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DEVONIAN SEDIMENTS OF EAST GREENLAND III

THE EASTERN SEQUENCE, VILDDAL SUPERGROUP AND PART OF THE KAP KOLTHOFF SUPERGROUP

BY

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WITH 82 FIGURES, 18 TABLES AND 11 PLATES

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Abstract

After the folding and metamorphism of the main Caledonian orogenic phases in East Greenland, the next event was the extrusion of the Kap Fletcher volcanics in Canning Land.

Vilddal Supergroup sedimentation then occured from Canning Land in the south, to Hudson Land in the north. Fluvial sandstones and conglomerates formed in eastern Gauss Halvø, and were then followed more widely, by a variety of fluvial and lacustrine sediments. Extensive lacustrine environments, of upper Middle Devonian age, accumulated up to 1500 m of sediment. Faulting and local folding about east-west axes, with deep erosion, terminated the Vilddal Supergroup sequence.

Kap Kolthoff Supergroup sedimentation of dominantly fluvial and sandy type, lasted from upper Middle Devonian to upper Upper Devonian times. It records the appearance, for the first time, of an eastern source for the Devonian sediments. This new feature extended from Canning Land in the south, to Hudson Land and Kap Franklin, in the north. The transition to this new crustal pattern is marked by the Kap Franklin volcanics and conglomerates, and by at least two phases of granite emplacement. A maximum of $2^1/_2$ km of Kap Kolthoff Supergroup sedimentation has been measured.

The uplift of fault-defined blocks then moved the eastern margin of the basin even further west in Kap Graah and Mount Celsius, Upper Devonian times.

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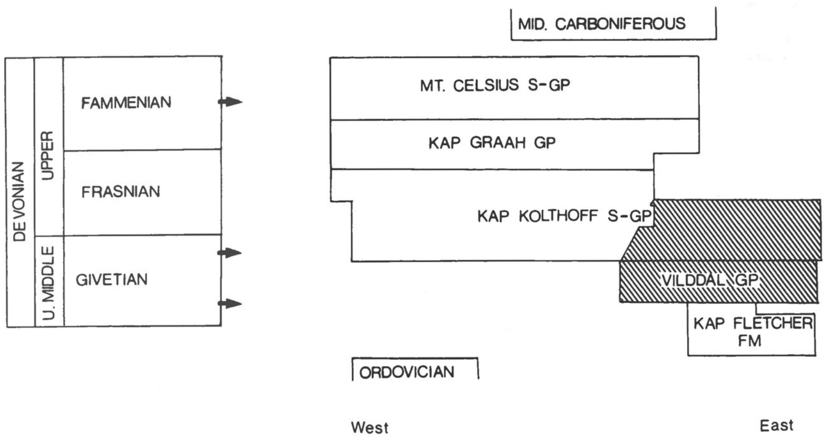


Fig. 1. Major litho-stratigraphic units of the Devonian succession of East Greenland, with their ages. The units described in this paper are shaded. Vilddal Gp should read Vilddal S-Gp.

INTRODUCTION

Along the eastern margin of the Devonian outcrop area in East Greenland, occur the only outcrops of the Vilddal Supergroup (Fig. 1 & 2). With the exception of the volcanic Kap Fletcher Formation, the Vilddal Supergroup is the oldest stratigraphic unit of the East Greenland Devonian succession. It, and the associated Kap Kolthoff Supergroup sediments are the subject of this paper.

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 and YEATS, in the first numbers of this volume of *Meddelelser om Grønland.*

In Number 1 (FRIEND and others, 1976), we have explained our use of a classification system for standard (generally 10 m) intervals, of our sedimentary logs. This classification is used throughout the present paper. A list and examples of the classes are presented here (Fig. 3–7). We usually refer to the classes using a label, consisting of a number and letter (eg. '4C'), and a short description (eg. grey-m., co. slst-flat). This short description means (i) predominant colour, grey, (ii) greatest proportion of (10 m) interval is m. siltstone in grade, next most abundant sediment is coarse siltstone in grade, (iii) commonest internal structure is flat-bedding.

In Number 2, we have provided general details of the sedimentary structures and fossils.

We shall describe the geology area by area, starting with the Kap Franklin area.

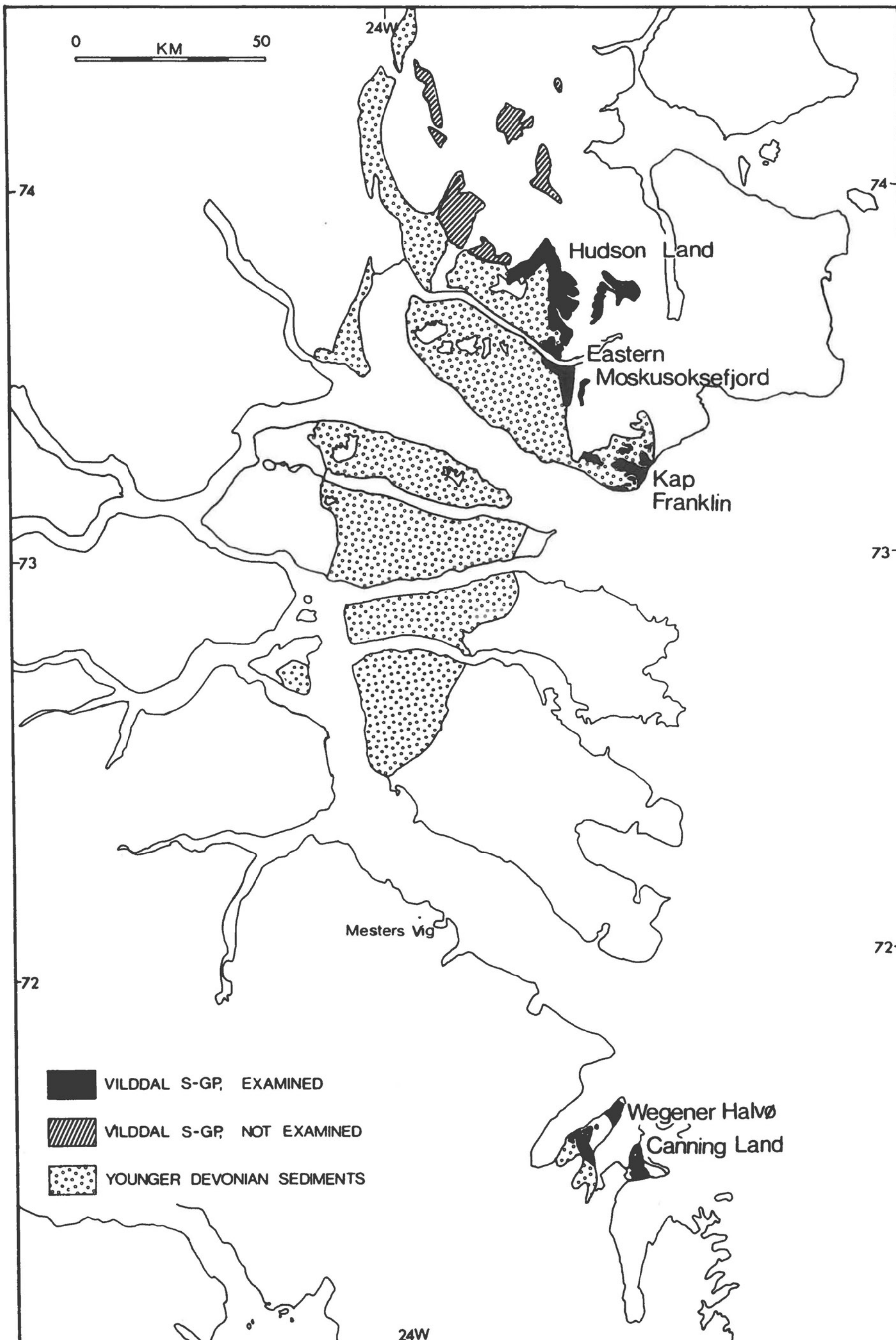


Fig. 2. Outcrop areas of the Vilddal Supergroup, and younger Devonian strata.

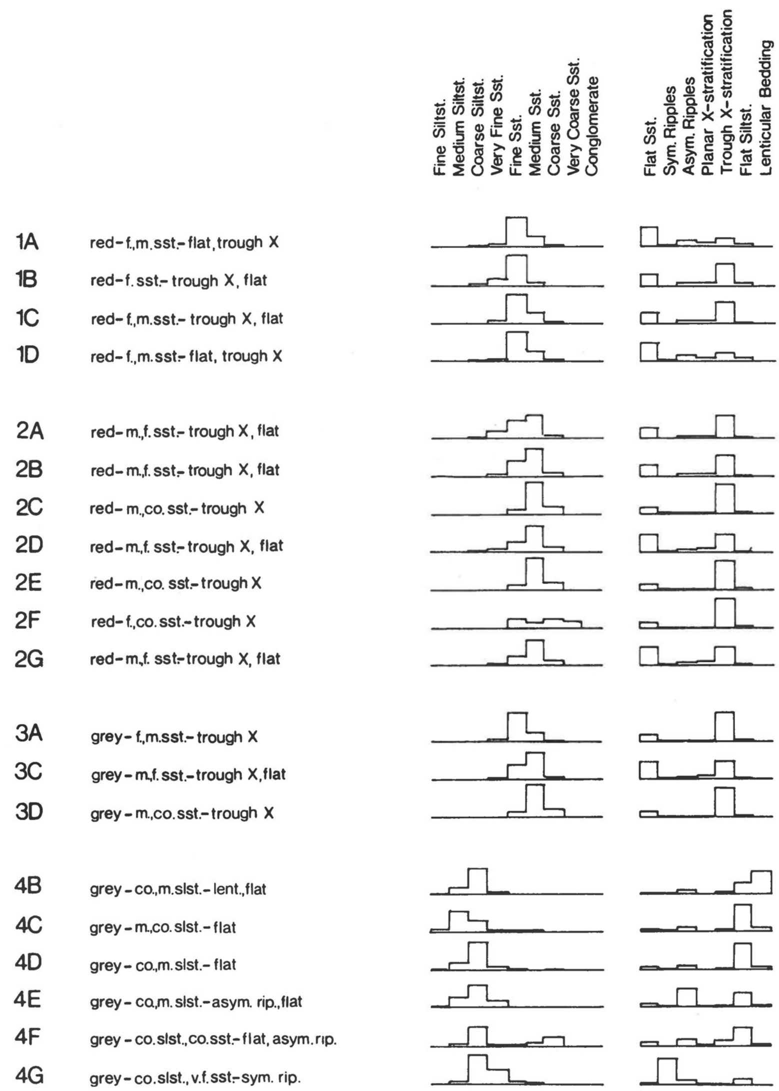


Fig. 3a. Sample group classification used in this paper for 10 m lengths of sedimentological log. The classification is fully described in No. 1 of this volume. Each row consists of sample group label, brief standard description, and average grain size and internal structure content.

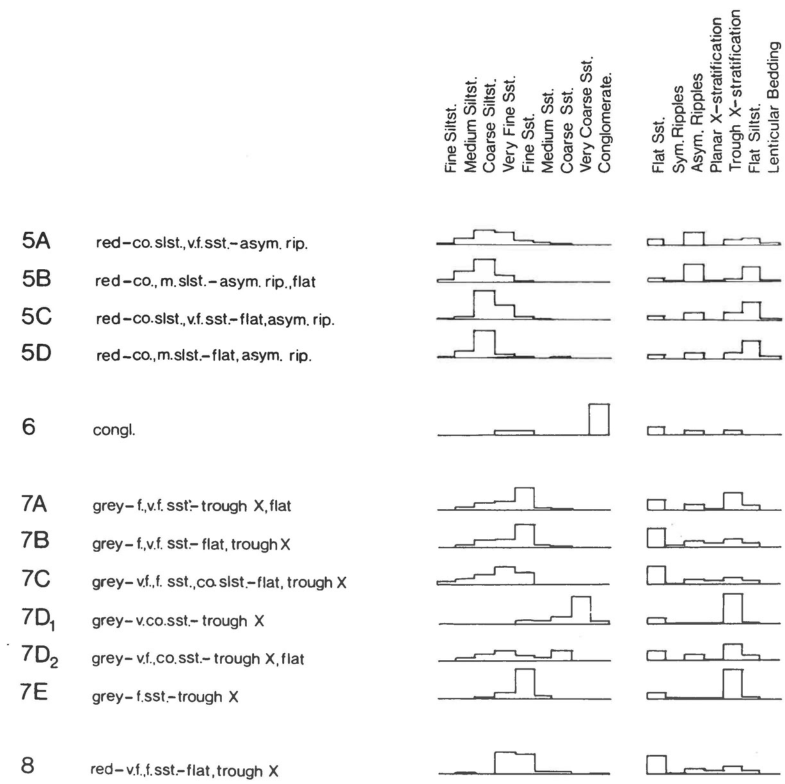


Fig. 3b. Continuation of fig. 3a.

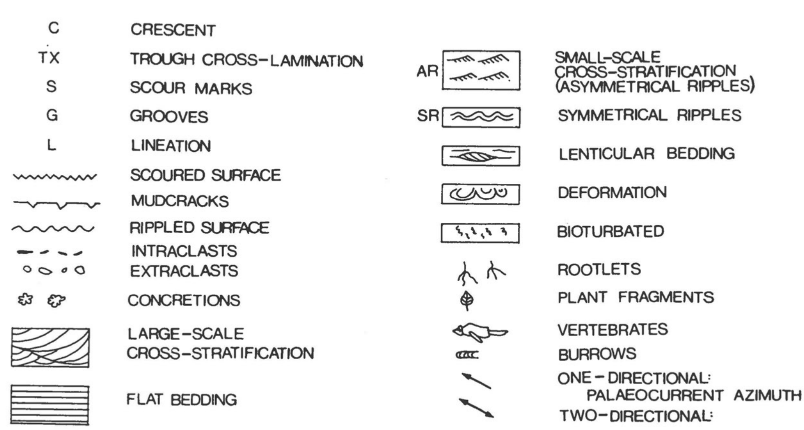


Fig. 4. Key to Figs. 5–7.

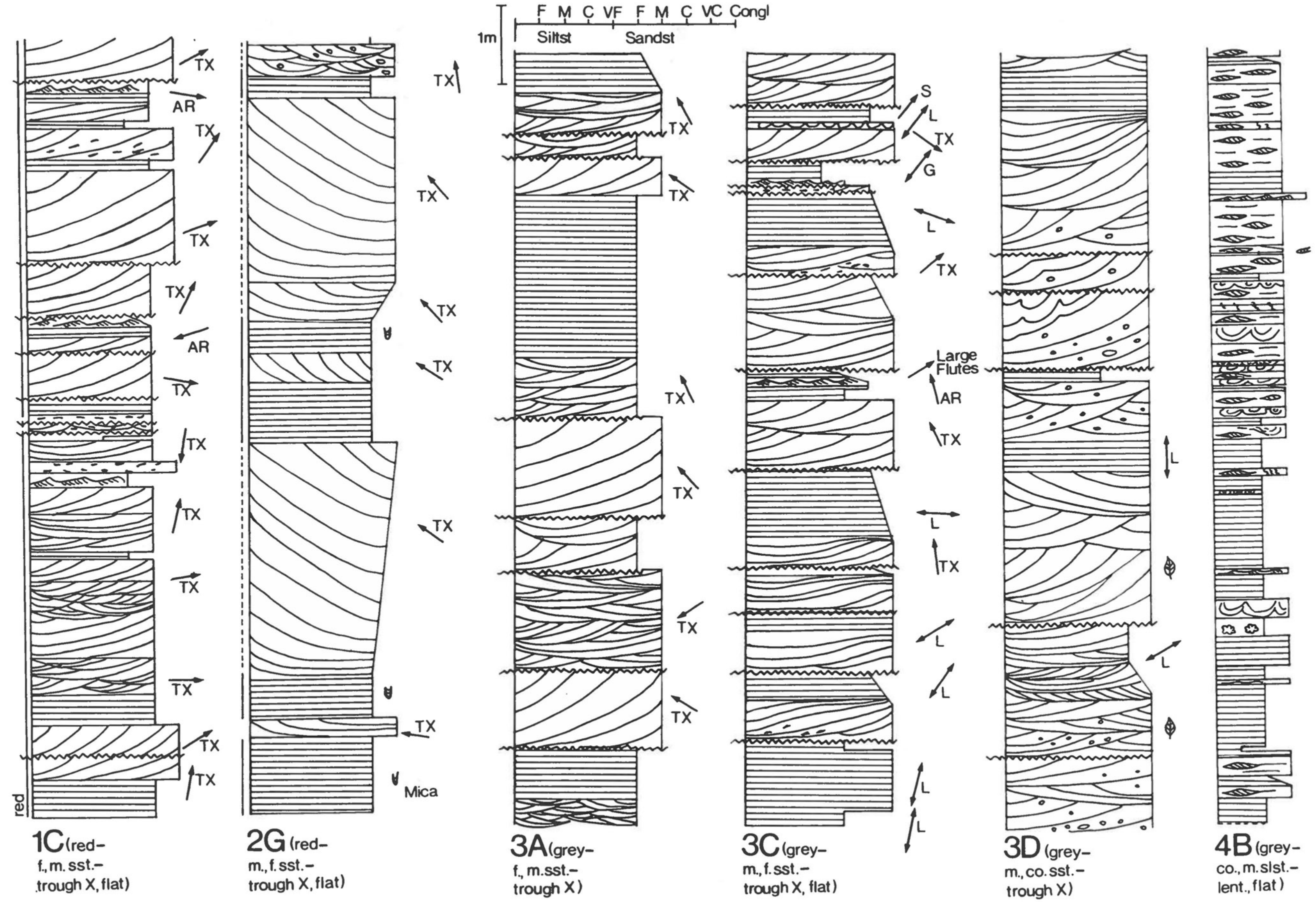


Fig. 5. Typical 10 m sample assigned to each sample group of the classification (see Fig. 3 and 4).

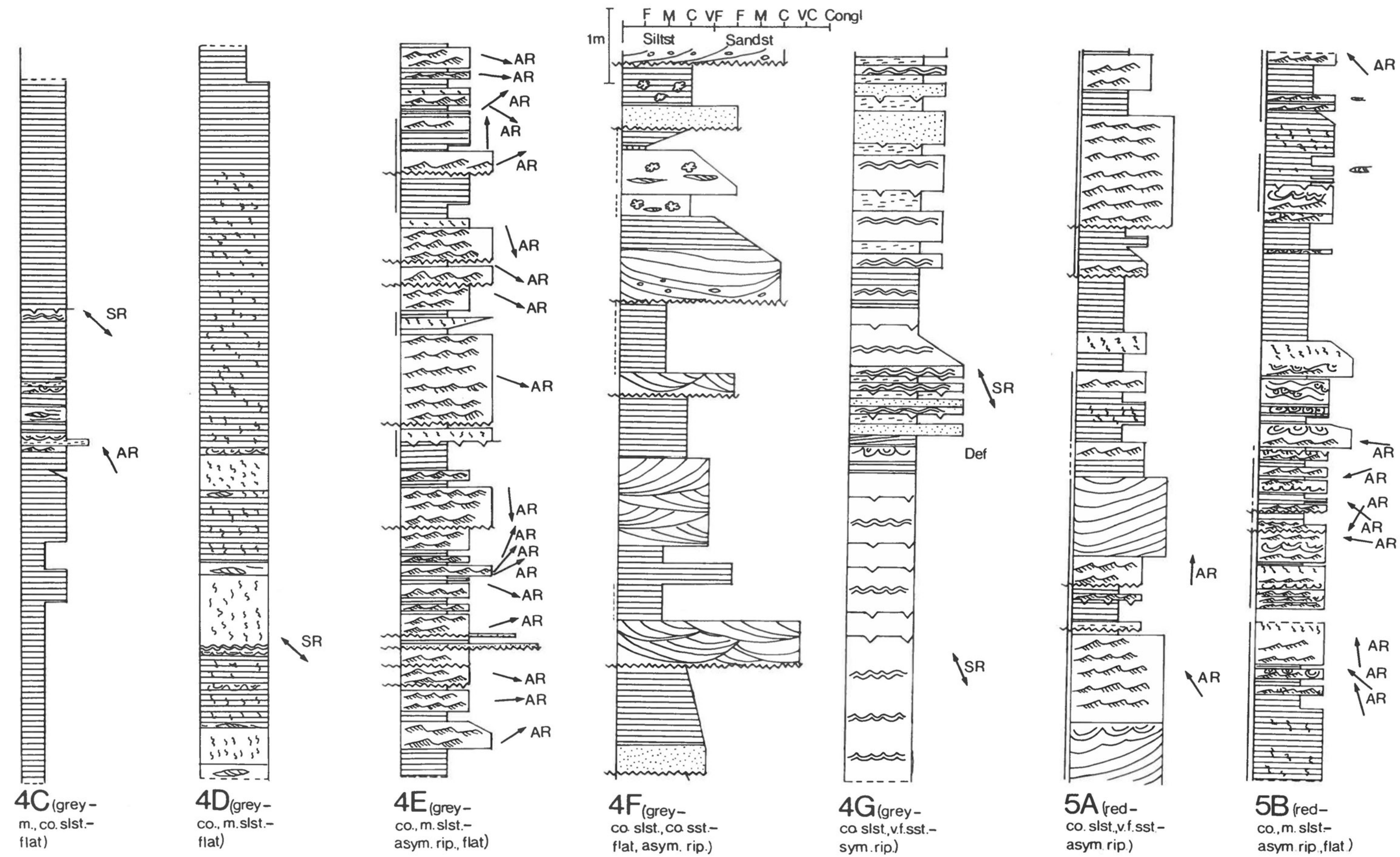


Fig. 6. Typical 10 m sample assigned to each sample group of the classification (see Fig. 3 and 4).

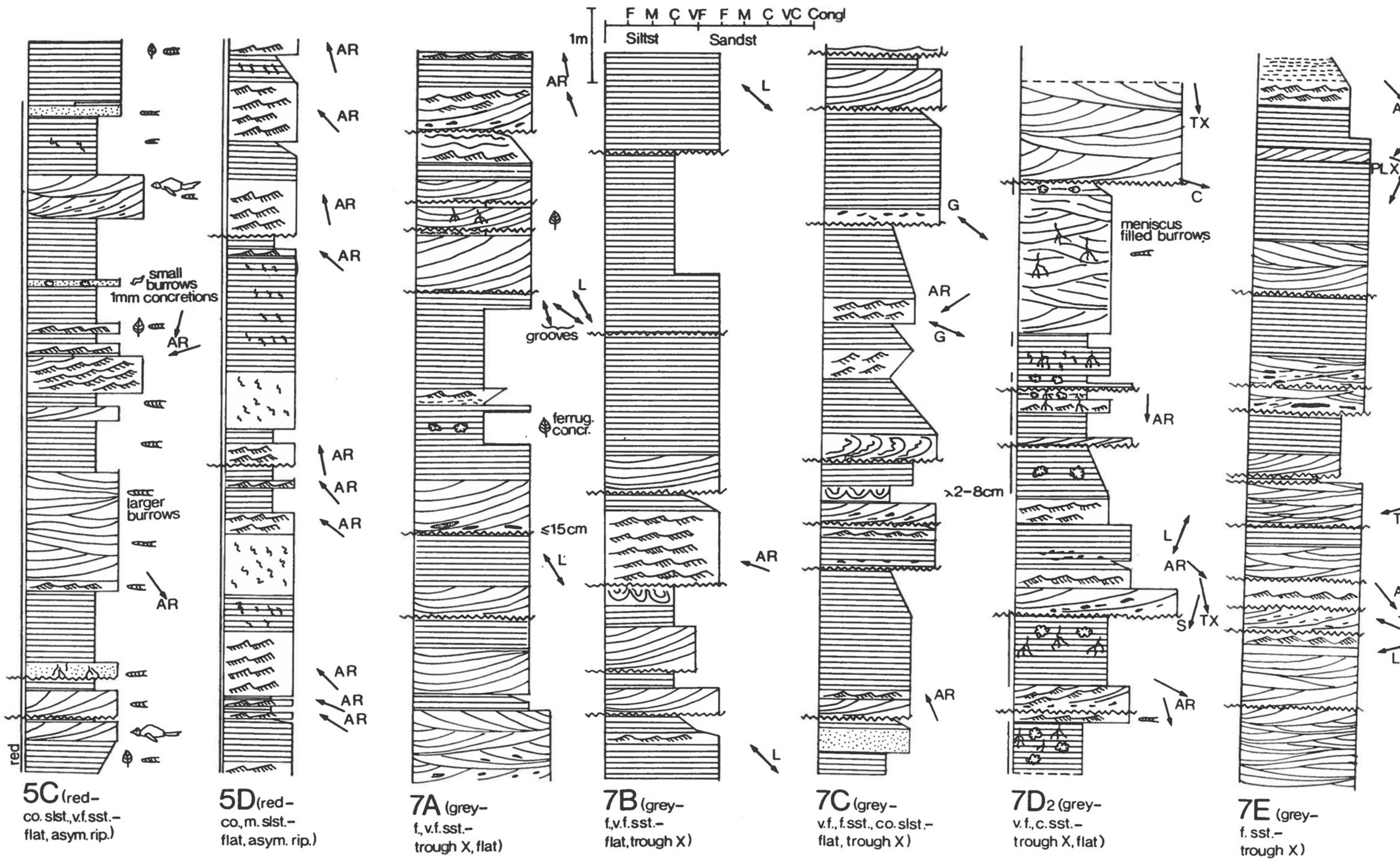


Fig. 7. Typical 10 m sample assigned to each sample group of the classification (see Fig. 3 and 4).

THE KAP FRANKLIN AREA

Stratigraphic Outline of the Area

The Devonian succession in the Kap Franklin area, following BÜTLER (1954), comprises three primary mappable units: the dominantly silty Vilddal Group, followed unconformably by the Kap Franklin Formation (mainly volcanics) and the Randbøl Formation (mainly sandstones and conglomerates). There are also small exposures of rocks referable to the Kap Graah Group and Mount Celsius Supergroup in the Margrethedal area (See Table 1 and map, Fig. 8).

Table 1. *Stratigraphic Outline Kap Franklin Area.*

Major unit	Age	Estimated thickness (m)
Mt. Celsius Supergroup } Kap Graah Group }	Upper Devonian	100?
Randbøl Formation	Middle Devonian	up to 900
Kap Franklin Formation	– –	up to 1250 (aggregate)
Vilddal Group	Middle Devonian (base not seen)	1350

Review of age

The Vilddal Group (Fig. 1) has yielded *Gyroptychius groenlandicus* JARVIK, and other small osteolepid and *Glyptolepis*-like fossils referred to the Upper Middle Devonian (Givetian) (JARVIK, 1950b). The Kap Franklin Formation contains only unidentifiable plant fragments, but the Randbøl Formation contains Coccosteomorph arthrodires, *Asterolepis säve-soderberghi* STENSIÖ, and small osteolepids and *Glyptolepis* (BÜTLER, 1954, p. 113), also referred to the Middle Devonian. Further west in Gauss Halvø and in Ymer Ø, the Kap Graah Group and Mt. Celsius Supergroup contain some of the classic Upper Devonian vertebrate faunas (BÜTLER, 1959; SÄVE-SÖDERBERGH, 1934).

Vilddal Group

This group may be divided into three parts (Table 2, map Fig. 9).

Table 2. *Vilddal Group Subdivisions.*

Unit	Estimated thickness (m)
Vilddal Red-and-green banded Siltstone Formation	750
Vilddal Grey Siltstone Formation	400
Vilddal Pebbly Sandstone-and-siltstone Formation	200

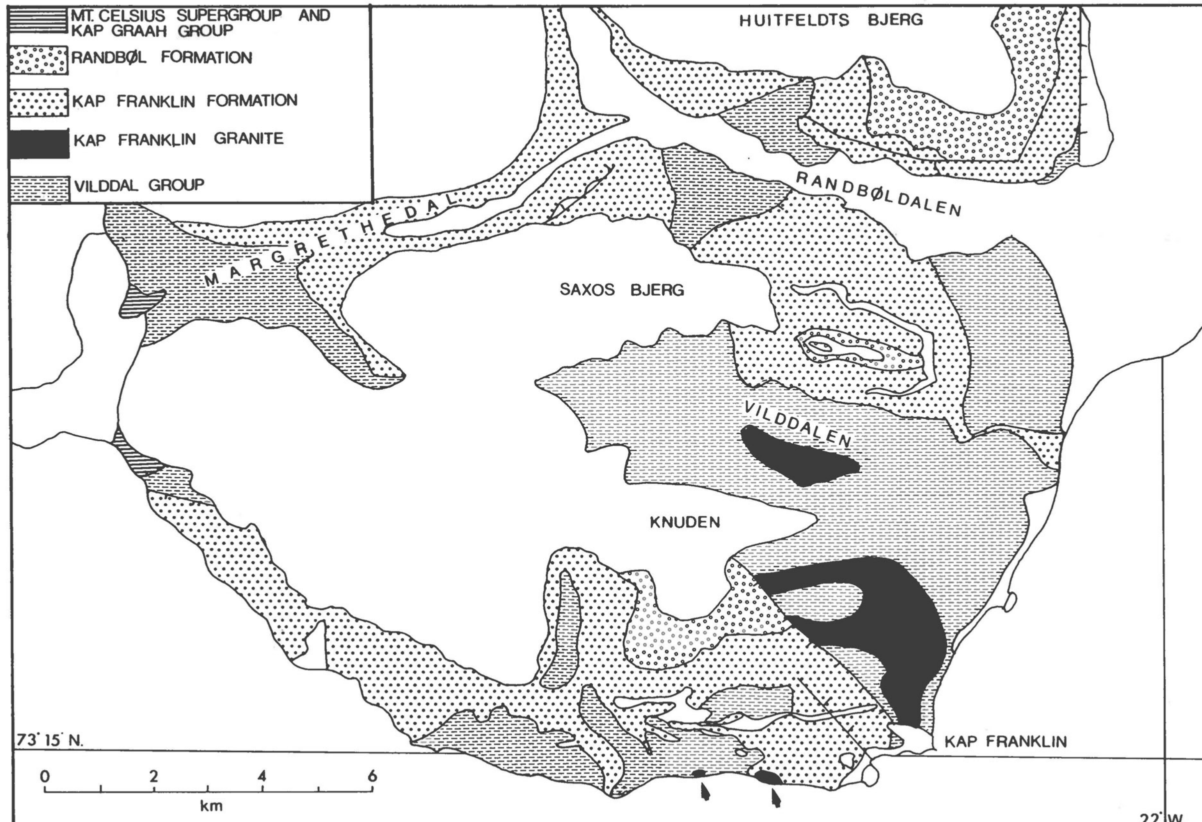


Fig. 8. Devonian geology of the Kap Franklin area (modified after Bütler, 1954. Pl. 6).

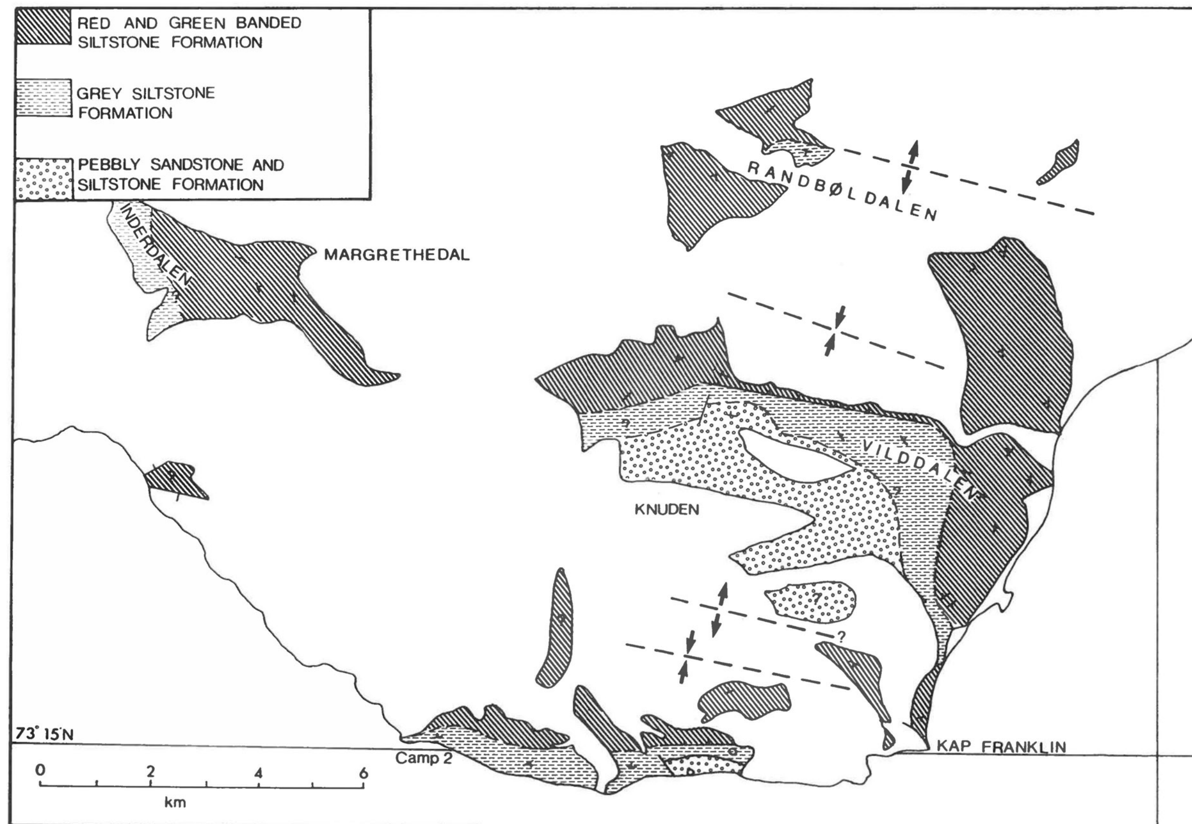


Fig. 9. Vilddal Group: Stratigraphic subdivisions, and pre-Kap Franklin Formation fold axes.

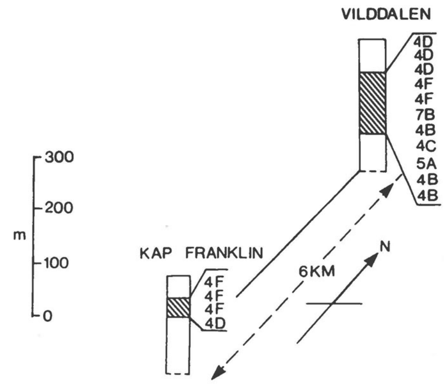


Fig. 10. Vilddal Pebbly Sandstone-and-siltstone Formation, stratigraphic distribution of sample groups.

Vilddal Pebbly Sandstone-and-siltstone Formation

This lowest division is exposed only in middle Vilddalen and along the coast south of Knuden (Fig. 9). It is characterised by an alternation of pale grey coarse and medium pebbly sandstones with darker grey-green and red flatbedded siltstones, often containing carbonate concretions, on a scale much less than 10 metres (sample-group 4F, grey-co. slst., co. sst.-flat, asym. rip.; 4D, grey-co., m. slst.-flat) (Fig. 10). Extraclasts in the sandstones, up to 6 cm in diameter, consist dominantly of grey and black limestones and quartzites derived from Cambro-Ordovician and Eleonore Bay Group rocks but local conglomerate sets also contain a few grey or greenish granitic clasts, and clasts of highly altered dark grey siliceous volcanic rocks.

The sandstones are petrologically peculiar in being composed largely (70 to 80 %) of carbonate grains. The base of the Vilddal Group is not exposed in the Kap Franklin area; the lowest horizons exposed in Vilddalen below the pebbly sandstones comprise 50 metres of grey siltstones resembling the middle division of the group. Palaeocurrents in this lowest formation trend eastwards (Fig. 11).

Vilddal Grey Siltstone Formation

Sandstone and large-scale cross-stratification are absent in this middle division, and small-scale cross-stratification due to current ripples is rare, but lenticular bedding is abundant. There is an overall upwards decrease in grainsize from coarse flat-bedded siltstones (4D, grey-co., m. slst.-flat) through coarse lenticular-bedded siltstones (4B, grey-co., m. slst.-lent., flat) into flat-bedded medium- and fine-grained siltstones (4C, grey-m., co. slst.-flat), though the grain size variation is actually cyclic on a scale of ca. 20 metres. This is visible in the field and

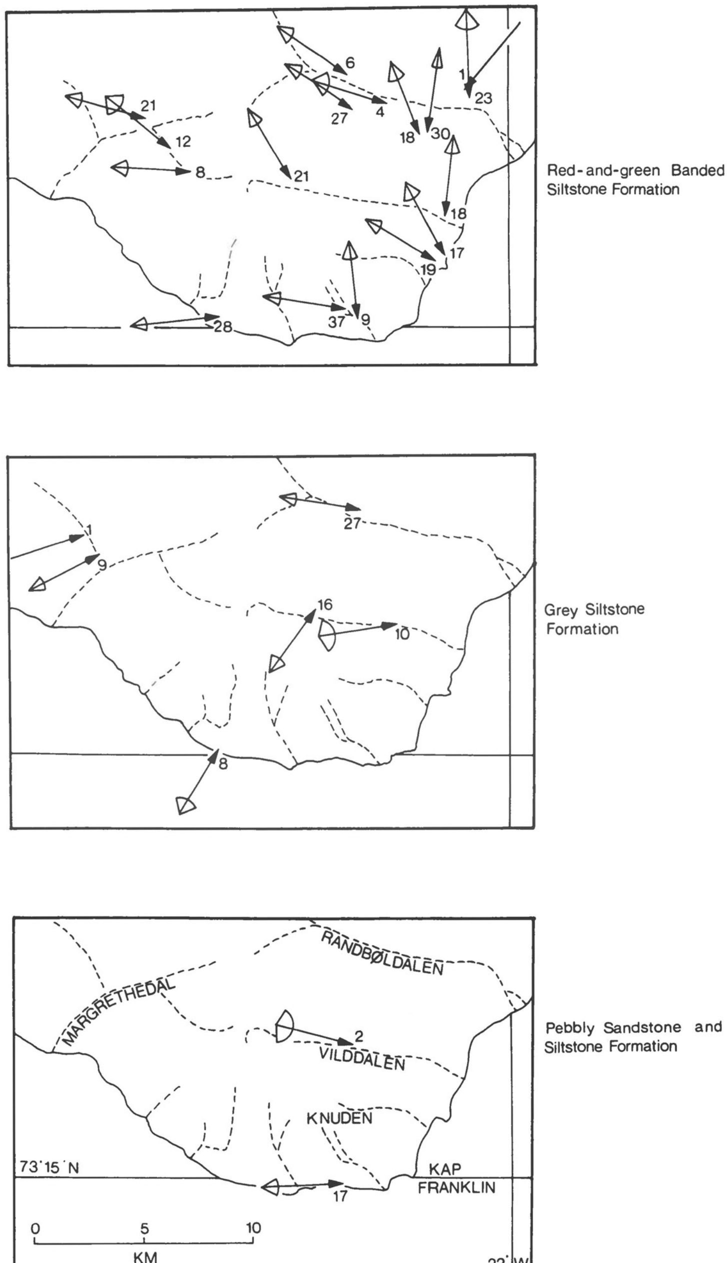


Fig. 11. Vilddal Group palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

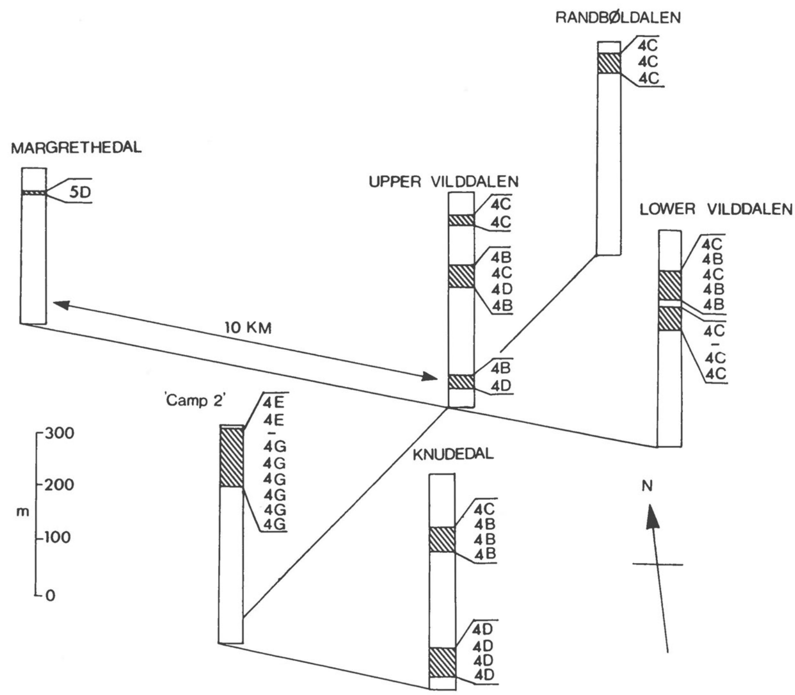


Fig. 12. Vilddal Grey Siltstone Formation, stratigraphic distribution of sample groups.

on aerial photographs as a succession of bluffs (coarser siltstone) alternating with weathered-out terraces (finer siltstone). The successions in the north and east are also finer grained (Fig. 12, 13), and black silty shales are encountered in lower Vilddalen. To the southwest, a section was recorded in grey very fine sandstones and coarse siltstones with symmetrical ripples and mudcracks (sample group 4G, grey-co. slst., v.f. sst.-sym. rip.) at the top of the formation. Vertebrate fragments are not as abundant as in the overlying formation: we have not found any referable to *Gyroptychius groenlandicus*, and Bütler (1954, p. 67) lists only the following fossils: osteolepids, crossopterygian teeth, *Glyptolepis*-like fragments, *Estheria* and plant remains. Palaeocurrents (Fig. 11) indicate flow mainly to the northeast, though suitable structures are rare in many sections.

Vilddal Red-and-green-banded Siltstone Formation

This upper division marks the return of deposition of more fluvial aspect. Channel-shaped units of very fine sandstone and coarse siltstone, and small-scale cross-stratified units referable to current ripple marks are common. Coarser sandstones and extraclasts are very rare, but sequences of flat-bedded pale-weathering black fine and medium shaly

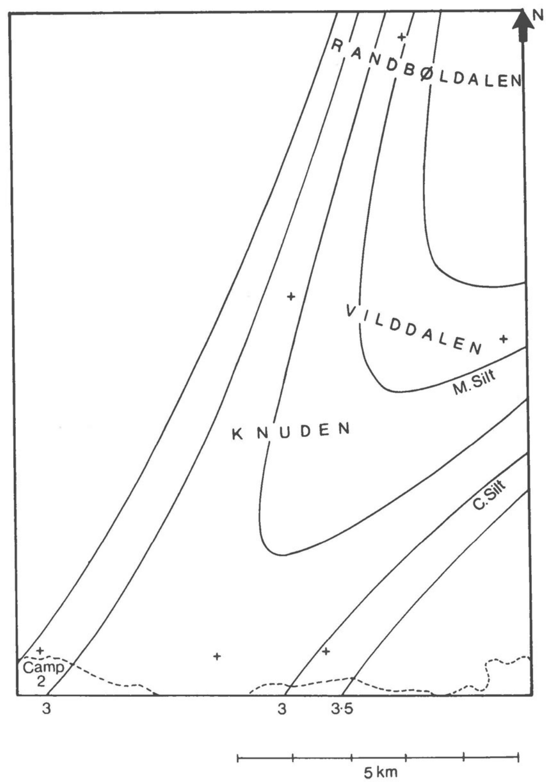


Fig. 13. Contoured quadratic trend surface, section mean grain size. Vilddal Grey Siltstone Formation.

siltstones are common in some of the green bands, often associated with vertebrate fragments and sometimes plant remains. In almost every case, the small crossopterygian *Gyroptychius groenlandicus* JARVIK was identified from its diamond-shaped body scales and distinctive fronto-ethmoidal shield, and it appears from BÜTLER's (1954, pp. 29, 33, 58, 67, 84) records that this species is restricted to this formation. In contrast to the Pebbly Sandstone-and-siltstone Formation, the sandstone consists of the more usual quartz-feldspar-mica assemblages.

The gross colour banding is on a scale of 10 to 30 metres. Red bands vary in sample group (5A, red-co. slst., v.f. sst.-asym. rip.; 5B, red-co., m.slst.-asym. rip., flat; 5D, red-co., m. slst.-flat, asym. rip), and green bands can contain both sample group 4E (grey-co., m. slst.-asym. rip., flat) and 4C (grey-m. co. slst.-flat) (Fig. 14). The latter differs from examples of 4C (grey-m., co. slst.-flat) in the underlying formation in that lenticular-bedding is normally absent, the siltstone may be rather calcareous, and chert concretions occur in examples from Randbøldalen. One 10 metre unit near the base of the formation proved to be transitional in character between sample group 4E (grey-co., m. slst.-

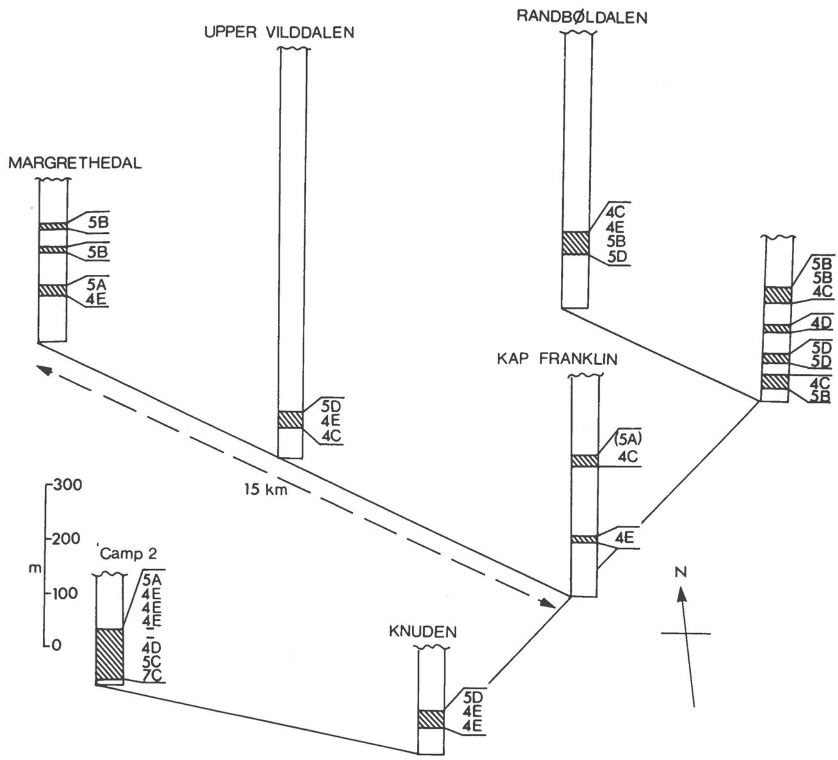


Fig. 14. Vilddal Red-and-green banded Siltstone Formation, stratigraphic distribution of sample groups.

asym. rip., flat) and 7C (grey-v. f., f. sst., co. slst.-flat, trough X) with the introduction of cross-stratified fine to very fine sandstone sets.

The overall palaeocurrent trend is strongly southeastwards, but the pattern tends to be somewhat centripetal, in that near the south coast the vectors are eastward-trending on average, while along the eastern edge southerly trends are noticeable (Fig. 11).

Kap Franklin Formation

Following BÜTLER (1954, pp. 41, 89), we can divide this formation into four members (Table 3), each of highly variable thickness (Figs 15, 16). The base of the Kap Franklin Formation is unconformable on various stratigraphic levels in the Vilddal Group, and also, on the coast 3 km west of Kap Franklin itself, on outlying exposures of the Kap Franklin Granite.

Kap Franklin Granite, part 1

This pluton, at least 7 km in diameter, consists largely of a coarsely crystalline adamellite, but also includes aplites and pegmatites (GRAETER,

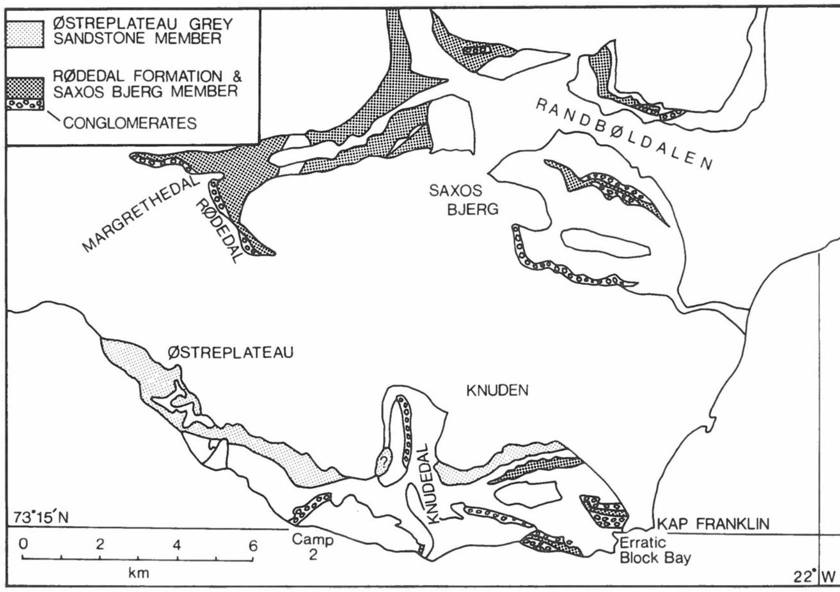


Fig. 15. Geological map of the sedimentary subdivisions of the Kap Kolthoff Supergroup near Kap Franklin and in Margrethedal. The term conglomerate includes sediments locally described as breccias.

1957). It is demonstrably intrusive into the lower levels of the Vilddal Group: veins of 'granite' are present in rather baked Vilddal siltstone country rock, for example, at the coastal localities (Fig. 8). Conglomerate of the Kap Franklin Formation here rests unconformably on the granite and locally contains clasts of the granite. The granite is therefore younger than the Vilddal Group, which contains Middle Devonian vertebrates, but older than the Kap Franklin Formation, which is in turn older than

Table 3. *Kap Franklin Formation Subvisions.*

Unit	Estimated Stratigraphic thickness (m)				
	S. Østre-plateau	S. Knu-den	S. Saxos Bjerg	NE. Sa-xos Bjerg	Huit-feldts Bjerg
Østreplateau Grey Sandstone Member	350	120	–	–	–
Upper Volcanic Member	100?	130	250	350	60
Saxos Bjerg Member II	3	18	10	40	35
Saxos Bjerg Member I	–	60	13	150	85
Lower Volcanic Member	–	70	–	360	at least 80

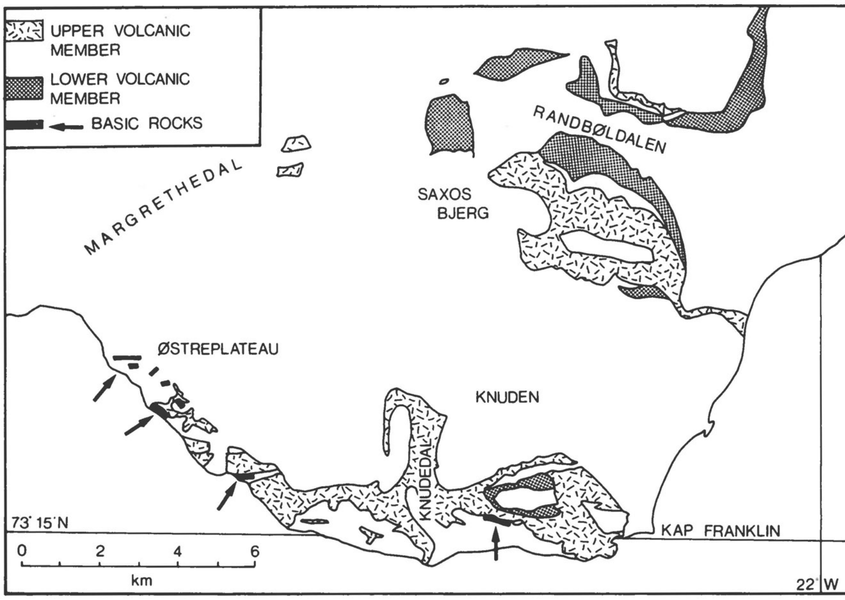


Fig. 16. Geological map of the volcanic sub-divisions of the Kap Franklin Formation near Kap Franklin, and the Rødedal Formation near Margrethedal.

the Middle Devonian Randbøl Formation. The granite was therefore emplaced, exposed to erosion, and buried again during Middle Devonian times, as Bütler (1954, p. 116) rightly argued.

The Kap Franklin Granite is thus a remarkably good example of a stratigraphically dated pluton. Haller & Kulp (1962) obtained a K/Ar radiometric age of 393 ± 10 m.y. from biotites extracted from a sample of the granite. Friend & House (1964), however, in attempting to correlate stratigraphic and radiometric time-scales in the Devonian system, pointed to the discrepancy between the Middle Devonian stratigraphic age and the apparently Lower Devonian radiometric age. A number of specimens of the granite were collected by us in 1968. Seven of these were analysed for whole-rock Rb/Sr isotope content, but proved too highly altered to give a meaningful date (Dr. I. R. Pringle, personal communication, 1970).

Further geological observations on the Kap Franklin Granite are considered later in this paper, in the light of stratigraphic relations in the lower part of the Kap Franklin Formation, as follows:-

Lower Volcanic Member

This attains a maximum thickness of 360 m on NE Saxos Bjerg, is 70 m thick south of Knuden, and is completely absent on the south side of Saxos Bjerg. Most of this member consists of massive red or

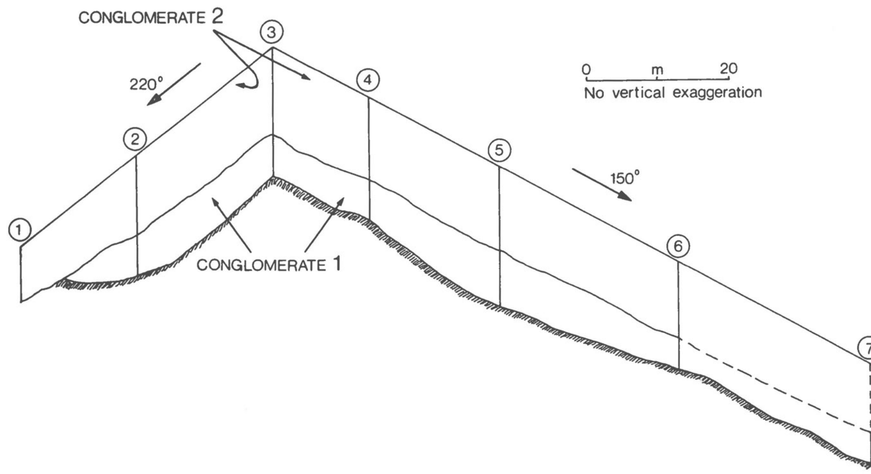


Fig. 17. Isometric ribbon diagram of conglomerate relations at locality (A042) on S. Saxos Bjerg. Seven numbered profiiles were measured at the two sides of a small valley. The two sides trend at 70° to each other.

purplish-brown felsite, with large phenocrysts of quartz (maximum 4.0 ± 1.1 mm) and sanidine (5.6 ± 1.2 mm). GRAETER (1957, p. 53) thought that some of these rocks were intrusive in origin. Some pink-grey rhyolite in Randbøldalen also shows delicate flow-banding in places.

Saxos Bjerg Member

This member, consisting of conglomerates, sandstones and red siltstones, is recognisable in various localities by the absence of products of contemporaneous volcanism. There are no pyroclastics or lavas, the conglomerates contain clasts of the underlying rhyolite, granite and Vilddal siltstones, and the sandstones and siltstones consist of the usual quartz-feldspar/mica assemblages, entirely terrigenous in origin. The member attains a maximum thickness of ca. 200 m on NE Saxos Bjerg, and is absent in large areas around Knudedal, for example.

In order to investigate their conditions of deposition, a special study was made of two conglomerates, 6 and 10 m thick at the base of the Saxos Bjerg Member on the south side of Saxos Bjerg. In these conglomerates many of the clasts are angular enough to make breccia an apt term for the rocks. Thickness relations, lateral extent and distribution of sections at each locality are shown in Fig. 17. The substrate consists entirely of siltstone.

A study of clast size was first made. In fig. 18, histograms illustrate the frequency of occurrence of mean maximum clast sizes for each of the two clast types present (rhyolite, siltstone) in each conglomerate. The distributions are approximately log-normal. Some statistics are given in Table 4. The largest rhyolite clasts are on average larger than the largest

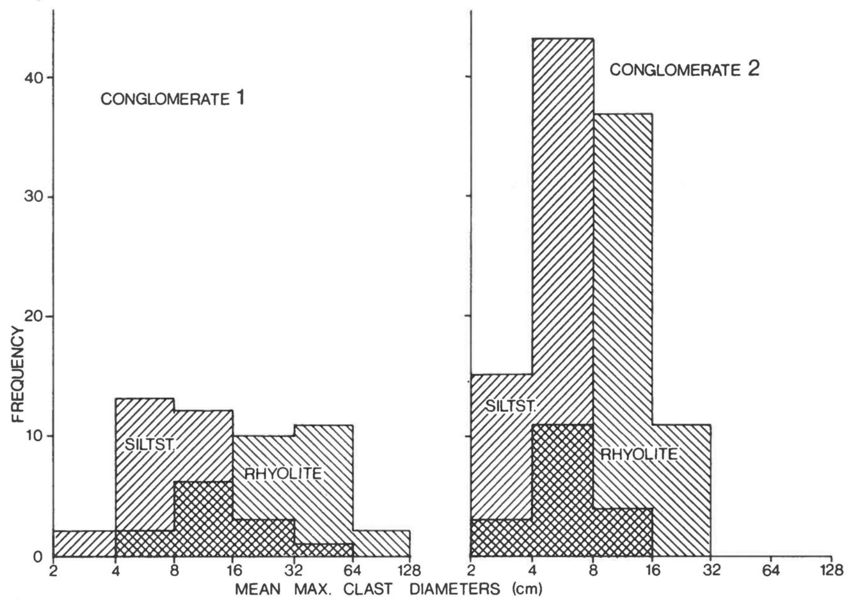


Fig. 18. Histograms of maximum clast size in conglomerates at locality (A042) on S. Saxos Bjerg.

siltstone clasts in both conglomerates; Student's "t" statistic calculated between clast types indicates significant difference at the 95 % confidence level. In Fig. 19, mean maximum clast size of rhyolite is plotted against that of siltstone clasts occurring in the same set. Reduced major axis regression lines (Miller & Kahn, 1962, p. 204) were calculated for each conglomerate, relating log mean maximum clast size of rhyolite to siltstone. The correlations are significant at the 95 % level; moreover the slopes of the two regression lines are not significantly different at this level. This indicates (a) that maximum clast sizes of each type are proportionally related, (b) that siltstone clast size declines at a lesser rate than that of coexisting rhyolite clasts, and (c) the relationship is probably the same in both conglomerates.

Four factors appear to influence clast size in a deposit: (a) the way in which a particular source rock breaks up to form the detrital starting

Table 4.

	Mean Max Clast data			(AO42)			(cm)
Conglomerate	Clast	Mean	Log-mean	Log SD	Min	Max	No.
1 (lower)	Rhyolite	25	3.23	0.67	6	78	31
–	Siltstone	9	2.19	0.54	3	44	31
2 (upper)	Rhyolite	11	2.38	0.43	4	27	62
–	Siltstone	5	1.68	0.30	3	11	62

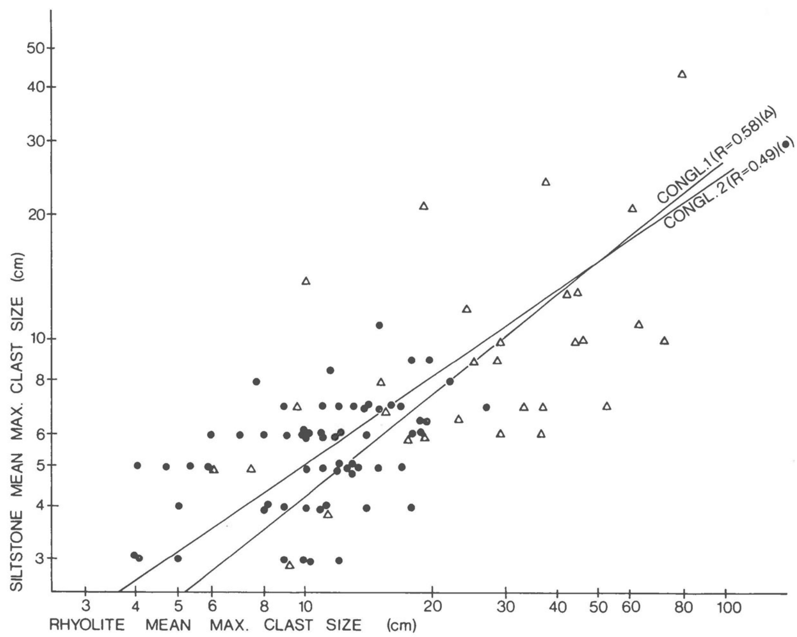


Fig. 19. Comparison of sizes of co-existing clasts of rhyolite and siltstone in Conglomerate 1 (Triangles), and Conglomerate 2 (dots) at locality (A042) on S. Saxos Bjerg.

material for stream and flood transport; (b) the rate of disintegration of a particular clast type during transport away from source; (c) the effect of clast shape on its ability to be transported by flows of varying power, and hence the distance from source area travelled before deposition; (d) post-depositional in-situ shattering; there is no evidence of the latter in this case, except at the unconformity between the two conglomerates.

A more distant source area for siltstone clasts than for rhyolite can be ruled out, as the substrate consists locally of siltstone. The size relationship can therefore be explained by siltstone clasts being smaller initially in the source area. Rhyolite clasts, larger to start off with, may have disintegrated more rapidly than siltstone during transport. Alternatively, the dominantly disc-shaped (ZINGG, 1935) siltstone clasts may have been more likely to move by saltation (or, for pebble sizes, in suspension) as suggested by BLUCK (1965) for small alluvial gravel fan deposits of Triassic age; the siltstone clasts would then have a greater transport rate than the more spherical rhyolite clasts of equivalent mass.

The mean maximum clast sizes for rhyolite and siltstone are significantly larger in conglomerate 1 than the corresponding means in conglomerate 2 (Table 4) confirming impressions gained in the field. The lower conglomerate therefore accumulated nearer its source area than the upper one.

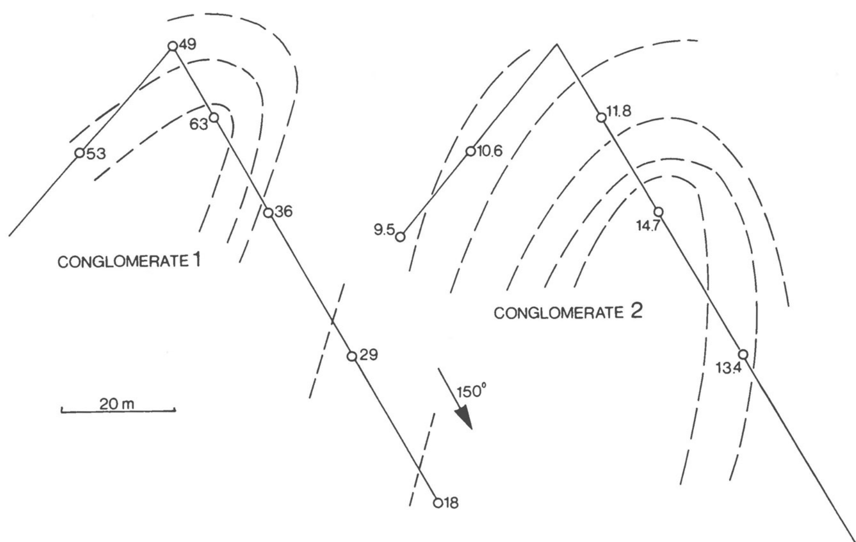


Fig. 20. Hand-drawn contour maps showing maximum rhyolite clast size (cm), averaged for each section, at locality (A042) on S. Saxos Bjerg.

Maximum clast sizes for rhyolite do not show any overall systematic variation vertically within the sections through each Conglomerate. For comparison between sections, a section average maximum clast size for rhyolite was calculated as:

$$\text{Average} = \frac{\sum_{1}^{n} (\text{mean max clast size}_i \times \text{thickness}_i)}{\text{Total thickness of section}}, \text{ in cm}$$

where i is each recorded set within the section. The resultant numbers were contoured by hand (Fig. 20). Several different patterns could be superimposed, the ambiguity resulting from the lack of three dimensional exposure. A fan-pattern for both conglomerates with an axis trending approximately 030° (true) is more probable than one trending 270° (true) because (a) the surface of the lower unconformity appears to rise up as a gentle valley side on the west side of the exposure (Fig. 17) and (b) two current ripple azimuths in sand lenses in the upper conglomerate give a vector mean azimuth of 035° (true). The axes of the two fans are displaced laterally by about 15 metres. The contours on conglomerate 2 are more widely spaced than on conglomerate 1, as one would expect if clast size decreases logarithmically away from source area (Blissenbach, 1954).

The textural characteristics and fan-shaped isopleth pattern together support Bütler's (1954, p. 111) interpretation of the Kap Franklin

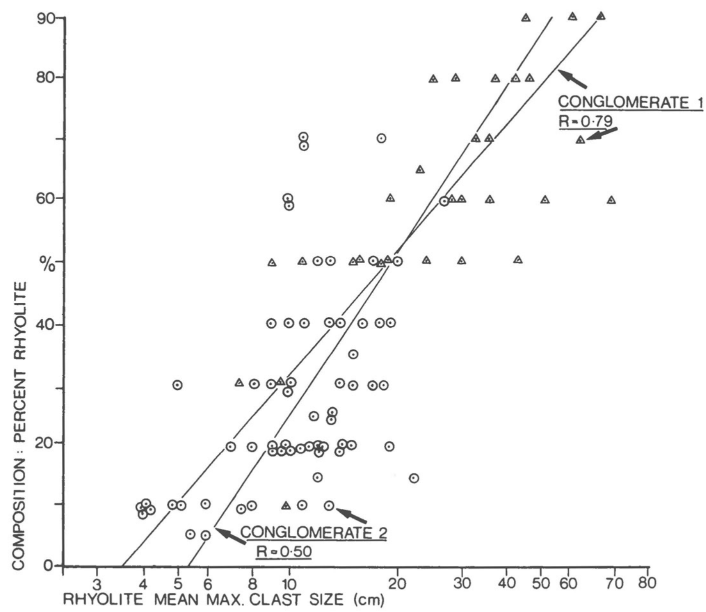


Fig. 21. Comparison of conglomerate composition and maximum rhyolite clast size, at locality (A042), S. Saxos Bjerg.

conglomerates as alluvial fan deposits. The high rate of decline in clast size suggests that these fans were small (ECKIS, 1928) compared with the recent fan described from Nevada by BLUCK (1964) (radius 5 km). Indeed, extrapolation downfan to the 1 cm isopleth suggests a fan length between 300 and 600 m, comparable with the Triassic examples (BLUCK, 1965) from South Wales.

In Fig. 21, composition is plotted against log maximum clast size for rhyolite in each of the two conglomerates. Reduced major axis regression lines yielded correlation coefficients significantly different from zero at the 95 $^{0}/_{0}$ level; the slopes of the two regression lines also appear significantly different at this level. This relationship cannot be wholly explained by operator bias to size in estimating composition but is precisely the relation one would expect from the size variation between clast types described: the larger the rhyolite clasts, the greater the proportion of volume of rock which they constitute. The mean compositions of each conglomerate are significantly different, as we would expect from the clast size differences. There is no systematic variation of composition vertically within sections. Lateral variation was approached along the same lines as clast size. In each conglomerate there is an overall trend for rhyolite percentage to diminish eastwards. This is consistent with clast size variation on a north easterly trending fan, but because the composition change is oblique or perpendicular to the fan

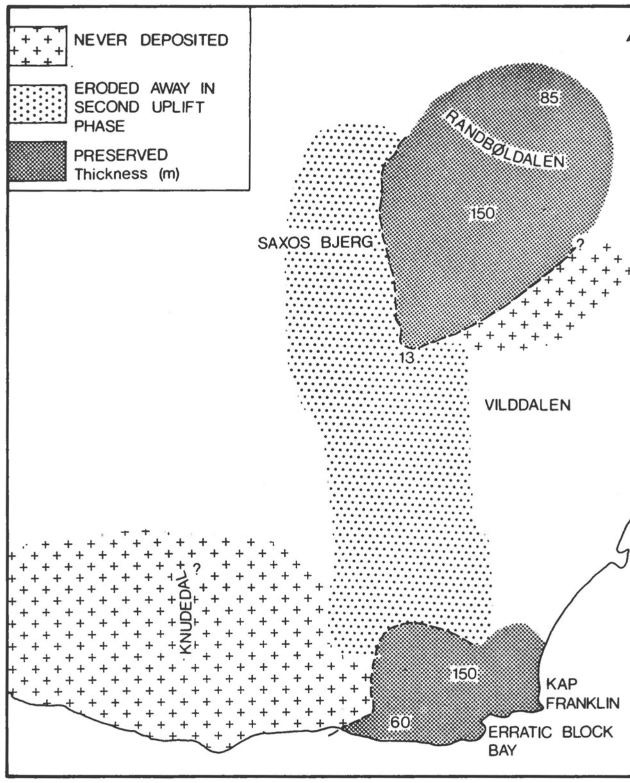


Fig. 22. Distribution of lower Conglomerate, Saxos Bjerg Member, Kap Franklin area.

axis, other factors must be involved. The depositional loci on modern alluvial fans, termed 'washes' in the U.S.A. (BULL, 1964; DENNY, 1965), are longitudinal features elongate along radii of the fans. Given an inhomogeneous source area distribution of lithologies, more rhyolite could have been transported along one side of the fan than on the other. BÜTLER (1954, pp. 41–42) also recorded this compositional trend in the Kap Franklin conglomerates.

We conclude that these conglomerates were deposits of small-scale alluvial fans. Pebbly siltstones and sandstones, possibly deposited as mudflows, form only a small proportion of the sequence: most of the conglomerate was probably deposited by relatively channelled stream floods, which diminished in power downfan, perhaps by seepage of water into the sediment surface, with consequent decrease in depth of flow. Locally along the unconformity between the two conglomerates, a thin zone occurs in which the clasts appear to have been shattered in situ: this may represent part of a 'desert pavement' (DENNY, 1965).

We shall now return to our consideration of various stratigraphical

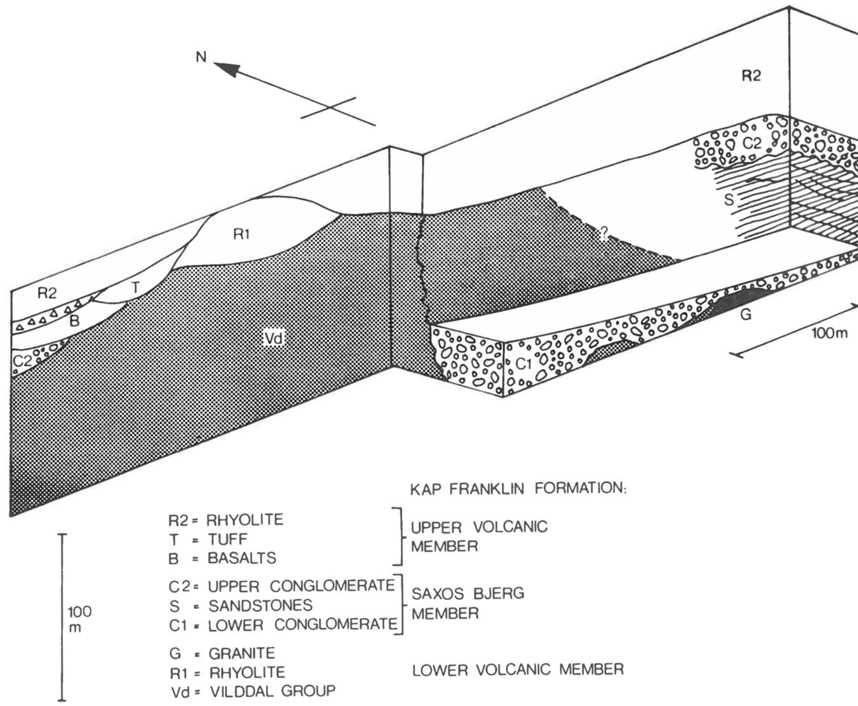


Fig. 23. Diagram showing stratigraphic relations, coast $3^1/_2$ km. W. of Kap Franklin.

points. In various localities one, or two, conglomerates may be present, ranging from 1 to 50 m in thickness. Where only one conglomerate is present, it normally rests unconformably on the underlying Vilddal Group and is immediately succeeded without important discontinuity by the Upper Volcanic Member. If the second onset of volcanism was more or less synchronous over the whole area, these single conglomerates must correlate with the upper horizon where two are present. In the latter case, the upper conglomerate rests on an erosion surface on the underlying sandstone, siltstone or conglomerate, often an angular unconformity. The areas in which this lower subdivision is preserved are shown in the map (Fig. 22). Its absence over a large part of this area can be attributed to (a) non-deposition, and (b) erosion.

On the south coast, south of Knuden, some $3^1/_2$ km west of Kap Franklin, the lower conglomerate, ca. 30 m thick, is banked unconformably against a steeply dipping erosion surface cut into the lower part of the Vilddal Group (Fig. 23). The strike of the unconformity is 060° (true) and palaeocurrent records from sandstone lenses in the conglomerate indicate stream flow eastwards, almost parallel to the unconformity. This is confirmed by the fact that the granite clasts are found in the breccia only to the east of the underlying granite outcrops: in a single

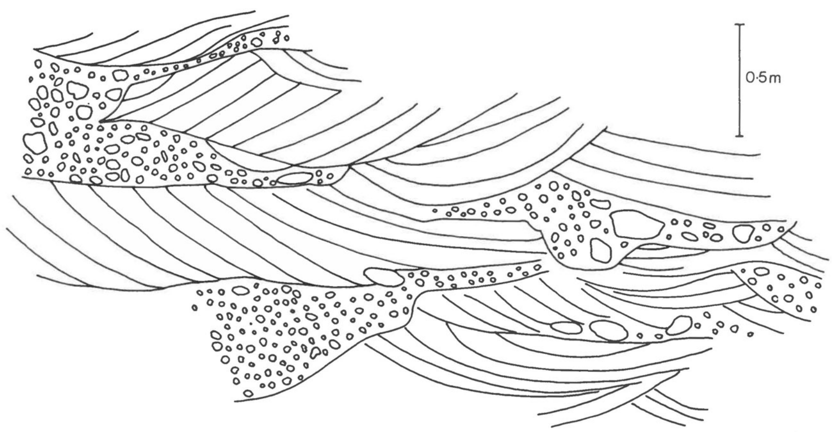


Fig. 24. Conglomerate-sandstone relations, Saxos Bjerg Member, $1^1/_2$ km W. of Kap Franklin.

layer of conglomerate 2 m thick, the maximum granite clast size also diminishes from 33 cm to 8 cm within 30 m eastwards. This and the angularity of the clasts are similar to the characteristics of conglomerates already described from this member on south Saxos Bjerg. In this case a small alluvial gravel fan appears to have infilled a valley with a source area to the west. The main clast constituents of the conglomerate-siltstone and rhyolite with typically large quartz and feldspar phenocrysts, can be seen in situ a little further west, overlapped on both sides by the Upper Volcanic Member (Fig. 23).

The 40 metres of grey planar cross-stratified medium sandstones (3D, grey-m. co. sst.-trough X) which overlie the lower conglomerate further east, indicate currents flowing to the north-west, oblique to the axis of the underlying gravel fan. The two systems can be seen to interfinger in exposures $1^1/_2$ km west of Kap Franklin at the back of "Erratic Block Bay" (name from Bütler, 1954, Plate 9), but the sandy stream appears to have been unable to transport the available gravel, for there is little mixing (Fig. 24).

The base of the upper conglomerate here scours down through the underlying sandstones northwards, at a rate of 20 m in 500 m laterally. Poor exposures of red flat-bedded very fine sandstones and cross-stratified fine sandstones at 340 m altitude on the south slope of Knuden probably represent the upper subdivision of the Saxos Bjerg Member. On NE Saxos Bjerg, the lower division comprises 50 m of rhyolite-rich conglomerate, followed by 100 m of reddish very fine sandstones and siltstones in which mudcracks are remarkably abundant. There is no sign of the northward continuation of the cross-stratified sandstones of Kap Franklin, unless it is as 10 m of grey fine sandstones (7A, grey-f.,

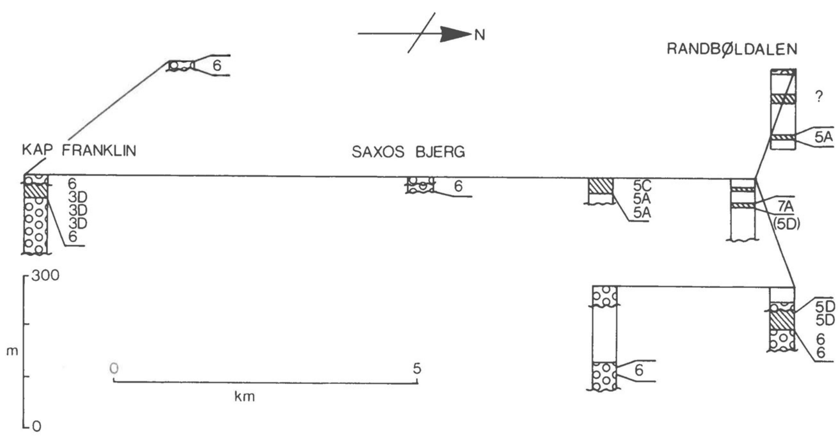


Fig. 25. Saxos Bjerg Member of Kap Franklin Formation, stratigraphic distribution of sample groups.

v.f. sst.-trough X, flat) on Huitfeldts Bjerg (Fig. 25). The sandy stream seems to have emerged onto a silty floodplain (Sample group 5A, red-co. slst. v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.), as described from the northern Sahara by WILLIAMS (1970). The falling-stage modifications of foresets (mud-cracks, symmetrical ripple marks) (cf. COLLINSON, 1970) in the sandstones at Kap Franklin are perhaps consistent with large seasonal changes in discharge.

To summarise, the palaeogeography during deposition of the lower subdivision of the Saxos Bjerg Member was probably as follows: an area of non-deposition or erosion existed to the south-west of Knuden, flanked by a number of small alluvial gravel fans; a floodplain of silt deposition developed to the north, and drained northwards (Fig. 26), while relatively impersistent sandy streams entered from the south-east.

Fig. 27 indicates that the crustal movements responsible for the second unconformity are essentially represented by uplift localised in the area between Knuden and south Saxos Bjerg. The lower conglomerate and sand/siltstones dip away from this area on both sides and thicken away north and southwards. The thinnest section is found at 650 m altitude on south Saxos Bjerg where the horizontal upper conglomerate truncates the lower conglomerate nipping at 30° (Fig. 28). BÜTLER (1954, pp. 41–42, Fig. 8) appears to have visited the locality, but missed this second unconformity, probably because the gulley in which it is exposed was filled with a late snow patch (as in 1970).

A new generation of alluvial gravel fans was formed on the eroded surface, occupying small valleys at intervals as far west as "Camp 2", $3^1/_2$ km west of Knudedal. Maximum clast sizes are highly variable,

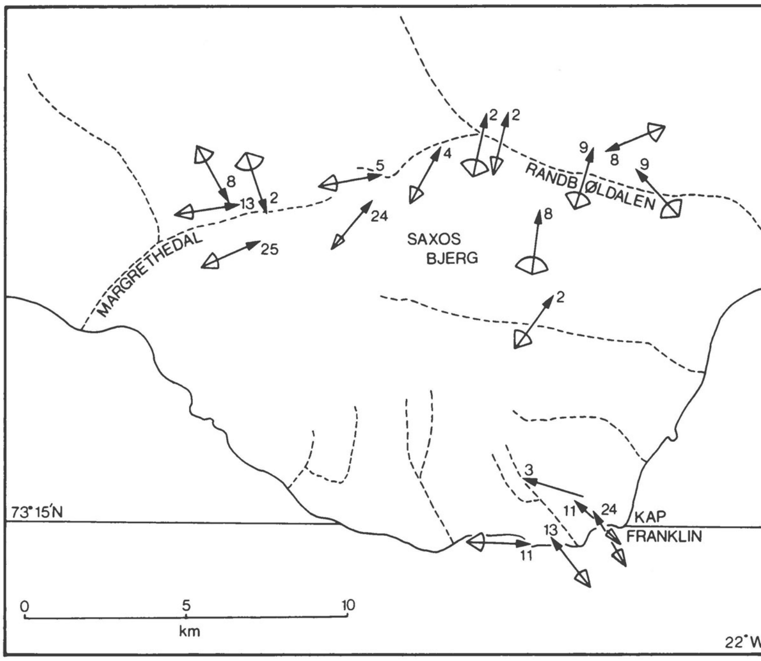


Fig. 26. Saxos Bjerg Member (Kap Franklin Formation) and the Rødedal Formation palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

from 100 cm on the south coast to 1 cm on Huitfeldts Bjerg, where this phase is marked by the influx of coarse pink arkosic sandstone derived from granitic sources to the east. Elsewhere the upper conglomerate consists of varying proportions of rhyolite and siltstone clasts, reflecting local differences in the constitution of the source areas.

Kap Franklin Granite, part 2

The known outcrop limits of the granite are shown on Fig. 27 and correspond approximately with the locus of uplift described above.

In the section on South Saxos Bjerg (Alt 630 m), 1 km due north of the northern margin of the granite exposed in Vilddalen, the upper Vilddal siltstones beneath the two conglomerates are folded into a series of concentric folds. Wavelengths range from 1 to 20 m, and fold axes plunge northwards (Fig. 29A). On the eastern margin of the granite, on the coast ca. 1 km north of Kap Franklin, similar structures were encountered in the Vilddal country rock, fold axes plunging northeast (Fig. 29C). A Fortran program modified after Fox (1967) was used to calculate three-dimensional vector mean plunges for the two localities (Table 5).

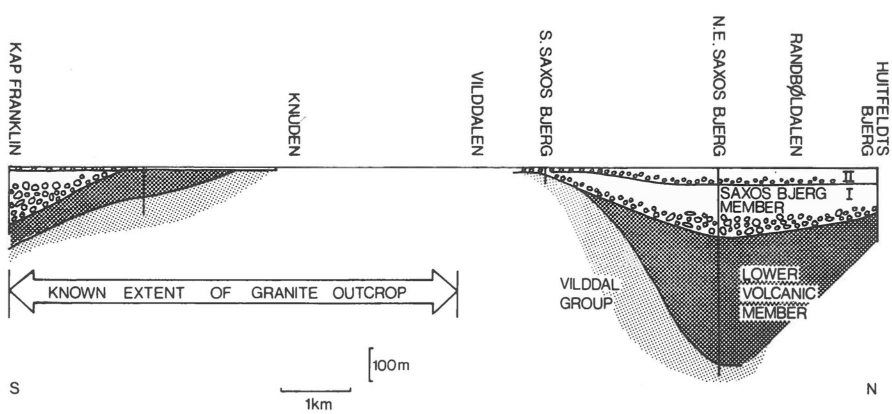


Fig. 27. Reconstructed cross-section, showing stratigraphic relationships before second Kap Franklin phase.

Table 5. *Small fold axes around margin of Kap Franklin Granite.*

Locality	Vector Mean Azimuth	Vector Mean Plunge	95 % circle of confidence
Northern Margin...........	043°	29°	14°
Eastern Margin............	079°	24°	14°

The circles of confidence (STEINMETZ, 1962) indicate that the mean azimuths in the two localities are significantly different at the 95 % level, and the amount of plunge is significantly different from zero. The orientations of the folds therefore appear to be geometrically related to the margins of the granite, in each case plunging away from the granite. The plunges were probably caused by uplift of the granite.

In the Saxos Bjerg locality, the effect of rotating the lower Saxos Bjerg Conglomerate back to horizontal through 30° about an east-west axis is to change the mean plunge of the Vilddal folds to 2° (Fig. 29B), which is not significantly different from zero. The present fold orientation thus originated during the phase of uplift marked by the second unconformity: therefore this uplift was caused by upward movement of the granite. On the south coast, however, the granite had already been exposed to erosion when the lower conglomerate was being deposited. Therefore at least two phases of upward movement of granite are recorded, each associated with the Saxos Bjerg unconformities. The second phase may also have exposed the granite to erosion again locally, for granite clasts of this type do occur in the upper conglomerate $1^1/_2$ km north-west of Kap Franklin, and in a gully infill adjacent to a rhyolite feeder dyke near the exit of Knudedal.

The generation of local unconformities during pulses of upward

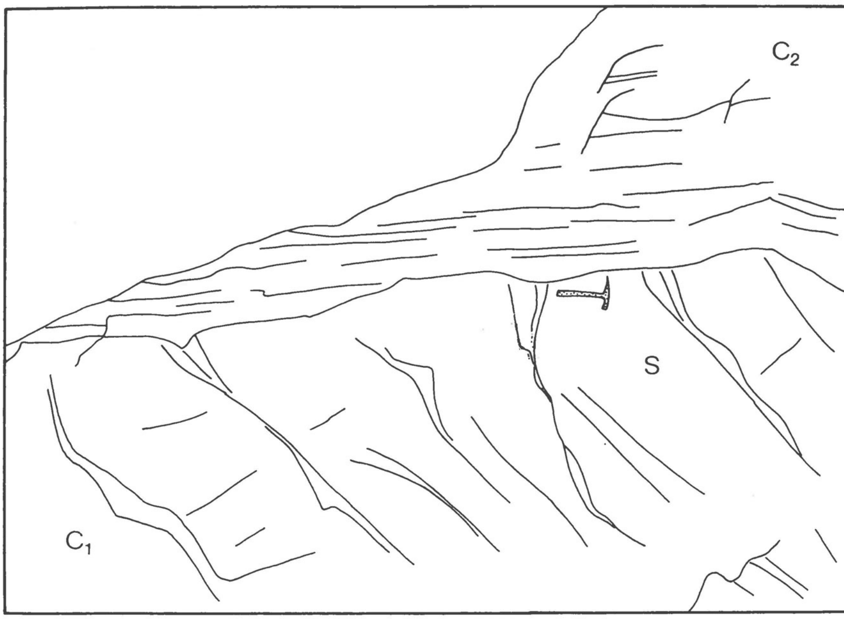


Fig. 28. Diagram (drawn from photograph showing second unconformity, Kap Franklin Saxos Bjerg Member at locality (A042) S. Saxos Bjerg. Hammer shaft 35 cm long. C_1, C_2 are conglomerates, S is siltstone.

movement is a well known characteristic of salt domes during diapiric growth, as, for example, in the Paradox Basin (ELSTON & LANDIS, 1960). A number of other features of the Kap Franklin Granite are worth mentioning in this context:

(a) There is no well developed metamorphic aureole. The only new minerals in the Vilddal siltstones near the margins are green chlorite and, rarely, (A104), small crystals of epidote. A number of carbonate rich lower Vilddal pebbly sandstones show diagenetic replacement of quartz and feldspar grains by carbonate, possibly associated with elevated temperatures in proximity to the granite. BÜTLER (1954, p. 58) found recognisable vertebrate fragments within a few metres of the contact. Thus much of the intrusion must have been relatively cool during emplacement.

(b) A large proportion of the granite mass as seen today appears messy and 'migmatitic' in texture due to the incorporation and partial assimilation of fragments of country rock. Most xenoliths have been sheared out and deformed to give an irregular foliation (Plate 1). Near the contact, the green Vilddal siltstone country rock locally contains stringers of coarse quartz and feldspar granules (Plate 2) sheared out of already solidified granite veins. One isolated outcrop, on the shore 4 km west of Kap Franklin (GRAETER, 1957, Fig. 10) consists entirely of this

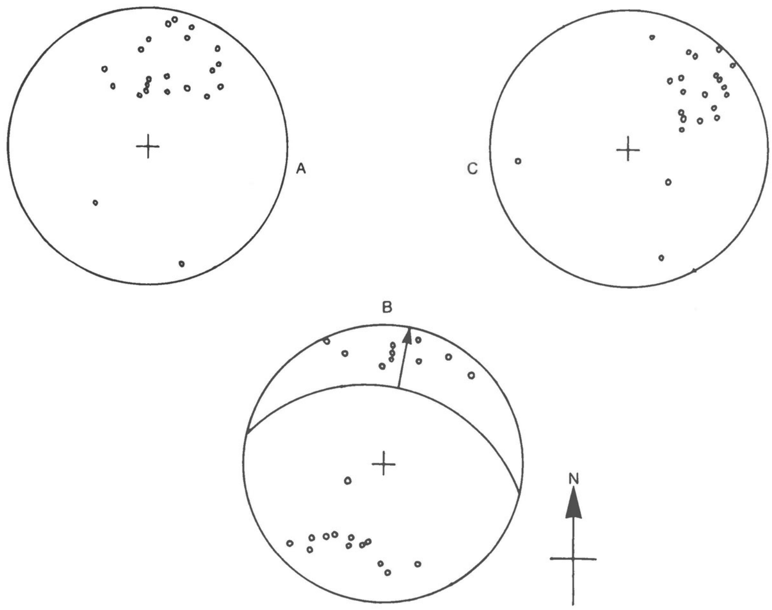


Fig. 29. Plunges of fold axes, Vilddal Group. A, northern margin of Kap Franklin Granite. B, effect on A of rotation to horizontal of lower Saxos Bjerg conglomerate. C, eastern margin of Kap Franklin Granite.

cataclastic mixture of granite and siltstone. Clearly, a large part of the movement occurred when at least the outer shell of the granite was almost completely solid. This is consistent with the second phase of movement, and agrees with GRAETER's (1957, p. 27) impression of intrusion in the form of a crystal 'mush' (Kristallbrei). The anomalous radiometric age cited above may perhaps be related to the complex history of movement and assimilation of country-rock at the margins. The inner core of the pluton is probably not exposed, as the granite was only just exposed to erosion in Middle Devonian times, and much of the Vilddal cover has not yet been removed by present-day erosion: only the outer part of the granite is thus exposed.

(c) The thickness of the Lower Volcanic Member and Saxos Bjerg Member preserved to the north and south of the granite uplift compared with their absence on top is reminiscent of the formation of 'rim synclines' adjacent to a salt dome during growth (HOLMES, 1964, p. 238).

All these features are characteristic of a high-level pluton. GRAETER (1957, p. 99) demonstrated that the rhyolites of the Kap Franklin Formation could be petrogenetically related to the same magmatic source as the granite. Since at least the second uplift phase is later than the first period of volcanism (Lower Volcanic Member) and earlier than the second volcanic episode (Upper Volcanic Member) there appears

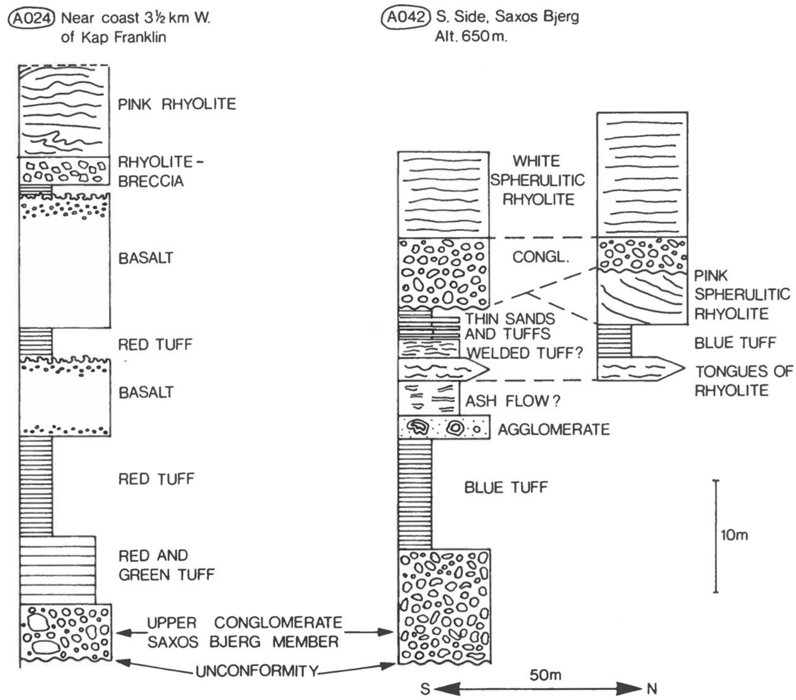


Fig. 30. Sections through base of Kap Franklin Upper Volcanic Member.

to be an equally strong temporal relation between these two forms of magmatic activity. When rhyolite flows were not being extruded at the surface, half-crystallised granite was heaved up, doming the surrounding country rock. This temporal and spatial relationship lends some support to HAMILTON & MYERS' (1967) idea that batholiths form at shallow depths in the crust and crystallise beneath a cover of their own volcanic ejectamenta. Some (eg. Baja California, and the Klamath Mountains) actually reached the surface and were eroded shortly after crystallisation. Monte Amiata (Tuscany) (RITTMANN, 1962, pp. 48, 126) is another example of a batholith linked to volcanoes on the surface.

Upper Volcanic Member

Attaining a maximum thickness (340 m) on NE Saxos Bjerg (Table 3), this member outcrops over a greater area (22 km^2) than the Lower Volcanic Member (14 km^2), and extends further south-west, although the volume of each member outcropping is about the same (ca. 5 km^3) (Fig. 16).

The Upper Volcanic Member rests unconformably on the underlying rocks, but up to 10 m of upper Saxos Bjerg conglomerate often separates the Upper Volcanics from the Vilddal Group, in areas where

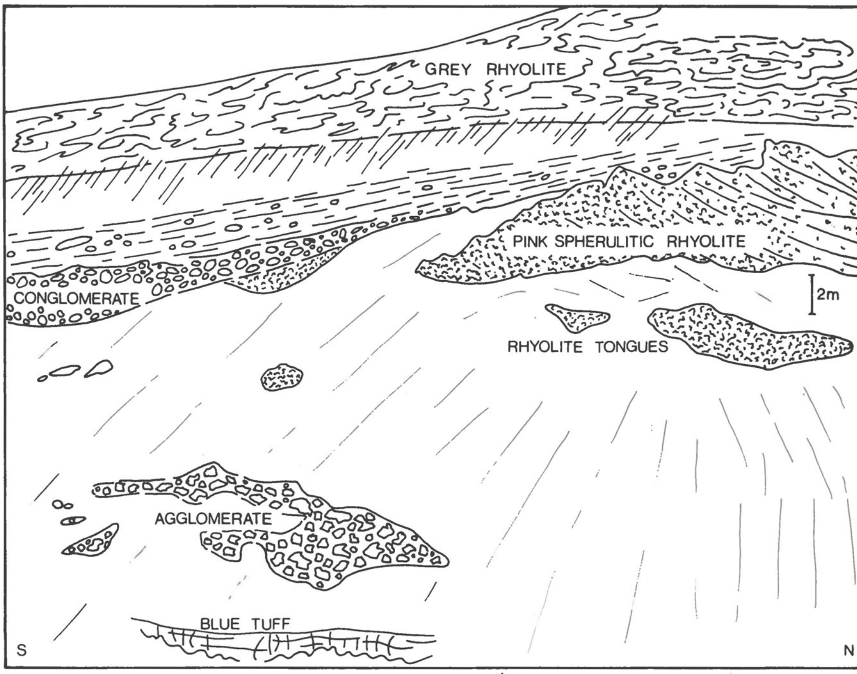


Fig. 31. Sketch of lava and pyroclastic outcrops, (A042), Kap Franklin Upper Volcanic Member, S. Saxos Bjerg.

the lower parts of the Kap Franklin Formation are missing. For example on north Saxos Bjerg, a fault down-throwing at least 350 m of Lower Volcanic Member to the east against the Vilddal Group, is truncated and over-stepped by the Upper Volcanic Member. The overlap on the coast south of Knuden has already been mentioned (Fig. 23).

A much greater variety of volcanic products is present compared with the Lower Volcanic Member. Two sections through the lower part of the Upper Member are summarised in Fig. 30. Following the second Saxos Bjerg conglomerate, in each case the initiation of volcanism is marked by pyroclastic deposits, representing the clearing of vents before effusion of lavas (RITTMANN, 1962, p. 85). A bright blue tuff is especially common at this horizon. On south Saxos Bjerg, a 2 m thick lens of agglomerate also occurs, containing irregular fragments of rhyolite up to 50 cm in diameter, each with a pale crust up to 1 cm thick interpreted as bombs. Most of the pyroclastic deposits are thought to be air-fall types, but a few thin tuffs have a distinctive laminar texture and may be welded tuffs of ash-flow origin.

The first lava flows in the south coast section are basalts (Fig. 30). Both have scoriaceous top surfaces, overlain by fine grained red crystal tuffs, and amygdales are common near the tops of the flows. The lower basalt has some large plagioclase phenocrysts, but the upper flow contains numerous phenocrysts of a pigeonite clinopyroxene, ophitically enclosing plagioclase laths. They are exposed continuously for about 300 m along the hillside. The only other basic rocks of Devonian age in the area occur further west along the coast about 5 and 7 km southeast of Margrethedal delta (Fig. 16) and include spilite (albite + chlorite) assemblages (A051), though there is no evidence for GRAETER's (1957, p. 66) assertion that these isolated flows and local volcanic breccias include 'pillow lavas'.

By far the largest proportion of the Upper Volcanic Member consists of siliceous lava flows: on south Saxos Bjerg, the first lava flow is a bright pink, spherulitic rhyolite. Isolated tongues of lava occur embedded in soft blue tuff underneath the main mass of rhyolite (Fig. 31). It contains phenocrysts of quartz and perthitic K-feldspar with a typical pseudo-shattered appearance, and spherulites up to 1 cm in diameter radiate out from phenocrysts into the groundmass. The main rhyolite flow wedges out southwards, and crude flowbanding curves upward in that direction, indicating local flow to the south (BENSON & KITTLEMAN, 1968; CHRISTIANSEN & LIPMAN, 1966) (Fig. 31). A thin conglomerate erosively overlies the pink rhyolite, and contains clasts of siltstone, spherulitic rhyolite, blue tuff and a red tuff which underlies the conglomerate further south. The conglomerate wedges out eastwards underneath a greyish-white porphyritic rhyolite, containing spherulites up to 12 cm in diameter.

In the south coast section, the first rhyolite flow overlies a breccia consisting entirely of angular fragments similar to the overlying flow. The lava consists of pinkish porphyritic rhyolite with phenocrysts of pink K-feldspar up to 4 mm in size, but no obvious quartz phenocrysts. The rock is locally spherulitic, with individual spheruliths up to 7 cm in diameter, and a delicate flow-lamination on a scale of 1 to 2 mm is well developed. A crude lineation appears on some flow surfaces, which also curve round the larger spheruliths. Perhaps a local inhomogeneity in the laminar viscous flow, causing separation of the streamlines, later provided a preferred nucleation site during devitrification, rather than spherulites crystallizing out before the groundmass solidified, as suggested by GRAETER (1957, p. 99). Locally the flow-banding is deformed into small flow folds (wavelength 10 cm) with recumbent axial planes facing westwards. About 100 metres further east, a bright blue-green tuff appears between the rhyolite and basalt flows: the rhyolite clearly has scoured its way down through the tuff westwards to rest on the basalt (Fig. 23). The breccia immediately below the rhyolite may represent part of the original "breccia-envelope" formed at the edges of the flow, and dumped like a ground-moraine when the flow was no longer confined by local topographic features (CHRISTIANSEN & LIPMAN, 1966).

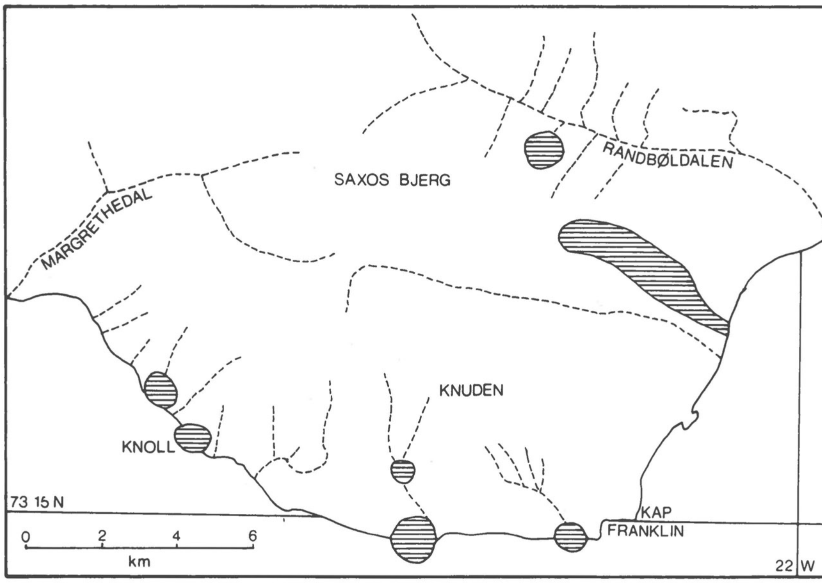


Fig. 32. Location of probable feeder dykes to rhyolites of Kap Franklin Formation.

The Upper Volcanic Member differs from the Lower member principally in having a greater proportion of pyroclastic deposits; basic rocks are present though rare; rhyolites tend to show flow-banding, lineation of flow surfaces, and spherulitic textures more abundantly than those of the Lower member; and, while feldspar phenocrysts attain a similar maximum size on average (3.7 ± 1.5 mm), quartz phenocrysts are significantly smaller (1.0 ± 0.8 mm). The experimental work of LOFGREN (1970) indicates that devitrification rates are significantly increased if Na- or K-rich solutions are present. Small but significant differences in volatile content of the rhyolites could therefore explain the spherulitic textures, composition and size of phenocrysts, and, by affecting viscosity, the flow structures, at different stages in their emplacement.

The volume and areal extent of the rhyolite complexes raises the question whether the lavas might really be ignimbrites (welded tuffs) rather than viscous coulées. The majority of the flows are lenticular, often wedging out; the delicate flowbanding shows no evidence of streaking-out of pumice lapilli (ROSS & SMITH, 1961) and clastic textures and rock fragments are not observed, either in the field or in thin section. Apart from the thin welded tuffs already mentioned on south Saxos Bjerg, only one other unit, 12 m thick, at the base of the member near Kap Franklin, can with any certainty be described as an ash-flow deposit: it contains numerous pumice lapilli, siltstone and rhyolite clasts

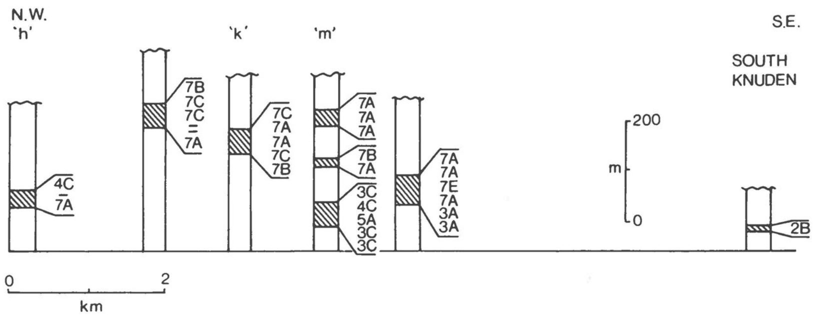


Fig. 33. Kap Franklin Formation, Østreplateau Grey Sandstone Member, stratigraphic distribution of sample groups. Localities indicated on Fig. 34.

(Plate 3) set in a fine grained siliceous groundmass, and large spheruliths are developed towards its top. The possibility that the other acid volcanics are rheio-ignimbrites (remobilised ash-flow deposits flowing down the slopes of a volcanic pile) (RITTMANN, 1962, p. 62) could account for some of the flow structures but a complete obliteration of clastic textures would be required.

The outcrop pattern is consistent with BÜTLER's (1954, p. 117) impression that most of the rhyolite flows were extruded from fissures. LONEY (1968) has described a recent rhyolite coulée from the Mono Craters, California, 75 m thick and 3.6 km long, extruded from a fissure: many of the small-scale structures (lineations, flow layering, folds) are comparable with the Kap Franklin rhyolites. An example of the other main type of rhyolite extrusion may be the 'Knoll', a prominent rhyolite headland, 500 m wide and 100 m high, situated 6 km south-east of Margrethedal delta (see Fig. 32) which was interpreted by GRAETER (1957, p. 70) as a possible endogenous dome (WILLIAMS, 1932). The location of rhyolite feeder dykes (Fig. 32) gives a maximum estimate of the spacing of eruption centres as 8 km: a larger number of dykes are probably not exposed. One visualises intermingling coulées from a series of small domes located along fissures. Individual flows may not have extended more than 3 km from source.

The present total volume of lava in the area is estimated at 10 km^3. If effusion was more or less uniform over the area, the total volume extruded may have been as much as 50 km^3. In view of the negligible volume of basic igneous rock formed at this time, the acid lavas could not have been derived by differentiation of basic magma alone. The lack of intermediate compositions suggests that most of the acid magma was derived by partial fusion, rather than assimilation, of sub-Devonian metasedimentary rocks, the heat source presumably being the basic magma from which the basalts were formed.

Østreplateau Grey Sandstone Member

The member is not present north of Knuden, either because volcanism continued longer in the north, or more probably because of erosion preceeding deposition of the Randbøl Formation. On the south face of Knuden (thickness 120 m) it is overlain unconformably by the Randbøl Formation: westwards, on the south side of Østreplateau, a thickness of between 300 and 400 m is overlain unconformably by the Permian (Fig. 15).

The succession consists largely of grey-green fine sandstones but some dykes, lava flows (spilite, rhyolite) and pyroclastic rocks are intercalated, indicating contemporaneous but sporadic volcanism. The dominant facies grouping (Fig. 33) is 7A (grey-f., v.f. sst.-trough X, flat); 7B (grey-f. v.f. sst.-flat, trough X); 7C (grey-v. f., f. sst., co. slst.-flat, trough X); 7E (grey-f. sst.-trough X), all grey fine sandstones with varying proportions of shallow large-scale cross-stratification, flat bedding with parting lineation, small-scale cross-stratification and some siltstone. Medium sandstone is represented by 3C (grey-m., f. sst.-trough X, flat) and 3A (grey-f., m. sst.-trough X). On south Knuden, somewhat redder sandstones with better developed cross stratification (2B, red-m., f. sst.-trough X, flat) were recorded. Red silt bands occur rarely: in one case (5A, red-co. slst., v.f. sst.-asym.rip.) the band was 9 m thick; another 3 m thick, was incorporated as a variant of 7A (grey-f., v.f. sst.-trough X, flat). Further west, grey silts (4C, grey-m., co. slst.-flat) become more frequent, but metamorphism by dykes makes it impossible to collect sedimentological data northwest of KOCH's (1931) stream 'h'. Large sand-crevices are a characteristic feature of the red silt bands. In each of two sections, over 2 km apart, and at different stratigraphic levels, a pyroclastic deposit 1 m thick is followed by 3 m of inter-laminated very fine sandstone and siltstone with mudcracks and ripple marks and then 3 to 4 m of grey very finely laminated medium siltstone of lacustrine aspect. One of the pyroclastic beds contains accretion lapilli (MOORE & PECK, 1962). If the similarity is not due to coincidence, then the same process of gradual ponding-up may have followed two volcanic events, in which the local drainage system was dammed by volcanic products, either lava or ash.

The sandstones have a characteristic 'dirty' greenish colour, are micaceous and often rich in unidentifiable plant debris. The palaeocurrent system (Fig. 34) is complex: two trends, one to the north and northeast, the other to the southwest, are discernible. Most of the latter comes from fairly low in the succession, but continues higher up at about the same stratigraphic level as the northeasterly trend. We are probably dealing with two interdigitating distributary systems.

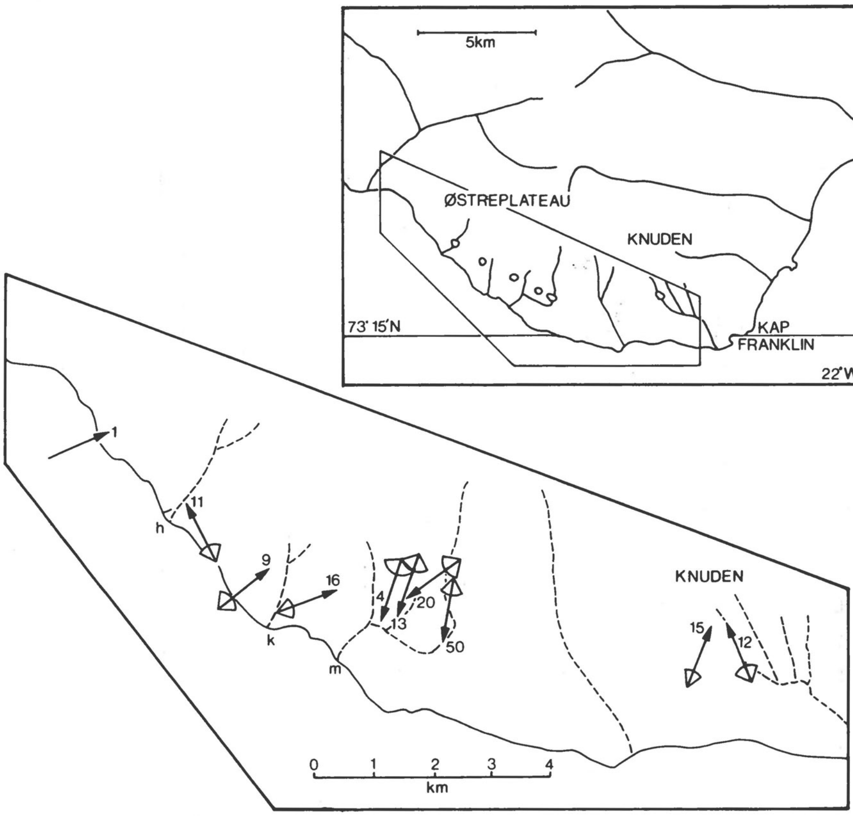


Fig. 34. Kap Franklin Formation, Østreplateau Grey Sandstone Member, palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

Some dolerite dykes near the north-west end of the outcrop are pre-Permian in age, for they are truncated by the Permian unconformity, as demonstrated by Maync (1949, p. 14). They contain the altered remains of olivine as the main ferromagnesian mineral and may represent a phase of Devonian volcanism later than the Kap Franklin Formation, such as, perhaps, the late Kap Kolthoff Supergroup – early Kap Graah Group activity at Kap Graah.

Randbøl Formation

The youngest of the Middle Devonian formations in the area is poorly exposed in erosional remnants high up on Knuden, Saxos Bjerg, and Huitfeldts Bjerg. There is a small discordance in dip between the Randbøl and the underlying Kap Franklin Formations but the basal unconformity locally shows a marked erosional relief of ca. 30 m. The top is truncated by the Permian unconformity. The succession consists

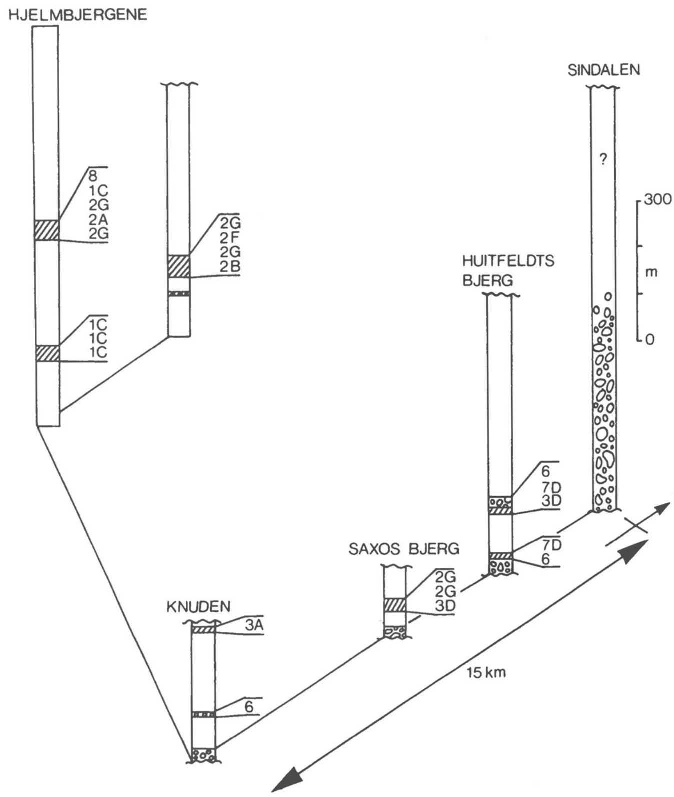


Fig. 35. Randbøl and Hjelmbjergene Red Sandstone Formations, Stratigraphic distribution of sample groups.

almost entirely of conglomerates and yellow, cream white, and reddish coarse and medium sandstones (sample groups $7D_1$, grey-v. co. sst.-trough X; 3D, grey-m., co. sst.-trough X; 2G, red-m. f. sst.-trough X, flat) (Fig. 35). The latter readily disintegrate into sandy screes.

Apart from the basal conglomerate, up to 40 m thick, at least one, possibly two, or more conglomerate horizons, 10 to 20 m thick, occur some 100 m higher up succession. The dominant clast types are:- red granite (sometimes a type with large muscovite crystals); white granite; metamorphic rocks including a biotite-rich gneiss and a distinctive spotted rock in which dark green 'porphyroblasts' (networks of fine sericite crystals) are set in a paler claygrade groundmass; and grey and purple orthoquartzites, in which quartz grains are more rounded and better sorted than in any Devonian sandstones. Unlike the Kap Franklin conglomerate, therefore, most of the clasts were derived from extra-basinal source areas. However, a few red rhyolite clasts in the basal conglomerate on Huitfeldts Bjerg, and some siltstone clasts on

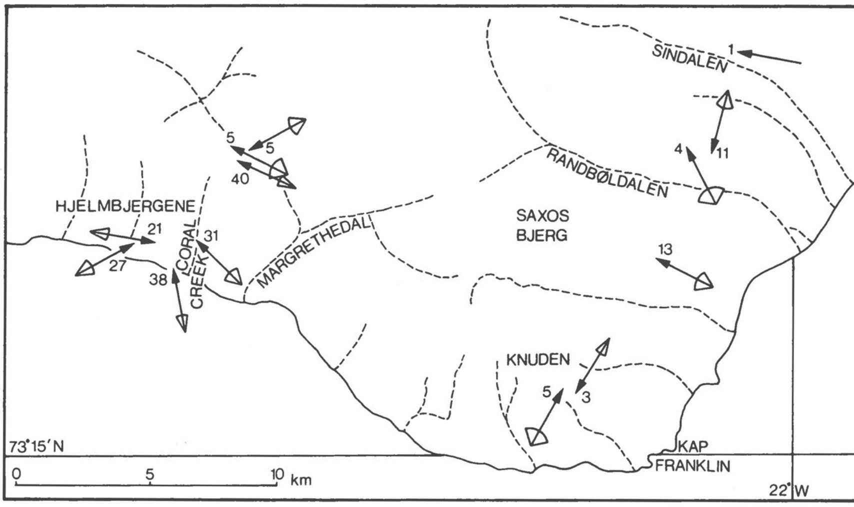


Fig. 36. Randbøl and Hjelmbjergene Red Sandstone Formations, palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

Knuden were probably derived from underlying Kap Franklin/Vilddal Group sources.

The maximum preserved thickness of the formation (ca. 900 m) occurs further north in Sindalen (Fig. 36), where the succession consists entirely of conglomerates. The lower part is very coarse, virtually structureless, and contains white granite, quartzite and low grade grey semipelite clasts. 400 m higher up the succession, the clast size declines, cross-stratified sandstone lenses appear, indicating flow to the west, and red granites and gneisses are common clasts. A quartzite-rich conglomerate horizon similar to that noted further north by MAYNC (1949, p. 23) marks the unconformable base of the Permian at 790 m altitude on the north side of the valley. Southwards, clast size in the conglomerates declines (Table 6), the conglomerates interdigitate with sandstones, and palaeocurrents from the conglomerates indicate flow to south or southwest, confirming BÜTLER's (1954, p. 45) postulated dispersal of detritus from the north. However, palaeocurrents in the sandstones trend westwards or northwestwards (Fig. 36). They contain the same clast types

Table 6. *Randbøl Formation, Conglomerates. Summary Clast Data.*

Locality	Mean Max. Size (cm) (Granite)	Percent Granite (Range)
Sindalen	19	60 to 100
S. Huitfeldts Bjerg	9	20 to 70
S. Knuden	7	40

as the conglomerates, and garnet is a common accessory. Mudflakes are also present in the finer sandstones. Clearly the lateral variation is due to the interdigitation of a large alluvial gravel fan (Sindalen) with an adjacent equally large sandy stream system (Saxos Bjerg), the axes of both trending westwards.

We found no fossils in the Randbøl Formation. BÜTLER (1954, p. 113) found Middle Devonian antiarch and crossopterygian remains in thin silty limestone interbedded with the basal conglomerate on SE Huitfeldts Bjerg. The fauna and lithofacies associations are analogous to those found near the base of the Ella Ø conglomerate on the western margin of the Devonian area.

Kap Graah Group and Mount Celsius Supergroup

BÜTLER (1954, pp. 94–96) mapped an outlier of his 'Mt. Celsius Series' on the coast 2 km east of the mouth of Margrethedal. It includes both the purple mudstones and red and grey coarse sandstone divisions (Remigolepis and Gröenlandaspis Series of SÄVE-SÖDERBERGH, 1934), much reduced in thickness (70 m) compared with 1400 m further west in Gauss Halvø. The sandstones dip 11° at 270° (true).

A little further east, exposed in KOCH's stream 'e' (BÜTLER, 1954, p. 93, Plate 10), a conglomerate 30 m thick is faulted up against more purple mudstones to the east, but westwards passes conformably up into the mudstones. The bedding dips 25° at 280° (true). The conglomerate is massive apart from upward-decreasing maximum clast size (maximum noted was 30 × 15 cm). 90 % of the clasts are greyish rhyolites, some red; the remainder includes red-spotted sandstones similar to those exposed in valley 'f' further east (Vilddal Group ?), and grey sandstones with quartz veins as seen in situ along shatter zones in the Kap Franklin Formation east of stream 'f'.

BÜTLER correlated this conglomerate with a similar one exposed just south of the junction of Inderdalen and Margrethedal. Here the beds dip uniformly 7° at 310° (true); 80 % of the clasts consist of rhyolite, including grey, blackish, and yellow types, while the rest include white quartzite, limestones, and some red sandstones and siltstones of Devonian type. BÜTLER (1954, p. 45), while admitting that the stratigraphic relation of this conglomerate to the siltstones of the Margrethedal 'series' to the north could not be observed, believed that the conglomerate occurred low down in the lowest division of that series. However, bedding dip directions in the adjoining siltstones are highly variable, not concordant with the conglomerate, and exposures of the latter appear, east of the stream junction, overlying a yellow felsite dyke which intrudes the siltstones. The conglomerate appears to truncate the dyke, clasts of which are a common constituent in the conglomerate. The conglomerate is therefore younger than the Margrethedal siltstones, and is also younger than the Østreplateau Grey Sandstone Member of the Kap Franklin Formation on the coast. The apparent conformity with the Remigolepis Group mudstones suggests that the conglomerate corresponds to the basal sandstones and conglomerates of BÜTLER's Mt. Celsius Series, renamed as the top of the Kap Graah Group by NICHOLSON (this vol., nr 5).

A third outcrop at an altitude of 235 m in the stream gorge of Inderdalen occurs just below the intersection of the Permian unconformity with the stream. It consists of a section 40 m thick, of hard white coarse and medium sandstones interbedded with red silts with large carbonate concretions, and with purple siltstones of Remigolepis Group type. The succession, mentioned by BÜTLER (1954, p. 98), dips 34° at 320° (true), and rests without angular unconformity on siltstones of the Inderdalen Formation (see below). However, a zone of intense weathering 3 m thick can be seen underneath the contact, and the underlying siltstones locally contain secondary accumulations of chlorite, a characteristic both of the Kap Graah/Mt. Celsius Supergroup sediments and of rocks immediately subjacent to their base. The sandstone-siltstone alternation probably correlates with the lowest part of the Remigolepis Group seen at the east end of Obrutschews Bjerg.

"Margrethedal Series"

BÜTLER (1954, p. 45–54) described all the pre-Permian rocks exposed in Margrethedal as the "Margrethedal Series". He divided the succession into four parts, progressively exposed up the valley:

1) Red sandstones,
2) Rødedal Conglomerate,
3) Volcanic tuffs,
4) More red sandstone.

We have just described the conglomerate which outcrops near the junction of Inderdalen and Margrethedal, notable for its high content of acid volcanic clasts of Kap Franklin Formation type. BÜTLER (1954, Table 1, p. 108) believed that this "porphyrkonglomerat" occurred low down in the lowest division of his Margrethedal series, so that the whole of the series could not be older than the Kap Franklin Formation and its volcanics. Our observations, however, suggest an unconformity between the conglomerate and the neighbouring Margrethedal siltstones; the conglomerate probably correlates with the Upper Devonian Kap Graah Group. We can therefore revise BÜTLER's correlation of the remainder of the Margrethedal Series.

The succession is most conveniently divided into two parts: the lower, Inderdalen Formation (BÜTLER's division 1), and the upper, Rødedal Formation (divisions 2 to 4), see Table 7.

Table 7. *Correlation in Margrethedal.*

	BÜTLER (1954)	This paper
		'Porphykonglomerat' (BÜTLER) (Kap Graah Group)
'Margrethedal Series'	4 red sandstone 3 tuff 2 conglomerate in Rødedal	Rødedal Formation (Kap Kolthoff S-gp)
	1 red sandstone (thought to contain 'Porphyrkonglomerat'	Inderdalen Formation (Vilddal S-gp)

Inderdalen Formation

We consider the Inderdalen Formation to be part of the Vilddal Group, and it is mapped as such in Figs. 8 and 9. We shall show that the Rødedal Formation correlates with the lower part of the Kap Franklin Formation.

In Margrethedal gorge, between the junctions of Inderdalen and Rødedal, the Inderdalen Formation consists of red-and-green banded siltstones with minor fine sandstones (5A, red-co. slst., v.f. sst.-asym. rip.; 5B, red-co., m. slst.-asym. rip., flat; 4E, grey-co., m. slst.-asym. rip., flat) (Fig. 14) very similar to the Vilddal Red-and-green banded Siltstone Formation. The trace fossil assemblage is similar (for example, horizontal meniscus-filled burrows), and vertebrate collections from the siltstones in the green bands include fragments of *Glyptolepis* sp. and *Gyroptychius groenlandicus* JARVIK, confirming the upper Middle Devonian age of this formation. Palaeocurrents trend east-southeast, fitting into the pattern for the upper part of the Vilddal Group (Fig. 11). Lower parts of the succession, exposed in Inderdalen, comprise mainly flat-bedded grey and reddish siltstones, with occasional symmetrical and asymmetrical ripple marks and lenticular bedding; this part probably correlates with the middle, Vilddal Grey Siltstone Formation. The base of the succession is not exposed.

Rødedal Formation

At the base of this formation, running along the east side of Rødedal, the 30 m thick Rødedal Conglomerate rests without marked angular unconformity on the Inderdalen Formation, though the contact cannot be seen. Palaeocurrents from cross-stratification in two localities indicate transport to the north-east and south-east from source areas of limestone, quartzite and red granite. No rhyolite clasts were found in the Rødedal conglomerate. A mean maximum clast diameter of 6 to 7 cm is attained.

The overlying tuff attains a maximum thickness of 100 metres, but thins to 10 metres in 700 m westwards. Bright red and green varieties occur, including deposits of accretion lapilli up to 7 mm diameter (Moore & Peck, 1962). Some of the tuffaceous material is locally mixed with terrigenous debris such as granite clasts. The whole of the volcanic phase in middle Margrethedal is represented by pyroclastics.

The following sediments, of which only 40 metres are preserved here, are remarkable for the lateral persistence of sets as thin sheets. The scouring and lenticularity of sets in normal facies of comparable grainsize (Plate 9) are virtually absent in this formation (Plate 4). This also is the only case where the 10-metre facies-profile fails to distinguish a facies recognisable in the field, for 10 metre units from this formation classify with acceptable communality into a variety of 'normal' groups with different set thickness and geometry characteristics. The grainsize ranges from fine sandstone to siltstones, with occasional medium sandstone and fine conglomerate sets. Colour ranges through purple, red, grey, yellow. Large-scale cross-stratification is very rare: flat bedding is the most important structure, but small-scale cross-stratification and symmetrical ripples also occur. Convolute lamination is locally very abundant as also are tool marks and other sole structures. Fine conglomerates appear occasionally (Fig. 37) as thin sets with slightly scoured bases and flattish bedding. Sorting between clasts and matrix is poor (Plate 5), and coarse sand grains of red rhyolite sometimes occur scattered in the siltstones. Clasts range up to 8 × 7 cm in size, and rhyolite makes up 50 to 100 $^0/_0$ of the clasts in Randbøldalen, the remainder including grey siltstone and blue tuff. Further west in Margrethedal, rhyolite clasts form only 20 to 30 $^0/_0$, and occur with granite, pre-Devonian quartzite and limestone clasts, in a number of pebbly horizons.

The bedding characteristics of this facies are reminiscent of turbidite sequences. The abundance of symmetrical ripples in a section of SW Huitfeldts Bjerg could indicate local wave action in a lake, but the occurrence of mudcracks in many sections indicates periods of subaerial desiccation. It is tentatively proposed that the sediment was deposited by mainly subaerial, sometimes subaqueous, flows of short duration, i.e. sheet floods, without development of a channelled drainage system. Sources of coarse clastic material were not far distant, but the stream power needed to transport pebbles into the area was only sporadically attained.

In upper Randbøldalen, the formation may be as much as 200 m

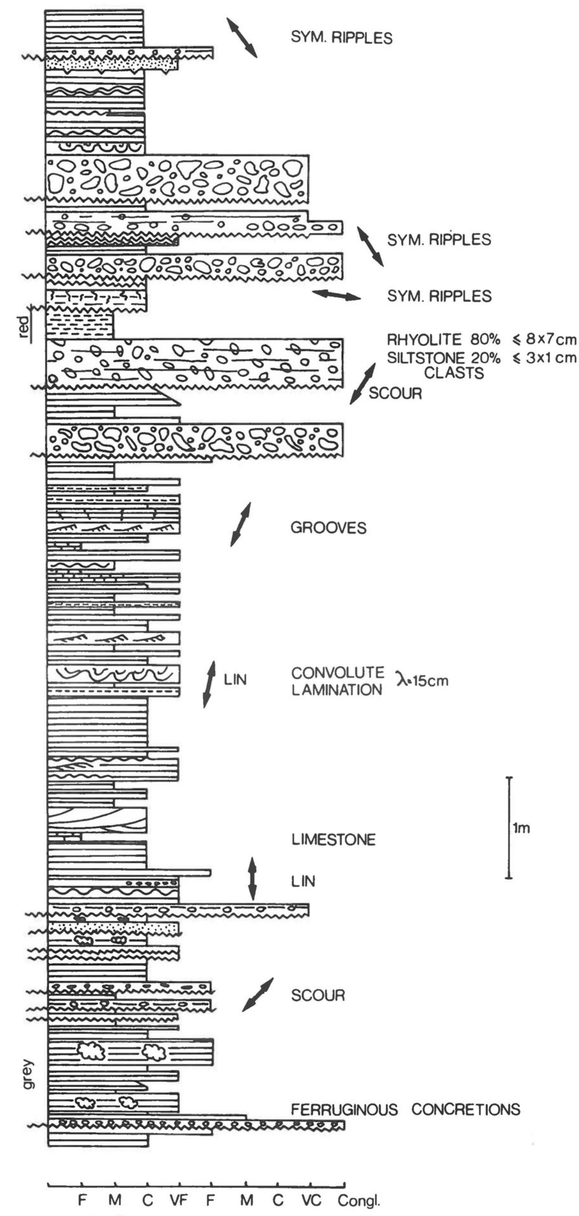


Fig. 37. Section (A054), Rødedal Formation, upper Randbøldalen.

thick. Correlation westwards through Margrethedal is complicated by poor exposure and the presence of gentle tectonic folding and a network of intersecting faults, with displacements up to 100 m. Conglomerate horizons 1.5 m thick are impossible to correlate over distances greater than $^1/_2$ km, and, in the pass between the two valleys, pyroclastic units,

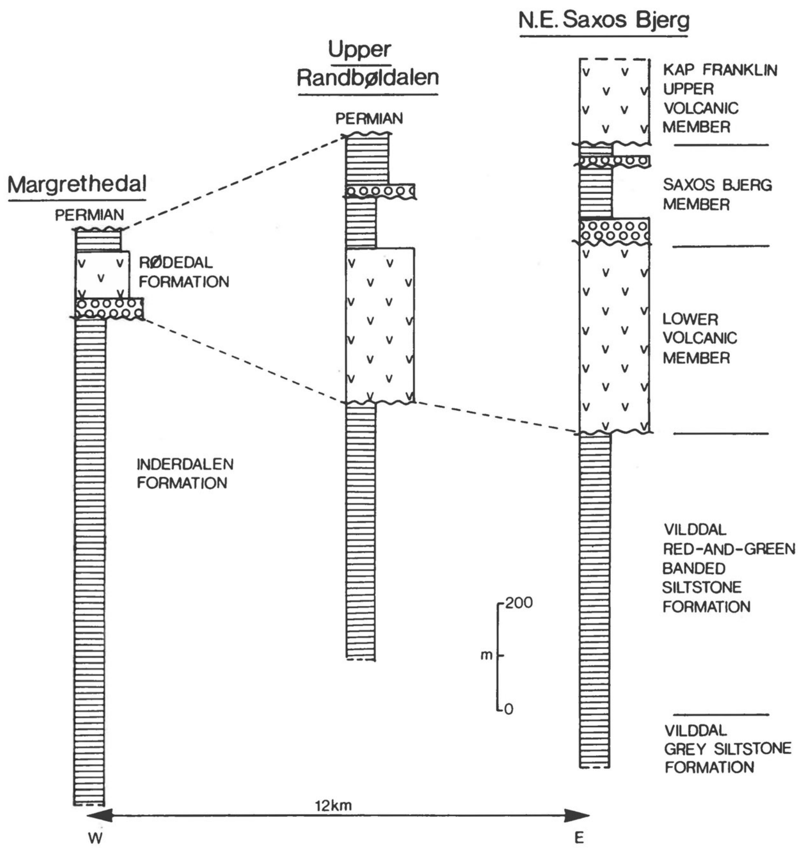


Fig. 38. Correlation of the Margrethedal 'Series'.

up to 50 m thick, including well preserved pumice-lapilli up to 2 cm in size, represent entirely local accumulations in the middle of the sedimentary sequence. However, in Randbøldalen, the base of the formation is marked by the two outcrops of pink rhyolite resting unconformably on the Vilddal Group on both sides of the valley. The large size (up to 6 mm) of both quartz and feldspar phenocrysts suggests that correlation with the Kap Franklin Lower Volcanic Member (Graeter, 1957, p. 55) is more likely than with the Upper Volcanic Member (Bütler, 1954, p. 54). The Rødedal Conglomerate is absent here: the conglomerate which Bütler (1954, Plate 6) mapped as the base of his Margrethedal series on the north side of the valley is 6 m thick, containing entirely rhyolite clasts up to a mean maximum of 29 cm. It occurs stratigraphically 100 m above the rhyolite and may correlate with one of the conglomerates of the Kap Franklin-Saxos Bjerg Member.

The red rhyolite outcrops near the pass in Margrethedal consist of the delicately flow-laminated type with small (0.5 mm) phenocrysts of quartz and feldspar, and with striated flow surfaces and flow-folding: relations to the local sequence are faulted, but the rhyolite probably correlates with the Kap Franklin Upper Volcanic Member.

We conclude that much of the Rødedal Formation correlates with the lower, not the upper, part of the Kap Franklin Formation. In particular, the palaeocurrents trend northeastwards, changing to north in Randbøldalen, merging into the northward drainage of the Saxos Bjerg Member (Fig. 26). The new correlation is summarised in Fig. 38.

Five vertebrate fragments collected from the sandstones of the Rødedal Formation, include the posterior median dorsal and anterior ventrolateral plates of *Asterolepis* sp., and the paranuchal plate of a coccosteomorph arthrodire. In contrast to the underlying formation no crossopterygian remains were found, but the Middle Devonian age of the whole of BÜTLER's "Margrethedal Series" is now confirmed.

Structural Sequence

The outcrop pattern of the subdivisions of the Vilddal Group (Fig. 9) indicates a system of broad folds with axial traces striking approximately east-west. This pattern does not appear in the overlying formations and hence the uplift, marked by erosion before the Kap Franklin Formation, accompanied a phase of north-south compression. Superimposed on this pattern are the doming effects of the Kap Franklin Granite and the broad folding with axial traces striking north-south which affects the Kap Franklin and Randbøl Formations. Unconformities within the Kap Franklin Formation have been shown to be generated locally by uplift of the Kap Franklin Granite; that between the Kap Franklin and Randbøl Formations simply marks differential uplift to the northeast. The age of the east-west compression phase can only be stated as pre-Permian, post-Randbøl Formation. Several such phases are recorded by BÜTLER (1959) further west in Gauss Halvø (Hudson Land phases 3 and 4; Ymer Ø phase), but because the Upper Devonian upper Kap Graah conglomerate rests unconformably on the middle part of the Vilddal Group in Margrethedal, much of the deformation in question could have occurred in the pre- and intra-Kap Graah Group phases (= Hudson Land phases 3 and 4), rather than the early Carboniferous Ymers Ø phase suggested by BÜTLER (1954, p. 120). Further evidence for this conclusion can be seen in Hjelmbjergene further west.

Most of the normal faults of the area displace the Randbøl Formation. Some are cut by Tertiary dolerite dykes, and the northwest-trending fault from Knuden to Kap Franklin is definitely pre-Permian. Many of the faults with small vertical displacements strike east-west and consistently downthrow into the mountainsides: Saxos Bjerg for example, can be regarded as an embryonic graben. One of these faults at the southern foot of Knuden moved before the Kap Franklin Formation, for upper Vilddal Group rocks are downthrown to the north of middle and lower Vilddal Group, but the overlying volcanics are unaffected: the fault became a feeder channel to the basalt flows above. The intra-Kap Franklin fault on the north side of Saxos Bjerg probably formed in response to crustal adjustments after transfer of magma (Lower Volcanic Member and Kap Franklin Granite) to the surface.

The fault bounding the eastern edge of the Giesecke Bjerge block displaces Tertiary dykes, and latest movement on the Main Fault (BÜTLER, 1954, p. 122) through upper Inderdalen is certainly post-Permian, also downthrowing to the east. A zone of intense deformation of the siltstones of the Inderdalen Formation in lower Inderdalen may be associated with the Main Fault: numerous faults, disharmonic folds and small-scale recumbent folds facing northwest contrast strongly with the gentle dip of the overlying Kap Graah Group and Mt. Celsius Supergroup. While this may be largely due to a difference in competence, one suspects that movements associated with the Main Fault may have occurred during middle Upper Devonian times.

Summary

In upper Middle Devonian times, the siltstones of the Vilddal Group were deposited by easterly flowing streams. There is no evidence of an eastern margin to the basin in the vicinity at this time. The Vilddal Group was folded, uplifted, and intruded by the Kap Franklin Granite. During a period of local erosion and sedimentation between two phases of acid volcanism (Kap Franklin Formation), the granite was exposed to erosion but was uplifted again a little later. A northerly draining silty floodplain was formed, with erosional areas flanked by small alluvial gravel fans, and influxes of sand were transported from sources in the east. In Margrethedal, the character of the drainage changed but sediment transport was still from the west. Sedimentation succeeding the second phase of volcanism is marked by fine sandstone deposited by two drainage systems: one from the northeast, the other from the southwest.

Further uplift and erosion was followed by the coarser sandstones and conglomerates of the Middle Devonian Randbøl Formation, transported westwards from granitic and metamorphic source areas: this final reversal of palaeoslope from eastwards to westwards marks the formation of an eastern margin to the basin not far to the east of the Kap Franklin area, actively supplying sediment to the basin. We see that the local magmatic activity took place during the reversal. During

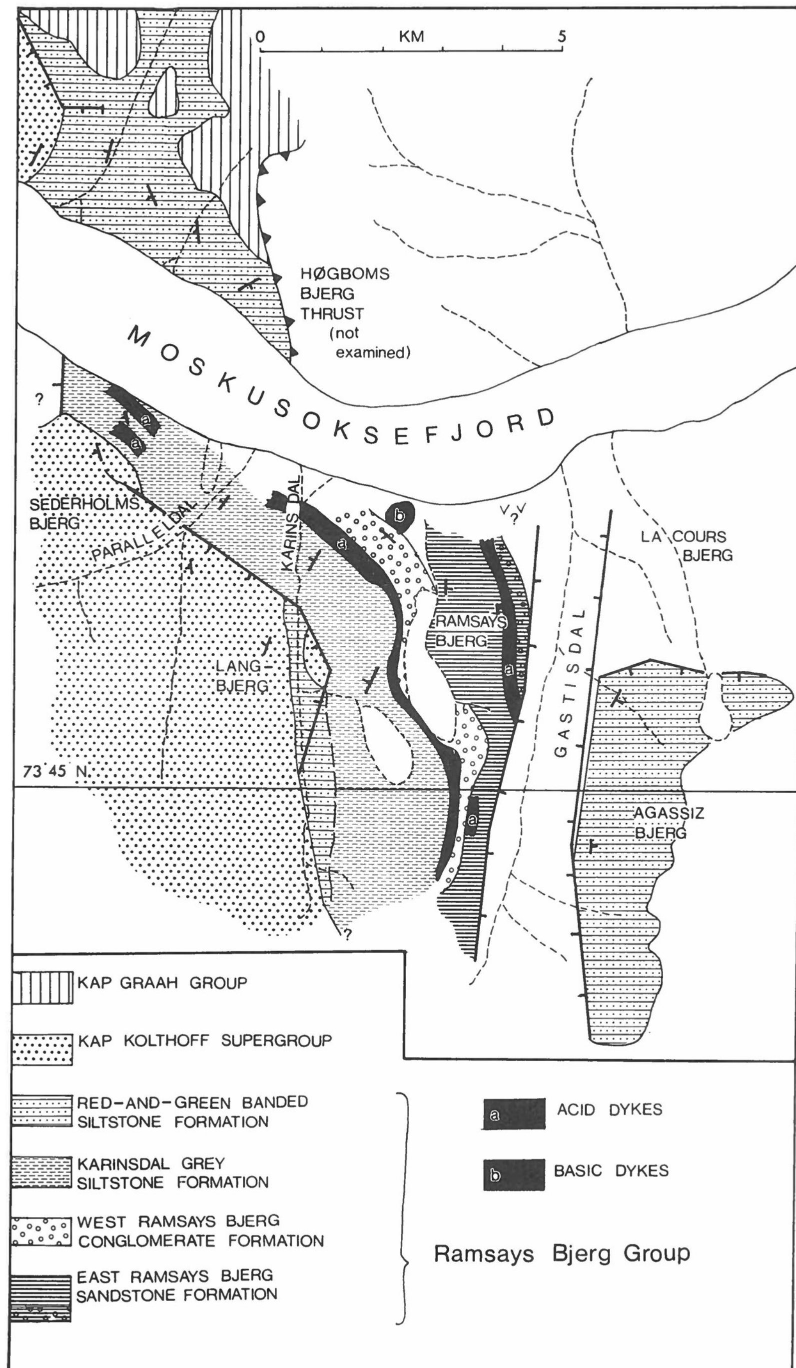


Fig. 39. Devonian geology of eastern Moskusoksefjord (modified after Bütler (1959, Pl. 3)).

the sedimentation of the Kap Kolthoff Supergroup, the area became part of the eastern margin, the Middle Devonian rocks were deformed and eroded, and finally the Upper Devonian Kap Graah Group and Mt. Celsius Supergroup were deposited with much reduced thickness in the area.

EASTERN MOSKUSOKSEFJORD

Stratigraphic Outline

In Eastern Moskusoksefjord, the Devonian succession comprises four main divisions (Table 8, map Fig. 39).

Table 8. *Stratigraphic Outline Eastern Moskusoksefjord*

Major Unit	Age	Estimated thickness (m)
Mt. Celsius Supergroup Kap Graah Group }	Upper Devonian	2600
Kap Kolthoff Supergroup	Middle to Upper Devonian	2000
Ramsays Bjerg Group	Middle Devonian (base not seen)	2600 (maximum)

Review of Age

The top two divisions, the Mt. Celsius Supergroup and Kap Graah Group, are known to be Upper Devonian in age (JARVIK, 1961; BÜTLER, 1959, p. 18), from their vertebrate faunas. In Gunnar Anderssons Land, Gauss Halvø and Kongeborgen, the following Upper Devonian vertebrates are reported from the top of the Kap Kolthoff Supergroup: *Bothriolepis jarviki* STENSIÖ, *Cladolus* sp. and *Holoptychius* sp. (BÜTLER, 1959, p. 164); the lower part, however, has yielded remains of Rhizodontids regarded by JARVIK as intermediate in age between the Middle Devonian *Gyroptychius groenlandicus* fauna and the Upper Devonian *Phyllolepis* fauna. BÜTLER therefore considered that the lowest part of the Kap Kolthoff Supergroup was upper Middle Devonian in age.

The lowest division, the Ramsays Bjerg Group, has yielded no determinable fossils, but because of its stratigraphic position is regarded as Middle Devonian (BÜTLER, 1959, p. 166). BÜTLER (1959, p. 171) proposed a correlation between this group and the Randbøl Formation of the Kap Franklin area, on the basis that conglomerates in both units contain granite clasts. Evidence for an alternative correlation with the Middle Devonian Vilddal Group is provided in the following paragraphs.

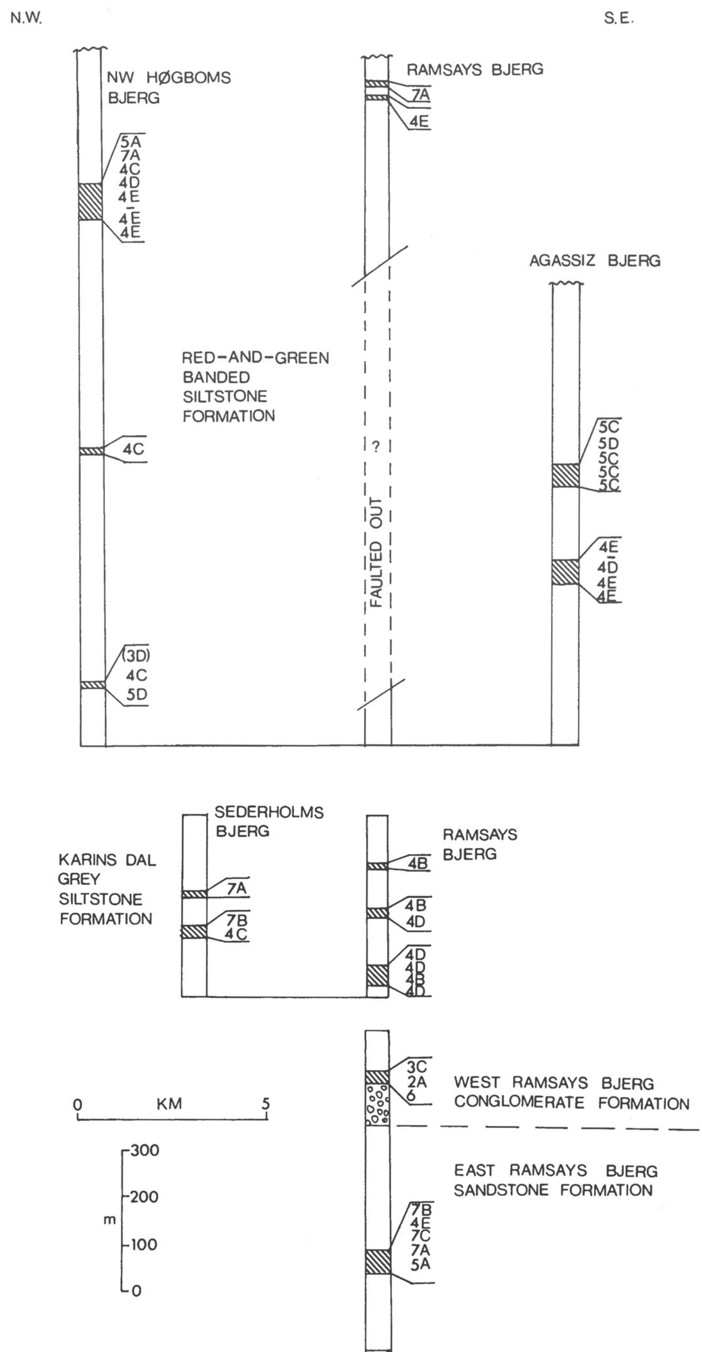


Fig. 40. Ramsays Bjerg Group, eastern Moskusoksefjord, Stratigraphic distribution of sample groups.

Table 9. *Ramsays Bjerg Group Subdivisions*

Unit	Estimated thickness (m)
Red-and-Green banded Siltstone Formation	1500 (max)
Karins Dal Grey Siltstone Formation	400
West Ramsays Bjerg Conglomerate Formation	200
East Ramsays Bjerg Sandstone Formation	500

Ramsays Bjerg Group

The whole of this group is not fully exposed in any one area. The succession (Table 9) has been compiled as follows:

Ramsays Bjerg

The succession described by BÜTLER (1959, pp. 82–88, Fig. 31), is essentially correct, from the lower of the two conglomerates exposed on the east side of the mountain up to the grey siltstones on the western shoulder of the mountain and in Karins Dal. The regional dip is about 30° to the west, though local folding causes some beds to dip eastwards.

The base of the succession cannot be seen. In Gastisdal, the sandstones exposed below the lower conglomerate, and regarded as part of the "Basal Series" by BÜTLER (1959, Fig. 40), actually form part of the shear zone associated with the western boundary of the Gastisdal graben, and their stratigraphic position is uncertain. Small faulted outcrops on the shore just west of Gastisdal delta include pyroclastics with accretion lapilli: they must be younger or older than the Ramsays Bjerg Group, which contains no contemporaneous volcanics.

Starting in the middle of the succession, the upper of the two conglomerates, exposed high up on the east side of the mountain, crosses over to the northwest flank (Fig. 39). Together with the overlying interbedded pale grey coarse-medium sandstones and red siltstones, sample group 2A (red-m., f. sst.-trough X, flat); 3C (grey-m., f. sst.-trough X, flat) (Fig. 40), it forms the *West Ramsays Bjerg Conglomerate Formation*. In the conglomerate, the mean maximum clast sizes are shown in Table 10); limestones and dolomites generally form a greater proportion of the clasts than quartzites and granites (Fig. 41). The latter are mostly white or greenish granites, but pinkish types appear about half way up the 90 m thick conglomerate and are almost as abundant as the white granites near the top. The conglomerate differs from the Randbøl conglomerates in that metamorphic clasts are absent whereas carbonate rocks are the dominant component. This composition resembles more closely that of some pebbly horizons in the lower part of the Vilddal Group, and sandstones associated with the conglomerate are also rich in carbonate. The overlying sand-silt alternations are comparable with

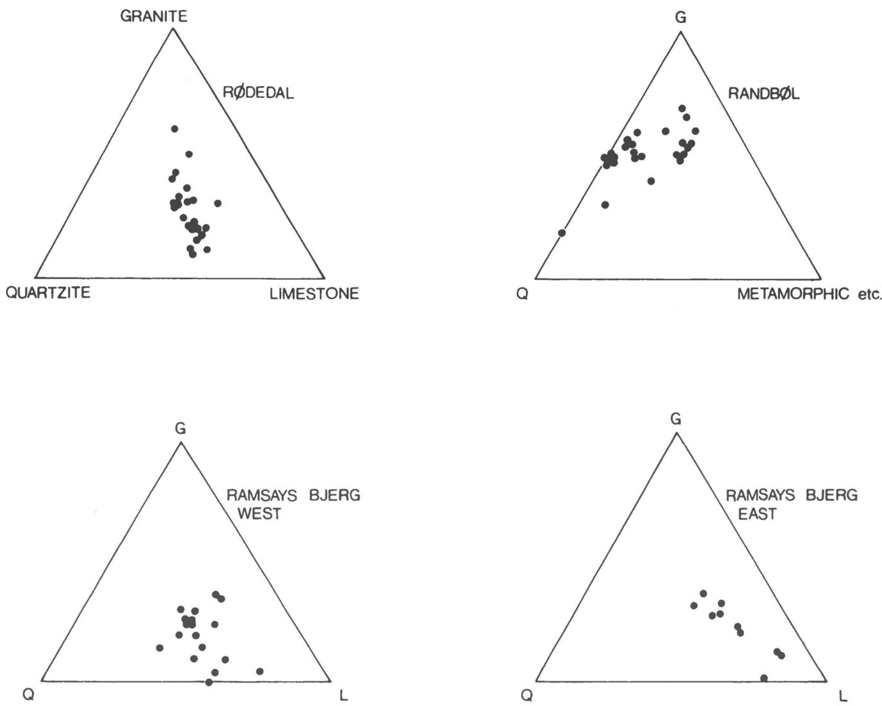


Fig. 41. Percentages of clast types at four different localities.

those recorded from the lower Vilddal Group, except that the thickness-proportion of siltstone is less; carbonate concretions are present in the red siltstone bands. Palaeocurrents also trend eastwards (Fig. 42).

Above this formation comes the *Karins Dal Grey Siltstone* Formation, in which sample groups 4B (grey-co., m. slst.-lent., flat); 4C (grey-m., co. slst.-flat); 4D (grey-co., m. slst.-flat) are well-represented (Fig. 40). Symmetrical ripple marks, lenticular-bedding and crack-fill ridges are characteristic features of the siltstones. The formation differs from the (middle) Vilddal Grey Siltstone Formation in the presence of bands of fine sandstone (7A, grey-f., v.f. sst.-trough X, flat; 7B, grey-f., v.f. sst.-flat, trough X), (Fig. 40), 10 to 20 m thick, interbedded with the siltstones. Large-scale cross-stratification within the sandstones appears to be unidirectional. The palaeocurrent pattern is confused. The sandstones were deposited by currents flowing southwest and east; the siltstones show currents trending northeast and west (Fig. 42). A few vertebrate fossils collected in 1970 included small unidentifiable hollow spines, a large crossopterygian cycloid scale, and a lateral plate of an antiarch, probably *Asterolepis* sp. The latter, regrettably, was found in terrace gravels at the mouth of Karins Dal but probably came from this formation. No remains of *Gyroptychius groenlandicus* were found.

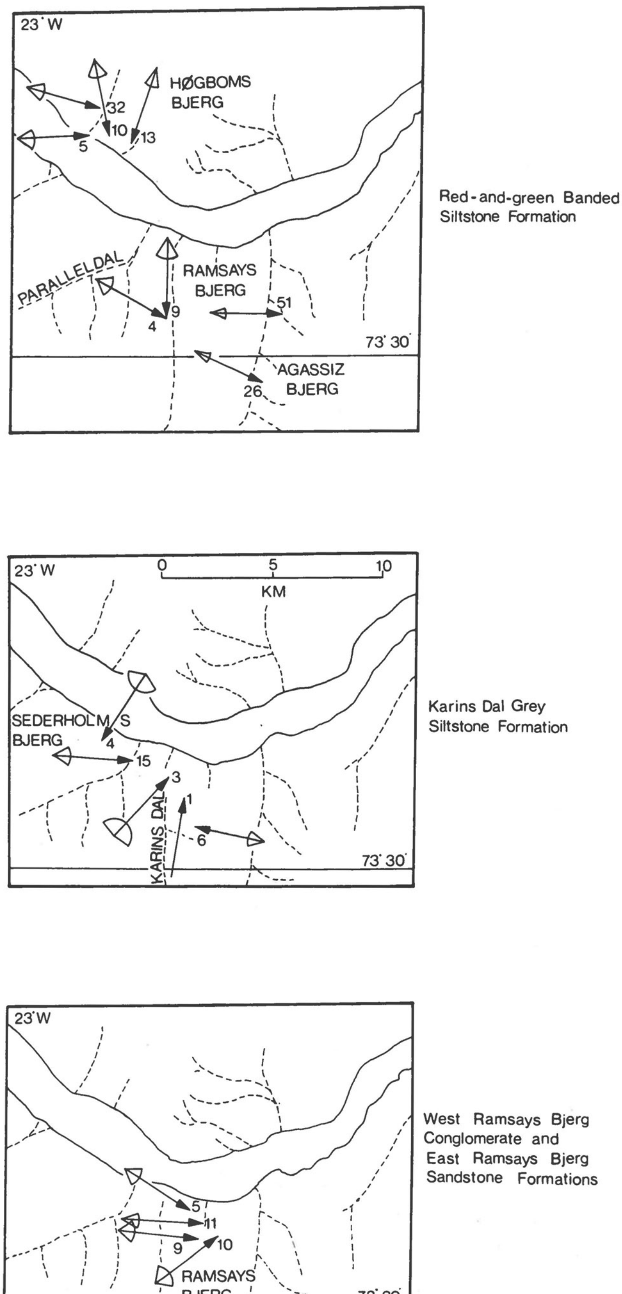


Fig. 42. Ramsays Bjerg Group palaeocurrents. Vector means are shown with number of measurements, and 95 % confidence limits on the vector means.

Table 10. *West Ramsays Bjerg Conglomerate Clast Data.*

Height in Section (m)	Mean Maximum Clast Sizes (cm) Granite	Quartzite	Carbonate	Percentage Composition G	Q	C
85.1	4.7	8.8	5.2	15	50	35
78.1	15.0	13.4	9.8	30	35	35
70.6	4.9	6.2	4.9	20	40	40
68.6	4.7	5.4	6.0	25	35	40
59.1	4.0	7.5	8.3	5	35	60
52.1	–	6.4	5.0	0	40	60
45.1	6.2	10.1	8.1	25	35	40
37.1	8.3	7.6	7.7	20	35	45
28.1	26.1	13.8	12.7	25	35	40
24.1	14.4	12.4	7.0	25	35	40
21.1	2.7	6.8	5.9	10	40	50
17.1	2.0	3.9	6.2	5	20	75
15.8	6.0	10.8	8.5	10	30	60
14.6	4.3	4.3	4.8	25	25	50
8.6	14.2	11.9	13.2	35	20	45
0.6	11.5	9.8	9.9	35	20	45
0	5.2	5.9	6.2	30	30	40

On eastern Ramsays Bjerg, the lower part of the Group begins with a 30 m conglomerate similar in composition to the West Ramsays Bjerg conglomerate. This is followed by the *East Ramsays Bjerg Sandstone Formation*, consisting largely of grey fine sandstones (7A, grey-f., v.f. sst.-trough X, flat; 7B, grey-f., v.f. sst.-flat, trough X; 7C, grey-v.f., f. sst., co. slst.-flat, trough X) with red (5A, red-co. slst., v.f. sst.-asym. rip.) and grey (4E, grey-co., m. slst.-asym. rip., flat) siltstones, (Fig. 40), becoming finer grained higher up. On the northwest flank of the mountain, the contact with the overlying conglomerate is not exposed. A large basic dyke does not intrude the conglomerate, and although the nature of sedimentation suddenly changed here, the evidence for an intervening erosion phase (BÜTLER, 1959, p. 84) is not conclusive; the contacts are not exposed, and no clasts of the dyke rock are found in the conglomerate. Palaeocurrents in the underlying sandstones trend northeastwards, so that no major change in drainage direction is involved (Fig. 42). If the correlation of the West Ramsays Bjerg Conglomerate Formation with the lower part of the Vilddal Group is correct, most of the East Ramsays Bjerg sandstones must represent a stratigraphic level lower than any seen in the Kap Franklin area.

Agassiz Bjerg

On the east side of the Gastisdal graben, downthrown south of the La Cours Bjerg crystalline area, a thick *Red-and-green banded Siltstone*

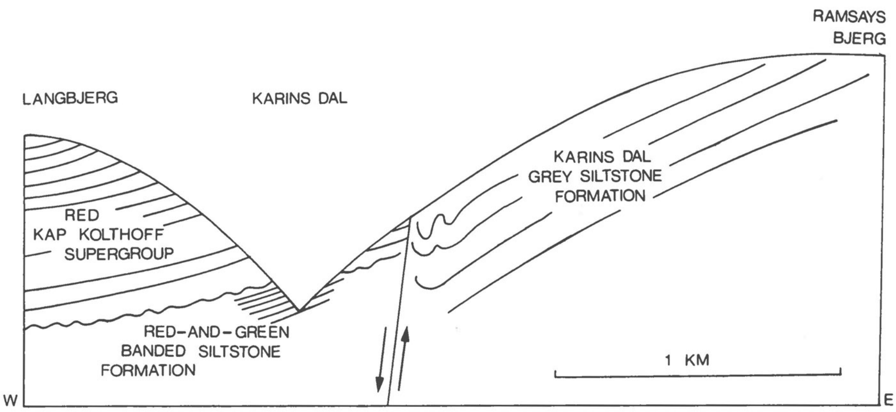


Fig. 43. Sketch cross-section of Karins Dal.

Formation occurs. This differs from the upper part of the Vilddal Group only in that red (5C, red-co. slst., v.f. sst.-flat, asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.) and green (4E, grey-co., m. slst.-asym. rip., flat; 4D, grey-co., m. slst.-flat.) bands (Fig. 40) are individually thicker (over 60 m). Palaeocurrents (Fig. 42) trend ESE.

Bütler (1959, p. 130) recognised the lithological similarity to the lowest Devonian rocks in Hudson Land, and therefore referred this formation to his "Basal Series", considered older than the Ramsays Bjerg succession. However the only locality where the stratigraphic relations of his two divisions are visible is around the "Inlier", at the west end of Moskusoksefjord, where both are represented by conglomerates.

If, on the other hand, the proposed correlations with the Vilddal Group are correct, we should expect to find red-and-green banded siltstones on top of the Karins Dal Grey Siltstone Formation, i.e. on the southwest slopes of Ramsays Bjerg. That this is the case is confirmed by the view from the top of Langbjerg, of red-and-green banded screes on these slopes, and by recording short sections (7A, grey-f., v.f. sst.-trough X, flat; 4E, grey-co., m. slst.-asym. rip., flat) with south and southeasterly palaeocurrents in Karins Dal stream gorge, near the exit of the western Ramsays Bjerg glacier, and underneath the Kap Kolthoff Supergroup sandstones of Langbjerg. Much of the banded siltstones is missing because of a fault along the valley, downthrowing to the west (see Fig. 43). Bütler's "Basal Series" is therefore the same as the Ramsays Bjerg Group in eastern Moskusoksefjord and in Hudson Land.

Høgboms Bjerg

On the north side of the fjord, west of the Høgboms Bjerg thrust (Bütler, 1959, pp. 95–100), the Ramsays Bjerg Group, dipping pre-

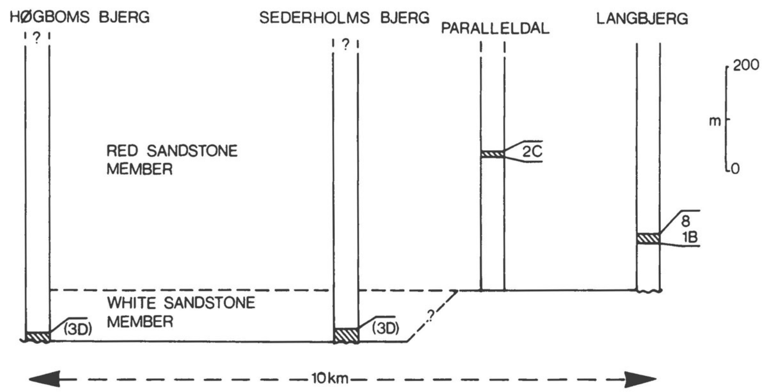


Fig. 44. Lower part of Kap Kolthoff Supergroup in eastern Moskusoksefjord, stratigraphic distribution of sample groups. Correction: Red Sandstone Member should be Red Sandstone, and White Sandstone Member should be Grey Sandstone.

dominantly to the west (BÜTLER, 1959, p. 55) is represented only by the Red-and-green banded Siltstone Formation. Here the formation is of the order of 1500 m thick; in addition to the usual red (5A, red-co. slst., v.f. sst.-asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.) and green (4E, grey-co., m. slst.-asym. rip. flat; 4D, grey-co., m. slst.-flat; 4C, grey-m., co. slst.-flat) siltstone sample groups, we note the presence of grey-medium (3D, grey-m., co. sst.-trough X) and fine (7A, grey-f., v.f. sst.-trough X, flat) sandstone (Fig. 40). Palaeocurrents trend south, passing up succession into a more easterly trend (Fig. 42). Small unidentified crossopterygian scales in the lower part (4C, grey-m., co. slst.-flat) may belong to the *Gyroptychius groenlandicus* fauna.

Sediments incorporated in the Høgboms Bjerg thrustmass are thought to include lower levels of the Ramsays Bjerg Group (BÜTLER, 1959, p. 97). They are very highly deformed and we have not examined them.

Kap Kolthoff Supergroup

This Supergroup is up to 2 km thick in Moskusoksefjord (BÜTLER, 1959, p. 165). The lowest part outcrops in the eastern part of the fjord, to the west of the Ramsays Bjerg Group.

On the east side of Langbjerg, the Kap Kolthoff Supergroup rests with apparent concordance on the Red-and-green banded Siltstone Formation. A thin grey pebbly horizon occurs at the base, containing clasts of red granite and quartzite. The following few hundred metres consist almost entirely of red, medium and fine sandstones (sample groups 2C, red-m., co. sst.-trough X; 1B, red-f. sst.-trough X, flat; 8, red-v.f., f. sst.-flat, trough X) (Fig. 44), with palaeocurrents trending north to northwest (Fig. 45). These are named the Langbjerg Red Sandstone. Exposures are poor, as the sandstones disintegrate readily

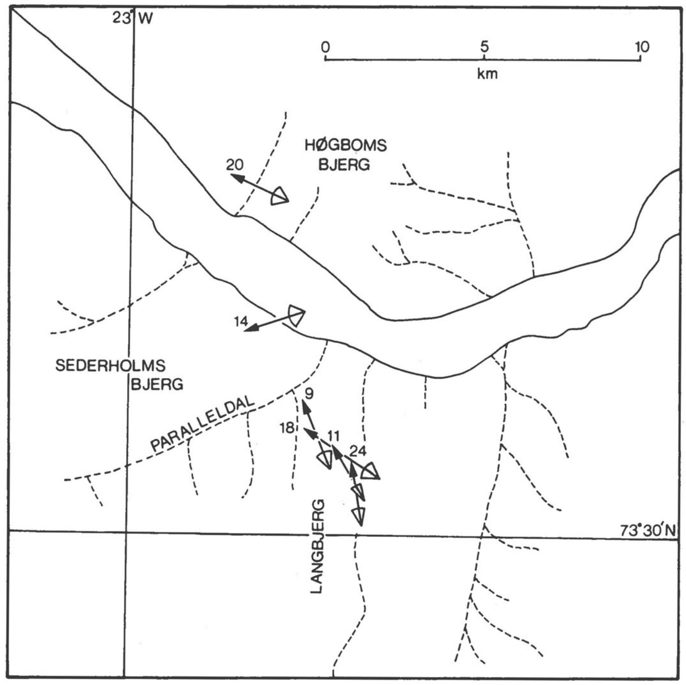


Fig. 45. Lower part of Kap Kolthoff Supergroup in eastern Moskusoksefjord, palaeocurrents. Vector means are shown with number of measurements and 95 % confidence limits on the means.

into scree; the lithology is similar to the Randbøl Formation red sandstones on Saxos Bjerg, but finer grained. The abrupt reversal of palaeocurrent direction and change of sediment type from the Ramsays Bjerg Group makes BÜTLER's (1959, p. 86) suggested gradual transition between the two groups unlikely.

On the northeast flank of Sederholms Bjerg, the base of the Kap Kolthoff Supergroup appears at 300 m altitude (not as shown by BÜTLER (1959, Plate 3)). Again the local dip is concordant with the underlying Ramsays Bjerg Group, but the latter is represented here by the Karins Dal Grey Siltstone Formation; the contact is erosional and overlain by a 2 m thick pebbly band containing pink granite, quartzite, and some (20 %) limestone clasts. The overlying coarse and medium sandstones are whitish-grey, and are named the Sederholms Bjerg Grey Sandstone; cross-set thickness increases from 10–30 cm up to 50 cm up succession, and the sandstones become red much higher up the mountainside. Palaeocurrents trend southwest (Fig. 45).

West of Høgboms Bjerg, on the north side of the fjord, the same Grey Sandstone Formation occurs, 100 m thick, resting concordantly this time on 1500 m of the Red-and-green banded Siltstone Formation. White quartzite and pink granite pebbles up to 4 cm in size occur, and cross-set thickness again increases from 10–20 cm up to 30 cm up succession. Palaeocurrents trend west-northwest (Fig. 45); red sandstones appear higher in the succession along the coast.

In other localities, such as Paralleldal and Karins Dal (Fig. 43), the contact between the two groups is a normal fault downthrowing to the west and south. The changing nature of the substratum of the Kap Kolthoff Supergroup in the various localities means that the base must represent an unconformity: the concordance with the substratum indicates that deformation of the Ramsays Bjerg Group occurred as block-faulting rather than folding. In particular, a large pre-Kolthoff fault must run under Moskusoksefjord, downthrowing to the northeast. Whether the Grey Sandstone Formation around the fjord is older than, or the same age as, the Langbjerg Red Sandstone cannot be determined. In either case, two drainage systems are involved: 'grey' sandy streams draining westwards, and the 'red' sandy streams draining northwestwards.

Structural Sequence

In eastern Moskusoksefjord, there is no evidence for a phase of north-south compression during the Middle Devonian, such as affected the Vilddal Group at Kap Franklin. The Ramsays Bjerg Group, however, was subject to pre-Kolthoff block-faulting. Together with the overlying Kap Kolthoff Supergroup, it was folded with axial traces striking NNE, and overlain with marked angular unconformity by the lower Kap Graah Group conglomerates on west Høgboms Bjerg (BÜTLER, 1959, p. 56) (Hudson Land phase 3). The latter are in turn partly overridden by the Høgboms Bjerg thrust (Hudson Land phase 4): on the south side of the fjord, on the northwest side of Sederholms Bjerg, this is represented by a high angle fault separating the tilted lower part of the Kap Graah Group on the west from crumpled Kap Kolthoff Supergroup on the east (BÜTLER, 1959, Figs. 18, 19), the whole complex being unconformably overlain by conglomerates and sandstones of the upper part of the Kap Graah Group, followed by the Mt. Celsius Supergroup. These show a broad gentle folding with NNE-striking axes, referred to the early Carboniferous Ymers Ø phase (BÜTLER, 1959, p. 82).

Along the eastern boundary fault of the post-Carboniferous Gastisdal graben, a wedge of granitic material is intruded. Nearly vertical foliation in this rock strikes 080° (true), suggesting a horizontal sinistral shear component along this fault. The magnitude of lateral displacement cannot be estimated, but we have no reason to believe that it was large. However, the possibility is raised of the existence of larger-scale sinistral strike-slip faults further east towards or beyond the Greenland coast.

Summary

The Middle Devonian Ramsays Bjerg Group, consisting dominantly of fine-grained sediments, was deposited by streams flowing mainly eastwards. The upper part of the group correlates with the Vilddal Group at Kap Franklin, not the Randbøl Formation as suggested by Bütler (1959, p. 171). After a phase of block-faulting, these rocks were unconformably overlain by the coarser sandstones of the Kap Kolthoff Supergroup. These were deposited by westerly flowing streams: the formation of new granitic source areas in the east, together with lithological similarities suggests a possible correlation of the lowest part of this Supergroup with the Randbøl Formation. The transition phase in reversal of palaeoslope, preserved in the Kap Franklin Formation, is not recorded here: either the Kap Franklin sediments were never deposited here, or they were eroded away. The latter is likely, because the Randbøl Formation rests unconformably on progressively lower horizons of the Kap Franklin Formation northwards along the Giesecke Bjerge. The thick red rhyolite dykes intruded above each of the Ramsays Bjerg conglomerates may represent the Kap Franklin magmatic activity.

The uplift and erosion associated with Upper Devonian deformation phases (Hudson Land phases 3,4) mark the partial incorporation of the area east of the Høgboms Bjerg-Sederholms Bjerg line into the eastern margin of the basin.

HUDSON LAND

Stratigraphic Outline

Two main Devonian outcrop areas in eastern Hudson Land (Fig. 46) were visited: 1) lower Stordal and Nordhoeks Bjerg,
and 2) upper Ankerbjergsdalen.

The main stratigraphic divisions in each of these areas are shown in Table 11.

Table 11. *Stratigraphic Outline Eastern Hudson Land.*

Major Unit	Age	Estimated thickness (m)	
		Ankerbjergsdalen	Stordal
Kap Graah Group	Upper Devonian	500	Not. pres.
Kap Kolthoff Supergroup	Middle & Upper Devonian	700	Not. pres.
Nordhoeksbjerg Group (Vilddal Supergroup)	Middle Devonian	1300	2200

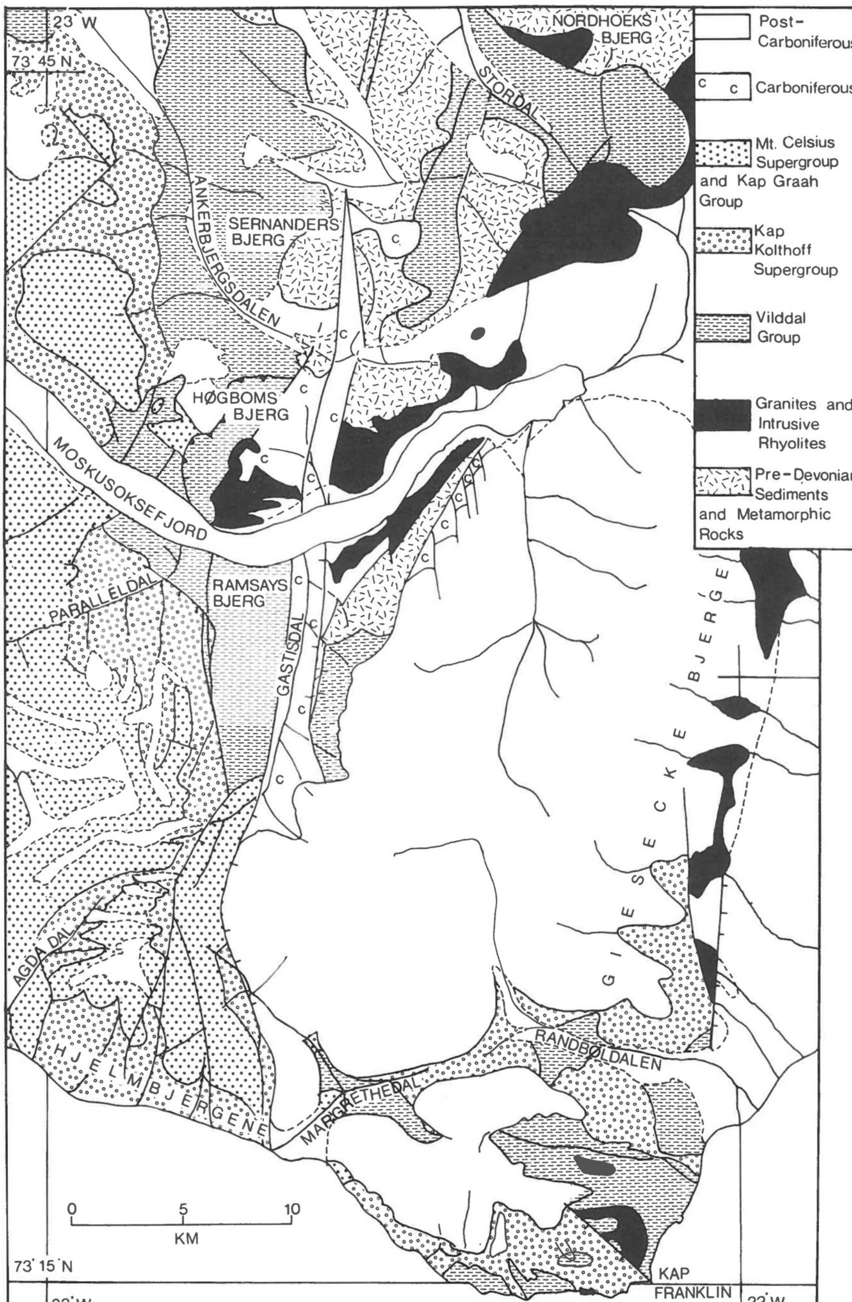


Fig. 46. Simplified geological map of Kap Franklin, Eastern Moskusoksefjord and East Hudson Land. Modified after KOCH & HALLER (1972).

Review of Age

The Kap Graah Group and Kap Kolthoff Supergroup of this area are continuous with the same units around Moskusoksefjord (BÜTLER 1959, Plate 3) where they are Upper and upper- Middle Devonian in age. In the lowest division in Hudson Land, the Nordhoeksbjerg Group (BÜTLER's (1959, p. 167) 'Basal Series'), we collected the macroplant fossil *Thursophyton milleri* (H. P. BANKS, rapid identification, April 1971), referred to the Middle Devonian, and samples containing the following spores: *Punctatisporites*, *Ancyrospora*, *Grandispora diamphida*, *Perotrilites? eximius*, *Samarisporites* (K. C. ALLEN, written communication, June 1971). Evidence for correlation with the Vilddal Group at Kap Franklin is given below.

Nordhoeks Bjerg

On Nordhoeksbjerg, no Devonian rocks younger than the *Nordhoeksbjerg Group* are preserved. This Group rests unconformably, but without dip discordance, on low-grade metamorphic rocks (quartzites, phyllitic pelites) of the Eleonore Bay Group, and is over 2 km thick. The stratigraphic subdivisions are listed in Table 12.

The basal, 300 m thick conglomerate consists almost entirely of limestone and quartzite clasts. The overlying Sandstone-and-siltstone Formation consists of closely alternating grey sandstone and red siltstone bands, sometimes thicker than 10 m (eg. grey sandstones: 3C, grey-m., f. sst.-trough X, flat; 3D, grey-m., co. sst.-trough X; 7E, grey-f. sst.-trough X; red siltstones: 5A, red-co. slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.), sometimes thinner (eg. mixed facies: 7D2, grey-v. f., co. sst.-trough X, flat; 2A, red-m., f. sst.-trough X, flat) (Fig. 47), and not unlike the Pebbly Sandstone-and-siltstone Formation of the Vilddal Group and the top of the West Ramsays Bjerg Conglomerate Formation. Palaeocurrents (Fig. 48) are to the east.

The following 300 m formation of green, cross-stratified medium (3D, grey-m., co. sst.-trough X) and fine (7B, grey-f., v.f. sst.-flat, trough X; 7C, grey-v.f., f. sst., co. slst.-flat, trough X) sandstones (Fig. 47),

Table 12. *Nordhoeksbjerg Group Subdivisions.*

Unit	Estimated thickness (m) (Nordhoeks Bjerg)
Red-and-green banded Siltstone Formation	1500
Green Sandstone Formation	300
Sandstone-and-siltstone Formation	100
Conglomerate	300

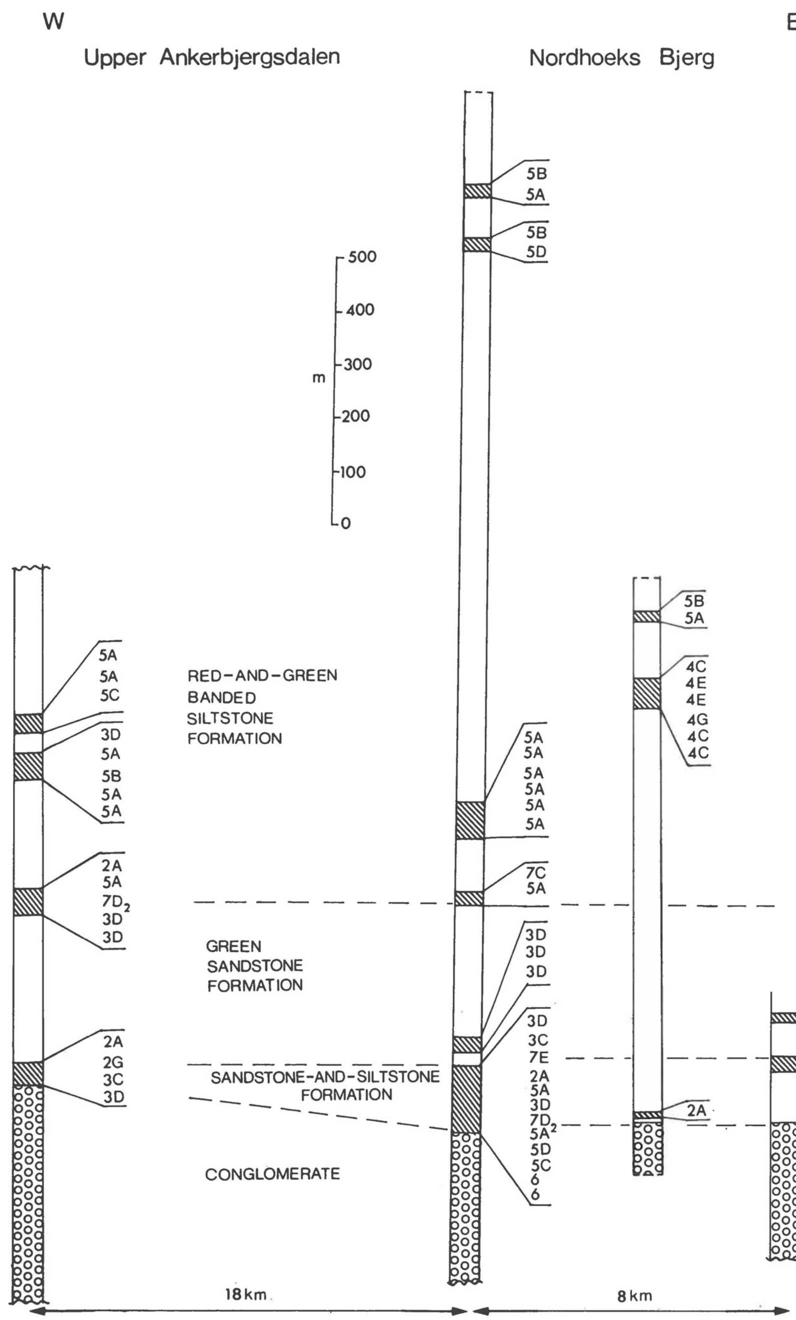
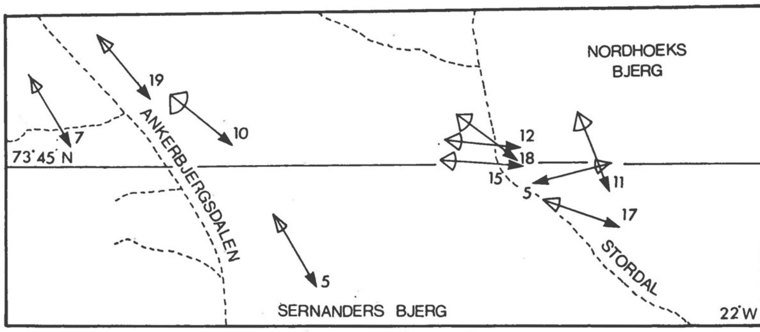
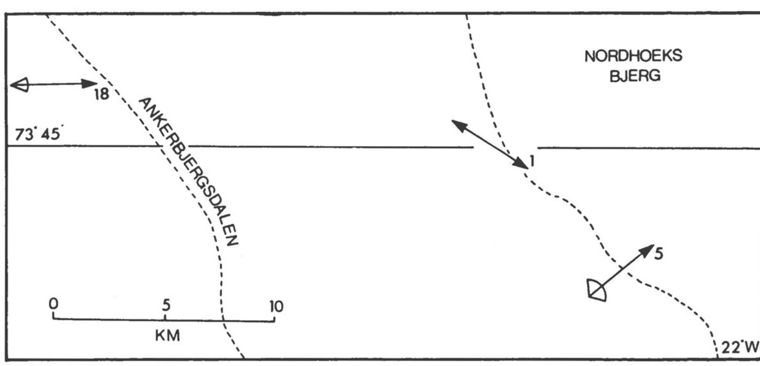


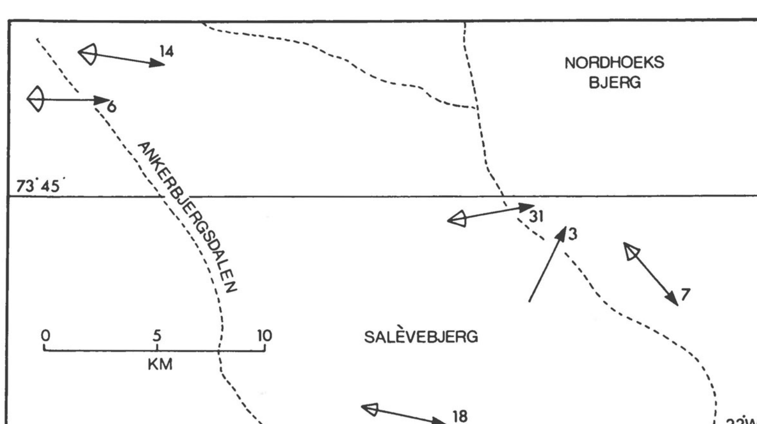
Fig. 47. Nordhoeksbjerg Group, Hudson Land, Stratigraphic distribution of sample groups.



Red-and-green Banded Siltstone Formation



Green Sandstone Formation



Sandstone-and-Siltstone Formation

Fig. 48. Nordhoeksbjerg Group, Hudson Land, palaeocurrents. Vector means are shown with number of measurements and 95 % confidence limits on the means.

at first sight seem difficult to correlate with any part of the Vilddal Group. Its stratigraphic position and thickness suggests that it should be contemporary with the Vilddal Grey Siltstone Formation, but requires that an entirely sandstone succession in the north be replaced by an entirely siltstone succession in the south. That this is the case is demonstrated by the intermediate nature of the equivalent Karins Dal Grey Siltstone Formation in eastern Moskusoksefjord, where the siltstones are interbedded with bands of grey sandstones (7A, grey-f., v.f. sst.-trough X, flat; 7B, grey-f., v.f. sst.-flat, trough X).

The very thick *Red-and-green banded Siltstone Formation* above confirms the correlation with the Vilddal Group: the familiar red siltstones (5A, red-co. slst., v.f. sst.-asym. rip.; 5B, red-co., m. slst.-asym. rip., flat; 5D, red-co., m. slst.-flat, asym. rip.) and green siltstones (4C, grey-m., co. slst.-flat; 4E, grey-co., m. slst.-asym. rip., flat; 4G, grey-co. slst., v.f. sst.-sym. rip.) form bands on a scale greater than 60 metres (Fig. 47), and palaeocurrents again trend towards east-southeast (Fig. 48). As in the Kap Franklin area, a little grey very fine sandstone (7C, grey-v.f., f. sst., co. slst.-flat, trough X) appears near the base of the formation.

Ankerbjergsdalen

Here the Nordhoeksbjerg Group rests unconformably on marble of the Eleanor Bay Group; the total thickness is reduced to ca. 1300 m, but the basal conglomerate division has thickened to 700 m, and contains granite and metamorphic clasts as well as quartzite and limestones, as in the Ramsays Bjerg conglomerates. The divisions recognised further east are not so distinct in Ankerbjergsdalen. Red siltstone (5A, red-co. slst., v.f. sst.-asym. rip; 5B, red-co., m. slst.-asym. rip., flat; 5C, red-co. slst., v.f. sst.-flat, asym. rip.) becomes abundant near the top of the group, but grey medium sandstone bands (3D, grey-m., co. sst.-trough X) are also recorded (Fig. 47), as on west Høgboms Bjerg. Most of the Red-and-green banded Siltstone Formation is missing, though the thickness of the division increases rapidly southeastwards to over 1 km on Sernanders Bjerg. As before, the whole group here shows easterly-trending palaeocurrents (Fig. 48).

The *Kap Kolthoff Supergroup* overlies the Nordhoeksbjerg Group on the west side of the valley, with little dip discordance, but, as in eastern Moskusoksefjord, rests on different stratigraphic levels of the underlying group in various places, and therefore must be unconformable. Locally it begins with a 20 m thick conglomerate containing clasts of granite, quartzite and limestone. The remainder of the Supergroup, as elsewhere, consists almost entirely of sandstone. Here grey medium sandstones (3D, grey-m., co. sst.-trough X; 3C, grey-m., f. sst.-trough X,

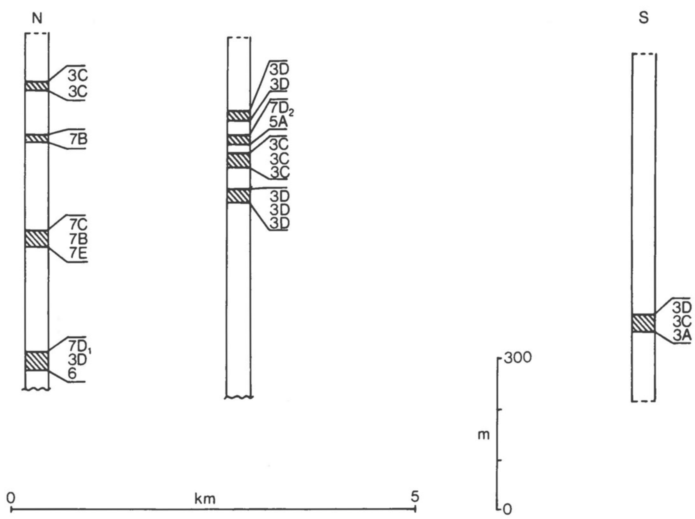


Fig. 49. Kap Kolthoff Supergroup in upper Ankerbjergsdalen, stratigraphic distribution of sample groups.

flat; 3A, grey-f., m. sst.-trough X) and grey fine sandstones (7B, grey-f., v.f. sst.-flat, trough X; 7C, grey-v.f., f. sst., co. slst.-flat, trough X; 7E, grey-f. sst.-trough X) are well represented (Fig. 49), and a single red siltstone band (5A, red-co. slst., v.f. sst.-asym. rip) is recorded. In contrast to the Kap Kolthoff Supergroup on Langbjerg, red sandstones are absent, except in a down-faulted outlier of uncertain stratigraphic position, where red sandstones and siltstones are followed by a conglomerate with clasts of pink granite, gneiss, vein quartz, and quartzite. This may correlate with a conglomerate exposed 50 m below the base of the Kap Graah Group further west near Hoelsbo fangst-station (Number 5 of this volume). The stratigraphic thickness of the division here (700 m) appears much less than along Moskusoksefjord. Palaeocurrents, too, trend southeast (Fig. 50) and evidently represent a different drainage system from the westerly directions recorded in eastern Moskusoksefjord.

Further west, the red sandstones of the Kap Graah Group abruptly overlie the Kap Kolthoff Supergroup, and again little dip discordance can be seen. This contrasts with the pronounced angular unconformity beneath the Kap Graah conglomerates on west Høgboms Bjerg. For an account of the Kap Graah Group further west in Moskusokselandet see Number 5.

Structural Sequence

As in eastern Moskusoksefjord, the first folding phase appears to post-date the Kap Kolthoff Supergroup, but the disparity of stratigraphic thicknesses of the Nordhoeksbjerg Group in Ankerbjergsdalen and

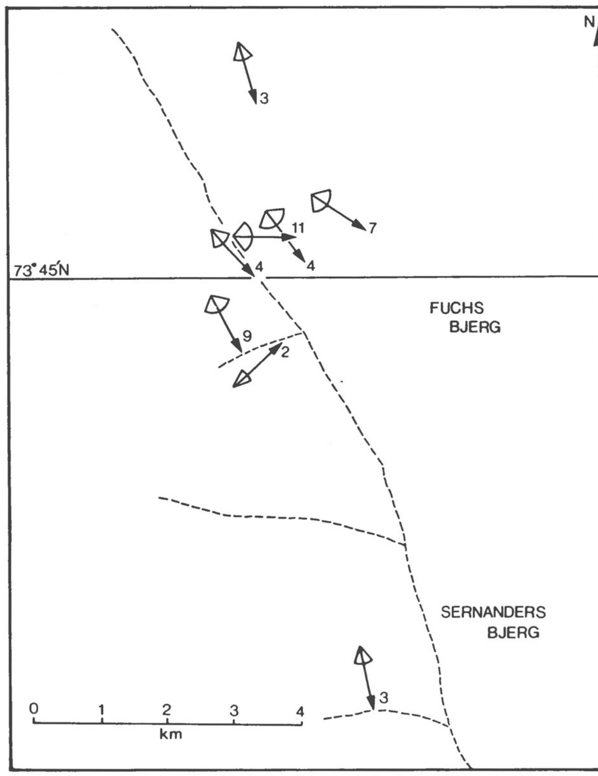


Fig. 50. Kap Kolthoff Supergroup in upper Ankerbjergsdalen, palaeocurrents. Vector means are shown with number of measurements and 95 $^0/_0$ confidence limits on the means.

Stordal suggest that a phase of block-faulting occurred before the Kap Kolthoff Supergroup, and that the uplifted Ankerbjergsdalen block was eroded back from the southeast to new source areas that eventually supplied detritus to the Kap Kolthoff Supergroup streams. The fault may have coincided with the post-Devonian Main Fault line along the Prospektdal-Gastisdal graben, described by BÜTLER (1957).

The folds described by BÜTLER (1940), affecting both the Kap Kolthoff Supergroup and Nordhoeksbjerg Group, have axes plunging SSW. They could have formed before the Kap Graah Group (Hudson Land phase 3), but the evidence here is ambiguous.

Summary

Our correlations of these areas with the Kap Franklin area and with Eastern Moskusoksefjord are summarised on Fig. 51.

The mainly fine-grained sediments of the Nordhoeksbjerg Group were deposited by streams flowing eastwards, and are correlated with

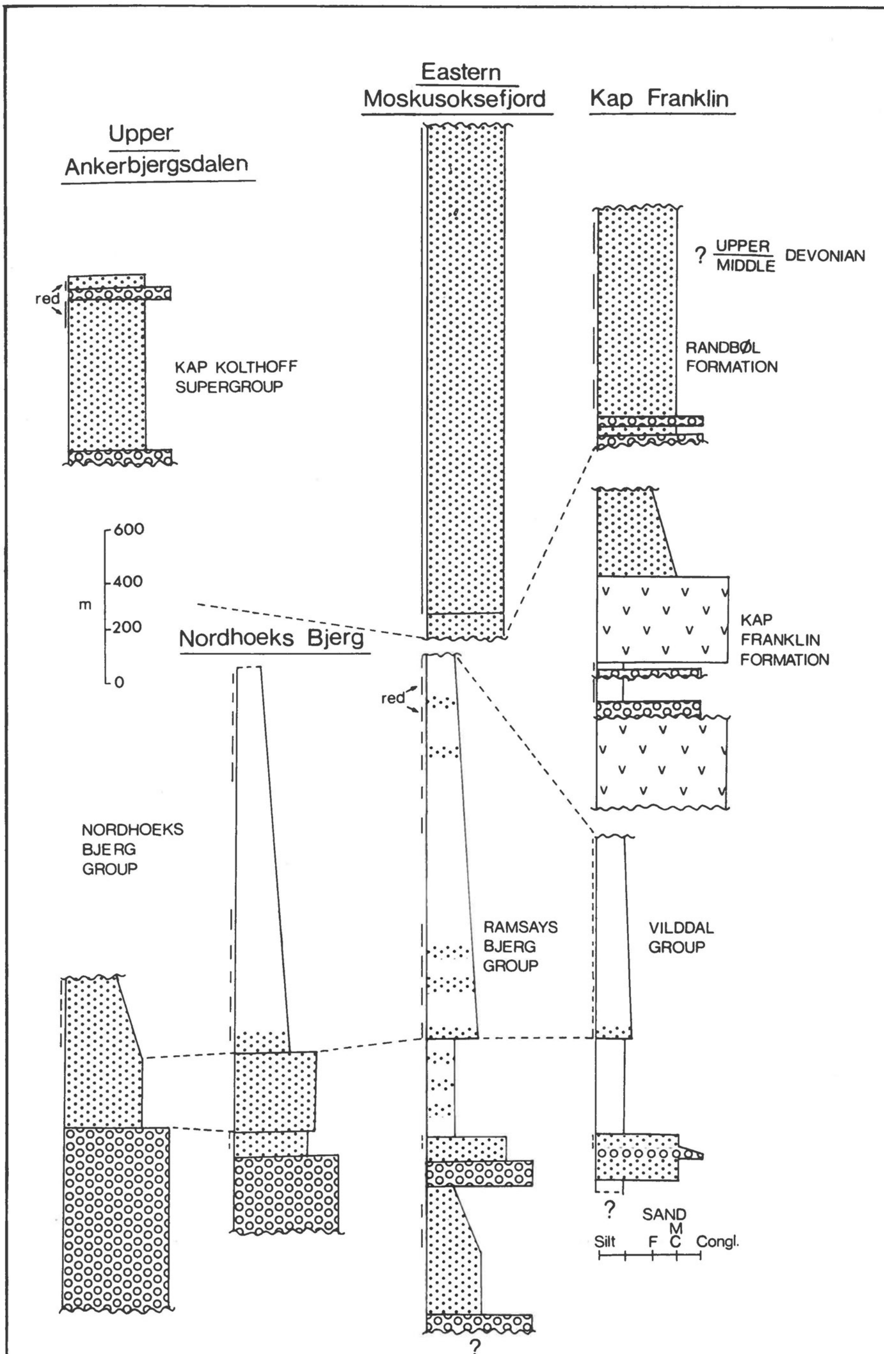


Fig. 51. Proposed correlations north of Kejser Franz Josephs Fjord.

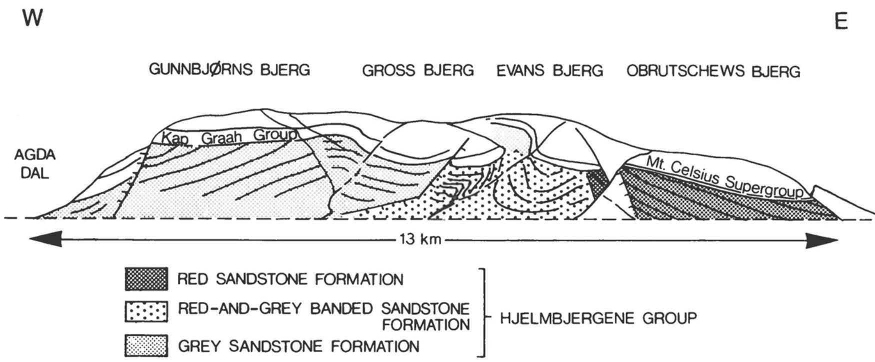


Fig. 52. Sketch of south side of Hjelmbjergene.

the Vilddal Group at Kap Franklin. After faulting and erosion, somewhat coarser grained sandstones of the Kap Kolthoff Supergroup were deposited by streams flowing to the southeast. No great change in direction of palaeoslope was involved therefore. The first evidence of the proximity of an eastern margin to the basin here is perhaps the southwesterly palaeocurrent trend of the overlying Kap Graah Group sandstones (see Number 5).

HJELMBJERGENE

This group of mountains forms the southern coast of Gauss Halvø between Agda Dal and Vestreplateau, just west of Margrethedal. The names of the four mountains, shown on Fig. 52, are taken from SÄVE-SÖDERBERGH (1934, Plate 9).

Stratigraphic Outline

Capping all the mountains, the Mt. Celsius Supergroup and the underlying relatively thin Upper Kap Graah Group (BÜTLER's (1959) basal sandstones of the Mt. Celsius Series, unconformably overlie more highly deformed sandstones, here referred to collectively as the *Hjelmbjergene Group* (Fig. 52).

Review of Age

The age and stratigraphic position of the Hjelmbjergene Group has been a matter for dispute. No determinable fossils have been found in it, and a variety of lithological correlations has been made. SÄVE-SÖDERBERGH (1934) referred all the rocks under the dark Remigolepis Group siltstones to his 'Lower Sandstone Complex', which included the entire Kap Graah Group and Kap Kolthoff Supergroup. KOCH & HALLER's (1972) map shows the grey sandstones at the west end as Kap Kolthoff

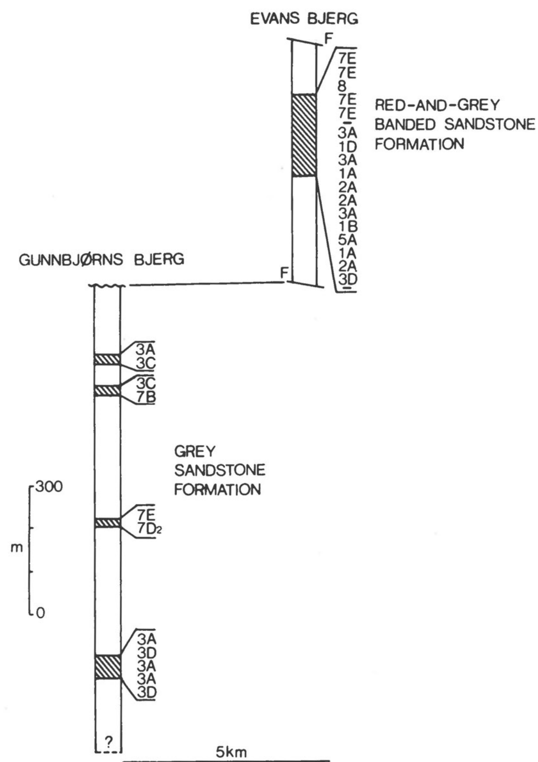


Fig. 53. Hjelmbjergene Group, stratigraphic distribution of sample groups.

Series, and the red sandstones at the east end as Kap Graah Series. BÜTLER (1954, pp. 104–107, Fig. 23) proposed that the same sequence represented the Vilddal Group passing up, and east, into the red Margrethedal 'series'. He later thought that the Ramsays Bjerg Series here passed up into the red Kap Kolthoff Series (BÜTLER, 1959, pp. 165, 166), while admitting a lack of field observations in this area. NICHOLSON (as a member of our Cambridge group) recognised in 1968 that the Hjelmbjergene Group showed no resemblance to either the Kap Kolthoff grey sandstones or the Kap Graah Group exposed further west in Gauss Halvø or at Kap Graah. Either drastic lateral facies changes are involved, or the Hjelmbjergene Group is older than the grey sandstone division of the Kap Kolthoff Supergroup. A possible correlation westwards with the Rødebjerg Formation on the western margin of the basin (Number 4) was suggested.

The critical geographical position of Hjelmbjergene midway between Kap Franklin and eastern Moskusoksefjord indicated the need for further field work here. In 1970, six field-days were spent on this coast. The results, combined with NICHOLSON's data, are summarised below:

Table 13. *Hjelmbjergene Group Subdivisions*

Unit	Estimated thickness (m)
Red Sandstone Formation	800?
Red-and-grey banded Sandstone Formation	500–600?
Grey Sandstone Formation	1100

Hjelmbjergene Group

The lithological divisions, summarised in Table 13, are the same as those described by BÜTLER (1954, Fig. 23).

Hjelmbjergene Grey Sandstone Formation

The lower Grey Sandstone Formation exposed on Gunnbjørns Bjerg and Gross Bjerg, forms a broad NNE-striking anticline, truncated by the upper Kap Graah Group. The base of the formation cannot be seen, and the contact with the Red-and grey Banded Sandstone Formation is a fault passing through the southeast corner of Gross Bjerg. The Grey Sandstone Formation includes medium (3D, grey-m., co. sst.-trough X; 3C, grey-m., f. sst.-trough X, flat; 3A, grey-f., m. sst.-trough X) and fine (7B, grey-f., v.f. sst.-flat, trough X; 7E, grey-f. sst.-trough X) sandstones (Fig. 53). No red sandstones are present, but a red siltstone band is visible high up on the southeast side of Gunnbjørns Bjerg. In this respect, it shows a similar sample group assemblage to the Kap Kolthoff Supergroup recorded by us in Hudson Land, and is only a little coarser-grained than the Kap Franklin Østreplateau Grey Sandstone Member exposed east of Margrethedal. Like the latter too, the sandstones tend to be drab greenish-grey, micaceous, with a dark green chloritic matrix. Occasional pebbles of red rhyolite, in addition to granite and white quartz, indicate that this formation cannot be older than the Kap Franklin volcanics. Palaeocurrents trend generally westwards (Fig. 54), but a mixture of northerly and southwesterly trends is apparent higher up the succession on western Gunnbjørns Bjerg, reminiscent of the interdigitating palaeocurrent systems recorded in the Østreplateau Grey Sandstone.

Hjelmbjergene Red-and-grey banded Sandstone Formation

The middle, Red-and-grey banded Sandstone Formation occupies the lower slopes of Evans Bjerg and the eastern shoulder of Gross Bjerg; isolated outcrops along the coast at the foot of Gunnbjørns Bjerg are probably downfaulted. On Evans Bjerg, the beds are folded into an anticline plunging 40° southwest, again truncated by the upper Kap Graah Group. As in the Grey Sandstone Formation, two palaeocurrent modes are present: a northwest trend passes up succession into a south-

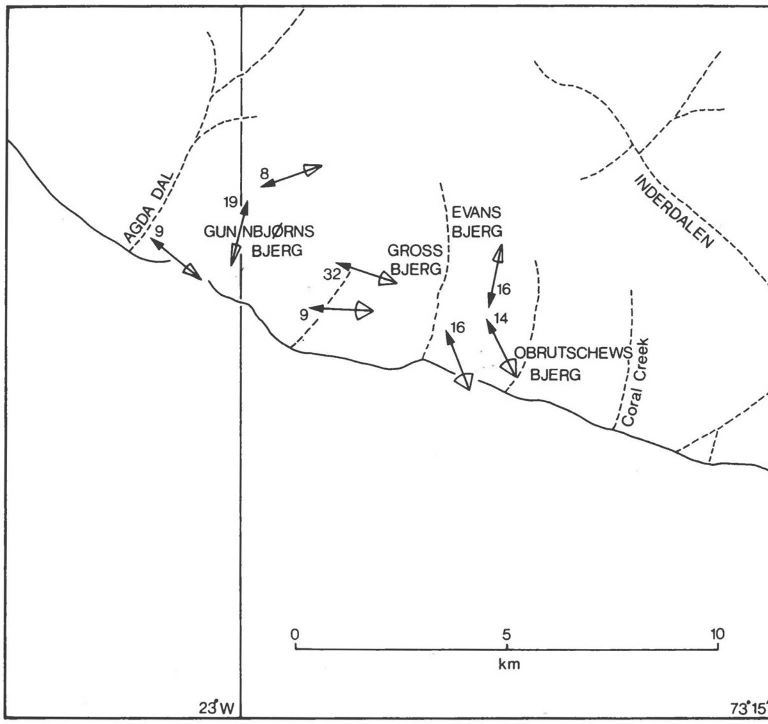


Fig. 54. Hjelmbjergene Group (Grey and Red-and-grey banded Sandstone Formations), palaeocurrents. Vector means are shown with number of measurements and 95 % confidence limits on the means.

ward trend (Fig. 54). However, red medium and fine sandstones appear in bands 10 to 30 m thick, including some sample groups not recorded anywhere else in this region (1A, red-f., m. sst.-flat, trough X) (Fig. 53), and the non-red sandstones are a brighter grey colour with a 'clean' carbonate matrix. The increasing abundance of such sandstone at the top of the Grey Sandstone Formation indicates a transition between the two formations, although the actual contact is a fault. Large-scale cross-stratified sets up to 3 m thick, often with bottomsets, are developed, and certain pebbly sandstone horizons high in the succession contain clasts of quartzite, red granite, red rhyolite and greenish sandstones of Østreplateau type.

Hjelmbjergene Red Sandstone Formation

The upper, Red Sandstone Formation is exposed on the north and south sides of Obrutschews Bjerg. The contact with the Red-and-grey banded Sandstone Formation is another pre-Kap Graah Group fault, on the southeast corner of Evans Bjerg, but we agree with Bütler (1954, p. 105) that a transition may exist, though not exposed. Red fine sandstones (1C, red-f., m. sst.-trough X, flat) with small pebbles of red granite, schist and quartzite, pass up succession eastwards into red medium sandstones (2A, red-m., f. sst.-trough X, flat; 2B, red-m., f. sst.-trough X, flat; 2F, red-f., co. sst.-trough X; 2G, red-m., f. sst.-trough X, flat) (Fig. 35), the palaeocurrents changing from eastwards to northwestwards (Fig. 36). A purple mudflow, 5 m thick, containing numerous scattered clasts, up to 2 cm., of green siltstone with some red rhyolite and quartzite, in a muddy matrix, outcrops higher in the succession at the southeast corner of Obrutshews Bjerg and in 'Coral Creek' (stream at the east end of the mountain named by KOCH (1931)).

There is no sign of the Rødedal Conglomerate which BÜTLER (1954, p. 102) claimed to have seen on the east side of Obrutschews Bjerg; however, on the north side of the mountain, we found a small outcrop of conglomerate containing approximately equal proportions of clasts, (mean maximum 6.6 cm), of red granite, quartzite, and low-grade semipelites, including the distinctive spotted rock type found in many conglomerates in the Randbøl Formation further east. Palaeocurrents from cross-stratification indicate flow southwestwards, i.e. away from the Randbøl conglomerate dispersal area in the Giesecke Bjerge, already postulated, while the overlying red sandstones were deposited by currents flowing northwestwards, in line with those on Saxos Bjerg (Fig. 36). Lithology, clast types and palaeocurrents all therefore support a correlation of this formation with the Randbøl Formation and with the Langbjerg Red Sandstone of the Kap Kolthoff Supergroup.

Structural Sequence

The folding of the Hjelmbjergene Group certainly occurred before the upper part of the Kap Graah Group was deposited unconformably on it. How much each of the Hudson Land Phases 3 and 4 (BÜTLER, 1959, p. 180) contributed is impossible to say. The upper part of the Kap Kolthoff Supergroup and probably the lower part of the Kap Graah Group are missing east of Agda Dal, which therefore forms a southward continuation of the tectonic dislocation through eastern Sederholms Bjerg and Høgboms Bjerg. Our colleague NICHOLSON suggests that debris eroded from the Hjelmbjergene block was already being deposited in lower Kap Graah Group times around Kap Graah, indicating uplift taking place during Hudson Land Phase 3. The basic dykes intruded into the Hjelmbjergene Group in various places and truncated at the Upper Kap Graah Group unconformity were probably part of the basaltic volcanic episode preserved at the base of the Lower Kap Graah Group on Kap Graah.

East of the post-Devonian Main Fault complex, in Margrethedal, the upper Kap Graah Group and Mt. Celsius Supergroup rest unconform-

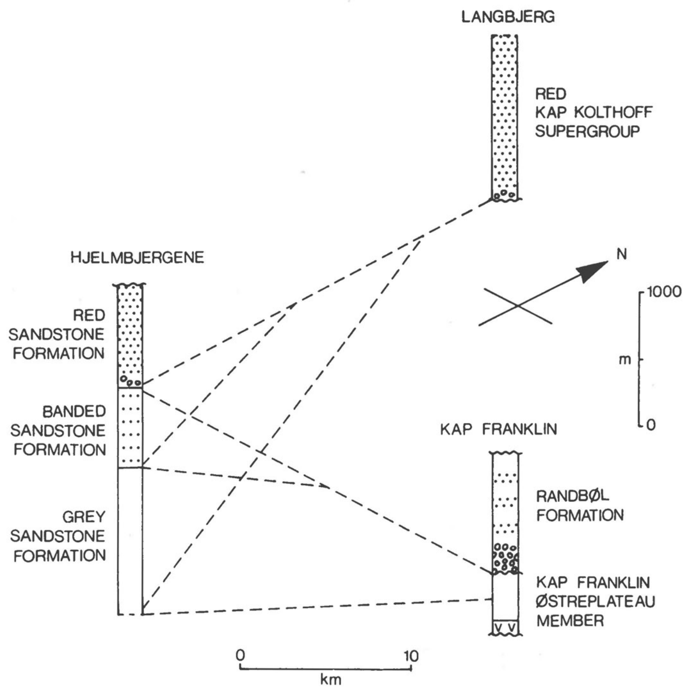


Fig. 55. Proposed correlation of Hjelmbjergene Group. In this diagram, stipple indicates redness.

ably on the Middle Devonian Vilddal Supergroup. In view of the southeasterly dip of the Hjelmbjergene Red Sandstone Formation, this indicates a westward downthrow of over 2 km along the fault before upper Kap Graah times, analogous to the movement at the northeast end of Sederholms Bjerg.

Summary

The Hjelmbjergene Group, a very thick, essentially continuous succession of grey-green and red sandstones, was deposited by streams flowing predominantly westwards, though it is clear that a number of drainage systems with northerly and southerly components was involved.

The lower, Grey Sandstone Formation probably correlates with the upper part of the Kap Franklin Formation (Østreplateau Grey Sandstone Member) further east, but is not preserved around eastern Moskusoksefjord. The upper, Red Sandstone Formation correlates both with the lowest part of the Kap Kolthoff Supergroup on Langbjerg (as Bütler (1959, p. 165) supposed), and also with the Randbøl Formation around Kap Franklin. The whole of the group is therefore largely Middle Devonian in age, but younger than the reversal of palaeoslope recorded at Kap Franklin. The middle, Red-and-grey banded Sandstone Formation is not preserved anywhere else in Gauss Halvø: it

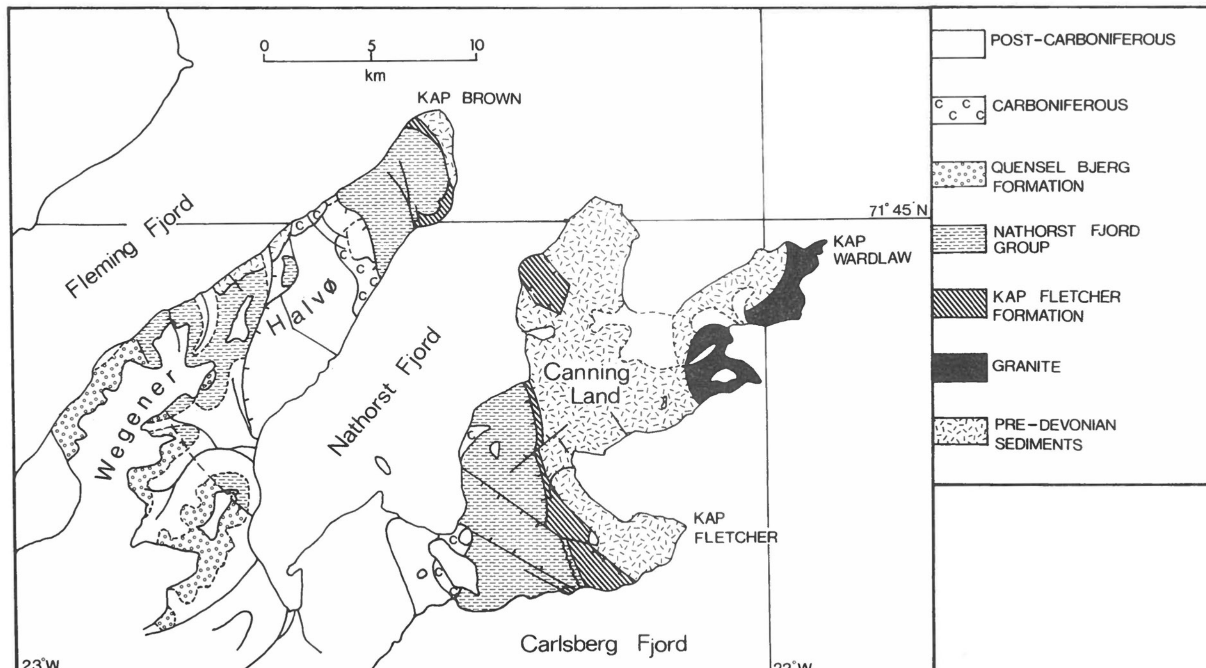


Fig. 56. Simplified geological map, Wegener Halvø and Canning Land, modified after Bütler (1948, pl. 4), Säve-Söderbergh (1937, pl. 2), Grassmück & Trümpy (1969, pl. 1).

Table 14. *Stratigraphic Outline. Canning Land and Wegener Halvø.*

Major Unit	Age	Estimated thickness (m)
Quensel Bjerg Formation (Kap Kolthoff Supergroup)	Middle to Upper Devonian	at least 350
Nathorst Fjord Group (Vilddal Supergroup)	Middle Devonian (Givetian)	1550
Kap Fletcher Formation	?Lower or lower Middle Devonian	?1000

was probably deposited here during the phase of erosion marked by the Randbøl basal unconformity further east (diagram, Fig. 55). This differential downwarp to the west foreshadowed the faulting between the Giesecke Bjerge and Hjelmbjergene blocks which accompanied the folding of the group and uplift before and during deposition of the Kap Graah Group. Only the top part of the latter (Number 5 of this Volume) followed by the Mt. Celsius Supergroup, unconformably overlies the Hjelmbjergene Group.

CANNING LAND AND WEGENER HALVØ

Stratigraphic Outline

The Devonian succession here is divided into three primary lithologic divisions, each separated by unconformities. (Table 14, map Fig. 56).

Review of Age

The lowest, volcanic Kap Fletcher Formation, has yielded no fossils, and its exact age is therefore unknown. It rests unconformably on the Pre-Cambrian Eleonore Bay Group, and is unconformably overlain by the Middle Devonian Nathorst Fjord Group. Bütler (1948, p. 88) regarded the Kap Fletcher volcanics as lower Middle, or Lower, Devonian in age.

The dominantly silty Nathorst Fjord Group contains a succession of Middle Devonian vertebrates and plants (Jarvik, 1961): the arthrodires *Heterostius* sp., *Homostius* sp.; the antiarch *Asterolepis säve-soderberghi* Stensiö; and the small crossopterygian *Gyroptychius groenlandicus* Jarvik; (Säve-Söderbergh (1937, p. 29), Stensiö & Säve-Söderbergh (1938), Jarvik (1950a)); and the plants *Thursophyton* sp., *Psilophyton* sp., and *Drepanophycus* sp., *Milleria* sp. (formerly *Protopteridium*), (H. P. Banks, rapid identification, April 1971).

The conglomerates and sandstones of the Quensel Bjerg Formation are very poor in fossils: Säve-Söderbergh (1937, p. 20, Fig. 5) found

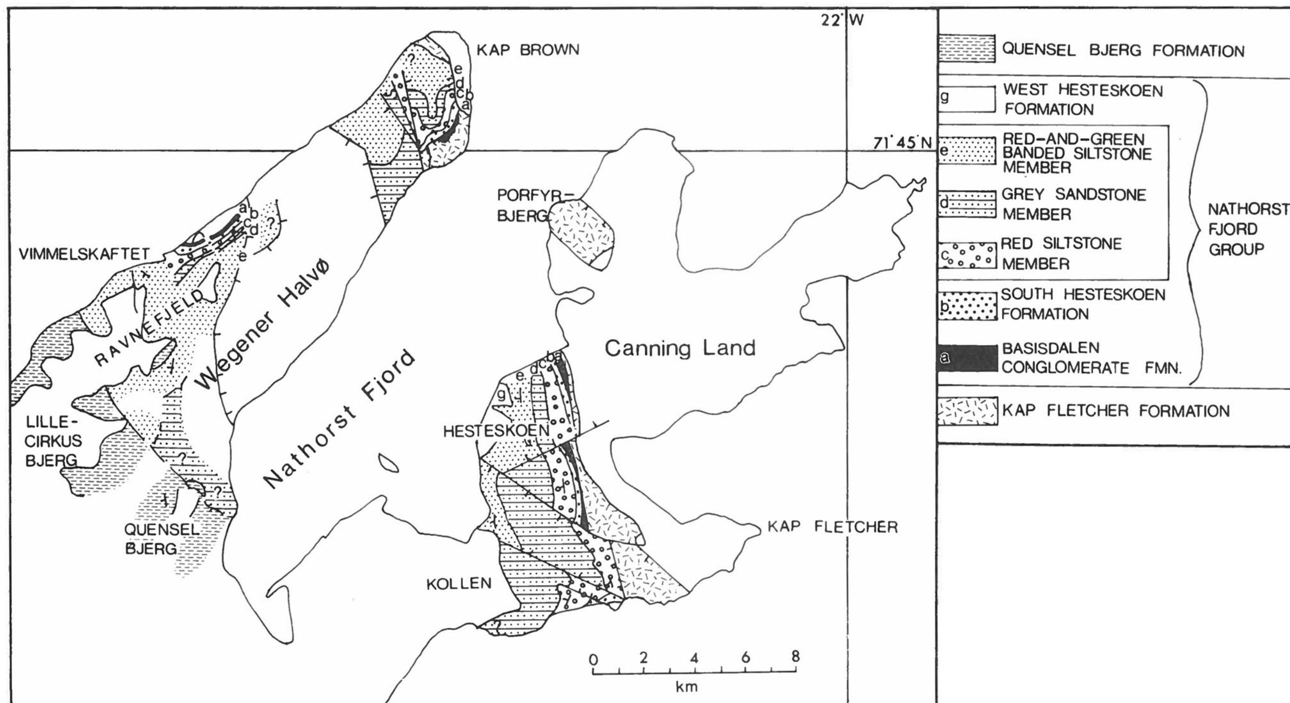


Fig. 57. Devonian geology, Wegener Halvø and Canning Land, modified after Bütler (1948, pl. 4), Säve-Söderbergh (1937, pl. 2), Grassmück & Trümpy (1969, pl. 1).

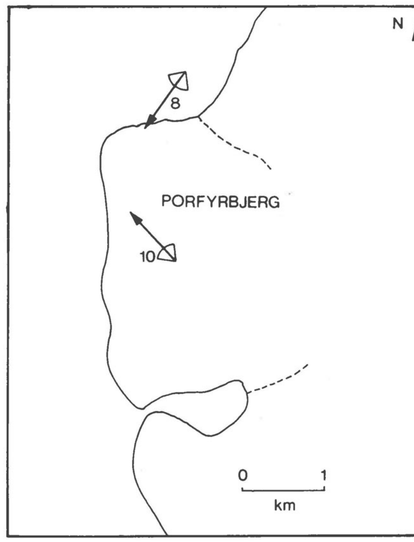


Fig. 58. Palaeoflow data of lava of the Kap Fletcher Formation on Porfyrbjerg, North Canning Land. Vector means are shown with number of measurements and 95 % confidence limits on the means.

a scale of the *Holoptychius* type, and tentatively assigned an Upper Devonian age to the formation. No determinable fossils were found by us in 1969.

Kap Fletcher Formation

Surficial rocks of this Formation outcrop in the mountain west of Kap Fletcher; on Porfyrbjerg; and at Kap Brown (map Fig. 57). Dykes, which NOE-NYGAARD (1937, p. 54) interpreted as a deeper level in the volcanic structure, intrude the Eleonore Bay Group at Kap Fletcher, Kap Brown and near Vimmelskaftet on Wegener Halvø (BÜTLER, 1949).

The basal unconformity of the Kap Fletcher Formation is nowhere exposed, but is inferred from the composition of the thin (not more than 10 m) basal conglomerate: dominantly limestones and dolomites, with 10 to 30 % quartzites and occasional grey shales, all derived from the underlying Eleonore Bay Group. There is no evidence for NOE-NYGAARD's (1937, p. 94) claim that volcanism had already occurred before deposition of the conglomerate. On southeast Porfyrbjerg, an influx of (75 %) quartzite clasts at the top of the conglomerate may represent a shift of drainage channels on the alluvial fan during local seismic disturbances preparatory to the onset of volcanism. The overlying 80 m of ash was itself disturbed and brecciated while only partially lithified (Plate 6).

As with the Kap Franklin volcanics, the first volcanic products are pyroclastics, with lavas becoming dominant higher up the succession.

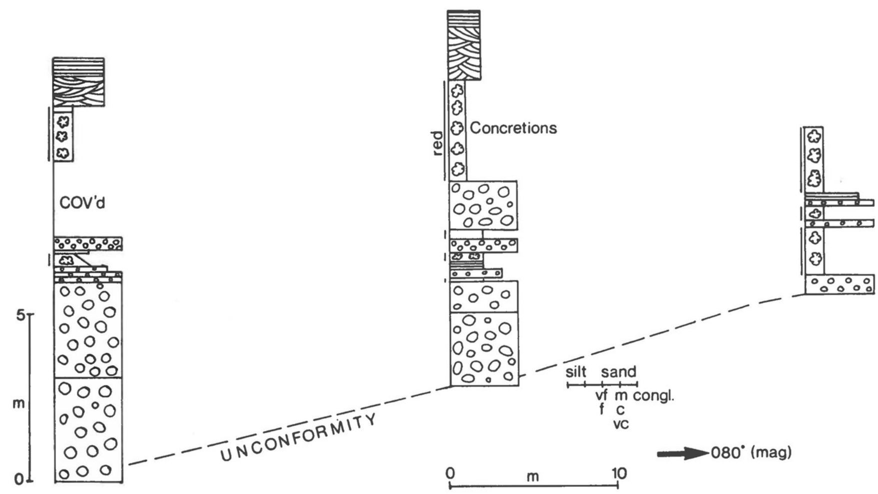


Fig. 59. Conglomerate-siltstone relations, above unconformity at base of Nathorst Fjord Group, Kap Brown.

The presence of a vague cross-stratification indicates occasional reworking of ash by streams, but there are no sediments analogous to the volcanic 'pause' of the Kap Franklin Formation.

The lavas have more intermediate compositions (rhyodacite, latite) (NOE-NYGAARD, 1937, p. 25) than the Kap Franklin rhyolites. Phenocryst assemblages include: quartz + K-feldspar + plagioclase + pseudomorphs after pyroxene; plagioclase + biotite + pseudomorphs after pyroxene. The lavas near Kap Fletcher are massive and apparently structureless; those further north, on Porfyrbjerg, show flow banding, lineation of flow surfaces, and flow-folding. Measurements of the direction of overfolding (Fig. 58, Plate 7) from two localities yielded vector mean flow directions (CHRISTIANSEN & LIPMAN, 1966) 100° apart. This is probably due to sampling (a) two different stratigraphic levels, and (b) the coulées from two separate eruption centres; this situation is similar to the pattern of small-scale volcanic eruptions from a number of vents or fissures inferred in the Kap Franklin area. Where the lavas are interbedded with ashes, the shape of a flow-complex is seen in section, in one example as a lens of radius $^1/_2$ km and maximum thickness 60 m.

RITTMANN (1940, p. 91) refers to morainic fragments of rhyodacites of similar type collected from Segelsällskapets Fjord (72°25′N.); this phase of volcanism therefore may not have been restricted to the Canning Land region.

Nathorst Fjord Group

This hitherto unnamed group is stratigraphically divided into four mappable formations (Table 15). The third and thickest of these (Vim-

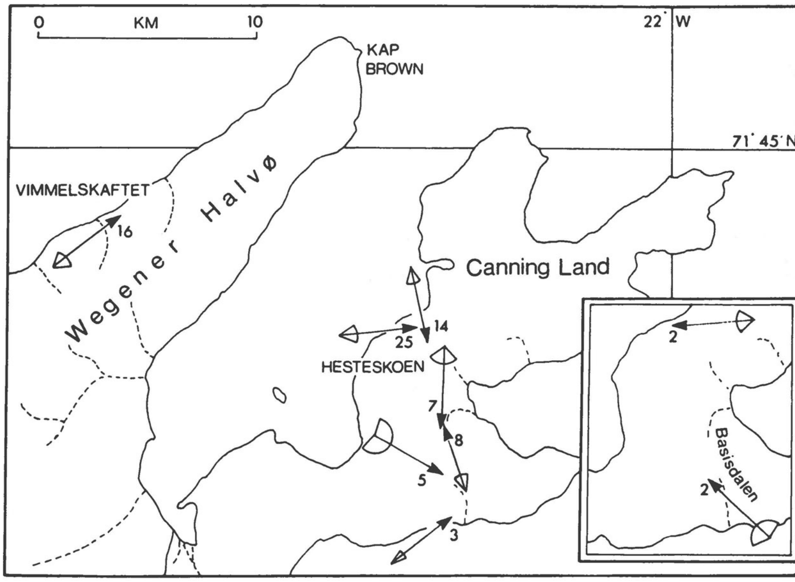


Fig. 60. South Hesteskoen Formation and Basisdalen Conglomerate (inset) palaeocurrents. Vector means are shown, with a number of measurements and 95 % confidence limits on the means.

melskaftet Formation) is further subdivided into three members, clearly mappable in Canning Land, but almost indistinguishable on Wegener Halvø, at Vimmelskaftet (Fig. 57). The resultant scheme is similar to the succession described by SÄVE-SÖDERBERGH (1937, pp. 10–17, 29) based on vertebrate faunas. BÜTLER's (1948, p. 53) lithological succession reported from the south coast of Canning Land contains several units repeated through normal faulting.

Basisdalen Conglomerate Formation

At the base of the group, a conglomerate 12 to 70 m thick is exposed at intervals along south and north Basisdalen and Porfyrdal on Canning Land (names from BÜTLER (1948, Plate 1), not the Geodætisk Institut

Table 15. *Nathorst Fjord Group subdivisions*

Unit		Estimated thickness (m)
West Hesteskoen Formation		?50
Vimmelskaftet Formation:		
Red-and-green banded Siltstone Member	(av. 450)	1000
Grey Sandstone Member	(av. 550)	
Red Siltstone Member		400
South Hesteskoen Formation		50
Basisdalen Conglomerate Formation		av. 50

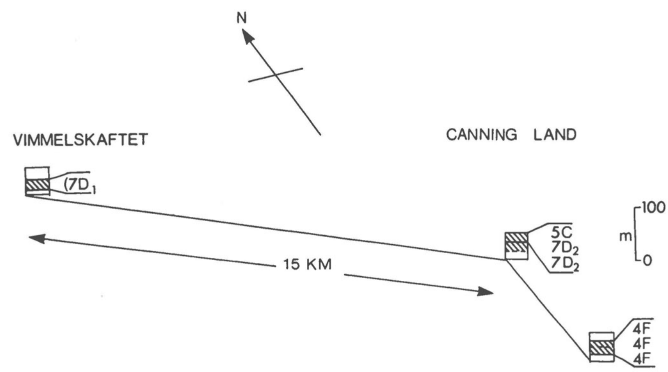


Fig. 61. South Hesteskoen Formation, stratigraphic distribution of sample groups.

1:250,000 map), at Kap Brown (Fig. 59) and Vimmelskaftet on Wegener Halvø. It is usually faulted down against the Kap Fletcher Formation, but the unconformity can be seen on the south east side of Kap Brown as a series of infilled valleys eroded into the underlying volcanics (Plate 8).

Clasts consist almost entirely of locally derived rock types, usually volcanic porphyries, but also Eleonore Bay Group quartzites and grey shales (forming 55 % at Vimmelskaftet) and rarer vein quartz and granite. The conglomerate, normally massive, is sometimes interbedded with red siltstones (Fig. 59); the clasts are generally angular. The only palaeocurrent indicators are a rare imbrication of clasts: on Canning Land the debris was transported from source areas in the eastern part of the peninsula (inset Fig. 60), probably down the surfaces of a number of small alluvial gravel fans.

South Hesteskoen Formation

This formation, corresponding to SÄVE-SÖDERBERGH's (1937) *Heterostius* Series, is recognisable by its bright greyish-white coarse arkoses. In the middle of this 50 m thick formation, a band of red siltstone 6 to 12 m thick, with carbonate concretions up to 16 cm in size, is present in all outcrops. The red siltstone is closely interbedded with the coarse non-red sandstones (7D2, grey-v.f., co. sst.-trough X, flat; 4F, grey-co. slst., co. sst.,-flat, asym, rip.) (Fig. 61). The sandstones above the red band are finer-grained (medium and fine) than those below (coarse and very coarse) and are often replaced laterally by siltstones (Fig. 62). This suggests that the lower sandstones were deposited in unstable channels scoured over the whole floodplain, whereas the upper sandstones were deposited in relatively stabilized channels constrained within banks on silty floodplain deposits.

The palaeocurrent pattern is not clear (Fig. 60), but easterly trends are dominant. The lower sandstone beds everywhere contain extra-

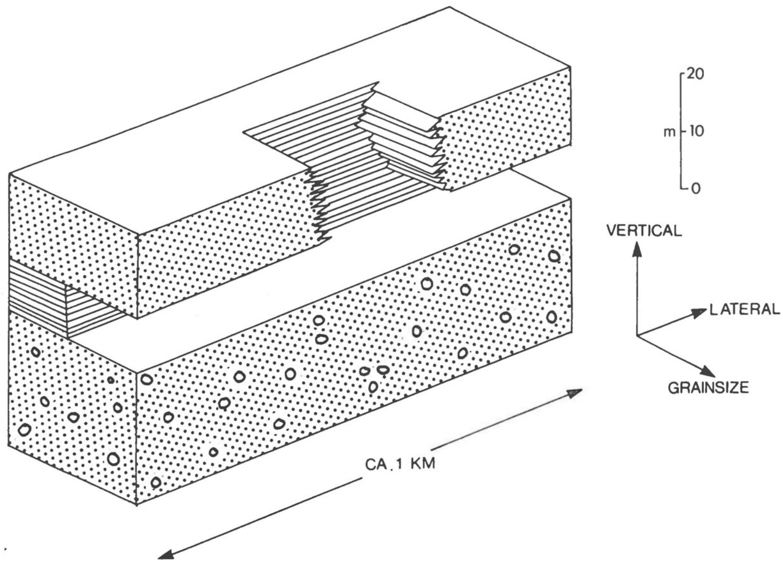


Fig. 62. Diagrammatic representation of sandstone-siltstone relations in South Hesteskoen Formation.

clasts: porphyritic lavas, granite, quartzite and greenish siltstone. Intraclasts of mudflakes, sometimes rafts up to 1.5 m long, and carbonate concretions, are also ubiquitous, except at Vimmelskaftet, where they are virtually absent, and the sandstones reach very coarse grade, the pebble to whole-rock ratio ranging up to 35 $^0/_0$. A few measurements suggest that mean maximum extraclast size decreases from 6.8 cm at Vimmelskaftet to less than 4 cm in south Canning Land.

Vimmelskaftet Formation: Red Siltstone Member

This member, corresponding to SÄVE-SÖDERBERGH'S (1937) *Asterolepis* Series, comprises red very fine sandstones and siltstones with thin pale grey fine and medium sandstones (5C, red-co. slst., v.f. sst.-flat, asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.) (Fig. 63). Palaeocurrents trend SSE (Fig. 64). At Vimmelskaftet, however, the sand/silt ratio has increased appreciably (7D2, grey-v.f., co. sst.-trough X, flat; 3A, grey-f., m. sst.-trough X; 3D, grey-m., co. sst.-trough X), and palaeocurrents trend eastwards. Some thicker grey sandstone bands (7A, grey-f., v.f. sst.-trough X, flat; 3D, grey-m., co. sst.-trough X) in Canning Land also show more easterly palaeocurrents, and it would seem that two drainage systems are involved: one eastward-flowing, depositing mainly sand; the other southward-flowing, depositing mainly silt. The siltstones characteristically contain type 4 cross-strata (Number 2) of the scour-and-fill type (Plate 9); abundant trace fossils including meniscus-filled burrows; bioturbated and leached horizons with plant

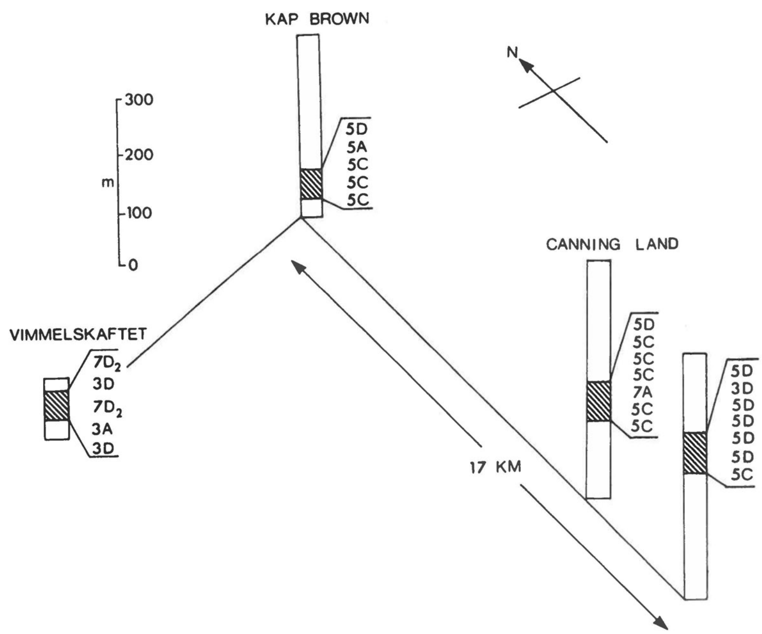


Fig. 63. Vimmelskaftet Formation, Red Siltstone Member, stratigraphic distribution of sample groups.

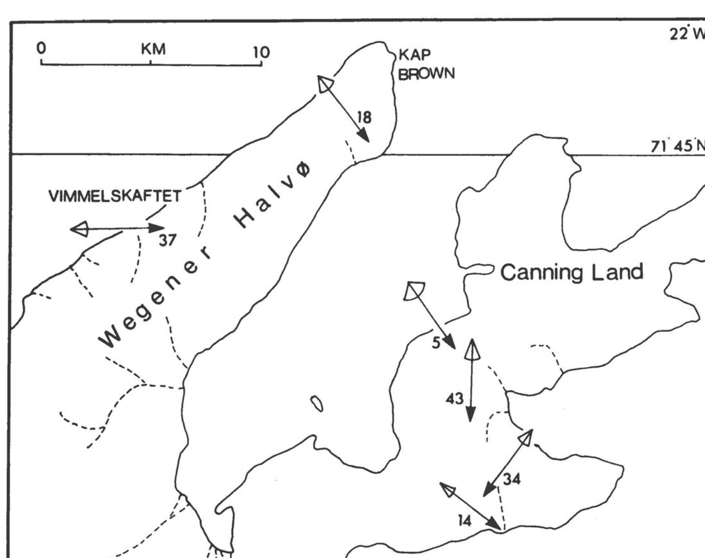


Fig. 64. Vimmelskaftet Formation, Red Siltstone Member palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

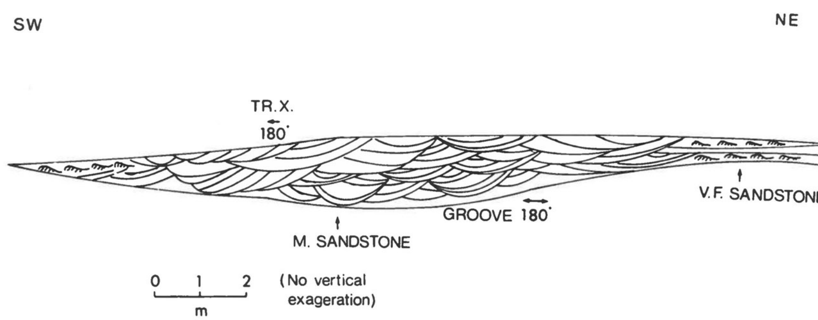


Fig. 65. Oblique section through sandstone body, Red Siltstone Member, S. E. Hesteskoen.

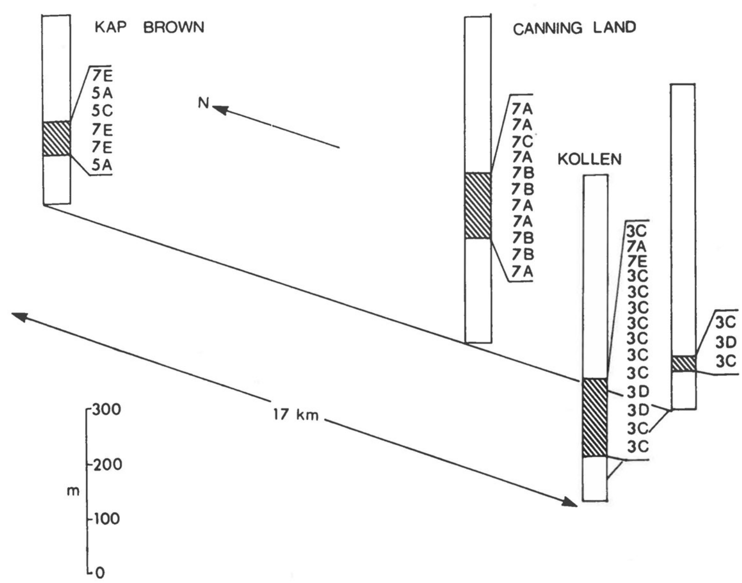


Fig. 66. Vimmelskaftet Formation, Grey Sandstone Member, stratigraphic distribution of sample groups.

rootlet marks and small carbonate concretions. The grey sandstone bodies are lens-shaped in sections normal to the dominant palaeocurrent direction (Fig. 65), and probably represent infilled stream channels. Vertebrate fragments (*Asterolepis* plates and crossopterygian teeth) are not infrequent in both sandstones and siltstones.

Vimmelskaftet Formation: Grey Sandstone Member

Grey sandstone units 10 to 20 m thick mark the transition upwards from the Red Siltstone Member into the Grey Sandstone Member (= Säve-Söderbergh's (1937, p. 29) division 3). At Kollen, in south Canning Land, the member consists almost entirely of grey medium sand-

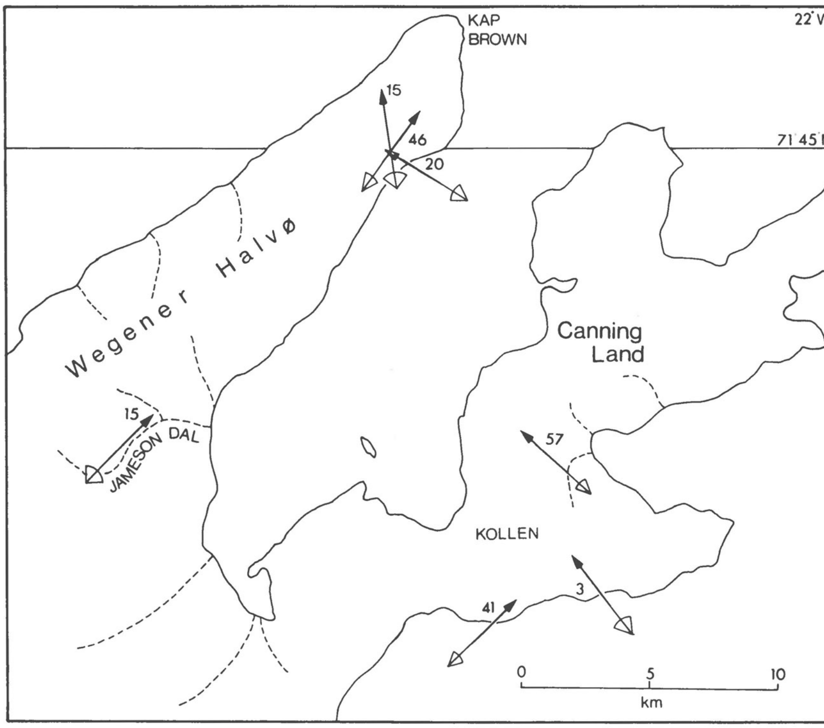


Fig. 67. Vimmelskaftet Formation, Grey Sandstone Member palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

stones (3D, grey-m., co. sst.-trough X; 3C, grey-m., f. sst.-trough X, flat) (Fig. 66). Further north, on Hesteskoen, grey fine sandstones with numerous plant fragments are dominant (7A, grey-f., v.f. sst.-trough X, flat; 7B, grey-f., v.f. sst.-flat, trough X; 7C, grey-v.f., f. sst., co. slst.-flat, trough X), and further still, at Kap Brown, grey fine sandstone bands (7E, grey-f. sst.-trough X) alternate with bands of red siltstone (5A, red-co. slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.) Palaeocurrents (Fig. 67) trend northwards, in a direction opposite to that of the underlying member.

Vimmelskaftet Formation: Red-and-green banded Siltstone Member

The transition upwards into this member is recorded at Kollen (Fig. 68), where grey fine sandstones (7A, grey-f., v.f. sst.-trough X flat; 7C, grey-v.f., f. sst., co. slst.-flat, trough X) pass upwards into siltstones. Elsewhere, this member comprises the assemblage of red siltstones (5A, red-co. slst., v.f. sst.-asym. rip.; 5B, red-co., m. slst.-asym. rip., flat; 5D, red-co., m. slst.-flat, asym. rip.) and green siltstones (4E, grey-co., m. slst.-asym. rip., flat; 4C, grey-m., co. slst.-flat) (Fig. 68) in

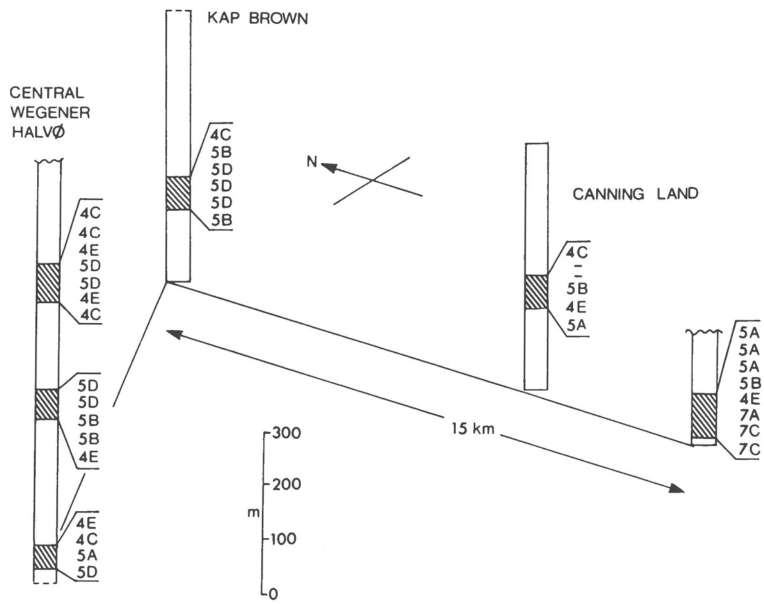


Fig. 68. Vimmelskaftet Formation, Red-and-green banded Siltstone Member, Stratigraphic distribution of sample groups.

bands ranging from 10 to 70 m thick, closely similar to the upper part of the Vilddal Group and its equivalents in the northern region. Here also *Gyroptychius groenlandicus* is found in green medium siltstone bands (4C, grey-m., co. slst.-flat) near the top of the member, and was used to define SÄVE-SÖDERBERGH's (1937, p. 29) fourth series. Palaeocurrents (Fig. 69) trend NNW, so that combined with the underlying Grey Sandstone Member, a large-scale (1000 m) fining-upward sequence with a constant palaeoslope is recorded.

West Hesteskoen Formation

A further division of the Nathorst Fjord Group, hitherto undescribed, concordantly overlies the red-and-green banded siltstones on the western ridge of Hesteskoen in Canning Land, at altitude 350 m. A few metres of conglomerate at the base are succeeded by red and yellow coarse sandstones. The composition of the conglomerate (50 % quartz and quartzite, 40 % greenish volcanics, 10 % black limestone) is distinct from that of the quartz-and quartzite-rich Carboniferous conglomerate with its overlying whitish-yellow coarse sandstone, which rests unconformably on the banded siltstones at ca. 400 m altitude. The bedding dips 20° to the west, so that the formation is poorly exposed as bedding planes forming the dip slope of the ridge (Plate 10): probably not more than 50 m thickness is preserved. The direction of transport

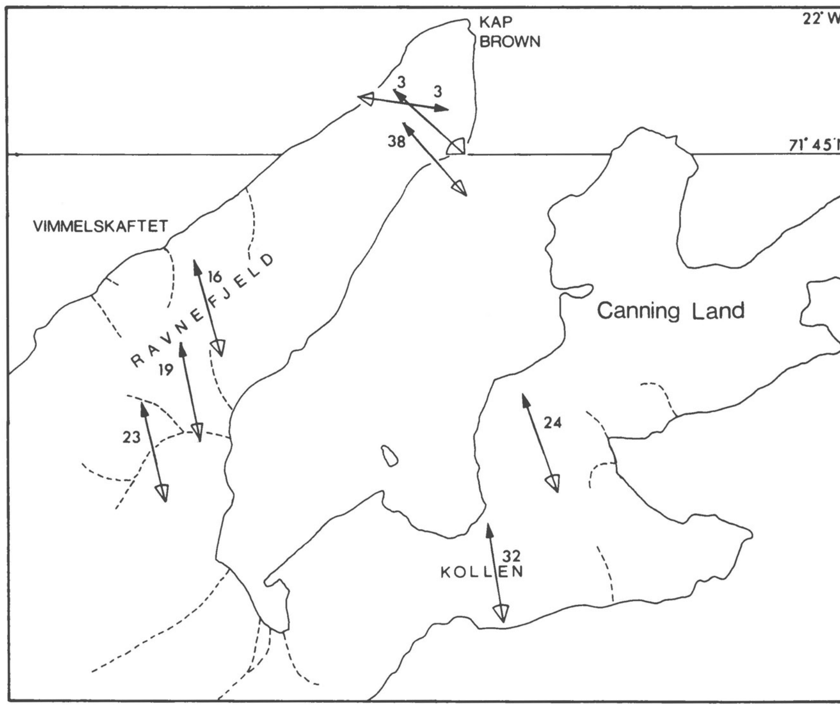


Fig. 69. Vimmelskaftet Formation, Red-and-green banded Siltstone Member, palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

of the sediment is not known: one ripple azimuth 350° (true) north from a sand lens in the conglomerate suggests that no large change in direction of palaeoslope may have occurred.

Quensel Bjerg Formation

This formation is preserved only in the southern part of Wegener Halvø (Fig. 70) and was first described by SÄVE-SÖDERBERGH (1937, p. 20) from Quensel Bjerg and Lille Cirkusbjerg. In Canning Land the Nathorst Fjord Group is unconformably overlain by Carboniferous conglomerates and sandstones, and Upper Permian marine beds (SÄVE-SÖDERBERGH, 1937, p. 14). In south Wegener Halvø, an important pre-Permian fault juxtaposes the Quensel Bjerg Formation to the south against the Nathorst Fjord Group to the north (Fig. 70). However, on the southeast face of Lille Ravnefjeld, a remnant of the former can be seen to rest unconformably on the latter: pink Quensel Bjerg Formation sandstones are banked up against an inclined erosion surface which has since been tilted to appear horizontal (Plate 11). Both divisions are truncated by the Permian unconformity.

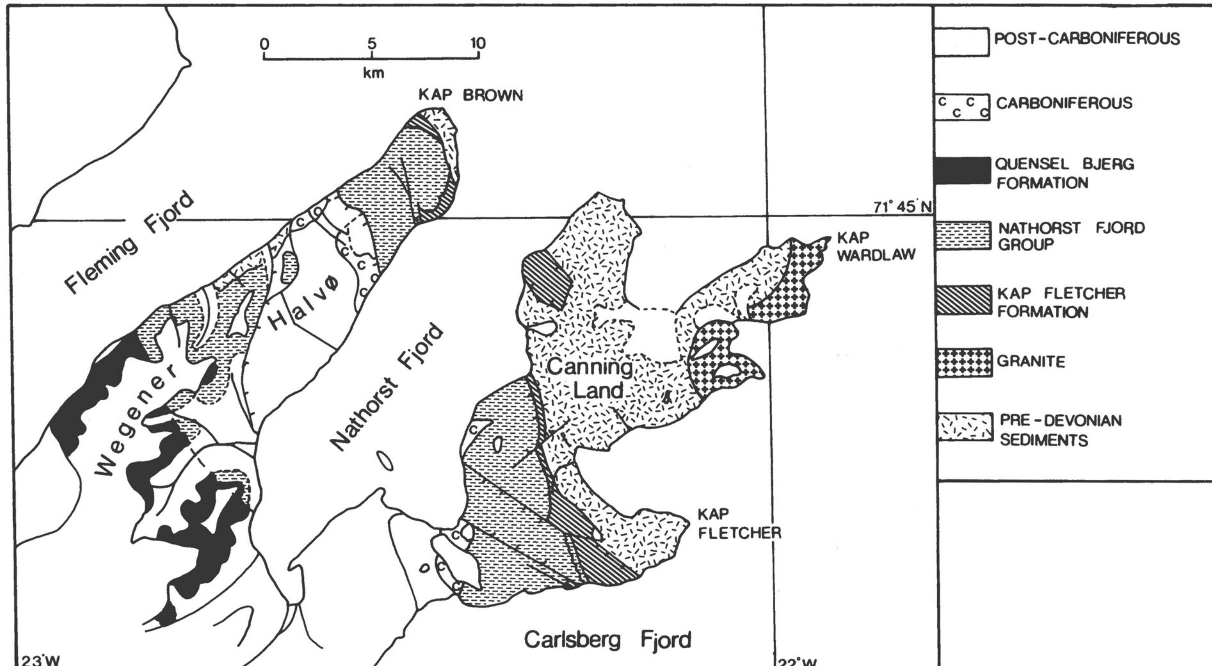


Fig. 70. Simplified geological map, Wegener Halvø and Canning Land, modified after Bütler (1948, pl. 4), Säve-Söderbergh (1937, pl. 2), Grassmück & Trümpy (1969, pl. 1).

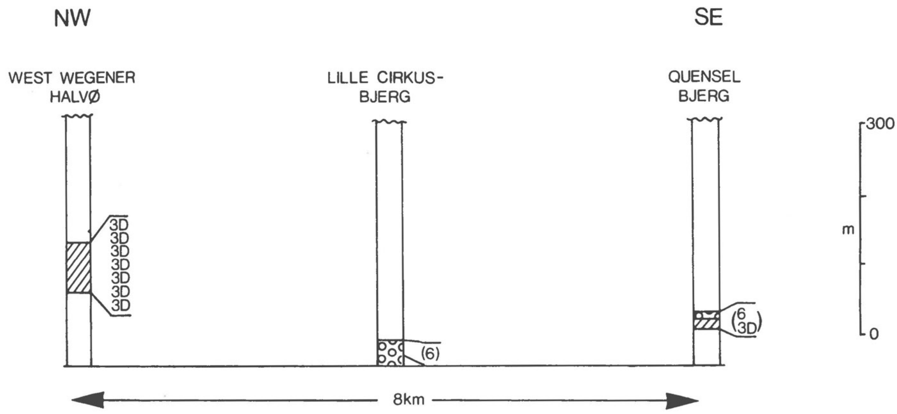


Fig. 71. Quensel Bjerg Formation, central Wegener Halvø, stratigraphic distribution of sample groups.

The formation is not well exposed except behind small glaciers in relatively inaccessible places. It consists almost entirely of grey, pink and yellow coarse to fine sandstones and conglomerates. Only one mark-sense section, in grey medium sandstones (3D, grey-m., co. sst.-trough X), was recorded (Fig. 71). A prominent conglomerate at 400 m altitude on the west side of Quensel Bjerg, less than 10 m thick, concordantly overlies grey coarse sandstones without significant difference in the vector means of cross-stratification palaeocurrent azimuths. Another, possibly basal, conglomerate is seen on NW Lille Cirkusbjerg. Both conglomerates contain 50 to 80 $^{0}/_{0}$ quartz and quartzite clasts (including a spotted type derived from the Eleonore Bay Group), the remainder being grey shales and chert, and, in the Quensel Bjerg example, pink granites and acid volcanic rock types. Mean maximum clast sizes (quartzite) of 6.7 cm (Lille Cirkusbjerg) and 4.7 cm (Quensel Bjerg) were recorded.

Palaeocurrents (Fig. 72) trend uniformly westwards.

Structural Sequence

On Canning Land, the Nathorst Fjord Group dips 10 to 50° westwards. A large-scale fold is visible in the group in Ravnefjeld (west Wegener Halvø), with fold axial trace striking ESE (Bütler, 1948, p. 55). Smaller-scale folds (wavelength ca. 10 m) exposed near the first main tributary junction in Jameson Dal, (Fig. 73), have axes plunging WSW and were probably formed during the same phase.

The Quensel Bjerg Formation, however, exhibits broad folds (wavelength ca. 2 km) with axes striking NNW. We agree with Bütler (1948, p. 56) that two folding phases therefore occurred: one before

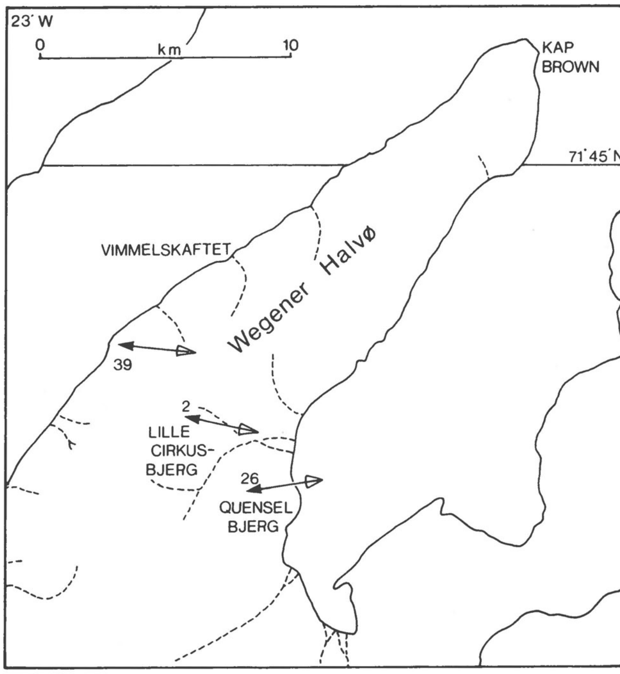


Fig. 72. Quensel Bjerg Formation, central Wegener Halvø, palaeocurrents. Vector means are shown, with number of measurements and 95 % confidence limits on the means.

deposition of the Quensel Bjerg Formation, the other later, but pre-Permian. Further, the principal stress orientations recorded by the two fold geometries are similar to those recorded in the Devonian rocks at Kap Franklin; in both areas, a phase of north-south compression preceded a phase of east-west compression.

Summary

Pre-Cambrian sedimentary rocks were eroded and unconformably overlain by the intermediate volcanics of the Kap Fletcher Formation, Lower or Middle Devonian in age. These in turn were deeply eroded, and small alluvial gravel fans deposited debris in topographic hollows. A relatively short phase of fluvial transport of coarse sand from the west was succeeded by the development of a silty floodplain, with stream transport southwards, and occasional influxes of sand from the west. In the upper part of the Nathorst Fjord Group, the drainage direction reversed to flow northwards, grey sandstones giving way with time to red-and-green banded siltstones. The influx of coarse sediment at the top of the group may mark the beginning of tectonism, in the uplift of new source areas. The whole of this Middle Devonian group was finally

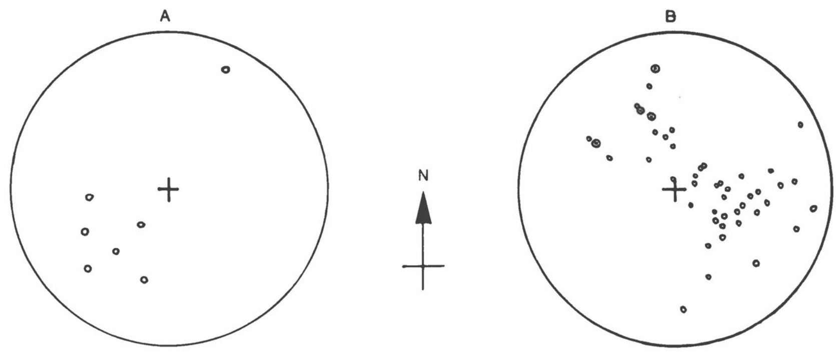


Fig. 73. Nathorst Fjord Group in Jameson Dal, South Wegener Halvø, fold data. A, plunge of small fold axes. B, poles to bedding surfaces, ring dots indicate overturned surfaces.

caught up in the deformation, and a period of erosion preceded the deposition of conglomerates and sandstones of the Quensel Bjerg Formation, possibly early in Upper Devonian times, by streams flowing due west. Further deformation and erosion took place before the Carboniferous and Upper Permian rocks, respectively, were deposited.

Correlation

Detailed correlation of this succession with that exposed in the northern region at Kap Franklin is difficult to check because Devonian rocks are deeply buried beneath Mesozoic rocks on Traill Ø and Geographical Society Ø. There is no particular reason for expecting these non-marine successions to show any similarity over a separation of 160 km; nor can we assume that the sediments accumulated in the same depositional basin.

ØRVIG (Dr. R. S. MILES, personal communication, May 1969), attempting to apply SÄVE-SÖDERBERGH's (1937) faunal succession from Canning Land, concluded that at Kap Franklin, where *Asterolepis* cf. *säve-soderberghi* appears later than *Gyroptychius groenlandicus*, BÜTLER had inverted the succession. BÜTLER (1959, p. 174) suggested that the two faunas had a wide overlapping vertical distribution in Greenland. This was confirmed by the collection in 1956 of some specimens similar to *Gyroptychius groenlandicus* in the Vimmelskaftet Red Siltstone Member ("*Asterolepis*" Series) in Canning Land (BÜTLER, 1959, footnote p. 174; JARVIK, 1961, Table 1). The observed differences can also be explained by the way the faunal types are largely restricted to different facies: they preferred to live in different environments. BÜTLER (1959, p. 174) also considered the possibility that the volcanics of the Kap Fletcher and Kap Franklin Formations might be the same age, but rejected it because *Heterostius* occurs at the base of the Nathorst Fjord Group, suggesting that the Kap Fletcher volcanics are significantly older than the Kap Franklin Formation. However, in view of the unreliability of fossils for correlation to this degree of detail, we propose instead to use the following lithostratigraphic criteria:

(a) In both areas, a lower, dominantly siltstone-rich group (Vilddal Supergroup), in which there is no evidence for the proximity of source areas immediately to the east, is succeeded unconformably by an upper, sandy and conglomeratic formation (Kap Kolthoff Supergroup), in which detritus was transported westwards from new eastern source areas.

(b) In both areas, the red-and-green banded siltstones occurring at the top of the lower group are remarkably similar in facies and fauna.

(c) Conglomerate and close alternations of coarse sandstone and siltstone occur in both areas at about the same stratigraphic level below the banded siltstones.

To ascribe these similarities to coincidence is conceivable, but it is more likely that the Nathorst Fjord Group does correlate with the Vilddal Group, as shown in Fig. 74. The main difference between the two is that the Red Siltstone Member in Canning Land must be equivalent to the Grey Siltstone Formation at Kap Franklin. However, we have already noted that this division is laterally the most variable in the northern region, so the difference is not surprising. The Quensel Bjerg Formation, like the similar Randbøl Formation in the north, records the uplift of an active eastern margin to the basin to the east of Canning Land. If it is Upper Devonian in age, then more time elapsed between the depositional phases in Canning Land than at Kap Franklin; this is consistent with the observation that erosion left only a small remnant of the sediments which mark the transition in palaeoslope reversal (West Hesteskoen Formation), compared with the Kap Franklin Formation.

We have not proved that the Canning Land area was part of the same depositional basin as the northern areas, though this seems likely. However, even if they formed separate basins, the similar lithological sequences and reversals of palaeoslope indicate a similar sedimentary and erosional response to a tectonic event common to them both.

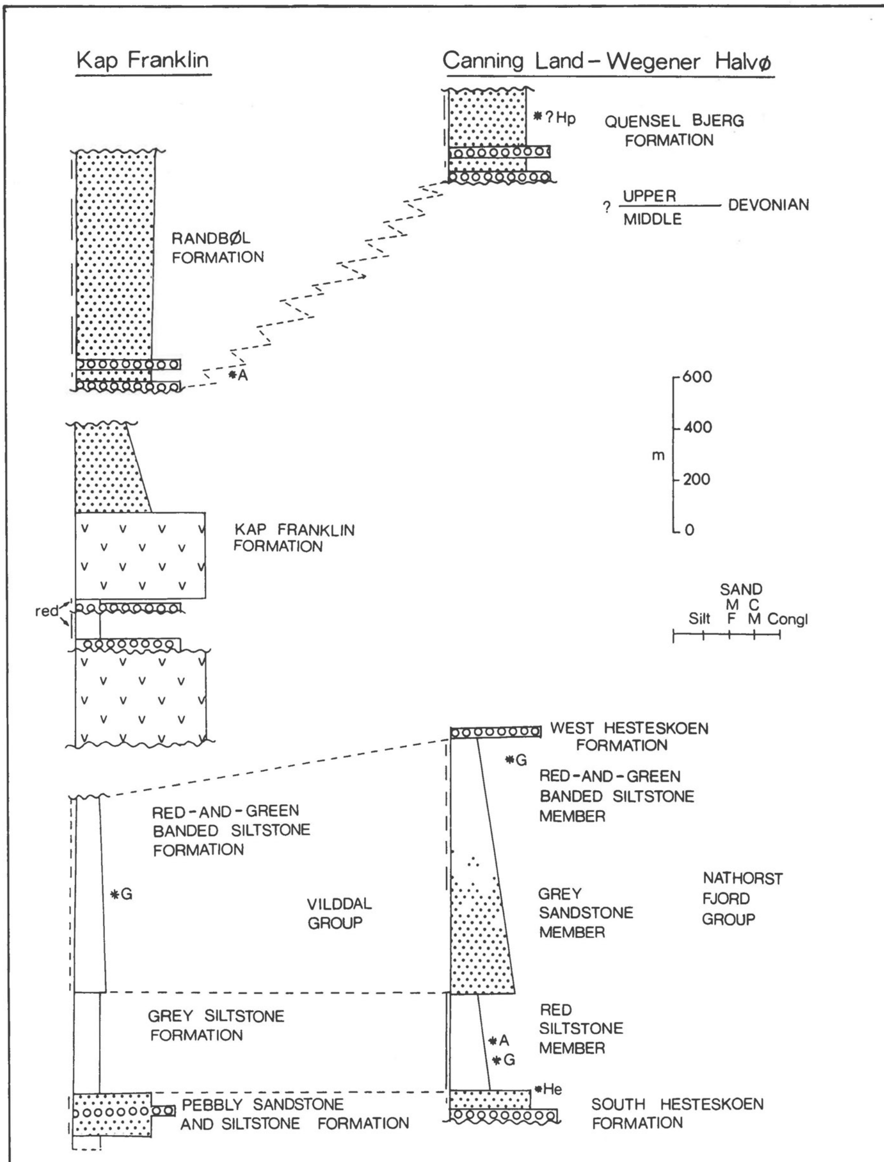


Fig. 74. Correlation of Canning Land Succession with Kap Franklin area. *A, *Asterolepis säve-soderberghi*, * He, *Heterostius* sp., * G, *Gyroptychius groenlandicus*, * Hp, *Holoptychius* sp.

ENVIRONMENTS AND PATTERNS OF SEDIMENTATION

Distribution of sample groups between stratigraphic divisions

The changes of palaeoslope and sediment type during the upper Middle Devonian in most of the areas discussed allow a convenient division between two major stratigraphic groupings. At Kap Franklin, we distinguished the lower, mainly fine-grained Vilddal Group from the overlying coarser-grained Kap Franklin and Randbøl Formations, here referred to collectively as the Giesecke Bjerge Group (Table 16). The partly equivalent Hjelmbjergene Group further west links this to the lower part of the Kap Kolthoff Supergroup in Moskusoksefjord.

It is of interest to compare the distribution of sample groups between these major divisions (Vilddal Supergroup and Kap Kolthoff Supergroup) throughout the eastern areas (Table 17). There is considerable overlap, especially in the grey sandstones (groups 3, 7). For example, the Grey Sandstone Member of the Nathorst Fjord Group in Canning Land (= Vilddal Supergroup) contains similar sample groups to the Kap Franklin Østreplateau Grey Sandstone Member, the Hjelmbjergene Grey Sandstone Formation, and the Kap Kolthoff Supergroup in Hudson Land. The main differences are: (a) Red sandstones (groups 1, 2) are mainly restricted to the Kap Kolthoff Supergroup; (b) Grey siltstones (group 4) are virtually restricted to the Vilddal Supergroup; and (c) Red Siltstones (group 5) are poorly developed in the Kap Kolthoff Supergroup, but abundant in the Vilddal Supergroup.

If there is systematic regional variation in sample groups for any given formation, we can explain these differences by reference to the changed position of the eastern region in relation to source areas: the rise of a new eastern margin to the basin was likely to bring coarser sediment to areas formerly distant from their sources. If the new drainage systems differed from their predecessors only in position and direction, we should expect to find the siltstone sample groups developed in the Kap Kolthoff Supergroup elsewhere in the basin. Our observations elsewhere show that this is not the case. Admittedly, the lower part of the Kap Kolthoff Supergroup is deeply buried in the central areas of Ymer Ø and Gauss Halvø, and further west, sediments were derived from a western margin to the basin, but in Moskusoksefjord, this division consists almost entirely of red and grey sandstones again. Widespread sedimentation of siltstones did not recur until the Upper Devonian Remigolepis Group. Therefore the crustal movements which included the rise of the eastern margin of the basin, resulted not only in a shift of drainage directions, but also in a major change in patterns of drainage and sedimentation.

Table 16. *Stratigraphic Grouping of Local Formations*

Main Divisions	Hudson Land	B. Moskus-oksefjord	Hjelmbjergene	Kap Franklin	Canning Land
Kap Kolthoff Supergroup	Kap Kolthoff Supergroup	Kap Kolthoff Supergroup	Hjelmbjergene Group	Giesecke Bjerge Gp. (= Randbøl Formation + Kap Franklin Fmn.)	Quensel Bjerg Formation
Vilddal Supergroup	Nordhoeks-bjerg Group	Ramsays Bjerg Group	–	Vilddal Group	Nathorst Fjord Group

Table 17. *Stratigraphic distribution of sample groups*

Sample groups	No. 10 m samples in Vilddal Supergroup	No. 10 m samples in Kap Kolthoff Supergroup
1A	–	2
1B	–	2
1C	–	7
1D	–	1
2A	5	4
2B	–	2
2C	–	1
2F	–	1
2G	1	7
3A	1	12
3C	16	10
3D	15	22
4B	15	–
4C	31	2
4D	15	–
4E	27	–
4F	8	–
4G	7	–
5A	31	6
5B	16	–
5C	19	1
5D	25	2
7A	13	12
7B	8	6
7C	7	5
7D1	–	3
7D2	6	2
7E	5	7
8	–	3

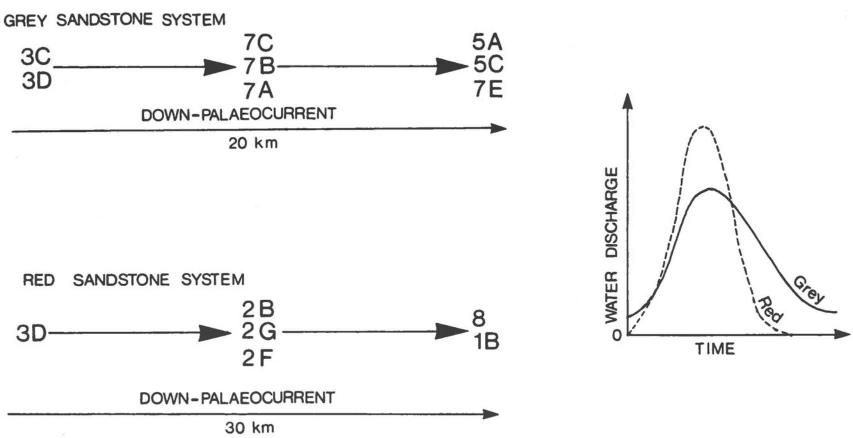


Fig. 75. Variation of sample groups down-current in grey and red sandstone systems, and suggested difference in water discharge patterns.

Sample groupings

A number of distinct sample groupings are recognisable within the various formations:-

(a) Grey sandstones (sample groups 3, 7), common in both Vilddal Supergroup and Kap Kolthoff Supergroup.

(b) Red Sandstones (sample groups 1, 2) mainly in the Kap Kolthoff Supergroup.

(c) Grey siltstones (sample group 4), mainly in the Vilddal Supergroup.

(d) Red siltstones (sample group 5), mainly in the Vilddal Supergroup, minor in the Kap Kolthoff Supergroup.

Grey Sandstone (sample groups 3,7)

We have already mentioned this grouping as a feature common to both the Vilddal Supergroup and the Kap Kolthoff Supergroup. The only lithological unit for which we have sufficient data and a simple one-directional palaeocurrent system is the Grey Sandstone Member (Vimmelskaftet Formation) of the Nathorst Fjord Group. The progression of sample groupings down-palaeocurrent is summarised in Fig. 75: coarse and medium sandstones with curved foreset cross-stratification in large sets, and flat bedding, give way downstream to fine and very fine sandstone with a lesser proportion of smaller, curved foreset low angle cross-stratified sets, rather more flat bedded sandstone, and small-scale asymmetrical ripples. Further downstream, the grey fine sandstones form distinct bands alternating with red siltstones (5A, red-co. slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.): the sandstones have a greater mean grainsize per 10 metres and a larger proportion of trough cross-stratification than those upstream, but taking the section as a whole, the mean grainsize has clearly decreased further. In a sense, the sandstones have become more sharply segregated from the siltstone component. The change occurs over a distance of only 20 km.

A facies change similar to the first two stages occurs over a distance of 8 km in the Nordhoeksbjerg Green Sandstone Formation on Nordhoeks Bjerg. Similar assemblages of sample groups occur in examples from the Kap Kolthoff Supergroup, but either lateral information within a formation was impossible to obtain because of the structural control of outcrops (Ankerbjergsdalen; Hjelmbergene Grey Sandstone Formation), or the situation was complicated by the interdigitation of two palaeocurrent systems (Kap Franklin, Østreplateau Grey Sandstone Member). In no other case was the third stage (7E, grey-f. sst.-trough X plus 5A, red-co. slst., v.f. sst.-asym. rip.) developed.

No certain interpretation of the morphology of the streams which deposited these sandstones is possible. However, several hundred metres of sandstone occur at the upstream end of this system, containing no fine (siltstone) members of fining-upward cycles of the type described by ALLEN (1964b) and ALLEN & FRIEND (1968). This suggests either that fine-grained overbank deposits were removed by erosion during the lateral migration of the streams, or, more likely in view of the thickness of the deposits, that the streams had erodible banks of sand. This, together with the high rates of sediment supply necessary for such an accumulation, is the essential ingredient for a pattern of anastomosing stream channels and braid bars (LEOPOLD *et al.*, 1964, p. 294). To judge by average trough cross-stratification coset thickness and the scale of vertical grainsize variation, bank-full depth was of the order of 1 to 2 metres, and channel widths about 15 metres. The irregular stacking of channel forms infilled with large-scale cross-stratified sets, and the presence of thin siltstones, often infilling smaller-scale abandoned anabranches, are consistent with the model for braided stream deposits proposed by ALLEN (1965b, p. 163), and resemble the Torridonian red sandstones of probable braided origin (SELLEY, 1969).

The downstream segregation of the sandstone channel deposits from the red siltstone, presumably overbank, deposits should have led to restriction of the rapid lateral movements of the talweg, characteristic of braided streams during flood (CHIEN, 1961; COLEMAN, 1969), by silty cohesive banks. Downstream, the river could have attained a single channel, possibly meandering, form as in the Yellow River below Kaotsun (CHIEN, 1961); however, the bedding relations in the grey sandstone bands at Kap Brown are not significantly different from those 'upstream' in Canning Land, so this adjustment may not have occurred. The possibility of local interfingering of a red silty fluvial system with the grey sandy stream, to explain the banding, is ruled out here because similar bands occur at this horizon 10 km laterally, near Vimmelskaftet, at a similar position down the palaeoslope.

Red Sandstone (sample groups 1,2,8)

The only data from the eastern region comes from correlation (Table 17) of the Randbøl Formation with the red Kap Kolthoff Supergroup sandstones of Langbjerg via the Hjelmbjergene Red Sandstone Formation. Vertical facies variation is considerable in each of these, and the situation is complicated by the merging of two palaeocurrent systems in Obrutschews Bjerg. Nevertheless, taking the sections with west to northwesterly palaeocurrent mean azimuths, we obtain the following succession of sample groupings (see also Fig. 75):

Proximal: 3D (grey coarse + medium sandstones) + 2G

Medial: 2G, 2B, 2F (red medium + fine sandstones)

Distal: 1B (red fine sandstone) + 8 (red very fine sandstones)

We may note that this change involves a downstream decrease in maximum and mean grainsize, as with grey sandstones, over a distance of 30 km (Saxos Bjerg to Langbjerg). Set size of large-scale cross-stratification appears initially to increase down-stream, with the development of type 2a (curved foreset with bottomset) sets up to 3 m thick with bottomsets on Obrutschews Bjerg, and then declines to a maximum of 0.4 m on Langbjerg, where flat bedded very fine sandstones are comparable to the flood deposits of Bijou Creek (McKee *et al.*, 1967). Isolated pebbly coarse sandstone beds on Langbjerg probably correspond to conglomerate units in Randbøldalen. A reversion to medium sandstone (2C, red-m., co. sst.-trough X) higher up the succession in Paralleldal may not be preserved in the Giesecke Bjerge due to the Permian unconformity.

We have to explain three features different from the Canning Land grey sandstone system:

(a) the red colour,

(b) the relative lack of siltstone even in the distal parts of the system, and

(c) the larger cross-stratified sets in the middle.

Red colour suggests that the deposits west of the Giesecke Bjerge were exposed to oxidising conditions above local water table for a considerable length of time each year (Friend, 1966). Water discharge was therefore highly seasonal in occurrence, suggesting moderately arid climatic conditions. This would explain the absence of plant fragments, which are common in the grey sandstones, and which may help to maintain reducing conditions in water-logged non-red sediments. According to Schumm (1969, p. 265), the effect of a decrease in precipitation in the headwaters of a stream in subhumid to semiarid climates is the reduction of vegetation density and the increase of both peak water discharge and the amount of sand moved through the channel. This might explain the greater downstream extent of sandstones in the red system. However, this relationship probably did not hold during the Devonian, when land plants of sediment binding type had not yet evolved (Schumm, 1968). Further, Schumm's (1969) equations predict an increase in width/depth ratio for the channel: the cross-stratification set size suggests an increase in depth, so that width would have to increase even more. It may be, therefore, that the greater downstream spread of sandstone, was due simply to the channel system being of larger scale than that responsible for the grey sandstones.

It is interesting that the only record of a mudflow interbedded with sandstones in the region is the one in the Hjelmbjergene Red Sandstone Formation on S.E. Obrutschews Bjerg: mudflows are characteristic of arid environments (Blissenbach, 1954) though not restricted to them.

As the vegetation-free floodplain dried out, the finer grades (silt) would have been winnowed out by wind, and it is in these facies, if any, that we might expect to find aeolian sandstones. Certainly some large-scale cross-strata (Type 2, curved foreset) on Obrutschews Bjerg, lacking mica particles and both extra and intraclasts, could be aeolian in origin, though this cannot be proved.

Floods on 'red' river systems were probably shorter and sharper than on 'grey' systems (Fig. 75). Consistent with this conclusion is the ubiquitous occurrence of siltstones probably of lacustrine origin in the Vilddal Supergroup, indicating a continuing input of water to balance losses by evaporation and seepage. However, within the Kap Kolthoff Supergroup, there is the suggestion that grey sandstones of two fluvial systems may have coexisted with the red sandstone system north of Moskusoksefjord. Clearer evidence of this coexistence is visible in the Rødebjerg Formation on the western margin of the basin. Evidently, rather local differences in precipitation relative to size of drainage basin were responsible for the observed patterns.

Red Siltstones (sample group 5)

These occur in three separate situations:

(a) Occasional 10 to 20 m bands (mainly 5A, red-co. slst., v.f. sst.-asym. rip.) in successions consisting dominantly of grey medium or fine sandstones (groups 3, 7), (examples already mentioned from Nathorst Fjord Group and Kap Kolthoff Supergroup);

(b) Thick successions (5A, red-co. slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.; 5D, red-co., m. slst.-flat, asym. rip.) up to 400 m, with occasional 10 m units of grey sandstone (3D, grey-m., co. sst.-trough X; 7A, grey-f., v.f. sst.-trough X, flat) (Vimmelskaftet Red Siltstone Member in Canning Land; Saxos Bjerg Member near Kap Franklin).

(c) Thick red bands (5A, red-co. slst., v.f. sst.-asym. rip.; 5B, red-co., m. slst.-asym. rip., flat; 5D, red-co., m. slst.-flat, asym. rip.) alternating with non-red siltstone bands (Group 4), (upper part of Vilddal Supergroup throughout eastern region).

(a) The first case can reasonably be interpreted as the chance preservation of overbank deposits of the 'grey' sandy streams by their lateral displacement. This displacement must have lasted long enough for several metres of overbank deposits to accumulate. WOLMAN & LEOPOLD's (1957) observations on vertical accretion rates of floodplains suggest that several thousand years may have been necessary. The lateral migration rates of most rivers are sufficient to move the channel over the whole floodplain in less than a thousand years. Even highly sinuous single channel streams such as the Menderes (RUSSELL, 1954) are relatively unrestricted in lateral movement by the development of clay plugs in abandoned meander loops. If the grey sandstones were deposited by braided streams of much greater lateral mobility, the preservation of overbank deposits becomes even more problematic. In the case of the Kap Franklin Østreplateau Member, contemporaneous volcanism could have led to river courses being restrained between lava fields. All other examples remain unexplained unless the river channels were restricted to areas of differential tectonic downwarp.

(b) We have seen that in the second case, the thicker grey sandstone units (3D, grey-m., co. sst.-trough X; 7A, grey-f., v.f. sst.-trough X, flat) probably represented lateral incursions from a separate fluvial system. Thinner sandstone units, (incorporated within 5A, red-co. slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.) probably were the channel deposits of the feeder streams of the siltstone system; the thicker red siltstones, were the overbank, floodplain deposits, with the scoops of siltstone cross-stratification scoured during flood. The lenticularity of the sandstone bodies suggests that the stream channels aggraded and then shifted their course by avulsion. Rarer finer-grained units terminating at one end in a channelform infilled with siltstone perhaps represent lateral migration of small sinuous stream channels in the more distal parts of the floodplain. Palaeocurrent azimuths, mainly from small-scale asymmetrical ripples in the silt-

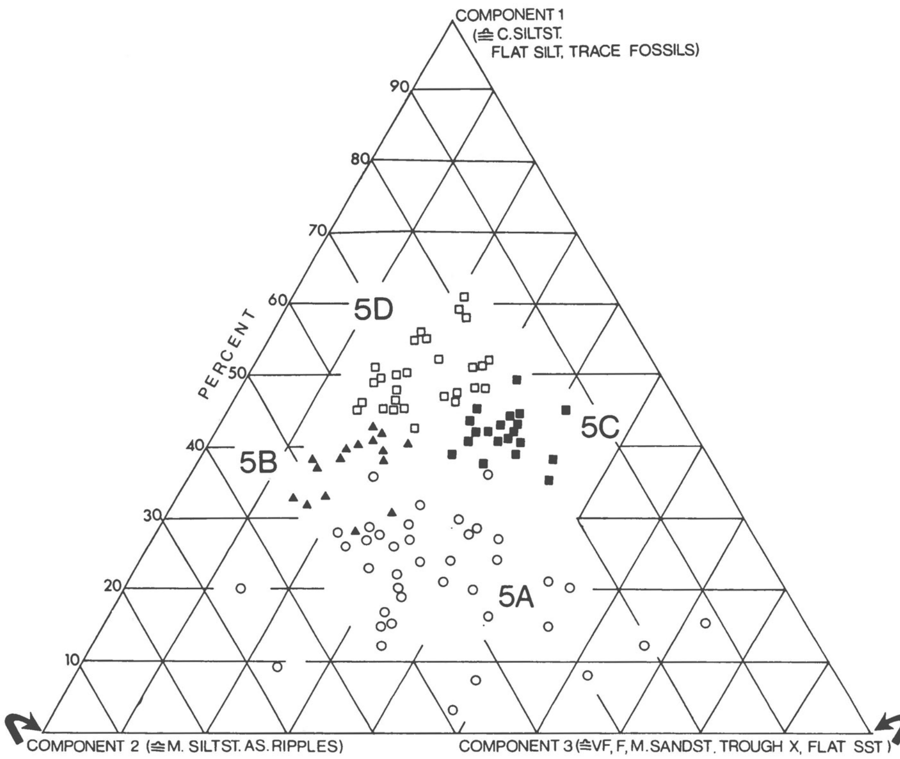


Fig. 76. Red Siltstone samples: component loadings of 10 m sample groups.

stones have a low variance, and the means are parallel to those obtained from large-scale cross-stratification in the smaller sandstone bodies. This is consistent with Wolman & Leopold's (1957) observation that flood waters tend to flow straight down the maximum gradient of the floodplains. Flood channels traversing the floodplain of Oued Biskra in the Northern Sahara (Williams, 1970) are more or less parallel to the main stream channel. The abundance of an antiarch fauna in the channel deposits, suggests that sufficient water supply was maintained to support the life of these organisms.

Three principal components were needed to subdivide the red siltstone of group 5. If component-loadings of individual 10 metre facies profiles are plotted on a ternary diagram (Fig. 76), the essential differences between the subdivisions become apparent. The third component is clearly correlated with the channel sandstone element: grainsizes from very fine to medium sandstone, with trough-cross-stratification and flat bedding (sandstone). The second component represents finer grainsizes ('medium siltstone') and current structures of lower stream power (asymmetrical ripples), while the first component represents deposition

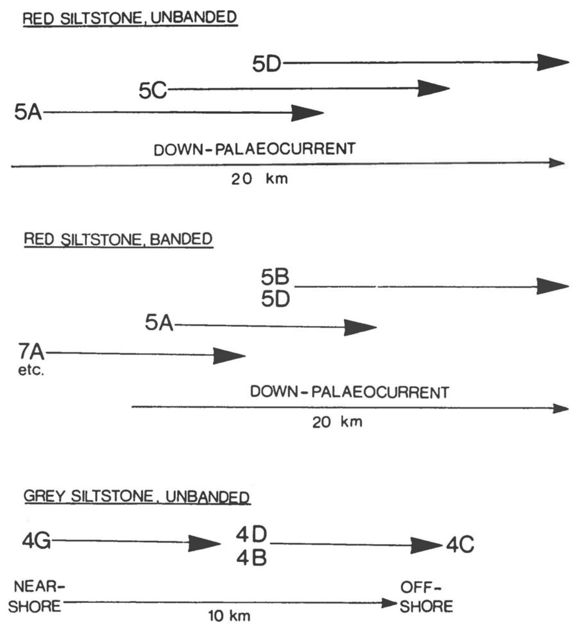


Fig. 77. Down-current variation in red and grey siltstone systems.

from suspension (flat siltstone) and the effect of deposit feeders in removing finer grades from the sediment (coarse siltstone). Thus, if both grainsize and stream power decline downstream, we should expect the loading on component 3 in 10 metre units to decline downstream, and samplegroup 5A (red-co. slst., v.f. sst.-asym. rip.) and/or 5C (red-co. slst., v.f. sst.-flat, asym. rip.) upstream should give way to 5B (red-co., m. slst.-asym. rip., flat) or 5D (red-co., m. slst.-flat, asym. rip.) downstream. This is the case in Canning Land (Fig 77). As the stream channels dispersed over the floodplain, some thinned and died out, increasing the ratio of overbank to channel deposits. A remarkably similar situation is recorded in the Aina Dal Formation (base of the Remigolepis Group) from eastern Ymer Ø to central Gauss Halvø. There too, there is evidence of subsidiary lateral influxes of sand. A possible modern analogue is the Kilombero valley in Tanzania (ANDERSON, 1961), where sandy alluvial fans about 12 km long extend from each side into a clay floodplain traversed by small stream channels.

(c) Our third system, which appears to have developed about the same time from Hudson Land to Canning Land differs from the second in the occurrence of sample group 5B (red-co., m. slst.-asym. rip., flat) rich in current ripples. The greater thickness of these stratigraphic divisions allows considerable vertical variation in facies. This appears to be less in the Kap Franklin area than elsewhere, for the mean loadings

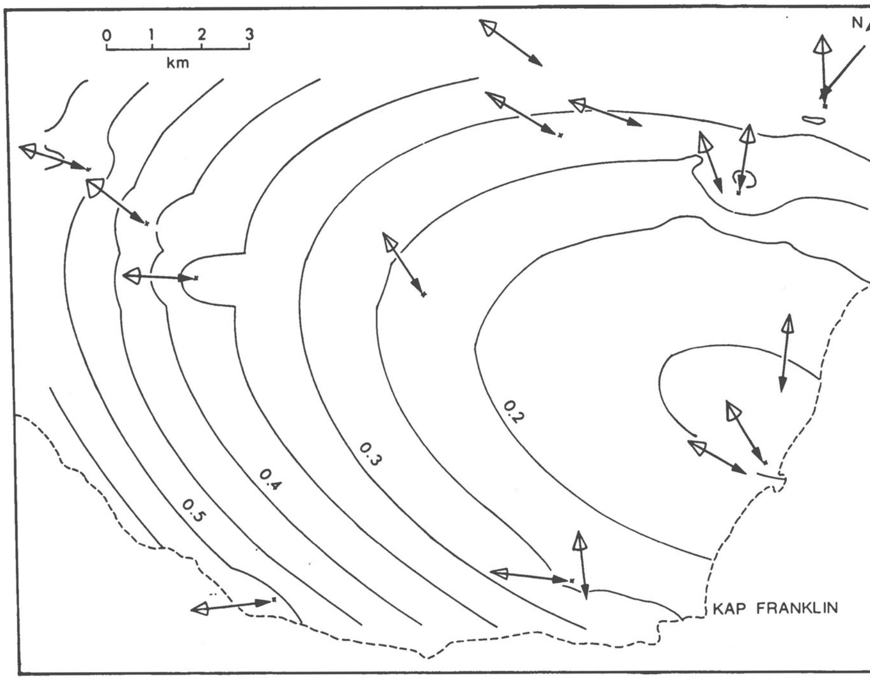


Fig. 78. Mean loadings per locality, red siltstones of sample group 5, component 3, Vilddal Red-and-green banded Siltstone Formation (contoured using iterative fit method of COLE (1968)). Palaeocurrents: Vector means are plotted with 95% confidence limits for means.

on component 3 per section decline regularly down the palaeoslope, as defined by palaeocurrent azimuths (Fig. 78). Thus 5A (red-co. slst., v.f. sst.-asym. rip.) gives way to 5B (red-co., m. slst.-asym. rip., flat) and 5D (red-co., m. slst.-flat, asym. rip.); grainsize and power decline downstream along the alternative route on the ternary diagram (Fig. 76). 5C (red-co. slst., v.f. sst.-flat, asym. rip.) is only well developed on Agassiz Bjerg, where red siltstone bands over 60 m thick may have approached the Red Siltstone Member of Canning Land in pattern.

Vertical variation in the Red-and-green banded Siltstone Member in Canning Land is more rapid than elsewhere: SÄVE-SÖDERBERGH (1937, p. 12) noted that the top of the division was finer-grained than the bottom. The facies therefore follow the predicted trend: 5A, red-co., slst., v.f. sst.-asym. rip., is well developed upstream (south Canning Land) and at the bottom of the member, while 5B, red-co., m. slst.-asym. rip., flat, and 5D, red-co., m. slst.-flat, asym. rip., are developed downstream (Wegener Halvø) and at the top of the member. A transition up from the medial part of the grey sandstone system (7A, grey-f., v.f. sst.-trough X, flat; 7C, grey-v.f., f. sst., co. slst.-flat, trough X) in

Canning Land is also recorded in the East Ramsays Bjerg Sandstone Formation. The upstream position of these sandstone sample groups relative to the red-and-green banded siltstone system is confirmed by the data from Karins Dal and Høgboms Bjerg relative to Agassiz Bjerg.

Grey-green Siltstones (sample group 4)

There are two major groupings:

(a) Grey siltstones alone (4G, grey-co. slst., v.f. sst.-sym. rip.; 4D, grey-co., m. slst.-flat; 4B, grey-co., m. slst.-lent., flat; 4C, grey-m., co. slst.-flat), distinguished by the development of lenticular bedding (in, 4B, grey-co., m. slst.-lent., flat) and symmetrical ripples (in 4G, grey-co. slst. v.f. sst.-sym. rip.) and the paucity of structures of current, as opposed to wave-current, origin (Vilddal Grey Siltstone Formation; Karins Dal Grey Siltstone Formation).

(b) Grey-green bands in red-and-green banded siltstone formations (4E, grey-co., m. slst.-asym. rip., flat; 4D, grey-co., m. slst.-flat; 4C, grey-m., co. slst.-flat) distinguished by the presence of current ripples (in 4E, grey-co., m. slst.-asym. rip., flat) as well as flat-bedded siltstone (4D, grey-co., m. slst.-flat; 4C, grey-m., co. slst.-flat).

Both systems are interpreted as lacustrine. Lake sediments were largely clastic in origin. Unlike the Green River Formation (Bradley, 1926, 1931, 1964) or the Great Salt Lake, Utah (Eardly, 1938), there are no pure limestones, oolites, stromatolitic deposits, oil shale or evaporites.

(a) Cross-lamination palaeocurrent azimuths in the Vilddal Grey Siltstone Formation indicate sediment movement to the north-east; mean grainsize decreases in this direction (Fig. 13) and vertically, so that a progression of facies can be constructed (Fig. 77) from near-shore abundance of symmetrical ripples and mudcracks (4G, grey-co. slst., v.f. sst.-sym. rip.) through lenticular bedded (4B, grey-co., m. slst.-lent., flat) and flat-bedded/bioturbated (4D, grey-co., m. slst.-flat) coarse siltstones into flat laminated medium siltstones (4C, grey-m., co. slst.-flat). The large-scale grainsize cycles already noted contain a zone of numerous thin sets with convolute lamination between the finely laminated medium siltstones and the bioturbated coarse siltstones. If this represents a shallowing sequence, the relative fall in water level may be responsible for the high pore-water pressures involved in the deformation (Graff-Petersen, 1967). Nearer shore, we should expect to find coarser sands or fine gravels representing beach deposits, but these are not preserved in the present outcrops. Twenhofel and McKelvey (1941) thought that no shoreline would be preserved in cases where lakes were filled in rapidly, and in a review of ancient lake deposits of the eastern U.S.A., Feth (1964) emphasised that criteria for recognition of shorelines in lakes older than the Pleistocene involving coarsening of grainsize were unsatisfactory. Nevertheless, one set 15 cm thick of grey fine sandstone, flat-bedded with parting lineation, occurs in the middle of grey flat-bedded siltstones in the locality with symmetrical ripple development (4G, grey-co. slst., v.f. sst.-sym. rip.). Its isolation from sequences with cross-stratification and current ripples, and its large proportion of carbonate detritus (unlike the quartz-rich fluvial sandstones of the overlying formation) suggest upper phase plane bed movement by near-shore wave action. Velocities 'near the bottom' greater than 60 cm/s must have been attained (INMAN, 1957, Fig. 9).

In eastern Moskusoksefjord, grey sandstone bands probably represent delta channel deposits. They abruptly overlie the grey siltstones, but pass up with rapid transition into further grey siltstones. Red siltstones are absent, and the sandstones may have been deposited in sublacustrine channels on the delta foreslope, as in the Rhone delta in Lake Geneva (HOUBOLT & JONKER, 1968). Further examples of lenticular bedding in siltstones of the post-Caledonian molasse include a small development in the Devonian Orcadian lake basin (N. G. T. FANNIN, personal communication 1970) and in the late Silurian of Hitra in Trondheimsled, Norway (PEACOCK, 1963, unpublished Ph. D. thesis University of St. Andrews).

(b) The other system shows less regular patterns of variation, partly because sample group 4E (grey-co., m. slst.-asym. rip., flat) is effectively a non-red version of the fluvial sample group 5B (red-co., m. slst.-asym. rip., flat) though both are also partly lacustrine in origin. However, flat medium siltstones (4C, grey-m., co. slst.-flat) rarely occur in association with the more proximal red siltstones (5A, red-co., slst., v.f. sst.-asym. rip.; 5C, red-co. slst., v.f. sst.-flat, asym. rip.). In eastern Moskusoksefjord and Nordhoeksbjerg, the middle of the Red-and-green banded Siltstone Formations is particularly non-red and fine grained. Such deposits are also developed at the top of the Nathorst Fjord Group in Wegener Halvø, and in Randbøldalen, where they contain chert concretions, and small crossopterygian remains. The abundance of vertebrate fragments rules out the possibility of a temporary playa lake, though the frequency of mudcracks suggests that some areas were subject to periodic exposure and desiccation, as in the interdistributary basins of the Senegal delta (TRICART, 1955). Small distributary channels probably coexisted with flooded embayments, and many of the smaller-scale bedding relationships can be explained by the lateral migration of channels over lake deposits. However, the scale of the banding (10 to 60 m thick and laterally extending over tens of km^2) suggests one large lacustrine area, rather than a series of individual flood-basin lakes, such as those of the Mississippi (COLEMAN

& GAGLIANO, 1965, p. 147), Brahmaputra (COLEMAN 1969, p. 232) or Amazon (SIOLI, 1957; WILHELMY, 1958). The banding either resulted from large-scale shifts in location of the delta, or from repeated crustal warping, as in the recent history of the margins of Lake Victoria (TEMPLE & DOORNKAMP, 1970).

The abundance of vertebrate remains in the green bands compared with the unbanded lake deposits may be attributed either to a prefeference for quiet water (flat bedding) rather than sporadic wave action (lenticular bedding), or to a need for the fresh water input from the silty streams (red bands): the composition of the waters of Lake Van in Turkey allow fish to exist only at the exits of streams along its shores (LYNCH, 1965, vol. 2, p. 46). However, there is no evidence that the 'unbanded' lake was saline, nor of mass mortalities caused by rapid turn-over of a stagnant hypolimnion (BRADLEY, 1948) in either system.

Alternating Pebbly Sandstone and Siltstone

10-metre units with bimodal grainsize distributions including sample group 7D2 (grey-v.f., co. sst.-trough X, flat) and 4F (grey-co. slst., co. sst.-flat, asym. rip.) occur in the Vilddal Supergroup at about the same horizon, usually just above one of the major conglomerate formations. Our observation of streams in Anatolia indicates that the association of fine-grained silty floodplains with braided stream channels of gravel and coarse sand may be a common phenomenon. The Ceyhan, which further downstream on the Cilician plain becomes a classic meandering single channel stream (RUSSELL, 1954), is braided upstream with a silty floodplain, at its emergence from the Nur Dağlari near Osmaniye. Another example is the Tortum Çay north of Erzurum, where it emerges from the mountains into a lake.

The association with the flat-bedded grey siltstones (4D, grey-co., m. slst.-flat) in the Vilddal Pebbly Sandstone-and-siltstone Formation may indicate that coarse alluvial fans plunged straight into the Vilddal lake, as occurs along the eastern fault margin of the salt lake, Tuz Gölü, south of Ankara.

CONCLUSIONS AND SPECULATIONS

Summary: Sedimentation and Tectonics of the Eastern Margin

After the main Caledonian orogenic phases of deformation and metamorphism (see HALLER, 1970), which occurred at some time between the Middle Ordovician and Middle Devonian, (BÜTLER, 1954, p. 110; WEGMANN, 1935), the oldest rocks to be preserved on the eroded fold belt were the acid-intermediate volcanics of the Kap Fletcher Formation in Canning Land.

Deposition of the Vilddal Supergroup

The oldest sediments of the Vilddal Supergroup first accumulated in eastern Gauss Halvø (East Ramsays Bjerg Sandstone Formation). Tectonic movements in the source areas must have been responsible for a later influx of conglomerates and coarse sandstones mainly from the west, extending younger Vilddal Supergroup sediments over a wider area, onto eroded remnants of the Kap Fletcher Formation and pre-Cambrian Eleonore Bay Group to the south (Canning Land) and north (Hudson Land). A lake was formed in Gauss Halvø, into which sandy streams (probably braided) entered in Moskusoksefjord. In Canning Land, a silty flood-plain developed well above water-table, draining southwards and flanked to the west by sandy alluvial fans (Fig. 79).

In later Vilddal Supergroup times (upper Middle Devonian – Givetian), a succession up to 1500 m thick, of red-and-green banded siltstones was formed by the interdigitation of fine-grained fluvial systems with a large lake. The development was remarkably similar in all the eastern areas (Fig. 79), though north of Kejser Franz Josephs Fjord sand streams drained south-eastward, while in Canning Land they drained northward. There is no evidence of an eastern margin to the basin in the vicinity throughout this time.

Deformation of the Vilddal Supergroup

The Vilddal Supergroup, up to $2^1/_2$ km thick, was faulted and locally folded with axial traces striking east-west, and deeply eroded in upper Middle Devonian times.

Deposition of the Kap Kolthoff Supergroup

The next period of sedimentation was represented by a number of sandy and conglomeratic alluvial fans, draining westwards from source areas in a newly uplifted eastern margin probably not far to the east (Fig. 79). In Gauss Halvø, the palaeoslope was reversed. At Kap Franklin, the transition phase is preserved in a local succession (Kap Franklin Formation) of fluvial sediments and acid volcanics, and a small granitic high-level pluton was intruded into the Vilddal Group at least twice, exposed to erosion, and buried again within upper Middle Devonian times.

Deformation of the Kap Kolthoff Supergroup

$2^1/_2$ km thickness of the Kap Kolthoff Supergroup is preserved in eastern Gauss Halvø. Its lower part is Middle Devonian in age (Randbøl Formation); its top, elsewhere in the basin, is probably Upper Devonian. The succession everywhere was deformed, with axial traces striking north-south, probably in Upper Devonian times.

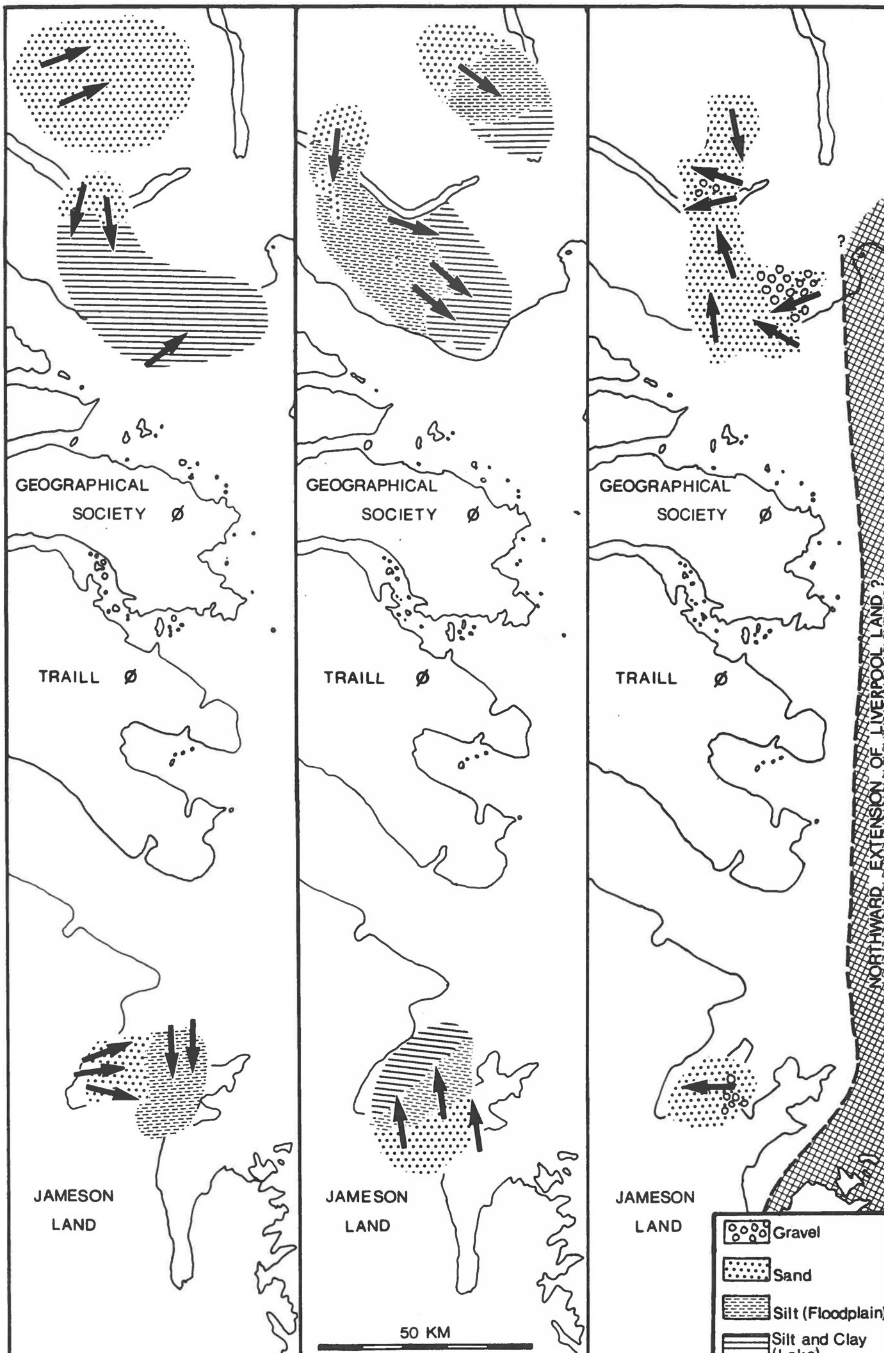


Fig. 79. Reconstruction of sedimentation patterns along the eastern margins of the Devonian outcrop. A, left, Middle Vilddal Group. B, centre, Upper Vilddal Group. C, right, Randbøl Formation and Lower Kap Kolthoff Supergroup.

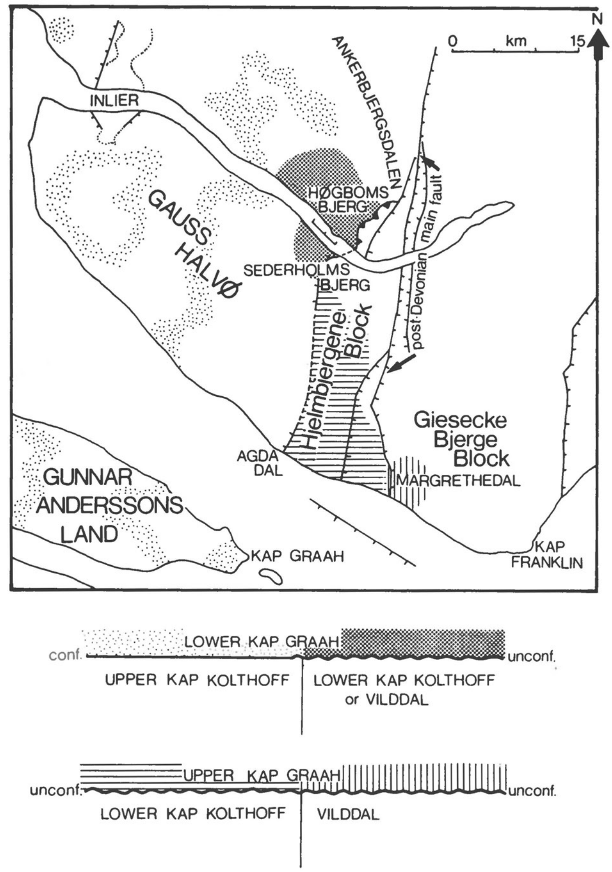


Fig. 80. Fault blocks in northern region. Diagram shows stratigraphic evidence for relative movements of the blocks during the Upper Devonian. Key, below, shows conventions for different stratigraphic boundary situations.

Deposition of Kap Graah Group and Mt. Celsius Supergroup

Erosion of the Giesecke Bjerge and Hjelmbjergene fault blocks (Fig. 80) in eastern Gauss Halvø ensued during deposition of most of the Kap Graah Group further to the west. The Middle Devonian groups were incorporated into the more westerly eastern margin to the basin. Upper Devonian sediments of the upper Kap Graah Group and Mt. Celsius Supergroup were finally deposited unconformably on the eastern blocks of Gauss Halvø. (Fig. 81).

Change in pattern of sedimentation

The streams which deposited the Vilddal Supergroup were small and numerous. Sediment transport was of short duration each year, but water supply was sufficient to maintain large permanent lakes in the basin. The Kap Kolthoff Supergroup streams also deposited most of

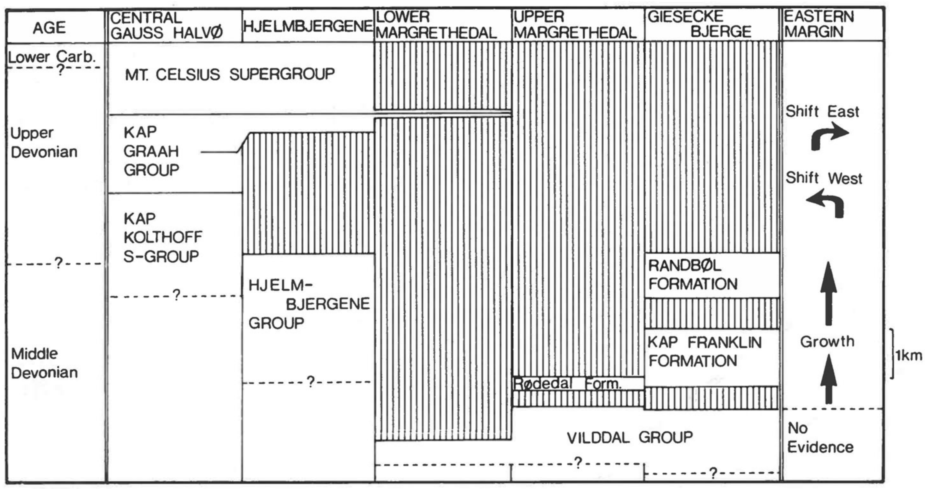


Fig. 81. Stratigraphic correlation in Eastern Gauss Halvø.

their sediment load close to source, but water supply was probably more intermittent than previously, leading to rather more arid conditions, at least for the lower part of the group. The tectonic development of a nearby eastern margin may have affected patterns of sedimentation not primarily by a steepening of local gradients, but by altering the balance of local climate, precipitation, and run-off.

Correlation across the basin

West of the Agda Dal-Sederholms Bjerg-Høgboms Bjerg line (the western edge of the Hjelmbjergene block, Fig. 80), possible equivalents of the Vilddal Supergroup outcrop only in western Hudson Land and Ole Rømers Land (Bütler, 1940) and around the Inlier in western Moskusoksefjord (Bütler, 1959, p. 39). Both cases consist dominantly of conglomerates. At the Inlier, two conglomerates underlie the Kap Kolthoff Supergroup, each separated by unconformities (Bütler, 1959, Fig. 9). The upper of the two conglomerates, which we found to be 1 km thick, contains clasts of limestone, quartzites, and greyish-white granites, comparable with the Ramsays Bjerg Group conglomerates further east.

The thick red and grey sandstone successions (Rødebjerg Formation) and conglomerates on the western edge of the Devonian outcrop in East Greenland (number four of this Volume), referred by Bütler (1959, p. 165) to his Ramsays Bjerg Series, lie conformably beneath his Kap Kolthoff Series (= Sofia Sund Formation of our usage). The Kap Kolthoff Supergroup is now defined to include both our Rødebjerg and Sofia Sund Formations. If the Giesecke Bjerge Group on the eastern margin is equivalent to the lower part of the Kap Kolthoff Supergroup in Moskusoksefjord, a correlation with the Rødebjerg Formation may be possible, especially as the Ella Ø conglomerate, near the base of the formation, contains upper Middle Devonian (Givetian) vertebrate remains and spores. It is of interest to note that the vertical sequence of sample groups in the Hjelmbjergene Group compares closely with that recorded by our colleague Yeats in the Rødebjerg Formation (Rødebjerg and Svedenborgs Bjerg) at the west end of Sofia Sund. In each case a grey sandstone system gave way to a red sandstone system, via a mixed sequence with bimodal palaeocurrent distributions in between. On the eastern margin the mixed sequence was deposited while the Giesecke Bjerge block was undergoing pre-Randbøl Formation erosion; on the western margin, YEATS has related the mixed sequence to proximity to the western boundary unconformity.

Palaeocurrents in the Rødebjerg Formation on the western margin are predominantly to the east so that for the lower part of the Kap Kolthoff Supergroup, the basin was bilaterally symmetrical about a north-south striking axis. This was also the pattern for the lower part of the Kap Graah Group. This does not support HALLER's (1970, Fig. 40) idea of a down-flexed tract for Devonian sedimentation with an axis striking northwest-southeast.

Extent of magmatic activity

The two major accumulations of Devonian acid volcanics were the Kap Fletcher and Kap Franklin Formations. Sporadic outbursts of volcanism have also been noted near the top of the Kap Kolthoff Supergroup and in the Kap Graah Group (BÜTLER, 1959, p. 176). RITTMANN (1940, p. 89) has referred to the persistence of acid magma types in the basin throughout the Devonian.

BÜTLER (1959, p. 175) noted the widespread distribution of volcanic clasts from the Kap Fletcher Formation in Eotriassic conglomerates as far south as Hurry Inlet (70°45'N, 22°30'W); such clasts are also common constituents of conglomerates and sandstones in both Devonian groups and the upper Permian in Canning Land and Wegener Halvø. BÜTLER therefore concluded that the volcanics once extended over a greater area than their present outcrops would suggest. RITTMANN (1940, p. 91) mentioned similar rhyodacites occurring further west at Segelsällskapets Fjord, and clasts in the Vilddal Pebbly Sandstone-and-siltstone Formation include a few highly altered biotite-bearing acid volcanic types. Contrary to BÜTLER's (1959, p. 176) conclusion, such volcanics may underlie the Vilddal Supergroup in the northern region, and were certainly present in Vilddal Group source areas.

The abundance of red rhyolite clasts in the Kap Graah Group, derived from the east of Kap Graah, and in Moskusoksefjord derived from the northeast, suggests that the Kap Franklin volcanics too were extruded over a much wider area.

The Kap Franklin Granite is the only post-orogenic granite in the region stratigraphically dated as Middle Devonian. MAYNC (1949) postulated a Devonian age for other granites outcropping along the eastern edge of the Giesecke Bjerge, though this could not be proved from field relations. Similarly, the Kap Wardlaw Granite, in northeast Canning Land, is petrogenetically similar to the Kap Fletcher Formation volcanics (NOE-NYGAARD, 1937, p. 124); and the Hurry Inlet Granite in southern Liverpool Land, regarded as possibly Devonian by KRANCK (1935), is another high-level pluton emplaced in its final stages as largely crystalline sheets (COE, 1971). The distribution of acid volcanics and granites probably of Devonian age indicates that considerable magmatic activity was concentrated along the eastern margin of the basin.

The Liverpool Land structure

Liverpool Land lies to the south-east of Canning Land. At the present, it consists almost entirely of crystalline rocks (KRANCK, 1935), some of which may be pre-Caledonian basement (Dr. K. COE, personal communication, Jan. 1971). This block appears to have been uplifted several times during the Mesozoic era, and formed a positive feature controlling sedimentation in the region.

Thickness of the Triassic succession in East Greenland diminishes on each side of the Jameson Land Basin, to Scoresby Land on the west and to Liverpool Land on the east (STAUBER, 1942). Feldspathic sandstones of the Mount Nordenskjöld Formation (Triassic) were deposited by westerly-flowing currents (TRÜMPY, 1960), and were probably derived from the Liverpool Land migmatites. Later, in Jurassic (upper Oxfordian) times, the Liverpool Land massif must have extended northwards either as an exposed ridge or submarine sill (DONOVAN, 1957).

Results presented in this paper suggest that the Liverpool Land horst may have begun its long life as a tectonic 'high' during the upper Middle Devonian, when its northward extension (Fig. 79) probably formed the eastern margin of the Kap Kolthoff Supergroup basin.

Trondheimsled, Norway

The younger of two sedimentary groups of Old Red Sandstone type in the Trondheimsled in W. Central Norway, consists of a succession of conglomerates on the island of Smøla, thought to be Lower or Middle Devonian in age (PEACOCK, 1963, unpublished Ph. D. thesis, University of St. Andrew's, Scotland). Clasts include local diorite, green sandstones,

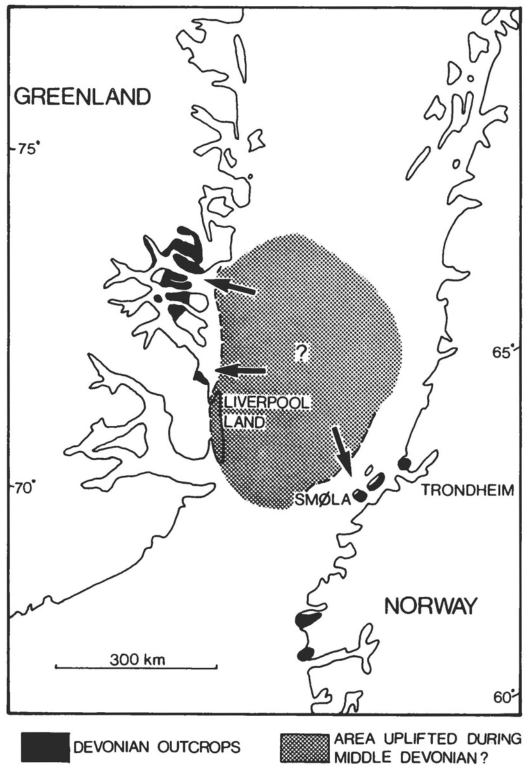


Fig. 82. Possible reconstruction of part of a Middle Devonian mountain range. Greenland and Norway positioned according to the computer-fit of BULLARD and others (1965).

metamorphics, and a red quartz porphyry not comparable with any *in situ* volcanics at present known from Norway. PEACOCK speculated on the possibility of derivation of these clasts from the Middle Devonian volcanics of east Greenland. Palaeocurrents, from imbrication, indicate derivation from the north.

We may note that on the computer best-fit of the 500 fathom contour of the North Atlantic continental shelves (BULLARD *et al.*, 1965), the distance between Canning Land and Trondheimsled is less than twice the distance between Canning Land and Hudson Land (Fig. 82). The Smøla conglomerates may therefore represent sediment dispersal to the other side of a mountain range, which probably included the Liverpool Land block, and which was uplifted in upper Middle Devonian times to form the eastern margin of the East Greenland basin.

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Appendix

Table 18. *List of stratigraphic terms, eastern sequence.*
(Areas are listed north to south; numbers indicate stratigraphic sequence and hierarchy)

HUDSON LAND

1. Vilddal Supergroup; 1.1, Nordhoeksbjerg Group
   - 1.1.1, Nordhoeksbjerg Conglomerate
   - 1.1.2, Nordhoeksbjerg Mixed Sandstone-and – siltstone
   - 1.1.3, Nordhoeksbjerg Green Sandstone
   - 1.1.4, Nordhoeksbjerg Red-and-green banded Siltstone
2. Kap Kolthoff Supergroup

EASTERN MOSKUSOKSEFJORD

1. Vilddal Supergroup; 1.1, Ramsays Bjerg Group
   - 1.1.1, East Ramsays Bjerg Sandstone
   - 1.1.2, West Ramsays Bjerg Conglomerate
   - 1.1.3, Karins Dal Grey Siltstone
   - 1.1.4, Ramsays Bjerg Red-and-green banded Siltstone
2. Kap Kolthoff Supergroup; 2.1, Sederholms Bjerg Grey Sandstone
   - 2.2, Langbjerg Red Sandstone

HJELMBJERGENE

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

MARGRETHEDAL AREA

1. Vilddal Supergroup; 1.1, Inderdalen Formation
2. Kap Kolthoff Supergroup; 2.1, Rødedal Formation
3. Kap Graah Group
4. Mount Celsius Supergroup

KAP FRANKLIN AREA

1. Vilddal Supergroup; 1.1, Vilddal Group
   - 1.1.1, Vilddal Pebbly Sandstone-and-siltstone
   - 1.1.2, Vilddal Grey Siltstone
   - 1.1.3, Vilddal Red-and-green banded Siltstone

(continued)

Table 18. *Continued.*

2. Kap Kolthoff Supergroup;	2.1, Giesecke Bjerge Group		
		2.1.1, Kap Franklin Formation	
			2.1.1.1, Lower Volcanic Member
			2.1.1.2, Saxos Bjerg Member
			2.1.1.3, Upper Volcanic Member
			2.1.1.4, Østreplateau Grey Sandstone Member
		2.1.2, Randbøl Formation	
3. Kap Graah Group			
4. Mount Celsius Supergroup			
CANNING LAND AND WEGENER HALVØ			
1. Vilddal Supergroup;	1.1, Nathorst Fjord Group		
		1.1.1, Basisdalen Conglomerate	
		1.1.2, South Hesteskoen Formation	
		1.1.3, Vimmelskaftet Formation	
			1.1.3.1, Red Siltstone Member
			1.1.3.2, Grey Sandstone Member
			1.1.3.3, Red-and-green banded Siltstone Member
		1.1.4, West Hesteskoen Formation	
2. Kap Kolthoff Supergroup;	2.1, Quensel Bjerg Formation		

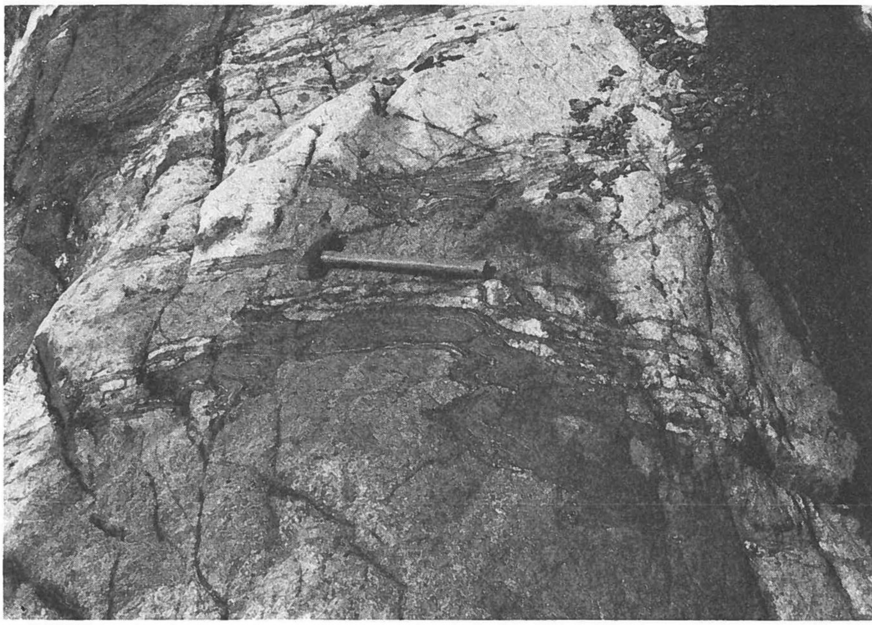

Plate 1. Migmatite textures, Kap Franklin Granite. Hammer shaft, 35 cm.

Plate 2. Granite vein sheared in siltstone country-rock, near margin of Kap Franklin Granite.

Plate 3. Ash flow tuff, Kap Franklin Upper Volcanic Member, Kap Franklin.

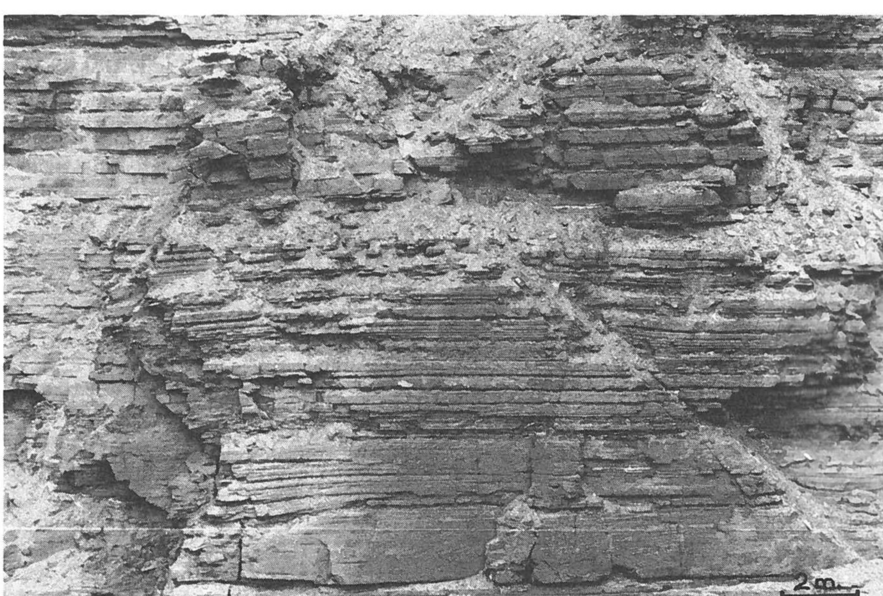

Plate 4. Sheet bedding in very fine sandstone, Rødedal Formation.

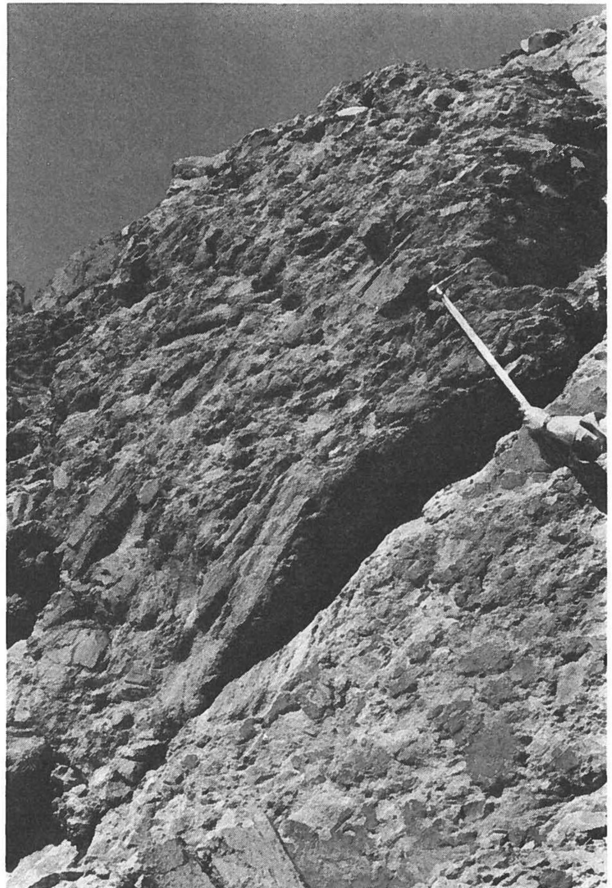

Plate 6. Brecciated ash, Kap Fletcher Formation, Porfyrbjerg, North Canning Land.

Plate 5. Texture of fine-grained conglomerate, Rødedal Formation, Randbøldalen.

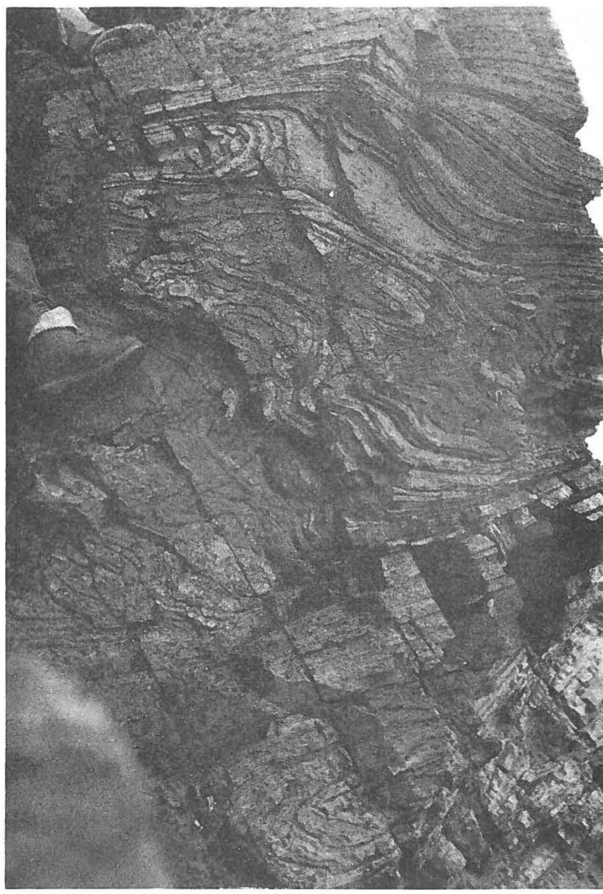

Plate 7. Flow folding in lava, Kap Fletcher Formation, Porfyrbjerg, North Canning Land.

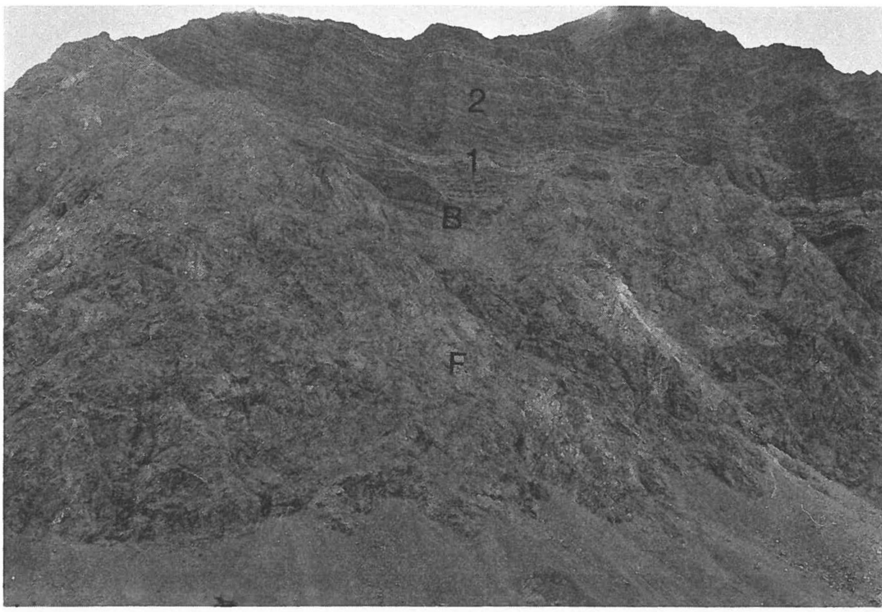

Plate 8. Unconformity between Kap Fletcher Formation (F), and Nathorst Fjord Group, S. E. Kap Brown. B, Basisdalen Conglomerate Formation. 1, South Hesteskoen Formation. 2, Red Siltstone Member.

Plate 9. Cross-stratification in red very fine sandstone and siltstones, Vimmelskaftet Red Siltstone Member, Kap Brown.

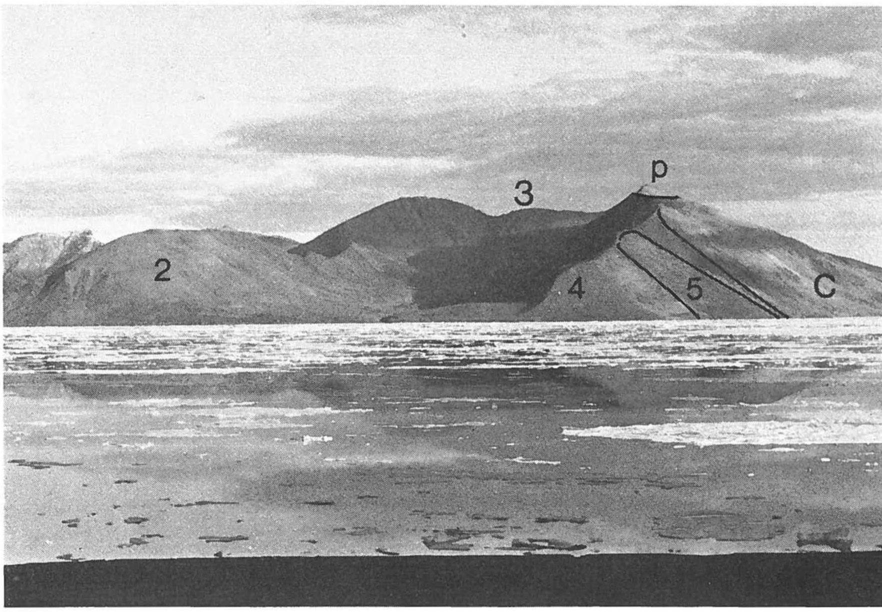

Plate 10. Hesteskoen, viewed from Kap Brown. 2, Red Siltstone Member. 3, Grey sandstone Member. 4, Red-and-green banded Siltstone Member. 5, West Hesteskoen Formation. P, Permian. C, Carboniferous.

Plate 11. Quensel Bjerg Formation unconformably above Nathorst Fjord Group, southeast side of Lille Ravnefjeld. 4, Red-and-green banded Siltstone Member. Q, Quensel Bjerg Formation. P, Permian.