THE STRATIGRAPHY OF THE UPPER ORDOVICIAN STAGE 5 IN THE OSLO–ASKER DISTRICT, NORWAY

PATRICK J. BRENCHLEY & GEOFFREY NEWALL

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The stratigraphy of Stage 5 (Upper Ashgillian) in the Oslo–Asker district is described. Three new formations are proposed: the Husbergøya Shales, the Langøyene Sandstones and the Langåra Limestone–Shale Formation. A type section for Stages 5a and 5b is designated. 5a is shown to be relatively consistent in thickness and stratigraphy throughout the area, but 5b is a regressive sequence characterised by rapid vertical and lateral facies changes and marked thickness variations reflecting Upper Ordovician diastrophism.

The local palaeogeography of Stage 5b is interpreted as an offshore sand bar migrating northwards giving predominantly clastic successions in the Oslo area, while to the north a deeper water, lower energy environment prevailed giving rise to an interbedded limestone–shale succession. The end of the regression is marked by a widespread oolite. Cutting the sequence are deeply incised channels of 5b age, many of which can be shown to cut lithified oolite at the top of the sequence.

P. J. Brenchley & G. Newall, Department of Geology, Brownlow Street, P.O. Box 147, Liverpool L69 3BX, England.

The Lower Palaeozoic of the Oslo area is one small part of a platform sequence which formerly covered several thousand square kilometres of the Baltic Shield and is now represented by residual patches in southern Norway, Sweden and Estonia. The total thickness of the Lower Palaeozoic in the Oslo area is approximately 1550 m of which about 470 m belongs to the Ordovician. The Ordovician sediments generally belong to a fairly restricted range of facies, varying mainly from shales to shales with nodular limestones. Thin sandstones occur at many levels within the sequence and continuous beds of thin limestone are also common. Only in the upper part of the Ordovician do coarse clastics form an important part of the sequence and it is the stratigraphy of these beds which is described here.

Detailed study of the Ordovician of the Oslo Region dates back more than 150 years and an account of the history of Lower Palaeozoic research is given in Størmer (1953). During the last twenty years there has been a concerted study of the Middle Ordovician of the Oslo Region and the stratigraphy and the palaeontology in particular are described in many papers. The Upper Ordovician in contrast has received very little attention since the classic studies of Kiær (1897, 1902). The boundary between the Ordovician and the Silurian has been discussed by Spjeldnæs (1957) and detailed sections for a part of Asker have been described by Lervik (1969) in an unpublished thesis.

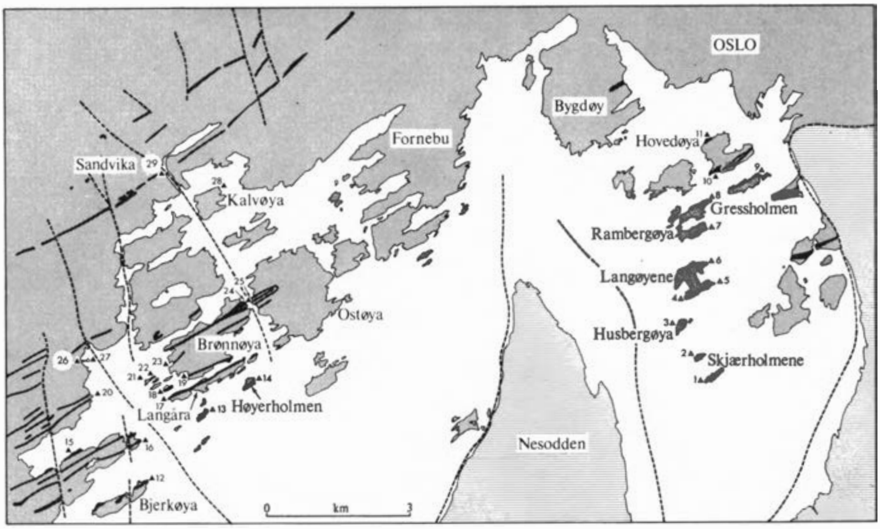


Fig. 1. Map showing the location of the 29 measured sections described in the text and shown in Figs. 4–9.

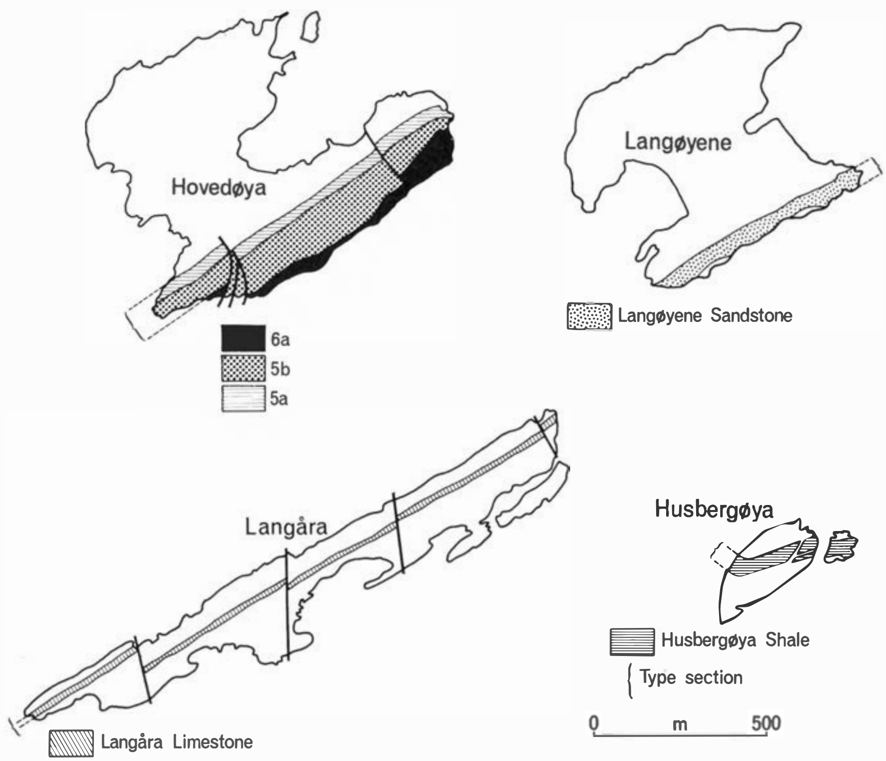


Fig. 2. Map showing the location of the type section of Stage 5 on Hovedøya, and the location of the stratotypes of the three new formations.

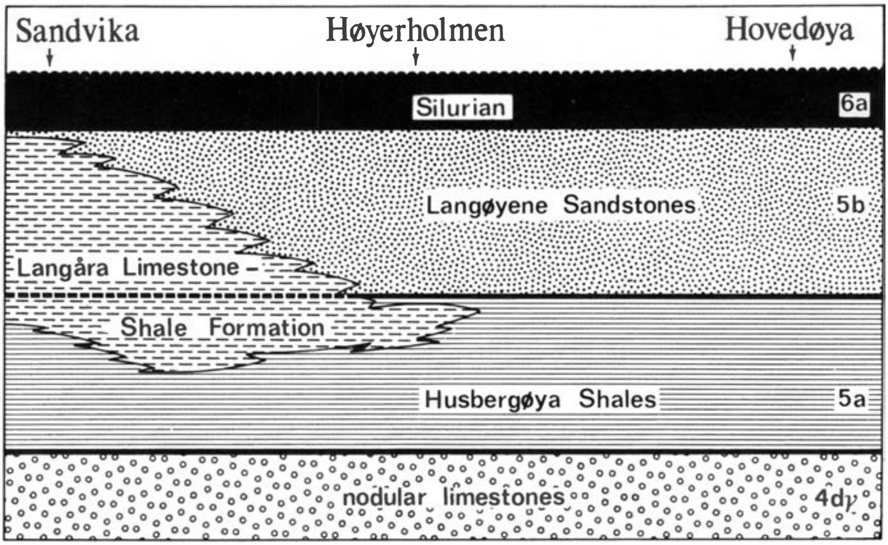


Fig. 3. Diagram illustrating the relationship between the stage boundaries and the formation boundaries.

Otherwise references to the Upper Ordovician have occurred in more general accounts of the Lower Palaeozoic of the Oslo area and notable amongst these is the facies analysis of the Lower Palaeozoic by Seilacher & Meischner (1965) and the accounts of the mineralogy and geochemistry by Bjørlykke (1974a, 1974b). Important discussions on Upper Ordovician sedimentation outside the immediate area are to be found in Major (1946) and in an unpublished thesis by Hanken (1974). Palaeontological studies pertinent to these rocks include those of Kiær (1899), Wedekind (1927), Spjeldnæs (1964), and Neuman (1969) for corals, Strand (1934) for cephalopods, Henningsmoen (1954) for ostracods, Størmer (1930) for trilobites, and Kiær (1902) for brachiopods.

This account is concerned with only part of the Upper Ordovician, namely Stage 5 which represents about 35 m to 85 m at the top of the Ordovician.

Throughout this text we have attempted to produce a consistent spelling for place names, and places referred to can be found on Cappelens bykart, Stor Oslo (1:30,000).

We frequently refer to measured sections located on Fig. 1 and shown in Figs. 4 to 9. Numbers given in brackets after place names refer to sections shown in these figures. We have based the stratigraphic account largely on the data from 29 measured sections; many others have been visited but have not been included because they are very incomplete or are tectonically disturbed. Interesting sections on Ormøya and Malmøya fall in the latter category. The section on Bleikøya has been measured and included in Fig. 5 but we believe the sequence is probably thickened by strike faulting and hence we have not included it when discussing the thickness of the sequences.

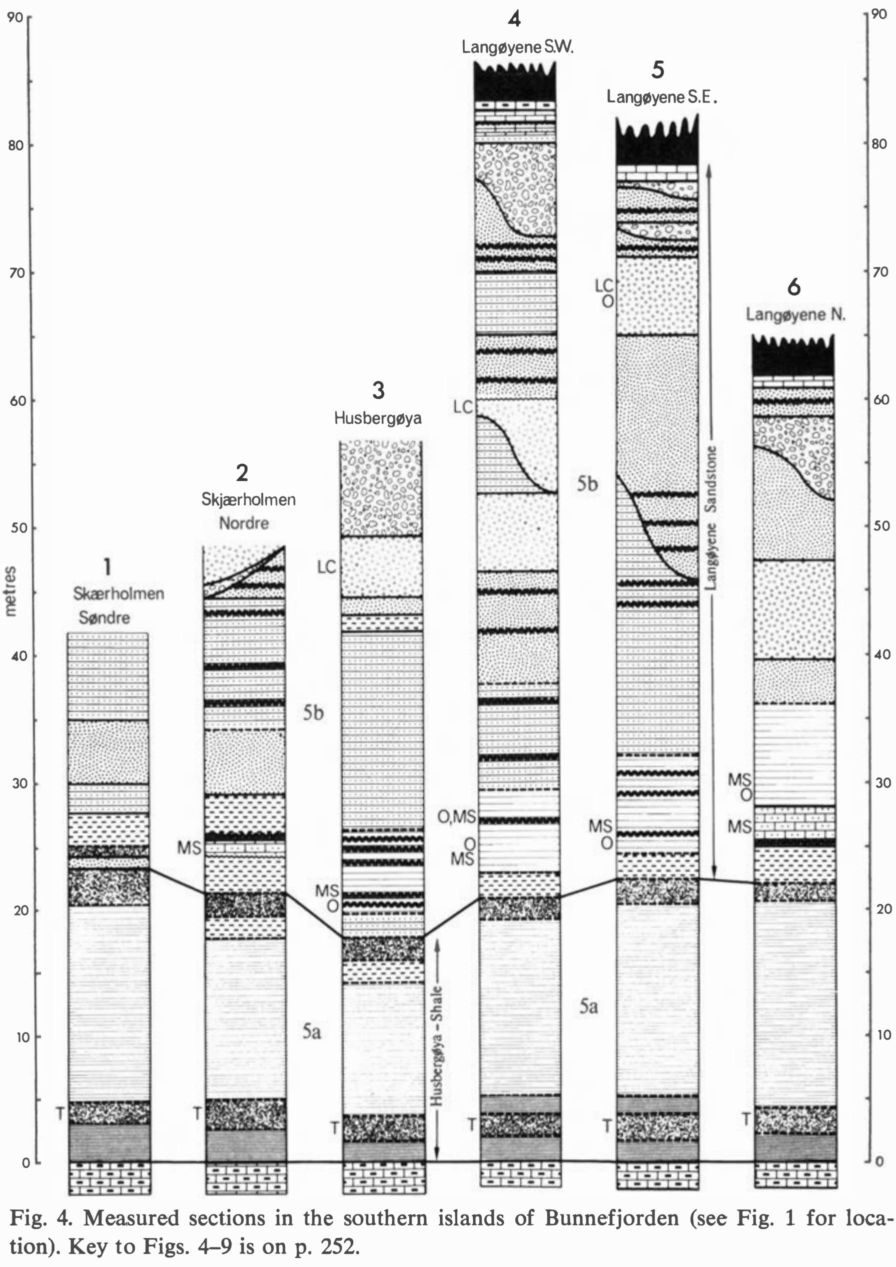


Fig. 4. Measured sections in the southern islands of Bunnefjorden (see Fig. 1 for location). Key to Figs. 4–9 is on p. 252.

Definition of Stage 5

DISCUSSION OF THE PROBLEM

Stage 5 has embraced a variable range of strata since Kjerulf introduced the term in 1857. Subsequent usage has greatly modified the stage so that the upper part of Kjerulf's Stage 5 is now usually included in Stage 6a. A definition of Stage 5 much closer to modern usage was made by both Dahll (1857)

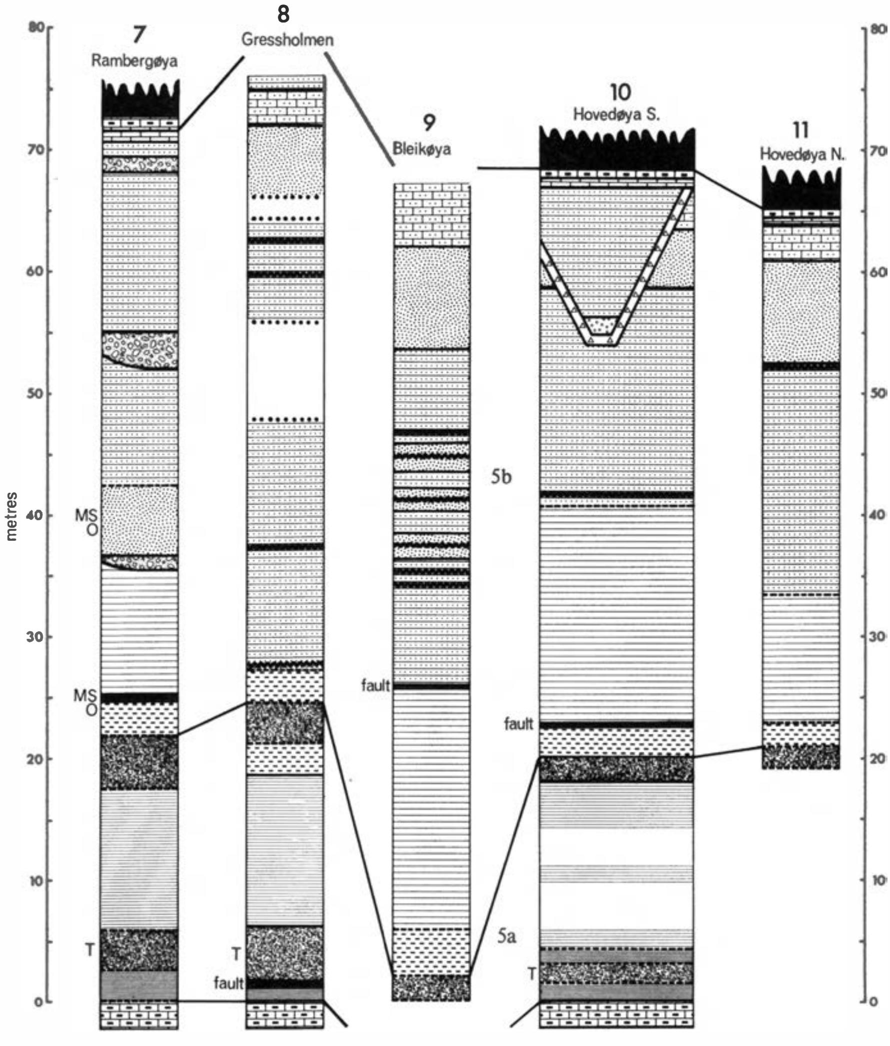


Fig. 5. Measured sections in the northern islands of Oslofjorden (see Fig. 1 for location). The exceptional thickness of the sequence on Bleikøya is likely to be the result of strike faulting.

and Brøgger (1884) who used Stage 5 as a subdivision of the sequence in the Skien–Langesund district (Table 1, p. 252). Dahll divided the upper part of the sequence into two parts, a lower, referred to as the Venstob or Herøkalk (5a) and a Kalksandstein at the top which he called 5b–d. Brøgger (1884) subsequently divided the Herøkalk into two parts, Isoteluskalk (Zone 4g) and Gastopodkalk (Zone 4h); the Kalksandstein was called Der 'Kalksandstein' (Stage 5).

Brøgger in 1887 produced his account of the stratigraphy of Stage 4 in the Oslofjorden area to accompany his map of the islands. He introduced the term 'Øverste Chasmopsnivå' (4dδ) for the rocks which at Ringerike and

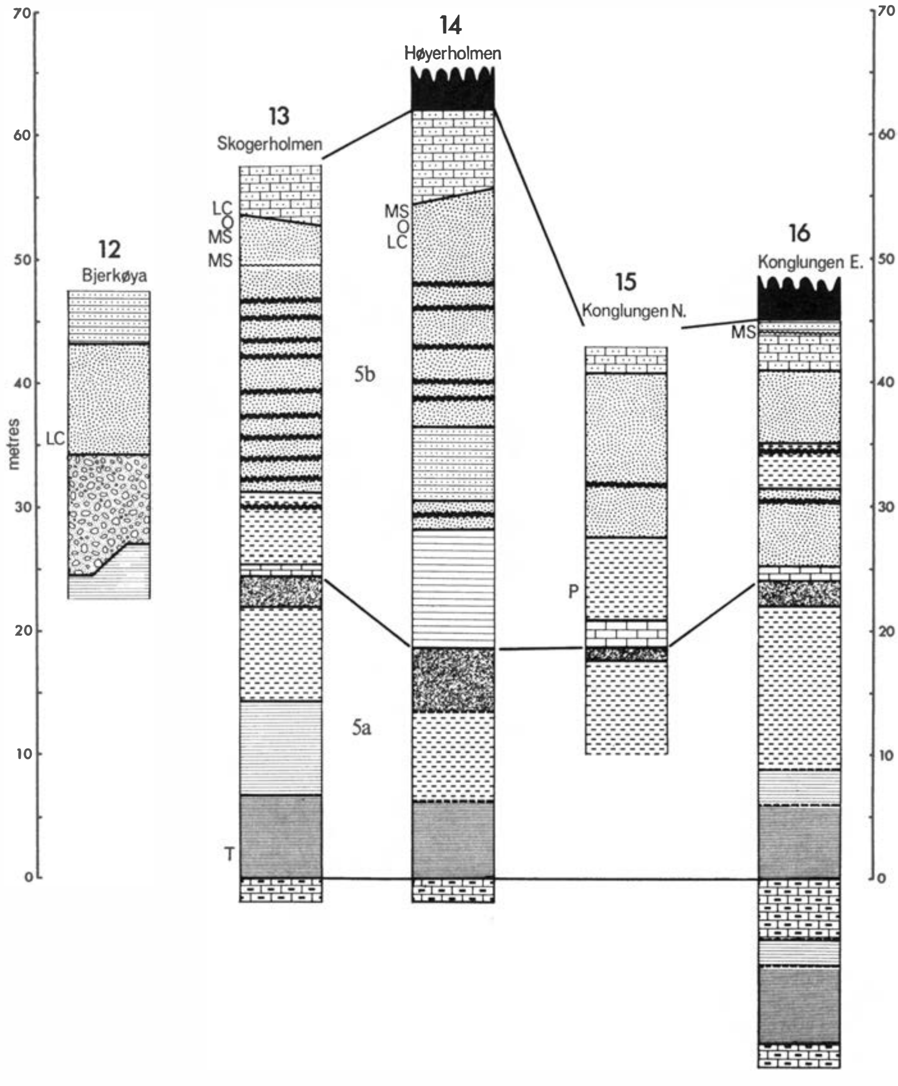


Fig. 6. Measured sections in the southern part of Asker (see Fig. 1 for location).

Skien–Langesund were called 'Gastropodkalk', i.e. 4h in Brøgger's work of 1884.

Kiær (1897) divided Stage 5 into 'Die Chasmopsschichten' (5a) and 'Die *Meristella crassa*-Schichten' (5b) based mainly on sections in Ringerike. The base of Stage 5 at Ringerike was recognised on faunal evidence and was regarded by Kiær as being the equivalent of the base of Brøgger's 4dδ. Later Kiær (1902), recognised beds of 5a and 5b age in Asker and drew the boundary between the two at the first appearance of *Holorhynchus giganteus*.

Given this historical background it is clearly useful now to refer Stage 5 to a type section. This section should be in the Oslo–Asker area since it was in this region that Kjerulf first applied the stage numbering system which

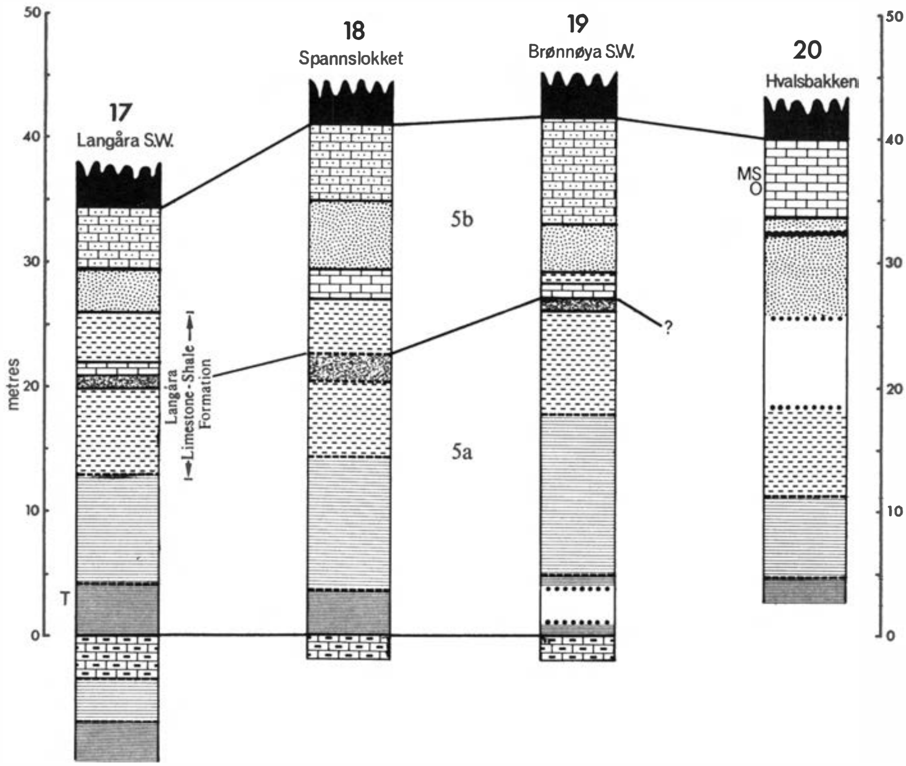


Fig. 7. Measured sections in the southern part of Asker (see Fig. 1 for location).

was further modified by Brøgger into a system which is more like that used today.

It also seems appropriate that the type section should be on one of the islands in Oslofjorden thus extending upwards the stratigraphic sequence of stages described by Brøgger in 1887. Although Brøgger refers to several sections in his account of 4dδ (5a of this account) we have not used any of these for reasons which are set out below. In selecting a type section we have sought a section which was: well exposed; had a clearly defined lower and upper boundary; included as extended a sequence as possible; was as fossiliferous as possible; and was reasonably accessible. Based on these requirements we have selected the section at Hovedøya S.W. as being the most suitable (Figs. 2 and 5).

According to the Code of Stratigraphical Nomenclature for Norway (1961) the Norwegian Cambro-Silurian 'Etasjer' and their subdivisions may be regarded as chronostratigraphical units. The boundaries between units have been based on lithological or on palaeontological data. A chronostratigraphic division is strictly speaking independent of both lithostratigraphic and biostratigraphic divisions. In practice it is commonly convenient to place the boundaries of a chronostratigraphic division to coincide with other types of stratigraphic boundaries. In this account we have proposed three new for-

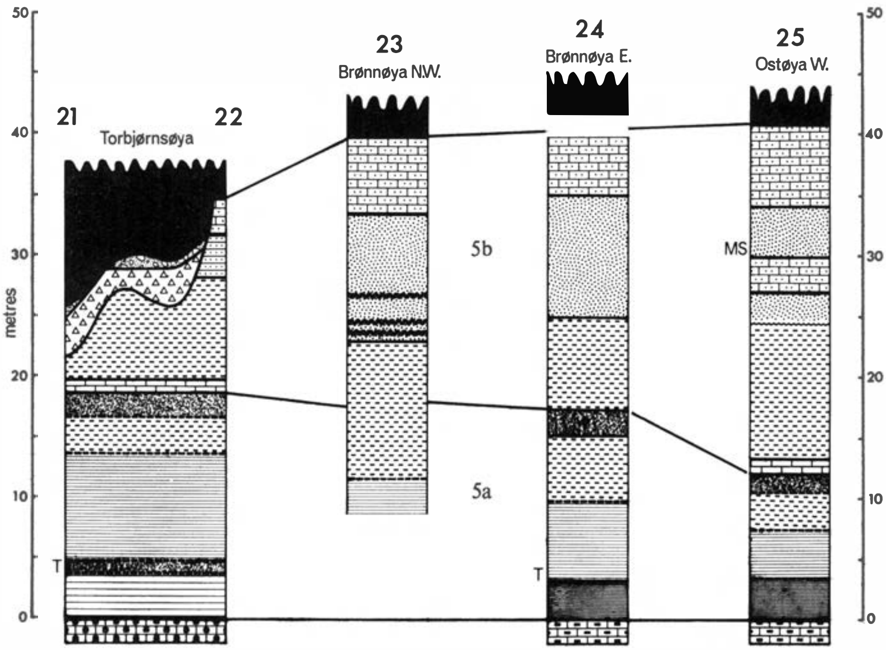


Fig. 8. Measured sections in the southern part of Asker (see Fig. 1 for location).

mations. Two of these formations (the Husbergøya Shale Formation and Langøyene Sandstone Formation) are included within Stage 5 in the Oslo-fjorden area, but a third (the Langåra Limestone–Shale Formation) is interposed between the two when the succession is followed westward into the Asker district. We have proposed that the base of Stage 5 be taken at the base of the first formation and the top of Stage 5 be taken at the base of the beds (6a) overlying the second formation. The contact between two of the formations is used to define the Stage 5a/5b boundary.

Stage 5a as it is here defined embraces 4dδ of Brøgger (1887), the 'Oberste Chasmopschichten' (5a) of Kiær (1897) and also the Gastropodkalk (5a) of Kiær (1902).

The base of Stage 5 falls at a well defined and laterally continuous lithological boundary. The rocks across this boundary are reasonably fossiliferous and it should be possible to recognise the chronostratigraphic boundary elsewhere on a biostratigraphic basis.

The top of Stage 5 is defined by the base of Stage 6. There is no doubt that Kiær (1908) placed the base of Stage 6 at the base of the 0.6 m thick nodular limestone which precedes shales and thin sandstones generally characteristic of the lower part of Stage 6 (Kiær 1908: 135 and fig. 27). The nodular limestone is well developed in the type section of Stage 5 at Hovedøya. Consequently the Stage 5/6 boundary as here defined conforms to that of Kiær.

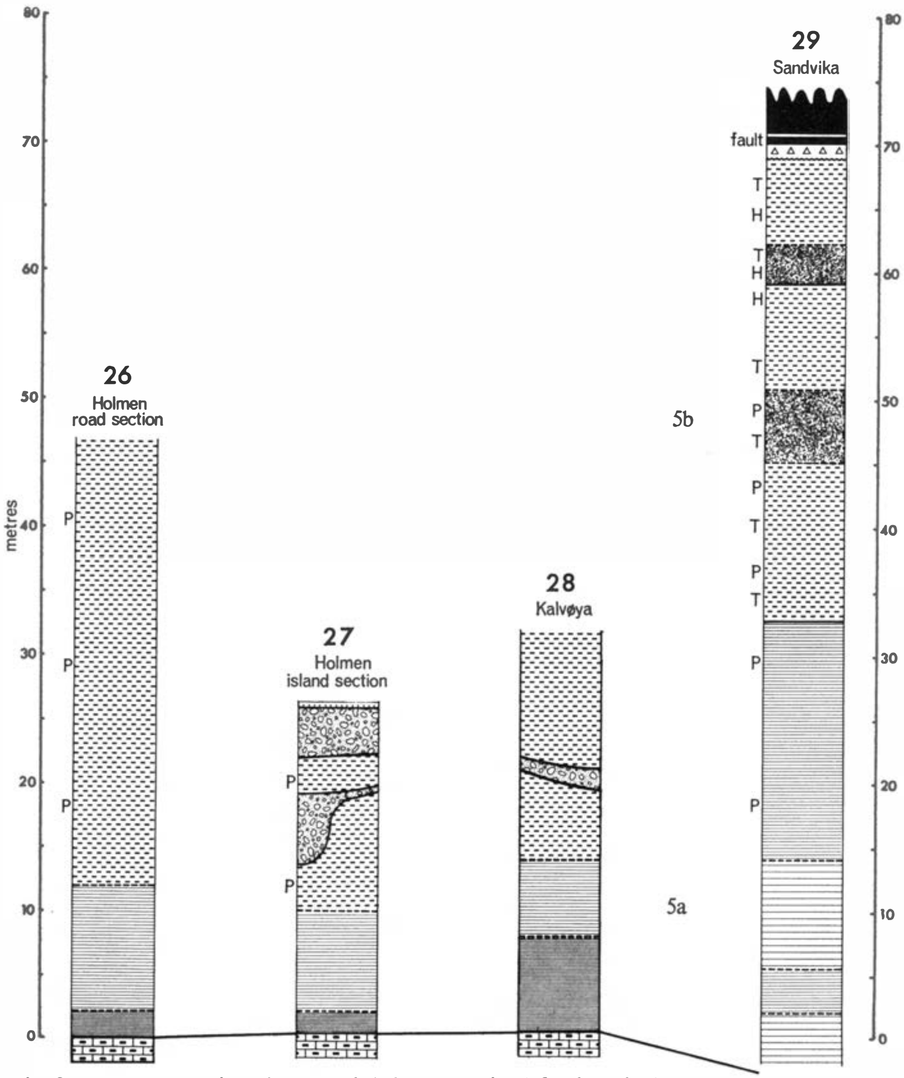
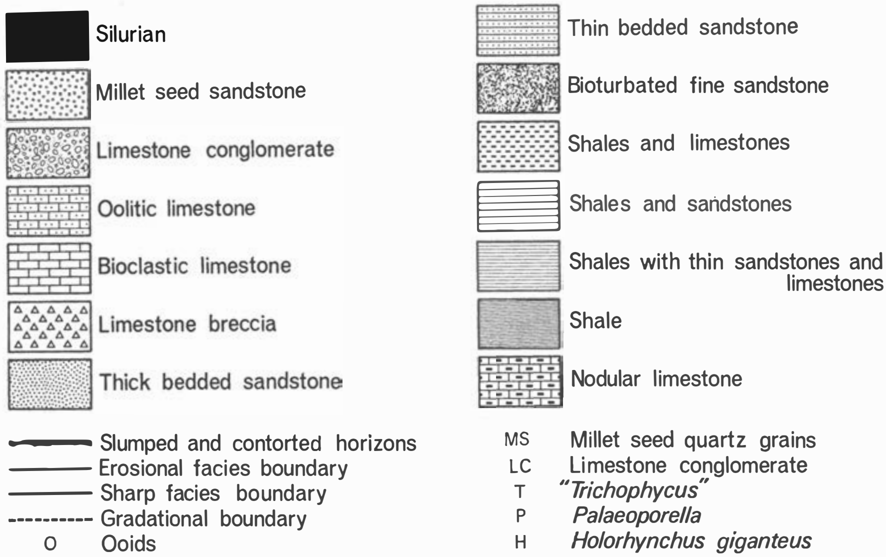


Fig. 9. Measured sections in central Asker (see Fig. 1 for location).

The proposed Stage 5a/5b boundary differs from previous usage (Kiær 1897, 1902) in that it is a chronostratigraphic boundary related to a lithostratigraphic boundary rather than a biostratigraphic boundary. The biostratigraphical unit Die Meristella Crassa-Schichten with *Holorhynchus giganteus* which Kiær (1897, 1902) regarded as characterising the base of Stage 5b in Ringerike and Asker cannot be recognised in the islands of Oslofjorden where the faunas are generally sparser. The Stage 5a/5b boundary was consequently designated at a lower level than that of Kiær, where there is a lithological horizon at the top of the Husbergøya Shale Formation which shows reasonable lateral continuity and can be identified throughout the islands of Oslofjorden and the more southerly part of Asker/Bærum. The beds at this



Key to Figs. 4–9.

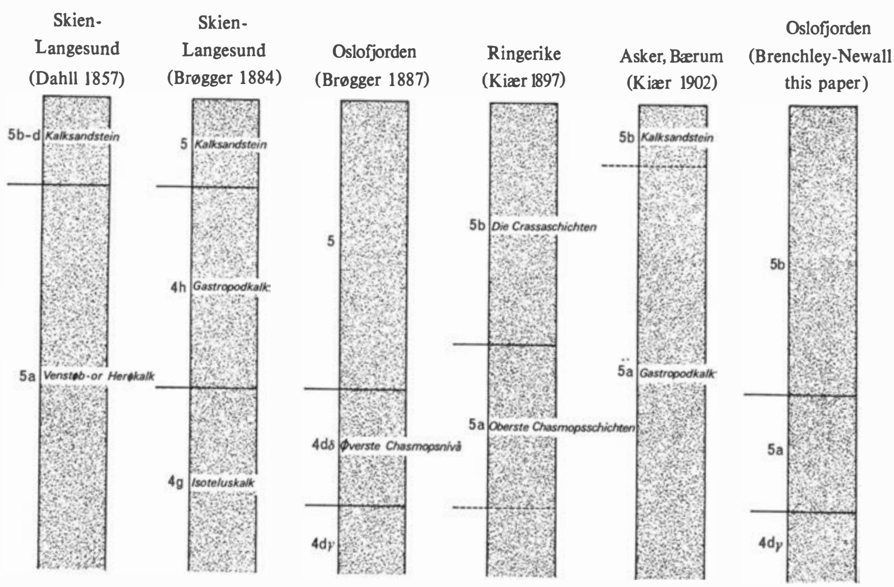


Table 1. Summary of historical development of Stage 5.

level are fossiliferous and contain a fauna including *Tretaspis* and cystoids at the top of 5a, and a brachiopod-bryozoa fauna at the base of 5b, so hopefully the boundary might be correlated on a biostratigraphic basis. If the 5a/5b boundary is placed any higher in the sequence it would fall within a complex and varied regime of sedimentary facies with accompanying lateral changes of biofacies. An example of such local biofacies development appears to be that of *Holorhynchus giganteus* which Kiær (1902) regarded as diagnostic of 5b in Asker, but which is only patchily represented in the upper part of some sections.

The lithological horizon we have selected at the top of the Husbergøya Shale can be recognised throughout the islands in Oslofjorden and can be identified in the more southerly of islands of the Asker/Bærum district. Above the Husbergøya Shale the facies of the Langøyene Sandstone Formation become so varied that it is commonly not possible to make detailed lithological correlations even between nearby sections (Figs. 4–9). Furthermore, the top of the Husbergøya Shale and basal part of the Langøyene Sandstone are the highest beds in the sequence in Oslofjorden which regularly contain fossils. The beds contain a fauna including *Tretaspis* sp., bryozoa, brachiopods, gastropods and cystoids and should be identifiable on a biostratigraphic basis.

The Stage 5a/5b boundary as here proposed is a little lower than that chosen by Brøgger (1884: 191) for the top of 4dδ. Brøgger apparently extended 4dδ up to the first development of flaggy fine sandstones (see the facies cross sections in Figs. 4–9), which is usually a well defined lithological horizon. This horizon occurs at a level from one to ten metres above the Stage 5a/5b boundary as defined here and we believe it represents a diachronous influx of sand into the area. Furthermore, with influx of coarser clastics fossils become infrequent. We believe therefore that by choosing the horizon a little lower than did Brøgger there are better lithological and biostratigraphical criteria for correlation of the Stage 5a/5b boundary.

Spjeldnæs (1957) proposed a further division, Stage 5c, for beds which lie on an erosional surface above the oolitic limestone near the top of 5b, and below 6a of the Silurian. Spjeldnæs regarded the 5c beds as post-dating an episode of folding and believed they lay with unconformity or disconformity on the underlying beds. We, however, do not recognise the unconformity and regard the '5c' beds as being channel fill sediments which are characteristic of most of Stage 5b. We have therefore not used the term 5c in this account.

PROPOSED STAGE BOUNDARIES

Stage 5. Type section Hovedøya S.W. (Figs. 2 and 5)

The base of Stage 5 is defined as the base of the Husbergøya Shales at the N.W. end of section on Hovedøya (Fig. 2). The boundary is very sharp and has well developed nodular limestones (4dγ) below and dark grey shales above. Details of the type section are shown in Fig. 5. The top of Stage 5 is defined by the base of a distinct bed (0.6 m thick) of nodular limestone – the lowest bed of Stage 6a. Stage 5 therefore includes all the beds below the nodular limestone (Kiær 1908: fig. 27).

Stage 5a/5b boundary

The boundary is chosen at the contact between the Husbergøya Shales and

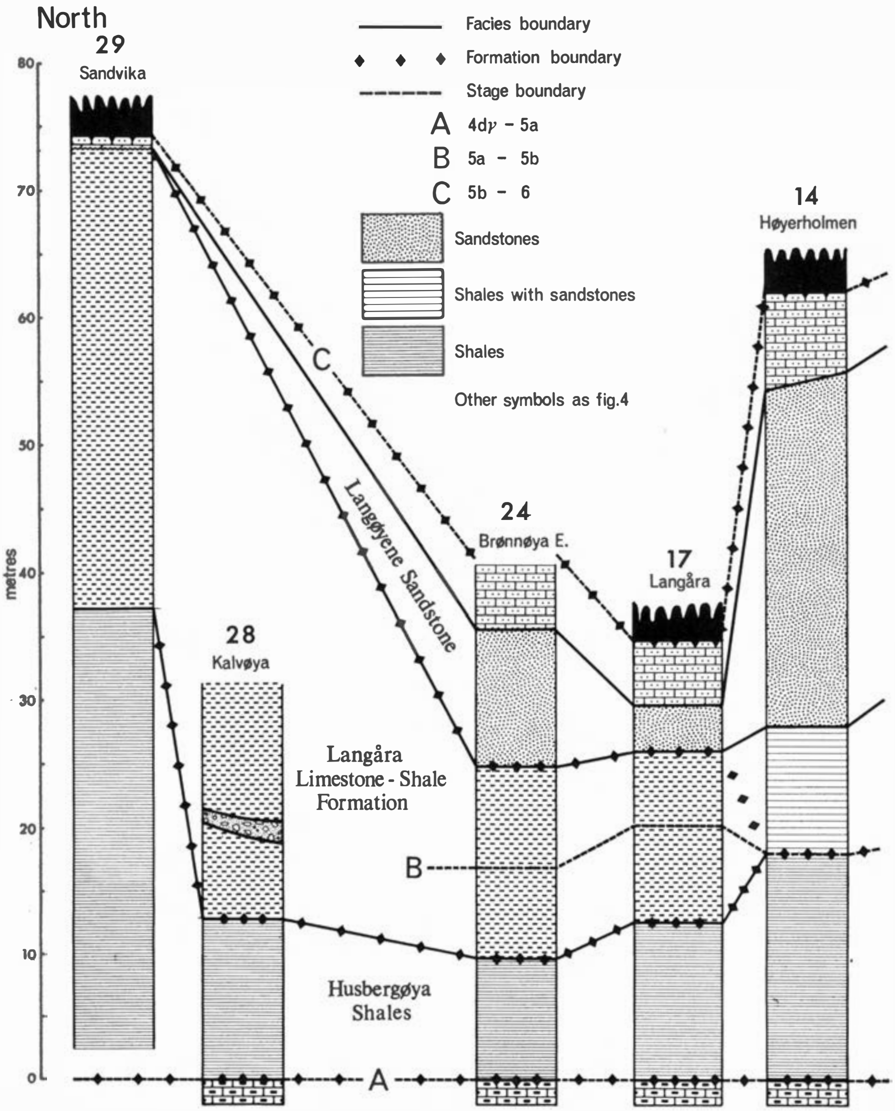


Fig. 10. Stratigraphic north/south profile, across Bunnefjorden with facies generalised to emphasise the 5b sandstone development in the south. A marks the base of 5a; B marks the 5a/5b boundary; C marks the top of 5b.

A broken line denotes a stage boundary; diamonds denote a formation boundary and a solid line shows the facies boundaries where they do not coincide with formation boundaries.

the Langøyene Sandstone in the Hovedøya section. The boundary occurs 21 m above the base of Stage 5 and is clearly recognisable at the top of the brown weathering bioturbated sandstone (about 2 m thick), this being the topmost bed of the Husbergøya Shales in this section. The boundary is overlain by silty shales with thin discontinuous limestones, these being the base of the Langøyene Sandstone Formation in this section.

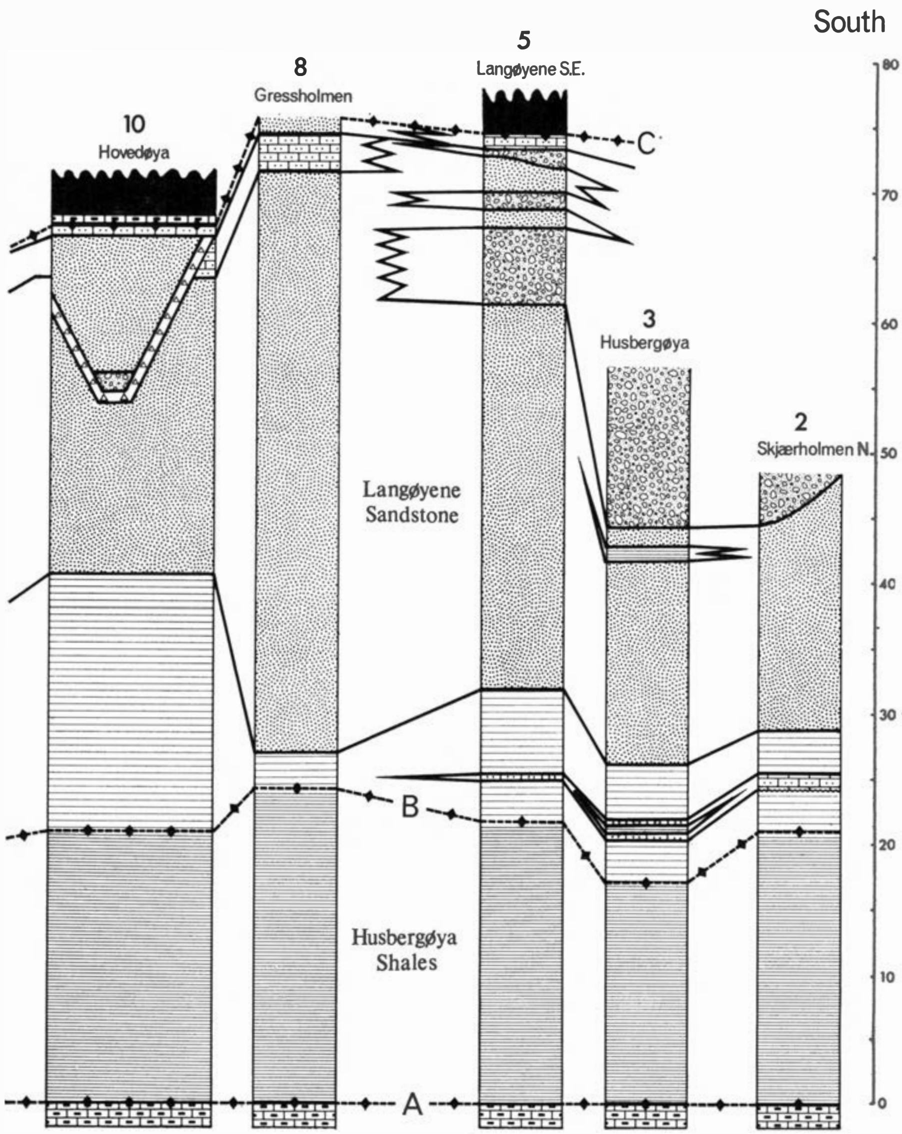


Fig. 11. Stratigraphic north/south profile across the Asker district. (Key as in Fig. 10).

PROPOSED NEW FORMATIONS

The three lithostratigraphic units here proposed are the Husbergøya Shale Formation, the Langøyene Sandstone Formation and the Langåra Limestone–Shale Formation. It would have been convenient to have chosen the stratotypes of two of the formations on Hovedøya in the type section of Stage 5, but here the Husbergøya Shales are not fully exposed and the Langøyene Sandstone Formation lacks its full variety of facies. We therefore selected the stratotypes on Husbergøya, Langøyene and Langåra (Fig. 2), where the formations are well exposed and there is a characteristic development of the representative facies.

The Husbergøya Shale Formation (type section N.W. Husbergøya) (Figs. 2 and 4, 18.5 m thick)
The base is defined by the sharp contact between nodular limestones below (4dγ) and shales above. The sequence, bottom to top, is as follows: 2.1 m shales with thin laminated sandstones, 1.5 m shales with sandstones reworked by '*Tricophycus*', 10.9 m shales and calcareous shales with an increasing proportion of sandstone, 2.0 m shales and calcareous shales and 2.0 m fine, brown weathering bioturbated sandstone.

The top is defined as the contact between the brown weathering sandstone and the overlying shales with laminated calcareous sandstone. Details of the sequence are described on p. 157 (Husbergøya Shale Formation), as the geographic extent of the formation.

The Langøyene Sandstone Formation (type section Langøyene S.E..) Figs. 2 and 4, 51 m thick)
The base is defined by the contact between brown weathering bioturbated sandstone (Husbergøya Shales) and overlying shales with buff laminated sandstones, and thin limestones. Slumped and contorted beds and oolitic limestone beds with well rounded, sub-spherical (millet seed) quartz grains occur within a few metres of the base. The sequence continues upwards with thin bedded sandstones, more massive sandstones, 'millet seed' sandstones and limestone conglomerates (Fig. 4). The top is defined by the contact between dark grey silty shales of 6a and an underlying sandy bioclastic limestone.

This distinctive coarse clastic facies of the Langøyene Sandstone Formation can be traced throughout the islands of Bunnefjorden and occurs on the southern islands in Asker. In other parts of Asker the formation is much thinner (as little as 8 m on Langåra, and at Sandvika it is represented by only a metre of brecciated oolite (Fig. 11)).

The Langåra Limestone–Shale Formation (type section Langåra) (Figs 2 and 7, 13 m thick)
At Langåra, beds of the Husbergøya Shale become more calcareous upwards as they pass gradationally into the Langåra Limestone–Shale Formation. We have chosen a rather arbitrary lower boundary to the formation in this gradational sequence at the uppermost distinct sandstone bed in the Husbergøya Shales which are here 12 m thick.

The top of the formation is clearly defined at the boundary between massive laminated quartz sandstones of the Langøyene Sandstone above and the Limestone and Shales below.

The 13 m of the formation so defined consist of silty grey shales with fine grained, irregular and sometimes discontinuous limestone beds a few centimetres thick. A few thin bioclastic limestones occur and there is one thicker bed of limestone (0.8 m thick) high in the formation.

The formation thickens northwards (26 m at Sandvika) and becomes more varied in its facies to include a *Palaeoporella*-coral facies, a *Holorhynchus* facies and a coral conglomerate facies (see Langåra Limestone–Shale Formation, p. 266).

The Stratigraphy

HUSBERGØYA SHALE FORMATION

This formation consists of a sequence of shales with increasing thin, interbedded calcareous beds and thin sandstones in the upper part, and topped by a bed of massive bioturbated fine sandstone. The lowermost shales succeed nodular limestones and this contact can be traced throughout the area. The upper part of the sequence becomes more calcareous when traced northwards and passes laterally into the Langåra Limestone–Shale Formation in Asker (Fig. 3). The thickness of the Husbergøya Shales is relatively constant (17–25 m) in Bunnefjorden but is generally thinner in Asker where it may be as thin as 10 m though it thickens to 35 m further north at Sandvika (Figs. 3 and 10).

Shale facies

Husbergøya section. – The shales at the base of the section overlie nodular limestones of stage 4dγ with a sharp contact and are only 2.5 m thick. They are grey, silty and have a crude fissility probably as a result of extensive bioturbation by *Chondrites*. Thin interbeds of laminated sandstone (1–4 cm thick) with some small scale ripple drift and extensively bioturbated upper and lower surfaces recur approximately every 20–30 cm. The fauna in the shales is sparse. The shales pass upwards into a more sandy horizon characterised by large trace fossils in the form of spreite which Seilacher & Meischner (1965) referred to the genus *Tricophycus*. We have retained the name *Tricophycus* in this account though it is likely that these fossils will prove distinct from this ichnogenus. The shale bed with the associated trace fossil horizon is widely recognisable. '*Tricophycus*' has been recognised at this level in all the sections in Bunnefjorden and most sections in Asker, though the trace fossils become sparser when these beds are traced northwards and we cannot identify a '*Tricophycus*' horizon at Holmen and Sandvika.

At most localities the spreite are confined to more sandy beds but they may penetrate down into the underlying shales; occasional burrows are found wholly within the shales, though these burrows themselves are sand filled. The spreite may be disturbed by later branching burrows of the *Chondrites* type.

There is usually a fauna associated with the sandy beds, particularly common being *Tretaspis* sp. and small orthoids, but calymenids, odontopleurids and graptolites have been found in the sections on the islands of Bunnefjorden. The sandy infills of the *'Tricophycus'* burrows also contain fossils and fragments of *Tretaspis* and graptolites were found. The beds are more fossiliferous generally in the Asker area and a rich and varied fauna can be seen at, for example, Brønnøya N.E. (24).

Shales with sandstones and limestones

Husbergøya section. – On Husbergøya the beds with *'Tricophycus'* pass gradationally upwards into silty shales again. Interbedded with this shale group are calcareous siltstone beds, commonly discontinuous, with indistinct upper and lower surfaces and little or no internal structure. Lithologically these beds appear similar to the silty shales with which they are interbedded except for a greater amount of carbonate: they would, therefore, seem to be essentially diagenetic in origin. Certainly they have the same *Chondrites* fauna as the adjacent shales.

Passing up the sequence thin laminated sandstones become more frequent. These beds are usually less than 4 cm thick and recur approximately every 15–50 cm. Fossils within this part of the sequence are sparse, being mainly trilobites, including *Tretaspis* sp. and isotelinids.

In the top 2 m of this facies, the interbedded sandstones are absent and calcareous beds predominate in the sequence. *Tretaspis latilimba* is common here and *Echinosphaerites* sp. and gastropods are frequent.

Comparison with other sections. – A similar sequence to that described for Husbergøya can be seen in most sections in Bunnefjorden though the uppermost calcareous beds are not always so well developed.

A generally similar facies is also found in most sections in Asker. At Høyerholmen (14), for example, the sequence is closely comparable with that on Husbergøya except that the calcareous beds are better differentiated and the sandstone beds less frequent. The upper part of this facies passes northwards into a more calcareous development and as such becomes included in the Langåra Limestone–Shale Formation. A fauna similar to that on Husbergøya is found everywhere, being more populous as the facies becomes more calcareous.

Brown bioturbated sandstone

Husbergøya section. – This unit of grey bioturbated fine sandstone, weathering buff to brown proves a useful marker for the top of Stage 5a. On Husbergøya the bed is 2 m thick massively bedded in units 10–40 cm thick, with rare thin silty shale partings. The fine sandstone bed passes both upwards and downwards gradationally into more calcareous siltstones. The unlaminated character of the bed appears to be the result of extensive bioturbation which might suggest a pause in sedimentation allowing the extensive reworking of the sediment. The main part of the bed is sparsely fossiliferous but the calcareous siltstones immediately above are richly fossiliferous and have been included in the succeeding Langøyene Sandstone Formation.

Comparison with other sections. – In some other sections of Bunnefjorden the brown sandstone may reach a thickness of nearly 5 m. Calcareous sandstone beds with parallel lamination may be interbedded within the brown sandstone or may sharply demarcate the top. In some sections fossils occur within the sandstone, notable being *Echinosphaerites* sp., *Tretaspis* sp. and bryozoa.

The bioturbated brown sandstones with cystoids can be recognised on Høyerholmen, Skogerholmen and Torbjørnsøya within the Langåra Limestone–Shale Formation but further north there is a progressive change in character and this useful marker horizon loses its distinctive character.

Relationship of Husbergøya Shales to Stage boundaries

The base of the Husbergøya Shales is marked by a sharp contact between nodular limestones below and shales above in sections throughout Bunnefjorden and Asker. Only in the Sandvika section (29) where exposure is poor we have not been able to identify the base to the Husbergøya Shales with confidence, however the lower part of the section exposed on Ringeriksveien is shaly and we believe is close to the base of the formation. This conclusion is confirmed by the nearly parallel section along Jongsåsveien which shows shale in contact with the underlying nodular limestone.

The base of the Husbergøya Shales coincides with the Stage 4dγ–Stage 5 boundary in the type section on Hovedøya. We regard the sharp lithological change at the base of Husbergøya Shales as probably synchronous throughout the area and we therefore believe that the base of Stage 5 can be correlated on lithological criteria throughout the Oslo–Asker region.

The top of the Husbergøya Shales coincides with the Stage 5a–5b boundary in the type section at Hovedøya. The brown bioturbated sandstone usually bearing cystoids which marks the top of the Husbergøya Shales can be identified throughout the islands of Bunnefjorden (Figs. 4, 5) and allows the correlation of the top of Stage 5a. The same brown sandstone horizon can be identified on Høyerholmen and Skogerholmen (Fig. 6) but it is here included within the Langåra Limestone–Shale Formation because the associated beds have become more calcareous. This lithological marker horizon nevertheless provides an essential link between the Bunnefjorden and Asker sections.

LANGØYENE SANDSTONE FORMATION

Before describing the facies in detail we have made some generalisations about the distribution of the facies and have grouped the successions accordingly.

This formation is characteristically developed in the sections of Bunnefjorden but is generally thinner in Asker where its thickness decreases northwestwards to as little as 1 m at Sandvika. The more southerly sections are characterised by a thick development of sandstone, they have slumps and other sedimentary disturbances and the formation has a large total thickness (53 m). These sandy sequences are cut by channels which are commonly filled by limestone conglomerates or 'millet seed' sandstones (Fig. 4). Included in this group are localities 1–7 in Bunnefjorden and Høyerholmen, Skogerholmen and Bjerkøya in Asker.

Further north (Gressholmen, Bleikøya and Hovedøya) the Formation is still mainly sandstone but includes more interbedded shale and the most northerly sections (Hovedøya) show little of the otherwise prevalent sedimentary disturbances. Limestone conglomerates are mainly lacking in these sections (Fig. 5). The succession is topped by a distinctive oolitic limestone bed.

A relatively thin group of sequences, in a central belt in Asker is characterised by laminated quartz sandstones topped by oolitic limestone. The main variation among these successions is in the thickness of the quartz sandstones (Figs. 7–8 and 11). Included in this group of sections are those on Langåra, Brønnøya, Ostøya, Torbjørnsøya, Spanslokket and at Hvalsbakken (17–25).

Of the northernmost group of sections (Kalvøya, Holmen and Sandvika) only Sandvika contains this formation, represented by a brecciated oolitic limestone bed less than 2 m thick.

Limestone and shale facies

Langøyene. – The section at Langøyene S.E. commences with about 2 m of shales with thin impure limestones lying with a gradational contact on the bioturbated brown sandstone of the underlying Husbergøya Shales. The limestones are not obviously bioclastic in type and commonly the upper and lower boundaries of each bed are not sharply defined and some beds are discontinuous. Interbedded with the shales and limestones are a few fine calcareous sandstones which have slightly erosional bases, and generally some ripple drift.

Comparison with other sections. – The thin basal limestone–shale facies, 3–4 m thick, is typical of all the islands in Bunnefjorden. Sandstones are present in variable amounts in all sections but are particularly common at Husbergøya where they obscure the calcareous nature of these lower horizons.

The fauna within this group of beds is generally rich, being characteristically composed of a variety of bryozoa, articulated entelletacean brachiopods and gastropods, while *Chondrites* is abundant throughout. In southern Asker at Høyerholmen and Skogerholmen the beds of these facies are rather more calcareous but yield a similar fauna to that found in Bunnefjorden. At nearby Skogerholmen beds of the same horizon include well developed limestones and have been included in the Langåra Limestone–Shale Formation.

Shales and sandstones facies

Langøyene S.E. – The lowest calcareous facies passes up transitionally into shales and sandstones (6.5 m thick) which are frequently slumped and contorted, marking the onset of an instability which was to affect many of the sediments of Langøyene Sandstones in the southern sections. The fine calcareous sandstones in this facies are in beds usually less than 15 cm thick and resemble those in the facies below. A particularly characteristic element of the facies is beds of oolitic bioclastic limestone containing 'millet seed' quartz grains. The oolitic beds are massive and generally unlaminated (or they may be laminated towards the top) and may be clearly graded. The beds vary in thickness from a few centimetres to nearly 1 m. These beds were apparently deposited very rapidly and frequently show sedimentary deformation structures where the oolitic beds have sagged into the underlying shale producing a range of forms of contorted bedding; blocks of limestone are commonly detached and surrounded by shale, which itself injects upwards into the limestone. The deformation appears to have occurred with little or no lateral translation and is probably related to the reversed density gradient created by the dumping of ooidal sediment on a mud surface. Very similar structures, though of smaller scale, have been created experimentally by Anketell et al. (1968, 1970).

The shales which are interbedded within this facies are also extensively folded but these folds appear to be translational slumps. The shales and thin interbedded laminated siltstones are deformed into isoclinal recumbent folds ranging in size from a few centimetres to about 2 m across the fold limbs. Some fold cores have become detached from their limbs, and there is evidence of considerable mobility of mud layers. One bed must have become effectively a mud flow and has preserved only whisps and fragments of the original bedding.

Comparison with other sections. – The shales and sandstones with oolitic limestone beds are present in all the southern sections of Bunnefjorden (2–7) except Søndre Skjærholmen (1) where the whole facies is replaced by thin bedded sandstones (Fig. 4). In the more northerly sections (Gressholmen, Bleikøya, Hovedøya) the sandstone and shale beds are present but the oolitic limestones and slumped beds are absent.

Thin bedded sandstone facies

Langøyene S.E. – Shales are subordinate in this facies which consists of thin sandstones, irregularly fissile siltstones and occasional thicker sandstones. The limits to this facies are arbitrarily assigned, for it passes up into progressively more thickly bedded sandstones and down into shales and sandstones. In the lower 8 m of this facies in Langøyene, the sandstone beds are generally less than 10 cm thick, and are fine calcareous sandstones. Some have no visible lamination, others have a slight grading and some are clearly parallel laminated or show ripple drift. The interbeds are siltstones which may be laminated and are sometimes contorted on a small scale, or are irregularly fissile.

Upwards in the sequence the sandstone beds are generally thicker and the interbedded siltstone becomes subordinate: contorted beds, however, remain quite common in the siltstones. The thicker sandstones have a planar horizontal stratification or commonly show ripple drift which may be in multiple sets.

Comparison with other sections. – A thin bedded sandstone facies occurs quite low in the formation in most other sections in Bunnefjorden but may recur at higher levels in the sequence. The facies as broadly defined includes a variety of bedded sandstones which may represent slightly different sedimentary environments.

Thin bedded sandstones comparable with those described from the lower part of the Langøyene sequence occur at a similar horizon on Husbergøya, Bleikøya and Gressholmen: further northwards more shale is interbedded with the sandstones.

The facies is developed higher up in the sequence on Rambergøya, Gressholmen, Langøyene S.W., Bleikøya and Hovedøya where it usually weathers a distinctive rusty or pinkish colour. The sandstone beds have trace fossils of the *Skolithos* type and the upper surfaces show *Monocraterion* and *Diplocraterion*.

Fossils are very scarce in all varieties of the thin bedded sandstone facies and consist of occasional rugose corals, tabulate corals, bryozoa and small orthoid brachiopods. Trace fossils, however, are very common, particularly the vertical burrows, *Skolithos* and *Monocraterion,* but also *Helminthoides,* gastropod tracks and *Planolites*.

Thick bedded sandstones

Langøyene S.E. – The thick bedded sandstones facies at Langøyene S.E. consists of beds of fine to medium sandstone varying in thickness from a few centimetres to more than a metre. There is subordinate interbedded fissile siltstone. The thicker beds may be massive or have a horizontal lamination or a very low angle cross stratification which appears to be related to shallow intrabed channels. Channelling at the top of and within beds is frequent. Ripple drift is common in thickly bedded units and may occur in multiple sets particularly towards the top of a bed. The ripple drift may be in the form of trough cross-lamination reflecting the presence of linguoid ripples which can occasionally be seen on the surface of the beds.

In the Langøyene section the thick bedded sandstone facies occurs for about 12 m above a large channel, at least 7 m deep. The facies has also filled the channel but has slumped down the steep side to give a variety of sedimentary folds and contorted sediments.

Comparison with other sections. – A similar facies to that on Langøyene is found low in the sequence on Søndre Skjærholmen and Rambergøya and sporadically in the middle part of other sequences on Langøyene. The thick bedded sandstone facies is particularly characteristic of the middle part of the sequences on Høyerholmen and Skogerholmen. In these sections the sandstones are extensively deformed into ball and pillow structures. Slump balls (pseudonodules of some authors) are well displayed on Skogerholmen and one bed has become so internally disrupted that much of the lamination has been largely destroyed.

A thick bedded light grey quartz sandstone facies is commonly developed near the top of many successions in Bunnefjorden. The sandstone is well sorted and forms thick planar laminated and cross-stratified beds with no intervening shale or siltstone beds. This development is usually less than 5 m thick and underlies the uppermost oolitic limestone facies (Hovedøya, Gressholmen, Bleikøya and Skogerholmen). On Langøyene N. similar quartz sandstones are overlain by limestone conglomerates. A rather similar sandstone facies commonly lies below the oolitic limestone in the Asker area. At Langåra there are 3 m of quartz sandstones with parallel lamination and cross-stratification overlying the Langåra Limestone–Shale Formation. This facies is unusually thin on Langåra but it ranges up to 10 m thick at Brønnøya E. (24) and 12 m at Konglungen N. (15). Much of the thickness variation of the Langøyene Sandstone Formation in this central part of Asker can be attributed to variation in the amount of this thick bedded sandstone facies in the sequence. Throughout the facies, parallel lamination is prevalent but shallow scours with low angle cross-stratification fill is quite common and a few beds have large scale cross-stratification.

'Millet seed' sandstone facies

Langøyene S.E. – Sandstones of this type succeed the thick bedded sandstones with sharp erosional contact at Langøyene S.E. The sandstone is bimodal in its grain size distribution having a coarse fraction of near spherical 'millet seed' grains and a finer fraction of angular quartz. There are occasionally ooids in the sandstone. The 6 m unit of sandstone has irregular trough cross bedding suggesting repeated episodes of scour and channel fill.

Comparison with other sections. – Similar 'millet seed' sandstones are found generally high in the sequence in the more southerly sections in Bunnefjorden (Fig. 4) but are virtually absent elsewhere. Fossils are uncommon but where present are usually transported fragments, particularly of tabulate corals. Quite common also are rounded limestone clasts. The facies is particularly well developed on Langøyene S.W. where at one horizon in fills a channel at least 6 m deep, has repeated cut and fill, and contains common siltstone clasts and 'favositid' fragments which commonly lie on the erosional surfaces.

Bioclastic limestone facies

Beds of recognisable biosparite are rare in this formation, and indeed within Stage 5 as a whole.

Langøyene S.E. and other sections. – The top of the sequence at Langøyene S.E. is marked by a rusty weathering sandy bioclastic limestone, 0.75 m thick. In some sections a bioclastic limestone of this type is overlain by less than a metre of nodular limestone, which marks the base of Stage 6a. This couplet of beds is found at the Stage 5/6 boundary at Langøyene S.W. (4), Rambergøya (7) and Hovedøya (10, 11). A distinctive shelly biosparite is found near the top of the sequence at Hvalsbakken where it includes some ooids and abundant articulated valves of *Barrandella*. This facies appears to be a local development covered with the oolites described in the later section (Oolitic limestone facies).

Limestone conglomerate facies

Langøyene S.E. – For several metres just below Stage 6a (Silurian) in Langøyene S.E. limestone conglomerates are interbedded with thick bedded sandstones which are highly contorted into non-translational sedimentary folds. The conglomerates consist of rounded limestone clasts, usually calcisiltites, corals and coral fragments in a matrix of 'millet seed' sand, finer quartz sand and occasional ooids. The conglomerates here are wackstones in the sense that the limestone clasts do not form a framework to the conglomerate but lie in the sand matrix.

The conglomerates lie on erosional surfaces which cut well down into the underlying sandstone, suggesting that the conglomerates are channel fill sediments. It can commonly be demonstrated that the conglomerates do fill channels but this cannot always be proved.

Comparison with other sections. – Limestone conglomerates are typical of most southerly sections in Bunnefjorden (2, 3, 4, 5, 6, 7) and are also present on Malmøya and Ormøya. They are present as a thin horizon in the bottom of the Hovedøya channel (10). In Asker they are generally less common but very similar conglomerates form a thick unit on the southernmost section (Bjerkøya 12). Limestone conglomerates of a similar type are also present in the Langåra Limestone–Shale Formation, described later.

Generally the conglomerates occur high in the sequence as on Langøyene but a thin development occurs on Rambergøya at a particularly low level, only 14 m above the base of Stage 5b and there is another thicker development 15 m higher up.

The clasts in the conglomerates are most commonly fine bioclastic limestone calcisiltites and calcareous siltstones. Crinoidal limestone and coarse bioclastic limestone are occasionally found as well as rare clasts of oolitic limestone. The clasts appear to have three origins: lithified limestone, unlithified siltstone and limestone, and coral debris. The unlithified nature of some limestones and siltstones is suggested by an interesting occurrence of armoured siltstone and limestone clasts on Bjerkøya.

Corals may be found within limestone clasts or free of any surrounding carbonate matrix. There is a considerable variety of rugose corals and particularly of tabulate corals which include favositid, halysitid and heliolitid types plus '*Syringopora*', *Sarcinula* as well as stromatoporoids and calcareous algae.

The conglomerates commonly show large scale cross-stratification, with sets over 2 m thick, of both planar and an irregular trough type. A common feature of the conglomerates is very well developed imbrication; the clasts may be stacked with a steep inclination or may be stacked nearly horizontally against steeply dipping foreset slopes (about 30° dip at Langøyene N.E.). At several localities the limestone conglomerates are seen to pass laterally into 'millet seed' sandstones (e.g. Langøyene N.E. and S.W.). Clearly the two facies are closely related, and it seems implicit that where the currents were not competent to carry the larger clasts only 'millet seed' sand and finer sand was deposited.

Oolitic limestone facies

This facies is absent in the type section at Langøyene S.E. but it is seen at Gressholmen and sections further north in Bunnefjorden and most of the sections in Asker (Figs. 4–9). This facies occurs as a distinctive unit of light grey or buff oolitic limestone between 3 and 8 m thick. Intermixed with the ooids are 'millet seed' grains which sometimes have become concentrated along well developed stylolites (these having both parallel and perpendicular attitudes to the bedding). The oolites are cross-stratified, mainly with trough beds having a set thickness of 50 cm or less. In Asker the limestone can be broadly divided into two parts; the lower part having large scale cross-stratification with set thicknesses up to 2 m (e.g. Høyerholmen) and the upper with horizontally stratified beds or with small scale cross-stratification. Fossils are sparse in the oolite and are mainly transported rugose corals.

The relationship of the Langøyene Sandstone Formation to the stage boundaries

The base of the Langøyene Sandstone Formation is believed to be synchronous throughout the islands of Bunnefjorden and to coincide with the Stage 5a/5b boundary. The base of formation is believed to be at the same level at Høyerholmen but elsewhere in Asker the base of the formation is diachronous, and becomes generally younger towards the north, while the Stage 5a/5b boundary lies within the Langåra Limestone–Shale Formation (Fig. 3).

The top of the Langøyene Sandstone everywhere coincides with the Stage 5b/6a boundary. The top of the formation is developed in a variety of facies but most commonly the uppermost beds are oolitic limestone which may be capped by less than a metre of sandy bioclastic limestone.

The lowest bed of Stage 6a is a nodular limestone (c. 1 m) in parts of Bunnefjorden but at many localities the stage starts with silty dark grey shales.

LANGÅRA LIMESTONE–SHALE FORMATION

The formation is only present in Asker and is absent in Bunnefjorden. The formation thickens northwards in Asker from about 6.5 m on Skogerholmen to about 35 m at Sandvika, and is represented by 13 m in the type section at Langåra. At Langåra and nearby sections in the south the facies is composed of shales and interbedded thin limestones while further north the facies becomes more varied and includes the *Palaeoporella* and *Holorhynchus* facies at some localities.

Limestone–shale facies

This facies is characteristically composed of shales with beds of irregularly bedded limestones a few centimetres thick, some of which are discontinuous. The limestones are generally fine grained and bioturbated, though a few are clearly bioclastic. Within the sequence at Langåra the facies includes a few whispy laminated fine sandstones near the base, which has a transitional downward passage into the Husbergøya Shales. About 7 m above the base of the formation there is a 1 m thick fissile calcareous sandstone rich in fossils, overlain by 0.8 m of bioclastic limestone.

Fossils are common throughout the formation at Langåra and include a variety of brachiopods, trilobites, gastropods, corals, bryozoa and orthocone nautiloids.

The limestone–shale facies is typical of the formation as it is developed in central Asker (Figs. 6, 7, 8, sections 15–25) and as far north as Kalvøya where the limestone element of the facies is particularly well developed.

Palaeoporella–coral facies

The distinctive character of the northern sections at Sandvika and Holmen arises from the development of shales with thick nodular or lenticular limestone beds typically with *Palaeoporella*. In the Sandvika section we have found *Palaeoporella* from a position about 23 m from the base of the exposed section continuing upwards through 39 m to within 11 m of the top. Interbedded with the shales and limestones are sandstones (0–15 cm thick) which at some horizons are more important than the limestones. At other levels bedding is largely destroyed by the development of large burrows seen as spreite of the so-called '*Tricophycus*' type. Throughout most the section there is a fauna of tabulate corals, rugose corals, a variety of brachiopods and some gastropods and bivalves.

The section at Holmen alongside the road is broadly comparable with Sandvika. The thick sequence with abundant *Palaeoporella* and corals extends through about 40 m to the top of the exposed section. The facies here contains more limestones than at Sandvika but sandstones and '*Tricophycus*' are much rarer.

A second section nearby occurs on a very small island, connected to the mainland by a narrow, dilapidated walkway (Fig. 9, section 27). Here is seen a sequence from the base of the Husbergøya Shales up into the lower part of the limestones of the *Palaeoporella*–coral facies. The sequence has been cut by a channel at least 5 m deep into which have slid blocks of *Palaeoporella*–bearing limestone of the type making the channel walls. Above this channel is a bed about 1–3 metres thick consisting of nodular limestones with *Palaeoporella* occurring in rolled limestone clasts and this bed is cut by another channel infilled with a conglomerate of limestone clasts in an ooidal matrix (Fig. 9, section 27).

Holorhynchus facies

The presence of the large pentameroid *Holorhynchus giganteus* in large numbers at a few horizons is a distinctive aspect of the upper part of some sections of Asker. In the area dealt with here it is however only present in two sections, namely Sandvika and at one locality at Holmen. At Sandvika the horizons at which *Holorhynchus* is common are typically irregularly fissile silty shales, with some irregular limestone beds and are extensively bioturbated by '*Tricophycus*'. The facies occurs for 8 m at a level 12 m from the top to a level 4 m from the top.

In both the sections at Holmen, which are shown in Fig. 9, *Holorhynchus* has not been found but the top of Stage 5 is unexposed. However, immediately to the east of Section 26, on a small island, about 2 m of siltstones with *Holorhynchus* are seen succeeding the *Palaeoporella*–coral facies. The sequence at this locality is folded and faulted and details of the succession are rather obscure but it appears likely that the facies represents a level high in the sequence as at Sandvika. A further occurrence of *Holorhynchus* is found if the sequence seen in the road section (26) is traced westwards along strike until it outcrops on Slemmestadveien. Here the *Holorhynchus* facies is again seen to succeed the *Palaeoporella*–coral facies high in the sequence.

Limestone conglomerate facies

Limestone conglomerates occur as a channel fill within the Langåra Limestone–Shale Formation at Kalvøya and Holmen (28, 27). The conglomerates in the two sections have many differences, however. At Kalvøya the conglomerate fills a broad, relatively shallow scour at a rather low level in the limestones and shales. The limestone conglomerate has clasts of bioclastic limestone, laminated siltstone, oolitic limestone, rugose corals, the tabulate corals *Sarcinula* and *Halysites* plus stromatoporoids and *Palaeoporella*. The matrix contains 'millet seed' quartz sand grains and occasional ooids.

At Holmen (27) the lower limestone conglomerate consists of a disrupted nodular *Palaeoporella* bearing limestone which has slid into a channel, probably with no further transport (see previous section, *Palaeoporella*–coral facies). A second limestone conglomerate about 1 m thick contains clasts of limestone with *Palaeoporella* and some oolitic clasts while the uppermost limestone conglomerate has limestone clasts in bioclastic and oolitic matrix.

Although limestone conglomerates are infrequent in the Langåra Limestone–Shale Formation of the area studied they are recorded by Kiær from Alfheim and Holterbråten and Lervik (1969) notes their occurrence in the Gjønnes and Østerås areas. It appears likely that they are commonly associated with erosion deep into the Stage 5 sequence, and that the composition of the conglomerates sometimes reflects the character of the beds being eroded.

Relationship of the Langåra Limestone–Shale Formation to the Stage boundaries

Neither the upper nor lower boundary of the formation coincides with the Stage boundary and both boundaries are almost certainly diachronous (Figs. 3 and 10). The lower boundary is everywhere gradational and the level at which limestones become a major element of the sequence varies from section to section within Asker. The upper boundary of the formation is usually sharply defined by the overlying massive sandstones of the Langøyene Sandstone Formation which may well have been deposited at different times at different localities.

The Stage 5a/5b boundary lies within the Langåra Limestone–Shale Formation. The Stage boundary can be traced with reasonable confidence, using the bioturbated brown sandstone at the top of the Husbergøya Shales as a marker horizon, from Bunnefjorden to Høyerholmen. Further north, where the boundary lies within the Langåra Limestone–Shale Formation it can only be traced with difficulty in Asker using lithological evidence. It does, however, appear possible to correlate this horizon through many sections by reference to the sequence at Skogerholmen, where the brown sandstone is still recognisable and is overlain by a metre of bedded fine grained limestone with a rich gastropod fauna. In most of the sections on Brønnøya, Ostøya, Konglungen, and Langåra, we believe we can identify this limestone which is underlain by bioturbated calcareous sandstones: we also tentatively identify the same horizon on Kalvøya and Nesøya. In all these sections it is the limestone rather than the sandstone which is distinctive. We have shown the correlation of this horizon in Figs. 4–9 and 11. In the most northerly sections (Holmen and Sandvika) we cannot identify the Stage 5a/5b boundary on the same lithological criteria as elsewhere.

EFFECT OF CHANNELLING ON THE STRATIGRAPHY

Channels have cut into the sequence at different times and have a wide variety of channel fill. The channelling causes the sequence to vary laterally in short distances and contributes greatly to the rapid lateral facies changes. The character of the facies filling the channels depends partly on the nature of the beds being chanelled and partly on their palaeogeographic situation. The more southerly channels which cut into the Langøyene Sandstone sequence may be filled with sandstone similar to the channelled beds (i.e. Langøyene, section 5) but are more commonly filled with 'millet seed' sand, limestone conglomerate, ooids and fine sand in variable proportions. The more northerly sections (in Asker) have channels cutting into the limestone shale facies, with a varied fill; the channel cutting low into the sequence at Holmen is filled with slumped and disrupted beds of *Palaeoporella* limestone of the same type as the channel walls while a slightly higher channel is filled with an ooidal limestone conglomerate. An ooidal fill is found at Nesøya, while at Kalvøya there is a thin 'millet seed' limestone conglomerate fill.

A difficulty sometimes arises in determining the age of the channelling and the time of the fill. Some channels are clearly cut, filled and covered and lie within the Stage 5 succession, while others appear to have been downcut from the top of Stage 5 and after being filled with late Stage 5 sediments are covered by shales belonging to Stage 6a.

The channels which occur within Stage 5b are seen in the southern sections of Bunnefjorden notably on Langøyene and Rambergøya where they cut into the varied facies of the Langøyene Sandstone Formation and are usually filled with limestone conglomerate. These channels appear to be tidal channels cutting through the offshore sand bar.

The late episode of channelling which cuts down from the top of Stage 5b and postdates the deposition of the oolitic limestone is important throughout the area. There is some evidence for a general pause in sedimentation after the deposition of the oolitic limestone since at several localities it occurs as a breccia in channels which cut the limestone (Hovedøya S.W., 10; Hovedøya S.E., and at Alnabru (Spjeldnæs 1957) Ostøya W, 25; Torbjørnsøya, 21; Sandvika, 29 and others not covered in this account). The oolitic limestone was clearly sufficiently lithified to form angular blocks and steep margins to the channels. Although channels cut into the underlying sandstone, blocks of sandstone are much less common in the channels and sand beds are seen slumped in the Hovedøya channel (10). It appears probable that the sandstones underlying the limestone had only a weak coherence at the time of channelling while the oolitic limestone was partly cemented. After deposition of the oolitic limestone and before the deposition of the Silurian, sedimentation was confined to channels except for a widespread thin sandy bioclastic limestone bed. In the Hovedøya channel approximately a metre of limestone conglomerate overlies the oolitic breccia and then 10 m of thin bedded sandstones, with beds rich in corals and some brachiopods near the top, complete the channel fill. A thin sandy bioclastic limestone coupled with a thin nodular limestone caps the succession and can be traced outside the channel where less than 100 m along the strike no sediment was preserved in the interval between the oolitic limestone and the capping of the bioclastic limestone – nodular limestone couplet. At a locality 250 m northeast of the channel the oolitic limestone is again channelled but is only cut down locally for about 2 m. The bioclastic limestone–nodular limestone couplet is irregularly developed and appears to lie on the eroded surface with no intervening clastic sediments. A similar situation apparently occurs at Torbjørnsøya (21 and 22) where the Silurian appears to lie directly on the irregular surface of the oolitic limestone blocks lining the channel.

It appears that although the Silurian generally lies on a planar surface, at some places there was insufficient deposition of sediment after the last episode of channel formation to fill in the channels. The shales and mud-stones of the Silurian then drape the irregular unfilled channels. At Torbjørnsøya downcutting is on a scale comparable with that at Hovedøya and the channel is lined with large blocks of oolitic limestone, together with slabs of quartz sandstone which are seen to have slipped and moved some way down the channel sides. In that part of the channel seen at the eastern end of the island there is about a metre of limestone conglomerate overlying the breccia. Elsewhere there is no evidence of current deposited channel fill before the Silurian. Apparently most of the channel remained unfilled until the Silurian shales were deposited so that they drape over the channel topography.

At some localities in Asker erosion has cut down low into the Stage 5 succession (Holmen, Kalvøya, Nesøya). It cannot always be demonstrated that the erosion extends down from the top of Stage 5 but the evidence from nearby sections at Holmen (26, 27) suggests that the channelling shown in section 27 has probably cut down through the beds with *Holorhynchus* into the *Palaeoporella* facies, implying that the erosion is of late 5b age. It is possible that all the channels in Asker belong to one late erosional phase which postdates the deposition of the oolitic limestone, and that there was a late Stage 5b episode of deposition confined to the channels.

The limestone breccias and overlying sediments were designated as Stage 5c by Spjeldnæs (1957), who believed that there was an episode of folding between the deposition of the oolite and the formation of the breccias. We do not find any evidence for folding, but believe that the linear outcrop of facies represents the original facies belts and the episode of erosion forming the breccias was the result of channelling rather than uplift. Although we accept that there may have been a hiatus in sedimentation after the deposition of the oolitic limestone it seems unnecessary to have a separate substage for the subsequent channel fill sediments, unless these can be shown to be of a significantly younger age.

STAGES 5a AND 5b IN THE OSLO–ASKER DISTRICT

Using the three lithostratigraphic boundaries described in previous sections it appears to be possible to correlate the lower and upper Stage 5 boundaries thoughout the whole of the Oslo–Asker district and to correlate the 5a/5b boundary over a substantial part of the area (Figs. 10 and 11). We believe the lithological boundaries to be synchronous, but we hope that it will be possible in the future to confirm the synchroneity of the boundaries using palaeontological data.

The thickness of Stage 5a varies from 23.5 m at Skjærholmen and Skogerholmen S. to 18 m at Husbergøya, Høyerholmen and Torbjørnsøya. At Brønnøya E. it may be as thin as 16 m but the section here may be affected by strike faulting. There is no apparent trend to the thickness variation of Stage 5a but the amount of variation is less than in Stage 5b.

The facies in Stage 5a are developed in a regular sequence throughout Bunnefjorden, and in this area, Stage 5a coincides with the limits of the Hus-

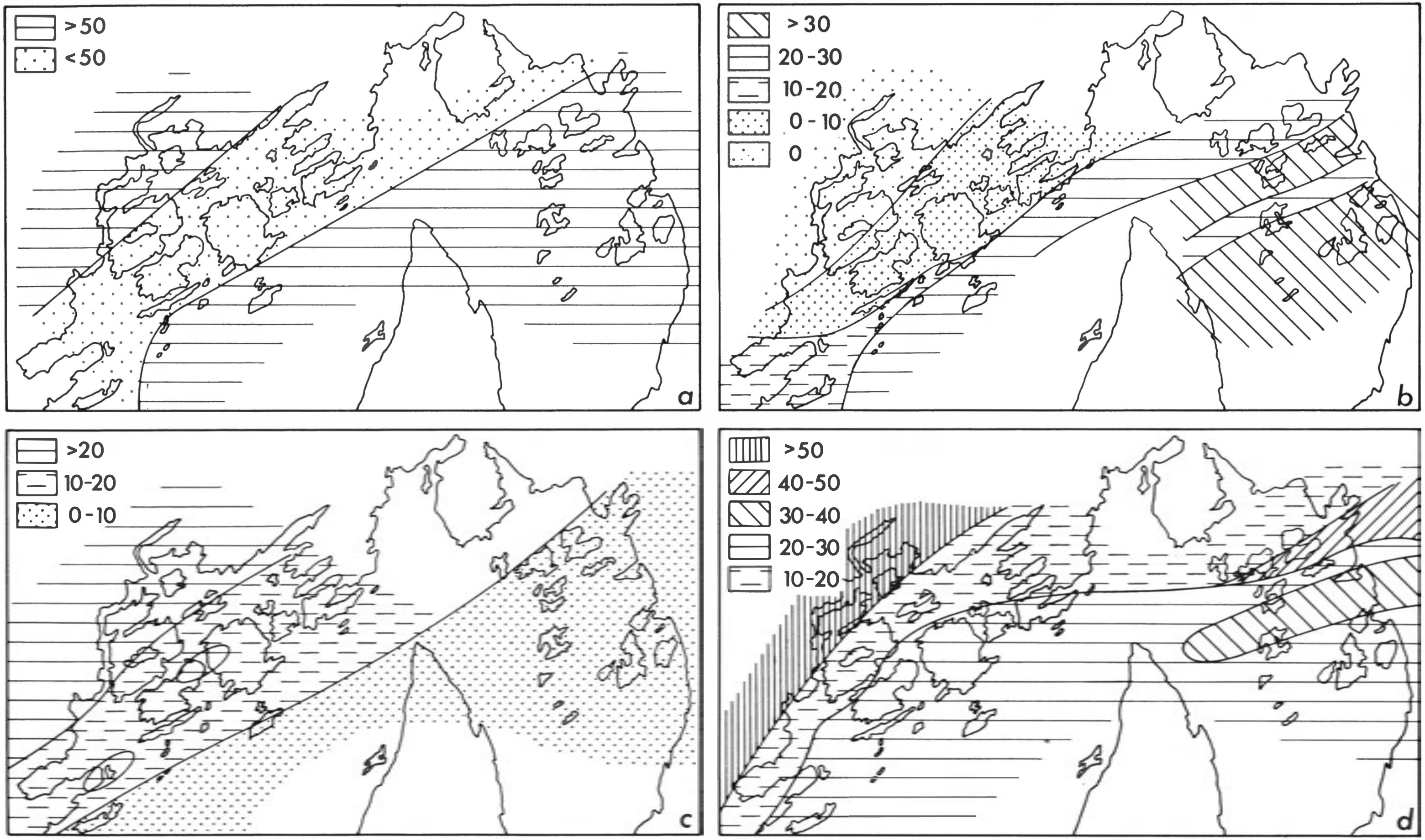


Fig. 12. Generalised maps showing the distribution and thicknesses of various facies. (No palinspastic adjustment has been made and the maps show facies not formations).
a. Total thickness of Stage 5. b. Thickness of sand facies. c. Thickness of calcareous facies. d. Thickness of shale facies.

bergøya Shales. Passing north into Asker the upper part of Stage 5a becomes more calcareous and is included within the Langåra Limestone–Shale Formation.

Considerable variations in the thickness of Stage 5b apparently mark the onset of an episode of Upper Ashgillian instability. Stage 5b is generally thick in the south (Bunnefjorden and south Asker, Fig. 11) where it is between 40 m and 60 m thick. It is generally thin in a central belt in Asker (12 m to 18 m) and thickens again to the north where it is possibly about 40–50 m thick at Sandvika.

Stage 5b is predominantly composed of coarse clastics rocks in the south which pass northwards into limestone–shales facies. The coarse clastics of the Langøyene Sandstone characterise all sections in Bunnefjorden and the southernmost islands of Asker (Bjerkøya, Høyerholmen and Skogerholmen). Northwards from Skogerholmen the facies transition into limestones and shales occurs in less than 1 km and is accompanied by a sharp reduction in the thickness of the stage. Throughout the central belt of Asker coarse clastics are only developed at the top of Stage 5 and further north they are further reduced until at Sandvika the limestone–shale facies occupies nearly the whole of Stage 5b. The distribution of the facies as developed in Stage 5 as a whole is illustrated in Fig. 12 which confirms the presence of N.E./S.W. linear facies belts as described by Kiær (1902).

Interpretation of the facies distribution

The development of the complex stratigraphy can best be discussed in the framework of a regressive cycle and the onset of diastrophism.

1. The lower part of the sequence is a relatively simple development from shale to calcareous shales with sandstones passing upwards into a bioturbated sandstone which possibly represents a pause in sedimentation. This part of the sequence is relatively uniform throughout all the islands but there appears to be a thinner development of it in parts of the Asker area (e.g. Brønnøya E, 24).

2. Above the brown bioturbated sandstone there is the onset of clastic deposition and differential subsidence gave rise to differences of up to 20 m in the thicknesses of even nearby sections. In spite of the complexity of the facies distributions certain generalisations can be made.

Thin or thick bedded sandstones representing a marked shoaling of the environment appear early in the most southerly sections (Søndre Skjærholmen, 1) and also in Gressholmen (8), but rather later in the northern sections of Hovedøya (10 and 11).

3. The thick sand sequences of the southern sections are cut by channels up to about 10 m deep. These channels may be filled with fine sand, which may be slumped (Langøyene S.E., 5), but channels are most commonly filled with 'millet seed' sandstones and limestone conglomerates. The conglomerate

filled channels do not extend into the thick sandstone sequences of Gressholmen nor into the less sandy sequences of Hovedøya.

4. The sequences on Hovedøya lack a thick well-developed shallow water sandstone sequence. Although thin bedded sandstones are developed in the upper part of the section they have more interbedded silty shale and lack the abundant vertical burrows of the more southerly sections. However, there is clearly an upwards increase in the amount of sandstone, and a shoaling of the top of the sequence is shown by the presence of thick bedded quartz sandstones and oolitic limestones.

The correlation of the oolitic limestones horizon with the clastic sequences to the south presents a difficult problem. Either the oolite was deposited over the whole area and has been eroded from the more southerly regions or the oolite was deposited as a shoreface shoal against a clastic barrier to the south, in which case the upper part of the clastic sequence with its limestone conglomerates is contemporaneous with the oolite.

5. The clastic sequence of Hovedøya and Gressholmen appears to be linked along the same facies belt with the sequences at Høyerholmen and Skogerholmen.

6. North of these clastic sequences there is a central belt in Asker (sections 15–25) characterised by shales and limestones in mid-section and sand facies only towards the top (Figs. 3 and 11). We believe that shales and limestones were initially forming north of the barrier bar sands represented by the more southerly sections, and that the shoal sands migrated diachronously north over the shale carbonate facies.

7. Further to the north, represented by the Holmen and Sandvika sections, a shale/limestone sequence was developing with a characteristic *Palaeoporella* and coral fauna throughout much of the sequence, and *Holorhynchus* bearing beds at the top. The coarser clastic sediments never reached this area.

8. A final shoaling over the whole area is represented by the oolitic limestone which caps most sections. It is possible that the oolites formed seaward of the sand bars which themselves never developed oolites (see sections 1–6).

9. There appears to be a pause in sedimentation after deposition of the oolitic limestone during which time the oolite was at least partially lithified: channelling occurred locally to a depth of 12 m and possibly considerably more. Sands filled some channels, others were filled with nodular limestone, limestone conglomerates and oolitic beds but others were left partially unfilled. The last episode of deposition is marked by the thin development of less than 1 m of sandy limestone commonly succeeded by a thin nodular horizon which although not present in all sections is represented in both north and south areas, implying a uniformity of depositional environment marking the base of Stage 6a.

We should emphasise that we have arbitrarily accepted the facies change from clastic and carbonate sediments to mainly shale and siltstone sediments as the Ordovician-Silurian boundary. According to Spjeldnæs (1957) this boundary must be close to the Ordovician–Silurian boundary because the lowest variety of *Climacograptus scalaris normalis* has been found in the lowest part of 6a on Ormøya (it is now thought, however, that this graptolite has a more extended range). Whether this facies change really does mark the system boundary everywhere could only be substantiated by a detailed faunal investigation.

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