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Atle Mørk & Snorre Olausen:  
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of the Oslo Region

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# NGU

## Norges geologiske undersøkelse

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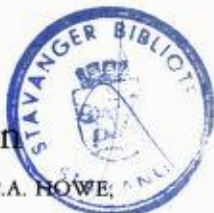
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# The Silurian succession of the Oslo Region

DAVID WORSLEY, NILS AARHUS, MICHAEL G. BASSETT, MICHAEL P.A. HOWE,  
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The marine Silurian succession of the Oslo Region displays a great variety of mixed clastic and carbonate lithofacies. Maximum thicknesses (<650 m) and most complete successions are seen in the central parts of the region in the Ringerike and Asker districts. Existing numerical stratigraphical units are based on a mixture of faunal and lithological criteria and are often diachronous. We herein propose the replacement of this scheme throughout the region by a series of formal lithostratigraphical units and use existing such units where possible. In these terms the entire marine succession comprises two groups and eleven formations, all of which are defined and described in this paper. Our new information on the age relationships and depositional environments of these units permits a new appraisal of the palaeogeographical evolution of the Oslo Region and adjacent sectors of the Caledonides during the Llandovery and Wenlock. Our work has restricted itself to the marine Silurian succession; the transition to the overlying red bed deposits of the Ringerike Group occurred in the late Wenlock in the Ringerike district. In order to present a complete review of Silurian deposits of the Oslo Region we also give a brief description of the red bed sequence.

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## CONTENTS

Introduction	2
Stratigraphy	4
The Bærum Group	8
The Solvik Formation	9
The Sælabbonn Formation	16
The Rytteråker Formation	19
The Vik Formation	22
The Ek Formation	25
The Bruflat Formation	27
The Reinsvoll Formation	30
The Skinnerbukta Formation	30
The Hole Group	32
The Brakøya Formation	33
The Malmøya Formation	36
The Steinsfjorden Formation	38
The Ringerike Group	42
Synthesis	44
Acknowledgements	53
References	53



## Introduction

The marine Lower Palaeozoic succession of the Oslo Region is approximately 1,250 m thick and is overlain by a similar thickness of late Silurian red beds. This sedimentary suite is exposed within a NNE–SSW trending graben (Fig. 1) which appears to have developed mainly in the Carboniferous and Permian (Ramberg & Spjeldnæs 1978, Olausen 1981a). Regional facies mosaics and thickness variations in the Lower Palaeozoic succession reflect the foreland character of the Oslo Region between the developing Caledonide orogenic zone (Nicholson 1979) and the cratonic development seen further east on the Baltic Shield. These features prompted Størmer (1967) to suggest that Lower Palaeozoic sediments were deposited in an intracratonic syncline which corresponded generally to the younger Permo-Carboniferous graben structure. Størmer tentatively associated this syncline with other Lower Palaeozoic basins along the southwestern and southern margins of the Baltic Shield (e.g. in Scania and Poland). An alternative hypothesis by Ramberg (1976) rather suggests the development of the Oslo Region as one of a series of offset fault-bounded basins along the margins of the shield area. Both authors clearly supposed that the margins of the Oslo Region's Lower Palaeozoic basin structure were generally coincident with those of the later Permian graben.

Lower Palaeozoic sequences are exposed throughout the region between Permian intrusive and extrusive complexes. Interpretation of the original geographical relationships of present exposures is complicated by earlier Caledonian deformation which had markedly different effects throughout the region. Exposures in southern districts show gentle dips, but WSW–ENE striking folds increase in intensity northwards to Mjøsa where Lower Palaeozoic rocks are exposed in highly deformed parautochthonous sequences immediately adjacent to major southeastwards directed thrust planes (Nicholson 1979, Nystuen 1981). The appreciable crustal shortening produced by Caledonian deformation must be borne in mind when assessing the lateral facies variations observed in present exposures. In spite of these complications, exposures are both widespread and often exceptionally fossiliferous. These features make the region an excellent area for detailed stratigraphical studies and many contributions through the last 150 years have produced progressively more refined correlations of the Lower Palaeozoic succession (see review by Henningsmoen 1960).

Although the age relationships of Cambrian and Ordovician sequences are relatively well understood, Silurian rocks have hitherto been poorly dated and their facies mosaics have often been misinterpreted because of erroneous intraregional correlations. This situation has developed, ironically enough, as a result of the monumental work of Kiær (1908) which described in detail the marine Silurian succession of the Oslo Region. Kiær's impressive descriptions and advanced interpretations of regional facies patterns had such a great impact that his work was long accepted as a definitive treatise on this part of the Lower Palaeozoic sequence. Much scientific activity was consequently directed to Cambrian and Ordovician units and only isolated aspects of the palaeontology and geology of the Silurian succession have been described in the last 75 years. Key reviews of the Silurian sequence in parts or all of the region are those of Henningsmoen (1960),

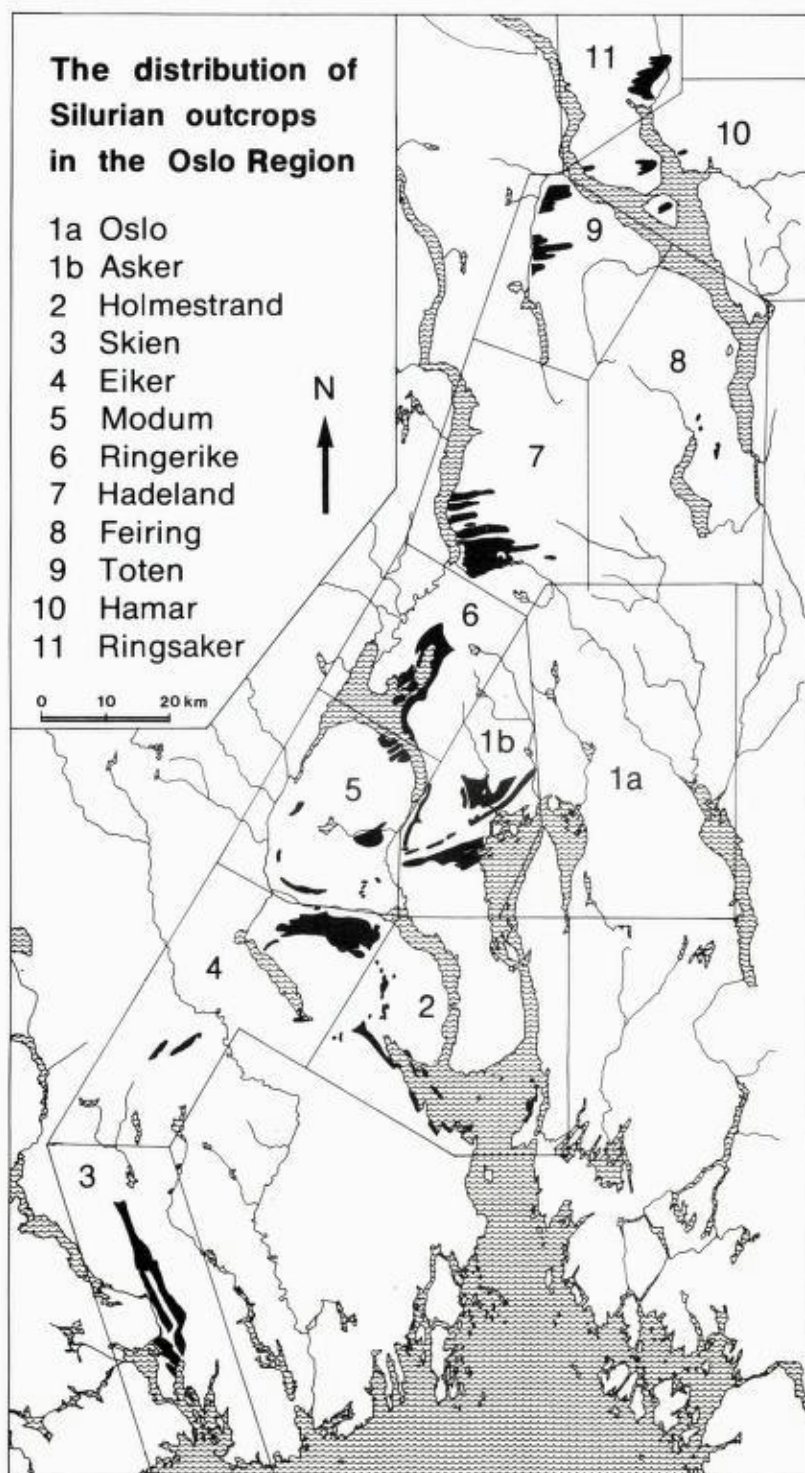


Fig. 1. Silurian outcrops of the Oslo Region showing the districts referred to herein (modified from Størmer, 1953).



Seilacher & Meischner (1964), Whitaker (1965, 1966), and Bjørlykke (1974a). These, and most other contributions until recently, generally accepted the original stratigraphical scheme of Kiær (1908), although some studies either questioned or altered some of Kiær's correlations (e.g. Henningsmoen 1954, Spjeldnæs 1957 & 1966, Hagemann 1966, Heintz 1969). A reconnaissance survey by Bassett & Rickards (1971) highlighted the diachronous nature of many of Kiær's units suggested by the above works. The need for a comprehensive revision of the existing stratigraphical scheme for Silurian rocks throughout the Oslo Region was evident.

A study of the regional stratigraphy and depositional environments of the marine Silurian succession was therefore initiated in 1976, both as a part of project 'Paleostrat' at the Paleontologisk museum, University of Oslo (grant no. D. 40.38-6 from NAVF, the Norwegian Council for Science and the Humanities) and as a Norwegian contribution to IGCP project 'Eostratigraphy'. Several research students and foreign workers have contributed to this study and biostratigraphical, palaeoecological and sedimentological surveys of most districts and stratigraphical units of the Oslo Region's marine Silurian succession are now in progress or have been completed recently. All this work makes it necessary to propose herein a lithostratigraphical framework for the entire sequence as a basis for further publications. We also present brief summaries of our biostratigraphical and sedimentological interpretations to demonstrate the chronological and palaeogeographical relationships of our major lithostratigraphical units. In order to present a complete review of present knowledge of the Silurian development of the Oslo region, we also give a brief summary of lithostratigraphical and sedimentological studies carried out in recent years on the late Silurian nonmarine red bed sequence (see especially Whitaker 1965, Turner 1974a,b,c and Turner & Whitaker 1976).

## Stratigraphy

### *Present Stratigraphical Scheme*

The numerical classification of the Lower Palaeozoic succession of the Oslo Region is based on a sequence of units first proposed by Kjerulf (1857). Kjerulf divided the marine deposits of the Oslo district into 'Etagen' 1 to 8\*; this terminology was further developed, modified and elaborated by subsequent workers. However, units were often defined using a mixture of bio- and lithostratigraphical criteria, and this is clearly seen in Kiær's (1908) proposals for the Silurian sequence.

Kiær redefined and refined Kjerulf's nomenclature and used this numerical system as his primary form for the division and correlation of the sequence in the various districts of the region. He divided marine Silurian rocks into stages 6 to 9; although he did not study the overlying red beds, he assigned them to stage 10 (Kiær *op.cit.* Profiltafel 1) which he defined as 'Devonian sandstone and

\* the German term 'Etag' is hereafter called stage, according to common usage, but with no chronostratigraphical implications.

conglomerate'. Kiær subdivided his major units using an alphabetical subnotation (e.g. 6a, 6b) and further subdivisions were based on the Greek alphabet (e.g. 6bβ) with numerical subscripts (e.g. 6bβ<sub>1</sub>). He often complemented this procedure with descriptive names for each subunit in order to highlight characteristic fossils (e.g. 6b, Ringerike: 'Die Zone mit *Rhynchonella Weaveri*'). Many such units are in reality lithologically based, and Kiær's 6b in Ringerike is a sandstone-dominated unit between two more shaly sequences.

Kiær also defined units on a mixed litho- and biostratigraphical basis ('Die Zonen 8a-b oder der Monograptusschiefer') or only on lithological character ('8d: Die Zonen mit dem Malmøkalk').

Kiær (1920) subsequently adopted a different approach to the stratigraphical subdivision of the Silurian succession in a paper describing algae from the Ringerike district. He there introduced a classification based on 'groups' (e.g. the Stricklandia and Pentamerus groups in his Lower Silurian Séries) and he also introduced some zonal subdivisions without using numerical designations. However, these zones were also based on both litho- and biostratigraphical criteria (e.g. 'the zone with the finely nodular *Rhynchonella nucula* limestone'). He promised a more comprehensive presentation of these new divisions, but other research and administrative duties prevented this work. Subsequent papers on the Silurian stratigraphy of the region followed Kiær's original numerically and alphabetically based subdivisions with their descriptive names. However, the groups proposed by Kiær (1920) were redefined as 'series' (Holtedahl 1953, Strand & Størmer 1955, Henningsmoen 1960). The resultant stratigraphical scheme for the Silurian rocks of the Oslo Region included subdivisions grouped into the Stricklandia (Stage 6), Pentamerus (7) and Lower (8) and Upper Spiriferid (9) series. Although recognizing the mixture of lithological and faunal criteria used for the definition of these units, Henningsmoen (1955) suggested that they could be assigned chronostratigraphical relevance, and this view has been followed by most workers until recently. Strand & Størmer (1955) also introduced a lithostratigraphically based terminology for the northern districts of the region, based on information which was published subsequently by Skjeseth (1963).

Stages 6 and 7 were originally correlated by Kiær (1908) with the British Lower and Upper Llandovery, Stage 8 with the Wenlock and Stage 9 with the Ludlow. Subsequent studies of vertebrate and other faunal elements (e.g. Henningsmoen 1954, Heintz 1969, Bassett & Rickards 1971, Bockelie 1973 and Turner & Turner 1974) rather suggest that the entire marine sequence should be assigned to the Llandovery and Wenlock, the transition to the overlying red beds occurring close to the Wenlock-Ludlow boundary. Continual revisions of the biostratigraphical zonation of Llandovery and Wenlock sequences elsewhere have produced a detailed framework which now enables relatively precise correlations to be made throughout the Oslo Region between different sedimentary facies. Of especial note are works on graptolites (Bjerreskov 1975, Rickards 1976), brachiopod phyletic lineages (Williams 1951, Ziegler 1966, Rubel 1977, Johnson 1979 and Mørk 1981), conodonts (Aldridge 1975) and other microfossils (Aldridge et al. 1979). Important biostratigraphical syntheses have also been presented by Ziegler, Cocks



& McKerrow (1968), Cocks (1971) and Cocks, Holland, Rickards & Strachan (1971). Comparisons of our data with these works have shown that most of the (both major and minor) currently accepted stage units are diachronous when traced through the Oslo Region.

We have considered several possible revisions of the present scheme: in view of the long-established use of the numerical stage system we could, for example, retain this scheme, either by redefinition and adjustment of unit boundaries or by recognition and tabulation of their informal and diachronous nature. However, we consider that such a procedure would increase existing confusion; furthermore, this numerical notation masks the facies variations observed throughout the region. We believe that an entirely new approach to the stratigraphical problems of the Oslo Region's Silurian sequence is warranted and therefore propose here formal and mappable lithostratigraphical units throughout the region and designate stratotypes for each unit. These units are of formational rank and are intended to *replace* the previously accepted four 'series' of the Silurian succession. We foresee a transitional period, especially prior to forthcoming detailed descriptions of individual units, where Kiær's minor subdivisions (e.g. 6b $\beta$ ) will still have to be used within our formational framework: we propose that these be used only as local and informal descriptive terms with no intraregional correlative significance.

The maps of Kiær (1908) provide an adequate basis for tracing our formational boundaries in most districts. Although we reorganize Kiær's units into our new formations in each area, our *formational* boundaries always follow (within any reasonable mappable scale) unit boundaries displayed on Kiær's maps. An exception is the northern districts where Silurian exposures were only briefly described and not mapped by Kiær. In these districts our own detailed studies generally support the proposals and summary map of Skjeseth (1963).

#### *Geographical nomenclature*

Størmer (1953) divided the Oslo Region into eleven districts in his description of Ordovician stratigraphy. Silurian outcrops occur in all of these districts but are best preserved in eight of them. Størmer's district 1 (Oslo-Asker) comprises the municipalities of Oslo, Bærum and Asker. We distinguish herein between Silurian exposures in Oslo (1a) and those in Bærum and Asker (1b-grouped under the name Asker) as shown in Fig. 1. For ease of reference we call Størmer's district 3 the Skien district and his district 10 the Hamar district. We use the terms central (Oslo and Asker), western (Holmestrand, Modum, Eiker and Ringerike), southern (Skien) and northern (Hadeland, Toten, Hamar and Ringsaker) districts in a purely geographical sense. Although Kiær (1908) discussed palaeogeographical relationships in terms of 'eastern', 'western' and 'mixed' facies developments, our work indicates the inadequacy of such a simple palaeogeographical zonation.

Places names used for our new formations are taken from those printed on the 1:50,000 maps of the *Norwegian Ordinance Survey (NGO)*, or on local economic or tourist maps where the former do not display the relevant name. Grid references are also taken from NGO maps using the M711 grid of the 1:50,000 series. The most important localities referred to in the text for the definition and description of our units are shown in Figs. 2a-3b.



There is at present some disagreement as to the naming of Norwegian lithostratigraphical units. Some workers maintain that the definite article endings of many place names should be retained in English language manuscripts as they appear on official maps (e.g. The Steinsfjorden Formation, as used herein). The alternative view (The Steinsfjord Formation) follows a ruling of the Norwegian Language Council in 1981. Nomenclature used in this paper has been accepted by NGU pending rulings from the newly established Norwegian Stratigraphical Committee. Future usage of our formational units must follow that commission's recommendations on this question.

#### *New lithostratigraphical units*

We here propose and describe eight new formations in the marine Silurian sequence of the Oslo Region; we also redefine and describe three units previously proposed by Skjeseth (1963) in the northern districts of the region. To complement the lithostratigraphical scheme previously established for the overlying red beds of the Ringerike Group (see p. 42) we also propose the establishment of the Bærum and Hole Groups to embrace the entire complex of marine facies described below. The fence diagram presented in Fig. 4 shows each formation's extent and thickness variations between major exposure areas through the region. We introduce member subdivisions in the type areas of some of the formations, but stress that the lack of formal proposals of members in many of our formational units reflects present state of research rather than lithological variation. Future refinements will result in the definition of additional members to characterise the total facies mosaic present.

Summaries of each formation's depositional environments are based on palaeoecological and sedimentological analyses which will be presented in later papers. Our palaeoecological work is best summarized using the 'Benthic Assemblage' concept of Boucot (1975). Individual palaeocommunities are assigned to one of the six assemblages proposed by Boucot, ranging from intertidal (Benthic Assemblage 1) through to deep water (Benthic Assemblage 6) faunas.

The age of each formation is briefly discussed using key faunal elements. Our correlation chart (Fig. 5) reflects present biostratigraphical knowledge in the major districts of the region and is conservative in the respect that we only depict diachronous formational relationships where we have concrete biostratigraphical evidence at this stage of our work. The chart does not attempt to infer the entire spectrum of formational diachroneity which we believe to exist within and between the districts of the region. Such refinements must await the results of more detailed biostratigraphical studies within each formational unit and district. In Fig. 5 we also show the relationship between Kiær's numerical units and our formational scheme in each district. We have found it natural to correlate our units with the standard stratigraphical scheme for the British Silurian sequence (Fig. 5, see Cocks, Holland, Rickards & Strachan 1971). Stages for the Wenlock and Ludlow Series which we use here were first proposed by Bassett, Cocks, Holland, Rickards & Warren (1975); these have now been formally accepted as international standards (Martinsson, Bassett & Holland 1981). The status of the Llandovery Series and

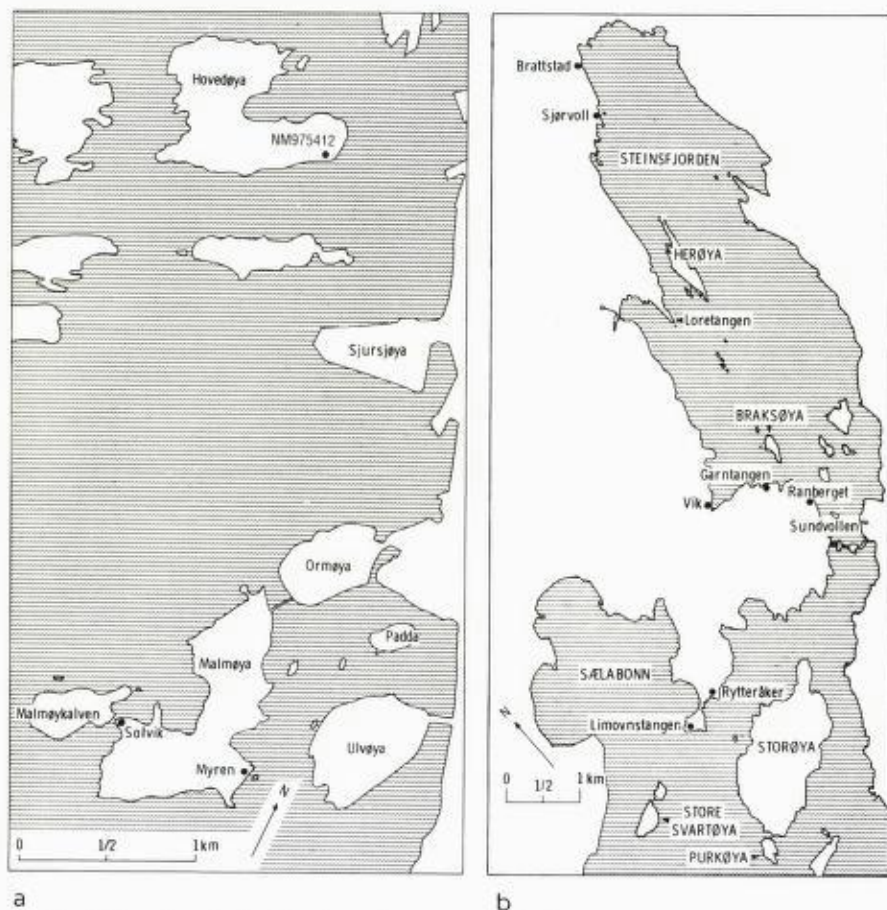


Fig. 2a, b. Maps showing key locations of exposures in the Oslo and Ringerike districts.

its stages has not yet been formalised internationally but we find it useful to correlate our units with the local British divisions of the Llandovery Series proposed by Cocks, Toghil & Ziegler (1970).

#### THE BÆRUM GROUP

The group's name is based on the municipality of Bærum. The group comprises the mixed clastic and carbonate marine sequences found throughout the Oslo Region which we assign to the Solvik, Sælabonn, Rytteråker, Vik, Ek, Bruflat and Skinnerbukta Formations; all of these units are defined and described below.

The base of the Bærum Group throughout the region is everywhere coincident with the lowermost occurrence of rocks earlier assigned to stage 6. In the Oslo, Asker and Holmestrand districts this corresponds to the base of our Solvik Formation; the boundary stratotype for the base of the Bærum Group is therefore that defined for the Solvik Group on Hovedøya in the Oslo district. In other districts the group's base corresponds to the base of our Sælabonn Formation. The



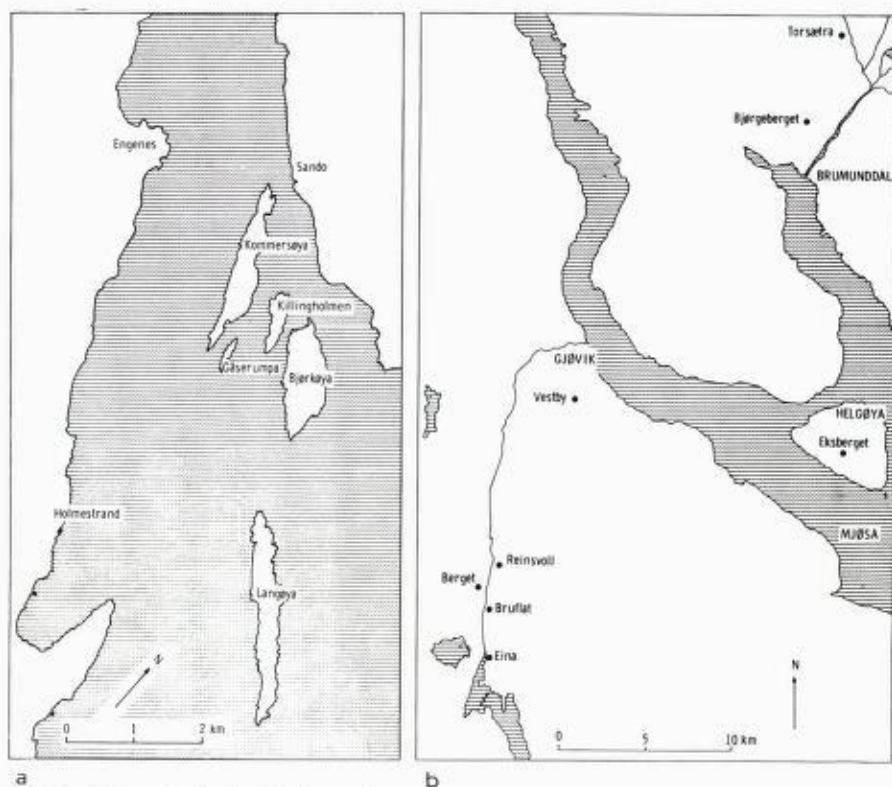


Fig. 3a, b. Maps showing key locations of exposures in the exposures in the Holmestrand and northern districts.

base in these latter districts is clearly disconformable; this is most easily seen in the northernmost districts where basal units infill and overlie karstic surfaces in the Caradoc (to early Ashgill?) Mjøsa Limestone.

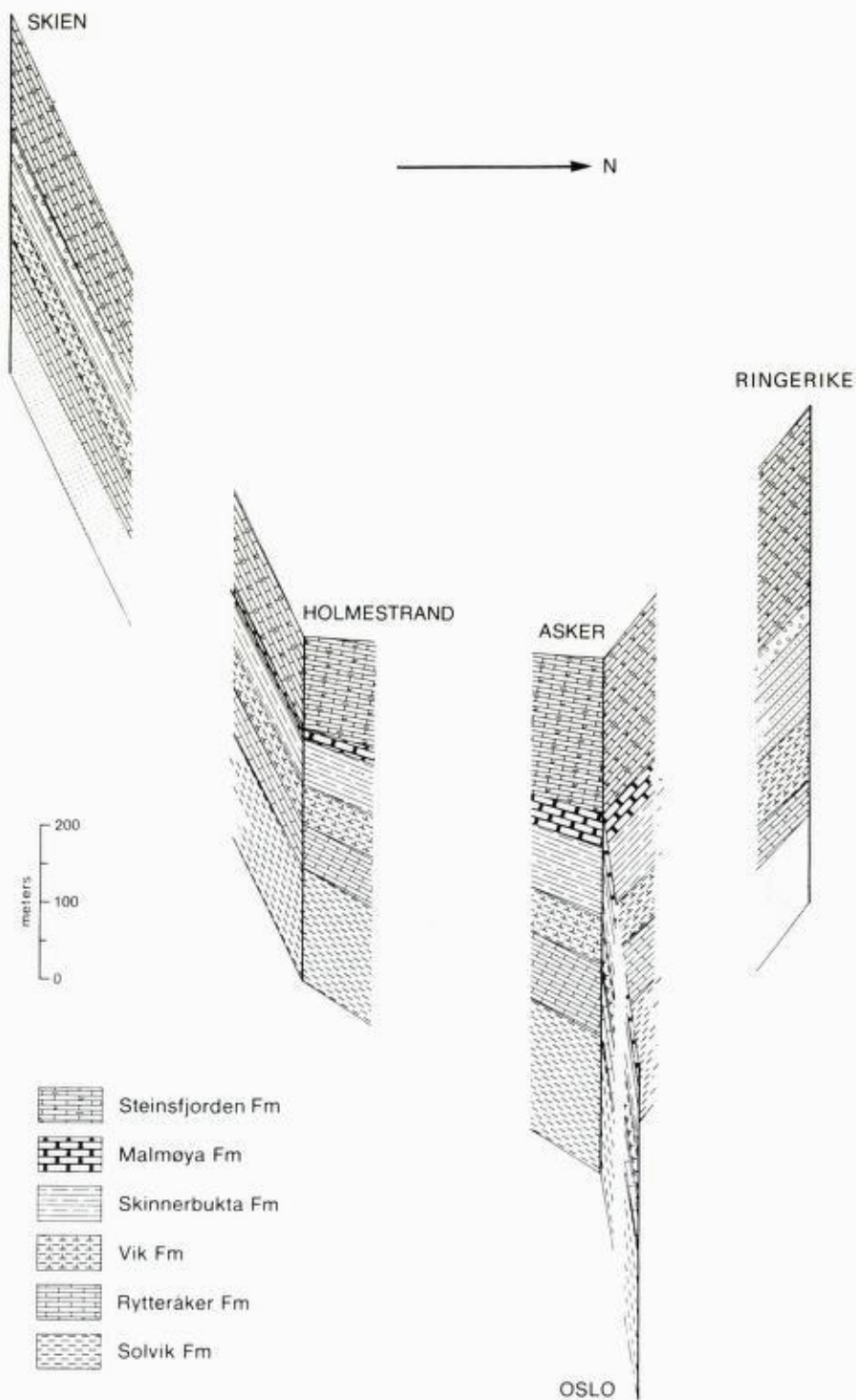
The composite thickness of the group is approx. 400 m in the Bærum district (Fig. 4). The group is thickest (600–650 m) in the northern districts of the Oslo Region but its top has not yet been definitely identified there. In all other districts the top of the group coincides with the boundary between 8b and 8c as defined by Kiær (1908). As discussed below (p. 32), under our description of the overlying Hole Group, this junction is sharply defined in the Ringerike and Skien districts, but is gradational in Oslo and Asker.

The group appears to range in age from the early Llandovery to the mid-Sheinwoodian (*riccartonensis* or low *rigidus* Biozone). The group's top is diachronous and youngs from the Ringerike and Skien districts towards Asker and Oslo.

#### THE SOLVIK FORMATION

##### Definition

The name of the formation is taken from Solvik (NM981378), a bay on the west coast of Malmøya, 5 km south of Oslo city centre (Fig. 2a). The formation corresponds essentially to stage 6 of Kiær (1908) in the Oslo, Asker and





Holmestrand districts. The Solvik Formation is characterised by dominant shales with very thin to thin siltstone and limestone intercalations (all quantitative terms which describe bedding and bed thicknesses used herein follow the scheme of Ingram 1954). Lithological variation (Fig. 6) suggests a twofold division into the Myren and Padda Members in the formation's type area on the Malmøya group of islands in the Oslo district. A complete type section cannot be designated and the basal stratotype of the Solvik Formation is defined on the south coast of Hovedøya (NM975412). Reference sections through the lower and upper parts of the formation are well exposed in two faulted but relatively continuous profiles

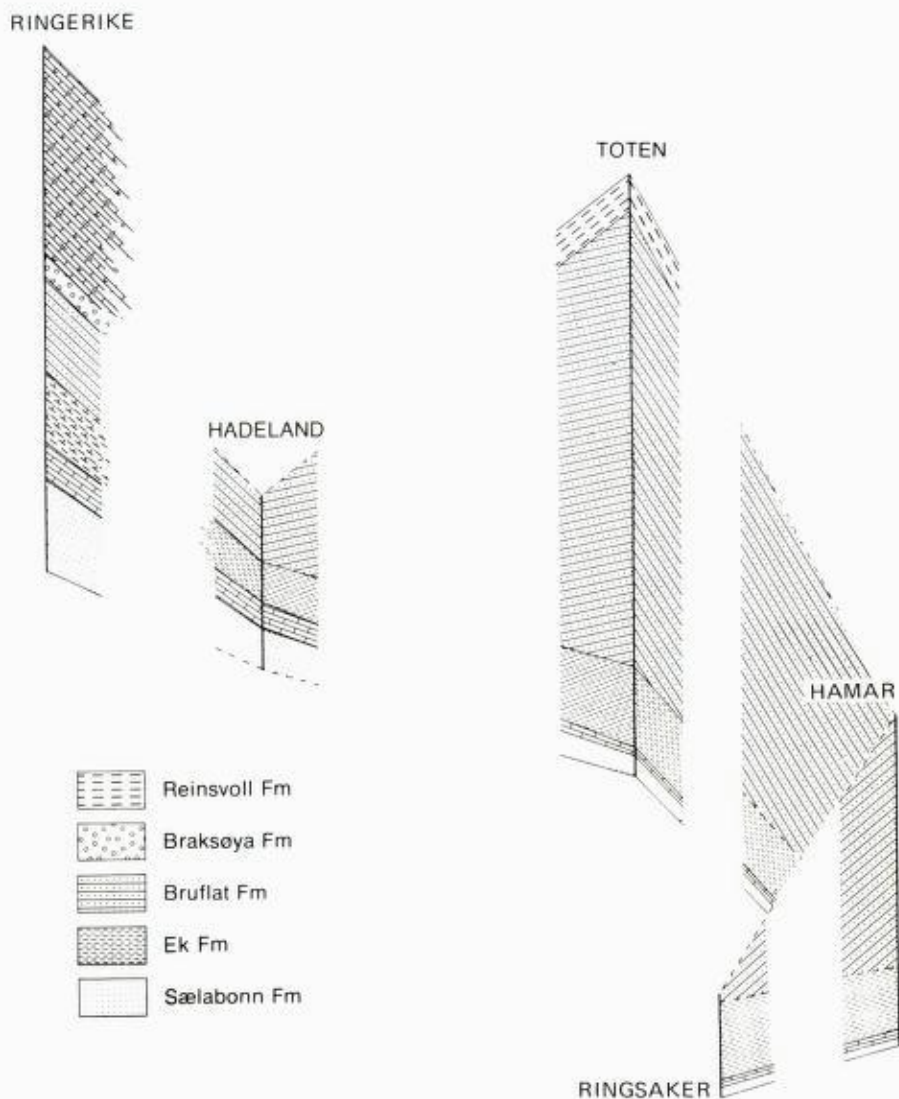


Fig. 4. A fence diagram displaying thickness variations of the marine Silurian succession throughout the Oslo region.

ORD	SILURIAN									
	LUDLOW		WENLOCK					LLANDOVERY		
SERIES and other divisions	STAGES and other divisions	BIOZONES	SKIEN	HOLMESTRAND	OSLO	ASKER	RINGERIKE	HADELAND	TOTEN	HAMAR
GORSTIAN	HOMERIAN	skivei	HOLMESTRAND FM	HOLMESTRAND FM		SINDVOLLEN FM	SINDVOLLEN FM			
		landfoll	?	?		?	?			
		masse	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
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		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		landfoll	?	?		?	?			
		SHEINWOODIAN	TELKYCHAN	rykkis						
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Fig. 5. A tentative correlation of the formational units proposed and described herein; comparisons with the previous numerically-based units are presented for each district.



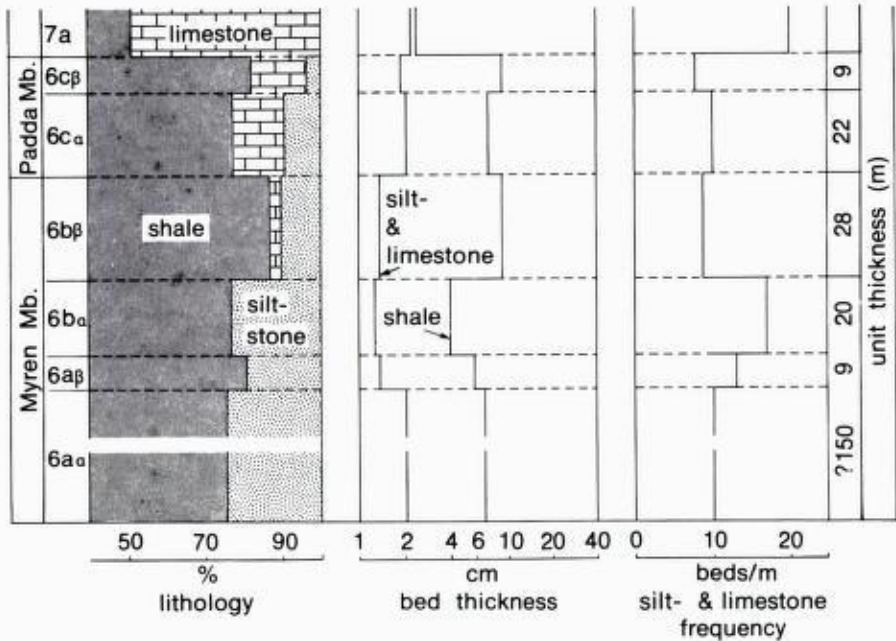


Fig. 6. A schematic log through the Solvik Formation on Malmøya (Oslo district) showing lithological variation and member boundaries.

on the east (NM988380) and west (NM981377) coasts of Malmøya, respectively; the top of the formation is seen in the latter section at Solvik. The formation is approximately 190 m thick in its type area, but faulting makes an exact determination difficult.

The lower boundary is defined by the sharp contact between underlying calcareous sandstones of the Langøyene Sandstone Formation (Brenchley & Newall 1975, equivalent to 5b of Kiær 1897, 1902) and the dark grey silty shales with minor siltstones of the Solvik Formation. A 60-cm-thick nodular limestone occurs locally as a basal development of the overlying unit (Fig. 7a). The base of the lowermost Myren Member is, by definition, coincident with the base of the Solvik Formation. The Myren Member is approximately 160 m thick and includes 6a and 6b of Kiær (1908) in the type area of the Solvik Formation. The name of the member is derived from a locality on the east coast of Malmøya (NM988380) which shows the most complete development of the lower parts of this unit. Detailed correlations of several partial sections both here and on the west coast of the island suggest a *minimum* thickness of 120 m for Kiær's 6a (in contrast to his suggested thickness of 50 to 60 m) and a total minimum thickness of approximately 160 m for the whole Myren Member. The member consists of shales with minor laminae and very thin interbeds of siltstone. Siltstones are most common in 6aα and 6bβ where they comprise 30% of the succession (Fig. 6). Body fossils are generally rare in the lower parts of the member, but *in situ* brachiopod associations dominated by *Leangella scissa* and *Protatrypa malmoeensis* characterize 6bα and 6bβ, respectively (Worsley 1971).

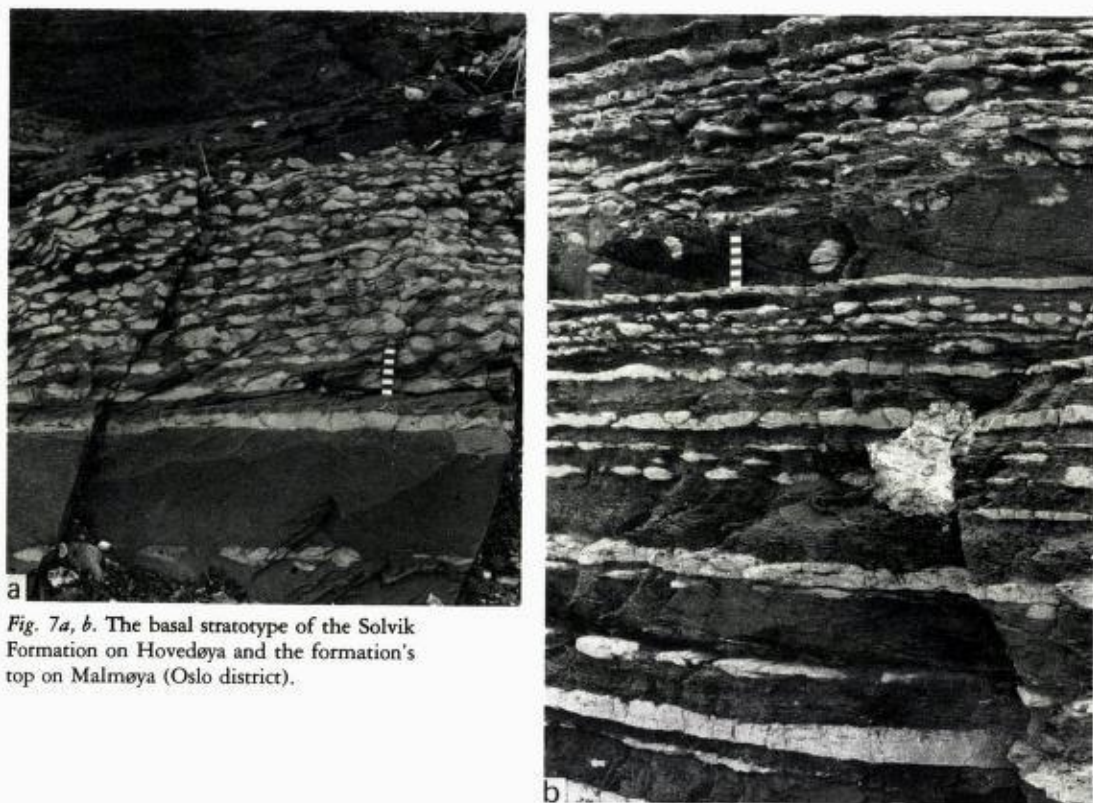


Fig. 7a, b. The basal stratotype of the Solvik Formation on Hovedøya and the formation's top on Malmøya (Oslo district).

The Padda Member corresponds in general to 6c of Kiær (1908) in the Malmøya area. Its name is derived from a small island northeast of Malmøya (NM992390) where the upper parts of the unit are well exposed, but its base is defined in a complete 30 m-thick type section on the west coast of Malmøya (NM981377). Although shales also dominate this member, thin interbeds and lenses of both calcareous siltstone and limestone occur together with calcareous nodules. The base of the Padda Member is defined at the sharp introduction of these interbeds above the highly shaly upper parts of the underlying units. Characteristic faunal elements are both *in situ* and reworked populations of *Stricklandia lens*; other brachiopods, bryozans, corals and stromatoporoids are also common.

The dominantly shaly Padda Member grades rapidly into the thinly interbedded limestones and shales (in approximately equal proportions) of the overlying Rytteråker Formation (Fig. 7b); the junction is taken at the first appearance of finely nodular limestone horizons assigned to the Rytteråker Formation. Bedding plane exposures show that many of these nodules are carbonate infills of endichnial burrows in the shales.

#### *Other occurrences*

The Solvik Formation is also seen in many exposures in the Asker and Holmestrand districts and its total thickness appears to be relatively constant.



The siltstones of the Myren Member thin and decrease in abundance westwards from the type area to Asker where beds which can be assigned to this unit interfinger with a more calcareous shale development throughout 6a and 6b of Kiær (1908). Marls and limestones in Kiær's 6c $\alpha$  at Spirodden (NM840338) contain both *Stricklandia lens*, abundant tabulate corals and stromatoporoids; these beds should be assigned to a new, as yet formally undefined, unit with member status (Baarli 1981). The occurrence of benthic algae in this unit at Spirodden was commented upon by Lauritzen & Worsley (1974) and Mørk & Worsley (1980). Kiær (1908) defined 6c $\beta$  in Asker as a 10 m-thick shaly sequence which he assumed to be directly overlain by the limestones of stage 7. However, a series of new road cuttings not available to Kiær show a 60 m thick sequence of shales and siltstones which lie between Kiær's 6c $\alpha$  and the overlying Rytteråker Formation. A detailed study of the entire Solvik Formation in the Asker district now in progress will result in the definition of several new members in this area (Baarli 1981).

Only the uppermost 25 m of stage 6 are exposed in the Holmestrand district on the island of Bjørkøya (NL764986) and these were re-examined by Mørk (1977). Both this exposure and cores from test boreholes through the entire lower Silurian succession in the subsurface of the neighbouring island of Langøya demonstrate a facies development clearly assignable to the Solvik Formation. Small, highly metamorphosed, exposures through parts of the formation are also seen on the island of Tofteholmen and on the nearby coast of Hurumlandet (Brøgger 1931).

#### *Depositional environments*

The shale-dominated sequence of the Solvik Formation reflects the rapid early Silurian transgression of the Oslo, Asker and Holmestrand districts and the establishment of sublittoral depositional environments in these areas. Siltstones of the Myren Member in the type area were storm generated and deposited in quiet muddy environments below normal wave base. Exposures through equivalent lower parts of the Solvik Formation in the Asker district show notably fewer siltstone intercalations than the type area and calcareous interbeds are more common. The transition to the shale and limestone facies of the Padda Member is abrupt in the type area. Both sedimentary structures and fauna indicate the establishment of shallower environments with intermittent periods of both current and wave reworking of the sea floor. Storm-generated siltstones seen in 6c $\beta$  in Asker and Holmestrand are thought to be time equivalents of the Padda Member. In contrast to the depositional regime of the lower parts of the formation, the Asker and Holmestrand districts were now in a more proximal situation than the type area. Faunal associations seen throughout the Solvik Formation in all three districts correspond generally to Benthic Assemblages 5 and 4 of Boucot (1975).

#### *Age*

Graptolites and abundant brachiopods form the basis for our dating (Fig. 5). Both the basal nodular horizon and immediately overlying shales contain sparse and non-diagnostic shelly faunas, but we have found *Climacograptus transgrediens*

11 m above the base of the formation on Ormøya (Fig. 2a). This graptolite ranges from the ?upper *persculptus* to lower *acuminatus* Biozones elsewhere and the base of the Solvik Formation therefore approximates to the Ordovician/Silurian boundary as taken at the base of the *persculptus* Biozone. Occurrences of subspecies of *Stricklandia lens* in the Asker district indicate that the top of the formation there approximates to the Idwian/Fronian transition (Baarli 1981).

#### THE SÆLABONN FORMATION

##### Definition

The Sælabonn Formation is best demonstrated in the Ringerike district (Fig. 2b) in a series of small coastal exposures around Sælabonn, a small bay in the northern part of Tyrifjorden. This formation corresponds in general to stage 6 of Kiær (1908) in the Ringerike, Skien, Hadeland, Toten, Hamar and Ringsaker districts. Our proposal incorporates the Helgøya Quartzite of Skjeseth (1963), reduced to member rank, in the three latter districts. The Sælabonn Formation is approximately 110 m thick in its type area, where it is characterised by varying proportions of sandstone, siltstone and shale. Sandstones dominate the middle part of the unit and lithological variation was clearly the basis for Kiær's (1908) tripartite subdivision into 6a, b & c. Formal proposals for subdivision into three members approximately equivalent to Kiær's units will result from work in progress in the Ringerike area (Thomsen 1981).

The entire Sælabonn Formation is not exposed in any one section in the type area; the basal stratotype for the formation is defined on Store Svartøya (NM678585) where the lower 11 m of the formation are also exposed (Fig. 8). A reference section through the middle of the unit is exposed on the east coast of Sælabonn (NM696606) and its upper parts are well displayed in the basal

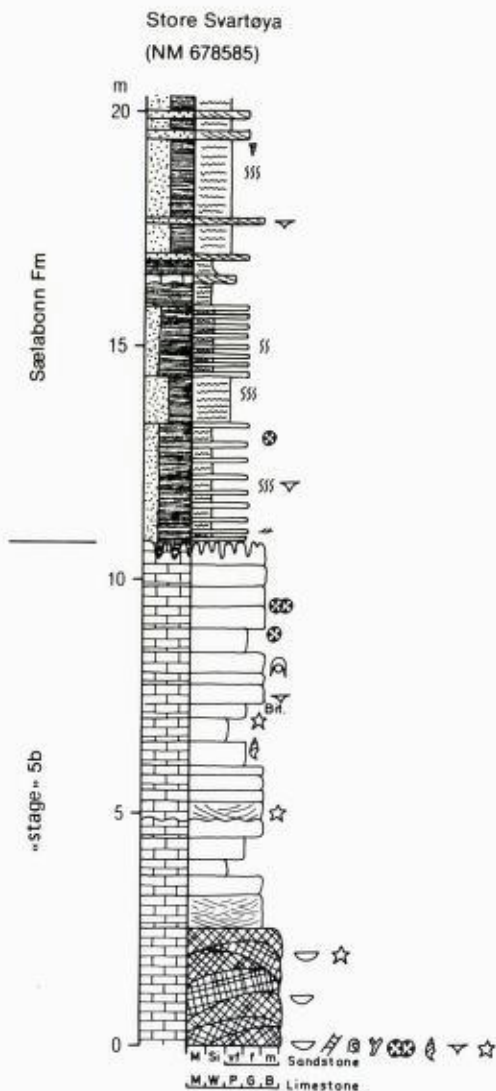


Fig. 8. A schematic section through the basal boundary stratotype of the Sælabonn Formation, Store Svartøya, Ringerike. For legend, see Fig. 9.



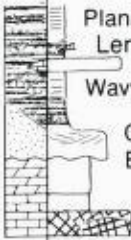
LITHOLOGY		SEDIMENTARY STRUCTURES & FOSSILS	
Shale/Siltstone		Planar lamination	
Carbonate lenses		Lenticular bedding	
Carbonate nodules		Wavy bedding	
Sandstone		Cross bedding	
Dolomite		Erosive contact	
Dolomitic limestone		Bioherm	
Limestone			
Evaporite xals.	Gutter marks	Graptolites	
Quartz pebbles	Breccia	Tabulate corals	
Phosphatic pebbles	Ripple lamination	Rugose corals	
Pisolites	Red colouration	Ostracodes	
Calcareous	Bioturbation, vertical	Trilobites	
Ooides	Bioturbation, horizontal	Brachiopods	
Peloids	Chondrites	Gastropods	
Bentonite	Algal mats	Bivalves	
Bituminous shale	Algae	Cephalopods	
Ripple marks	Stromatoporoids	Tentaculitids	
Wave ripples	Bryozoans	Echinoderms	
Desiccation marks			

Fig. 9. Symbols used in the stratigraphic sections presented herein.

stratotype for the overlying Rytteråker Formation at Limovnstangen (p. 20). The base of the Sælabonn Formation is defined on Store Svartøya where crinoidal biosparites of 5b show a karstic upper surface and are overlain by silty shales with minor thin limestones and siltstones (Fig. 8). This 20 m-thick lower development of the formation coarsens up into medium to thickly bedded sandstones with minor siltstones and shales (6b of Kiær 1908, 50 m thick). These further fine up into thin to medium interbeds of siltstone and shale with increasing limestone intercalations towards the junction with the overlying Rytteråker Formation.

#### Other occurrences

Exposures elsewhere in the Ringerike and Skien districts indicate a similar tripartite development to that of the type area. The base is exposed at several localities in the southern parts of the Skien district (e.g. Skrapekleiv NL381523) where silty shales of the formation overlie a thin (0.5–1 m) very coarse sandstone which has an erosive contact with small biohermal structures and biosparites of upper 5b (Rønning 1979). Exposures north of Skien at Jønnevall in Gjerpendalen (NL321708) show an erosive contact with 5b, but the base of the formation there consists of sandstones which grade up into the silty shales assigned to 6a by Kiær (1908). Metamorphosed outcrops assigned to this formation are also seen in the Eiker district.

In Hadeland, Owen (1978) defined the Skøyen Sandstone Formation as a

sandstone and shale unit with a gradational base (to his Kalvsjø Formation, 5a of earlier workers) and top (to our Rytteråker Formation). This unit is 120 m thick and correlates with Stages 5b and 6 of earlier workers. Because of poor exposure Kiær (1908) and Major (1946) were unable to define the boundary between 5b and 6 in Hadeland, and Owen's approach is eminently justifiable as present exposures do not display the precise contact between these units. However, sections examined by us suggest an important change in sedimentological development in the middle of Owen's Skøyen Sandstone and the upper 60 m of this unit show a tripartite development similar to that of the Sælabonn Formation in the adjacent Ringesrike district. Pending further detailed analysis we suggest as an interim measure that Owen's Skøyen Sandstone be regarded as an informal unit, the upper part of which is clearly correlative with the Sælabonn Formation at Ringesrike.

Further north, in the Toten, Hamar and Ringsaker districts, the Sælabonn Formation is represented *in toto* by the thin Helgøya Quartzite Member which rests on eroded surfaces of the Mjøsa Limestone. Sandstone infills of the karstic topography marking the top of this limestone are seen at several localities in Toten. The Helgøya Quartzite's original type section at Eksberget (PN087355) on Helgøya (Skjeseth 1963) is poorly exposed and a hypostratotype is proposed in a disused quarry at Vestby near Gjøvik (NN921379). The member is 9 m thick there (Fig. 10). The lower 5 m consist of medium to thickly bedded sandstones

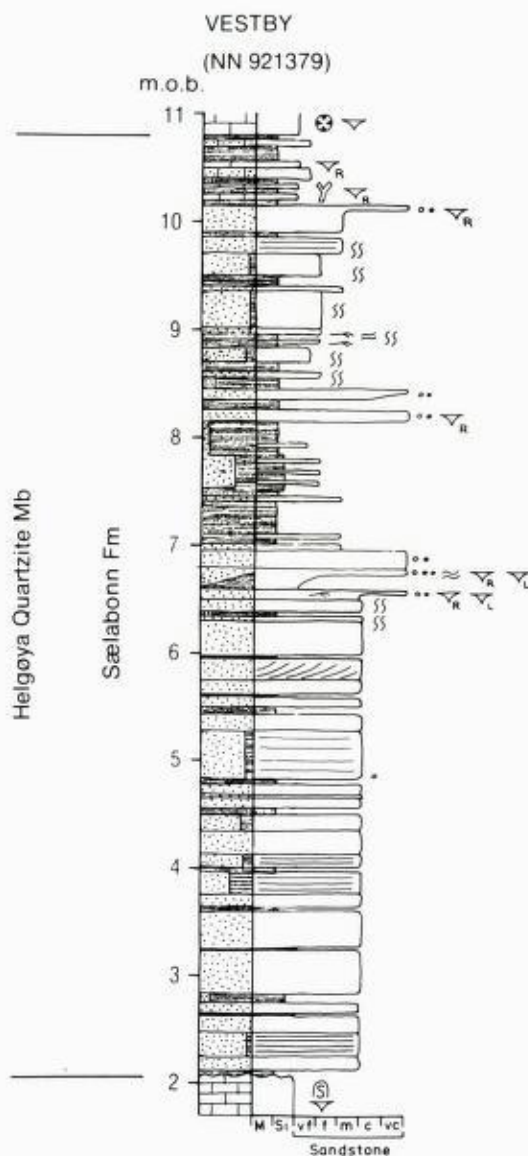


Fig. 10. Hypostratotype through the Helgøya Quartzite Member of Sælabonn Formation at Vestby (Toten district).

with thin shaly partings; these grade up into thinly interbedded sandstones and shales, with limestone intercalations uppermost marking the transition into the overlying Rytteråker Formation. Other exposures further north in Brumumddalen (PN076586) and on Helgøya indicate an essentially similar, but thicker development (15 to 30 m).

#### *Depositional environments*

Basal sandstones and shales in the Ringerike and Skien districts reflect the early Silurian transgression of these areas. Sandstones in the middle of the formation represent a subsequent progradational episode and deposition in coastal environments. The upper parts of the unit in both areas suggest renewed transgression, with a gradual transition from clastic to carbonate-dominated sedimentation. Exposures in Hadeland suggest a similar depositional history. The thin sandstones of the Helgøya Quartzite Member in the Toten, Hamar and Ringsaker districts reflect the transgression of an area which had been emergent throughout the late Ordovician. This development appears to correlate with the upper part of the Sælabonn Formation in its type area. In all districts the transition to the overlying Rytteråker Formation suggests a complex and irregularly diachronous cut-off of coarse clastic supply as a result of continuous transgression. The faunas of the formation are reminiscent of Benthic Assemblages 1 to 3 of Boucot (1975).

#### *Age*

A general Rhuddanian to Idwian age is suggested in the type area by brachiopods (Thomsen 1981) and conodonts (R.J. Aldridge, pers. comm. 1981). The occurrence of *Borealis borealis* around the junction with the overlying Rytteråker Formation indicates a middle Idwian age for the uppermost beds of the Sælabonn Formation in its type area (Mørk 1981). However, the base of the formation has not yet been definitively dated.

### THE RYTTERÅKER FORMATION

#### *Definition*

The name of this formation is derived from Rytteråker Farm (NM699594) on the west coast of Tyrifjorden in the Ringerike district. The formation's character is well demonstrated in this type area, especially in coastal exposures around Limovnstangen, a peninsula 1 km south of Rytteråker Farm.

The Rytteråker Formation is essentially equivalent to 7a and 7b of Kiær (1908) throughout the Oslo Region. Our formational proposal replaces the term 'Pentamerus Limestone' which has been widely used subsequent to Kiær's work. Whereas many workers (e.g. Henningsmoen 1960) have applied this term in a sense which generally conforms to our Rytteråker Formation, Kiær applied it only to those restricted parts of our Rytteråker and overlying Vik Formations which contain abundant pentamerids. This varying usage prompts our rejection of the name 'Pentamerus Limestone' in spite of its priority. Pending the results of our work, Owen (1978) and Høy & Bjørlykke (1980) used the informal terms 'Engen limestone' and 'Limovnstangen formation' in the Hadeland and Hamar/



Ringsaker districts respectively. Sequences assigned to those units are here grouped within the Rytteråker Formation.

The limestone dominated sequence of the Rytteråker Formation is approximately 50 m thick in the type area; Kiær's tripartite division (7a, 7b $\alpha$ , 7b $\beta$ ) was based both on faunal composition and on varying proportions of limestone and calcareous shale within the unit. A single complete type section is not seen, but the basal stratotype is defined on the northern tip of Limovnstangen (NM691591) and reference sections through the middle and upper parts of the formation are exposed along both coasts of this peninsula. The top is seen under the basal stratotype of the overlying Vik Formation on the limb of a small syncline whose axis defines the northern coast of Limovnstangen (NM695596).

The basal stratotype of the Rytteråker Formation shows a gradational development: interbedded thin to medium siltstones and shales of the Sælabonn Formation show intercalations of limestone beds upwards. The base of the Rytteråker Formation is defined at the quantitative dominance of limestone over siltstone (Fig. 11). Our formational base is therefore 5.5 m higher in the section than the junction between 6c and 7a defined by Kiær (1908) and corresponds to Kiær's bed XIV (Kiær 1908: Profiltafel II). Limestones with pentamerids become increasingly abundant through the basal 10 m of the formation and grade upwards into thickly bedded biosparites in the middle 25 m of the unit (7b $\alpha$  of Kiær 1908). These beds are composed of finely comminuted pentamerid and crinoid debris; small bioherms are found at the top of this sequence throughout the Ringerike district (Hanken, Olausen & Worsley 1979). The uppermost 17 m of the formation (7b $\beta$  of Kiær 1908) consist of planar limestone beds and well-bedded calcareous nodules with

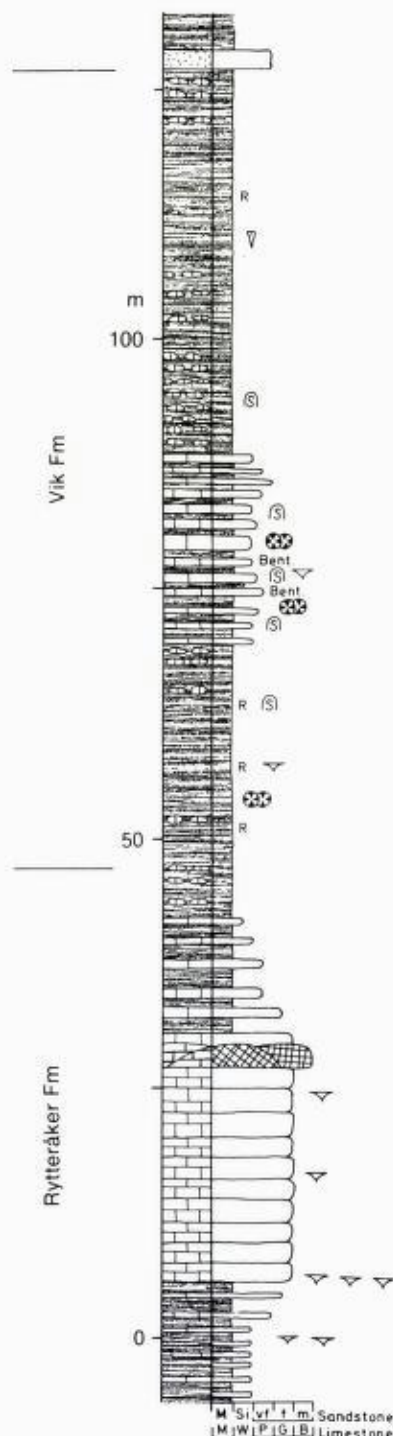


Fig. 11. A general section through the composite stratotypes of the Rytteråker and Vik formations in Ringerike.

interbedded shales; the shale content increases towards the contact with the overlying Vik Formation.

#### *Other occurrences*

Although the character and content of carbonates in the Rytteråker Formation vary from district to district, the unit can be traced throughout the Oslo Region. The formation thins markedly northwards from the type area (Fig. 4); it thickens southeastwards and southwards to 65 m in Oslo/Asker and 80 m in Skien.

Exposures in Hadeland show a gradational contact with the Sælabonn Formation, interbedded limestones and shales passing up into a thickly-bedded pentamerid biosparite unit. This is erosively overlain by interbedded limestones and shales with both bioclastic and general carbonate content decreasing upwards to the contact with the Ek Formation (see p. 25). The Rytteråker Formation thins progressively northwards through the Toten, Hamar and Ringsaker districts. Northernmost exposures at Torsæter Bridge in Brumunddalen (PN076586) show a 15 m-thick sequence of interbedded thin limestone beds, nodular horizons and shales.

Sequences assigned to the Rytteråker Formation share many common features in Asker, Oslo, Holmestrand and Skien. The base is gradational in all cases, either from the more sandy Sælabonn or more shaly Solvik Formations. Thin, fine-grained limestones and shales occur in equal proportions in the lower parts of the unit in all these areas. Limestone beds thicken and coarsen upwards and shale content decreases into the middle and upper parts of the unit. The transition to the overlying Vik Formation is often rapid, marked by the renewed development of interbedded limestones and shales.

#### *Depositional environments*

The Rytteråker Formation represents the establishment of relatively shallow carbonate depositional environments throughout the Oslo Region at a time when earlier source areas for coarse clastic material were submerged. The pentamerid biosparites of Hadeland and Ringerike represent high-energy shoals, with crests which may have been intermittently emergent (e.g. in Hadeland). Biohermal development on the upper surfaces of the shoals in Ringerike was probably initiated subsequent to a relative rise in sea-level which resulted in stabilization of the shoals' highly mobile substrates. Other districts show more distal marine carbonate sequences. However, in all these other districts a general shallowing-upwards trend throughout the lower and middle parts of the formation is indicated by an increase of better sorted and thick bedded biosparites at the expense of shale and fine-grained limestones. Abundant pentamerids, corals and stromatoporoids together with benthic algae in all districts indicate that the formation was not deposited in water of any great depth. The fauna is typical of Benthic Assemblage 3 of Boucot (1975).

#### *Age*

Occurrences of the pentamerids *Borealis* and *Pentamerus* suggest a somewhat



diachronous base for the Rytteråker Formation, ranging from the middle to late Idwian in Ringerike and Hadeland to the late Idwian or early Fronian in central and southern districts (Mørk 1981). The transition to the Vik and Ek Formations is dated by the graptolite and brachiopod faunas of these overlying units (pp. 25 and 27).

#### THE VIK FORMATION

##### *Definition*

The development of this formation is best demonstrated in widespread but partial exposures throughout the Ringerike district. Easily accessible sections are seen in roadside cuttings immediately east of Vik (NM715609), prompting our use of this formational name. The formation generally corresponds to stage 7c of Kiær (1908) in the Ringerike, Oslo, Holmestrand and Skien districts and to Kiær's 7b $\beta$  and 7c in Asker. The Vik Formation is approximately 80 m thick in its type area and shows a tripartite development with varying proportions of both red\* and greenish grey shales, marls and limestones. This tripartite development was the basis of Kiær's (1908) subdivision into 7c $\alpha$ , 7c $\beta$  and 7c $\gamma$ ; the members proposed by Aarhus (1978) generally correspond to Kiær's subdivisions. We here modify the provisional nomenclature of Aarhus and propose the establishment of the Storøysundet, Garntangen and Abborvika Members (in ascending order) in the Vik Formation in its type area. A single type section for the formation cannot be designated but a basal stratotype is defined in a coastal section northwest of Rytteråker Farm (NM695596). This section shows the gradation from thinly interbedded limestones and greenish grey shales of the underlying Rytteråker Formation into predominantly red shales. The base of the Vik Formation is defined at the sharp transition from limestone to shale dominance 4 m below the lowermost occurrence of red shales.

The base of the Storøysundet Member is, by definition, coincident with the base of the Vik Formation. The basal stratotype displays 12.5 m of the member, but a total thickness of approximately 20 m in the type area of the Vik Formation is suggested by other coastal exposures around Storøysundet (NM69558). The red shales of the Storøysundet Member contain minor bioclastic limestone lenses, small calcareous nodules and occasional greenish grey shale interbeds. A diverse but sparse fauna includes crinoids, brachiopods, stromatoporoids and tabulate corals.

The middle 13 m of the Garntangen Member are exposed in the E68 road section near Garntangen (NM720609) on the coast of Steinsfjorden. The member is also well exposed on the west coast of Storøya (NM690576 to NM694582) where its basal stratotype is defined. Its base is taken at the marked increase in limestone interbeds 3 m above the uppermost red shales of the underlying unit. The Garntangen Member is approximately 25 m thick and consists of thinly bedded limestones and calcareous nodules with minor greenish grey marls. Fresh

\* Red units, referred to here and subsequently, show colours varying from pale to dark reddish brown, 10R5/4 to 10R3/4 of the Standard Rock Color Chart. Greenish grey beds correspond to 5GY 6/1 of the same chart.

exposures in the road section near Garntangen display 19 bentonitic horizons which vary from a few mm to 12 cm thick (Fig. 12a, see also Hagemann 1966). This part of the Vik Formation has a more rich and diverse fauna than the adjacent members and both corals and stromatoporoids are abundant; brachiopods (especially *Pentamerus oblongus*, *Pentameroides* cf. *subrectus* and *Costistricklandia lirata*) are also common in certain beds.

The upper Abborvika Member consists of greenish grey to red shales with interbedded finely nodular limestones. A sparse fauna of crinoids, cephalopods and brachiopods is seen. The member is estimated to be 35 m thick in its stratotype on Purkøya (NM688571); the base is defined by the transition from the abundant limestones of the underlying unit into greyish green calcareous shales with sparse evenly bedded and calcareous nodular horizons. These beds pass up into red shales with irregular very finely nodular horizons about 18 m above the base of the member. The upper 3 m of the member consist of greenish grey shales; these are sharply overlain by siltstones of the Bruflat Formation and the junction is well exposed on Purkøya (Fig. 12b).

#### *Other occurrences*

Although exposures in the Holmestrand district show a similar tripartite development to that of the type area, the middle unit in Holmestrand (well exposed on Killingholmen, NL753995) consists of thickly bedded biosparites with corals, stromatoporoids and coquinas of *Pentameroides* sp. This unit was assigned to  $7c\beta$  or the 'Upper Pentamerus Limestone' by Kiær (1908). In the Skien district a 10 m thick grey shale sequence (Kiær's  $7c\alpha$ ) passes up into nodular limestones and greenish grey marls which apparently are directly overlain by shales of the Skinnerbukta Formation (8a/b of Kiær 1908).

Exposures assigned to the Vik Formation on Malmøya in the Oslo district consist of irregularly varying proportions of greenish grey shales and marls with finely nodular limestones. A notable feature is the occurrence of exceptionally well preserved articulated crinoid stems up to several metres long. Occasional thin intraformational conglomerate horizons are also found on Malmøya; these contain eroded and redeposited corals and calcareous nodules, reflecting the early diagenetic formation of these nodules. Occasional easily weathered interlaminae may represent bentonitic horizons. Exposures in the Asker district have still not been examined in detail, but we provisionally include both  $7b\beta$  and  $7c$  of Kiær in the Vik Formation in this district. We further note that sections seen here appear transitional between the Ringerike and Malmøya developments.

The Vik Formation thins southwards from 80 m in the type area to 45 m in the Skien district. Red coloured shales are only developed in Ringerike and Asker; bentonites have not yet been found in Holmestrand and Skien.

#### *Depositional environments*

Sediments and faunas of the Vik Formation suggest somewhat deeper depositional environments than those of the underlying Rytteråker Formation, with greater (although still fine-grained) clastic influx. Shales near the base and top of the





a

*Fig. 12.* a) Vik Formation, bentonites at Vik (Ringerike).

b) Junction between the Vik and Bruflat Formations in Ringerike.



b

formation in Ringerike, Holmestrand and Skien contain faunas characteristic of Benthic Assemblages 4 and 5 of Boucot (1975). The presence of abundant corals and stromatoporoids (and associated benthic algae) typical of Benthic Assemblage 3 suggests the development of shallow marl banks in the Garntangen Member of the type area. A comparable unit in Holmestrand comprises a bioclastic shoal rich in pentamerid and coral debris. Interpretations of the local red colour of the Vik Formation's shales will be discussed further below (p. 50).

#### *Age*

Our correlation of the unit is based both upon occurrences of the brachiopods *Pentamerus*, *Pentameroides* and *Costistricklandia* and on conodonts (R. J. Aldridge pers. comm. 1981). The brachiopods suggest that the Garntangen Member may be equivalent to the C<sub>4</sub>/C<sub>5</sub> transition in the British sequence and conodonts indicate a slightly older (C<sub>4</sub>) age for the base of the Vik Formation. A markedly diachronous top is suggested, ranging from mid-C<sub>5</sub> equivalent in Ringerike to late C<sub>6</sub> in Oslo (Fig. 5).

#### THE EK FORMATION

##### *Definition*

The formation's name was proposed by Skjeseth (1963); its name is derived from Eksberget (PN087355) on the island of Helgøya in the Hamar district. The Ek Formation is approximately 95 m thick in this type area; exposures assigned herein to the Ek Formation are dominated by greenish grey to dark grey (often graptoliferous) shales. We consider the Ek Formation to comprise all units assigned by Kiær (1908) to stage 7c in Hadeland, Toten, Hamar and Ringsaker and we retain Skjeseth's concept of the formation. Exposures in the Hadeland district show a transitional development to the Vik Formation but are more like the development of the Ek Formation in its type area; we therefore incorporate the informal 'Askilsrud shale' of Owen (1978) from Hadeland within our Ek Formation.

Poor exposure and complex tectonics make a satisfactory definition of the formation difficult. The type section proposed by Skjeseth (1963) along the 'new road' (Kiær 1908: Fig. 100) at Eksberget is now largely overgrown, but no better exposures are known at present. The base of 7c at Eksberget was described by Kiær at the transition from red nodular limestones and shales (here assigned to the Rytteråker Formation) to greenish grey marly shales with darker grey graptoliferous horizons. Kiær noted approximately 95 m of such shales, the lower 65 m with numerous graptolite horizons and the upper 30 m with a sparse shelly fauna. The nature of the top of the Ek Formation is poorly understood on Helgøya. The boundary with the overlying Bruflat Formation is best seen in this latter unit's basal stratotype in the Toten district.

##### *Other occurrences*

Several small exposures are seen in the Ringsaker district around Torsæter Bridge in Brumunddalen (PN077584 to PN077589) approximately 20 km north of Eksberget. Exposures there are highly tectonised and dark grey graptoliferous





*Depositional environments*

The shales of the northern districts were deposited in deep water environments distal to the prograding sandy deposits of the overlying Bruflat Formation. This foredeep passed laterally southwards into shallower shelf environments with the mixed carbonate and mud facies of the Vik Formation. The Hadeland exposures reflect this transition, but are on balance more akin to the Ek Formation.

*Age*

Re-examination of Kiær's collections from his 'new road' on Helgøya and of new collections from Toten suggest that the base of the Ek Formation in its type locality should be correlated with the upper part of the *crispus* Biozone. Kiær (1908:416) recorded a 'Zone with *Monograptus turriculatus* and *Petalograptus palmeus*' from a horizon 2.7 m above the base of the Ek Formation. We consider this zone to contain a *griestonensis* Biozone fauna. Graptolites indicate a probable *maximus* Biozone age for the base of the Ek Formation in its hypostratotype in Hadeland. A *turriculatus* Biozone fauna is seen 5 m above the base of the formation. Two poorer faunas 3 m and 3.5 m above the base suggest correlation with the *maximus* Biozone. A low *crenulata* Biozone age is suggested by graptolites from the top of the unit in Hadeland and Toten; sparse shelly faunas support this conclusion, indicating an equivalence to the C<sub>5</sub>/C<sub>6</sub> transition.

## THE BRUFLAT FORMATION

*Definition*

We here adopt, define in detail and extend the use of the formational unit proposed by Strand & Størmer (1955) and Skjeseth (1963) for Toten, Hamar and Ringsaker, with its name derived from Bruflat (NN877256) in Toten. Kiær (1922) introduced the term 'Mariendal Series' for rocks which we assign to this unit in the Ringsaker district; Kiær's term has never been widely used, whereas the Bruflat Formation is now generally accepted. The informal term 'Mariendal Beds' was used by Ramberg & Spjeldnæs (1978) for units which we assign to the Bruflat Formation. We here geographically extend Skjeseth's (1963) formational concept to include units assigned to 8a and 8b by Kiær (1908) in Ringerike and Hadeland.

Because of incomplete exposure and complex tectonics, a single type section cannot be designated. The type area around Bruflat shows a tightly folded and faulted series of anticlines and synclines exposing various parts of the unit. Best exposures are seen in several road and railway cuttings between Eina (NN875229) and Reinsvoll (NN884283). The base of the formation is defined in the southern end of a railway cutting (NN875238), 800 m north of Eina Railway Station. A composite section has not yet been satisfactorily established in the type area, but a thickness of 400–550 m is suggested (Fig. 14). The formation is characterised by varying proportions of sandstones, siltstones and silty shales. The lower part of the formation in the type area consists of medium to thickly bedded very fine calcareous sandstones and silty shales, the base of the formation being defined by the first occurrence of sandstones. Many of the sandstones have erosive bases, and show planar lamination passing up into rippled tops. The upper 200 m of the



formation consist of irregular and intergrading alternations of fine calcareous sandstones, siltstones and bioclastic limestones, often in thick beds with only thin shaly partings. Relatively diverse shelly faunas occur sporadically. A gradational upper contact with red shales assigned to the Reinsvoll Formation is seen in an exposure north of Bruflat (see p. 30).

#### Other occurrences

Several exposures in Brumunddalen show only a poorly fossiliferous shaly development of the formation (river bank and road cuttings near Torsæter Bridge (PN0757-PM0758)). At Bjørgeberget (PN0555) reddened shales uppermost in the Bruflat Formation yield a fauna with *Cyrtia exorrecta* (Kiær 1922). Approximately 125 m of the formation are exposed in Hadeland and neither the top of this unit nor any younger units are preserved in this district. However, comparison with Ringerike indicates that the Hadeland exposures represent most of the formation's original development in this district (railway cuttings at Gulla, NM7882).

Numerous partial sections in Ringerike show an attenuated development of the Bruflat Formation. A composite reference section can be studied on the islands of Purkøya and Storøya. The base is seen on the northwest coast of Purkøya (NM688571), the middle parts in good but discontinuous exposures on Storøya (NM691571 to NM690574) and the top is exposed at Vintergutangen, the northernmost point of Storøya (NM710586). A total thickness of approximately 115 m is indicated. The base is taken at the first thick siltstones which sharply overlie the greenish grey shales and nodular marls uppermost in the

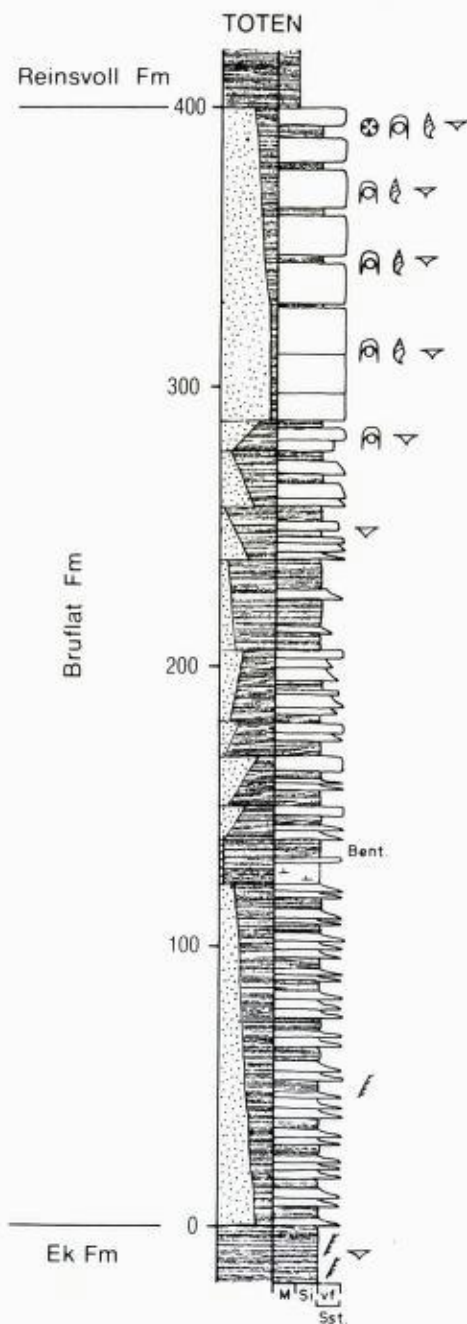


Fig. 14. Schematic section through the Bruflat Formation at Bruflat (Toten).

Vik Formation. The lower part of the Bruflat Formation (8a of Kiær, approximately 70 m thick) consists of a rhythmic sequence of shales (with shelly faunas) and more silty intervals; siltstones become more common upwards and 8b of Kiær (approximately 45 m thick) consists of medium-bedded siltstones and sandstones with bioclastic limestones and minor thin shales. We have not seen the desiccation cracks reported by Størmer (1942) in the uppermost beds, but the top of the unit is marked by an erosive contact with the limestones of the overlying Braksøya Formation.

#### *Depositional environments*

The formation shows a coarsening-upwards sequence in the type area, reflecting a large-scale coastal progradation into and over the graptoliferous shale environments of the Ek Formation. Distal storm generated sandstones in the lower parts of the Bruflat Formation are overlain by sediments typical of wave-dominated clastic shelf environments with faunas assignable to Benthic Assemblage 4 of Boucot (1975).

The formation shows a similar coarsening (and shallowing) upwards trend in Ringerike to that seen in the type area. Storm-generated siltstones in the lower part of the unit (8a) were deposited below normal wave base in quiet muddy environments with faunas typical of Benthic Assemblage 5. The uppermost part of the formation (8b) shows abundant evidence of wave reworking, with faunas which can be assigned to Benthic Assemblage 4. The erosive contact with the overlying Braksøya Formation is noteworthy: clasts of the Bruflat Formation's sandstones found immediately above this contact may suggest emergence prior to renewed marine deposition in the carbonate dominated environments of the Braksøya Formation.

#### *Age*

Skjeseth (1963) tentatively correlated his Bruflat Sandstone of the northernmost districts with stages 8 and 9 of more southerly areas and subsequent workers (e.g. Størmer 1967, Bjørlykke 1974a) generally assumed a Wenlock age for the formation although Bjørlykke noted that 'the age of the Bruflat Sandstone is not very well defined'. Exposures both in the Ringerike and northern districts contain graptolite, conodont, brachiopod and coral taxa which are all characteristic of the uppermost Telychian ( $C_6$  or *crenulata* Biozone). No diagnostic Wenlock faunal elements have yet been found, but we cannot yet rule out the possibility that the formation may extend into the basal *centrifugus* Biozone of the Wenlock.

Bassett & Rickards (1971) first presented revised datings of the formation in the Ringerike district; however, their results were somewhat confusing as the apparent occurrence of cyrtograptids in beds assigned to 8a near Vik suggested a Wenlock age for this locality in contrast to the Llandovery faunas of nearby exposures of 8b. Although several cyrtograptid taxa have been described from the uppermost Llandovery (Jackson & Etherington 1969) it is now clear that the cyrtograptids in question did not originate from Ringerike. The graptolites found in both 8a and 8b at Ringerike (*Monograptus vomerina vomerina*, *M. parapriodon*



and *Retiolites geinitzianus*) clearly indicate correlation with the *crenulata* Biozone. Aldridge (1974) described an *amorphognathoides* assemblage of conodonts from 8b in Ringerike; this conodont assemblage ranges into the early Wenlock, but the total fauna, including the brachiopods *Costistricklandia lirata lirata*, *Cyphomeroidea wisgoriensis*, *Protomegastrophia undata* and the rugose coral *Palaeocyclus porpita* suggests a Telychian age.

Both conodont and brachiopod shelly faunas found in the upper parts of the Bruflat Formation in its type area contain the same key elements as listed above, thus suggesting a close correlation with Ringerike (Fig. 4). The reddened 'Cyrta shales' found by Kiær (1922) on Bjørgeberget in the Ringsaker district lack distinctive faunas. No typical Llandovery faunal elements occur, however, and these beds (probably the youngest parts of the Bruflat Formation preserved in the Oslo Region) may extend into the early Wenlock.

#### THE REINSVOLL FORMATION

##### *Definition*

This unit has not been described previously and we have identified it with certainty only in the Reinsvoll area of the Toten district. The Reinsvoll Formation is not assigned to any of the groups described herein at this stage, but is provisionally described here in view of its potential regional significance. The Reinsvoll Formation consists of poorly exposed red shales of unknown total thickness. Its basal stratotype is exposed on a farm track between Highway 4 and Berget, on the eastern bank of the Hunselv river in Toten (NN876269). The lower 21 m of the Hunselv section consist of calcareous sandstones with bioclastic interbeds and shaly partings; these beds are assigned to the Bruflat Formation and the upper 10 m of this sequence are reddened. These are overlain by approximately 15 m of monotonous red shales which we here assign to the Reinsvoll Formation, but the nature of the contact with the underlying beds is obscure. Similar red shales have also been seen in trenches dug for a new housing development immediately south of Reinsvoll (NN886279). Loose blocks are also present in drift above a nearby road-cutting. No definite equivalents of the Reinsvoll Formation have yet been found in Hadeland. In the Hamar and Ringsaker districts the Bruflat Formation is unconformably overlain by rhomb-porphry lavas and by the Brumunddalen Sandstone (Kiær 1922, Rosendahl 1929) of probable Permo-Triassic age. The junction, seen at several places on Bjørgeberget (PN0555) is poorly exposed, and the presence of the Reinsvoll Formation there can neither be confirmed nor rejected.

Depositional environments and age of the Reinsvoll Formation are uncertain. Although the formation is certainly younger than the underlying Bruflat Formation, no identifiable fossils have yet been found.

#### THE SKINNERBUKTA FORMATION

##### *Definition*

This formation's name is derived from Skinnerbukta, a bay on the northwestern coast of Malmøya in the Oslo district. The Skinnerbukta Formation corresponds to stages 8a and 8b of Kiær (1908) in Oslo, Asker, Modum, Holmestrand and

Skien. In spite of some tectonic disturbance a reasonably complete type section can be defined in cliffs on the east coast of Skinnerbukta (NM894381). The unit is approximately 80 m thick in its type section and consists of dark grey graptoliferous shales.

The base is defined immediately above a sequence of shales with both nodular and continuous limestone interbeds which constitute the base of the exposure. Although the nodules are larger, and the limestone beds thicker, than those usually seen in the Vik Formation, this sequence is assigned to that formation. The overlying dark grey shales of the Skinnerbukta Formation contain occasional thin marly horizons which are sometimes slightly bioturbated. The total calcareous content of the formation increases upwards and its upper parts consist of somewhat paler calcareous shales. These uppermost beds also show an increasing abundance of limestone interbeds and the gradational top of the unit is defined by the base of the overlying Malmøya Formation (p. 36). Graptolites and hyolithids dominate the fauna of the formation in the type section; some rare shelly elements have been found, including scattered lingulids, gastropods, crinoids and small specimens of *Eoplectodonta transversalis*.

#### *Other occurrences*

The formation is also exposed at several localities in Asker, Holmestrand and Skien. Exposures at Bærum in the Asker district (Øverland, NM876449, Jong NM846404 and Gjettum NM850022) suggest a thickness of 90 m; shales there contain both graptolites and low diversity benthic faunas. Metamorphosed exposures on Kommersøya (NL750990) and at Sando (NM740013) in Holmestrand show a more diverse benthic fauna with several brachiopod and trilobite taxa, while graptolites are rare. Exposures in Skien (e.g. around Kapitelberget, NL367628) mark the continuation of this ecological gradient as benthic faunas there show a moderate diversity and approach a composition similar to that seen in the Bruflat Formation of Ringerike. Thin limestones are common, and form distinct horizons (often bioclastic lenses) in the upper part of the unit. However, the absence of coarse clastic material leads to the assignment of the Skien sequence to the Skinnerbukta, rather than to the Bruflat Formation.

#### *Depositional environments*

In its type area, the Skinnerbukta Formation's shales were deposited in low-energy, usually anaerobic environments. The occasional presence of bioturbation and of (highly restricted) benthic elements suggests periodic flushing of a generally anoxic mud bottom. Several of these elements may represent either epiplanktic taxa drifted into the area attached to floating algae or possible giant spat. The only clearly benthic element is *Eoplectodonta transversalis*; the few individuals found are small and apparently stunted, suggesting restricted bottom conditions adverse to shelly colonisation. Bioturbation and benthic diversity increase upwards in the formation in the type area, suggesting a generally shallowing trend. Benthic faunal diversity also progressively increases from Oslo, through Asker and Holmestrand, to Skien and faunas found there may be assigned to Benthic Assemblages 5 to 4 of Boucot (1975).



*Age*

The faunal evidence suggests a marked regional diachroneity of the Skinnerbukta Formation's lower and upper boundaries, which became older from Malmøya to Skien. Graptolite faunas in the type section suggest that the base of the formation there is approximately correlative with the Llandovery/Wenlock boundary, although the basal 10 m (8a of Kiær 1908) may possibly be assigned to the latest Llandovery *crenulata* Biozone. Revision of the correlation of Bassett & Rickards (1971) suggests that elements typical of the Wenlock *centrifugus*, *murchisoni* and *riccartonensis* graptolite Biozones are found upwards through the formation on Malmøya and its upper parts extend into the *rigidus* Biozone. Both the base and top of the Skinnerbukta Formation become progressively older southwards, and benthic faunas near the top of the formation in the Skien district contain elements which, as noted under our discussion of the Bruflat Formation, are typical of the uppermost Llandovery (e.g. *Costistricklandia lirata lirata*, *Palaeocyclus porpita* and *Isorthis mckenziei*).

Comparison with Ringerike suggests that the Skinnerbukta Formation in its type area is laterally equivalent to the (combined) uppermost parts of the Bruflat Formation, the entire Braksøya Formation and the lowermost parts of the Steinsfjorden Formation of the latter district. This complex facies mosaic will be further discussed below.

## THE HOLE GROUP

The group's name is based on the municipality of Hole in the Ringerike district; the group comprises the carbonate-dominated sequences which constitute the upper parts of the marine Silurian succession in the central, western and southern districts of the Oslo Region. These sequences are assigned to our new Braksøya, Malmøya and Steinsfjorden Formations. Representatives of the group are not preserved in the northern districts of the region.

The base of the group is generally coincident with the base of 8c of Kiær (1908). In Ringerike, Modum and Skien this corresponds to the base of our Braksøya Formation and the boundary stratotype for the base of the Hole Group is that defined herein for the Braksøya Formation in Ringerike. The junction with underlying Bærum Group is sharply defined there. In other districts (Oslo, Asker and Holmestrand) the group's base corresponds to the base of our Malmøya Formation, with a gradational lower junction. The composite thickness of the group is 275 m in Ringerike and 240 m in Asker, thinning southwards to 120 m in Holmestrand and 170 m in Skien. The group's top is not preserved in the Oslo district, but its upper boundary to the Ringerike Group in other districts corresponds to the gradational junction between stages 9 and 10 of Kiær (1908).

The Hole Group is correlated with most of the Sheinwoodian and Homerian. Its base is diachronous, younging from Skien and Ringerike to the Oslo district and its top is placed somewhat below the Homerian/Gorstian boundary in the Ringerike district. Several workers have suggested large-scale regional diachroneity of the junction between the Hole Group and the overlying Ringerike Group (e.g.

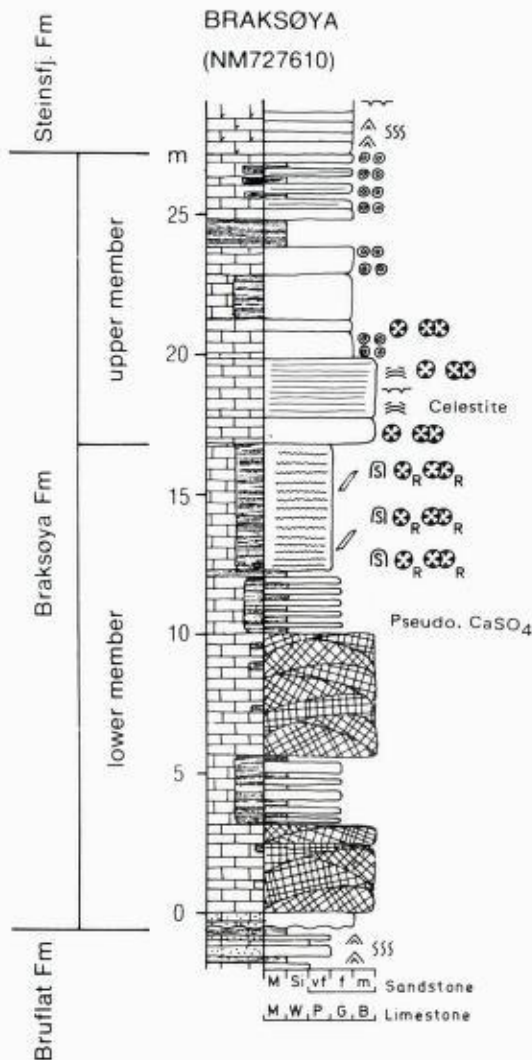


Fig. 15. The type section of the Braksøya Formation, Ringerike.

basal limestones. A lower biohermal member is 17 m thick and is characterised by thinly bedded marls with massive biomicrite and biolithite structures (up to 7 m high and 15 m wide) which we interpret as small patch reefs (Fig. 16, c.f. Kiær 1908, Fig. 19c). These contain algae, bryozoans, tabulate corals, stromatoporoids and other problematical organisms both as framework and binding element in the reefs' structure (Hanken, Olausen & Worsley 1979). The patch reefs pass both laterally and vertically into marls of variable thickness which contain a varied brachiopod fauna, and occasional horizons show large, current-oriented, rugose corals (Whitaker 1965). Scattered pseudomorphs after celestite or gypsum are also seen in the marly sequence. The upper part of this member

Spjeldnæs 1967, Bjørlykke 1974 and Ramberg & Spjeldnæs 1978). We still lack precise biostratigraphical documentation of this relationship (see p. 41).

#### THE BRAKSØYA FORMATION *Definition*

The formation is best demonstrated on the west coast of Braksøya (NM727610) in Ringerike, where a complete type section can be designated (Fig. 15); the formation is 27 m thick there and consists of a complex carbonate development with minor marls and shales. The Braksøya Formation corresponds to 8c and 8d of Kiær (1908) in Ringerike, Modum and Skien. We provisionally subdivide the formation into two informal members, pending the results of works in progress by S.O. and N.M. Hanken.

The base of the Braksøya Formation in its type section is clearly defined by limestones which overlie the eroded top surface of the Bruflat Formation. Small sandstone and shale clasts from the underlying formation are seen in these



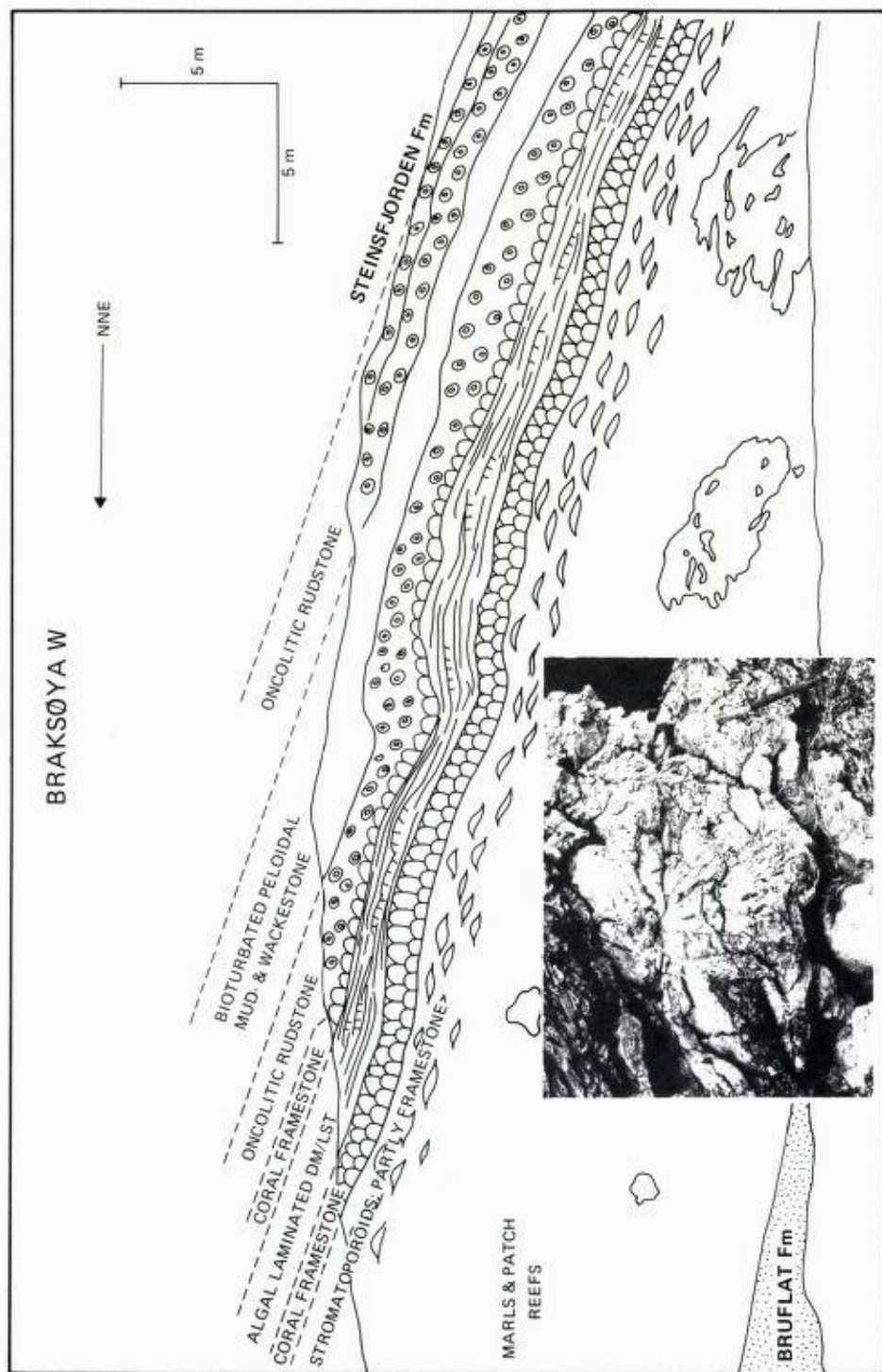


Fig. 16. Biohermal development in the Braksøya Formation at Braksøya, Ringerike. Inset shows detail from the patch reefs.

consists of a 3.5 m thick, black, bituminous shale with *in situ* tabulate corals and stromatoporoids; individual colonies over 1 m<sup>3</sup> in size are present.

The upper, well-bedded member is 10 m thick in the formation's type section and consists of thickly bedded limestones with marly partings and occasional desiccation cracks. Thinly (algal?) laminated limestones (with fenestral fabrics and pseudomorphs after evaporite nodules), coral biostromes and oncolitic biosparites also occur. The top of the Braksøya Formation is taken below the first appearance of thinly interbedded limestones and shales here assigned to the overlying Steinsfjorden Formation.

#### *Other occurrences*

The complex and varied development of the Braksøya Formation is well demonstrated in several exposures elsewhere in the Ringerike district (Geitøya NM6956, Storøya NM7057 and Sønsterud NM7251). Wherever it is exposed, the contact with the underlying Bruflat Formation is erosive. As might be expected, the patch reefs and marls in the lower member of the formation show variable local developments, and in some exposures this member consists of only one of these lithofacies.

Exposures in Modum and Skien are provisionally included in the Braksøya Formation. A lower biohermal member is well developed in both districts (especially at Kapitelberget, NL367628 in Skien). However, the upper part of the formation in both districts contains interbedded limestones and shales similar to those assigned to the Malmøya Formation in the Holmestrand and central districts and unlike those of the upper member at Ringerike.

#### *Depositional environments*

All exposures assigned to the Braksøya Formation indicate the establishment of marginal marine carbonate depositional environments following a short (and biostratigraphically indefinable) period of erosion (and ?emergence) near the Llandovery/Wenlock boundary. The fauna and flora of the patch reefs indicate shallow, clear water, marine environments; however, both the restricted character of the flora and fauna and the occurrence of evaporites in marl sequences at Ringerike suggest periodic hypersaline conditions. Desiccation cracks and evaporitic pseudomorphs seen in the upper parts of the formation in the type area also indicate intra/supratidal depositional environments. Such features have not been observed in the Modum and Skien districts and this suggests deposition in more distal marine environments. Faunas are comparable to those assigned to Benthic Assemblages 2 and 3 by Boucot (1975).

#### *Age*

Brachiopods, corals and ostracodes seen in the type section of the Braksøya Formation contain no diagnostic Llandovery elements, and the base of the overlying Steinsfjorden Formation contains brachiopods (including *Eocoelia angelini*) with a Sheinwoodian (*riccartonensis* Biozone) age. Faunal elements therefore suggest a low Sheinwoodian (pre-*riccartonensis* Biozone) age similar to



that of the Upper Visby Beds of Gotland (Bassett & Cocks 1974). The occurrence of *Eocoelia angelini* in the upper part of the Braksøya Formation in the Skien district suggests a somewhat later transition there to beds assigned to the Steinsfjorden Formation. Thus, the Braksøya Formation in its type area is considered to be a time equivalent of the Skinnerbukta Formation in the Holmestrand and central districts. The development in Skien overlies beds assigned to the Skinnerbukta Formation; the top of the Braksøya Formation in this district is approximately correlative with the junction between the Skinnerbukta and Malmøya Formations of Holmestrand and the central districts (Fig. 5).

#### THE MALMØYA FORMATION

##### *Definition*

Kjerulf (1857) introduced the term '*Malmøya Limestone and Shale*' for exposures of his stage 8 on Malmøya in the Oslo district. Kiær (1908) assigned the lower (more shaly) part of Kjerulf's unit to 8c and the upper massive limestones to 8d; he applied the term '*Malmøya Limestone*' both to the latter limestones and to units he assigned to 8d in Asker, Holmestrand and Skien. Kiær's practice was also followed by Strand & Størmer (1955) in their definition of the '*Malmøya Limestone*'. Our redefinition and use of the Malmøya Formation is based on Kjerulf's original designation; both Kiær's and subsequent applications of this term only to the upper part of Kjerulf's unit are rejected. Our use of the Malmøya Formation therefore generally corresponds to Stages 8c and 8d of Kiær (1908) in Oslo, Asker, Eiker and Holmestrand. Only the lower and middle parts of the Malmøya Formation are exposed on Malmøya and these represent the youngest Silurian strata preserved in the Oslo district. The basal stratotype defined on Malmøya (NM985382) is therefore supplemented with a parastratotype from Gjettum in the Asker district (NM875449). The formation is approximately 35 m thick at Gjettum (Fig. 17), and both its base (Malmøya) and top (Gjettum) are gradational. The base is defined on Malmøya at the first development of continuous limestone beds above the graptoliferous shales with marly horizons of the underlying Skinnerbukta Formation. The lower part of the formation (8c of Kiær) shows varying proportions of continuous, nodular and lenticular limestone beds, all with interbedded shales. These grade up into thickly to massively bedded biosparitic limestones and faunal diversity increases correspondingly. The lower and middle parts of the formation at Gjettum show a similar development to beds preserved on Malmøya; the massive limestones seen in both areas grade upwards in the Gjettum section into coral and stromatoporoid biostromes and biosparrites high in the formation. These show a gradational contact with the thinly interbedded micritic limestones and shales (with a more restricted fauna) which we assign to the overlying Steinsfjorden Formation.

##### *Other occurrences*

The Malmøya Formation is also exposed on Kommersøya (NL7499) and at Sando (NM738015) in the Holmestrand district; its base there is obscure and the junction with the underlying Skinnerbukta Formation may be faulted. As in the type area,

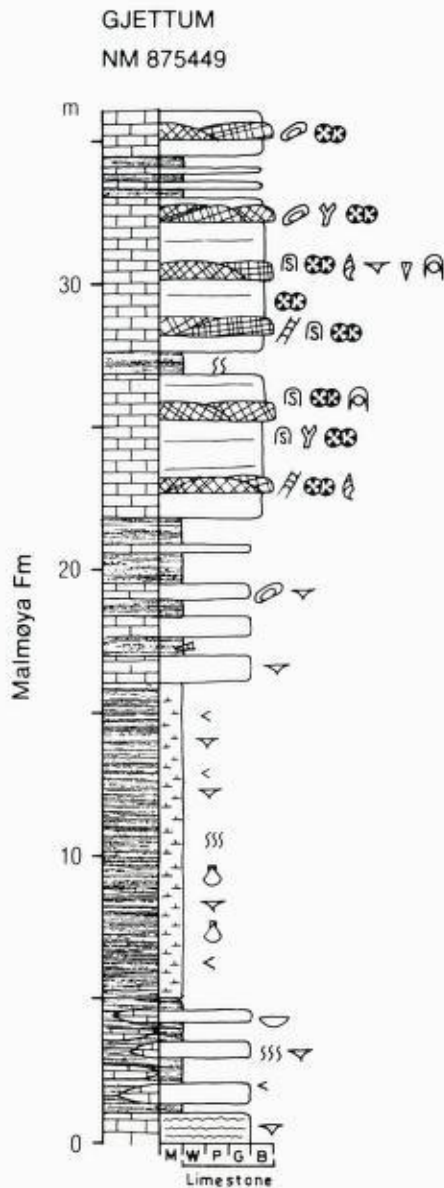


Fig. 17. Parastratotype of the Malmøya Formation at Gjetlum (Asker district).

the unit shows a gradation upwards from interbedded limestones and shales into thickly bedded limestones with coral biostromes and biosparrites.

the unit shows a gradation upwards from interbedded limestones and shales into thickly bedded limestones with coral biostromes and biosparrites.

#### *Depositional environments*

Thinly-bedded limestones in the lower parts of the formation are interpreted as storm-generated units deposited distally to the carbonate shoals which are represented by the overlying thickly bedded biosparites and coral biostromes. The entire sequence reflects progressively shallowing depositional environments in the Holmestrand and central districts, with progradation of carbonate shoals over the basal shales of the underlying Skinnerbukta Formation. High energy environments on the shoals are suggested by the reworked corals of the biostromes; however, all the units assigned to the formation were deposited in subtidal environments and no evidence of emergence is seen. The fauna is reminiscent of Benthic Assemblages 4 to 3 of Boucot (1975).

#### *Age*

The base of the Malmøya Formation is younger than the *riccartonensis* (possibly early *rigidus*) Biozone graptoliferous shales in the upper parts of the Skinnerbukta Formation. Faunal elements within the Malmøya Formation have a general, but nondiagnostic Wenlock aspect. The brachiopod

*Eocoelia angelini* occurs in the lower parts of the formation (8c) at Gjetlum and on Kommersøya. This brachiopod suggests a correlation with the mid-Sheinwoodian *riccartonensis* Biozone (Bassett & Rickards 1971, Bassett & Cocks 1974, Bassett 1979). Available evidence therefore suggests a diachronous base for the Malmøya Formation, ranging from the *riccartonensis* Biozone in Holmestrand and Asker to the *rigidus* Biozone on Malmøya. Basal units in Holmestrand and Asker (8c) are considered to be time equivalents to the upper parts of the Braksøya



Formation of Skien (8d) and to the basal unit of the Steinsfjorden Formation in Ringerike (9a). The basal units of the Malmøya Formation on Malmøya are somewhat younger and are correlated with 8d in Holmestrand and Asker, 9a in Skien and 9b in Ringerike. The age of the transition between the Malmøya and Steinsfjorden Formations in Asker and Holmestrand is still uncertain.

#### THE STEINSFJORDEN FORMATION

##### *Definition*

This formation is best demonstrated on the coast and islands of Steinsfjorden in the Ringerike district. A single type section cannot be designated, but the type area comprises numerous overlapping coastal exposures in the northwestern part of Steinsfjorden, together with the adjacent islands of Herøya, Småøyene and Braksøya. The basal stratotype is defined at Loretanen (NM728637) and representative sections through the formation are seen northwards along the coast to Brattstad (NM3668) and on Herøya (NM7363). The gradational contact to the overlying clastic red bed deposits of the Ringerike Group is well exposed at Ranberget (NM725604). The Steinsfjorden Formation is approximately 260 m thick in the type area (Fig. 18) and contains irregularly varying proportions of greenish grey shales and marls, red dolomitic shales, dolomites and limestones. Variation in these components forms the basis of a subdivision into three members proposed by Olausen (1978). The formation corresponds to Stage 9 of Kiær (1908) and we here assign outcrops preserved in Ringerike, Asker, Eiker, Modum, Holmestrand and Skien to this unit.

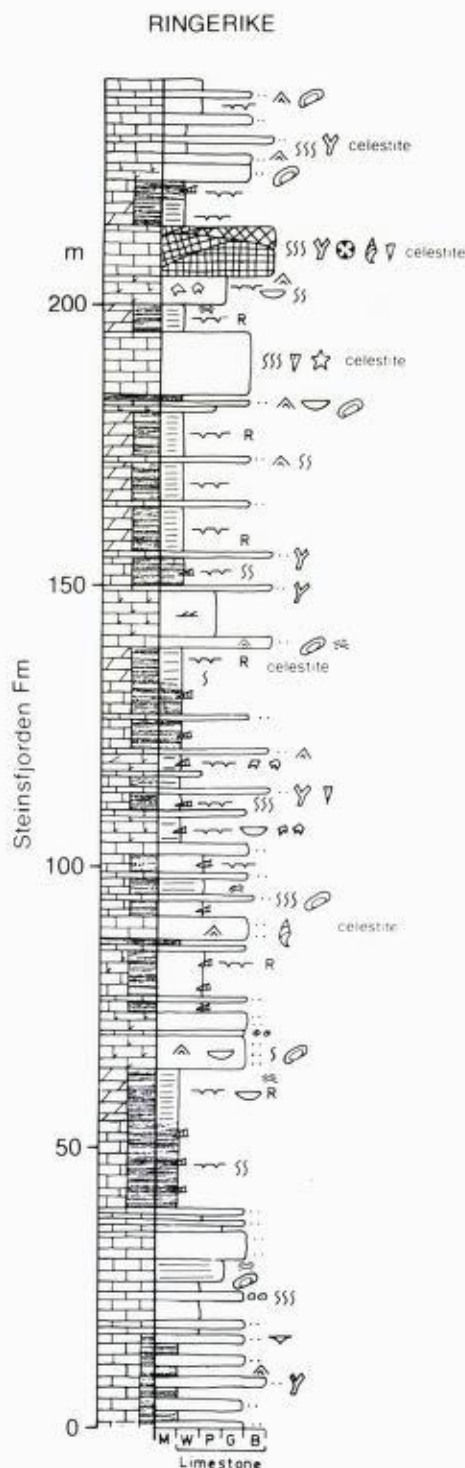


Fig. 18. A composite section through the Steinsfjorden Formation, Ringerike.

The base of the Steinsfjorden Formation at Loretangen is defined at the first occurrence of thinly interbedded limestones and shales which overlie the thickly bedded limestones of the Braksøya Formation. Olausen (1978) assigned the basal 200 m of the Steinsfjorden Formation to the Sjørvoll Member (9a-d and lower 9e of Kiær 1908). This member consists of variably interbedded dolomitic limestones and limestones with red and greenish grey shales and marls. Mudflake conglomerates, desiccation cracks and algal laminated dolomitic limestone are common; the fauna shows a low diversity dominated by euryhaline elements often showing high individual abundance. A noteworthy eurypterid fauna (Størmer 1934b, 1938) occurs together with algae (Høeg & Kiær 1926) in beds assigned to 9d by Kiær (1908).

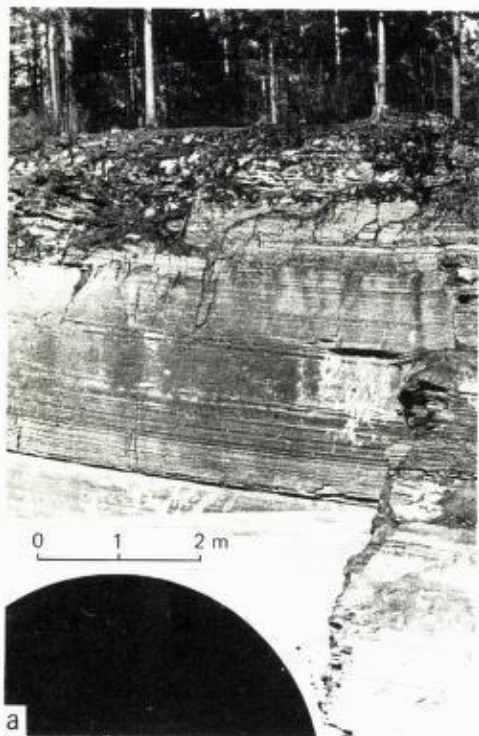
The overlying Brattstad Member (upper 9e and 9f of Kiær 1908) is 30 m thick and consists of medium to thickly bedded limestones in its lower and upper parts, with interbedded marls and dolomitic limestones in the middle of the member (Fig. 19). The limestones contain a relatively rich and varied fauna; 1 to 3 m thick massive favositid and oncolitic biostromes (the 'Favosites Limestone' of Kiær 1908) are characteristic of the uppermost beds of the member. The basal stratotype of the member is defined in a coastal exposure at Brattstad (NM745670) at the first occurrence of massive lumpy bedded limestones which lie above marls with desiccation cracks assigned to the Sjørvoll Member.

The overlying greenish grey marls with thin limestone beds and nodular horizons assigned to the Ranberget Member (30 m, 9g of Kiær 1908) display mudflake conglomerates, desiccation cracks and ripple marks. The fauna is restricted to bryozoans and ostracodes, with significant horizons containing agnathans and eurypterids. The base of the member is defined in the E68 road section between Vik and Sundvollen at the first appearance of marls over the massive lumpy bedded limestones of the Brattstad Member. A 4 cm-thick bentonite occurs 2 m above the base of the member (Jørgensen 1964). The upper boundary is gradational, with interbedded limestones and greenish grey shales passing up into red mudstones and sandstones of the Ringerike Group. The junction is defined arbitrarily at the overall change in colour from greenish grey to red sediments; this transition is accompanied by the disappearance of the few remaining *in situ* marine faunal elements.

#### *Other occurrences*

Units assigned to the Steinsfjorden Formation in other districts show a thinner development than that of the type area (Asker 200 m, Holmestrand 115 m, Skien 140 m). The lower parts and the upper transition to the Ringerike Group are everywhere broadly similar to the type area. However, the middle parts of the unit in these other areas are dominated by limestones (which are quarried in the Skien and Holmestrand districts) with more normal stenohaline faunas. Both patch reefs and biostromes are found in these middle parts of the formation in Holmestrand, while biostromes also occur in Asker, Modum and Skien. The biostromal 'Favosites Limestone' of Kiær (1908) can be found in all these districts in the upper parts of the formation.





Favositid biostrome ending the transgressive sequence.

Bedded to nodular limestone with abundant brachiopods, bryozoans, oncolites and minor corals.

Amplexoporid biostrome with some oncolites.

Bentonite overlain by bedded pelbiosparites and biomicrites.

Thinly bedded biosparites, pelbiomicrites and laminated (?algal) dolomitic limestones to calcareous dolostones with abundant desiccation cracks and minor celestite.



*Fig. 19a.* The Brattstad Member in its type section, Ringerike.

*Fig. 19b.* Facies of the Steinsfjorden Formation, Asker.

*Depositional environments*

In its type area the formation contains mixed carbonate and mud lithofacies associations mostly deposited in supratidal, intertidal and restricted subtidal environments. Rhythmic lithological variations seen within the unit represent small-scale transgressive and regressive events, the transgressive periods marked by the deposition of thin biostromal banks. The presence of early diagenetic dolomite and celestite suggests arid conditions in the type area (Olausen 1978 & 1981b). The lower and upper parts of the formation in other districts were also deposited in peritidal environments, but the unit's middle parts suggest more open subtidal conditions which permitted the development of biostromes and patch reefs with a highly diverse flora and fauna on marginal areas of the inner shelf. The favositid bioherms and biostromes seen in the upper part of the formation in all districts mark a larger scale transgressive episode; for a short time this resulted in normal marine conditions in all districts, prior to a regional regression which culminated in the deposition of the overlying red beds of the Ringerike Group.

*Age*

Sequences which we assign to the Steinsfjorden Formation were originally correlated with the Ludlow. However, studies of agnathans (Heintz 1969), ostracodes (Martinsson 1969) and thelodonts (Gross 1967, Turner & Turner 1974) suggest that the transition from marine to red bed deposition at the top of the Steinsfjorden Formation approximates to the Wenlock/Ludlow boundary, thus placing the entire formation within the Wenlock. The age of the base of the Steinsfjorden Formation was first clarified by Bassett & Rickards (1971) using the occurrence of the brachiopod *Eocoelia angelini*. We have already noted the mid-Sheinwoodian age of this brachiopod: its occurrence in the lower parts of the Steinsfjorden Formation in Ringerike and in varying parts of underlying units in other districts suggests that the base of the formation youngs progressively from Ringerike through Holmestrand and Skien to Asker (Fig. 5). We therefore consider the lower parts of the Steinsfjorden Formation in its type area to be time equivalents of the entire Malmøya Formation of Asker and of the upper parts of the Malmøya and Braksøya Formations in Holmestrand and Skien respectively.

The ostracode and thelodont faunas described from the upper beds (9g) of the Steinsfjorden Formation in Ringerike (Gross 1967, Martinsson 1969, Turner & Turner 1974) suggest a correlation with the Halla Beds of Gotland (Gross 1968). Recent work on Gotland (Bassett *et al.* in press.) suggests that the Halla Formation lies within the *nassa* Biozone. The youngest marine faunas of the Steinsfjorden Formation may therefore have a slightly earlier age than that suggested near to the Wenlock/Ludlow boundary by among others Turner & Turner (1974:190). We have as yet little faunal evidence to date the upper parts of the Steinsfjorden Formation in other districts. The youngest faunas found at Holmestrand (in 9d) have a Sheinwoodian character, and faunas elsewhere from higher in the formation have a general Wenlock aspect. We have therefore no biostratigraphic data as yet to test the sedimentological models of Spjeldnæs (1966) and Bjørlykke (1974) which suggest a regionally diachronous contact with the overlying Ringerike



Group, younging from Ringerike towards Asker and the south. Studies of thelodonts found in the Asker district (S. Turner pers. comm. 1982) may resolve this question.

#### THE RINGERIKE GROUP

Red beds assigned to the Ringerike Group have a conformable and gradational contact with the Steinsfjorden Formation in the Ringerike, Asker, Holmestrand, Eiker and Skien districts. The Ringerike Group is in turn unconformably overlain by sediments (the Asker Group of Dons & Györy 1967, Henningsmoen 1978) and/or lavas. The Asker Group was previously thought to be Permian in age, but fusulines found recently have a mid/late Carboniferous aspect (Olausen 1981a).

Kiær (1908) assigned the red beds of Ringerike to stage 10 and suggested a Devonian age. Subsequent work concentrated on the remarkable fauna of agnathans, crustaceans and eurypterids in the lower parts of this red bed sequence (Kiær 1911, Kiær 1924, Størmer 1934a, Størmer 1935, Heintz 1939 (and Hanken & Størmer 1975). Agnathans were also described from similar red beds on Jeløya on the eastern side of outer Oslofjorden in the Holmestrand district (Kiær 1931, Heintz 1974). The entire red bed development was for many years assigned to stage 10 in most works (e.g. review of Henningsmoen 1960), but later workers called the sequence either the Ringerike Formation (Spjeldnæs 1966), the Ringerike Sandstone Series (Whitaker 1966) or the Ringerike Sandstone (Heintz 1969). Knowledge of the lithostratigraphy and sedimentology of this red bed development has been greatly increased by the work of Whitaker (1964, 1965, 1966, 1980), Turner (1974a, b, c) and Turner & Whitaker (1976). These studies were chiefly directed towards the Ringerike district, although Turner (1974a) and Turner & Whitaker (1976) also presented information on Asker and Holmestrand.

Turner (1974a) proposed the Ringerike Group to embrace all red bed units earlier assigned to stage 10. The group comprises an approximately 1,250 m thick sequence of red siltstones and sandstones in its type area in the Ringerike district. Turner also defined the Sundvollen (lower 500 m) and Stubdal, (upper 750 m) Formations within the Ringerike Group in its type area. The type section of the Sundvollen Formation on the western slopes of Kroksund (NM7259) consists mostly of red siltstones and sandstones arranged in fluvial upwards fining sequences. Interbedded marine mudstones and limestones of tidal inlet origin suggest coastal plain to estuarine environments. The Stubdal Formation's type section in Stuvdal (NM7766) is dominated by sandstones (with intraformational conglomerates), reflecting deposition by braided stream systems prograding over the more fine-grained deposits of the underlying formation. Palaeocurrent indicators and the petrology of sandstones in both formations suggest drainage systems with sources in the developing Caledonides to the north and northwest of the present Ringerike district (Turner & Whitaker 1976). The maximum preserved thickness of the Stubdal Formation is seen at Stuvdal; when traced southwards the preserved thickness of the formation decreases rapidly because of pre-Carboniferous tilting and erosion.

Units assigned by Turner (1974a) to the Ringerike Group in the Asker district at Kolsås show a broadly similar stratigraphy to that of the type area, although the total thickness of the group there is only 500 m. The Sundvollen Formation is 100 m thick and consists of siltstones and mudstones with minor sandstones; there is no clear organisation of these components. An estuarine environment was suggested by Spjeldnæs (1966) and Turner (1974a) also noted that the transition from marine to red beds was more gradual at Kolsås than in Ringerike. The Stubdal Formation consists of finer grained sandstones than those seen in the type area, although the mineralogical content is similar in both Ringerike and Asker. Thus the entire Ringerike Group in Ringerike and Asker is regarded as a south to southeastwards prograding unit.

The Holmestrand Formation of Turner (1974a) is exposed on both the east (Jeløya) and west coast of outer Oslofjorden in the Holmestrand district. Turner defined the type section of the formation between Engenes and Smørstein (NL723999) in the Holmestrand area. An approximately 600 m thick sequence is dominated by medium-grained sandstones with extraformational conglomerate clasts, a development which Turner & Whitaker (1976) contrasted with the red beds seen in the Ringerike district. They suggested deposition of the Holmestrand Formation's sandstones by braided streams draining westwards, citing clast composition and sandstone mineralogy as suggesting the erosion of Precambrian basement complexes to the east of the Oslo graben. This interpretation contrasts with the results of other workers (F. Andreassen pers. comm. 1978) which suggest deposition of the Holmestrand Formation on coastal floodplains with palaeocurrents from the northwest. An explanation of these conflicting views is suggested by recent studies of the junction between the Ringerike and Asker Groups (Olaussen 1981a); these indicate that some of the red beds assigned by Turner & Whitaker to the Holmestrand Formation may in fact be Carboniferous in age. More detailed work is clearly necessary; and studies of the metamorphosed 300 m-thick sequence generally assigned to the Ringerike Group in Eiker and Skien are also needed before reliable palaeogeographical interpretations can be presented.

Early descriptions of the agnathan and arthropod faunas in beds assigned to the basal parts of the Ringerike Group in its type area followed Kiær's (1911) assumption of a Downtonian age. Later works (Heintz 1969:25, Turner & Turner 1974:190) suggested an early Ludlow age for the same units. However, as the youngest marine faunas found in the Steinsfjorden Formation are now thought to indicate a *nassa* Biozone age, the lowermost red beds could be also of Wenlock age. Turner (1974a) considered the Holmestrand Formation to be age equivalent to the Stubdal Formation of Ringerike, but we have no data on the age of the marine to red bed transition in Holmestrand. A fossiliferous horizon found in the lower parts of the Holmestrand Formation at Smørstein by Prof. G. Henningsmoen contains a plectambonitacean brachiopod and a single poorly preserved chitinozoan with 'a general Ludlow aspect' (S. Laufeld pers. comm. 1980). Agnathans found on Jeløya (NL953923) suggest an early Downtonian age (Heintz 1974); although these finds are from the lower parts of the 230 m-thick exposed



sequence of the Holmestrand Formation, we do not know how far they are above the marine to red bed transition. Present evidence, albeit sparse, does not suggest any substantial diachroneity between the Ringerike and Holmestrand districts and we provisionally consider the Holmestrand Formation to be a lateral equivalent of the Sundvollen Formation of Ringerike (Fig. 5).

## Synthesis

Our correlations and environmental interpretations of the proposed formational units permit a better understanding of the palaeogeographical evolution of the Oslo Region in the Silurian. This review discusses earlier work in the context of our results and presents general models which will be tested and refined in the course of studies now in progress. At this stage we present general nonpalinspastic lithofacies distribution maps rather than attempt detailed palaeogeographical interpretations on the basis of insufficient data. The varying degrees of deformation seen in the different districts (Nystuen 1981) should be borne in mind when these facies distributions are evaluated, as appreciable N-S crustal shortening in the central and northern districts of the region has produced the apparently arcuate lithofacies belts seen today, (see e.g. Størmer 1967). Our maps (Fig. 20) reflect lithofacies distributions at the six stage boundaries between the Rhuddanian and Gorstian.

### *Pre-Silurian development*

Most of the Cambrian and Ordovician sediments of the Oslo Region were deposited in relatively stable and tranquil shelf environments with little coarse clastic supply and relatively low rates of sedimentation (see e.g. Bjørlykke 1974a: Fig. 13). A series of NNE-SSW trending facies belts were developed in the Caradoc (Størmer 1967: Fig. 16); shallow marine carbonates with reefs in northern and southern districts passed eastwards into more distal muddy environments. This situation changed radically during the Ashgill, when a regional regression resulted in subaerial exposure of the Ringsaker, Hamar and Toten districts. This regression was accompanied first by the migration of reefoid facies from Hamar through Hadeland to Ringerike, with a subsequent development of clastic-dominated sequences in all districts still submerged. This development was earlier interpreted as an epeirogenetic response to the Horg orogenic phase within the southern Scandinavian sector of the developing Caledonides (Størmer 1967). However, it may also reflect glacio-eustatic sea level changes resulting from the development of the Gondwanaland ice-cap (see review in Brenchley & Newall 1980).

The erosion of land areas in Toten, Hamar and Ringsaker in the late Ashgill produced significant karstic features in the top of the Caradoc Mjøsa Limestone. The uppermost parts of the shallow marine clastic and carbonate sequences in the Ringerike and Skien districts also display erosional and karst features which suggest intermittent non-deposition and subaerial exposure (Hanken 1974 & 1979, Rønning 1979). The central districts show a complex of NE-SW trending sandy and oolitic shoals (Kiær 1902, Brenchley, Newall & Stanistreet 1979,

Brenchley & Newall 1980). The local development of channel structures (with conglomerate and breccia infills) cutting into these shoals was interpreted as indicating contemporary folding in the Oslo and Asker districts by Kiær (1902) and Spjeldnæs (1957). Later workers (e.g. Lervik 1970, Brenchley & Newall 1975) have found little evidence for folding, and the channel development may reflect both eustatic fall in sea-level and local adjustments along block margins in the underlying basement. The conglomeratic infills of many channels were probably formed by the erosion of intermittently (?tidally) exposed beach-rock on shoal crests. However, large blocks of sandy limestone seen locally (e.g. in channels on Hovedøya in the Oslo districts), may rather reflect minor local tectonic uplift and somewhat more prolonged subaerial erosion of these shoals. Local thickness variations and synsedimentary deformation structures in this sequence may also indicate small scale movements in the Ashgill.

Earlier workers have often advocated the presence of a 'Telemark Land' as a more or less permanent feature along the western margins of the Oslo Region throughout the Lower Palaeozoic. Bjørlykke (1974a) envisaged this area as consisting of a positive arch with sand shoals separating the Oslo Region's syncline from the geosynclinal development to the west. Brenchley and Newall (1977) further suggested that these shoals prograded eastwards in the course of the Ashgill regression. However, facies patterns in the Ashgill and Rhuddanian successions of the easternmost Oslo district may also reflect the presence of similar shoals over positive areas to the *east* of the margins of the syncline, with the Ashgill regression producing progradation over both western and eastern margins of the depositional basin.

#### *The early Silurian transgression of the Oslo Region*

Shales and minor thin siltstones of the Solvik Formation directly overlie the contrasting sandstones and oolites of the Ashgill Langøyene Formation in the Oslo and Asker districts (Brenchley & Newall 1975). No basal conglomerates have been found – indeed, the shales of the Solvik Formation locally drape over the margins and infill the central parts of channels developed (but not completely filled) during the deposition of the underlying unit. The rapid and large-scale nature of the transgression producing these basal shales is suggested by the graptolites and relatively distal quiet-water benthic faunas found immediately over the formational base. This transgression may be related to the melting of the Gondwanaland ice-cap at this time (Brenchley & Newall 1980). Graptolites suggest that the transgression occurred at some time within the early Rhuddanian (either *persculptus* or *acuminatus* Biozones).

Earlier accounts have suggested a gradual continuous transgression of the Oslo Region throughout the early Silurian (e.g. Spjeldnæs 1957, Bjørlykke 1974a) so that the basal deposits of our Sælabonn Formation in Ringerike would correlate with the upper parts of the Solvik Formation of Oslo and Asker. Present evidence (Fig. 5) rather suggests that marine depositional environments were rapidly established in the early Rhuddanian in all but the northernmost districts of the region, with coastal deposits of the Sælabonn Formation in western and southern



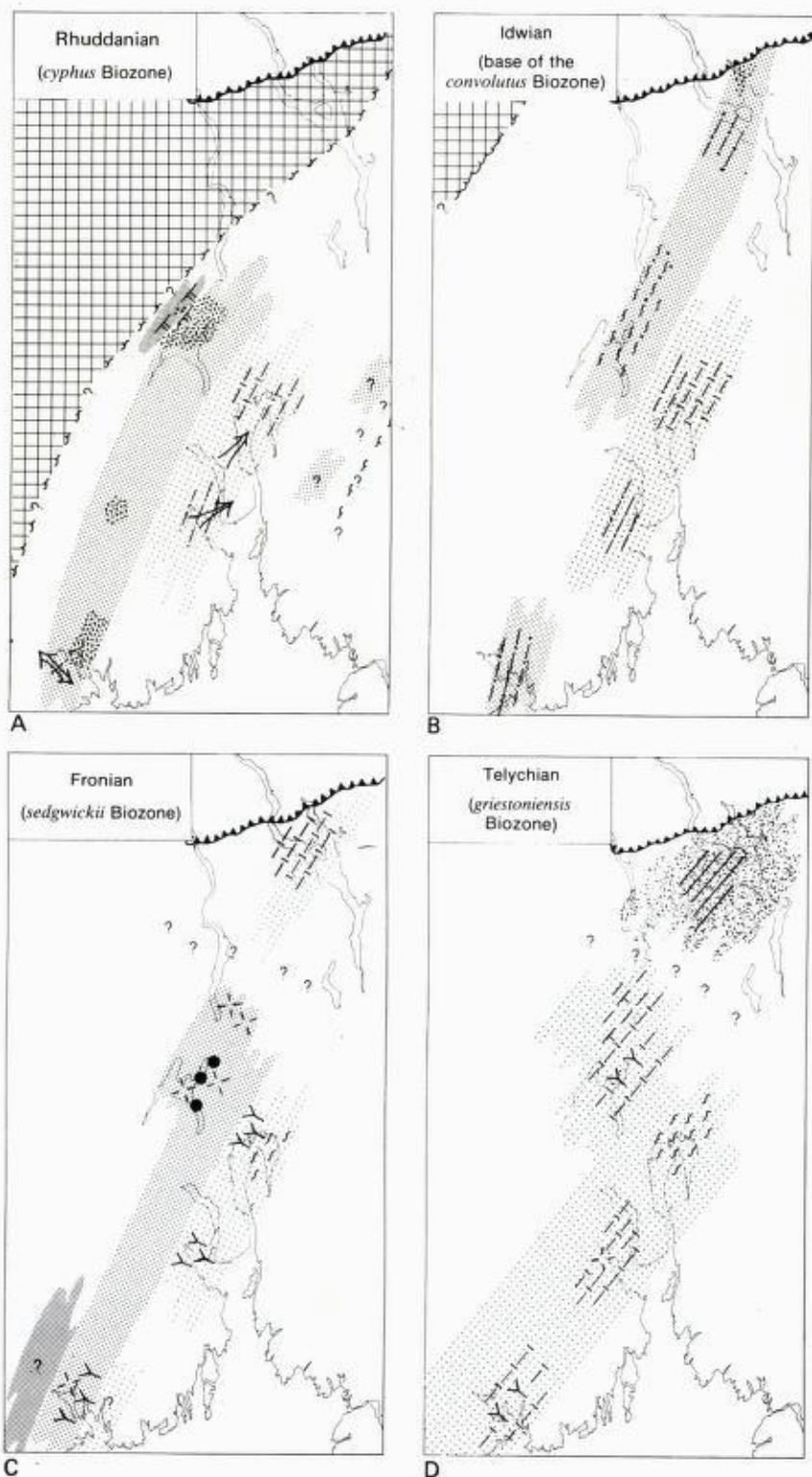
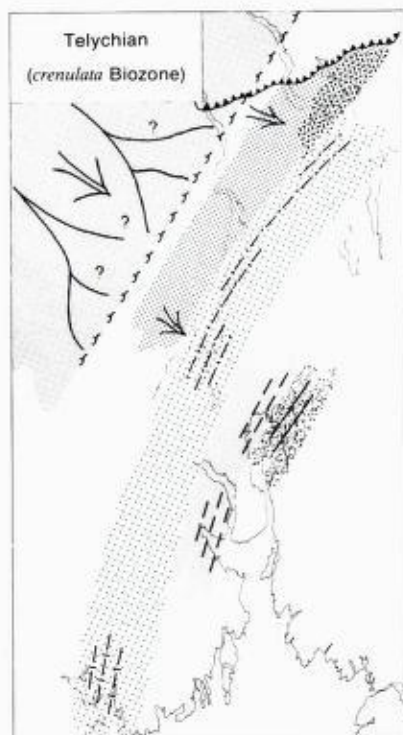
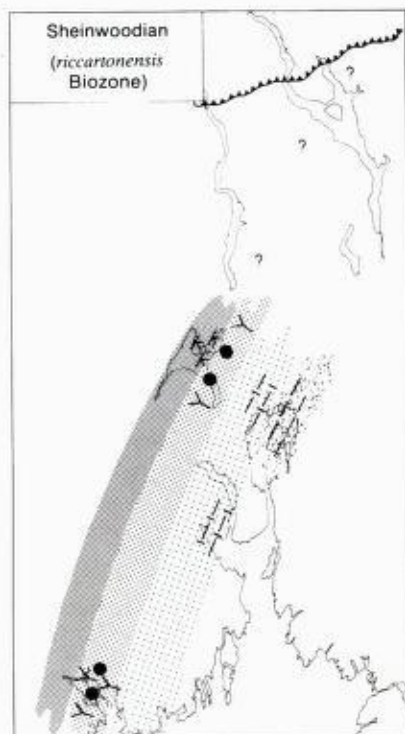


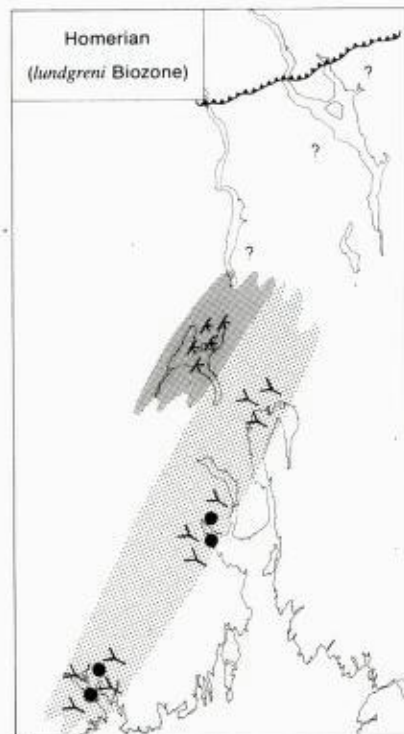
Fig. 20, a-b. 'Time-slice' maps showing lithofacies distributions near stage boundaries within the Llandovery and Wenlock. For legend, see Fig. 21.



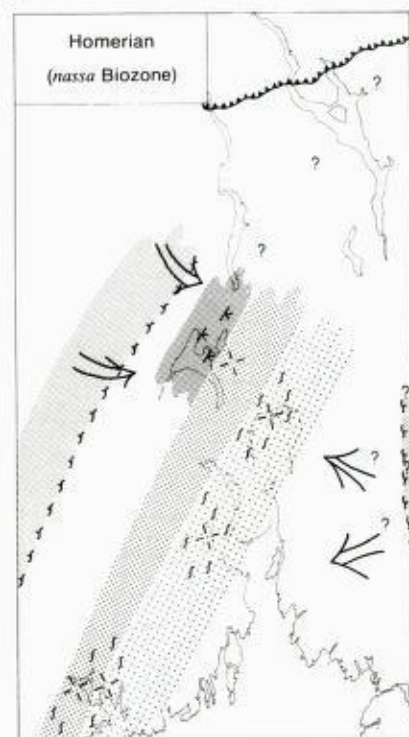
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

















MAIN FACIES BELTS		SEDIMENT TYPES/STRUCTURES	
	Exposed land areas		Sand- & siltstone
	Inferred fluviodeltaics		Bioherms
	Lagoon		Grainstones
	Shoals-inshore shelf		Packstones
	Offshore shelf		Calc. mud- & wackestones
	Slope		Interbedded shales and limestones
	Basin		Calcareous shale
	Shoreline		Marl & limestone
	Caledonian front		Grey shales
	Inferred current directions		Black shales
			Interbedded shales and silt-/sandstones
			Brackish water sediments
			Dolomites/evaporites

Fig. 21. Symbols used in Fig. 20.

districts passing eastwards into the distal environments of the shale-dominated Solvik Formation. A better understanding of the biostratigraphy of late Ordovician and early Silurian units in the Ringerike and Hadeland districts is necessary before this transgressive episode can be fully interpreted.

#### *Rhuddanian and early Idwian*

The development of the Sælabbonn Formation in the western and southern districts suggests that the transgression of these areas was followed by renewed coastal progradation in the late Rhuddanian, producing the massive sandstones seen in the middle of the formation. A renewed transgressive phase in the mid-Idwian is suggested by the fining-upwards sequence seen above these sandstones in Ringerike and Skien; this transgression resulted in an submergence of the northern districts and the deposition of the Helgøya Quartzite Member on karstic surfaces of the Mjøsa Limestone.

The shale-dominated Solvik Formation in the Oslo and Asker districts shows several noteworthy features. The lower parts of the Myren Member display relatively thick and frequent siltstone interbeds in their easternmost localities on Malmøya. Equivalent sequences in Asker contain thinner and less common siltstones with more frequent marly interbeds; both sediments and fauna suggest more distal, but probably shallower, depositional environments in Asker. In both Malmøya and Asker initial rapid transgression was followed by a gradual

shallowing until the mid-Idwian when a reverse geographical pattern of deposition then developed. Storm-generated siltstones deposited in low-energy mud environments are found in Asker but a more marly development on Malmøya contains faunas and sedimentary structures indicating shallower and (at least intermittently) wave-reworked bottom conditions. The transition to these upper developments of the Solvik Formation is relatively sharp in both areas; the apparently synchronous abrupt shallowing on Malmøya and deepening in Asker may have been caused by local block movements. The total facies mosaic seen throughout the Oslo Region supports this conclusion, as the transition apparently coincides with the mid-Idwian transgression of the northern districts. The Asker development can be understood within this mosaic, but the Malmøya sequence can only be explained by a contemporaneous slight uplift of the eastern parts of the depositional basin which produced more distal but shallower environments there. Exposures on Bjørkøya (Holmestrand) of the upper parts of the Solvik Formation are similar to Asker, although sedimentary structures and faunas suggest somewhat more proximal environments in Holmestrand.

#### *Late Idwian and Fronian*

The late Idwian development of the region shows the diachronous establishment of carbonate-dominated environments reflecting the gradual submergence of western and northern source areas. Ringerike, Hadeland and Skien retained their marginal marine character, with thinly interbedded bioclastic limestones and shales rapidly grading up into thick and massive bioclastic limestones. These were deposited on shallow shoals with mobile substrates repeatedly reworked by wave and tidal activity. Holmestrand, Asker and Oslo first became the site of carbonate-dominated deposition around the Idwian/Fronian transition. Although the massive bank developments observed further west are not seen in these more distal areas, a general coarsening and shallow-upwards trend marks the early Fronian development in these districts.

Small patch reefs found on the top of the bioclastic shoals in Ringerike indicate a mid-Fronian stabilization of those mobile bodies. Reef structures show several developmental stages from stabilization to diversification phases, but their growth was probably terminated by renewed rapid deepening and increasing influx of clay. Similar trends are seen in both central and southern districts.

The nodular limestone development of the Rytteråker Formation seen in the northernmost districts suggests more distal depositional environments with low sedimentation rates. The positive nature of the northern districts in the late Ordovician and early Silurian was now ended, presaging the marked subsidence of those areas in the early Telychian.

#### *Telychian*

The gradational top of the carbonate-dominated Rytteråker Formation is best dated in the northern districts, where overlying shales contain *maximus* to *crispus* Biozone graptolite faunas. The age evidence is more circumstantial in other areas, but the development of the uppermost Rytteråker Formation and the basal parts



of both the Vik and Ek Formations in all districts indicate both deepening depositional environments and increasing clastic supply around the Fronian/Telychian transition. A new sedimentational pattern now emerged: marked subsidence of the northern districts produced graptolitic shale environments which shallowed southwards into more calcareous sequences with both faunas and sedimentary structures suggesting more moderate depths of deposition.

Bentonites are found in the Ek, Vik and Bruflat Formations; these have previously been suggested as a means of precise correlation between various districts (Hagemann 1966). However, both our graptolite and other faunal evidence indicates that the bentonites rather represent a prolonged period of intermittent volcanic activity ranging throughout the *turriculatus* to *crenulata* Biozones. The local red colour of the Vik Formation's shales has earlier been interpreted as a result of deposition in continental environments (Hagemann 1957), an interpretation which cannot be supported by our faunal and sedimentological data. Whitaker (1965, 1977) interpreted these marine deposits as the weathering products of lateritic earths resulting from volcanic activity in the developing Caledonides. Bentonites do occur with red shales in the Ek Formation, but there are many other examples of marine red shales with no evidence of contemporaneous volcanism (and *vice-versa*). Whatever the *primary* source of the red shales, it is more interesting to consider the factors which have resulted in the preservation of primary red colours. Franke & Paul (1980) note that marine red shales always contain  $>2\%$   $\text{Fe}_2\text{O}_3$ , and consider that the reduction of primarily-deposited ferric iron complexes was prevented by the generally oligotrophic nature of such shales' depositional environments. These conclusions fit well with the occurrence of red shales in the Vik Formation: the red units contain sparse faunas while intercalated more fossiliferous and calcareous units are grey-green, possibly suggesting diagenetic reduction of primary red muds. Both the Vik Formation's red shales and similar Lower Palaeozoic units elsewhere have earlier been ascribed to 'deep shelf, basin and ocean floor' depositional sites (Ziegler & McKerrow 1975), and Silurian red shales in the Baltic area are found with *Clorinda* community representatives in outer shelf environments (Bassett *et al.* in press.). Although red shales in the Oslo Region are associated with somewhat shallower bottom conditions than those suggested by Ziegler & McKerrow, known occurrences *are* found in areas marginal to the contemporaneous graptolitic basin facies development of the northern districts.

The transition from the Ek or Vik Formations to overlying units is clearly diachronous and Malmøya in the Oslo district is the only locality where this transition approximates to the Llandovery/Wenlock boundary. In Ringerike and northern districts we date the transition to the Bruflat Formation as lower  $C_6$  or base *crenulata* Biozone. Contrary to previous assumptions we now know that the Bruflat Formation is almost entirely of Llandovery age, with only the uppermost beds possibly extending into the Wenlock. This suggests very high rates of sedimentation for the Bruflat Formation in the late Telychian – especially in the northern districts – and prompts a closer examination of the formation's depositional environments. Bjørlykke (1974a:27) suggested a probable 'delta

slope environment with deposition of distal turbidites' and later (Bjørlykke *op.cit.*:31) he envisaged the unit as representing 'a true deltaic facies' reflecting '... the initiation of a period of delta sedimentation, which gradually filled up the shallow sea with clastic sediments'. Although the lower parts of the formation in the type area in Toten do show features which may be compatible with Bjørlykke's model, its upper parts rather suggest that an initial rapid progradation with high sedimentation rates was followed by stabilization and the establishment of a wave-dominated clastic shelf environment characterised by extensive reworking of sediments and faunas in the uppermost Telychian. Initial progradation rapidly filled the foredeep established during the Fronian in the northern districts but this was followed by a change in depositional regime; neither delta top nor coastal environments are suggested by the uppermost development of the formation in the northern districts.

The Bruflat Formation in the Ringerike district shows a somewhat similar (although thinner) coarsening and shallowing-upwards sequence to that seen in the type area. Siltstones and shales deposited below storm-range wave base grade up into wave-reworked sandstones and siltstones with minor shales. The faunas also suggest a shallowing-upwards trend, but the most proximal faunal associations seen are only typical of Benthic Assemblage 4 of Boucot 1975. Neither sediments nor faunas suggest any appreciably more distal development in Ringerike than that of the northern districts. Thus the Bruflat sandstone reflects a major easterly to southeasterly directed progradation of a coastline lying west of both Ringerike and the northern districts. This progradation infilled the northerly basinal areas but depositional equilibrium was rapidly established, with the development of a wave-reworked platform in both areas. The subsequent development of the northern districts is conjectural in the absence of proven younger Silurian deposits. The break in deposition marking the top of the Bruflat Formation in Ringerike suggests a short period of emergence around the Llandovery/Wenlock boundary prior to the establishment of marginal marine carbonate environments in the Lower Wenlock.

The development of the Vik Formation in Holmestrand and Skien is essentially similar to that of Ringerike. The transition to the overlying Skinnerbukta Formation (penecontemporaneous with the Vik/Bruflat formational boundary in Ringerike) is also marked by a deepening trend in these other districts. However, although faunas in Skien suggest a subsequent shallowing in the uppermost Telychian, coarse clastic supply was negligible, and the sequence there consists of shales with minor calcareous siltstones and marls. A similar break in deposition to that seen in Ringerike occurs near to the Llandovery/Wenlock boundary in Skien. This part of the succession is both contact-metamorphosed and poorly exposed in Holmestrand. In the Oslo and Asker districts deposition of nodular limestones and marls assigned to the Vik Formation continued through most of the Telychian, with no signs of shallowing or break in deposition in the uppermost Llandovery. In contrast, the late Llandovery there was marked by continued deepening leading to deposition of the graptoliferous shales of the Skinnerbukta Formation.



In summary, the uppermost Llandovery was marked by subsidence throughout the depositional basin, with subsidence being most marked in the northern districts in the early to mid-Telychian. In these districts and in Ringerike we see a subsequent shallowing trend, with a major clastic progradation which terminated in the late Telychian. The Holmestrand and Skien districts were not at any time near any significant clastic source areas, suggesting relatively greater uplift of the northwestern basin margins closer to the developing Caledonides. The more gradual but continued deepening seen in the Oslo and Asker districts suggests that the total facies patterns reflect ongoing regional transgression coupled with local and differential tectonic movements along lineaments marking the western margins of the basin. These were responsible both for the northerly Bruflat development and for the short period of uplift seen near the Llandovery/Wenlock boundary in Ringerike and Skien. However, the continuing transgression produced first a cut-off in clastic supply and subsequently the development of carbonate environments along the western margins of the basin in the early Wenlock.

#### *Sheinwoodian and Homerian*

Previous interpretations of early Wenlock facies relationships through the region have been influenced by the assumption of a Wenlock age for the Bruflat Formation. Størmer (1967) therefore envisaged a 'period of unrest' at that time. Subsequent authors (e.g. Bjørlykke 1974a, Ramberg & Spjeldnæs 1978) considered the Bruflat Formation as representing the initiation of a continuing southwards deltaic progradation which culminated in the deposition of the Old Red sediments of the Ringerike Group. As we have noted previously, the Bruflat Formation represents a clastic influx which started and finished in the late Llandovery; there is no evidence that this depositional episode is the same as that which resulted in deposition of the Ringerike Group in the late Wenlock. Although Wenlock sequences are not preserved in northern districts, exposures in the rest of the region suggest the development of NW-SE trending carbonate facies belts with little clastic supply.

Marginal marine environments with reefs developed in the Ringerike and Skien districts, after a short and as yet undefined period of emergence in the early Sheinwoodian. This reef zone passes through more distal marly sequences in Holmestrand into basinal shales in Asker and Oslo; faunas in the latter districts suggest gradual deepening from restricted benthic environments in Asker to more pelagic conditions on Malmøya. The reefs of Ringerike are overlain by sediments with a restricted lagoonal nature, suggesting a regressive episode in the mid-Sheinwoodian, which produced the basinwards migration of reefs and banks to a belt passing through Holmestrand. These structures protected an extensive hinterland where the restricted shallow subtidal to supratidal facies sequences now preserved in Ringerike developed; the Asker and Oslo districts, meanwhile, continued to be the sites of more open marine depositional conditions. Small reef structures developed in the Holmestrand and Skien districts in the late Sheinwoodian and early Homerian. In Holmestrand a common feature is the occurrence of small patch reef cores in highly fossiliferous biostromes; these suggest the repeated

wave destruction of incipient reef developments and fully developed reef structures only occur in 9d following a marked transgressive episode in the mid-Homerian. Contrary to previous suggestions the Wenlock is *not* marked by any ongoing regressive trend; following regression in the mid-Sheinwoodian the area remained stable until the mid-Homerian when the short-lived *transgressive* development noted above produced the marine biostromes of the Favosites Limestone which occur interbedded with lagoonal deposits in Ringerike. The available evidence suggests that this sharp transgressive pulse was followed in the late Homerian by large-scale coastal progradation and the deposition of terrestrial red beds in Ringerike. This transition was probably diachronous, with red bed deposition commencing somewhat later in the Asker district. We have as yet no evidence of the age of the transition to red bed deposition further south in the region.

The Wenlock development of the Oslo Region was therefore not marked by continuous regression and coastal progradation. Depositional environments were characterised by low clastic supply and the establishment of stable carbonate platform environments subject to minor transgressive and regressive pulses. This pattern terminated in the late Homerian as a result of renewed large-scale regression and progradation. McKerrow (1979) has suggested a eustatic fall in sea level in several areas east of the Iapetus Ocean in the late Wenlock. A subsequent transgressive episode in the early Ludlow is not seen in the Oslo region as local uplift in this segment of the Caledonides transformed the entire depositional basin into a site of terrestrial sedimentation.

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