bjerg (5–6 km distant) than to the Kap Graah sequence 10 km to the northwest. It is unfortunate that the base of the Group is not seen on N. Celsius Bjerg; its total thickness is unknown, and it is not certain whether or not volcanism occurred there.

The relationship suggested in Figure 26 between the lower pebbly sandstone division of Kap Graah and the pebbly sandstones of S. Celsius Bjerg is one of at least two possibilities: the division may form an isolated wedge at this locality on the palaeoslope (as shown); or it may be laterally-connected with the S. Celsius Bjerg pebbly succession. This latter possibility seems the less likely of the two, as the palaeocurrent vector means determined from both areas are westerly directed. The close correspondence of pebble types between the upper and lower pebbly sandstone divisions at Kap Graah together with the common westerly palaeocurrent trend suggests that they may merge proximally.

Considering the volcanic clasts present in the pebbly sandstones of each area, it is noteworthy that basalt fragments are confined to the sandstones immediately above and beneath the lava and tuff horizons, and that they do not appear in large numbers. This distribution suggests rapid sedimentation over the sites of volcanism.

The rhyolite intrusion at Kap Martha is the only body of this type known *in situ* in the Kap Graah Group. However, in the lower 100 m of the lower pebbly sandstone division at Kap Graah large blocks of similar rhyolite occur, derived from an easterly or north-easterly source which, in view of the size of the blocks, can hardly have been distant. Large blocks of rhyolite do not occur in the pebbly sandstones of S. Celsius Bjerg.

The palaeocurrent data are of no assistance in determining the geometry of the lower pebbly sandstone division, which was probably built up by streams transporting sand and gravel into the area. The presence of large fragments of sandstone strongly resembling those of the Kap Kolthoff Supergroup suggests that an upland area to the east with a cover of these rocks was undergoing denudation. This material was introduced together with quartz and quartzite, derived either from the Supergroup or directly from the Eleonore Bay Group (Pre-Cambrian). On northern Gunnar Anderssons Land the latter clast types were introduced from the north.

The succeeding red arkose division at Kap Graah is not represented on S. Celsius Bjerg, nor is it present as such at S. Udkiggen. As was shown above it grades laterally into a mixed fluviatile and probably aeolian succession, which shares the same general palaeocurrent direction. At Kap Graah it is probable that most of the division is of fluviatile origin, yet it contains virtually no extraformational clasts and very little intraformational material. It is interpreted in Figure 26 as an easterly-thinning wedge, between the pebbly divisions, which may grade laterally towards the south into the Kap Kolthoff Supergroup succession. Unfortunately there is no indication of its presence or absence on N. Celsius Bjerg. On N. Udkiggen the laterally-equivalent succession includes a thicker red, probably aeolian sequence, following a fluviatile unit containing pebbles similar to those of the pebbly divisions of Kap Graah.

The upper pebbly division on Kap Graah is reduced in thickness westwards by about 150 m in 10 km; it is not represented in the N. Udkiggen succession. There is no indication as to whether it is part of a sheet laid down by a series of westerly-flowing streams, or whether it represents a fan wedging out southwards as well as westwards. It is possible that the clasts of the upper pebbly sandstone division may have been reworked from more-easterly deposits of the lower pebbly sandstones.

It is suggested in Figure 26 that the Celsius Bjerg pebbly sandstones are more or less equivalent stratigraphically to the upper pebbly sandstone division on Kap Graah. The clast types are similar (though they occur in somewhat different proportions); the palaeocurrent distributions are similar in both formations; and their thicknesses are comparable. The observation that the pink pebbly sandstones of Rudbecks Bjerg occupy a lesser proportion of the Kap Graah Group succession than on S. Celsius Bjerg indicates southerly thinning of this unit.

The green-spotted fluviatile sandstones which follow the upper pebbly sandstone division on Kap Graah are laterally correlated with a coarser division on N. and S. Celsius Bjerg. The palaeocurrent vector mean trends in both these areas are to the west and west-northwest. The sandstones are less pebbly on Kap Graah, and contain a substantial fish fauna. On S. Celsius Bjerg there is clear evidence of westerly-thickening of the green-spotted sandstones, whereas they are barely present on N. Celsius Bjerg. The basalt grains from which the green spots developed (present also on Gauss Halvø) were introduced to the area by streams flowing from the east and southeast. They persist in the succession and were probably derived from an upland area at least partially capped by basalt lavas. With the appearance of green-spotted medium and fine-grained sandstones quartz pebbles become the dominant extraclasts; progressively these become less numerous, and the upper half of the Kap Graah Group is characterised by the dominance of intraformational clasts.

The uppermost part of the Group, never well-exposed, is characterised by more-northerly palaeocurrents on Celsius Bjerg and Kap Graah, and thickens northwestwards. It is more micaceous than the sandstones below, and gradually fines upwards to pass transitionally into an interval of sample group 5A (red-v. f. sst., co. slst.-trough X, flat), of the Remigolepis Group. At the highest level of the Group the palaeocurrent measurements made indicate development of a north to north-easterly dipping palaeoslope. The summaries of the following two sections will discuss the development of the upper part of the Kap Graah Group further to the north.

The Zoologdalen succession is of considerable interest as it does not resemble any other Kap Graah Group section described from Ymer Ø, and because these most-westerly outcrops of the Group afford the only evidence of an easterly-inclined palaeoslope (other than a slight eastward component seen in the vector means obtained from Watsons Plateau and Rødtop). Clasts of Eleonore Bay Group (Pre-Cambrian) limestones derived from the west may have been transported from the margin of the Kap Graah Group basin, or they may have been derived secondarily from Middle Devonian conglomerates or from the Kap Kolthoff Supergroup.

KAP GRAAH GROUP ON S. GAUSS HALVØ, BETWEEN MARGRETHEDAL AND WATSONS PLATEAU

The Hjelmbjergene Group

Before describing the development of the Group on the N. shore of Kejser Franz Josephs Fjord a brief comment will be given on the Middle Devonian rocks which outcrop along the eastern part of this coastline.

In the Hjelmbjergene, between Obrutschews Bjerg and Agda Dal, the Kap Graah Group lies unconformably across a Middle Devonian succession which is named here the Hjelmbjergene Group. Work on these mountains is incorporated in Nr. 3 of this volume, by ALEXANDER-MARRACK & FRIEND. It will suffice here to note that three divisions may be recognised in the coastal exposures.

(3) The uppermost, red fine and medium sandstones (Red Formation) of the Group on Obrutschews Bjerg, about 800 m thick, consisting of sample groups 2G (red-m., f. sst.-planar X, flat), 2A (red-f., m. sst.-trough X, flat) and 1C (red-f., m. sst.-trough X, flat). The palaeocurrent directions measured in this division vary from northerly to northeasterly, a feature in common with the red Kap Kolthoff Supergroup sandstones of Langbjerg, and with part of the red Randbøl Formation of E. Gauss Halvø.

(2) The 500–600 m green and red-banded sandstone succession of Evans Bjerg and E. Gross Bjerg, consisting of green and grey cross-

stratified medium sandstones alternating with red flatbedded fine and very fine sandstones. Sample groups 3D (grey-m., co. sst.-trough X), 3A (grey-f., m. sst.-trough X), 2A (red-f., m. sst.-trough X, flat) and 7E (grey-f. sst.-trough X, flat) are the best represented. These sediments do not resemble other formations on E. Gauss Halvø, but are reminiscent of the succession at Solstrand on Strindbergs Land. Their palaeocurrent vector means vary in direction from southerly to northwesterly;

(1) The lower part of the succession forms Gunnbjörns Bjerg and W. Gross Bjerg, consisting of grey-green fine and medium sandstones with some red siltstone units. It is of the order of 1100 m thick, with sample groups 3C (grey-m., f. sst.-flat, trough X), 3A (grey-f., m. sst.-trough X) and 7B (grey-f. sst.-planar X, flat) of importance. Palaeocurrent directions recorded were variable, with northwesterly trends predominant. ALEXANDER-MARRACK & FRIEND (Nr. 3 of this volume) compare this division with the Østreplateau Grey Sandstone member (Kap Franklin Formation of the Kap Kolthoff Supergroup).

The Hjelmbjergene Group does not appear in the western limb of the Stensiøs Bjerg syncline; instead, the Kap Graah Group lies conformably there on the Kap Kolthoff Supergroup and it is evident that a major structural discontinuity (which does not affect the Mount Celsius Supergroup) occurs below sea level west of Agda Dal. In addition to this feature a lateral facies change must occur in this inaccessible interval, with the development on Smith Woodwards Bjerg of two divisions which are not represented in the Agda Dal area. The structural discontinuity will be discussed below. It is of regional significance in the development of the Kap Graah Group and we must look to other areas for further information as to its nature.

The Kap Graah Group successions between Margrethedal and Watsons Plateau at the localities indicated in Figure 2 will now be summarised, and their relations assessed.

The Kap Graah Group on Obrutschews Bjerg and Evans Bjerg

BÜTLER has briefly referred to the Obrutschews Bjerg Kap Graah Group sandstones, as the basal beds of his "Mount Celsius Series" (1954, pp. 102–103; 1959, p. 161). He recognised that there is an unconformity surface at the base of the division, and suggested that it may correlate with the unconformity visible in the upper part of Sederholms Bjerg, south of Moskusoksefjord.

The outcrop of the Group on Obrutschews Bjerg and Evans Bjerg is shown in Figure 27. Observations made at the localities lettered in Figure 27 are summarised by Figure 28, in which two features are prominent.

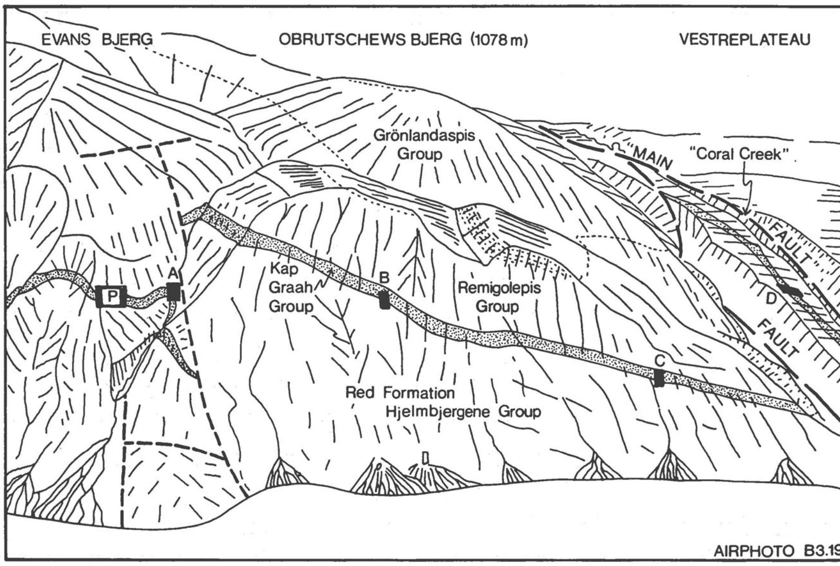

Fig. 27. Sketch, based on oblique aerial photograph, showing south face of Obrutschews Bjerg and Evans Bjerg. The photograph of Plate 13 was taken at locality P.

(1) Easterly thinning of the Group, from approximately 75 m at the western end of the mountain to about 50 m at the eastern end; the outcrop is terminated by the major "post-Devonian Main Fault". In the western part of the main face, and in the deep ravine separating Obrutschews Bjerg from Evans Bjerg, 75–80 m of white pebbly sandstones are present, forming broken cliffs (Plate 13). At the eastern end of the south face of Obrutschews Bjerg, and in "Coral Creek" (Figure 27), only the upper beds of the Group are exposed. SÄVE-SÖDERBERGH (1934, p. 16), however, recorded the full thickness of the Group above the Vestreplateau as 51 m.

(2) The second obvious feature is the upward-fining of the beds (best seen in western Obrutschews Bjerg) from medium and coarse pebbly units of sample groups 3C (grey-m., f. sst.-flat, trough X), 3D (grey-m., co. sst.-trough X) and 6 (congl.), to very fine sandstones classified in 7D (grey-f., v. f. sst.-trough X, flat) and 7E (grey-f. sst.-trough X, flat). With upward-fining the mean set height of the cross-strata also diminishes. The geometry of the sandstone bodies is suggested by Plate 13, which shows a 59 m wall on Evans Bjerg in which sheets and lenticular bodies can be discerned. Nearly all of these beds appear internally structureless, and those festoons which are visible are rarely internally laminated. Scour surfaces are common, sometimes many metres in lateral extent.

Details of clast ratios and sizes were obtained at locality C on

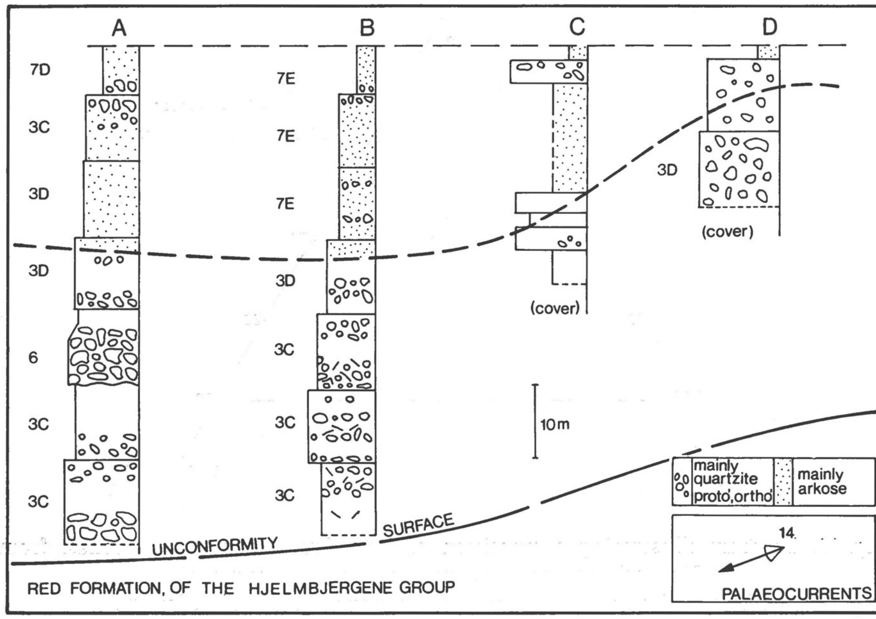

Fig. 28. Comparison of sections measured in Kap Graah Group, at localities indicated on Fig. 27.

Obrutschews Bjerg (Table 7). This assemblage is generally typical of the upper part of the Group here; in the lower beds intraformational pebbles are sometimes absent. In the westernmost sections examined the clasts tended to be confined to specific horizons, within the lower half of the succession, but in the more central exposures they are more evenly distributed.

Petrographically two intergradational types of sandstone are recognisable:

(1) Protoquartzites (and rarely orthoquartzites) containing large polycrystalline grains of quartz, and occasional rhyolite clasts. The quartz grains exhibit pressure solution phenomena and are cemented by quartz. An original grain boundary is sometimes still visible by means

Table 7. *Clast data, Kap Graah Group, locality C on Obrutschews Bjerg (obtained from 100 clasts).*

	Quartz (white)	Quartzite (sedimentary)	Rhyolite, Rh. tuff	Intrafmn siltstone
Composition	21 %	16 %	59 %	4 %
Modal roundness	0.7	0.5	0.3	(varies)
Modal long axis, *in situ* (cm).	3	2–3	4 (up to 20)	3–4

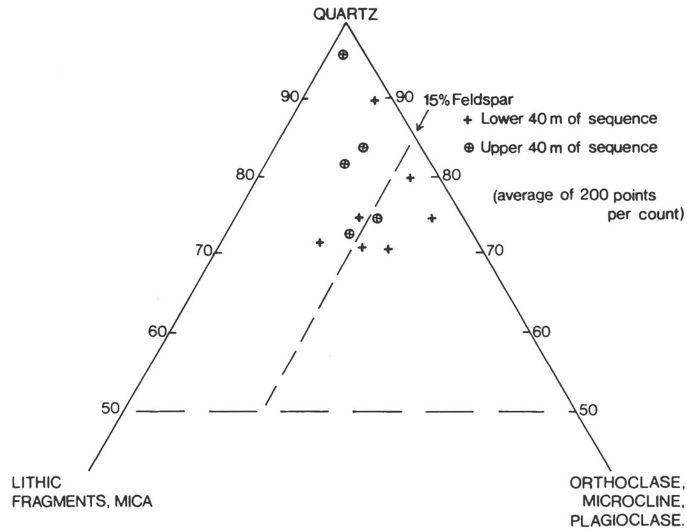

Fig. 29. Diagram illustrating composition of Kap Graah Group sandstones, from Obrutschews Bjerg, determined by pointcounting.
(Mistake: Lower should read upper, upper should read lower).

of an iron oxide pellicle. In such instances most of the grains are seen to have been subrounded. The protoquartzites form the matrix of the lower, pebblier part of the succession, and the massive medium sandstones of the middle part. Within these beds primary sedimentary structures are rarely seen.

(2) arkoses, often intensively weathered, in which orthoclase is the dominant feldspar (occasionally with authigenic overgrowths). Frequently they are cemented by calcium carbonate, sometimes replacing chlorite and sometimes secondary to quartz overgrowths. The arkoses form the fine-medium and very fine-grained less pebbly units, often greenish due to chloritisation of the matrix. In Figure 29 some point-count data are plotted to indicate the variations in composition exhibited by these two petrographic types.

Limited palaeocurrent data obtained from locality D indicated southwestward directions (Figure 28), consistent with the westerly thickening of the Group. The rhyolite clasts present in considerable numbers may have been derived from the "Giesecke Block" area to the east of the "Main Fault", which contains granitic intrusions and rhyolitic centres.

These sediments may be interpreted as a fluviatile pebbly accumulation near the margin of the Kap Graah Group basin. The abundance of coarse pebbly sediment, preserved in broad channels and virtually structureless internally, the presence of extensive scours, the absence of preserved fine-grained sediments, and the upward-fining of the suc-

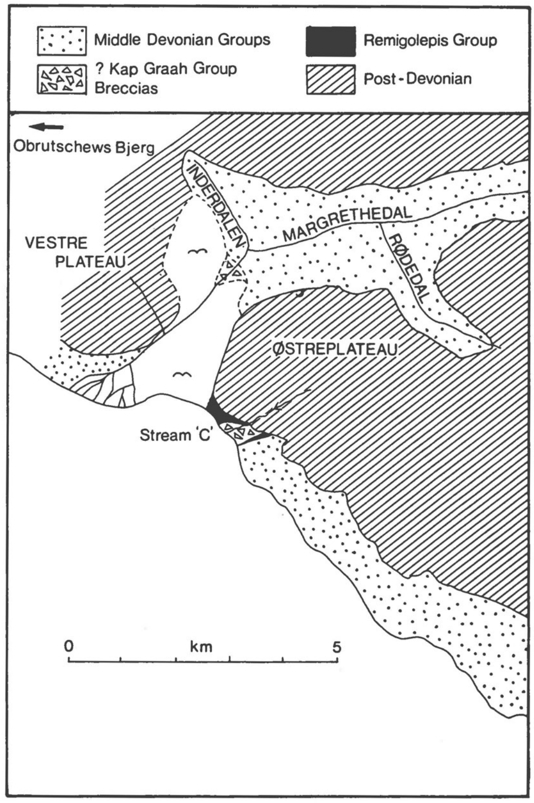

Fig. 30. Sketch map of lower Margrethedal showing outcrops of ? Kap Graah Group breccias, and Remigolepis Group.

cession support this conclusion. Fish fragments are virtually absent, and only after prolonged search were several poorly-preserved bones found in the topmost part of the succession.

BÜTLER has described a sequence of 40–50 m of very similar rocks 12 km to the north, in upper Gastisdal (1955, p. 111), which probably belong to the Kap Graah Group as it is defined here.

Breccia Outcrops East of the "Main Fault"

Two outcrops of red rhyolitic breccia which may belong to the Kap Graah Group were examined east of the "Main Fault" line. Their location is shown in Figure 30.

The outcrop in Margrethedal (BÜTLER, 1954, pp. 45–47, p. 97) consists of at least 30 m of red very fine sandstones, with some lenses of red coarse sandstone, containing tightly-packed angular clasts which are usually about 10 cm in diameter (but may reach 30 cm). At least 80 % of them are rhyolitic, of several types: grey; dark flow-banded

Table 8. *Clast data, red breccia east of Margrethedal (? Kap Graah Group). Based on 50 clasts, randomly chosen.*

Clast type	%	Observed max. sizes (cm.)
Dark-brown porphyritic rhyolite.................	65	27×18
Grey rhyolite, with quartz and feldspar phenocrysts. Some flow-banding..............................	17	28×12
Grey fine quartzites with quartz veins; red-grey	17	–
sandstones; quartz. Possibly from the Kap Franklin	1	–
Group (Middle Dev.)...........................	<1	–

quartz-feldspar porphyry; and yellow "felsite". The remaining 20 % consist of red and green very fine sandstones, green siltstones, white quartz and quartzites, and fragments of concretionary and dark limestones.

At the north end of the outcrop one poor exposure suggests that the breccia lies across a yellow felsite dyke cutting the folded and faulted red sandstones and siltstones of the "Margrethedal Series". Clasts of similar composition to this dyke rock occur within the breccia. It is therefore suggested that the red breccias may be lying on an erosion surface, dipping westwards at a low angle, and are not part of the "Margrethedal Series".

The second breccia outcrop is on the coast (Figure 30; MAYNC, 1949, p. 13; BÜTLER, 1954, p. 93). It forms a 10 m cliff in which 80–90 % of the clasts are angular rhyolites, as detailed in Table 8, diminishing upwards in size. Some irregular lenses of red sandy siltstone are present, and some cross-stratification is visible. Purple siltstones are interbedded with the breccias at the top of the cliff, very similar lithologically to those of the Remigolepis Group occurring in faulted contact on the east side of the outcrop, and also present in uncertain relationship to the breccias in very poor coastal exposures to the west.

The probable unconformity at the base of the Inderdalen-Margrethedal outcrop suggests that this breccia may belong to the Kap Graah Group rather than to the "Margrethedal Series" as BÜTLER thought (1954, pp. 45–47); and the probable upward passage of the coast breccia into purple mudstones strongly suggests that it also may be correlated with the Obrutschews Bjerg succession of the Kap Graah Group.

The pebble suite of the Kap Graah Group sandstones on Obrutschews Bjerg consists of pink rhyolite and tuff, quartz, and quartzite; in contrast, quartz and tuff pebbles are very minor components of the breccias, and their rhyolite fragments are considerably larger than those seen on Obrutschews Bjerg. However, if the breccias originated as locally-derived fans it is possible that substantial clast type variation could occur over a limited distance; ALLEN (1965b, p. 168) refers to this phenomenon. The rhyolite clasts of the breccias may be derived from the Kap Franklin extrusives, or from later intrusions in Margrethedal. Their quartzite and limestone clasts may be derived directly from the Eleonore Bay Group or from Cambro-Ordovician formations; or they may be reworked from the Rødedal conglomerates (Middle Devonian).

In Inderdalen at 235 m, BÜTLER (1954, p. 98) found a third outcrop of rocks similar to the Kap Graah Group sandstones west of the "Main Fault". It consists of 40 m of white medium and coarse sandstone, interbedded towards the top with red and purple siltstones resembling those of the Remigolepis Group, and separated from the underlying Middle Devonian Inderdalen Formation (with no apparent unconformity) by a 3 m weathered zone (ALEXANDER-MARRACK, personal communication).

The Kap Graah Group on Gross Bjerg

On the eastern cliffs above the valley separating Gross Bjerg from Gunnbjørns Bjerg, at 770 metres, a 150 m measured section passing through almost the entire succession of the Kap Graah Group was obtained. This section is represented in Figure 31; the succession may be divided into four parts.

(1) The lower part consists of 60 m of sandstones, lying unconformably on the Hjelmbjergene Group. Initially these are highly pebbly, classifying in sample groups 3D (grey-m., co. sst.-trough X), 2C (red-m., co. sst.-trough X) and 2E (red-m., co. sst.-trough X); the upper units are less pebbly, consisting of 2E (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X). Three clast counts were made in the lower 30 m. The lowest horizon examined contained clasts exclusively derived from the underlying Hjelmbjergene Group, with basalt and sandstone blocks up to 30 cm in diameter. Approximately 10 m higher a marked influx of much smaller, rounded quartz pebbles is present; and a further 5 m higher, pink porphyritic and flow-banded rhyolite fragments appear with the quartz. Thereafter these clast types remain associated.

Few palaeocurrent data were obtained from this interval, but westerly or southwesterly transportation is indicated (as was found at Obrutschews Bjerg). The overlying 30 m of sandstones of sample groups 2E (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X) are more uniform, less pebbly, and of reduced mean cross-stratification set height (Figure 31), with a more southerly-directed palaeocurrent vector mean.

(2) Arbitrarily separated, the following 15 m of the succession consists of sample group 3A (grey-f., m. sst.-trough X), in which the clasts are

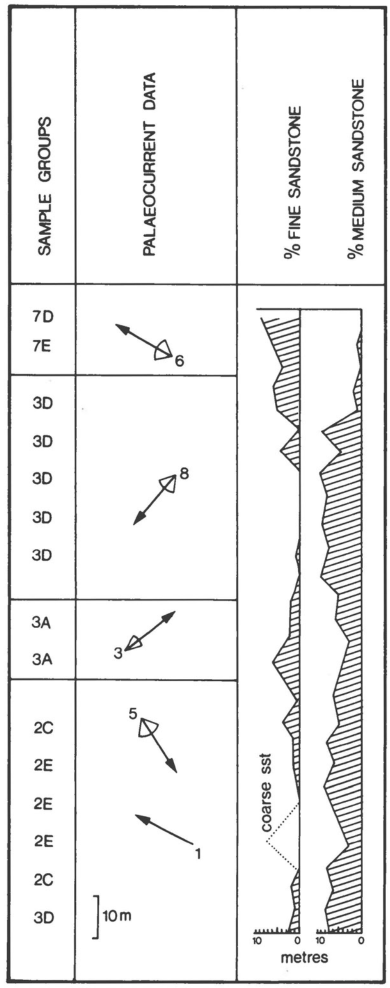

Fig. 31. Data collected from 150 m of logged section in the Kap Graah Group of Gross Bjerg.

of intraformational types only. Green spots are present in the finer sandstones. Lenses of red siltstone up to 0.4 m thick appear, possibly shallow abandoned channel deposits. The interval is terminated by the siltstone-sandstone unit illustrated in Figure 6B, which from the lack of a basal scour surface is thought to represent overbank sedimentation rather than an abandoned-channel deposit. Palaeocurrent directions measured in this interval are greatly divergent from those obtained in the sandstones below.

(3) A major scour surface then initiates a 50 m interval of medium-grained sandstone cosets, almost entirely of sample group 3D (grey-m., co. sst.-trough X). Quartz and rhyolite clasts are few, and restricted to

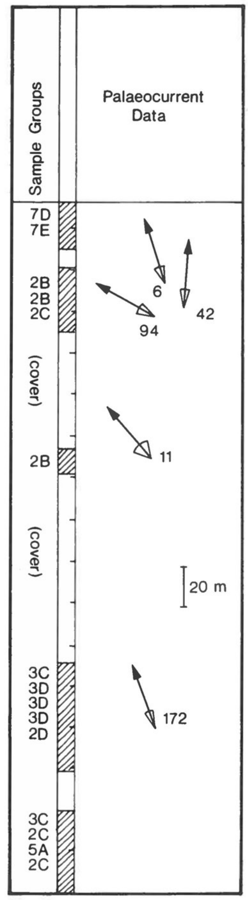

Fig. 32. Data collected from the Kap Graah Group Succession at Agda Dal. Parts of the succession logged in detail are shown by oblique-lined blocks.

the basal 10 m of this succession, but intraformational clasts are abundant. In this interval the siltstone bodies illustrated in Figure 6A, occur. These are lenses, bounded above and below by major laterally-extensive scours. Some of them contain clasts at their bases, and cross-laminated horizons.

(4) The remaining part of the Group consists of sample groups 7E (grey-f. sst.-trough X, flat) and 7D (grey-f., v. f. sst.-trough X, flat), sheets of fine and very fine sandstone interbedded with siltstones containing well-developed concretionary carbonate. Säve-Söderbergh (1934, p. 20) found fish fragments in the upper 7 m of this interval. The palaeocurrent vector mean given for the sequence in Figure 31 was obtained on E. Gross Bjerg. The upper parts of the W. Gross Bjerg measured profile present considerable access difficulties. This lithology passes transitionally into the siltstones of the Aina Dal Formation

(Remigolepis Group), with an interdigitation of sample groups 7D (grey-f., v. f. sst.-trough X, flat) and 5A (red-v. f. sst., -co. slst.-trough X, flat) at the base.

The Kap Graah Group at Agda Dal

7 km to the west of the Gross Bjerg section, on Nathorsts Bjerg (Plate 14), the Group is 330 m thick. It may be separated into two divisions (Figure 32).

(1) The lower division is about 130 m thick, with an unconformable base marked by an angular discordance and by a thin conglomerate of material derived from the underlying Hjelmbjergene Group. Sample Group 5A is developed immediately above the unconformity, and several fossiliferous horizons in this lithology were found in the Agda Dal cliffs (including a new locality about half a kilometre east of the head of the delta) with *Phyllolepis*, *Bothriolepis*, *Holoptychius*, and a dipnoan. Vertebrates are not common above this stratigraphic level in the Group at Agda Dal.

The remainder of the lower division is modally medium-grained, consisting of sample groups 3D (grey-m., co. sst.-trough X) and 3C (grey-m., f. sst.-flat, trough X). The sandstones contain pebbles of quartz, quartzite, rhyolite, and occasional siltstone. Rhyolite forms a lower proportion of the clasts than at Gross Bjerg. Many palaeocurrent directions were obtained from the terraces west of Agda Dal, indicating north-west to north-north westerly transportation of sediment.

(2) The upper division is about 200 m thick, consisting mainly of modally fine sandstones of sample group 2B (red-m., f. sst.-trough X, flat). It is poorly-exposed in its lower parts (Plate 14). Extraformational clasts are virtually absent. Green-spotting due to the development of chlorite around basalt grains is particularly well-developed in the sandstones.

In the upper 30 m the division passes transitionally into the Aina Dal Formation, through micaceous fine and very fine sandstones of sample group 7D (grey-f., v. f. sst.-trough X, flat). In these uppermost beds the palaeocurrent vector means are more northerly-directed than those obtained lower in the division.

The Kap Graah Group Succession on Smith Woodwards Bjerg

This section describes the succession of the Group between Parallel-dal and eastern Smith Woodwards Bjerg, in which three major divisions are recognised:

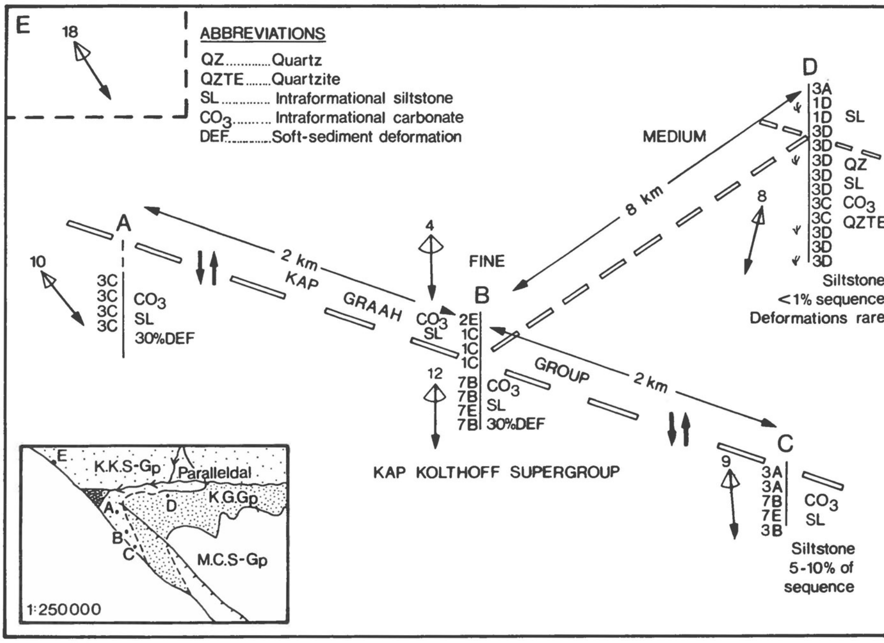

Fig. 33. Fence diagram representing relationships between sections logged in the upper Kap Kolthoff Supergroup and lower Kap Graah Group on western Smith Woodwards Bjerg. Palaeocurrents are drawn relative to a True North running vertically up diagram. Sample groups, clast type and other features are shown. Double arrows indicate transitional nature of boundary. On insert map, K. K. is Kap Kolthoff, K.G. is Kap Graah and M.C. is Mount Celsius. Scale should be 1:500.000.

The lower division

The lower division is exposed in the coast cliffs east of Paralleldal, and is approximately 250 m thick. Only the lower part of the division was examined, as summarised in Figure 33. The Group is not clearly defined by a sharp colour change from the underlying Kap Kolthoff Supergroup sandstones, as it is on Watsons Plateau and in W. Moskusoksefjord; here a zone of red-grey alternation is present, with no unconformity evident. The lack of extraformational clasts in the division is one of its notable features as is the abundance of soft-sediment deformations: up to 30 $^0/_0$ of the sets are affected by cuspate and fold structures.

These characteristics are shared by the uppermost Kap Kolthoff Supergroup sequence at Smith Woodwards Bjerg, as indicated by Figure 33. The sandstones of the Supergroup exhibit southerly palaeocurrent directions, and towards the south the content of extraformational pebbles decreases.

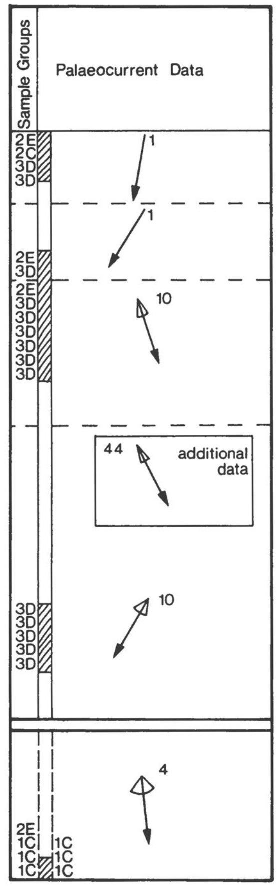

Fig. 34. Data collected from the lower and middle Kap Graah Group, on W. Smith Woodward Bjerg. Numbers on palaeocurrent vector mean arrows are number of measurements. Blocks with oblique lines indicate parts of succession logged.

The middle division

In the central part of W. Smith Woodwards Bjerg a 400 m division of poorly-sorted medium-coarse sandstones forms the second stratigraphic unit recognised. Approximately 200 m of detailed section were measured, as summarised in Figure 34. The relative positions of these sections are subject to an uncertainty of the order of 10 %, due to the effects of numerous faults. Three colour-based subdivisions can be made:

(1) The section measured in the lowest unit, of cream-yellow arkose, classifies mainly into sample group 3D (grey-m., co. sst.-trough X). A gradual upward -coarsening is evident, with an apparent decrease in the number of extraformational clasts. In the upper part of the unit soft-sediment deformations are more common, with about 25 % of the sets affected whereas only 5 % are recorded as deformed in the sec-

tion obtained in the lower part of the unit. The pebbles are of exotic and intraformational origin, including carbonate nodules and green siltstone clasts up to 10 cm in diameter, occasional carbonaceous and pyritic nodules, grey-white quartz and quartzite clasts, and pink rhyolite fragments up to 4 cm.

(2) A pale-pink notably pebbly unit follows, 50 m thick, in which extraformational pebbles are dominant. It is slightly coarser than the unit beneath, and very poorly sorted. Sandstones of this unit contain up to 25 % orthoclase and microcline, and relatively minor plagioclase; large polycrystalline quartz grains are abundant.

(3) The third subdivision (50 m) is pale grey, consisting of sample groups 3D (grey-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X) and 2E (red-m., co. sst.-trough X). It is characterised by the considerably reduced mean set height, relative to the unit below, and by its decreased extraformational clast content. Those present are of the types noted previously.

The upper division

In eastern Smith Woodwards Bjerg the upper division of the Group is approximately 850 m thick. It may be divided into three units (Figure 35).

(1) Only about 100 m of the lower subdivision have been examined, of its total thickness of approximately 350–375 m. It consists mainly of arkoses classifying in sample group 2E (red-m., co. sst.-trough X), and contains at least 3 varied intervals with siltstones. Only one of these was examined, and it proved to contain intervals of sample group 7E (grey-f. sst.-trough X, flat), 3C (grey-m., f. sst.-flat, trough X) and 2A (red-f., m. sst.-trough X, flat). Near the top of the lower subdivision, in a fluviatile interval, the brief appearance of green-spotted sandstones is noteworthy.

At the base of the upper division a sequence of large-scale cross-strata is present, with sets of type 1 (planar) up to 2.5 m high, classifying in sample group 2E (red-m., co. sst.-trough X). In this interval clasts are very rare and vertebrate remains are absent. It may be of aeolian origin.

(2) A distinctive and varied 80 m unit of siltstones and sandstones is present above the lower subdivision, in which two features are notable:

(a) within the larger sandstone units, which are fine-grained and up to 2 m in thickness, large-scale low-angle cross-stratification of type 3 is developed (illustrated in Plate 2). Generally the foresets are inclined at right-angles to the vector mean palaeocurrent direction determined from the subdivision.

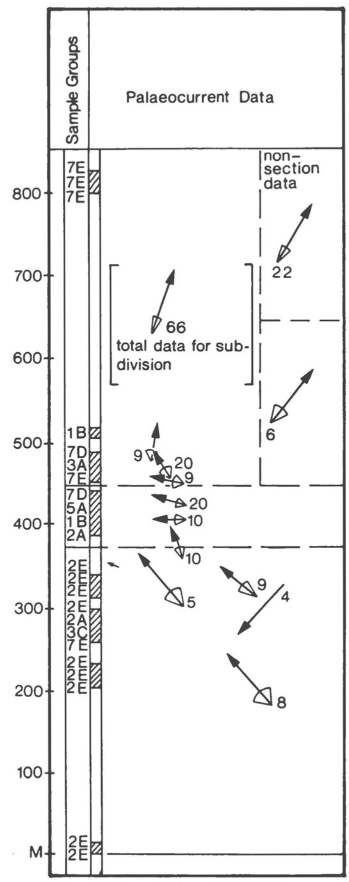

Fig. 35. Data collected from the upper Kap Graah Group on East Smith Woodwards Bjerg. Numbers on palaeocurrent vector means are numbers of measurements. Blocks with oblique lines indicate parts of succession logged.

(b) the siltstones are bedded in sheets of varied colours (including yellow and grey-blue) in the upper part of the unit. They contain many vertebrate remains (particularly in an interval of sample group 5A (red-v. f. sst., co. slst.-trough X, flat), identified as *Phyllolepis*, *Holoptychius*, and *Bothriolepis* sp.

(3) The final subdivision is approximately 400 m thick, exposed in a very large cliff on E. Smith Woodwards Bjerg. Sample group 7E (grey-f. sst.-trough X, flat) is important in the succession, with 1B (red-f. sst.-trough X), 7D (grey-f., v. f. sst.-trough X, flat) and 3A (grey-f., m. sst.-trough X). Sample group 7E (grey-f. sst.-trough X, flat) probably forms much of the upper part of the subdivision, which exhibits less variation than the lower part. Green spots are present in the upper three-quarters of the subdivision, and vertebrate remains

are to be found throughout. The highest beds of the subdivision are transitional into the Aina Dal Formation.

This highest subdivision of the Group compares closely with the top part of the succession in Paralleldal. During a brief visit to the southwest end of Sederholms Bjerg, which is very poorly exposed, a short section was measured approximately 350 m below the base of the Aina Dal Formation. The section classified in sample group 1B (red-f. sst.-trough X), and did not contain green spots. Fragments of *Holoptychius* and *Phyllolepis* were collected. The only record of green spots in the Group in Paralleldal is that of SÄVE-SÖDERBERGH (1934, p. 38), who briefly described a profile from central Sederholms Bjerg in which green-spotted sandstones were found at about 130 m from the top of the Group.

The Kap Graah Group on Watsons Plateau

The total thickness of the Group on Watsons Plateau is at least 700 m, of which the lower 300 m were logged. The Group may be divided into 4 units (Table 9):

(1) The lowest division forms near-vertical cliffs, in sharp contrast with the underlying grey softer sandstones of the Kap Kolthoff Supergroup. It follows the Supergroup conformably and consist of approximately 150 m of medium red sandstones of sample group 2E (red-m., co. sst.-trough X), with no associated siltstones.

The mean cross-stratification set height is almost twice as great as in the following divisions, with tabular sets of type 1 (planar) up to 2.5 m high. Soft-sediment deformations occur rarely, of cuspate and irregular types; interlamination of coarse and finer sandstones is common; no ripple cross-lamination was seen; virtually no clasts are present, and vertebrates are absent; and mudcracks are rare, occurring only in micaceous thinner-bedded fine sandstones which are laterally persistent. The absence of many of the features characteristic of fluviatile sandstones suggests that these sediments may be of aeolian origin.

(2) The next division is 40 m thick, consisting of sample groups 7E (grey-f. sst.-trough X, flat) and 1B (red-f. sst.-trough X). The division is undoubtedly of fluviatile origin, containing many intraformational siltstone and carbonate pebbles and numerous fish fragments (which include plates of *Bothriolepis*). Trace fossils are abundant, particularly in micaceous units.

SÄVE-SÖDERBERGH (unpublished manuscript, describing field work in 1934) made a profile about 5 km southeast of the succession described here, recording *Bothriolepis* in "greenish rock types" forming terraces at approximately 100 metres and at 150 metres from the base of the Group. He commented that his locality occupies very nearly the same

Table 9. *Data on the Kap Graah Group succession of Watsons Plateau, W. Gauss Halvø.*

Division	Sample Groups	Cross-strat mean set ht (m)	mean of greatest 10 % sets	% sets with soft def	% sets with intrafmn clasts
division 4 (red, 250 m)	—	(no data)			
division 3 (red, approx 200 m)	2E 2E 2E 2E 2E	0.50	1.15	30 %	9 %
	2B 2B 2B 2F	0.40	0.75	10 %	20 %
division 2 (grey, 40 m)	1B 7E	0.40	0.60	4 %	42 %
division 1 (red, 150 m)	2E 2E 2E 2E 2E 2E 2D 2E 2E 2E 2E 2E	0.75	1.90	10 %	1 %
	3D 3D	Kap Kolthoff Supergroup			

PALAEOCURRENT DATA

	Vector mean	Confidence limits	Readings
division 3	181°	26°	20
division 2	154°	32°	9
division 1	155°	18°	15

stratigraphic position as that of KULLING in the "Bothriolepis Cleft", which separates Watsons Plateau and Fletts Plateau (KULLING, 1931, p. 13; SÄVE-SÖDERBERGH, 1932, pp. 27–28; 1933, p. 38; 1934, pp. 29, 41, 43).

(3) The third division is about 200 m thick, of which the lower 90 m were logged. The division is dark-red, with 40 m of sample group 2B

(red-m., f. sst.-trough X, flat) followed by a succession of red medium sandstones, exhibiting an increased mean set height and numerous soft-sediment deformations, which classified into sample group 2E (red-m., co. sst.-trough X). No ripple marks or cross-lamination are preserved in this latter interval; less flat-bedded sandstone is present; and no fish fragments were noted. Southerly palaeocurrent directions were obtained (Table 9).

(4) The fourth division was inaccessible from the gullys in which the measured sections were made. It is a chestnut-red unit forming the top of the plateau, estimated from air photographs to be at least 250 m thick.

Lithostratigraphic Correlation of the Kap Graah Group Sections Described between Margrethedal and Watsons Prateau

In Figure 36 the successions from the six localities described in this section have been drawn up, using the base of the Aina Dal Formation as a datum. Due to erosion the Group is absent from the 20 km interval between the western part of Smith Woodwards Bjerg and Watsons Plateau, which contains only the Kap Kolthoff Supergroup in the broad anticline passing west of Paralleldal; and the Stensiøs Bjerg syncline carries the Group wholly or largely below sea level for a distance of about 15 km between Agda Dal and E. Smith Woodwards Bjerg. Reference to this latter gap has already been made in connection with the Kap Kolthoff Supergroup-Hjelmbjergene Group relationship. It may also conceal important lateral facies changes within the Kap Graah Group.

On S. Gauss Halvø the Group may be considered in three parts:

(1) On W. and central Smith Woodwards Bjerg the Kap Kolthoff Supergroup is followed conformably by the lower red and middle white divisions of the Kap Graah Group, collectively 650 m thick. The base of the lower red division is not sharply defined, and the sediments probably were laid down under very similar fluvial conditions of deposition to those of the Supergroup. In common with the Supergroup, these two divisions exhibit southerly palaeocurrent directions and they lack vertebrate remains. The lower red division lacks extraformational clasts, as does the Supergroup here.

The middle white division is coarser, a monotonous succession of sample group 3D (grey-m., co. sst.-trough X) fluviatile sandstones with pebbles of quartz and quartzite, and rhyolite. A lithological analogue of this 400 m division is not present in the Agda Dal succession to the east or in the Watsons Plateau sequence to the west, and it must be assumed to wedge out laterally towards both areas. To the east of Smith

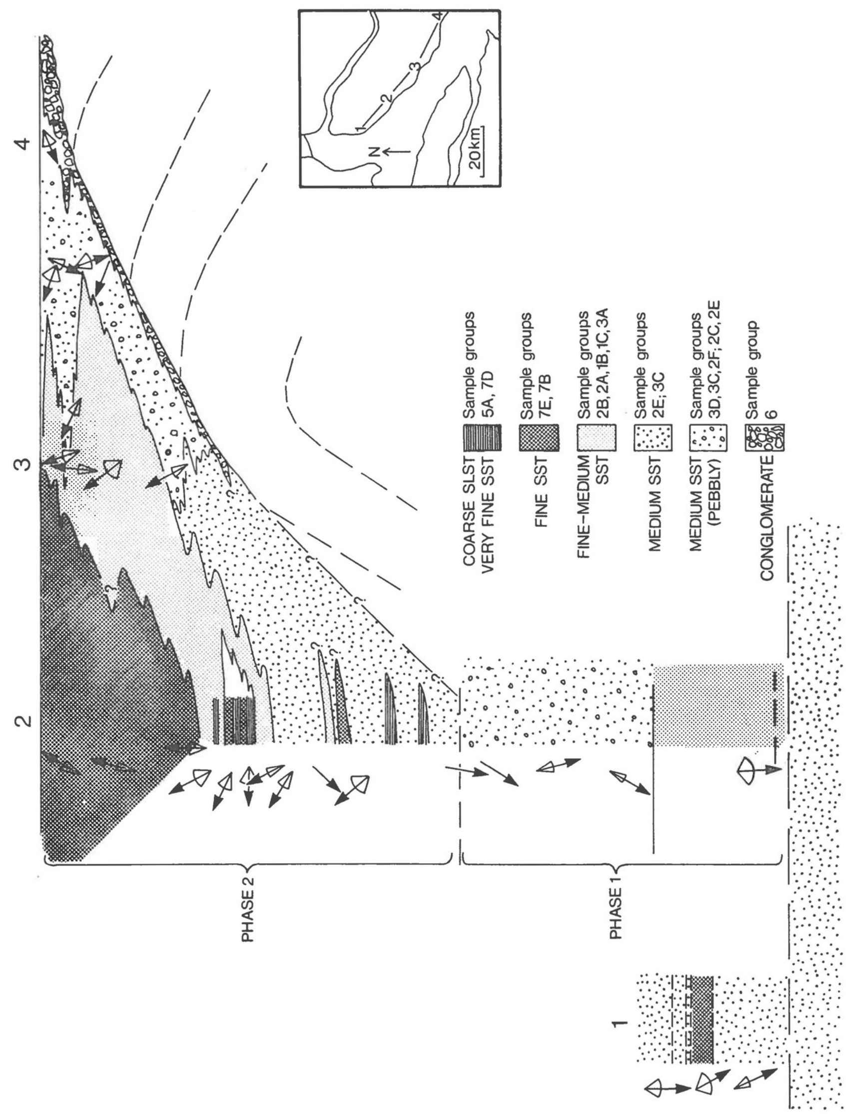

Fig. 36. Diagram showing variation in the Kap Graah Group from N.W. to S.E. along the coast of Southern Gauss Halvø.
1—Watsons Plateau, 2—Smith Woodwards Bjerg,
3—Agda Dal, between 3 and 4—Gross Bjerg,
4—Obrutschews Bjerg to Margrethedal.
A thickness of 300 m is represented by 2 cm.

Woodwards Bjerg the lateral facies change occurs below sea level. A sketch in SÄVE-SÖDERBERGH's unpublished manuscript, made from Zoologdalen, shows the division to be barely present in the southern part of Sederholms Bjerg, but the exposures in this area (and on the west side of Smith Woodwards Bjerg, above Paralleldal) are too poor to confirm whether or not this is so.

(2) On Watsons Plateau the only lithological boundary in common with the Smith Woodwards Bjerg succession is the junction between the Group and the Kap Kolthoff Supergroup. Southerly to southeasterly palaeocurrent directions were obtained, as at Smith Woodwards Bjerg, but the sandstones at the base of the Group are thought to be of aeolian rather than fluviatile origin. The succeeding grey, 40 m fluviatile sandstone division with *Bothriolepis* has no lithological equivalent on Smith Woodwards Bjerg, and the red pebbly fluviatile sandstones above, which dominate the Group here, do not resemble the succession developed at the corresponding interval above the base of the Group on Smith Woodwards Bjerg. To the succession at Zoologdalen there is no lithological similarity, though it is noteworthy that *Bothriolepis* and *Phyllolepis* were found in the lowest beds of the Group by SÄVE-SÖDERBERGH (ms).

(3) The thickness and lithofacies variations shown by the Group between Obrutschews Bjerg and Smith Woodwards Bjerg have been emphasized in Figure 36 by placing the sample groups into modal grain size classes.

The conglomerates at Inderdalen correlate laterally with pebbly medium sandstones containing conglomerate lenses, on Obrutschews Bjerg and Evans Bjerg. Palaeocurrent data suggest that these sediments were transported southwestwards. The pebbly sandstone body thickens and divides westward of Evans Bjerg into two wedges. The lower wedge consists mainly of sample groups 3D (grey-m., co. sst.-trough X), 3C (grey-m., f. sst.-flat, trough X), 2E (red-m., co. sst.-trough X) and 2C (red-m., co. sst.-trough X), containing abundant pebbles of quartz, rhyolite, and quartzite. It lies unconformably on the Hjelmbjergene Group, and at its base a conglomerate with Middle Devonian clasts is developed. At Agda Dal the basal conglomerate is reduced in thickness and is immediately followed by a thin development of sample group 5A (red-v. f. sst., co. slst.-trough X, flat), with a vertebrate fauna. This is overlain by pebbly sample group 3D (grey-m., co. sst.-trough X) sandstones of the lower wedge.

Fine fluviatile sandstones of sample group 2B (red-m., f. sst.-trough X, flat) form an important part of the succession at Agda Dal, and are of interest for their development of green spots. There is only a minor development of sample group 2C (red-m., co. sst.-trough X) in the upper part of the Agda Dal succession to represent the western deposits of the upper wedge of medium sandstone, which is best developed on Gross Bjerg. It is notable that the upper wedge, derived from the east and northeast (as was the lower wedge), contains few extraformational clasts.

Between Agda Dal and Obrutschews Bjerg the uppermost 20 m of the Group consist of sample groups 7E (grey-f. sst.-trough X, flat) and 7D (grey-f., v. f. sst.-trough X, flat) forming a transition into the overlying Aina Dal Formation siltstones. On Evans Bjerg and Gross Bjerg there is an interdigitation of 7D (grey-f., v. f. sst.-trough X, flat) and 5A (red-v. f. sst., co. slst.-trough X, flat) at the base of this formation.

There is no obvious lithostratigraphic correlation between the Smith Woodwards Bjerg and Agda Dal successions of the Group. Above the medium-coarse middle white division follows a probable aeolian interval, passing into a fluviatile sequence containing siltstones and (about 200 m above the middle division) a limited influx of green-spotted sandstones. Northerly to north-northwesterly palaeocurrent directions were recorded from these rocks, rather than southerly directions, and they contain no extraformational clasts. It is therefore suggested in Figure 36 that the lower part of the Agda Dal succession probably correlated with this mixed aeolian-fluviatile interval rather than with the middle white division below.

An alternative possibility is that the 80 m siltstone-sandstone interval of sample groups 5A (red-v. f. sst., co. slst.-trough X, flat), 7E (grey-f. sst.-trough X, flat) and 7D (grey-f., v. f. sst.-trough X, flat) on Smith Woodwards Bjerg, which contains *Phyllolepis*, *Bothriolepis*, and *Holoptychius*, may correlate with the 5A (red-v. f. sst., co. slst.-trough X, flat) unit at the base of the succession at Agda Dal (which contains the same fauna). The predominantly 2E (red-m., co. sst.-trough X) succession which follows the middle division on Smith Woodwards Bjerg may have been deposited prior to the onset of deposition of the Group in the Hjelmbjergene area, if this is so. The upper half of the upper division on Smith Woodwards Bjerg consists of sample group 7E (grey-f. sst.-trough X, flat) primarily, and this is laterally correlated with modally fine and medium sediments at Agda Dal; both successions are green-spotted.

The palaeocurrent data suggest that the medium sandstones of Obrutschews Bjerg to Gross Bjerg, the fine and medium sandstones of Agda Dal, and the fine sandstones and siltstones of Smith Woodwards Bjerg were derived from different source areas, and therefore the basinward lithofacies variations exhibited by the Group in this area must be explained in terms of a multiple depositional system. The pebbly medium sandstones were introduced from the east and northeast; and the finer sediments farther to the west were laid down by northerly-flowing streams. These relationships will be considered further below.

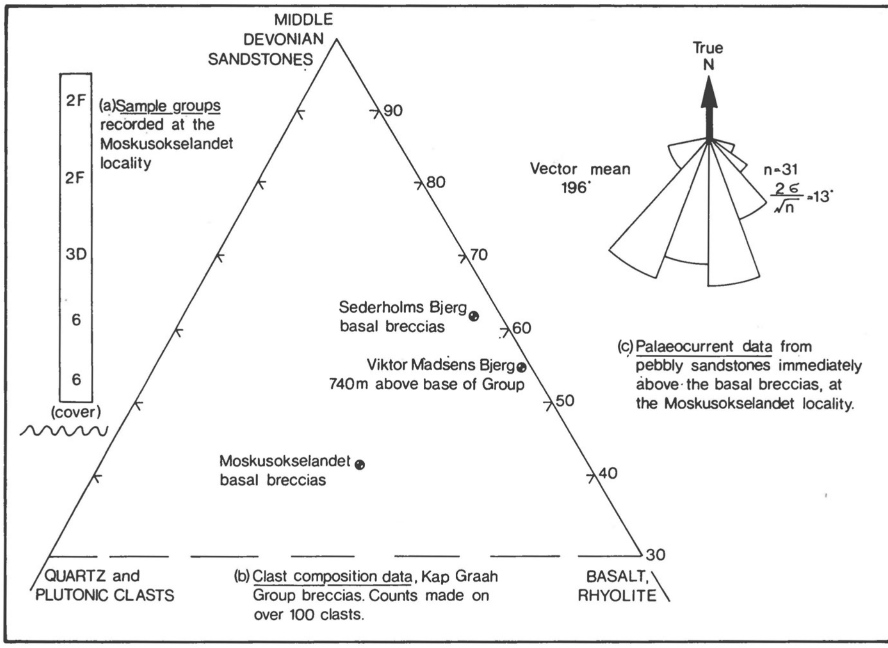

Fig. 37. Analytical data from Kap Graah Group conglomerates of the Moskusoksefjord area: a) Sequence of 5 10 m samples measured from basal unconformity in Moskusokselandet, b) Clast composition data, c) palaeocurrent data.

THE KAP GRAAH GROUP IN MOSKUSOKSEFJORD AND VICTOR MADSENS BJERG

This section completes the detailed descriptions of the Kap Graah Group successions examined, by considering the Victor Madsens Bjerg and Sederholms Bjerg areas, and observations made on the north side of Moskusoksefjord.

The Basal Breccia of the Group on Moskusokselandet

On the north shore of Moskusoksefjord only the lower part of the Kap Graah Group is preserved. It lies across the tilted sandstones of the Kap Kolthoff Supergroup and is bounded to the east by the Høgboms Bjerg-Sederholms Bjerg thrust (Bütler, 1959, p. 96–97). The basal breccias of the Group to the west of Høgboms Bjerg lie on an irregular unconformity surface (Plate 15), truncating dykes and a lava flow in the Supergroup (Bütler, 1959, p. 68), thinning westwards until at Forbindelsesdal they and the unconformity surface are no longer present.

The breccias are bedded in 2–4 m units above the unconformity surface, containing clasts up to 1 m in diameter.

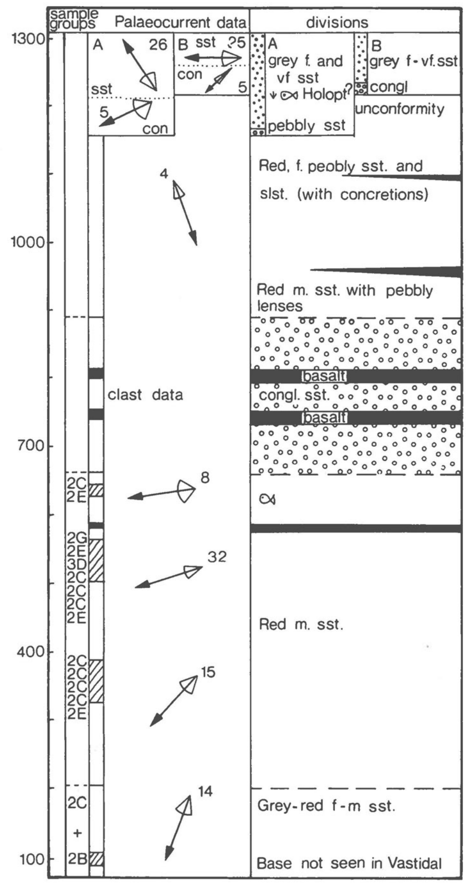

Fig. 38. Data collected from Kap Graah Group on Victor Madsens Bjerg. Numbers beside palaeocurrent vector mean arrows are numbers of measurements. Parts of section logged are indicated by oblique-line blocks.

Typical sizes for sandstone blocks are 30 × 20 cm, and for basalt fragments 20 × 20 cm. Palaeocurrent data from the pebbly sandstones immediately overlying the breccias given in Figure 37 show that they were derived from the north or northeast; the breccia blocks below were probably of relatively local origin. An estimate of the composition of a sample of the breccia is plotted in Figure 37, together with two other conglomerate counts from Sederholms Bjerg and Victor Madsens Bjerg. Much of the material is composed of green fine and medium-grained sandstones, no doubt from the Middle Devonian, and of basalt. The ratios of the clast types vary markedly from bed to bed, and the content of green sandstones declines abruptly in the overlying pebbly sandstones. Rhyolite clasts are present, of minor importance in the breccia but more numerous in the overlying sandstones, with quartz.

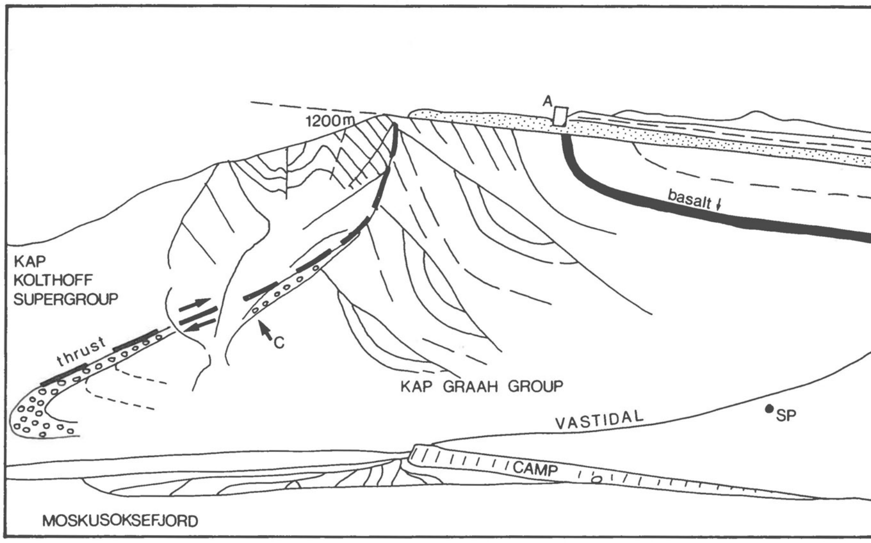

Fig. 39. N.E. Sederholms Bjerg, showing the position of the Høgboms Bjerg—Sederholms Bjerg thrust surface (after BÜTLER, 1959, p. 59, Fig. 18). C—clast data, A—Aina Dal Formation measured section, SP—locality at which Plate 16 was taken.

The Kap Graah Group on Victor Madsens Bjerg and Sederholms Bjerg

In Victor Madsens Bjerg, on the south side of the fjord, the Kap Graah Group succession is fully-preserved, and capped by the Remigolepis Group. Figure 38 summarising the sequence was compiled from profile and section data obtained from the fjord face of Victor Madsens Bjerg near Vastidal (the valley on the eastern side of the mountain), and from altimeter profile observations on the northeast flanks (Plate 17). BÜTLER (1959, p. 78) has sketched the succession of the central part of the mountain.

No unconformity or conglomerates marking the base of the Group were seen in Vastidal, but on Sederholms Bjerg steeply-dipping coarse conglomerates and breccias which closely resemble those of Moskusokselandet are present in the vicinity of the thrust zone (Figure 39). A clast composition plot representative of these is given in Figure 37. The lower 200 m of the Group exposed in the Vastidal river cliffs consists mainly of sandstones which classify in sample groups 2C (red-m., co. sst.-trough X) and 2B (red-m., f. sst.-trough X, flat). Much of the succession is obscured by vast debris fans. The clasts present include quartz and pink rhyolite, but intraformational green siltstones are predominant.

The following 450 m consist mainly of sample group 2C (red-m., co. sst.-trough X), with subsidiary 2E (red-m., co. sst.-trough X). Towards the top of the interval there is an increase in the content of extraformational clasts (of quartz, quartzite and rhyolite), and though the mean cross-stratification set height remains more or less constant the larger sets preserved tend to increase in thickness. In the lower part of this unit lenticular siltstones are present, up to 2 m thick, separated by 4–7 m cosets of cross-stratified and flat-bedded sandstones resting on laterally-extensive scour surfaces. Gradually the proportion of coarse-grained sandstone present increases, and the thickness of the cosets increases. Concomitantly the siltstone lenses become thinner, sandier, and fewer in number. In the upper part of the interval siltstone beds are rarely more than 0.2 m thick and frequently they are partings rather than lenses. Lenticular bodies of fine sandstone are present. At 600 m the first of several basalt sills is present, approximately 8 m thick. Basalt pebbles occur occasionally in the sandstones beneath it.

Above 650 m the following 225 m of the Group consist of conglomeratic coarse sandstones (Figure 37). They were inaccessible in the gulleys examined on the fjord face of the mountain, and poorly-exposed on the altimeter profile route. The main clast types present are grey and grey-green sandstones, similar to those which are so prominent in the basal breccias: porphyritic rhyolites; amygdaloidal and non-vesicular basalt; limestones (probably from the Eleonore Bay Group or the Cambro-Ordovician formations); and minor amounts of concretionary limestone and brown siltstone. These types are present throughout the conglomeratic division. The clast diameters do not usually exceed 5–10 cm, but individual basalt fragments may attain 25 × 10 cm. The major beds are apparently structureless internally, some reaching 2.5 m in thickness. Interbedded with them are grey, less pebbly sandstone lenses up to 0.5 m thick. Within this pebbly division two porphyritic basalt sills are present, up to 20 m thick.

At the entrance to Gletscherdal (point x, Figure 40) JOHANSSON (1935, p. 25) reported a fossil locality with *Bothriolepis*, *Phyllolepis*, and *Holoptychius*, immediately underlain by a red pebbly sandstone up to 20 m thick, with 4 cm clasts. This unit is stratigraphically several hundred metres beneath the top of the Group, but lacking clast composition data and knowledge of the full thickness it is difficult to relate it to the successions of Victor Madsens Bjerg and southern Gauss Halvø. It is possible that it may correlate with the pebbly sandstone occurring between 650–875 m on Victor Madsens Bjerg. Alternatively it might be related to the uppermost pebbly sandstones seen on Sederholms Bjerg (Fig. 38).

The interval between 900–1100 m above the base of the Group was very poorly exposed on the profile route. The succession consists of red-grey medium and fine micaceous sandstones with pebbly horizons,

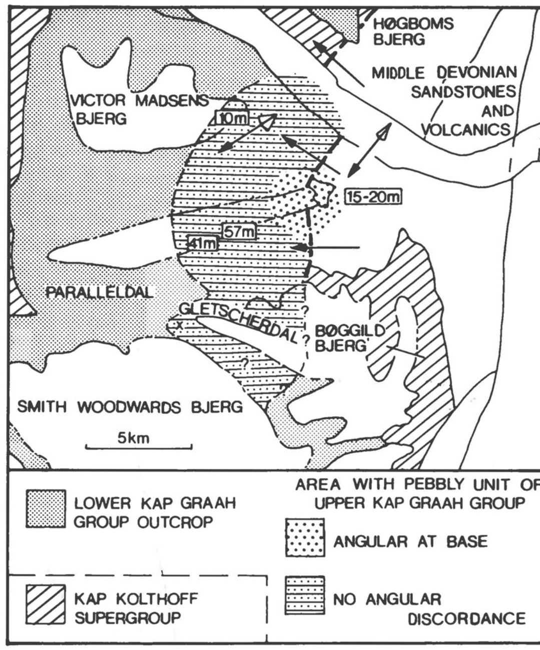

Fig. 40. Sketch map of Sederholms Bjerg area, Eastern Moskusoksefjord. Distribution and thickness of Pebbly unit of upper Kap Graah Group is shown, and the nature of its base. X marks fossil locality mentioned in the text.

containing clasts 1–2 cm in diameter. These are of the types previously noted, together with basalt granules. According to BÜTLER's summary several basalt horizons are present at this stratigraphic level on central Victor Madsens Bjerg. A new fossil horizon was located at 1000 m above the base of the Group, containing plates of *Bothriolepis* and *Phyllolepis* up to 20 cm in length, together with jaw bone fragments and cycloidal bones of *Holoptychius*. The bones occur in a succession of red medium and fine-grained cross-stratified sandstones with pebbly beds, interbedded with thin, poorly-bedded siltstones.

The final division of the Group is of considerable interest. On Victor Madsens Bjerg it lies on the underlying divisions with no angular discordance, but on the neighbouring Sederholms Bjerg it rests on an unconformity surface, lying across the thrusted contact between folded Kap Kolthoff Supergroup sandstones and uptilted Kap Graah Group sediments and basalt intrusions (Plate 17, Figure 39; BÜTLER, 1959, p. 60). On Sederholms Bjerg the unconformable division is 90 m thick, with a 15 m conglomerate at the base. This was derived from the northeast (Figure 40) and contains 3–4 cm clasts of pink and grey porphyritic rhyolite, green and white medium sandstones, quartzite, quartz, and white limestones. On Victor Madsens Bjerg the conglomerate is represented only by several metres of highly pebbly coarse red sandstone, followed by 10 m of very poorly sorted red muddy sandstones in 1–2 m sets.

In Figure 40 a plot has been made of the extent of this conglomeratic sandstone unit, using additional data from JOHANSSON's map of Paralleldal (1935, Plate 3, and pp. 8–10, 29). In addition to the outcrop of pebbly sandstone at point x, he recognised a wedge of red pebbly sandstone in several profiles made on the south side of central Sederholms Bjerg, thinning and becoming less pebbly westwards, and eventually disappearing. The unit was also seen on Circusbjerg, but was not examined in detail, and its further eastward extension was not determined. JOHANSSON did not observe an angular unconformity at its base. The clast types present were not identified, but they were stated to reach 3 cm in diameter. Fish remains were found at the very base of the unit.

On Sederholms Bjerg and Victor Madsens Bjerg the succession above the conglomerates consists of grey and red fine and medium-grained flat-bedded and cross-stratified sandstones, reaching 150 m in central Sederholms Bjerg. Detailed sections were not obtained, but the sample groups represented probably include 1B (red-f. sst.-trough X) and 1C (red-f., m. sst.-trough X, flat). The sandstones are highly calcareous, and contain grey siltstone clasts. Gradationally they become very fine-grained, green, with plant stems and occasional holoptychiid bones, this lithology forming the final 20 m of the Group. These rocks pass rapidly but transitionally into the siltstones of the Aina Dal Formation.

Other Observations on the N. Shore of Moskusoksefjord

Ankerbjergsdalen

On the north side of the plateau of Moskusokselandet, approximately 15 km north of Moskusoksefjord, we measured a short section on an outcrop at the base of the Kap Graah Group. The contact with the Kap Kolthoff Supergroup was sharp and conformable. The basal beds are pebbly, quartzite being the dominant clast type with subsidiary gneiss and other metamorphic rocks. On the basis of three readings, a palaeocurrent vector mean of 213° was obtained (confidence limits 17°), which is consistent with the southerly-southwesterly trend exhibited by the Group in Moskusoksefjord.

Hoelsbo-Forbindelsesdal

The mountain (.1358) behind Hoelsbo fangststation, east of the crystalline inlier, consists of grey sandstones of the Kap Kolthoff Super-

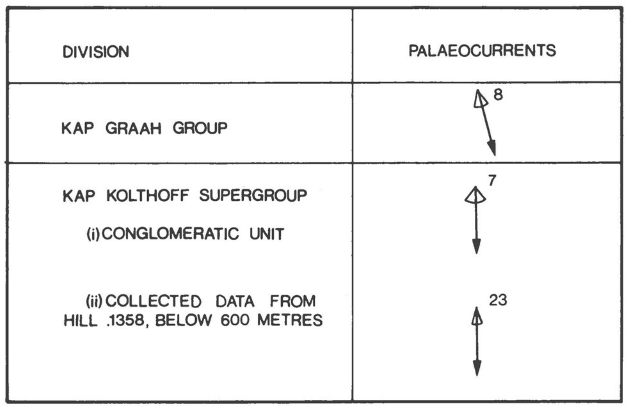

Fig. 41. Diagram summarising palaeocurrent data collected on mountain (.1358) behind Hoelsbo Fangststation, Moskusoksefjord. Numbers are numbers of measurements.

group, succeeded by red Kap Graah Group sandstones which contain a basaltic horizon. An examination was made of the west ridge of the mountain up to 1100 m, a route followed also by SÄVE-SÖDERBERGH in 1934 (unpublished manuscript). On this profile the contact between the two divisions could not be examined due to scree development, but farther to the east in the main face it is sharply defined with no angular discordance.

The lowest 50 m of the Kap Graah Group succession were not examined, due to this cover. The lowest-exposed sediments are red medium-coarse arkoses with large irregular siltstone clasts and occasional small pebbles of quartz and limestone. They exhibit cross-stratification of types 2 (curved foreset) and 1 (planar), with a mean set height of 0.6 m, and contain occasional siltstone lenses up to 10 m in apparent diameter and up to 0.2 m thick. One worn fish bone was found, and SÄVE-SÖDERBERGH also collected several indeterminable fragments. Palaeocurrent data obtained indicated northerly derivation of the sediment (Figure 41).

The volcanic unit on Hoelsbo was not examined, but a visit made to the mountain on the west side of Forbindelsesdal (.1612) indicated that the stratigraphically-equivalent basalt horizons there represent contemporaneous volcanism. A short section at 650 metres on the central part of the mountain recorded a complex of lavas and basalt breccias which is undoubtedly of Devonian age. A 5 m highly lenticular basalt flow incorporates sandstone fragments within its vesicular base, and basalt and sandstone blocks in its upper part. It is succeeded by a mixed 10 m series of tuffites with basalt fragments, and grey fine-grained sandstones with dark, probably ashy bands.

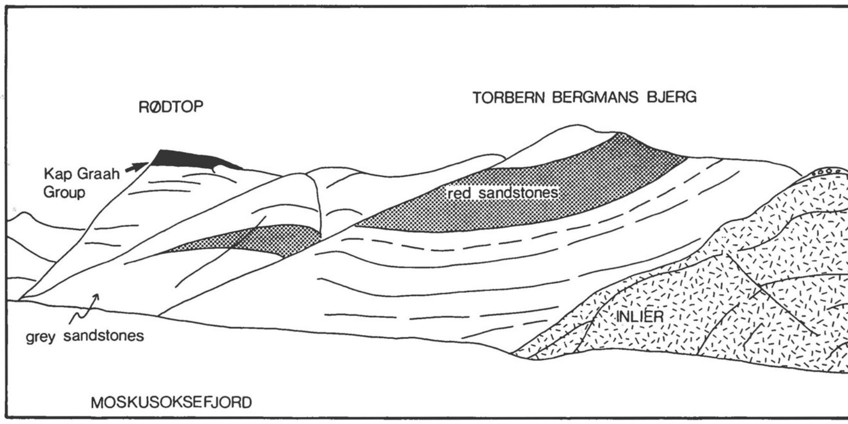

Fig. 42. North shore of Moskusoksefjord, west of "inlier", after BÜTLER (1959, p. 50, Fig. 13). The Kap Graah Group, on Rødtop, rests on the grey and red sandstones of the Kap Kolthoff Supergroup.

BÜTLER (1959, pp. 70–76) has described in detail several basalt lava, tuff, and agglomerate complexes from this area, and it is clear from his account that in earlier Kap Graah Group times basaltic volcanism was occuring on a substantial, if local, scale in intimate association with sedimentation. RITTMAN (1940) has termed the basalts of this area pigeonite-olivine-tholeiites.

The Kap Kolthoff Supergroup is poorly exposed on hill .1358, best-seen below the western ridge and in small crags east-northeast of the fangststation. Short measured sections from these latter localities classified in sample group 3D (grey-m., co. sst.-trough X). Southerly palaeocurrent directions were obtained wherever small outcrops yielded information (Figure 41). About 100 m below the top of the Supergroup a notable feature is the presence of 2–4 cm granite clasts (including dark gneissic types) in a 60 m conglomeratic very coarse sandstone, together with quartzite, vein quartz, intraformational siltstones, and limestone fragments which were probably derived from the Pre-Cambrian succession. The conglomeratic interval can be traced as a persistent terrace around the head of the large valley on the northwest side of hill .1358, and is also found at the same stratigraphic level 10 km further east on hill .1612. A clast count there showed limestone forming about 10 $^0/_0$ of the total, with vein quartz and quartzite roughly equal in number.

East of the inlier in western Moskusoksefjord several rhyolite outcrops are present in the Supergroup, consisting of red alkali-rhyolite with sanidine and quartz phenocrysts. DALVESCO (1954) described the outcrops behind the fangststation, recognising 70 m of tuff with red lapilli, bombs, and half-metre lava flows followed by up to 100 m of

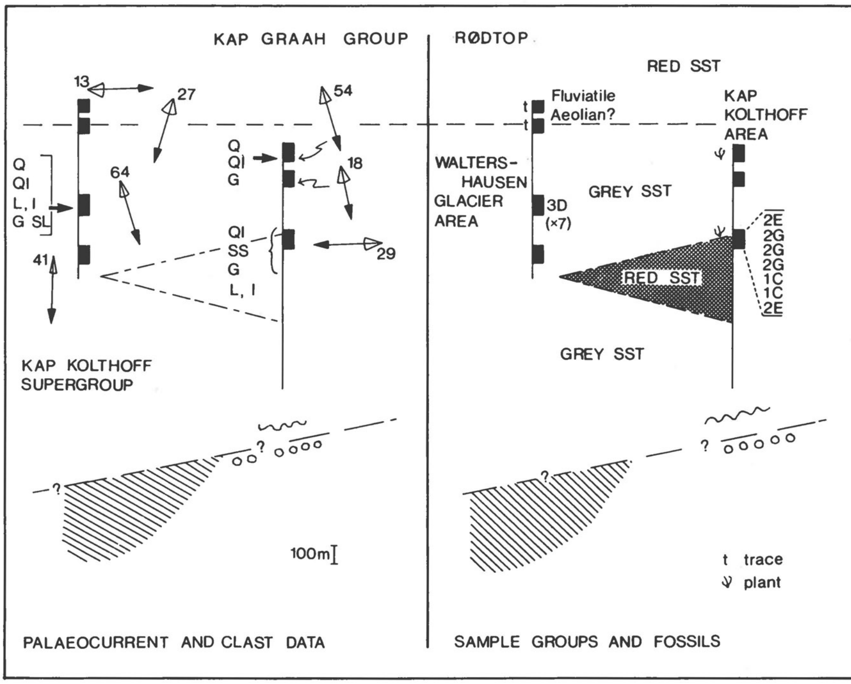

Fig. 43. Summary of data collected from Kap Kolthoff Supergroup and Kap Kolthoff area. Logged sections are shown by black blocks, numbers by palaeocurrent vector means are numbers of measurements. Clast types: Q—quartz, QI—quartzite, L—limestone, I—intraformational, G—granite, SL—slate, SS—sandstone.

lavas which were probably erupted from several vents. On the opposite side of the fjord a dissected chimney with radial flows was described.

Rødtop and Kap Kolthoff

We gathered information from the east side of the Waltershausen Gletscher, from Kap Kolthoff, and from Rødtop (Figure 42) at the entrance to Moskusoksefjord. These data are summarised in Figure 43.

Rødtop consists mainly of grey sandstones (sample group 3D (grey-m., co. sst.-trough X)), of the Kap Kolthoff Supergroup, deriving its name from the Kap Graah Group sandstones which form the summit plateau. Bütler's statement (1959, p. 163) that this outlier of the Group is unconformable is not supported by the presence of an angular discordance, though the base is very sharply defined by the colour change. The lower 35 m of the succession may be of aeolian origin, consisting of large-scale cross-stratified red medium-grained sandstones with no clasts, exhibiting well-graded laminae which are offset by small synsedimentary faults. Between this unit and the topmost beds of the plateau (which may also be of aeolian origin) is an undoubtedly fluviatile succession of grey and red medium-grained sandstones containing pebbles of quartz and quartzite, with occasional red siltstone beds. The palaeocurrent directions recorded from the aeolian and fluviatile units are to the south and east, respectively.

Three features of the Kap Kolthoff Supergroup beneath are noteworthy, for comparison with the Hoelsbo succession: (1) the consistently-maintained southerly palaeocurrent trends of the grey facies; (2) the presence of granitic and limestone clasts in the grey succession, in addition to quartz and quartzite; (3) a red, westerly-thinning wedge is developed on the west side of the inlier, within the grey succession, consisting of sample groups 2E (red-m., co. sst.-trough X), 2G (red-m., f. sst.-planar X, flat) and 1C (red-f., m. sst.-trough X, flat). Westerly palaeocurrent indications were obtained in the unit, which is not so sharply defined as Figure 42 suggests.

The Base of the Group in Moskusoksefjord, Lithostratigraphic Correlation with the Smith Woodwards Bjerg Succession

To "Hudson Land Phase 3" is attributed the tilting of the Kap Kolthoff Supergroup in the E. Moskusoksefjord area (BÜTLER, 1959, p. 181). The most easterly outcrops of the Kap Graah Group lie across this upturned succession, with the development of a coarse and evidently locally-derived breccia. The clast types present in this basal breccia (green and grey sandstones, basalt, and red rhyolite) are representative of the Middle Devonian rocks immediately to the east of the thrust planes at Høgboms Bjerg and Sederholms Bjerg. This unconformity is not to be confused with the unconformity at the base of the Group between Obrutschews Bjerg and Agda Dal, which probably correlates (in response to the same tectonic events) with the unconformity in the upper part of the Group on Sederholms Bjerg.

Our examination of the base of the Group in Ankerbjergsdalen suggested that there is no angular unconformity there, or basal breccias, in contrast with the situation found on the north side of the fjord opposite Victor Madsens Bjerg. In central Moskusoksefjord, where the base of the Group is apparently conformable, the lowest Kap Graah Group sediments are fluviatile. In the more westerly outcrops of the Group they are probably of mixed fluviatile and aeolian origin. In all of the outcrop areas examined west of Victor Madsens Bjerg, the palaeocurrent vector mean trends obtained from the basal beds of the Group were found to be southerly; this continues the trend exhibited throughout the Kap Kolthoff Supergroup sandstones. It is of interest that an influx of markedly coarse, pebbly sandstones from the north was noted in the upper-

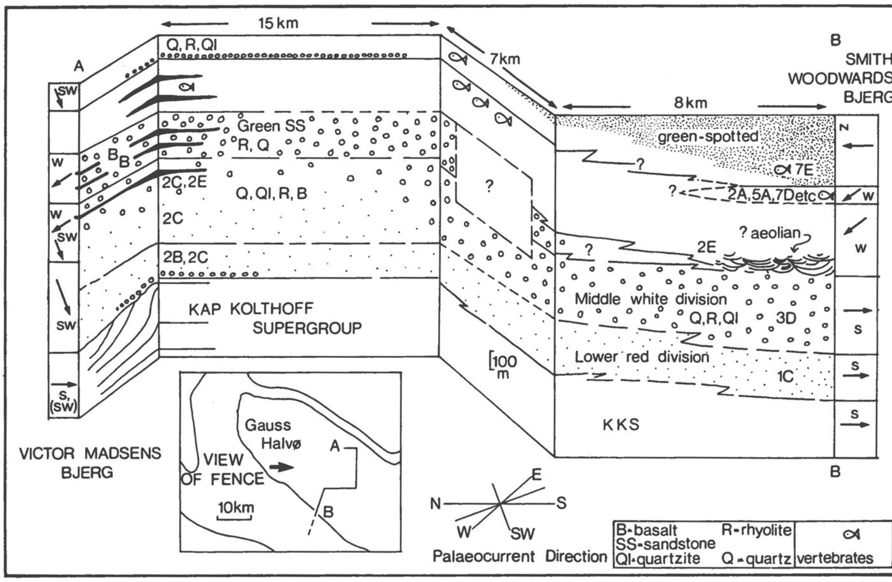

Fig. 44. Suggested lithostratigraphic correlation between Kap Graah Group successions of Victor Madsens Bjerg and Smith Woodwards Bjerg.

most Supergroup succession of western and central Moskusoksefjord, containing granite and gneiss in addition to quartz and quartzite pebbles. In contrast, the content of extraformational pebbles in the basal Kap Graah Group outcrops of Moskusoksefjord is very minor.

Figure 44 compares the successions of the Group at Victor Madsens Bjerg and Smith Woodwards Bjerg; these are separated by 20 km. It will be suggested below that much of the Victor Madsens Bjerg sequence may have been deposited while the Hjelmbjergene area to the southeast was undergoing removal of its cover of Kap Kolthoff Supergroup sediments. Within the 900 m of pebbly and conglomeratic medium sandstones deposited at Victor Madsens Bjerg no aeolian sediments are thought to be represented. Fluvial channel sands probably predominate, with siltstones of minor importance and restricted mainly to the lower, finer part of the sequence. The palaeocurrent directions measured in this interval are more or less uniformly southwestward.

The lower red and middle white divisions of Smith Woodwards Bjerg may be, at least in part, contemporaneous with this succession, but were deposited by southerly-flowing streams rather than by southwesterly directed rivers, and do not contain Middle Devonian or basalt clasts. They are richer in intraformational pebbles and in plant remains but, in common with the Victor Madsens Bjerg sequence, fish fragments are extremely rare. The middle white division is probably laterally-correlated with the 400 m pebbly unit beneath the lowest basalt horizon

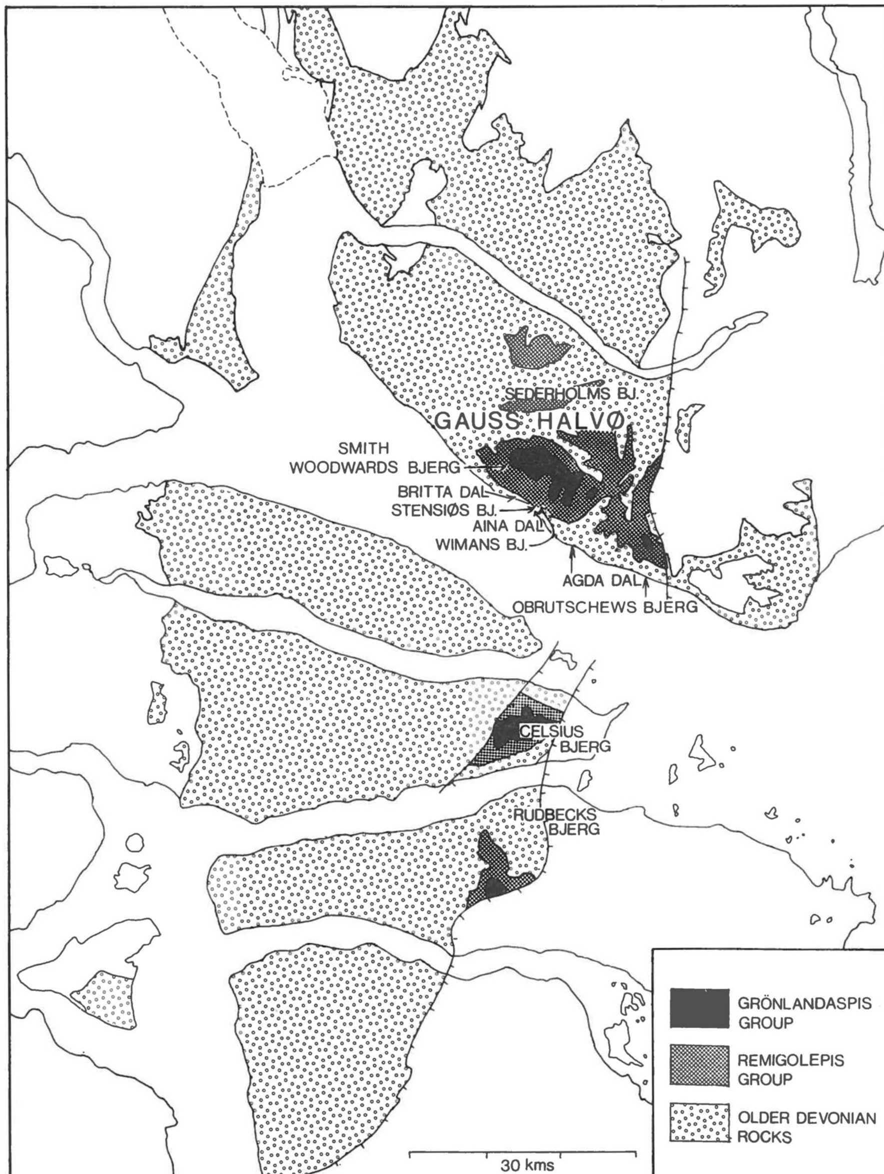

Fig. 45. General geological map of distribution of the two Groups of the Mt. Celsius Supergroup.

of the Victor Madsens Bjerg succession; neither contains pebbles of Middle Devonian rocks. The following, markedly pebbly division of Victor Madsens Bjerg, which contains Middle Devonian clasts, is shown in Figure 44 to wedge out westwards and southwards. The probable aeolian development at the base of the upper division on Smith Woodwards Bjerg may be laterally equivalent to it.

The succeeding finer sediments in both areas contain very few extraformational clasts, and the characteristic Kap Graah Group vertebrate fauna appears. The uppermost pebbly part of the Victor Madsens Bjerg sequence correlates with part of the thicker upper division of Smith Woodwards Bjerg. It consists of a conglomeratic sandstone unit (perhaps a fan) with a local unconformity at its base, followed by increasingly fine fluviatile sandstones which pass gradationally into the red floodplain siltstones of the Aina Dal Formation.

Further observations on the correlation of the Kap Graah Group successions, and tentative suggestions as to their time relations, are made in the final section.

THE MOUNT CELSIUS SUPERGROUP

All of the Upper Devonian Old Red Sandstone succession following the Kap Graah Group is included in the Mount Celsius Supergroup, which corresponds to BÜTLER's Mount Celsius Series (1959, p. 18).

This section outlines the stratigraphic subdivisions recognised and summarises the regional development of the Supergroup. The five siltstone and sandstone-siltstone sample groups which form much of the succession have already been described. Details of their spatial relations and probable environments of deposition are now given.

Stratigraphy

The Supergroup is divided into two Groups, their distribution indicated in Figure 45.

The Remigolepis Group

The Remigolepis Group is the equivalent of SÄVE-SÖDERBERGH's "Remigolepis Series" (1934, p. 46). The units distinguished on Gauss Halvø, and given Formation status here, were also the divisions employed by SÄVE-SÖDERBERGH and JOHANSSON (1935, p. 34). Separate formation names for the Celsius Bjerg successions of the Supergroup are not required.

The lowest division defined is the Aina Dal Formation, whose base is the base of the Supergroup. It is recognised in all of the outcrop areas, with a conformable, rapid transition from the Kap Graah Group. It consists of red coarse and medium siltstones, divisible into two members in central Gauss Halvø where it attains a thickness of up to 80 m. The upper, medium siltstone member contains a notable vertebrate fauna, including the earliest-known amphibia.

The Wimans Bjerg Formation, 200 m thick at Wimans Bjerg and Stensiøs Bjerg, consists of grey siltstones and contains no vertebrates.

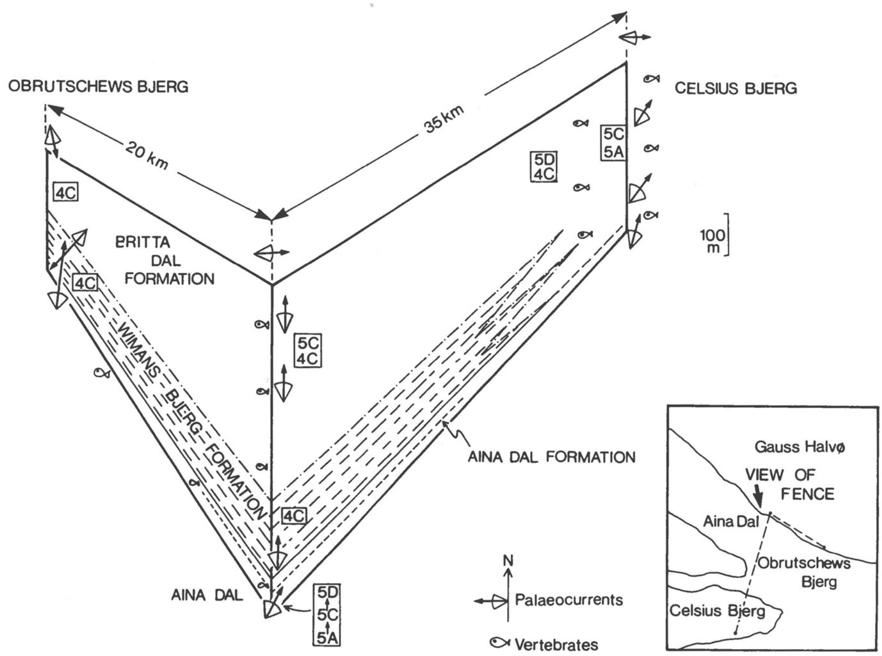

Fig. 46. Fence diagram showing variation within the Remigolepis Group.

It is not developed on Ymer Ø, though the sample group of which it is composed is present there.

The Britta Dal Formation, arbitrarily separated from the overlying sequence, consists of red and grey siltstones and subsidiary red sandstones. It is 550 m thick on Stensiøs Bjerg, and contains a rich fauna.

The regional thickness variations and general palaeocurrent trends exhibited by these formations are illustrated by Figure 46. At Stensiøs Bjerg the Group is approximately 830 m thick, as the top is now defined, and all three formations reach their maximum-known thickness. Further to the north on the long mountain ridge of Sederholms Bjerg a very similar though incompletely-preserved slightly finer sequence is present (Plate 18).

Towards Obrutschews Bjerg the Group's thickness is considerably reduced. The red siltstone Aina Dal Formation thins to less than 10 m on E. Obrutschews Bjerg; the Wimans Bjerg Formation siltstones are proportionately less-reduced, but become finer grained and exhibit a bimodal palaeocurrent distribution; and in the thinner Britta Dal Formation regular colour-banding of red and grey siltstones is well-developed, and the succession is devoid of sandstones except in the uppermost part.

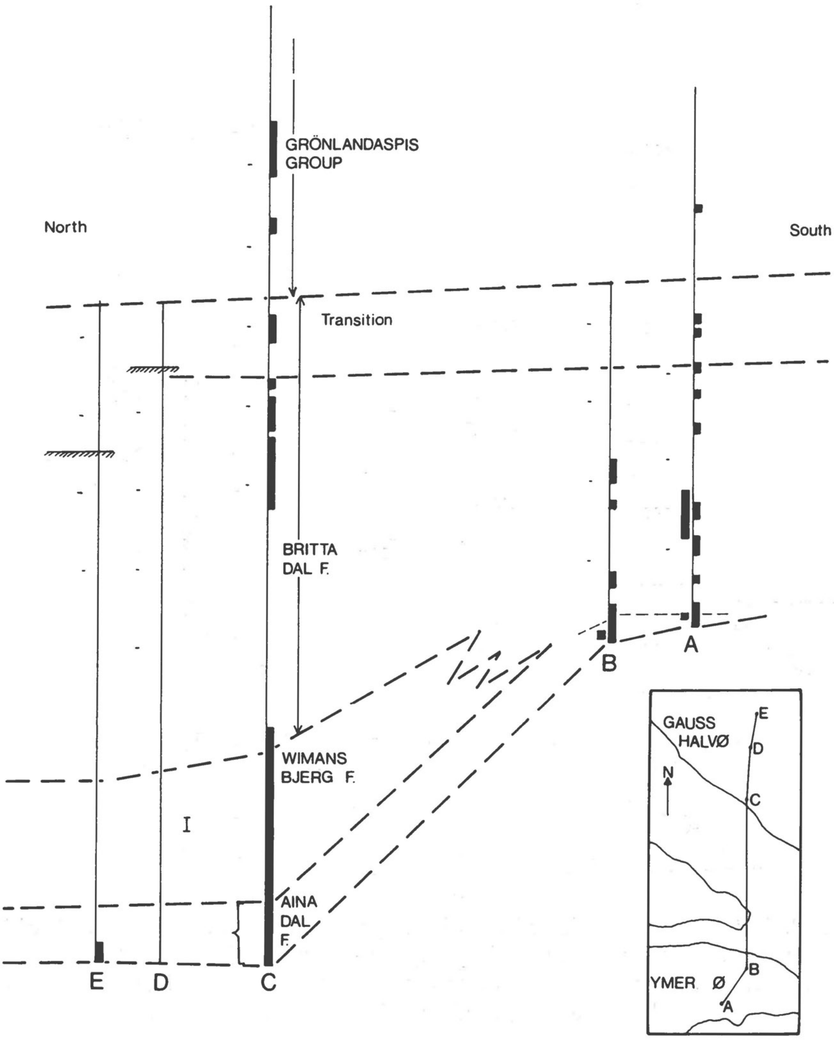

Fig. 47. Simplified chart of successions investigated in Mt. Celsius Supergroup. A and B—S and N Celsius Bjerg, C—Stensiøs Bjerg, D—Remigolepis ridge (studied by JOHANNSON, 1935), E—profile 4 (JOHANSSON, 1935). This diagram acts as a key to Fig. 48 and 49. Parts of successions logged are shown by black blocks.

Southwards from Stensiøs Bjerg the Group's thickness declines to about 430 m on Celsius Bjerg. Plate 19 illustrates the succession of N. E. Celsius Bjerg, which is in some respects intermediate in character between those of Stensiøs Bjerg and S. Celsius Bjerg. A basal sandy red siltstone probably correlates with the Aina Dal Formation further north. The Wimans Bjerg Formation and the Britta Dal Formation are represented here by a sandier, predominantly red succession of siltstones and sandstones.

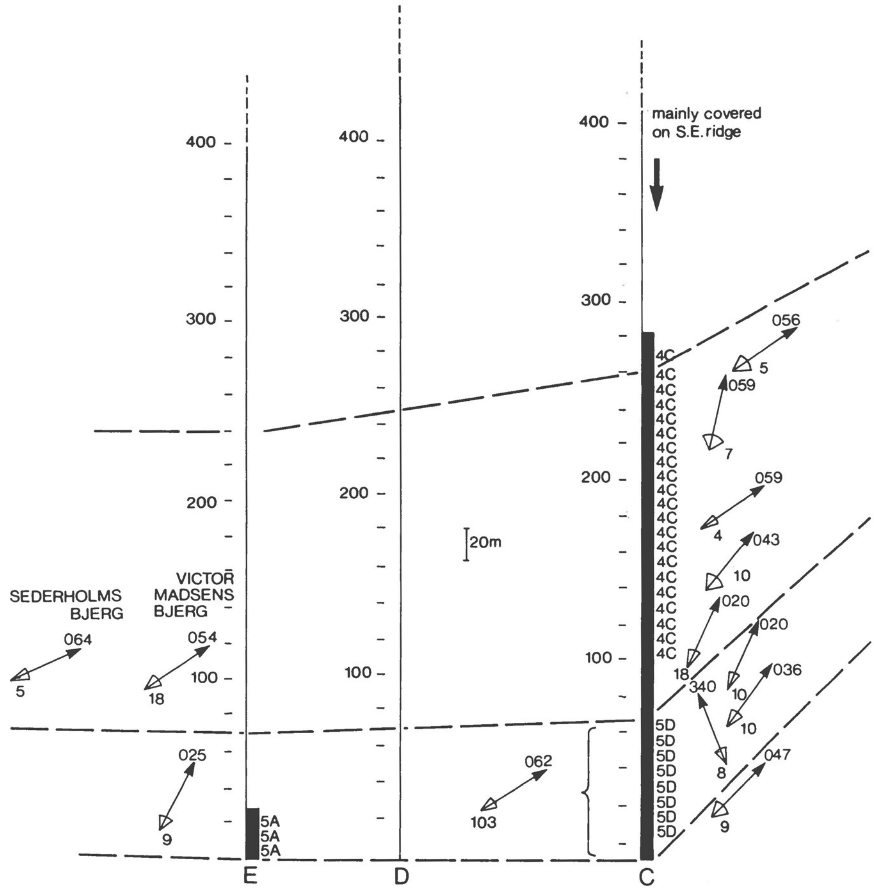

Fig. 48. Details of data collected from lower parts of succession E, D and C (of Fig. 47). Logged successions and sample groups are shown. Palaeocurrent vector mean arrows have true north azimuth at arrow head, and number of measurements at tail, beside 95 % confidence limits on vector mean.

On Celsius Bjerg the palaeocurrents are directed to the northeast or east, rather than to the north as on Gauss Halvø. Vertebrates are present throughout the Celsius Bjerg succession.

The Grönlandaspis Group

In an unpublished ms. SÄVE-SÖDERBERGH introduced the term "Grönlandaspis Series" for the grey, predominantly sandstone succession which follows the Remigolepis Group, and subsequently the term was adopted by BÜTLER (e.g. 1959, p. 58). There is a gradation between these two divisions and the base of the Grönlandaspis Group is arbitrarily defined (Figures 47–49) on Celsius Bjerg and Stensiøs Bjerg, at the level at which multistorey sandstones appear and *Remigolepis* disappears. Red siltstones become unimportant above this level.

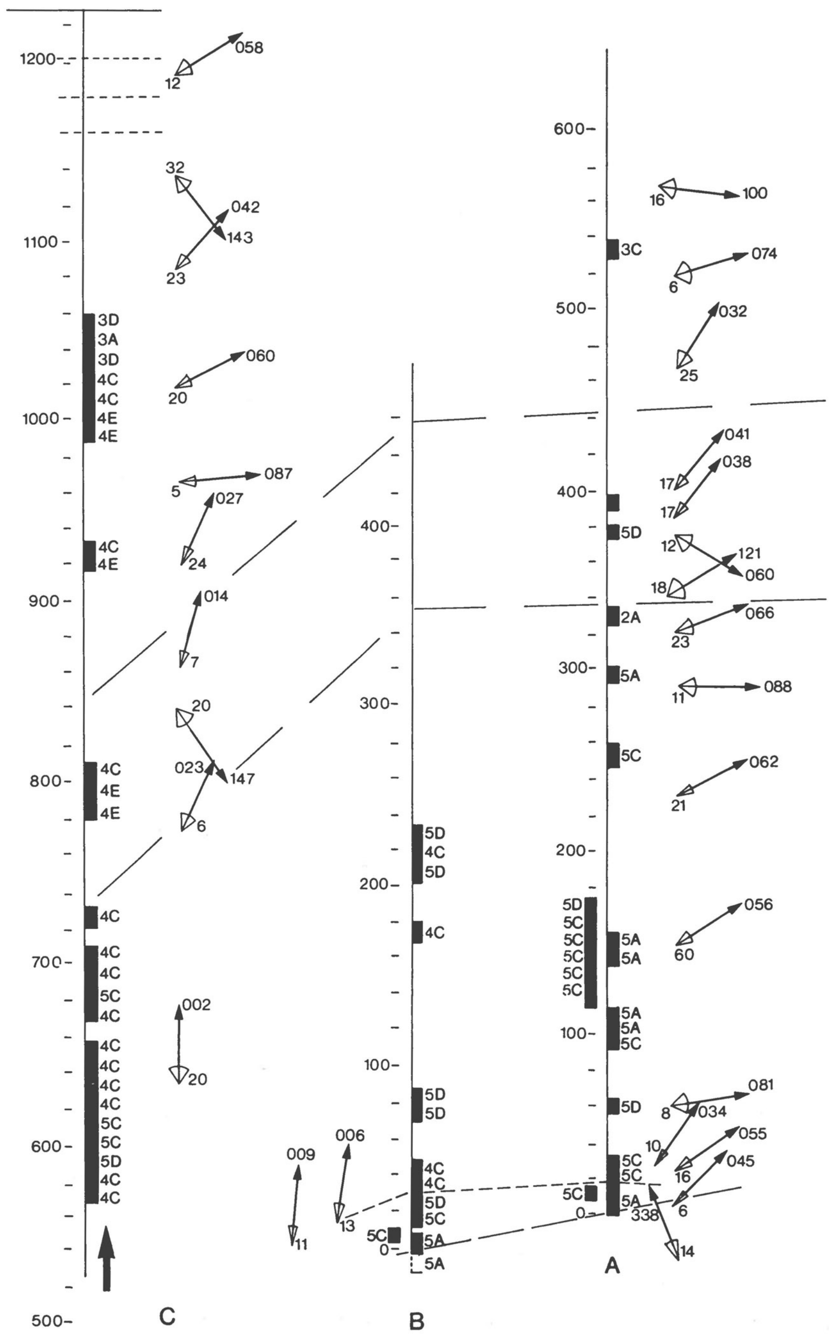

Fig. 49. Details of data collected from upper part of section C, and from sections A and B (of Fig. 47). Same conventions as Fig. 48.

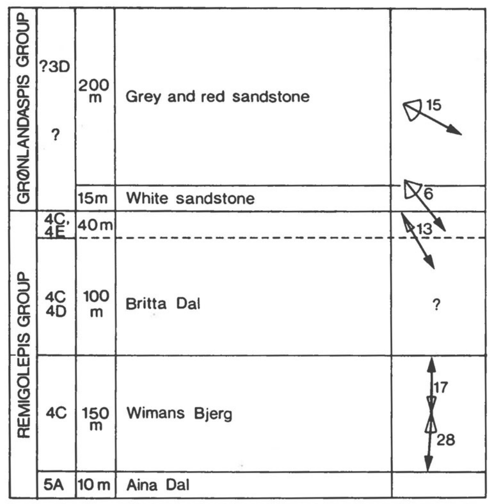

Fig. 50. Summary of our observations on the Mt. Celsius Supergroup on Obrutschews Bjerg. This should be compared with Table 10.

Unfortunately it is not possible to provide a detailed survey of the Grönlandaspis Group succession because its outcrop areas are very poorly exposed, forming mountain plateaux. Large boulder fields or areas of 'felsenmeer' cover the summits of Obrutschews Bjerg, Celsius Bjerg and Stensiøs Bjerg; and mantles of debris extend on to the slopes below, obscuring the lower parts of the Group. Snow cover also hindered observation on several occasions. The synclinal outlier preserved west of Rudbecks Bjerg (Figure 45) was not visited, but according to Bütler (1955) it is very poorly exposed.

Table 10. *Summary of observations made at Obrutschews Bjerg by* Säve-Söderbergh *and* Bütler, *not to scale.*

Säve-Söderbergh, 1934		Bütler, 1954	
163 m	"Upper Sandstone Complex", mainly brick-red sandstone mottled with white; some light-red quartzite, conglomerates alternating with white coarse quartzite.	200 m	White coarse quartz sandstone and conglomerate.
12 m	White/grey coarse arkose.	50 m	Grey shale and calc. sandstone.
182 m	Grey and varicoloured marl, and fine-medium sandstone, grey limestone. little sandstone. "Arthrodire Sandstone Series"	30 m	Grey/pale yellow sst. and green clay shale.
		30 m	Brown-green sandy soft shale.
107 m	"Remigolepis Series"	150 m	"Remigolepis Series"

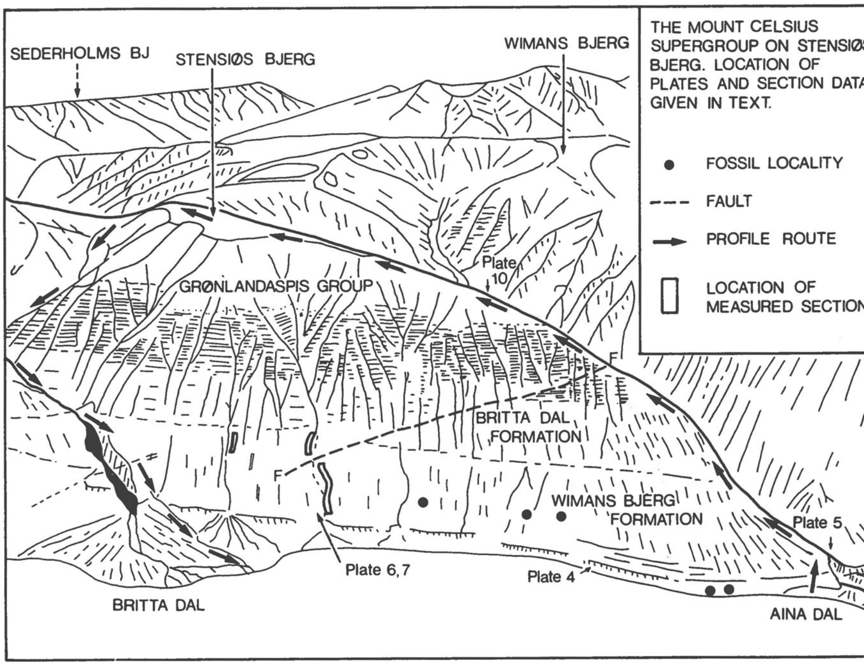

Fig. 51. Sketch of Stensiøs Bjerg showing sub-division of Mt. Celsius Supergroup. Grønlandaspis should read Grönlandaspis.

Accordingly, the information available does not warrant detailed stratigraphic subdivision of the Group. Figure 50, Table 10 and Table 11 present the revised successions of the Group on Obrutschews Bjerg and S. W. Celsius Bjerg, and summarise the brief observations and the subdivisions made by Bütler and Säve-Söderbergh.

(1) On Obrutschews Bjerg there is a 40 m transition zone between the Britta Dal Formation and the medium sandstones of the Grönlandaspis Group. Southerly palaeocurrents (Figure 50) were recorded from the fine sandstones of this interval. Most of the following succession is covered by scree, but the clast content is noteworthy: white and yellow quartzpebbles predominate, and no plutonic pebbles reached the area from the north.

(2) On S. E. Celsius Bjerg the lower 200 m of the Group were examined, as summarised in Figures 47–49. The sandstones of this succession were deposited by streams from the west, and contain the arthrodire *Grönlandaspis*. Only intraformational pebbles are present.

On S. W. Celsius Bjerg over 500 m of the Group are preserved (Table 11), but the succession is very poorly exposed. Ou the plateau of the mountain (Plate 20) the uppermost 150 m of the Group are of medium sandstone with quartz pebbles, introduced from the northwest. They overlie a black shale in which Bütler found fragments of palaeoniscoids. Near the summit a 25 m red pebbly arkose occurs, above which *Holoptychius* bones were occasionally found.

Table 11. *Stratigraphic divisions of the Grönlandaspis Group, S. W. Celsius Bjerg. Fossil locality heights given are relative to sea level. Cf. Plate 20.*

		Division	Faunas, palaeocurrents	BUTLER, 1955	SÄVE-SÖDERBERGH	
	V 50 m	Upper grey medium and coarse sst with large-scale cross-strata and extraformational pebbles.	**Holoptychius* at 1250 m*		Upper sst Complex	
	25 m	Red, medium trough cross-strat. sst, carbonate nodules.	palaeocurrent vector mean 154°	7		
Grönlandaspis Group	80 m	Lower grey medium and coarse sst with large-scale cross-strata, pebbles of quartz up to 20 cm.	**Holoptychius, Grönlandaspis* at 1150 m*			Grönlandaspis Series
	40 m	Grey/green/black shales, carbonate nodules, very fine sst.	palaeoniscoids, plants	6	Arthrodire Sandstone Series	
		(covered) Medium cross-stratified and flat-bedded sandstone.	**Holoptychius, Grönlandaspis, "Knorria"* at 900 m*	5		
	440 m	(covered) Fine and medium cross-strat. and flat-bedded sst, intra-formational conglomerates.	**Grönlandaspis* at 700 m*			
Remigolepis Group	100 m	Remigolepis Group-Grönlandaspis Group (transition) Red siltstones and grey sandstones.	*Holoptychius, Remigolepis* etc.	4		Remigolepis Series

(3) On Stensiøs Bjerg the Group is also about 500 m thick, and the succession is relatively well-exposed. Figures 47–50 contain data from the southeast ridge of the mountain (Figure 51). The Group consists mainly of grey sandstones of sample groups 3D (grey-m., co. sst.-trough X) and 3A (grey-f., m. sst.-trough X), with the lower part transitional from the Britta Dal Formation. The source of the sediment was to the southwest and west, as on Celsius Bjerg.

Near the summit there is a 20 m black shale, very similar to that observed on Celsius Bjerg (SÄVE-SÖDERBERGH, 1933, p. 31). It is followed by red and then grey medium sandstones, as on Ymer Ø, which exhibit large-scale planar cross-stratification of type 1.

There is, therefore, the basis for lithostratigraphic correlation between the Celsius Bjerg and Stensiøs Bjerg upper successions of the Grönlandaspis Group. The Obrutschews Bjerg sequence appears to be rather anomalous, in its lack of a prolonged transitional interval at the base and its early development of quartz pebbles.

According to BÜTLER (1961, p. 194) at least the upper part of the Grönlandaspis Group is of Carboniferous age. The view of JARVIK (1950, p. 14), however, is that the Group is probably entirely Devonian. K. C. ALLEN (University of Bristol) collected spores from the Group but these could not be dated.

The Distribution of Sample Groups in the Mount Celsius Supergroup

Figures 47–49 summarise the distribution of the sample groups, together with palaeocurrent data, in the Celsius Bjerg and Stensiøs Bjerg successions of the Supergroup. Published observations from Paralleldal have been added (JOHANSSON, 1935).

Sample group 5A (red-v. f. sst., co. slst.-trough X, flat) is present on Gauss Halvø only at the base of the Aina Dal Formation. Usually it is succeeded by 5C (red-co. slst., v. f. sst.-flat, asym. rip), but at Obrutschews Bjerg 5A (red-v. f. sst., co. slst.-trough X, flat) is immediately followed by 4C (grey-co. slst.-flat). On Gross Bjerg and Evans Bjerg it was found to alternate with the uppermost sample group of the Kap Graah Group, 7D (grey-f., v. f. sst.-trough X, flat), but this is not seen further to the west where the Aina Dal Formation exceeds 40 m. It occurs at the base of the Remigolepis Group on N. Celsius Bjerg; on S. Celsius Bjerg it is more abundant than elsewhere, occurring intermittently to 300 m above the base of the Group in association with 5C (red-co. slst., v. f. sst.-flat, asym. rip).

Sample group 5D (red-m. slst.-flat, asym. rip.) is best represented on Gauss Halvø in the upper part of the Aina Dal Formation west of Agda Dal (Plates 4, 5). In the Britta Dal Formation it is an important sample group on Obrutschews Bjerg, forming colour banded siltstone sequences with sample group 4C (grey-co. slst.-flat), and it also appears in that formation on Stensiøs Bjerg, in association with 4C and 5C (red-co. slst.-v. f. sst., -flat, asym. rip.).

It is a minor sample group on N. and S. Celsius Bjerg, containing a slightly-increased proportion of sandstone.

Sample group 5C (red-co. slst., v. f. sst.-flat, asym. rip.) separates 5A (red-v. f. sst., co. slst.-trough X, flat) and 5D (red-m. slst.-flat, asym. rip.) in the Aina Dal Formation. In the Britta Dal Formation and on N. Celsius Bjerg it occurs in association with sample groups 4C (grey-co. slst.-flat) and 5D (red-m. slst.-flat, asym. rip.), or with 4C (grey-co. slst.-flat) alone. It forms a continuous succession of at least 40 m on S. E. Celsius Bjerg, and it is at least as important as sample group 5A (red-v. f. sst., co. slst.-trough X, flat) in the Remigolepis Group there.

Sample group 4C (grey-co. slst.-flat) forms the Wimans Bjerg Formation on Gauss Halvø, and it is also a major sample group in the Britta Dal Formation, together with 5C (red-co. slst., v. f. sst.-flat, asym. rip.) and 5D (red-m. slst.-flat, asym. rip.). It forms most of the Remigolepis Group succession of Gross Bjerg and Obrutschews Bjerg, occurring with 5D (red-m. slst.-flat, asym. rip) in strongly colour-banded sequences. It is present in the N. Celsius Bjerg succession, with 5C (red-co. slst., v. f. sst.-flat, asym. rip.) and 5D (red-m. slst.-flat, asym. rip.), but is possibly absent from S. Celsius Bjerg.

Sample group 4E (grey-co. slst., f. sst.-flat, trough X) was recorded only on Stensiøs Bjerg, associated with 4C (grey-co. slst.-flat) in the transition between the Remigolepis Group and the Grönlandaspis Group and in the lower part of the latter. It probably characterises this interval at Obrutschews Bjerg, also.

With the increasing development of sandstones in the lower part of the Grönlandaspis Group, sample groups 3C (grey-m., f. sst.-flat, trough X), 3D (grey-m., co. sst.-trough X), and 3A (grey-f., m. sst.-trough X) are represented. An interval of sample group 3C (grey-m., f. sst.-flat, trough X) from the Group on S. E. Celsius Bjerg is illustrated in Figure 5, along with our account of these sample groups.

Mutual Relations and Environmental Interpretation of the Siltstone and Siltstone-sandstone sample groups

An introductory description of the sample groups which form the Remigolepis Group and much of the lower part of the Grönlandaspis Group has been given already. They consist of siltstone, and of siltstone-sandstone, and are virtually absent from the underlying Upper Devonian Old Red Sandstone divisions. It is possible to be more specific in discussing their environments of deposition than was the case with the sandstone sample groups described above.

Sample Groups 5A (red-v. sst., co. slst.-trough X, flat), **5D** (red-m. slst.-flat, asym. rip.) **and 5C** (red-co. slst., v. f. sst.-flat, asym. rip.)

Sample groups 5A (red-v. f. sst., co. slst.-trough X, flat), 5D (red-m. slst.-flat, asym. rip.) and 5C (red-co. slst., v. f. sst.-flat, asym. rip.) collectively form the Aina Dal Formation, and their distribution is summarised in Figure 52. It is clear that sample group 5D (red-m.

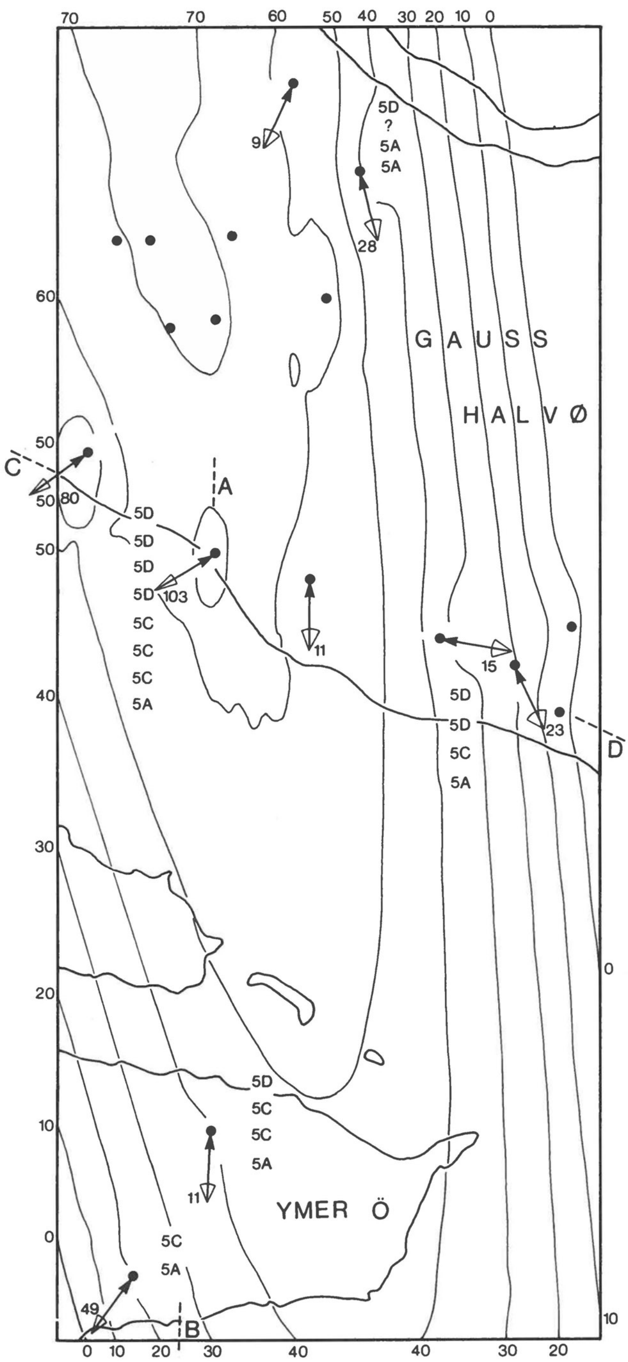

Fig. 52. Summary of features of the Aina Dal Formation (Remigolepis Group, Mt. Celsius Supergroup). Localities marked by black spots. Isopachs plotted by iterative-fit trend surface computer program. Sequence of sample groups shown for some of the localities. Numbers by palaeocurrent vector means are numbers of measurements. Letters refer to sections of Fig. 53.

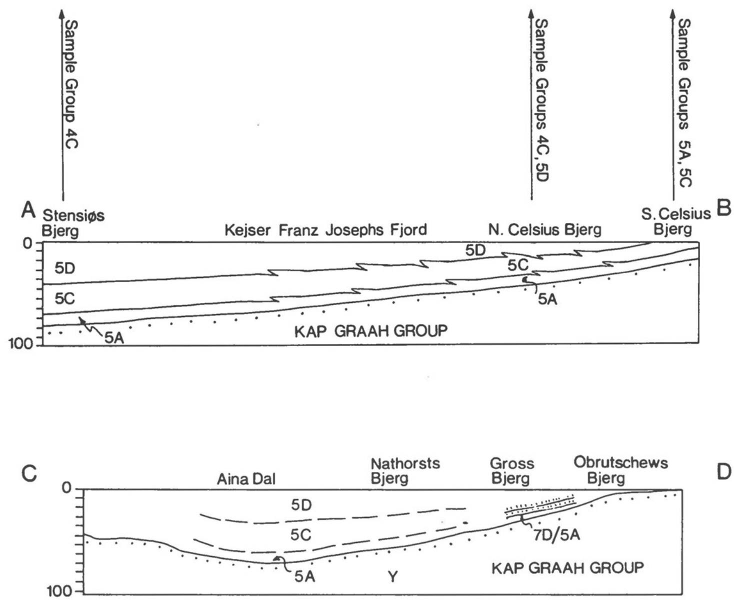

Fig. 53. Sections across the Aina Dal Formation along lines indicated in Fig. 52.

slst.-flat, asym. rip.) does not occur in direct contact with 5A (red-v. f. sst., co. slst.-trough X, flat); 5C (red-co. slst., v. f. sst.-flat, asym. rip.) always separates them when they are both present in a succession. From the uniform palaeocurrent distribution the spatial relationships depicted in Figure 53 may be derived. It appears that 5D (red-m. slst.-flat, asym. rip.) is the most distal sample group and that 5A (red-v. f. sst., co. slst.-trough X, flat) is the most proximal, associated with 5C (red-co. slst., v. f. sst.-flat, asym. rip.). Much of the Remigolepis Group sequence of S. Celsius Bjerg consists of sample groups 5A (red-v. f. sst., co. slst.-trough X, flat) and 5C (red-co. slst., v. f. sst.-flat, asym. rip.).

This conclusion is consistent with the sedimentological parameters which have been summarised (Table 12) for each sample group. The transition from sample group 5A (red-v. f. sst., co. slst.-trough X, flat) to 5D (red-m. slst.-flat, asym. rip.) is illustrated by a ternary diagram, Figure 54, in which it can be seen that the proportion of cross-lamination per 10 m interval varies little during the change; the amount of flatbedded siltstone steadily increases.

Successions of red sandstones and siltstones which in many respects resemble those of sample group 5A (red-v. f. sst., co. slst.-trough X, flat) have been described by ALLEN (1962, 1965b), FRIEND (1965), and others, with emphasis laid upon the "fining-upward" cycle and the nature of the cross-stratification. The coarse member of the cycle is

Table 12. *Comparative statistics for sample groups 5A, 5C, 5D, 4C, and 4E. The p values are the probabilities of the presence of a sedimentary structure at least once in a 10 m interval of the sample group.*

Sample group	Arithmetic mean cross-stratification coset height (metres).	Arithmetic mean cross-stratification set height (metres).	Arithmetic mean flat-bedded sandstone bed thickness, m.	Arithmetic mean flat-bedded siltstone bed thickness, m.	Approx. number of ripple cross-laminated beds per 10 m interval.	p scour at base of bed.	p tool marks at base of bed.	p mudcracks in the interval.	p soft-sediment deformation.	p intraformational conglom./10 m.
5A.........	1.70	0.24	0.22	0.70	7	0.8	0.2	0.8	0.9	1.0
5C..........	1.50	0.46	0.23	0.70	6	0.9	0.1	0.9	0.6	0.9
5D.........	–	0.35	0.14	1.60	5	0.5	–	0.9	0.6	0.9
4C..........	–	–	–	1.20	20	–	–	1.0	1.0	0.1
4E.........	1.30	0.30	0.27	1.80	<1	0.8	–	1.0	0.4	0.8

generally considered to represent fluviatile channel sediments; the fine, siltstone units are thought to be overbank, flood plain deposits.

There can be little doubt that sample group 5A (red-v. f. sst., co. slst.-trough X, flat) sediments formed under broadly similar conditions to those envisaged by Allen and Friend. The existence of large-scale, low-angle cross-stratification with foreset dip directions deviating considerably from the overall vector mean palaeocurrent direction is an important comparative feature. However, the transition from sandstone coset to flat-bedded siltstone is frequently an abrupt one, rather than a passage through flat-bedded or cross-laminated finer sandstones (Figure 7), with the result that the succession may consist of sharply-defined alternations rather than fining-upwards cycles.

It is suggested that the siltstone sheets of sample group 5D (red-m. slst.-flat, asym. rip.) represent channel-fill deposits, on the basis of their geometry and the fact that current flow appears to have taken place parallel to the apparent direction of elongation of the bodies. Deposition of highly cohesive sediment tends to occur on the margins of a channel, gradually reducing the depth-width ratio, as Schumm (1961) noted. The sample group presumably represents deposition on a silt floodplain or fluvio-lacustrine complex, in which sand was a very minor component.

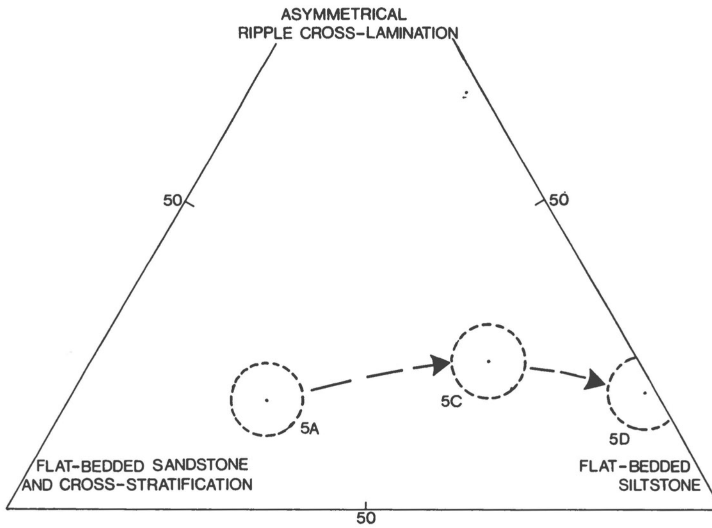

Fig. 54. Ternary diagram illustrating change in proportion of different structures in passing between sample groups 5A, 5C and 5D.

Sample Group 4C (grey-co. slst.-flat), lateral correlation

Measured sections consisting of sample group 4C (grey-co. slst.-flat) were obtained from the upper part of the Wimans Bjerg Formation at two localities on Stensiøs Bjerg, separated (Fig. 51) by approximately 1.5 km. In order to compare and correlate the sections the following parameters were studied: the thickness of the unit (as defined in Figure 10); the thickness of the thin-bedded complex; the thickness of red siltstone in each unit; the mean and maximum thickness of the thin-bedded siltstones per complex; and the number of thin-bedded siltstones per complex.

These parameters were plotted to scale for both sections, and a correlation then became obvious (Figure 55). The maximum and mean thin-bedded siltstone thicknesses are of little assistance in the correlation problem, but the variations shown by the other parameters in both sections are in close accord. The succession of the green siltstone variants of the sample group occurring at the top of the Formation was independently used to confirm that the correlation is satisfactory.

The fact that such a detailed correlation can be made suggests that sedimentation in the two areas was occurring under virtually identical conditions on a surface of very low relief, probably in response to the same depositional events. Observations made at several other localities, in the lower 40 m of the Formation, have also suggested that sedimentation events are laterally traceable for up to 5 km.

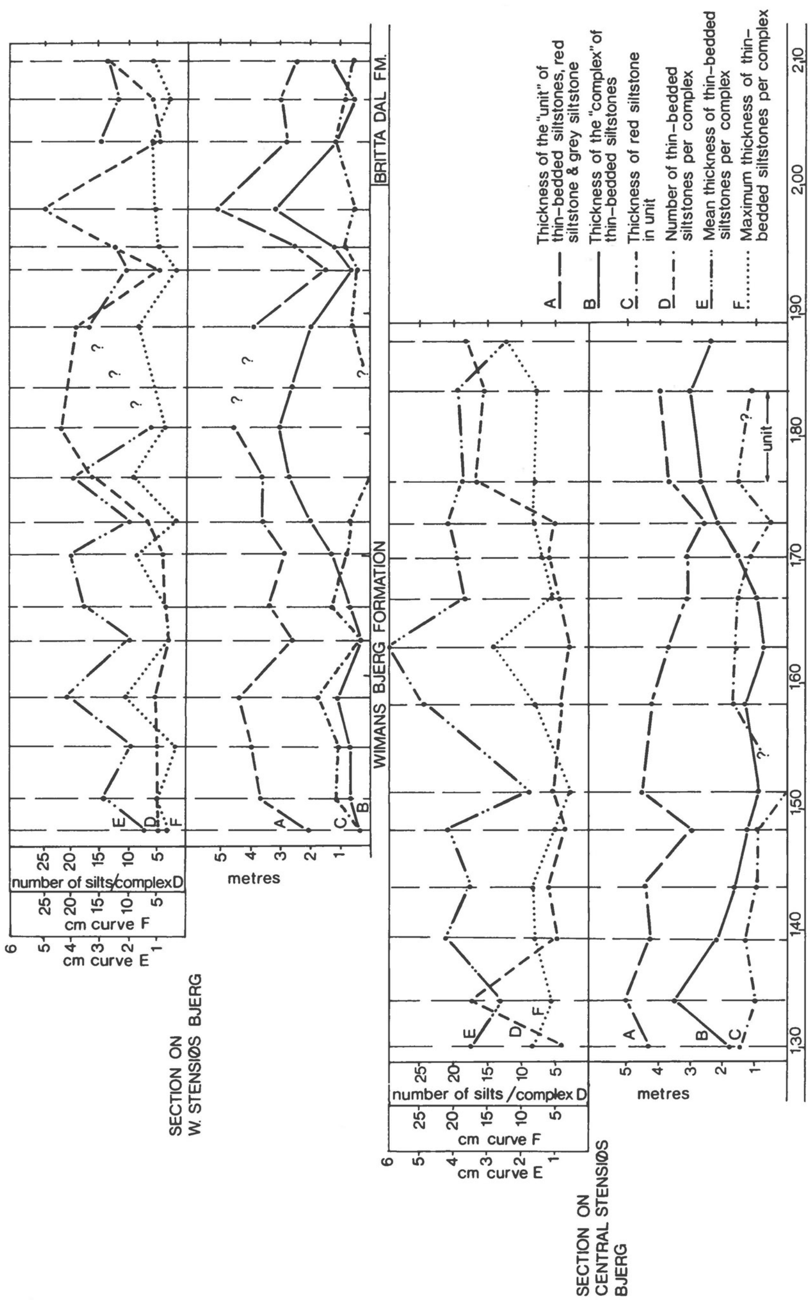

Fig. 55. Comparison of two sections, 1.5 km apart in the upper Wimans Bjerg Formation, classified in sample group 4C. The "unit" and "complex" terms are defined in Fig. 10.

The Environment of Deposition of Sample Group 4C (grey-co. slst.-flat)

Accounts of sedimentation on playa and piedmont surfaces, particularly those given by WILLIAMS (1970) and Hunt et al (1966), describe similar successions to those of sample group 4C (grey-co. slst.-flat). In these environments the sediments may grade from marginal gravels and sands to silts and clays in the centre of the depositional area. There is little evidence that large gravel fans existed marginally to the Remigolepis Group, but it is of interest to note the presence of 70–80 m of conglomeratic sandstones on Obrutschews Bjerg (Kap Graah Group), immediately and sharply succeeded by a succession of sample groups 4C (grey-co. slst.-flat) and 5D (red-m. slst.-flat, asym. rip.).

Marginal conglomerates (when present) wedge out rapidly (WILLIAMS, 1970, p. 54), and clasts are rarely moved onto the playa (HUNT *et al.*, 1966, p. 65; HUNT & MABEY, 1966, p. 85). Even flood water from torrential storms may be lost as ground water to permeable marginal gravels (HUNT *et al.*, 1966, p. 22), and it is the general case that incised channels are only present on the more marginal parts of playas. Cross-stratified, cross-laminated, and flat-bedded sands accumulate within these channels.

The lower parts of the floodplain are virtually smooth, carrying water only in sheet floods (HUNT *et al.*, 1966, p. 19; WILLIAMS, 1970, p. 54, 58). WILLIAMS (1970, p. 54–55) indicated the importance of horizontal bedding in playa sediments; beds of clayey silts and fine sands extend for hundreds of metres near the marginal fans, and in more distal areas 2–3 m thick sheets of grey clays may extend for several km. This is a point of close comparison with the Wimans Bjerg Formation succession, as is the absence of fossils (cf. HUNT & MABEY, 1966, p. 97).

WILLIAMS considered all the preserved sediments beneath the playa and floodplain surface to be fluvial deposits, laid down during periodic floods. Aeolian sands may be present on the surface, but appear to have a low preservation potential. Development of salt crusts (even if of very limited thickness) and the cohesiveness of clay-silt sediments, when damp, mitigate against dune formation.

The accumulation of sample group 4C (grey-co. slst.-flat) sediments is envisaged in broad, shallow depressions on surfaces of very low relief. The internal sedimentary structures and the high degree of sorting of the thin-bedded siltstones indicate that they were the deposits of traction currents. The rare intraformational chips of siltstone or carbonate granules in the relatively thicker beds, together with the absence of irregular or flute-marked scour surfaces, demonstrate the relatively minor ability of the streams of the depositional environment to erode their beds. The maximum observed thickness of a thin-bedded siltstone in the Wimans Bjerg Formation was 30 cm, and no very fine sandstone bodies were present.

Following rainfall, the depressions or pans would collect temporary standing sheets of water, fed into them by sheetwash and small ephemeral streams. Initial sedimentation would consist of the dumping of poorly-sorted sheets of silt and clay into the pans. Later current flows would wash mud from the upper layers of the sheets and develop asymmetrical ripple forms. Subsequent wave action might round the ripple crests, and develop symmetrical cross-laminae.

If no further sedimentation occurred the symmetrical ripples would eventually acquire a network of desiccation cracks, whose spacing and depth would depend on the texture and cohesion of the sediment. In the late stages of the flooding event, wet sediment areas many times greater than the pool areas would exist. If deposition from suspension continued, the ripple forms would be infilled, and a thicker silt bed would be developed, usually with a planar top surface.

In the hydroplastic sediment convolute laminae might develop. Pore-water retention is greatly facilitated by the presence of clay laminae, and drying to produce a hard impermeable crust further impedes water loss. Convolution development is attributed to uneven loading and variable shear stress transmission during ripple migration across the bed. Thus the deposition of one cross-laminated thin-bedded siltstone, and its underlying less well-sorted siltstone, would be accomplished. Subsequent repetition of these events would build up the "complex". WILLIAMS (1970, p. 59) noted that the floodplain deposits which resulted from one inundation of floodwater consisted of 5 cm of laminated and cross-stratified clay-pellet sand, overlain by 1–2 cm of clayey silt with cross-laminae and "rib and furrow" structure.

WILLIAMS considered that the 2–3 m sheets of flat-bedded clays which he described were of fluvial origin. These appear to be analogues of the major poorly-sorted sheets of flat-bedded silty claystone which follow the development of the complex. Within the sheet very few sedimentary structures are visible, possibly as a result of desiccation (WILLIAMS, 1970, p. 59). Poorly-defined horizons of brecciated siltstone can be attributed to the disruptive development of mudcracks. The reddening of the upper part of the sheet can be ascribed to oxidation, when the growth of caliche granules would be limited and then arrested as the moisture in the siltstone was lost. Secondary reduction of the upper reddened part of the sheet might occur with groundwater percolation during the next flood-event.

At Obrutschews Bjerg and Gross Bjerg the following factors distinguish the successions of sample group 4C (grey-co. slst.-flat): the siltstones are finer-grained, and claystone greatly predominates; the complexes are less well-defined, and contain fewer red siltstone beds; the thin-bedded siltstones are more numerous and of reduced and more uniform thickness, with fewer ripple and desiccation cracks; the thickness of the siltstone separating the complexes is reduced; and the palaeocurrent divergence is much greater than at Stensiøs Bjerg.

Considered together with the fact that the Remigolepis Group is only approximately 300 m thick at Obrutschews Bjerg, compared with the 800 m or so at Stensiøs Bjerg, these variations are consistent with the suggestion that the Obrutschews Bjerg sediments represent more central basinal accumulations. Floods in the more central parts of a playa would generally be of lesser magnitude than in the more marginal areas, carrying less sediment (which would be of a finer grade), and depositing a thinner succession. A virtually negligible gradient would exert little control over stream flow directions, and wind-induced currents in standing water sheets might also contribute to palaeocurrent variation. This latter phenomenon has been reported by Hunt et al. (1966, p. 11, p. 65).

Only in the Britta Dal Formation, on Obrutschews Bjerg, were concretionary carbonate nodules of considerable size observed in sample group 4C (grey-co. slst.-flat). Their development there may have been controlled by the presence of near-surface ground water, containing concentrations of mineral salts. Such a situation frequently characterises playas. No evidence of gypsum or halite deposition in the sediments of the Remigolepis Group has been obtained, but dolomite rhombs are present in siltstones of sample groups 4C (grey-co. slst.-flat), 5D (red-m. slst.-flat, asym. rip.) and 5C (red-co. slst., v. f. sst.-flat, asym. rip.). Williams (1970, p. 60) reported the probable presence of dolomite in the surface layers of the Saharan playa which he described, together with halite and minor quantities of gypsum, calcium carbonate, and quartz. With repeated flooding minor salt crusts would no doubt be dissolved, leaving no evidence of their presence.

The only vertebrate remains which have been found in the Wimans Bjerg Formation occur at the base, within the lowest few metres of the transitional deposits. By contrast there is no faunal break in the Celsius Bjerg successions of the Remigolepis Group, and the lack of bones in the Wimans Bjerg Formation further to the north suggests that those sheet floods which did cross the supposed playa surfaces were of inadequate power to transport bones from more-southerly areas. According to the interpretation given above, fish would not have existed in the 4C (grey-co. slst.-flat) depositional environment, primarily because of the absence of stream channels. Vertebrate remains reappear with the development of channel sandstones in the Britta Dal Formation.

Sample Group 4E (grey-co. slst., f. sst.-flat, trough X).

Sample group 4E (grey-co. slst., f. sst.-flat, trough X) is represented only in a restricted stratigraphic interval, above the predominantly siltstone succession of the Remigolepis Group on Gauss Halvø. The sandstone intervals of the sample group probably represent channel sandstones laid down by streams of increased power, reaching the former playa areas from the west. They may be regarded as precursors of the greater development of sandstones in the Grönlandaspis Group.

TECTONIC AND ENVIRONMENTAL EVOLUTION OF THE UPPER DEVONIAN OLD RED SANDSTONE ON GAUSS HALVØ AND YMER Ø

Upper Devonian Fault Movements

In the western limb of the Stensiøs Bjerg syncline, on W. Smith Woodwards Bjerg, the Kap Graah Group follows the Upper Devonian top of the Kap Kolthoff Supergroup conformably. At Agda Dal and in the Hjelmbjergene further to the east, however, a thinner Kap Graah Group succession rests on the Middle Devonian Hjelmbjergene Group with angular unconformity. In the 15 km interval between these two areas the Group is carried below sea level in the syncline, and the coastline is formed by the Mount Celsius Supergroup. This striking contrast between the sub-Kap Graah Group successions in the syncline limbs indicates the presence of a major fault-line pre-dating the Mount Celsius Supergroup and the later parts of the Kap Graah Group, with a substantial westerly downthrow.

Bütler (1959, p. 163; 1954, p. 106) has suggested that the Høgboms Bjerg—Sederholms Bjerg thrust extends southwards, beneath a later cover of the Mount Celsius Supergroup, to pass below sea level slightly to the west of Agda Dal. The thrust, a high-angle reverse fault which brings Middle Devonian sandstones into contact with folded early Kap Graah Group successions, probably represents a late movement along a major fault separating two structural blocks. Its most southerly outcrop is at Bøggilds Bjerg, 15 km south of Høgboms Bjerg, and 15 km north of Agda Dal. The suggestion that it extends to Agda Dal, and possibly to Ymer Ø, is in accord with the following observations:

(1) there are several normal faults at Agda Dal, in the western shoulder of Gunnbjørns Bjerg, which post-date the Mount Celsius Supergroup and exhibit westerly downthrows of 300–400 m. These may be related to an older fault line;

(2) if projected southwards from the Agda Dal area the fault-line would intersect the site of the basalt volcanism at Kap Graah, and join the major western boundary fault of the Celsius Bjerg massif. The large red rhyolitic tuff and lava intrusion in the Kap Kolthoff Supergroup sandstones west of Celsius Bjerg, and the numerous basalt dykes there, may also be related to such a fault-line;

(3) the presence of a fault separating two blocks may have influenced the location of the Stensiøs Bjerg syncline axis, formed during the Ymer Ø Phase of folding in post-Grönlandaspis Group time. At Kap Graah and Teglbjerg, in the southerly continuation of this syncline, the steep and abrupt inclination of the eastern limb caused SÄVE-SÖDERBERGH (1932a, p. 24) to speculate on the existence of a "tectonic line" here.

The area between the Høgboms Bjerg-Agda Dal line and the "post-Devonian Main Fault" (BÜTLER, 1957) of the Margrethedal area is termed here the Hjelmbjergene Block. Its southern boundary is probably defined by a fault off the northern shores of Kejser Franz Josephs Fjord. The "Main Fault" was active in Devonian times. Considering that the basal breccias of the Kap Graah Group rest on the Middle Devonian Vilddal Group to the east of the fault in Margrethedal, and on the southeasterly-dipping Red Sandstone Formation of the Hjelmbjergene Group on the west side of the fault, on Obrutschews Bjerg, ALEXANDER-MARRACK (personal communication) concludes that the westerly downthrow on the fault-line, prior to the movements which occurred in post-Devonian times, may have amounted to 2 km. On S. E. Evans Bjerg the fault separating the Red Sandstone Formation from the older Red and Grey Banded Formation of the same Group no doubt also owes part of its net downthrow to pre-Kap Graah Group movements.

BÜTLER (1959) has stated that the north-south boundary faults of the Nordfjord graben developed in his Hudson Land Phase 3, but in the uniformly-southerly palaeocurrent distributions of the successions of the Watsons Plateau-Rødtop area there is no indication of their topographic expression.

The Kap Kolthoff Supergroup

A full review of the Kap Kolthoff Supergroup (the most extensive of the Upper Devonian Old Red Sandstone divisions at the present day) will not be made here. From our observations on the upper parts of the Supergroup on Gauss Halvø and Moskusokselandet some general statements can be made:

(1) the major outcrop area of the Supergroup is to the west of the Hjelmbjergene Block. In W. Gauss Halvø, in Moskusokselandet, and in central Ymer Ø it consists of at least 2000 m of monotonous sandstones

of sample group 3D (grey-m., co. sst.-trough X), in which very few vertebrates have been found. Southerly palaeocurrents are predominant;

(2) in E. Gunnar Anderssons Land, on Celsius Bjerg, and in the red wedge on Torbern Bergmans Bjerg west of the Moskusoksefjord inlier, westerly palaeocurrent directions were recorded;

(3) on the Hjelmbjergene Block the red sandstones of the Langbjerg area, east of Bøggilds Bjerg, have been referred to the lower part of the Supergroup. They extend southwards beneath a cover of Mount Celsius Supergroup and late Kap Graah Group sediments, and probably correlate with the Red Sandstone Formation of Obrutschews Bjerg. ALEXANDER-MARRACK measured northwesterly palaeocurrents on Langbjerg;

(4) in its northerly outcrop area the Supergroup contains granite, gneiss, and limestone pebbles (especially in its upper parts). To the south of Smith Woodwards Bjerg extraformational clasts are of minor importance; and on E. Gunnar Anderssons Land and S. E. Celsius Bjerg they occur only at the top of the Supergroup, comprising fragments of contemporaneous volcanic and sedimentary rocks derived from the east and northeast.

The Kap Graah Group, First Phase of Deposition

The development of the Kap Graah Group is conveniently considered in terms of two depositional phases, which can perhaps be related to BÜTLER's Hudson Land Phases.

The deposits of the first phase of the Group (Figure 56) were laid down under similar conditions of sedimentation to those of the Kap Kolthoff Supergroup. In W. Gauss Halvø and on central Ymer Ø southerly-flowing rivers (and perhaps winds) laid down sediments over 1000 m thick, exhibiting no angular unconformities, or volcanic rocks, and very few extraformational pebbles. Vertebrates are rather more common than in the Kap Kolthoff Supergroup, with a fauna near the base of the Group including *Phyllolepis*, *Holoptychius*, and *Bothriolepis*.

In the succession formed to the east of those areas, towards the western margins of the Hjelmbjergene Block, the palaeocurrents are westerly-directed and the sandstones contain extraformational pebbles, or even become conglomeratic. At Kap Graah marked lithofacies variation occurs within 5–10 km laterally, parallel to the palaeoslope direction, and basalt and rhyolite volcanism was intimately associated with fluviatile sedimentation. No aeolian sediments are thought to be associated with these more-easterly successions of the first depositional phase (with the possible exception of parts of the red arkose division of Kap Graah).

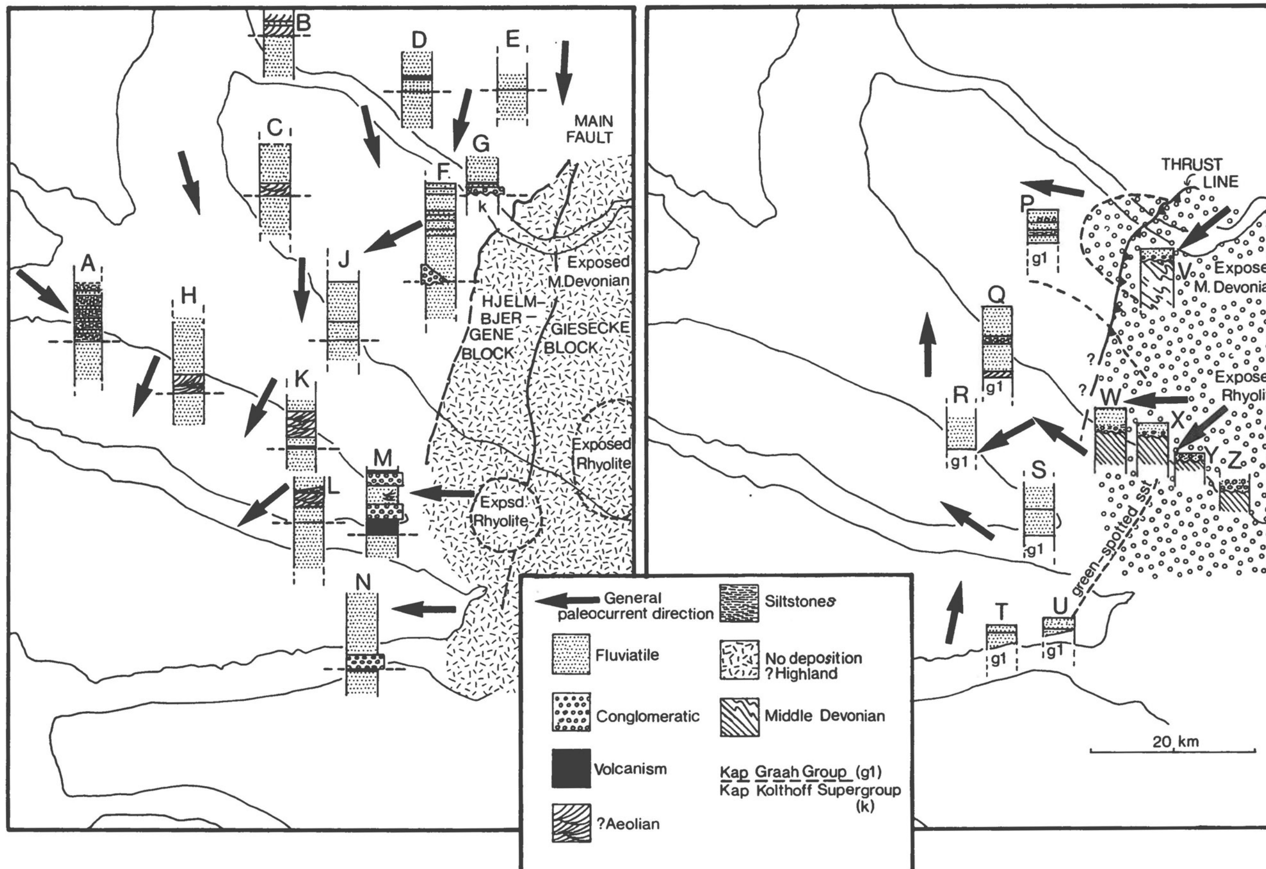

Fig. 56. Summary of palaeocurrents and lithological successions for A) first phase of deposition of Kap Graah Group and B) second phase of deposition of Kap Graah Group.

The westerly palaeocurrents and the easterly coarsening of the sandstones imply that highland areas existed to the east. No deposits of the first phase of sedimentation are now preserved east of the Agda Dal-Høgboms Bjerg line. During the first phase the Hjelmbjergene Block (and probably the Giesecke Block further to the east) was relatively elevated, and its cover of sandstones of the Kap Kolthoff Supergroup (and possibly of the lowermost parts of the Kap Graah Group) was stripped off and the debris transported westwards and southwestwards. Large quantities of white sandstones very similar to those of the Supergroup are present in the conglomeratic sandstones of Kap Graah and of Celsius Bjerg, together with rhyolite clasts which may have been derived from the southern parts of the Giesecke Block area. Some green siltstones which may have been derived from the Vilddal Group are also present.

Green sandstones similar to those of the Grey Formation of the Hjelmbjergene Group form a very minor component of the Ymer Ø pebbly sandstones. Possible factors contributing to this virtual absence are (1) lack of exposure of the Group during most of the first phase of deposition; (2) rapid weathering of sandstones near the site of erosion; (3) transportation of the material westwards rather than southwestwards.

There is no westerly component in the palaeocurrent distributions obtained from the first phase sandstones of central Smith Woodwards Bjerg, and thus no evidence that the Hjelmbjergene Block influenced sedimentation 15 km to the west of Agda Dal. However, the major lateral lithofacies changes observed at Kap Graah (an area occupying a comparable position near the eastern margin of the first-phase basin) indicate that a change in the palaeocurrent directions from westward to southward might well take place within this interval.

Further to the north, along the western margin of the Hjelmbjergene Block, Middle Devonian sandstones were exposed at an early stage during the first phase of deposition of the Group. The angular unconformity surface at the base of the Group west of Høgboms Bjerg is overlain by boulders of Middle Devonian sandstones and basalt; and on Victor Madsens Bjerg clasts of Middle Devonian green-grey sandstones are very numerous in the northeasterly-derived pebbly sandstones of the middle part of the Kap Graah Group succession. Basaltic volcanism was widespread and prolonged in Moskusoksefjord during the first phase.

On the western side of the outcrop area of the Group, west of Zoologdalen, the only suggestion of a westerly margin to the first phase of sedimentation is afforded by a siltstone-sandstone succession yielding easterly-directed palaeocurrents, and (at its base) clasts of limestones which resemble Pre-Cambrian types.

The elevation of the Hjelmbjergene Block may perhaps be attributed to BÜTLER's 'Hudson Land Phase 3' movements. Subsequent uplift and faulting may have been related to sedimentation, possibly by the mechanism of differential loading suggested by WALCOTT (1970). The basalt dykes which cut the Hjelmbjergene Group may be related to the volcanism of Kap Graah and Moskusoksefjord.

The Kap Graah Group, Second Phase of Deposition

The second phase which can be recognised is characterised by (1) the more easterly extent of the later part of the Group across the Hjelmbjergene Block; (2) reorientation of palaeocurrent directions in the more basinal parts of the succession; (3) the numerical increase of the vertebrates; and (4) the development of green-spotted sandstones. Recognition of the onset of the second phase of deposition is difficult in the more basinal parts of the Group's outcrop area. Due to later erosion, the deposits referred to the second phase occupy a smaller area than those of the first phase (Figure 56).

Between Margrethedal and Agda Dal the Hjelmbjergene Block is unconformably overlain by Kap Graah Group sandstones, increasing westwards in thickness from 80 m to 330 m. The presence above the unconformity surface of fragments exclusively derived from the Hjelmbjergene Group demonstrates that removal of the Kap Kolthoff Supergroup sandstones from the southern part of the Block was complete by this time. From easterly and northeasterly sources medium sand and pebbles of rhyolite, quartz, and quartzite were supplied to the surface of the Block.

West of the Block fine-grained sandstones and siltstones were brought into the basin by river systems from the south, in which vertebrates flourished. The interaction between the northerly and the westerly-directed sediment dispersal systems is seen in the succession at Agda Dal, where fine-medium sandstones exhibit northwesterly palaeocurrent trends. West of the Agda Dal-Høgboms Bjerg line, the unconformity is absent, and clasts derived from the Hjelmbjergene Group do not appear.

Further to the north, at N. E. Sederholms Bjerg, movements along the Høgboms Bjerg-Sederholms Bjerg thrust-plane elevated the northern part of the Hjelmbjergene Block and in the vicinity of the fracture caused uptilting of the Kap Graah Group sediments of the first phase. Development of a local unconformity followed, and clasts of similar types to those of the Obrutschews Bjerg sandstones were introduced from upland areas to the northeast.

On Ymer Ø the upper succession of the Group consists of grey

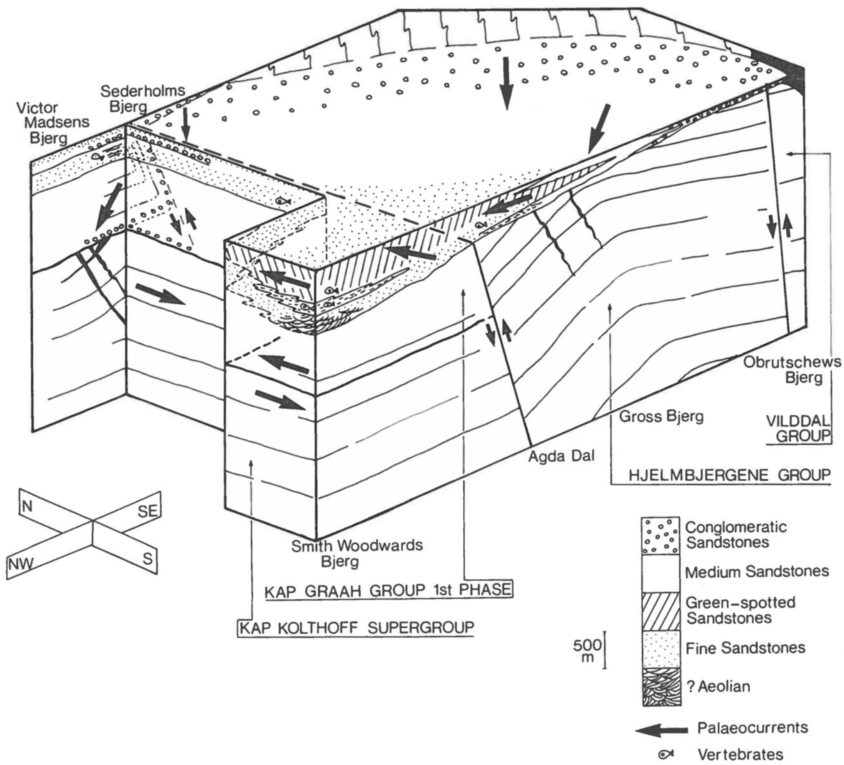

Fig. 57. Block diagram to illustrate structural setting of the second phase of Kap Graah Group sedimentation, and compare with palaeocurrents of first phase. The palaeocurrent of the first phase on Smith Woodwards Bjerg should be northward (not southward as shown here).

fine-grained sandstones, from which northwesterly to northeasterly palaeocurrent directions were obtained. Green spots are well-developed in these sandstones, and occur also in the second phase sandstones of Gauss Halvø, between Smith Woodwards Bjerg and Gross Bjerg and as far north as central Paralleldal (Figure 57). It has been shown that they originated by the chloritisation of basalt grains; the source of the grains was probably a southerly area of basalt lavas undergoing erosion.

The northerly palaeoslope of the second phase, developed in central Gauss Halvø and central Ymer Ø, represents a reversal relative to that of the first phase of deposition, and was maintained as the dominant palaeoslope during the accumulation of the Mount Celsius Supergroup. Possibly the northern part of the central Gauss Halvø Block was downwarped during Bütler's "Hudson Land Phase 4", by movements associated with uplift on the southern and western margins of the basin.

The vertebrate faunas of the Kap Graah Group are mainly confined to the second phase of deposition. The fauna from the base of the Group at Watsons Plateau and W. Zoologdalen (comprising *Phyllolepis sp.*, *Holoptychius sp.*, and *Bothriolepis jarvіki*) belongs to the Kap Graah first phase, and was not contemporaneous with the fauna present at the base of the Group at Agda Dal. This belongs to the second phase, and contains the large *B. groenlandica*, *Phyllolepis sp.*, *Holoptychius sp.*, and a dipnoan. The Agda Dal vertebrates are probably equivalent in age to those of ORVIN's locality at Kap Graah; to those from the upper parts of the Group on central Smith Woodwards Bjerg, and at the Paralleldal localities of JOHANSSON and others; and to the fauna from the new locality on Victor Madsens Bjerg.

The Remigolepis Group

The northerly palaeoslope established during the second phase of development of the Kap Graah Group was maintained in central Gauss Halvø throughout the deposition of the succeeding Remigolepis Group. The Group follows the second phase sandstones of the Kap Graah Group with complete conformity. The thickness of the Remigolepis Group varies relatively little in central Gauss Halvø, but on the Hjelmbjergene Block it is notably reduced and in the lower part of the Group (in the Aina Dal Formation) there is a westerly component in the palaeocurrent distribution. Figure 46 summarises the thickness variations and palaeocurrent trends of the three formations recognised.

The dominant lithology is siltstone; and with the regional development of the red siltstones of the Aina Dal Formation the vertebrates characteristic of the Kap Graah Group are replaced by a new, more diverse assemblage of fish and amphibia: *Remigolepis*, *Holoptychius*, *Ichthyostega*, *Soederberghia*.

The Aina Dal Formation was succeeded in central Gauss Halvø by unfossiliferous siltstones (200 m thick at Stensiøs Bjerg), which probably accumulated in a playa environment. In the Obrutschews Bjerg area a thinner but still-finer sequence of similar sediments was laid down. The subsequent reestablishment of dominantly-fluviatile channel and floodplain sedimentation on Gauss Halvø, represented by the Britta Dal Formation, is marked by the return of vertebrates. The fauna of this Formation differs from that of the Aina Dal Formation in the presence of an additional tetrapod type (*Acanthostega*), a new large crossopterygian (*Eusthenodon*), and several new lung fish (*Jarvikia* and *Oervigia*). The Britta Dal Formation at Obrutschews Bjerg is markedly thinner and finer-grained than on central Gauss Halvø.

The vertebrates were able to persist throughout the fully-fluviatile succession of the Remigolepis Group of Ymer Ø, which is approximately half the thickness of the Gauss Halvø succession. The palaeocurrent data obtained from Celsius Bjerg indicate north-easterly transportation of sediment throughout the period of deposition of the sequence.

The Grönlandaspis Group

During the accumulation of the Grönlandaspis Group there was a gradual increase in the importance of mediumgrained sandstones introduced principally from the west and, in the Obrutschews Bjerg area, from the north. Late in the succession, extraformational pebbles became numerous.

Of the previous fauna, only *Holoptychius* persisted as increasingly coarse fluviatile sediments were laid down. The latest-known arthrodire, *Grønlandaspis*, entered the area together with early palaeoniscoids.

The original thickness of the Grönlandaspis Group was possibly much greater than that now preserved, probably including Lower Carboniferous sandstones. Denudation of the Devonian sediments may have been well-advanced by late Carboniferous times, and BÜTLER (1961) has suggested that source material for part of the Upper Carboniferous successions of Prospektdal (east of Høgboms Bjerg) and of Kap Humboldt (easternmost Ymer Ø) may have been derived by weathering of the Remigolepis Group.

With the Grönlandaspis Group the record of Upper Devonian Old Red Sandstone sedimentation in East Greenland ends.

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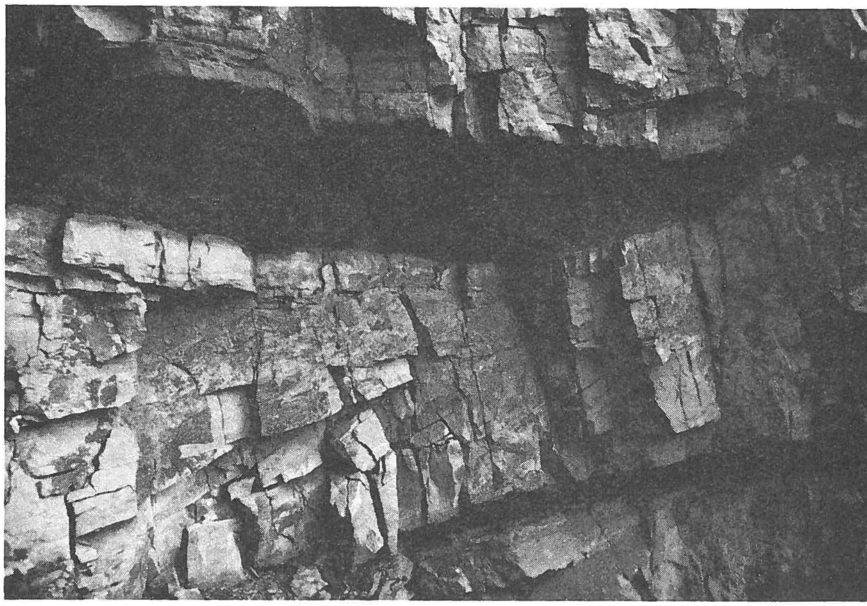
Appendix

Table 13. *List of stratigraphic terms, central sequence*
(only formal units are listed here; numbers indicate stratigraphic sequence and hierarchy).

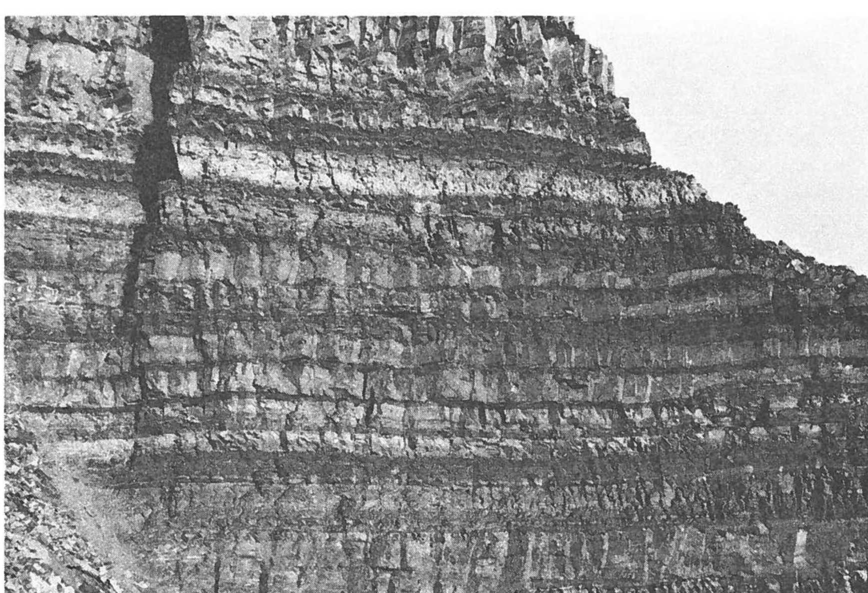
1. Vilddal Supergroup	1.1. Vilddal Group
	1.1. Inderdalen Formation
2. Kap Kolthoff Supergroup	2.1. Hjelmbjergene Group
	2.1.1. Hjelmbjergene Grey Sandstone
	2.1.2. Hjelmbjergene Red and Grey banded Sandstone
	2.1.3. Hjelmbjergene Red Sandstone
	2.1. Rødedal Formation
	2.1. Giesecke Bjerge Group
	2.1.1. Kap Franklin Formation
	2.1.2. Randbøl Formation
3. Kap Graah Group	(no formal subdivision)
4. Mount Celsius Supergroup	4.1. Remigolepis Group
	4.1.1. Aina Dal Formation
	4.1.2. Wimans Bjerg Formation
	4.1.3. Britta Dal Formation
	4.2. Grönlandaspis Group

Færdig fra trykkeriet 28. december 1976

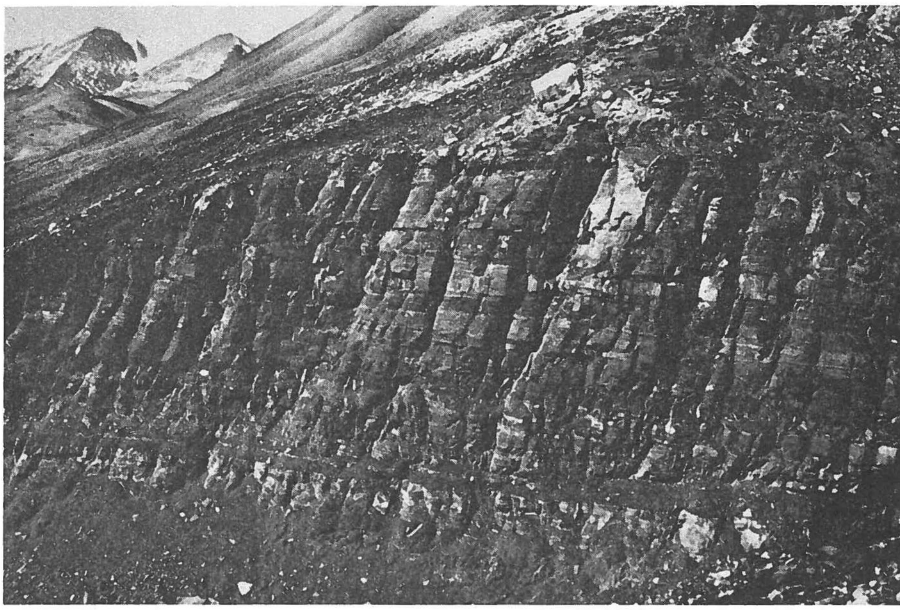
PLATES



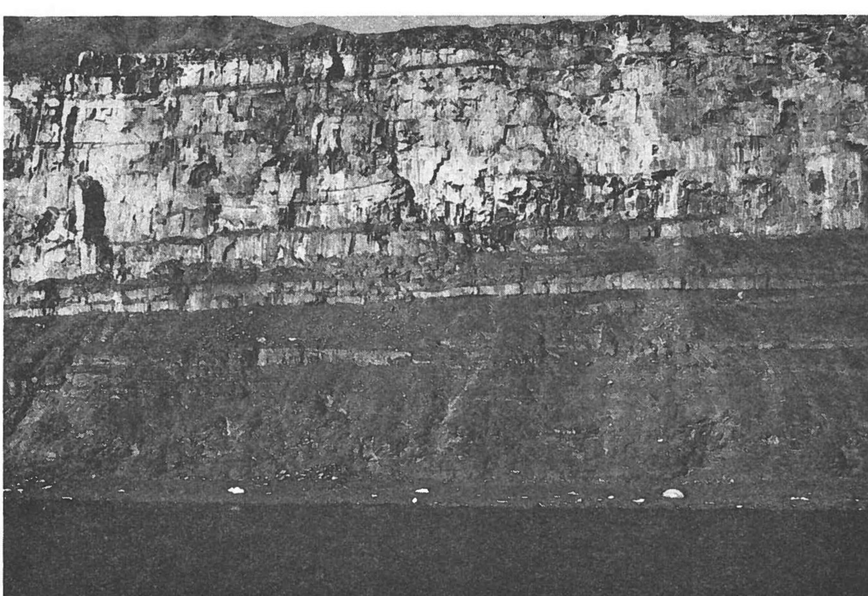
1. Siltstone lens bounded by scour surfaces, Kap Graah Group on W. Gross Bjerg.



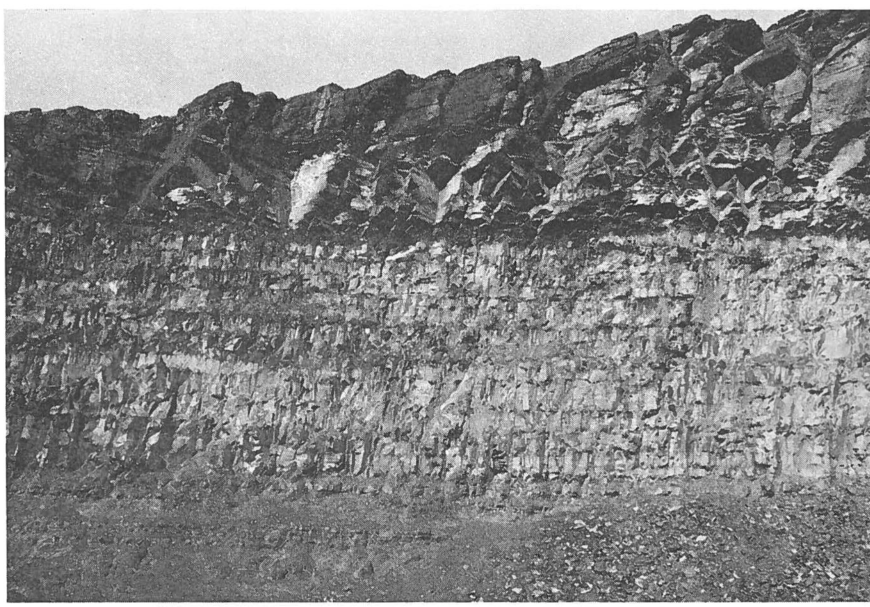
2. Sample group 5A, E. Smith Woodwards Bjerg (Kap Graah Group). Section almost at right-angle to palaeoslope determined for division.



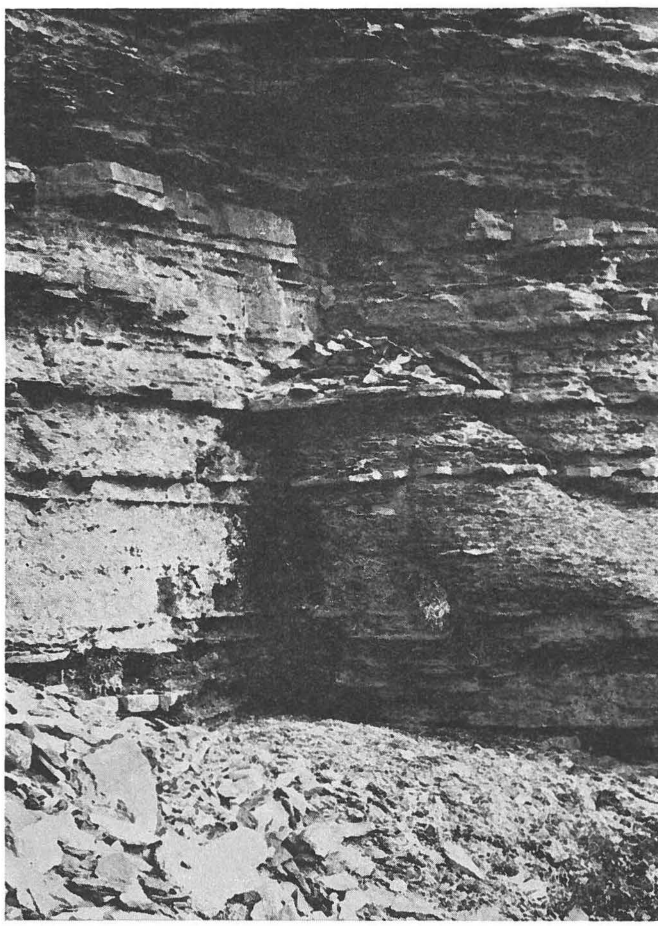
3. Sample group 5A, S.W. Celsius Bjerg (Remigolepis Group). Cliff face almost parallel to the grand palaeocurrent vector mean determined for the Group.



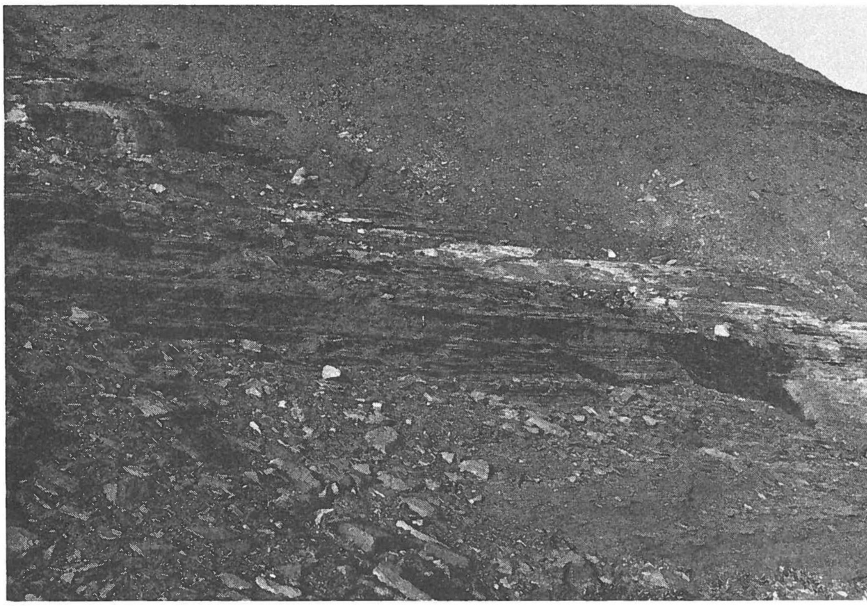
4. Shoreline cliffs of Aina Dal.



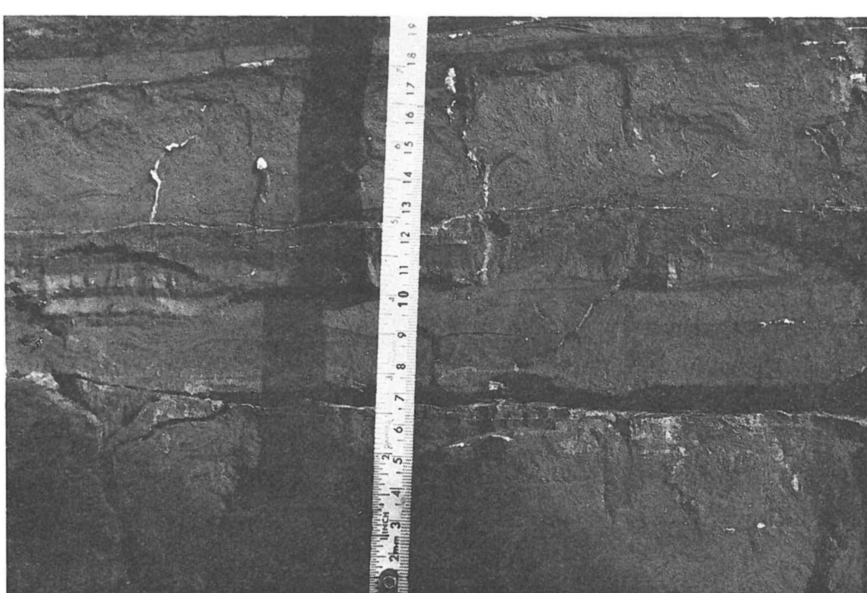
5. Red siltstones of sample group 5D, upper member of the Aina Dal Formation at Aina Dal. The overlying dark sequence belongs to the Wimans Bjerg Formation (sample group 4C).



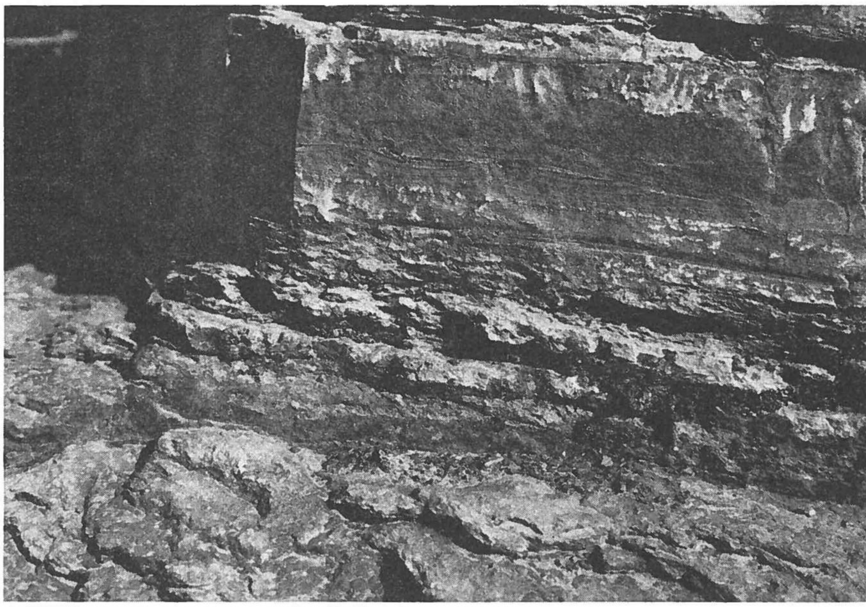
6. Sample group 4C, transitional sequence between the Wimans Bjerg Formation and the Aina Dal Formation; Stensiøs Bjerg, location shown in Fig. 51.



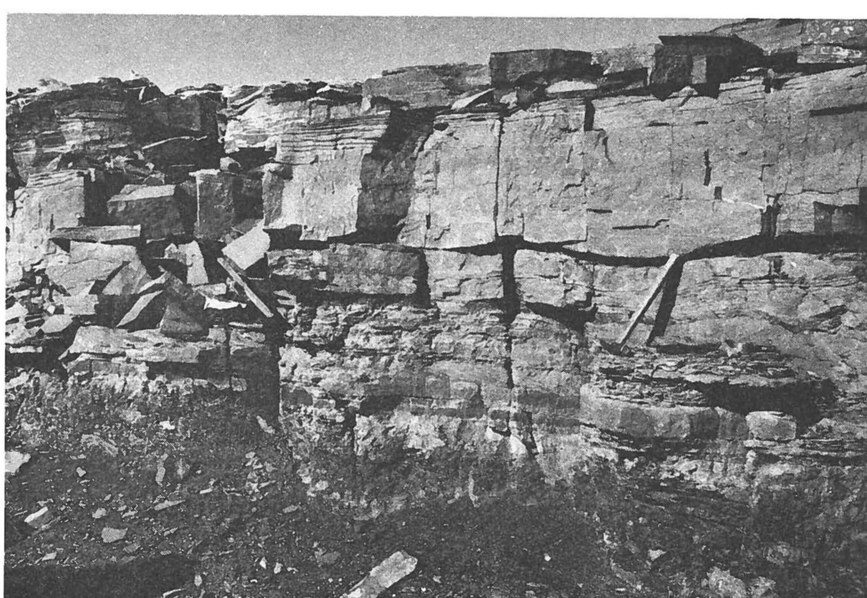
7. Sample group 4C, lower 50 m of the Wimans Bjerg Formation, Stensiøs Bjerg (Fig. 51); the thin, harder horizons are the "thinbedded siltstones" containing ripple cross-laminae and deformations.



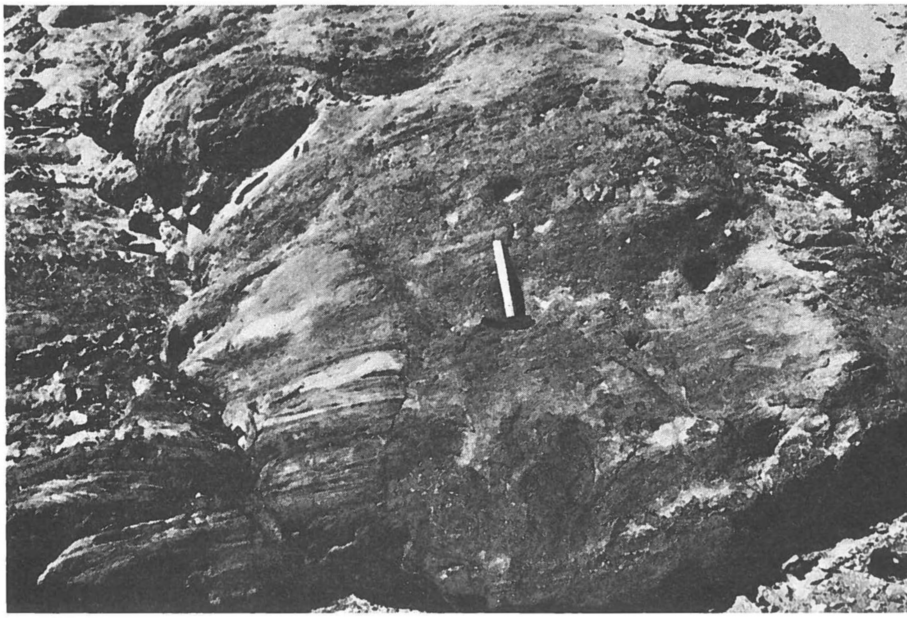
8. Sample group 4C, composite thicker siltstone with internal softsediment deformations. Wimans Bjerg Formation, Stensiøs Bjerg.



9. Sample group 4C, coarse sandy siltstone bed with ripple crosslaminae. Wimans Bjerg Formation, Stensiøs Bjerg.

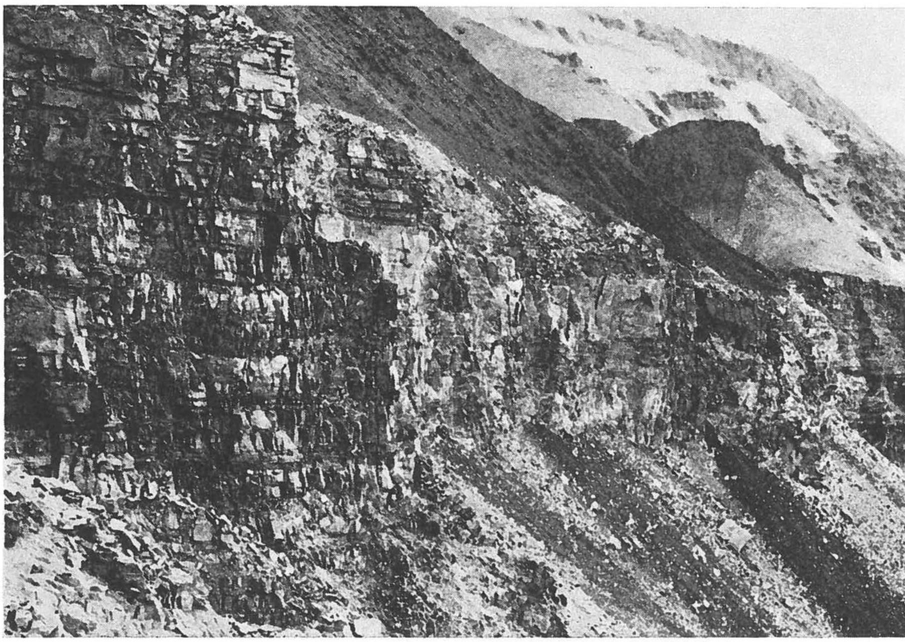


10. Sample group 4E sandstone unit overlying grey siltstones. Grönlandaspis Group, S. E. Stensiøs Bjerg.



11. Volcanic division, Kap Graah Group, near Kap Graah. Steep-sided channel scoured into flat-bedded tuffite, infilled with tuffite containing basalt blocks.

12. Large-scale cross-stratification, red arkose division of the Kap Graah Group, near Kap Graah.



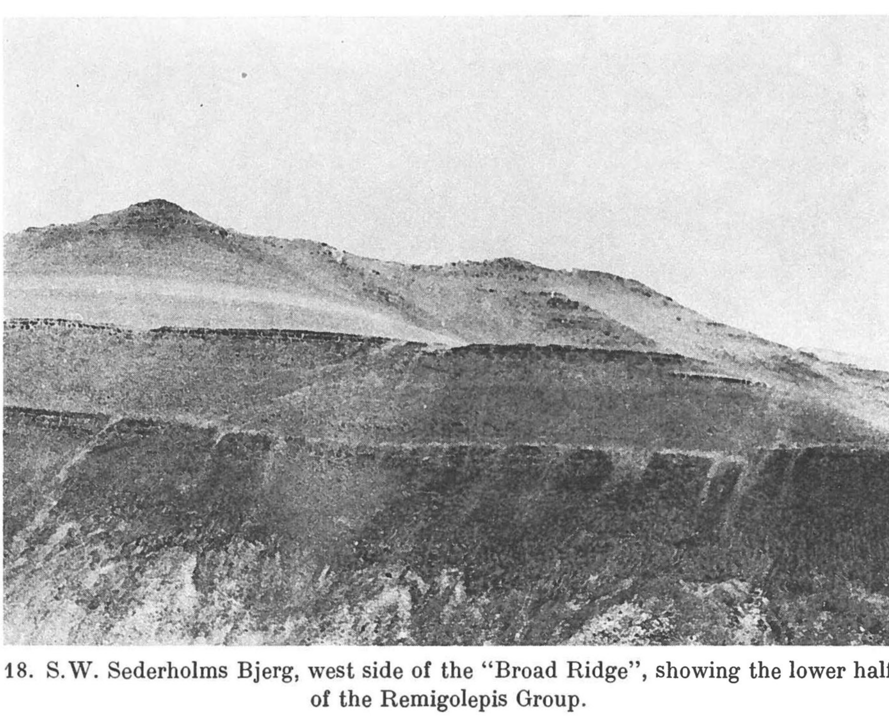
13. Sandstones of the Kap Graah Group on Evans Bjerg (location P., Fig. 27).

14. S.E. Nathorsts Bjerg, viewed across Agda Dal. Lower part of the mountain formed by the Kap Graah Group; the darker succession above consists of the Remigolepis Group.

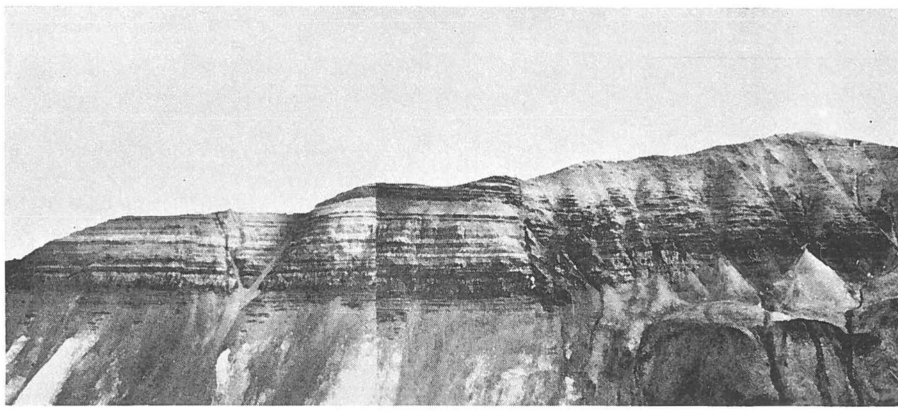
15. Kap Graah Group basal conglomerates, Moskusokselandet (opposite Victor Madsens Bjerg). The conglomerates lie on an uneven surface, across sandstones of the Kap Kolthoff Supergroup.

16. N.E. Sederholms Bjerg. (see Fig. 39).

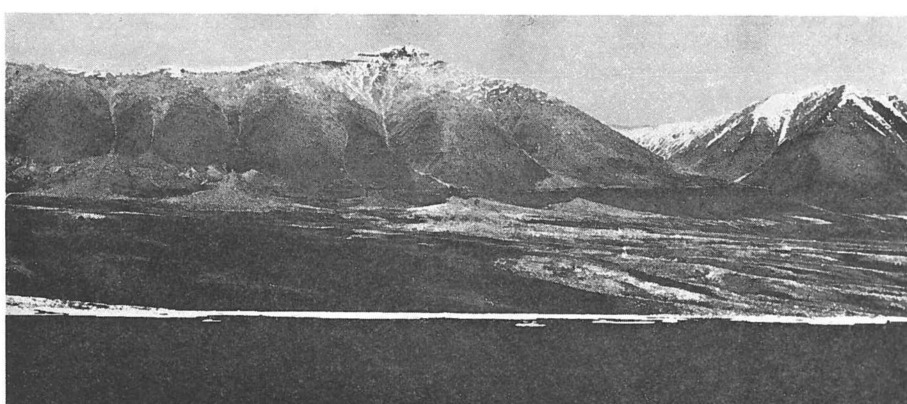
17. N.E. Victor Madsens Bjerg, viewed from Sederholms Bjerg. The profile route was to the left of the large gulley near the centre of the photograph; exposures commence at 750 metres.



18. S.W. Sederholms Bjerg, west side of the "Broad Ridge", showing the lower half of the Remigolepis Group.



19. Mount Celsius Supergroup succession, N.E. Celsius Bjerg.



20. S.W. Celsius Bjerg. Foreground, Kap Graah Group; lower mountain slopes, Remigolepis Group; upper mountain, Grönlandaspis Group.