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THE RØDE Ø CONGLOMERATE OF INNER SCORESBY SUND AND THE CARBONIFEROUS(?) AND PERMIAN ROCKS WEST OF THE SCHUCHERT FLOD

A GENERAL SEDIMENTOLOGICAL ACCOUNT

BY

J. D. COLLINSON

WITH 34 FIGURES AND 2 TABLES
IN THE TEXT

KØBENHAVN
C. A. REITZELS FORLAG
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Abstract

The Røde Ø Conglomerate is a formation of red sandstones and conglomerates in the inner part of Scoresby Sund. It has an elongated north–south outcrop within an area of high-grade metamorphic rocks. It is bounded on the west by a normal fault, downthrowing to the east and dying out northwards. The sediments rest unconformably on migmatites along their eastern boundary. Within the Røde Ø Conglomerate, four lithofacies associations are recognised. A conglomerate association is the most abundant and occurs along the western side of the outcrop against the fault. It is coarse and poorly sorted, and easterly palaeocurrents are suggested. The association is interpreted as the product of alluvial fans building eastwards. This association passes laterally eastwards through an interbedded complex into a silty sandstone association which, in turn, passes into a gypsiferous sandstone association. These are both thought to be largely suspension deposits at the distal limit of the fans. The gypsum is the result of near surface precipitation due to high evaporation. On Storø, on the eastern side of Rødefjord and east of the other associations, a cross-bedded sandstone association referable to a normal fluviatile model occurs. Palaeocurrents here were to the north and north–west. It is suggested that movements along the western boundary fault were probably the cause of the rapid uplift needed to supply the coarse sediment.

The rocks west of the Schuchert Flod were described by Kempter (1961) who recognised three major subdivisions, the Bjørnbos Corner Formation of alleged Carboniferous age, the Gurreholmsdal Formation (Lower Permian) and the Karstryggen Group (Upper Permian). The Bjørnbos Corner Formation is an arkosic conglomerate whose sedimentation is not obviously related to any presently observed tectonic feature. The Gurreholmsdal Formation shows a pattern of sedimentation broadly similar to the Røde Ø Conglomerate with conglomerates in the west, near the Stauning Alper Fault passing eastwards and downcurrent into finer arkoses and eventually into micaceous sandstones which have northerly palaeocurrents. Sediment supply is again thought to have been due to movement on the western fault margin.

It is not possible to date the Røde Ø Conglomerate by comparison with the Schuchert sequence in any conclusive way, though it can be tentatively suggested that the same regional tensional event might have been responsible for both sedimentary events.

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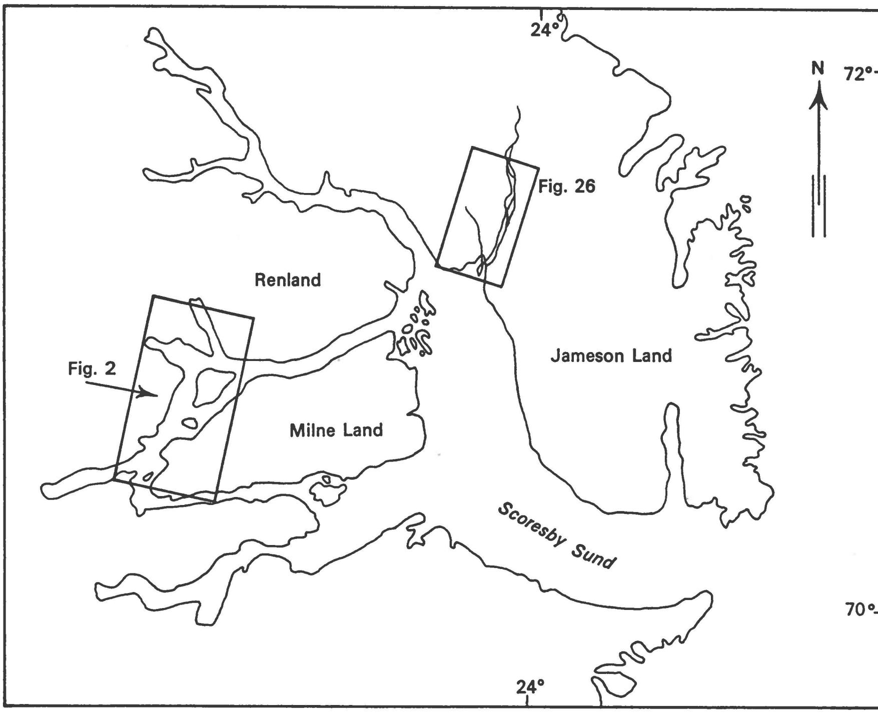

Fig. 1. Outline topographic map of Scoresby Sund showing the localities of areas described and indicating the Figure numbers of the enlarged geological maps.

INTRODUCTION

The object of this investigation was to map and make sedimentological observations on the red sandstones and conglomerates, the Røde Ø Conglomerate, of inner Scoresby Sund and if possible to determine their stratigraphical position. The Permian sediments of the valley of the Schuchert Flod were also briefly examined for comparative purposes. The Røde Ø Conglomerate has been described briefly by Bay (1896) and Bütler (1957), and the extent of its outcrop was roughly known. Bütler (1957) first considered, on the basis of lithological comparison, that the Røde Ø Conglomerate was of Carboniferous age but later (1961) thought that it might be Permian by comparison with rocks in the valley of the Schuchert Flod described by Kempter (1961). Bütler described the gross lithological characteristics of the conglomerates, noting the presence of large boulders, their alternating grain size and their intense red colouration. He considered that they overlay a peneplain cut into the gneissic basement and suggested that the conglomerates were derived from the west on the basis of changes in clast size. Kempter's (1961) description of the sequence west of the Schuchert Flod was more extensive and included alleged Carboniferous, Lower and Upper Permian sediments. He recognised several members in the Lower Permian Gurreholmsdal Formation and presented a map of these (see Fig. 26).

The fieldwork upon which this account is based was carried out during the 1970 Expedition of the Geological Survey of Greenland to Scoresby Sund. About four weeks were spent on the Røde Ø Conglomerate and ten days on the Schuchert sequence. The area of the Røde Ø Conglomerate was given roughly even coverage from five camps while the Schuchert sequence was studied from one camp in Revdal supplemented by a half day of helicopter reconnaissance.

In the following account, the two areas will be described separately and then briefly compared.

THE RØDE Ø CONGLOMERATE

The outcrop area and its topography

The outcrop of the Røde Ø Conglomerate is confined to a strip of country, elongated north–south, in the innermost part of Scoresby Sund (Fig. 1). The area (Fig. 2) divides itself naturally into four sub-areas; a) C. Hofmann Halvø between Rypefjord and Harefjord, b) The western side of Rødefjord south of Harefjord, c) the western side of Storø and d) Rødeø itself. These sub-areas have areas of 70, 100, 5 and 2 km^2 respectively. The first three sub-areas form a coherent group while Rødeø is isolated, some 20 km to the south.

The area between Harefjord and Rypefjord is divided by a major stream draining the ice cap through a deep ravine. North of the stream the land rises in one large rounded hill to 860 m. The overall rounded form of the hill is dissected by deep canyons along its eastern and southern sides and the uppermost 300 m of the eastern side stands as a near-vertical cliff. The canyons have well developed alluvial fans at their mouths where they drain directly into Rypefjord. South of the stream the topography is more varied. The land rises to 1010 m in a rounded hill which is also cut by canyons and gulleys but of less extreme relief than those to the north. To the south–east, the hill slopes gently towards the tip of C. Hofmann Halvø and vegetation cover increases. Exposure in this lower area is confined to the banks of the more deeply incised streams. Further towards the tip of the peninsula, more irregular topography marks the outcrop area of the migmatites. Outcrop of the conglomerate on the western coast of Rypefjord is blanketed by marine terraces south of the stream and by alluvial fan deposits north of it, giving an unexposed coastal strip up to 1 km wide. On the northern shores of Harefjord the conglomerates are exposed along the coast in low cliffs over much of the outcrop length, though exposure dies out eastwards.

The area south of Harefjord is divided by a major stream, Lerelv. Between Harefjord and Lerelv the conglomerate forms a plateau at about 750 m with a maximum height of 900 m. The plateau sides fall steeply to the fjord and are deeply dissected by spectacular canyons giving superb exposure (Fig. 3). The canyon walls are, however, very steep and loose and are largely inaccessible. On the plateau top, exposure

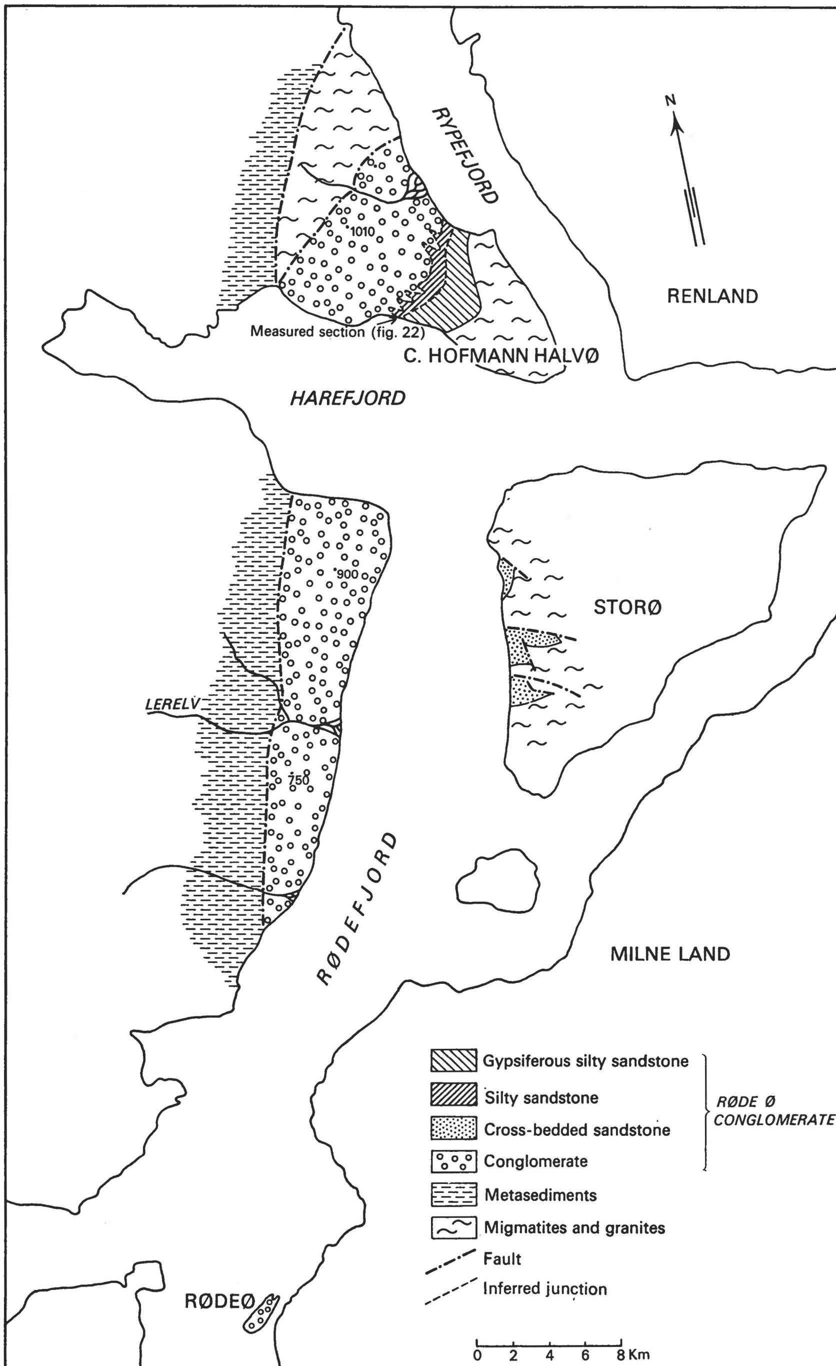

Fig. 2. Geological map of the Rødefjord area, showing the distribution of lithofacies associations in the Røde Ø Conglomerate.

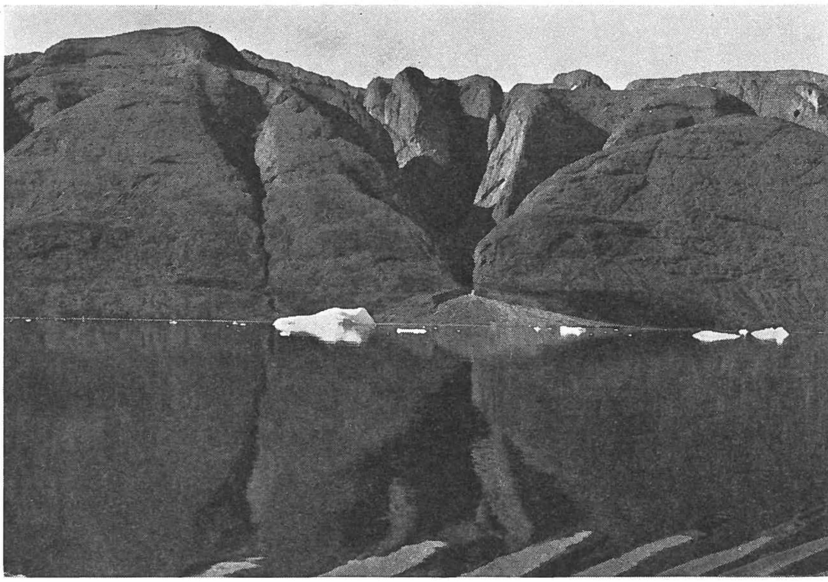

Fig. 3. The deeply incised canyon topography cut into the conglomeratic association of the Røde Ø Conglomerate on the western side of Rødefjord between Harefjord and Lerelv. The plateau top is about 900 m above sea level.

is non-existent. The lower, poorly drained areas are heavily vegetated and boulder-strewn while the higher parts are covered with shattered conglomerate, moraines and erratic blocks. The canyons die out to the south in the area north of Lerelv. South of the stream, the plateau level continues, still with steep slopes down to the fjord and with occasional canyons. Cliffs at the coast increase in height southwards. Outside the canyons and cliffs, the rock is largely covered with glacial debris except on the steepest slopes where accessibility becomes a problem.

Exposures of the Røde Ø Conglomerate on Storø are confined to three small, fault-controlled blocks. The western side of Storø slopes rather gently towards Rødefjord. Prominent cliffs, which cross the slope diagonally, are upfaulted margins of metamorphic areas, and the sediments are confined to the lower, less rugged areas below them. The sediment area is quite well vegetated and exposure is largely confined to stream banks.

Rødeø is composed entirely of conglomerates and slopes gently to the northwest from the top of the near-vertical cliff which bounds it on the south–east. Exposure in the cliff and along its top is good but exposure on the slope is poor because of vegetation.

Fig. 4. Unconformable base of the conglomerate in the stream at northern end of the outcrop, 1 km from the Rypefjord coast. Just above the rule (1 m long) a wedge of sediment protrudes down into the shattered migmatite.

Field relationships of sediments and metamorphic rocks

The sediments of the Røde Ø Conglomerate are unmetamorphosed and relatively undisturbed and outcrop in a north–south elongated strip within a terrain of high-grade metamorphic rocks. The western boundary of the sediments is, with the exception of one locality, a fault. The rocks west of the fault are migmatites in the area north of Harefjord and mainly metasediments in the area to the south.

The exception to a faulted western contact occurs at the northernmost end of the boundary where, for a horizontal distance of some 50 m, the conglomerates seem to overlie the migmatites unconformably. The locality is in the south bank of a stream draining to Rypefjord at an altitude of 230 m and about 1 km from the coast. The outcrop shows the shattered and reddened but uncrushed top to the migmatites passing upwards through angular conglomerate into conglomerate with rounded pebbles. The gradational contact undulates somewhat and, at one point, a wedge of medium sandstone, 30 cm wide at the top, protrudes down some 60 cm into the migmatites (Fig. 4). At this northern end of the area the fault plane, where exposed, has a low dip (22°) to the east. South of Harefjord this steepens to reach observed values of 45°. The northerly reduction in dip, the evidence of an unconformity in the north and the lack of any evidence for the continuation of the fault at its projected

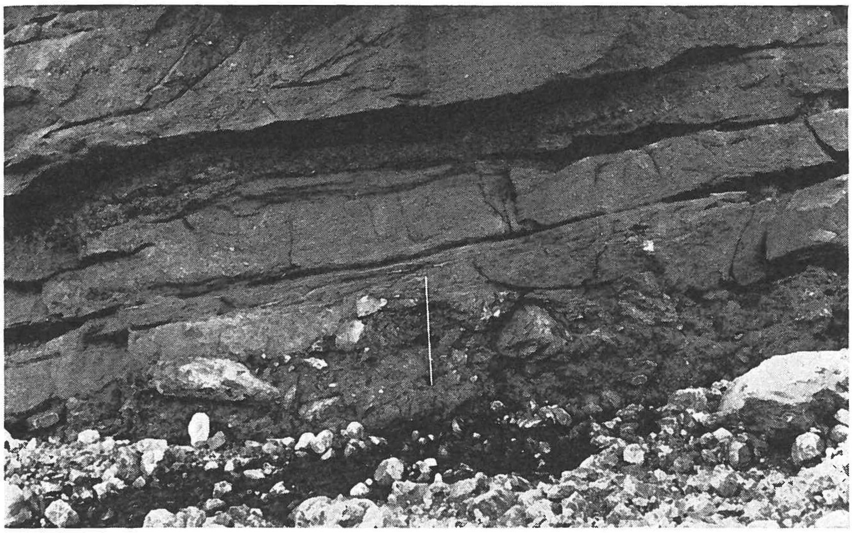

Fig. 5. Unconformable base of the Røde Ø Conglomerate on Storø. The coarse basal conglomerate passes rapidly into sandstones of the cross-bedded sandstone association.

position on the eastern side of Rypefjord (J. D. FRIDERICHSEN, personal communication, 1971) all suggest that the fault is dying out to the north.

The eastern contact of the sediments with the metamorphics is less well exposed. For much of the length of outcrop it is below the waters of Rødefjord and Rypefjord. Where it occurs on land it is poorly exposed. Across C. Hofmann Halvø it is nowhere exposed though the topography, as seen on aerial photographs, suggests an unconformity, dipping westwards. On Storø the contact is often faulted but mapping evidence and one exposure (Fig. 5) suggest that it is an unconformity dipping to the west. The faulting has broken the sediment outcrop into isolated blocks. There is no evidence for any great relief on the surface of the unconformity; a range of 1 m was observed at its one exposure in the middle of the three Storø blocks. This would seem to support BÜTLER's (1957) idea of a peneplain.

The sediments

Sediments can be described in the field in terms of their grain-size characteristics, their composition, colour, sedimentary structures and textures and post-depositional features. On the basis of such a description it is often possible to subdivide a sedimentary sequence into a number of lithofacies and to describe the sequence in terms of the scale and nature of lithofacies variation. Often distinct associations of lithofacies can be recognised and these may be environmentally significant. In a highly variable sequence it is often customary to describe the lithofacies and then to discuss their relationships. In the Røde Ø Conglomerate, however, the sequence can be divided immediately into clearly defined associations with little overlap of lithofacies between them. The sequence will, therefore, be described immediately in terms of lithofacies associations. Four associations have been recognised.

1) Conglomerate Association
2) Cross-bedded Sandstone Association
3) Silty Sandstone Association
4) Gypsiferous Sandstone Association

Only three adjacent stream sections were found which could not be assigned to one of these associations and these are described as

5) Interbedded Conglomerate and Sandstone Complex

The associations are described in order of decreasing average grain size.

1. Conglomerate Association

Distribution and thickness: This is by far the most abundant lithofacies association in the present day exposures. It is the only association found in sub-area 2 and on Rødeø and it also forms a large part of sub-area 1. It is absent from Storø. The base of the association is never seen and the present erosion level determines its top so that any thickness measured is a minimum value. The maximum thickness exposed is greater than 1010 m, the height of the highest hill. The uncertainty about the figure in terms of sediment thickness is due to the impossibility of separating tectonic from depositional dips in the conglomerates.

Grain size: The association consists of interbedded coarser and finer units from a continuum ranging from medium sandstone to boulder conglomerate. Generally, the grain sizes of the interbedded units are not as widely divergent as the end members of the continuum and the grain sizes of the coarser and finer units tend to vary together. Therefore, in the case where the coarser units are pebble to cobble conglomerates, the finer units might be medium to coarse sandstone while if the coarser units are rich in boulders, the finer units might be pebble conglomerate.

The largest observed clast was of 4 m diameter (Fig. 6), and boulders up to 1 m are common. There is no obvious change in maximum grain size over the area of the association, and only the conglomerate of Rødeø is significantly different from the rest in being finer and more homogeneous. The sediments as a whole are very poorly sorted, and only occasional pebble lenses show much sign of sorting. Sandstones from sandy lenses and beds were disaggregated and sieved with $^1/_2\ \varphi$ intervals. The results

Fig. 6. Very coarse conglomerate in a gulley on the south side of Lerelv. The large boulder on the right (man standing on top for scale) is about 4 m in diameter.

are shown in Figure 7 as cumulative curves, and statistical parameters of distributions are given in Table 1.

Table 1. *Statistical parameters of grain-size distributions of sandstones.*

Sample No.	Locality	Association	Median	Inman Mean	Inman deviation	Inman skewness
			φ	φ		
133707	Rypefjord west side	Conglomerate	0.9	0.725	1.425	−0.12
133716	Harefjord, north side	–	1.0	1.15	1.05	+0.14
133721	Harefjord, south side	–	1.6	1.525	1.075	−0.07
133728	Rødeø	–	0.9	1.05	1.10	+0.14
133713	Harefjord, north side	Interbedded Complex	1.3	1.425	1.225	+0.10
133730	Storø, central block	Cross-bedded	2.2	2.225	1.075	+0.023
133732	Storø, central block	– –	0.7	0.8	1.1	+0.091

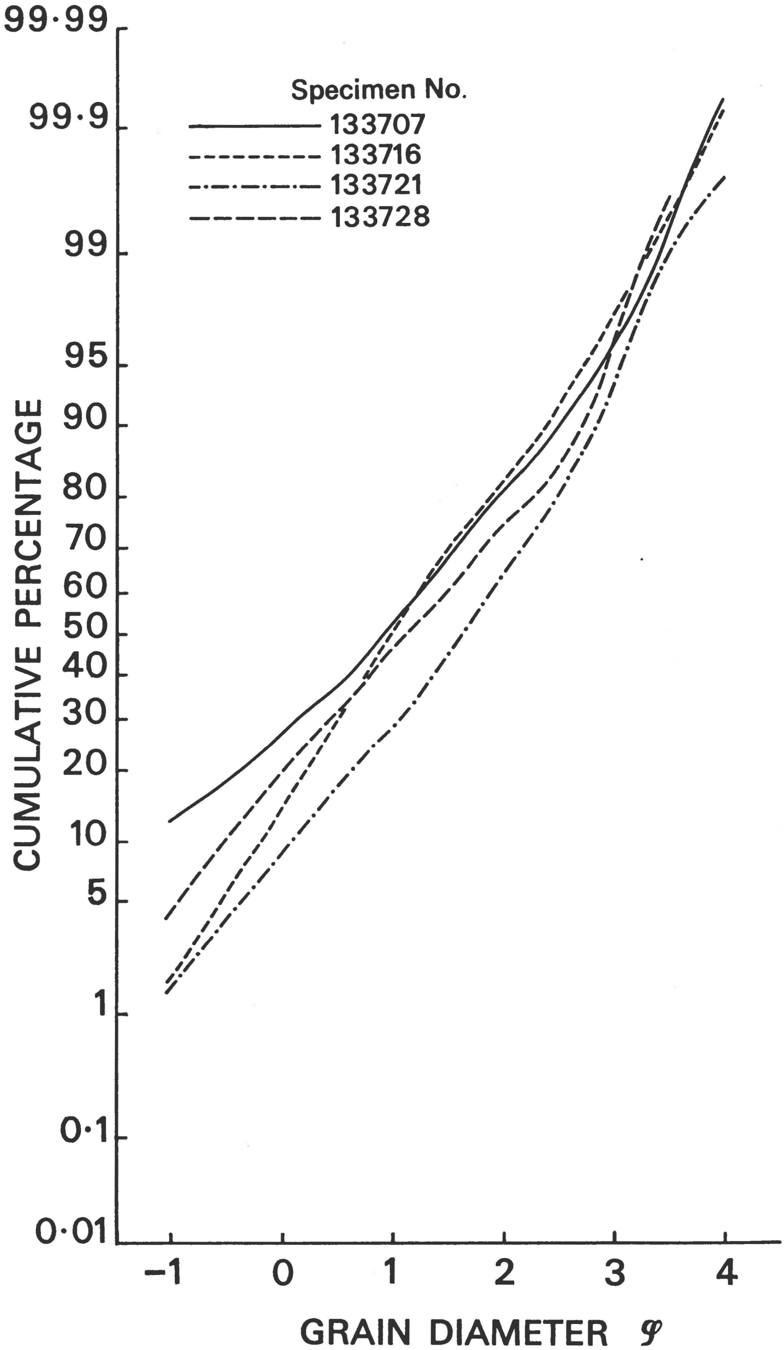

Fig. 7. Cumulative grain-size curves for disaggregated sandstone from the conglomeratic association. Sieved at $^1/_2$ ø intervals and plotted on probability paper. Locations can be obtained by reference to Table 1.

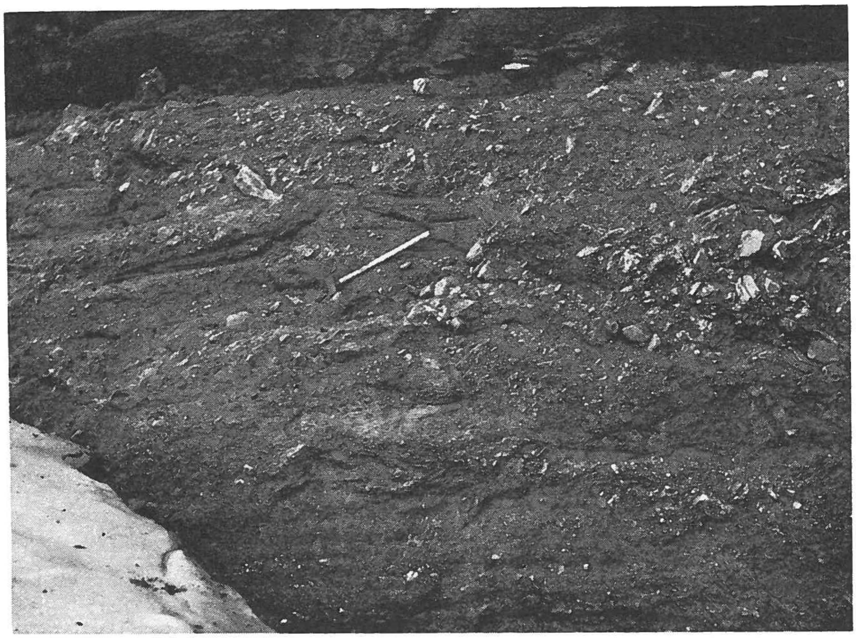

Fig. 8. Melange of intraformation clasts and extraformational pebbles in the conglomerate association in stream on north side of Harefjord.

Large clasts: Almost all the large clasts are of metamorphic rock, for the most part highly garnetiferous, quartz-rich metasediments, similar to lithologies found in the Caledonian crystalline sequences which outcrop extensively to the west of the fault. Vein quartz, micaceous foliated clasts and gneissic material of granitic composition are also common. Clasts of bright, orange-stained, feldspathic material are present. This matches up well with fault breccias associated with the western boundary fault and with faults generally in the metamorphic terrain. No systematic study was made of clast type distribution and no obvious trends are suggested by normal field observations. Granitic gneiss clasts seem slightly more abundant in the north while foliated clasts are more conspicuous along the north side of Harefjord. No clasts of unmetamorphosed older sedimentary rock are found. At one locality, on the north side of Harefjord, a 70 cm thick unit is composed largely of chaotically arranged blocks of sandstone, similar to that of the finer interbedded units, along with normal pebbles and cobbles (Fig. 8). This is suggestive of some local intraformational scour and deposition. All clasts have reddened surfaces to a greater or lesser degree. The pebbles and larger clasts tend to be rather angular and would be mostly classed as sub-angular to sub-rounded. Some of the larger boulders are conspicuously rounded and would be classed as sub-rounded to rounded.

Petrography of the sandy units: In the field, the composition of the sandier units is difficult to even estimate because of the intensely developed red coating of the grains. Most of the sandstone is very friable and seldom fractures across grains. It is, however, possible to see that the sediments are rich in feldspar.

Point counting of thin sections confirms the abundance of feldspar and also shows that biotite and garnet are common constituents (Table 2). The quartz is almost always strained and polycrystalline grains are common. Both plagioclase and alkali feldspars are common, and they vary greatly in their freshness. In some specimens the grains are entirely fresh, but more commonly they show some degree of alteration. In the extreme case, the feldspar grain is an unresolvable cloudy mass of sericite, but in one case a plagioclase was altering internally to zoisite. Early alteration tends to follow cleavage traces. In some cases the feldspar grains are altered to such an extent that they merge with intergranular clay matrix (e.g. sample 133726, Table 2). Larger clasts of metamorphic rock are coarse-grained and are of quartzitic or quartzo-feldspathic composition with secondary mica and garnet. For the most part, however, the intergranular spaces are occupied by a cement or are void. The cement, when present, is either calcite or siderite, and the general friability of the sediments is probably due to the leaching of these cementing minerals. Some detrital grains are coated with a thin dark layer, of hematite or limonite. Other grains, particularly quartz, show varying degrees of corrosion, possibly associated with the precipitation of the carbonate cement.

Sedimentary structures: The interbedding of the coarser and finer units is variable in scale, depending largely on the grain sizes involved in the coarser layers. If these are small (i.e. pebbles and cobbles), then interbedded units may be of the order of tens of centimeters, whereas if boulders and larger cobbles predominate, coarser beds upwards of 1 m may be involved. Interbedding is mainly gradational and lenticular (Fig. 9). Beds pass vertically and laterally into beds of different grain sizes with little major erosion. Lateral extents of beds are related rougly to bed thickness. Beds 20–30 cm thick might be traceable over 20–30 cm for example, though there is considerable variation in the thickness/lateral extent ratio.

There is considerable evidence of erosion between beds on a small scale and concave upwards surfaces of small relief are quite common, both between coarser and finer units and within finer ones. More important erosion surfaces are rare. One channel, about 1 m deep, was seen on the coast on the northern side of Harefjord (Fig. 10). Here the channel is filled with finer sediment than that into which it is cut.

Fig. 9. Typical gradational interbedding of coarser and finer horizons in the conglomerate association. Wall of northernmost canyon on west side of Rødefjord. Rule is 1 m long.

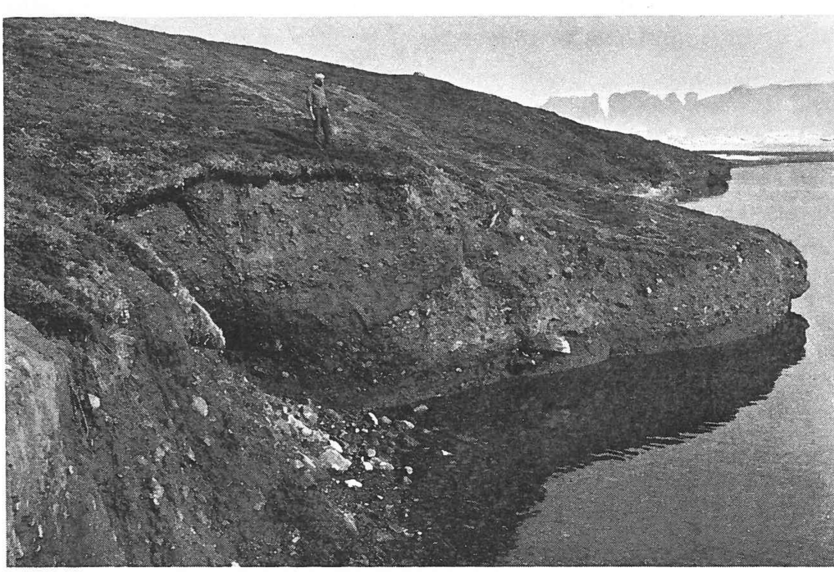

Fig. 10. Small channel within the conglomerate association, north shore of Harefjord, 2 km east of the western boundary fault.

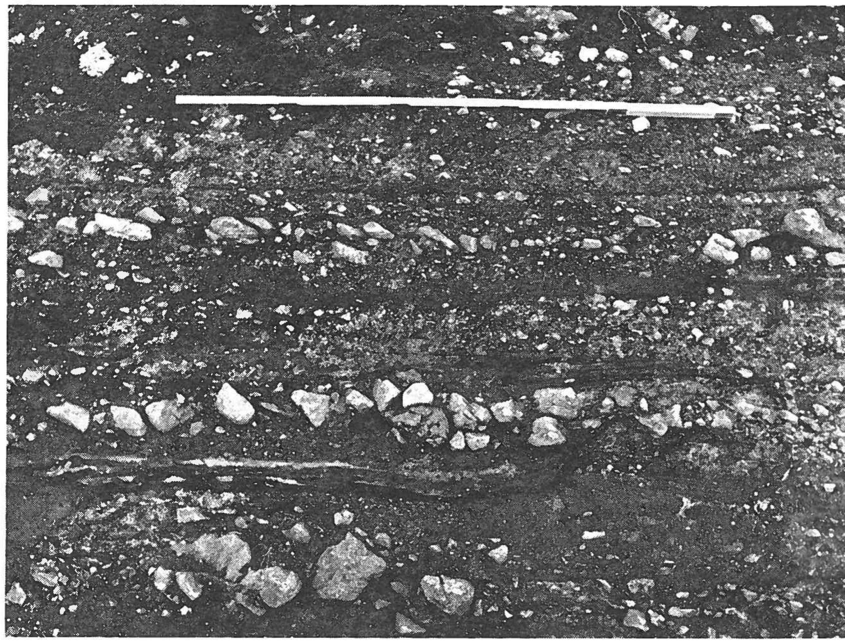

Fig. 11. Imbrication of pebbles in conglomerate association in southern wall of the canyon of the large stream draining into Rypefjord. Rule is 1 m long.

Within the coarser and finer units, sedimentary structures are not clearly developed. In some coarser units it is possible to recognise pebble imbrication if sufficient tabular pebbles are present (Fig. 11). More often, a disordered arrangement occurs. In the finer units, bedding and lamination are more obvious though again rather unspecific in type. All gradations from parallel, horizontal lamination through irregular inclined lamination to clear cross-bedding are recognised, the last being rare (Fig. 12). Sets are normally 10–20 cm thick and are generally of indeterminable shape though tending to be lenticular. Normally only isolated sets are found, though rare, thin cosets occur. Directional measurement of these cross-beds is difficult, due to the vertical, two dimensional nature of exposures, and only a handful of reliable readings were obtained. In more parallel bedded sandstones, primary current lineation was recognised on bedding planes at several localities, particularly on the north coast of Harefjord which is, in fact, the area in which structures are best developed in the finer sediments.

Exceptions to the gradational interbedding, other than channels, occur where particularly large boulders or groups of boulders and cobbles have clearly influenced the deposition of the surrounding fine-grained sediments (Fig. 13). Sometimes the cobble or boulder concentration forms a rather well sorted, grain supported framework. The cobble–

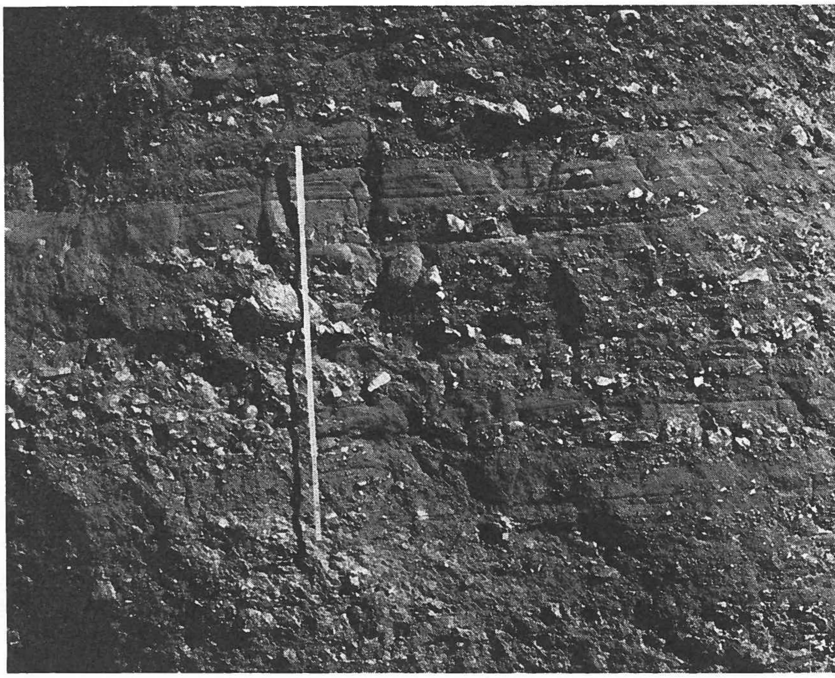

Fig. 12. Lenticular sandstone beds within the conglomerate association showing, in places, a rather poorly developed cross-bedding. Wall of canyon cut into eastern side of 860 m hill in north of area. Rule is 1 m long.

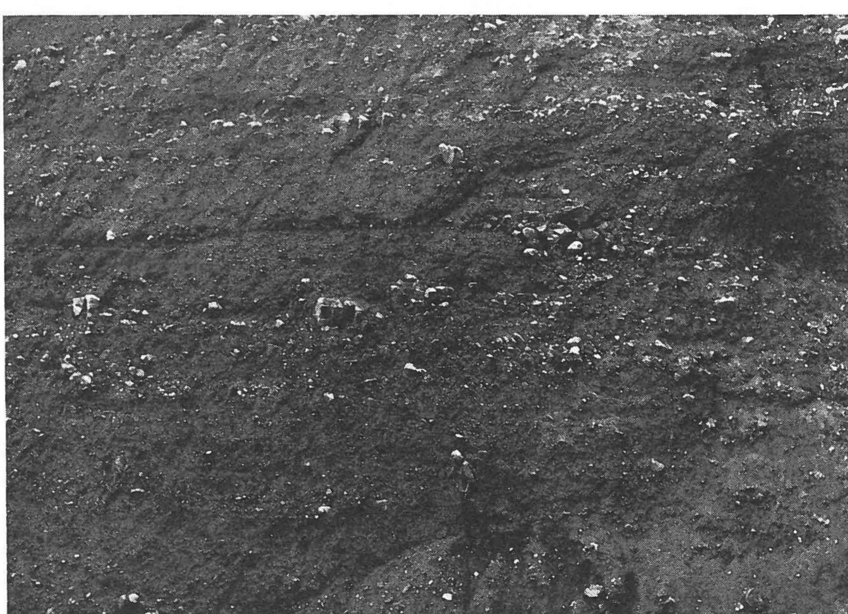

Fig. 13. A coarse pebble-supported patch within the conglomerate association, in upper right hand quarter of the photograph. Figure bottom right-centre for scale. Canyon wall south side of Harefjord.

boulder concentration was presumably a topographic feature at the time of deposition and, as such, produced a local hydrodynamic environment due to eddy separation.

Fabrics: The orientations of the long axes of cobbles in the range 10–20 cm were measured in the horizontal plane at two localities and both show a preferred orientation (Fig. 14). A similar analysis on the surface of one of the recent alluvial fans in the area gave a similar preferred

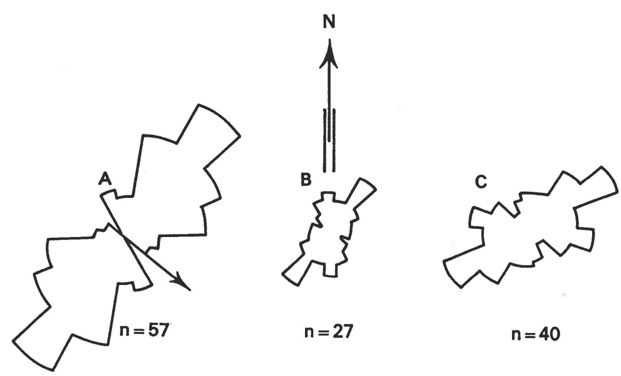

Fig. 14. Histograms of pebble long-axis orientations from (A) the surface of a recent fan in Rypefjord, (B) a conglomerate bedding plane in a canyon on the east side of Rypefjord and (C) a conglomerate bed in the glacially sculptured platform on the northern side of Harefjord. 'n' indicates sample size. Arrow in (A) indicates the slope of the fan surface.

orientation at right angles to the slope of the fan. Lack of suitable horizontal surfaces on which to make such measurements prevented widespread application of the technique for palaeocurrent investigation.

Diagenetic features: The conglomerates are almost entirely reddened, the degree of reddening being to some extent governed by the grain size of the sediment. This has the effect, particularly in sandier beds, of helping to emphasise the bedding, in that finer sands tend to be slightly darker. Only rarely are the conglomerates reduced locally to a green-grey colour and then only as thin layers a few centimeters thick.

At most outcrops, the conglomerate is deeply weathered and very friable and this makes it almost impossible to collect cohesive specimens of the sandy beds. On a glacially sculptured platform, on the north side of Harefjord, however, the ice erosion cuts through pebbles and matrix alike, suggesting that in its unweathered state the rock is quite strongly cemented (Fig. 15). Cavernous weathering, seen in the walls of some of the canyons, suggests a fairly soluble cement. The carbonate cement of some of the sandier units has already been noted.

Fig. 15. Elongate glacially-cut ridges on the platform north of Harefjord. Conglomerate matrix and pebbles are cut through equally.

Palaeocurrents: In all, only 16 measurements of palaeocurrent direction were made over the whole outcrop area of the Conglomerate Association. These included cross-bedding, primary current lineation and pebble fabric.

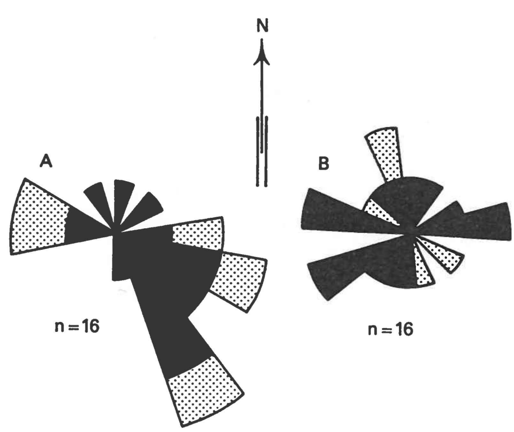

Fig. 16. Histograms of palaeocurrents from (A) the conglomerate association and (B) the cross-bedded sandstone association of Storø. Black areas indicate measurements where both direction and sense are known. Stippled ornament represents measurements of direction only (i.e. double ended).

The data are presented in Figure 16A as a histogram and show the generally eastward-flowing nature of the currents, though with such sparse data it is not possible to be very confident.

Interpretation of the association: The highly fluctuating nature of the grain size and the very large boulder diameters suggest that highly fluctuating but occasionally highly competent currents were developed in the environment. The poorly sorted nature of much of the sediment suggests rather rapid fall-off in stream power and consequent rapid dumping of material. These features, plus the frequent slight scouring between beds, the essentially unidirectional current pattern and the generally lenticular nature of the bedding make the association comparable with the deposits of recent alluvial fans or braided streams. BLISSENBACH (1954) described recent alluvial fans and their deposits and recognised two types of flood flow, sheet flood and stream flood. Sheet floods are short-lived phenomena which give rapid and widespread deposition of poorly sorted and structureless sediment and which, by virtue of their high density and viscosity, are capable of transporting very large boulders. Stream floods, on the other hand, are less extensive, being related to the overflow of fan channels and are more long-lasting. They are, therefore, more capable of producing better sorted sediment with some internal structure such as cross-bedding and imbrication.

Those cross-bedding directions opposed to or transverse to the general trend are explicable in terms of alluvial fans. Excavation of present day fans in Rypefjord showed cross-bedding transverse to the fan slope due to the lateral migration of a bar, and POWER (1961) explained reversed cross-bedding directions in fanglomerates as due to antidune 'backset' bedding. High flow regimes are certainly to be expected on alluvial fan surfaces.

The differences in the development of bedding throughout the conglomerates can best be explained in terms of stream and sheet floods. It seems, however, that there are no obvious trends in the distribution of the products of the different types of flow through the conglomerate. The most extensive development of stream-flood deposits would seem to be on the north coast of Harefjord and the most spectacular development of sheet-flood deposits, the sections on the southern side of Lerelv, where 1–2 m diameter boulders are common and diameters up to 4 m are recorded.

2. Cross-bedded Sandstone Association

Distribution and thickness: This lithofacies association occurs in the three fault-controlled blocks on Storø. As tectonic dip in these areas is similar to the topographic slope, and the sediments overlie the metamorphics unconformably, there is only a relatively thin exposed sequence of up to about 50 m.

Grain size: The association is a complex of several lithofacies ranging in grain size from siltstone up to conglomerate. Conglomerates are poorly

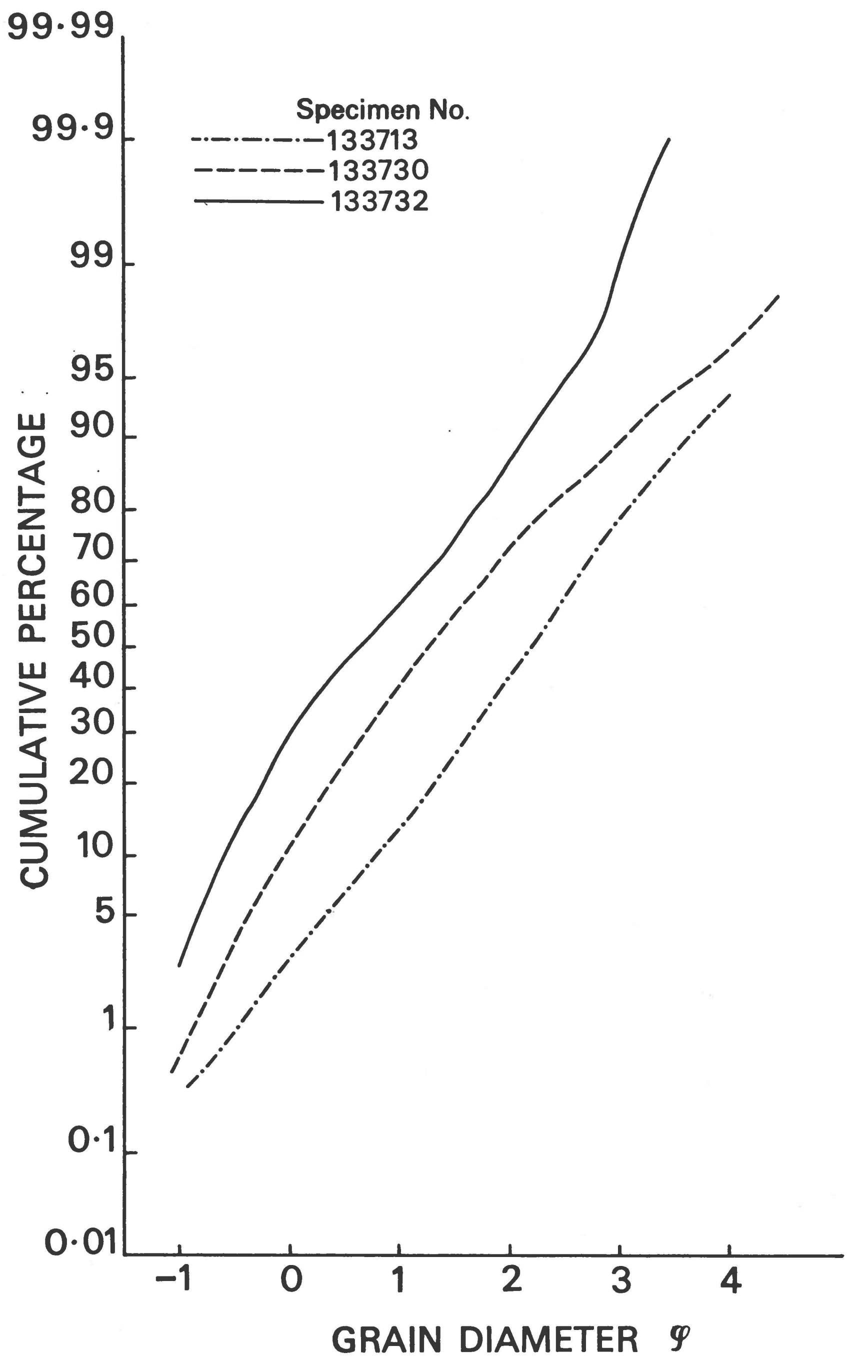

Fig. 17. Cumulative grain-size curves of disaggregated sandstones from the cross-bedded sandstone association and the interbedded complex. Locations can be obtained by reference to Table 1.

Table 2. *Composition of sandstones from point-count analysis (400 points).*

Sample No.	Locality	Quartz	alkali feldspar	Plagio-clase	Biotite	Garnet	Opaque	Clay
(a)	Conglomerate Association							
133716	Harefjord, north side	42.5	38.2	4.75	3.96	9.75	1.05	1.58
133726	2 km south of Lerelv	45.2	23.2	5.82	3.87	4.35	–	17.9
133728	Rødeø	33.6	37.0	6.37	9.55	5.15	–	8.1
(b)	Cross-bedded Sandstone Association							
133729	Storø	46.5	20.75	–	11	0.5	–	21.25
133730	Storø	56.5	17.3	–	4.15	–	0.3	20.55
(c)	Interbedded Complex							
133714	Harefjord, north side	46.25	17.05	6.3	4.2	3.44	0.2	22.9

sorted in beds up to 1 m thick with clasts up to cobble size. The sandstones are of variable grain size, are generally poorly sorted and may occasionally be pebbly (Fig. 17). They are by far the most important sediment type volumetrically.

Petrography: Pebbles in the conglomeratic parts of the association seem to be mainly of metamorphic origin, though in some conglomerates there are clasts of finer sediment of intraformational origin. The sandstones are arkoses similar in many ways to the sandy lenses of the conglomeratic association but with a lack of plagioclase and a high mica content (Table 2). The mica content is even higher in the finer siltstones. The sediments are generally reddened but occasional greenish reduction patches also occur.

Sedimentary structures: The conglomeratic horizons are devoid of recognisable structures or fabrics. The sandstones, on the other hand, are abundantly cross-bedded in both trough-shaped and tabular sets up to 1 m thick (Fig. 18). These can form cosets commonly up to 5 m in thickness. Less commonly, the sandstones are parallel laminated with bedding planes showing primary current lineation and, rarely, soft sediment deformational structures are seen. Some thin sandstones, interbedded within a thick siltstone unit in the northernmost fault block are sharp-based with internal parallel lamination and rippled tops. The siltstones are generally horizontally laminated.

Organisation of lithofacies: The sandstone units, as far as can be judged, occur in parallel-sided, sharp-based units of wide lateral extent, and up

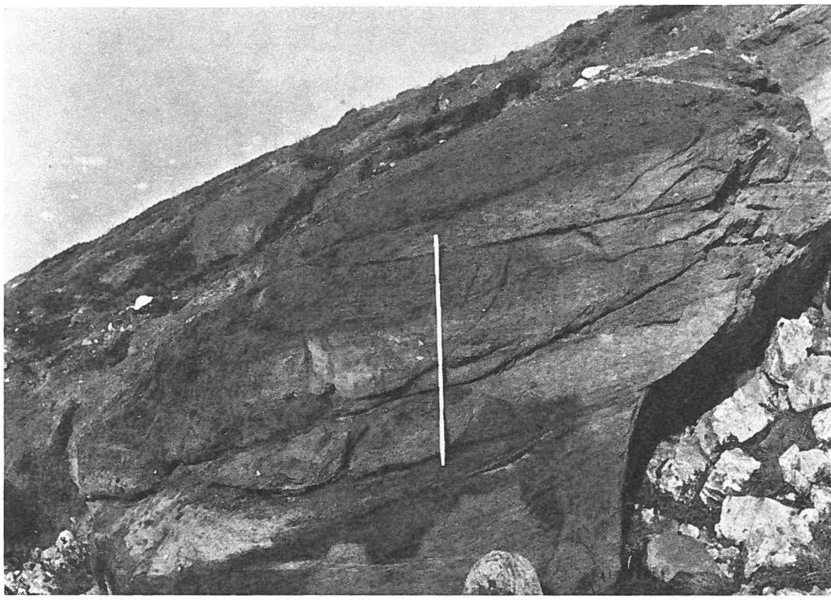

Fig. 18. Cross-bedding in sandstone in the central one of the three fault blocks on Storø. Rule is 1 m long.

Fig. 19. Basal erosion surface to a cross-bedded sandstone unit in the cross-bedded sandstone association on Storø. The erosion surface corresponds with the overhang. Below are thinly bedded fine sandstones and siltstones. The relief on the surface is some 50 cm and pebbles occur in the base of the sandstone. Rule is 1 m long.

to at least 20 m thick (Fig. 19). The conglomerates are up to 1 m thick and are found both within and at the base of these laterally extensive units. They too are generally laterally extensive. A conglomerate occurs in the top of a sandstone unit in all three fault blocks, but exposure is too fragmented to be sure of its being stratigraphically continuous. The finer siltstones are interbedded with the sandstone units and, on the coast of the northern fault block, at least 30 m are exposed with the thin sandstone interbeds mentioned above. The occurrence of clasts of siltstone in the base of some sandstone units has been mentioned.

Palaeocurrents: Current directions measured from the sandstone units are presented in Figure 16B as a histogram. While only a few measurements were recorded, they suggest a rather high vector variance possibly with a general trend towards the north–west.

Interpretation of the association: Although data are scarce, this association seems broadly to fit a model of more normal fluviatile sedimentation with sharp-based laterally extensive cross-bedded sandstones being referable to the deposits of laterally migrating channels and the siltstones being referable to overbank environments. The conglomerates in the base of some units and within them are probably lag conglomerates and possibly suggest multiple migration of the channels. The thin, sharp-based sandstones within the siltstones could be crevasse splays injected into the overbank environments at flood periods.

3. Silty Sandstone Association

This association is volumetrically small and is not thought to justify the systematic treatment of the first two associations. It is confined to a narrow strip of country lying between Harefjord and Rypefjord, and immediately to the east of the conglomerates. Any extension that it might have had to the south is now below Rødefjord. In the area of outcrop, up to about 130 m of the association can be demonstrated in a stream section on the north side of the peninsula, though this is only a minimum figure as, like the conglomerates, neither base nor top are seen.

The association consists predominantly of red, silty sandstone which may be locally reduced to grey-green. The sandstones vary between coarse and fine and are all poorly sorted with a high proportion of silt, both as matrix and as interlaminated units. Sand grains are commonly rather angular and sometimes reach granule size in small lenticular laminae.

Bedding in the sandstones is thin and generally rather lenticular. Some cross-lamination occurs, though it is seldom measureable. Slight

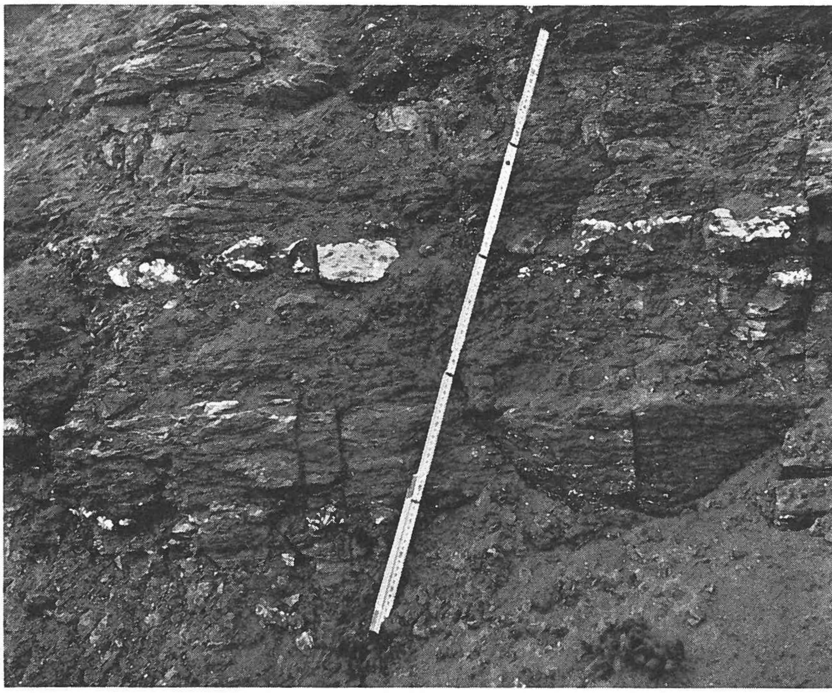

Fig. 20. Horizon of large gypsum nodules in the gypsiferous sandstone association: smaller nodules occur at the levels of the top and bottom of the rule (1 m long). Stream bank on south-west side of Rypefjord.

changes in overall grain size give a gradational, larger-scale bedding. The only current direction measured in the association was directed to 70° east of north. The petrographic characteristics of sample 133713, presented under the Interbedded Complex (Fig. 17 and Table 2) are similar to those of this association. The association is the product of an environment in which the supply fluctuated and arrived partly in suspension and partly by traction.

4. Gypsiferous Sandstone Association

This association is not thought to merit an extended systematic description. It is confined to stream sections on both the northern and southern sides of C. Hofmann Halvø, where at least 160 m of it are present. In grain size and general primary depositional characteristics the sediments are similar to those of the silty sandstone association. They are dominantly red though with quite a lot of green-grey reduction patches and horizons. The principal difference is the presence within the sediments of nodular gypsum. The nodules are between 1 and 20 cm in diameter (Fig. 20). The larger nodules often occur along distinct horizons giving

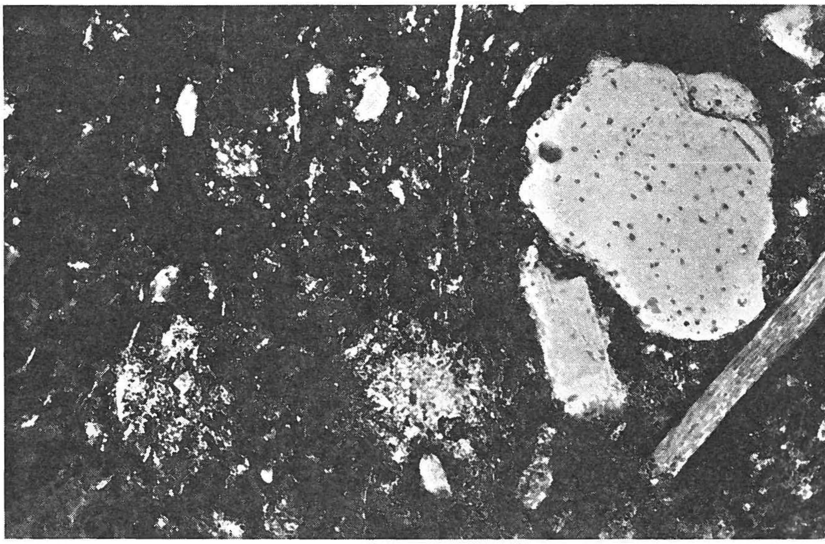

Fig. 21. Photomicrograph of a sandstone from the gypsiferous sandstone association showing strong resorption of quartz and feldspar grains and also spongy patches of calcite marking the former positions of totally resorbed clastic grains. ×246: Plane polarised light.

almost continuous beds up to 20 cm thick, while smaller nodules up to 2–3 cm in diameter occur disseminated through the sandstones. Green-grey reduction seems to be associated with the development of gypsum. There is a crude cyclicity to the occurrence of the gypsum in parts of the sequence in that sediment with large nodules passes gradationally up into sediment with small nodules and eventually into sandstone with no macroscopic gypsum. This type of cycle, which is generally about 30–50 cm thick, is repeated many times in the vertical sequence though gradations in the opposite direction do also occur. In other parts of the sequence, the whole of the sandstone is permeated by small gypsum nodules which vary in the intensity of their development. Hints of suncracks were seen on some bedding planes.

In thin section, a sandstone from this association shows small angular grains and larger more rounded grains in a poorly sorted population. Quartz grains are commonly strained and frequently fractured. Feldspars are abundant with both alkali and plagioclase types. Many of the alkali feldspars are in various stages of alteration to clays. Polycrystalline quartz, quartz–feldspar and quartz–feldspar–mica grains occur and garnets are conspicuous. There is a high proportion of fine brown matrix–cement which is to a large extent unresolvable optically. It is probably a complex mixture of clay minerals and secondary carbonates, calcite and siderite. Many grains have dark rims while others, both quartz and feldspar and particularly the smaller grains, are highly corroded. Indeed some grains seem to have been totally replaced by calcite and their position is only detected by patches of clearer calcite within the matrix–cement (Fig. 21). It is possible to see all stages of alteration from fresh feldspar to calcite relicts. The overall impression is that quite a large proportion of the original clastic material has been replaced by the largely carbonate matrix.

The environment of deposition of this association was probably no different to that of the silty sandstone association. The difference is in the post-depositional effects of the environment on the sediments.

The gypsum nodules are similar to those described by HARDIE & EUGSTER (1971) from Sicily though there the nodules are in skeletal carbonate sand. These they compare with the anhydrite nodules growing just below the sediment surface of the present day Sabkha of the Persian Gulf (e.g. EVANS *et. al.* 1969). These are forming close to the water table which is itself very close to the sediment surface. The difference, therefore, between the environments of the Silty Sandstone and the Gypsiferous Sandstone Associations might be purely one of topographic level in relation to the water table. In the Silty Sandstone Association, the water table may have been well below the sediment surface while in the case of the gypsiferous sandstone it may have been at or close to the surface.

5. Interbedded Conglomerate and Sandstone Complex

The Conglomerate and Silty Sandstone Associations interdigitate over a rather narrow zone which is only exposed on the north side of Harefjord. The apparently randomly interbedded unit is termed a complex. The stream sections in which the complex is exposed all trend slightly obliquely to the outcrop belts of the associations and therefore any section has elements of both lateral and vertical variation. The section which was examined in detail (Fig. 22) shows, in its lowest part, a complex and apparently random interbedding of fine conglomerates, coarse sandstones, silty sandstones, fine sandstones, with silty laminations and siltstones. The units vary in thickness from 10 cm to about 3 m, the silty sandstone and the conglomerates giving the thicker beds. The conglomerates are generally fairly fine-grained and the coarse sandstones are sometimes pebbly. Cross-bedding and primary current lineation occur within finer parts of the conglomeratic units while the coarse sandstones are essentially structureless.

A grain-size curve of a coarser sandstone unit is shown in Figure 17 and a point count analysis of a slightly finer sandstone is presented in Table 2. The rather abundant matrix is a mixture of clay minerals and largely sideritic cement.

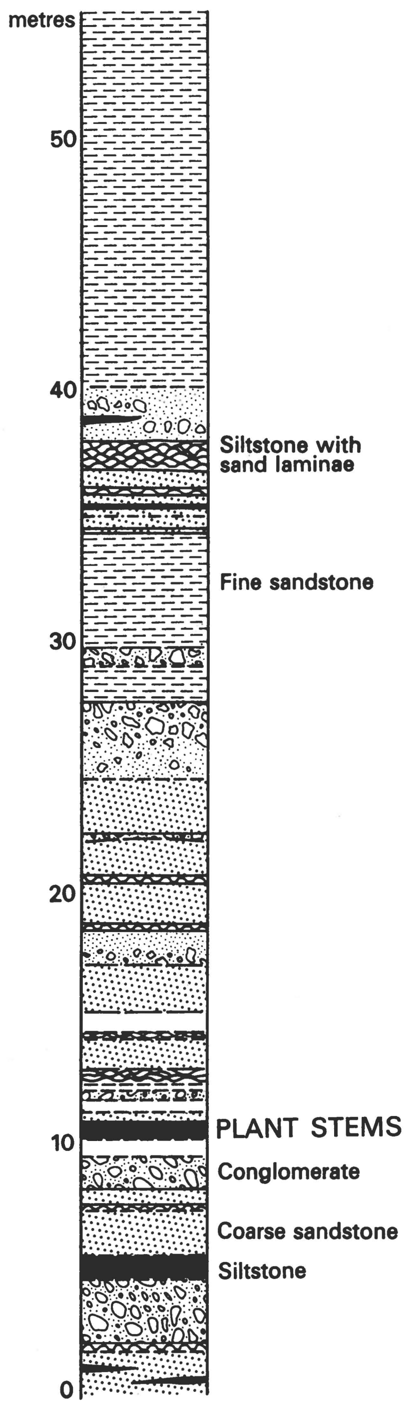

Fig. 22. Measured section through the interbedded complex exposed in a stream section on the north side of Harefjord. Continuous lines indicate sharp lithological changes, and broken lines indicate gradational changes.

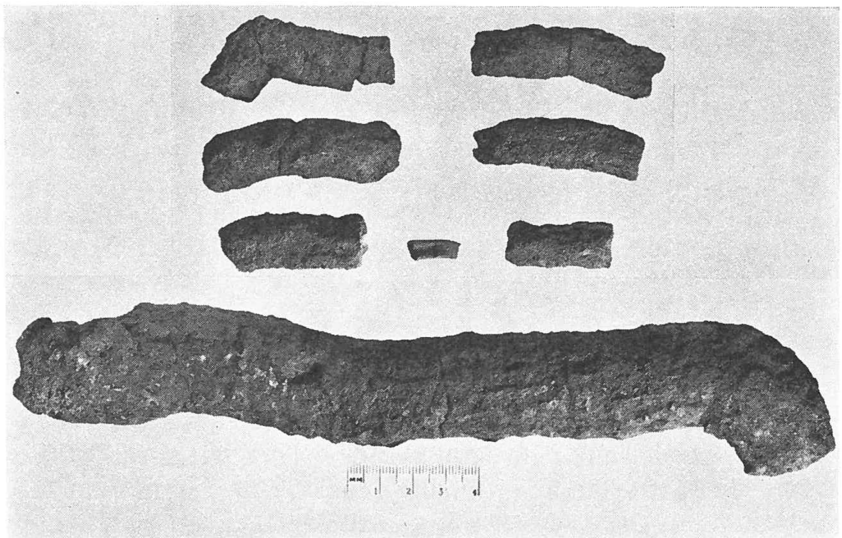

Fig. 23. Sand filled tubes (? plant stems) from a siltstone unit in the interbedded complex. See Figure 22 for precise horizon.

Within a 75 cm thick siltstone unit, tube-like structures were found lying parallel to the bedding (Fig. 23). These are usually about 1 cm in maximum diameter, being somewhat flattened parallel to the bedding. One is 3 cm in diameter. The more common, smaller ones are about 5–6 cm long but the large one is 24 cm with a sharp bend at one end. They are filled with coarse sand, showing a rough lamination parallel to the bedding, which is much coarser than the surrounding sediments. The actual material which formed the tube is now no longer present, and so the preserved structures are internal casts. These have a poorly defined lengthwise grooving. It is possible that the structures are the casts of some type of hollow-stemmed plants which either grew in or were washed into the environment. The grain size of the fill precludes their being any type of burrow. Even if they are plants, how they come to be filled with such coarse sediment is not clear.

In one of the interbedded sandstone and siltstone horizons, the sandstones were often lenticular with internal cross-lamination and on the top of one sharp-based sandstone bed, a good ripple form was present.

In the upper part of the sequence, the units become much thicker and are broadly interbedded silty sandstone and conglomerate, until, eventually, continuous coarse conglomerates are reached.

The sequence does not fall into any clear pattern. The complexly interbedded part of the sequence may represent an environment at the distal limit of coarse bed-load transport on the alluvial fans, represented by the conglomerates to the west. The most distal bed-load deposits are represented by the coarse sandstone and fine conglomerates while the siltstones and silty interlaminations indicate the presence of areas of suspended sediment deposition.

The upper part of the sequence, with its thicker and more clearly defined units, may represent a period of more important large-scale fluctuations in the distal limit of the fans and could be a function of climatic or tectonic changes.

Distribution of lithofacies associations and palaeogeography

The distribution of lithofacies associations within the Røde Ø Conglomerate is very simple as far as the limited evidence shows. The four associations would appear to form elongate strips lying parallel to one another and to the western boundary fault. The true extents of the strips parallel to the elongation are unknowable, and the possibility of other associations having been present between the gypsiferous sandstone and the cross-bedded sandstone cannot be ruled out. The fact that there are no vertical transitions between associations means that the environments which the associations represent had fairly stable positions through time. It is therefore possible to describe one palaeogeography for the whole of the period of deposition of the exposed sediments. A schematic block diagram of the environmental situation is presented in Figure 24.

The coarsest clastic sediments were laid down in the western part of the area as a series of coalescing alluvial fans, probably derived from a source area fairly near to the west. Distally the fans passed out into environments into which only the finer, mainly suspended sediment fraction of the total load was carried. This environment, in its more distal parts, apparently had a high rate of upward groundwater movement with high surface evaporation leading to the near-surface precipitation of nodular gypsum. The distal passage from gypsum-free to gypsiferous sandstone is possibly a reflection of the level of the water table, the gypsum-free area being slightly higher topographically and therefore more likely to have been in permanent contact with groundwater. The water table in the more distal, lower lying area would have been closer to the sediment surface and surface evaporation might have been able to draw water upwards through the sediments. The occasional presence of mudcracks, and the overall reddening of the sediments supports the idea that the environment of deposition was essentially subaerial. Sediment transport on the fans was probably a highly ephemeral phenomenon, though very powerful when active. The interbedded sandstone and conglomerate complex zone represents a local interdigitation of coarser and finer environments, probably caused by local shifts in the position

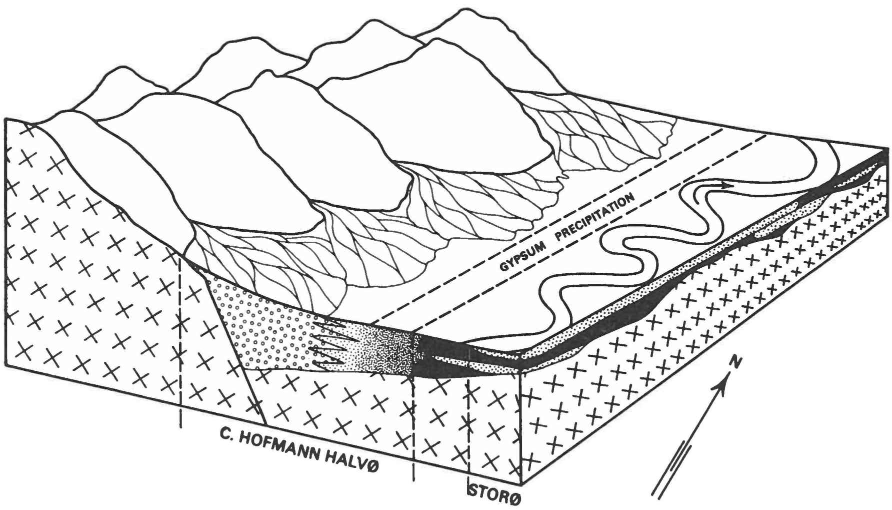

Fig. 24. Schematic block diagram of the environmental situation envisaged for the deposition of the Røde Ø Conglomerate.

of the distal limit of coarse bed-load transport. This lateral passage from fanglomerates into silty sandstone and eventually into sediment with gypsum nodules corresponds closely with the situation envisaged by HARDIE & EUGSTER (1971) in the Miocene of Sicily.

The rapid rate of sedimentation indicated by the sediments implies high erosion rates in the source area and suggests that any resistance to erosion, such as plant growth, was very limited.

Further out from the fans, beyond the area of fine sediment accumulation, it seems that an independent sediment dispersion system operated. The general fluviatile aspect of the Cross-Bedded Sandstone Association and the palaeocurrent pattern derived from it suggest the presence of less ephemeral streams flowing broadly to the northwest. The absence of plagioclase feldspars in the sandstones tends to suggest an independent provenance. This association, however, is not demonstrably the lateral equivalent of the other associations and could, in fact, represent part of an earlier palaeogeography as the sediment involved is only just above the basal unconformity. However, there is no evidence of the association above the unconformity on C. Hofmann Halvø.

Tectonic-sedimentary relationships

The palaeogeographic setting outlined above demands an area of high relief undergoing rapid uplift to the west of the present outcrop area. The sediments are bounded to the west by a major normal fault which is possibly dying out to the north. West of the fault are high-grade metamorphic rocks with no evidence of any equivalents of the sediments. While it cannot be proved with the present evidence, it does not seem unreasonable to suggest that the present western boundary fault might have been active during the deposition of the sediments giving the high relief area to the west which the sedimentation pattern demands. This is not to suggest that the alluvial fans were entirely confined to their present area of outcrop and it seems likely that their apices might well have been some distance to the west of the fault. The eastern boundary to the sediments is everywhere an unconformity. The unconformity dips to the west towards the fault and, if the contemporaneous nature of the fault is accepted, the northwesterly directed palaeocurrents in the Storø sediments may reflect this tilting. The fault pattern on Storø is not related to the sedimentation and clearly post-dates it.

The development of a fault-controlled basin must be associated with a period of local crustal tension, and the observed low dip of the fault plane suggests that considerable crustal lengthening might be involved. If we assume that the observed maximum dip of the fault plane (45°) is a typical figure, then the amount of crustal lengthening is of similar size to the throw of the fault. This must be at least 1000 m, the maximum observed thickness of the conglomerates. If the unconformity surface is projected westwards with a 10° dip, a typical figure, then a throw of at least 2 km is suggested.

It will be noted that the western boundary fault, north of Harefjord, trends NE–SW and in so doing diverges considerably from the direction projected from south of the fjord. In fact, H. Rutishauser (personal communication, 1970) has found that there is also a continuation of the projected line as a second fault north of Harefjord with metasediments to the west faulted against the migmatites. If this relationship is due to vertical movement along the fault, a westerly downthrow is suggested, and the migmatites then form a triangular horst block, bounded to the east by the conglomerates and to the west by metasediments. If the situation is so simply explained, it suggests that the western boundary fault, south of Harefjord, may be an old fault, reactivated at the time of conglomerate deposition and reactivated in an opposite direction to its original throw. The reactivation north of Harefjord may have been more complex with at least some of the second generation movement being taken up by the western boundary fault of the conglomerates, which trends north-east–south-west.

At the eastern end of the outcrop area of the conglomerate on C. Hofmann Halvø, the dips are to the west at about 10°. Towards the west the dips first flatten off and then begin to steepen in the opposite direction until near the fault plane they are of the order of 20°. It is difficult to be sure to what extent this dip is tectonic and to what extent it is

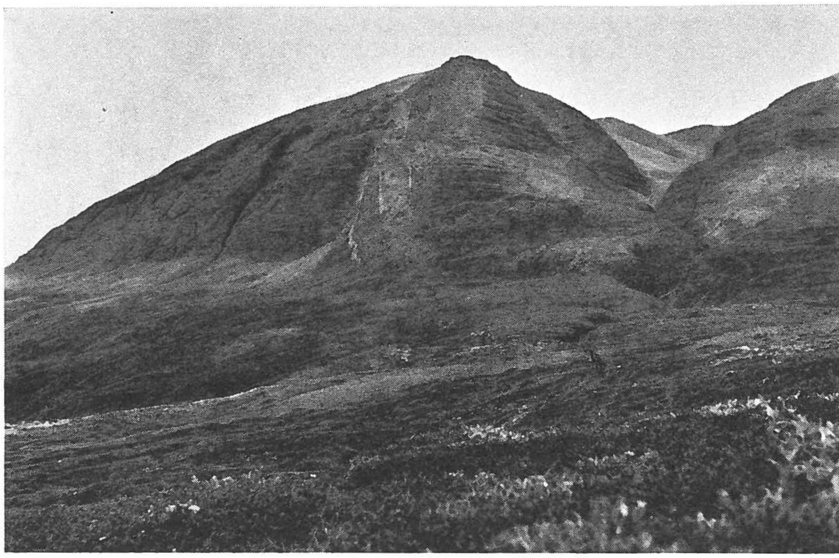

Fig. 25. Dyke complex in the hill 1 km south of Lerelv. The two branches of the dyke thin antipathetically and are linked by a thin connecting dyke.

depositional, reflecting the alluvial fan surface. Recent fans slope at 10° or more near their apices.

Within the conglomerates it has not been possible to detect any faulting. The lack of marker horizons in the conglomerates makes this difficult but the absence of any major joint patterns or possible fault planes makes it unlikely that there is any significant displacement.

Igneous activity

Igneous rocks are confined to the area south of Lerelv and to Rødeø. They occur as dolerite dykes intruded into the conglomerates and metamorphics. The dykes, which are more or less vertical, trend approximately north-east–south-west. Local divergence from the vertical occurs where a dyke crosses the western boundary fault and follows it at a lower angle dip for some 20 m in the tributary of the southernmost major stream. The lack of any disturbance of the dyke suggests that all fault movement has taken place prior to intrusion. Dyke thicknesses vary from 2 m up to about 40 m for a complex dyke which occurs in the hill immediately to the south of Lerelv. This dyke splits and switches its major thickness from one branch to the other (Fig. 25). All dykes bake the conglomerate into which they are intruded for a distance roughly related to the thickness of the dyke. The dyke on Rødeø is 1 m thick and trends north-east–south-west. The intrusions are generally presumed to be of Tertiary age and final fault movements must then be pre-Tertiary.

THE SEDIMENTS WEST OF THE SCHUCHERT FLOD

Introduction

In the short time spent in the area, it did not seem advisable to begin any systematic study, especially in the light of KEMPTER's (1961) work, but more worthwhile to examine as many different lithologies as possible and to try to see how well KEMPTER's scheme was workable. These notes are based on KEMPTER's subdivision and attempt to add some sedimentological detail to his description. The general geology of the area is shown in Figure 26.

Topography and exposure

The landscape to the west of the Schuchert Flod and south of the Bjørnbo Gletscher is dominated by the spectacular vertical cliffs formed by the Upper Permian reef limestones of the Karstryggen Group. These cap the plateau and the cliffs are 70–80 m high. Below the cliffs, steep slopes are generally scree covered and large landslips of the limestones are common, particularly south of Revdal. Occasional streams cut down through the scree cover and expose the underlying sediments but exposure is very patchy except in Revdal and its tributaries where much deeper erosion gives quite good and continuous exposure.

To the west, in Gurreholm Dal and in Øvre and Nedre Arkosedal, the hill tops are generally covered with frost-shattered blocks, and exposure is confined to the steeper slopes, to some ridge crests and to some of the more deeply eroded stream beds.

North of the Bjørnbo Gletscher the narrow strip of ground which exposes the Bjørnbos Corner Formation is low lying with rather isolated sandstone ridges protruding from the vegetation. The area is bounded on the west by a steep slope which reflects the faulted junction with metamorphics to the west.

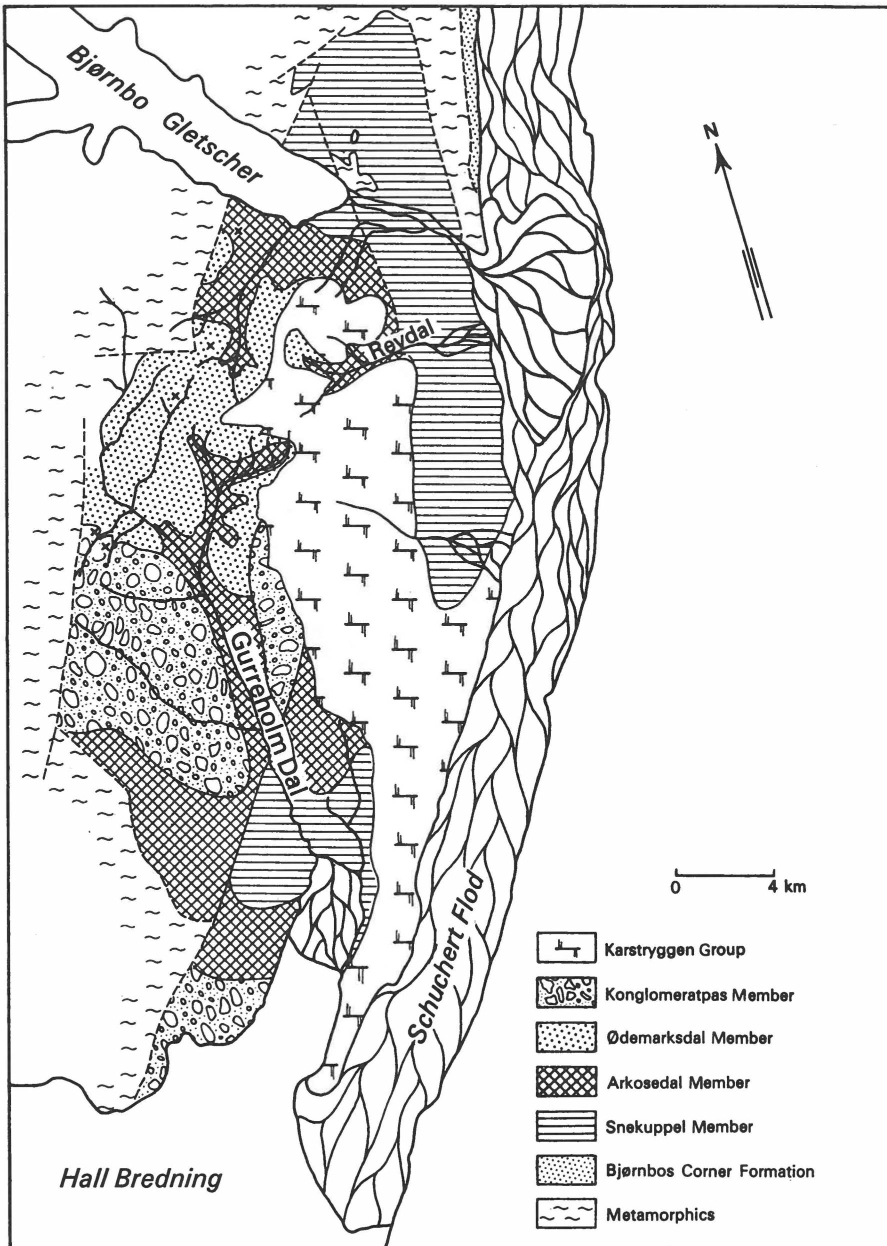

Fig. 26. Geological map of sediments west of the Schuchert Flod, compiled from KEMPTER (1961) with slight modifications. Small crosses indicate observation points in helicopter reconnaissance.

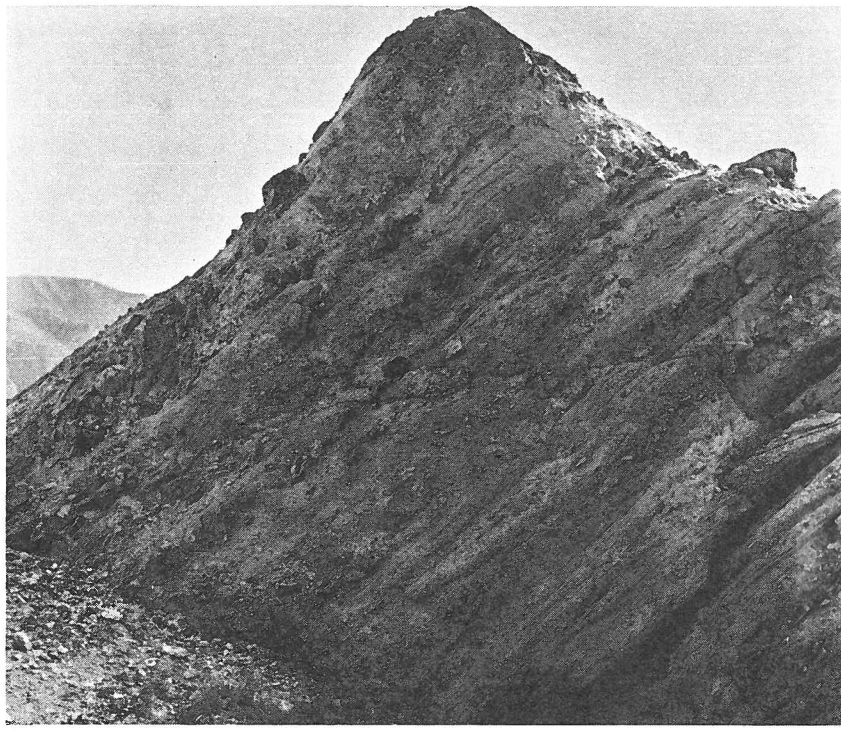

Fig. 27. Arkosic conglomerate in the Bjørnbos Corner Formation. Exposure meter in centre of exposure is 10 cm long.

The sediments

1. Bjørnbos Corner Formation

The relationship of this areally limited unit to the other sediments in the area is unknown. It is faulted against metamorphics to the west, and exposure dies out under glacial and post-glacial sediments in other directions. The sediments dip to the north-east, the strike swinging from about 140° in the south to about 170° in the north. Dips decrease northwards from 34° to about 20°. The strike direction, it will be noted, is not parallel to the trend of the western boundary fault. KEMPTER suggested a Carboniferous Age for the formation on indirect evidence. He also suggested a minimum thickness of the order of 1000 m, which seems reasonable.

The sediments outcrop as a series of ridges, parallel to the strike. The thicknesses of the sandstones exposed in the ridges vary from 2 m to about 6 m. They are coarse conglomeratic arkoses with pebbles of granite and well indurated greenish quartzite. Mostly the grains are very coarse sand to granule in size. The granitic pebbles tend to be more angular than the quartzites. There is a rough interbedding between conglomeratic horizons and coarse sandstones which sometimes show cross-bedding but are more commonly parallel bedded (Fig. 27). The interbedding is broadly similar to that of the Røde Ø Conglomerate, but differs in that, while overall grain size is finer with fewer cobbles and no boulders, the grain size of the sandy background is much coarser.

There are a few concave upwards surfaces and some signs of erosion where granule beds sharply overlie coarse sandstones. In the slack features between the ridges of coarse sandstone, there is generally no exposure though in one there was poorly exposed, green, parallel-laminated, medium sandstone. It seems reasonable to assume that the slacks represent finer lithologies.

Palaeocurrents are rarely measurable and only two readings were obtained, one, cross-bedding, to 169° and the other, primary current lineation, trending north–south.

Overall, the sequence seems to become finer upwards with increasing gaps between the exposed ridges.

The relationships of both the tectonic dip and the palaeocurrents to the western fault suggest that the deposition of the sediments is not immediately relatable to the movement of the fault as suggested for the Røde Ø Conglomerate.

2. Gurreholmsdal Formation

From floral evidence, KEMPTER showed that this formation was of Lower Permian age. During the course of the present reconnaissance, an extensive fish fauna was found and it is hoped that this may enable a more precise stratigraphical attribution to be made. The formation nonconformably overlies Caledonian gneisses north of the Bjørnbo Gletscher and is overlain by Upper Permian sediments with an angular unconformity. KEMPTER estimated a total thickness of about 2000 m for the formation though only 600 m were seen in any one section. He divided the formation up into four members and for this report his scheme will be followed in spite of some reservations.

Snekuppel Member. According to KEMPTER's map (1961, Fig. 4), this member outcrops as a broad strip along the eastern edge of the area. The sediments in this area, in particular in the lower parts of Revdal, are thinly bedded medium-fine, dark grey or green, micaceous sandstones. The only large clasts are mudflakes of intraformational origin. The sandstones are generally parallel laminated with primary current lineation, but are also frequently cross-laminated with some units showing ripple drift (Fig. 28). Cross-bedding occurs with sets up to 60 cm (Fig. 29). Interbedded with the sandstones are units of siltstone, and more rarely of mudstone, which in one case bears a rich and well-preserved fish fauna.

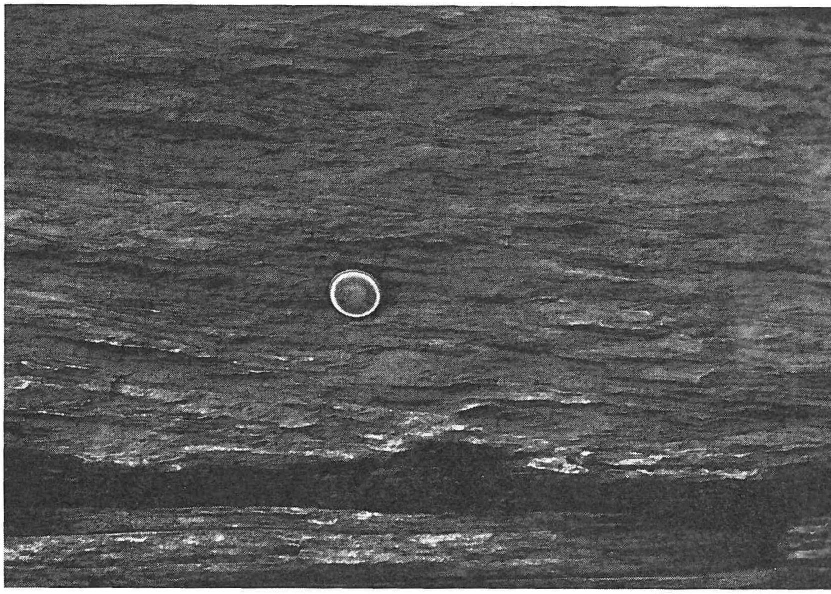

Fig. 28. Ripple-drift cross-lamination in fine micaceous sandstone of the Snekuppel Member of the Gurreholmsdal Formation. Revdal. Lens cap is 3.5 cm diameter.

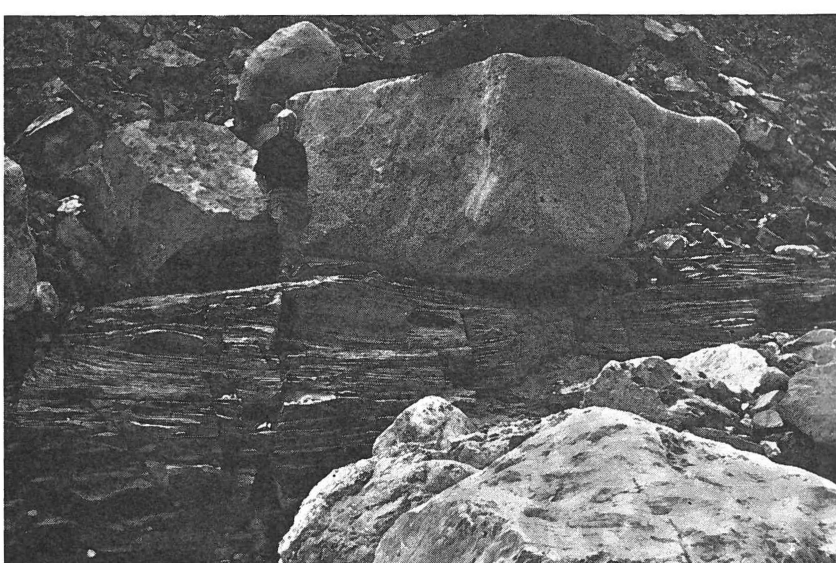

Fig. 29. Cross-bedded set with tangential foresets in the Snekuppel Member, Revdal.

The sandstones often show patterns of cracks on their bedding planes which are probably of desiccation origin.

While the interbedding of the different lithologies often appears somewhat random, in some parts, smaller sequences becoming finer grained upwards are developed with sharp erosive bases. Cross-bedded sandstones in the lower part of the sequence pass up into ripple cross-laminated and/or parallel laminated sandstone and eventually into siltstone. This type of unit is compatible with deposition by a laterally

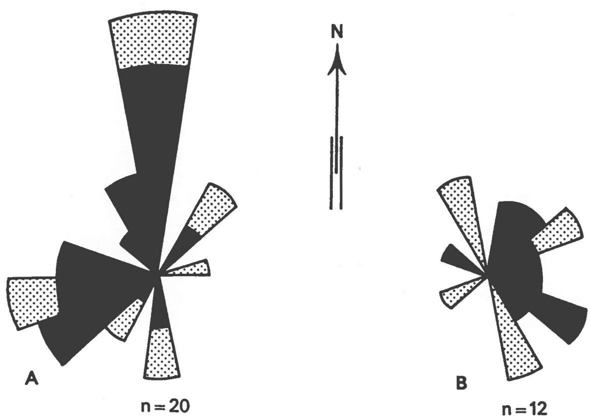

Fig. 30. Histograms of palaeocurrent directions from (A) the Snekuppel Member and (B) the Arkosedal Member of the Gurreholmsdal Formation. Black areas are for measurements of both direction and sense of movement, stippled for measurements of direction only (i.e. double ended).

migrating channel. The siltstone units, which may be up to 10 m thick and which may represent an overbank environment, are broken up by thin sandstones which may be crevasse splay deposits. These thin sandstones may be cross-bedded and may show erosional features on their bases. Some of the sandstones within the sequence are carbonaceous and one ripple cross-laminated unit had vertical plant fragments cutting across the original cross-lamination.

Randomly interspersed in these fine sediments are beds of arkose which increase in importance upwards. These will be discussed under the Arkosedal Member.

Palaeocurrent measurements in the fine-grained micaceous sandstones show directions to the north and west with a lack of readings to the south and east (Fig. 30A).

On KEMPTER's map (1961, fig. 4) the Snekuppel Member is shown as ending at the foot of Revdal and being overlain by the Arkosedal Member. In fact the lithofacies assemblage extends much farther up Revdal than is shown and has a complex interfingering relationship with the Arkosedal Member lithology.

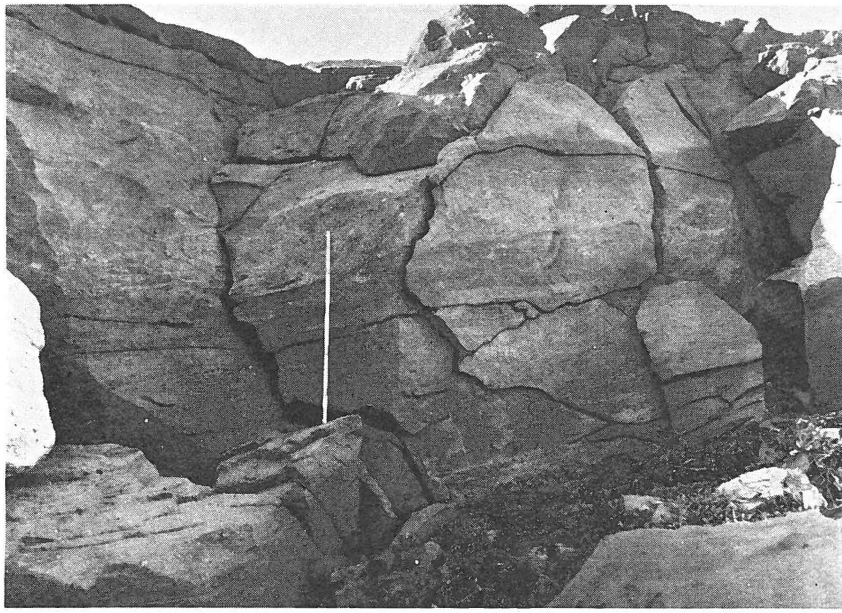

Fig. 31. Composite unit of graded arkose beds in the Arkosedal Member. Cross-bedding in lower half of outcrop. South side of Bjørnbo Gletscher: Rule is 1 m long.

Arkosedal Member. This is essentially an arkose with granitic pebbles as Kempter stated. On the hills west of Øvre Arkosedal it is seen to be a coarse, angular arkose with parallel and cross-bedding. In the higher parts of Revdal, it is similar though somewhat finer and the sequence is less homogeneous. Traced eastwards the arkoses pass into isolated sharp-based beds up to 5 m thick, interbedded with finer sediments of the Snekuppel lithology. These more isolated arkose beds, which were briefly mentioned under the Snekuppel Member, are sometimes cross-bedded and sometimes graded but are otherwise structureless. Some show multiple grading suggestive of a multiple origin (Fig. 31) while others show ripple marked and polygonally cracked surfaces (Figs 32 and 33). Palaeocurrents in the arkoses show directions dominantly to the east, in contrast to those from the Snekuppel lithologies (Fig. 30 B).

It is difficult to estimate the importance of vertical and lateral lithological changes in the Revdal stream section and only more detailed work than the exposure probably allows could produce a definite answer. The author feels that there is probably a strong element of east–west lateral change in lithology.

If the relationship is correct, it suggests a rather complex palaeogeography with one dispersion system to the east bringing fine-grained micaceous sediment from the south and east in a more or less fluviatile

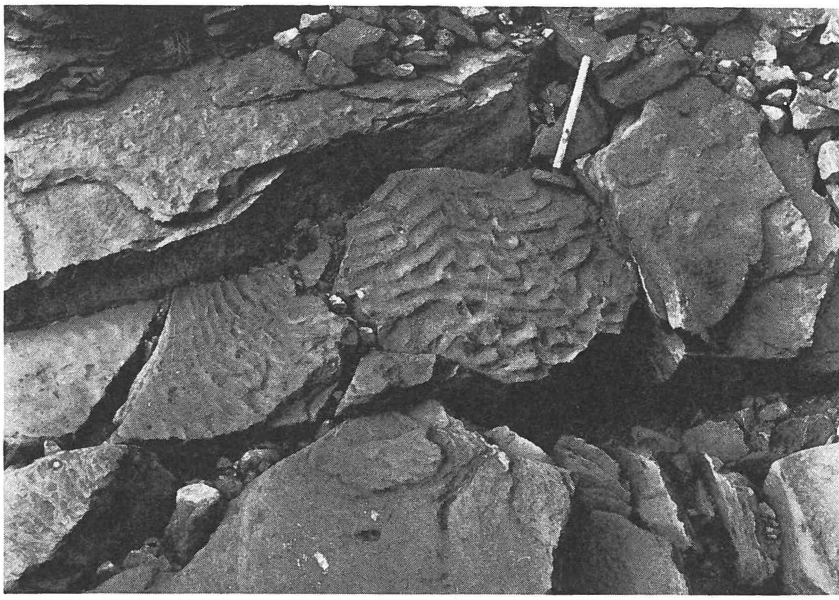

Fig. 32. Linguoid ripples on a bedding plane of arkosic sandstone in the Arkosedal Member. Stream bed on south side of Bjørnbo Gletscher. The ripples seem to show the intersection of two ripple fans.

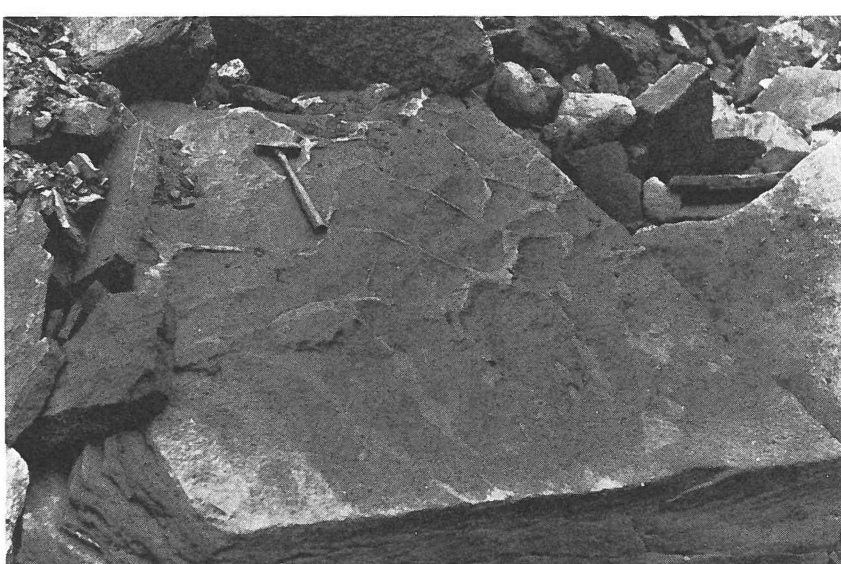

Fig. 33. Suncracks on a bedding plane of the Arkosedal Member. Loose block in Revdal.

environment with extensive overbank areas and occasional ponds (for the fishes). A second dispersion system to the west bringing coarser arkosic sediment from that direction interfered with the finer system and possibly even superseded it or at least pushed it eastwards if the vertical lithological change is significant. This western system was not obviously fluviatile in nature and the similarity of some of the more distal arkoses to turbidites suggests that the main process might have been one of occasional flash floods. More proximally, the arkoses and conglomerates could represent some sort of fan system but they are nowhere near so coarse as the fan deposits of the Røde Ø Conglomerate and may have been of a lower slope. The palaeoslope and the sediment generation associated with the Arkosedal sediments, and possibly also with the Ødemarksdal and Konglomeratpas Members, may have been associated with activity along the Stauning Alper Fault to the west.

Ødemarksdal Member. This member was seen at two localities. One is in the upper parts of Revdal and the other on the plateau top at the northern end of Gurreholmsdal. In the Revdal section there is no obvious difference between the sediments mapped by Kempter as Ødemarksdal and those mapped as Arkosedal. In the exposure on the plateau top, the arkosic sandstones are much less reddened than those in Revdal and cross-bedding at this locality is directed towards 068°, a direction compatible with the dispersion pattern of the Arkosedal member.

Konglomeratpas Member. Two localities were visited in this unit. Both are in western tributaries to Gurreholmsdal in the northern part of that valley, and about 1 km east of the Stauning Alper Fault. The first locality is definitely within the Konglomeratpas Member and shows very poorly sorted coarse conglomerate with boulders up to 1 m. The bedding shows gradational lateral and vertical grain-size changes, similar to those seen in the Røde Ø Conglomerate. Indeed the only small-scale difference is the colour. The Konglomeratpas Member is dominantly grey with some red-stained layers which roughly follow the bedding. On the larger scale, it seems that broadly coarser and finer units of several metres thickness can be recognised and traced for at least several hundreds of metres laterally, something not seen in the Røde Ø Conglomerate.

The other exposure, some 200 m stratigraphically lower and about 1 km distant, and possibly just within the top of the Ødemarksdal Member, exposes a unit of medium–fine sandstone beds some 8 m thick. The sandstone beds themselves are up to about 80 cm thick and are sharp-based with mudflakes in their lower parts. Internally they are either cross-bedded or parallel laminated. Between the sandstones, which are parallel sided and laterally extensive, are thin mudstone units a few centimetres thick. The bases of the sandstones show very spectacular

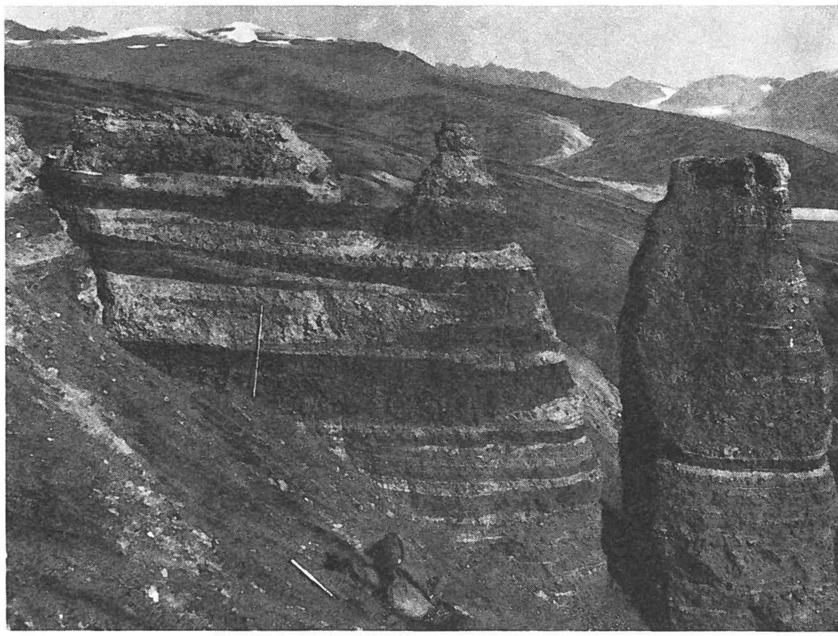

Fig. 34. Basal conglomerate of the Karstryggen Group: southern corner at the foot of Revdal. Rule is 1 m long.

development of suncracks which had developed in the underlying mudstones and been buried by the subsequent sand. These sandstones probably are the product of flash floods spreading out over a normally dry and desiccated environment.

Both above and below the sandstone unit are fine purple and green conglomerates. The overlying conglomerate passes up into the coarse conglomerate described above.

General comments on the Gurreholmsdal Formation. The interrelationships of the lithologies of the Gurreholmsdal Formation do not seem to be as simple as KEMPTER suggested. There is probably much more lateral transition between lithologies. If this were so, it might considerably reduce the total thickness of the formation and also reduce the need for the complex faulting which KEMPTER invokes in areas of poor exposure.

3. Karstryggen Group – basal conglomerate

This unit, about 30 m thick, is laterally extensive and overlies the angular unconformity separating Upper from Lower Permian. It is a medium to fine conglomerate, with a high proportion of granitic pebbles and cobbles. It also contains pebbles of vein quartz and of dark green micaceous sandstone similar to that occurring in the underlying Snekuppel Member.

It is bedded in gradational lenticular beds which show a coarse–fine alternation similar to that seen in the Røde Ø Conglomerate (Fig. 34). Imbrication suggests currents to the south and south-east at Revdal and there are faint hints of cross-bedding in the finer beds.

The conglomerate is generally red, but irregular reduction layers roughly follow the bedding. The conglomerate's general similarity to the Røde Ø Conglomerate suggests a similar depositional environment, but the wide lateral extent and low thickness argue against alluvial fans and more for a braided alluvial plain where the depositional processes are somewhat similar.

CONCLUSIONS

One of the purposes of looking at both areas was to see if they could in any way be correlated on the basis of lithological comparison. Any attempted stratigraphical correlation based on lithological comparison is highly suspect from the start and between sequences in small, fault-controlled basins hardly worth beginning. All that can be safely said is that the Gurreholmsdal Formation and the Røde Ø Conglomerate both have similar depositional patterns with coarse sediment being derived from highly active source areas at the western sides of the basins and building out eastwards into finer environments with independent dispersion patterns. Contemporaneous faulting might have controlled the erosional and depositional areas. It may be coincidental that the basin current pattern is at least partially to north in each case. The only way in which any contemporaneity might be invoked is by suggesting that the faulting was due to the same regional tensional event. The nature of such an event is speculative. The parallelism of the faulting with the continental margin, and the eventual passage upwards to marine conditions in Late Permian times possibly suggests that the tensional event could have foreshadowed the later more important events which led to the development of elongate north–south marine basins in the Mesozoic and to the eventual opening of the North Atlantic.

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Department of Geology
The University
Keele
Staffordshire
Great Britain

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