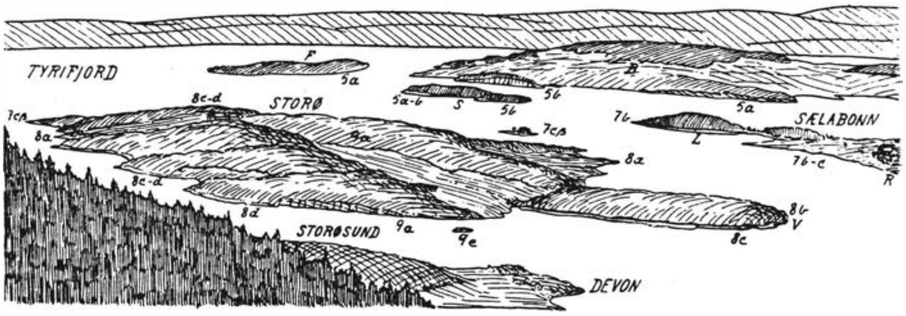

THE SILURIAN SUCCESSION OF THE OSLO REGION

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Cover figure taken from Kiær (1908) of Silurian exposures in Ringerike from "Kongens Utsikt".

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ABSTRACT

The marine Silurian succession of the Oslo Region is up to 650 m thick and displays a great variety of mixed clastic and carbonate lithofacies. We propose the replacement of the existing numerically based stratigraphical scheme for the succession by a series of formal lithostratigraphical units. The entire succession comprises two groups and eleven formations, all of which are defined and described herein. Our studies of the age relationships and depositional environments of these units permit a revised synthesis of the palaeogeographical evolution of the Oslo Region during the Llandovery and Wenlock. We also briefly review recent work on the Ludlow red bed deposits of the Ringerike Group.

1. INTRODUCTION

The marine Lower Palaeozoic succession of the Oslo Region is approximately 1,250 m thick and is overlain by an almost equally thick red bed sequence of late Silurian age. 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, Olaussen 1981). 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 syneclise which corresponded generally to the younger Permocarboniferous graben structure. Maximum subsidence occurred in the late Silurian and Størmer tentatively associated this syneclise with other basins of similar age along the southwestern and southern margins of the Baltic Shield (e.g. in Scania and Poland). An alternative, but not entirely conflicting, hypothesis by Ramberg (1976) rather suggests the development of an off-set series of 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 patchily exposed throughout the region between and beneath Permian intrusive and extrusive complexes. Interpretation of the original geographical relationships of present exposures is complicated both by Permian faulting and metamorphism and 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 lying immediately south of 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, well preserved 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 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 is particularly unfortunate as these deposits' developmental patterns clearly reflect important tectonic events in the neighbouring Caledonides and miscorrelations of the Oslo Region's Silurian succession have inevitably produced incorrect models for the penultimate development of the southern Norwegian sector of the Caledonian orogen. This situation has developed, ironically enough, within the present century as a result of the monumental work of Kiær (1908) which described in detail the marine Silurian succession of the Oslo Region; this work was impressive, not least because of its advanced interpretations of regional facies patterns and its impact was such that it has since been accepted as the definitive work on this part of the Lower Palaeozoic sequence. Much scientific activity has consequently been directed to Cambrian and Ordovician units and only isolated aspects of the palaeontology and geology of the Silurian succession have been described in the ensuing 70 years. Key reviews of the Silurian sequence in parts or all of the region are those of Henningsmoen (1960), Seilacher & Meischner (1964), Whitaker (1966, 1977), and Bjørlykke (1974). These and most other contributions (see our comprehensive bibliography) implicitly accepted the original stratigraphical scheme of Kiær (1908), although the results of some studies either questioned or altered some of Kiær's correlations (e.g. Henningsmoen 1954, Heintz 1969). However a reconnaissance survey by Bassett & Rickards (1971) demonstrated the diachronous nature of many of Kiær's units and clearly indicated the need for a revision of Kiær's stratigraphical scheme throughout the entire Oslo Region.

A study of the regional stratigraphy and depositional environments of the 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 the IGCP project 'Ecostratigraphy'. 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. Much of the basis for this paper consists of resulting unpublished information (partly collated in theses) collected both by the present authors and by other colleagues. The latters' information is acknowledged wherever appropriate, but we especially note here the contributions of R.J. Aldridge, B.G. Baarli and N.-M. Hanken. Work in progress makes it necessary to propose herein a lithostratigraphical framework for the entire sequence which accords with modern stratigraphical standards. We also present summaries of our biostratigraphical and sedimentological interpretations in order to give a broad review of 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 1974 a,b,c and Turner & Whitaker 1976).

2. 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 "Etagen" 6 to 9; although he did not study the overlying red beds, he assigned them to "Etage" 10 (Kiær op.cit. Profiltafel 1) which he defined as "Devonian sandstone and conglomerate". Kiær further 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. $6b\beta_1$). 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 fact lithologically based, and Kjærs 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 Zone 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 "series") and he also introduced some subdivisions - "zones" - 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, groups proposed by Kiær (1920) were redefined as "series" (Holtedahl 1953, Strand & Størmer 1955, Henningsmoen 1960). Strand & Størmer also introduced a lithostratigraphically based terminology for the northern districts of the region, based on information which was published subsequently by Skjeseth (1963). The resultant stratigraphical scheme for the Silurian rocks of the Oslo Region included subdivisions grouped into the Stricklandia ("Etage" 6) Pentamerus (7) and Lower (8) and Upper Spiriferid (9) "series".

Although recognizing the dual base for the definition of these units, Henningsmoen (1955) suggested that they could be assigned chronostratigraphical relevance, and this practice has been followed by most workers until recently.

"Etagen" 6 and 7 were originally correlated by Kiær (1908) with the British Lower and Upper Llandovery, "Etage" 8 with the Wenlock and "Etage" 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) would 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), conodonts (Aldridge 1979), and brachiopod phyletic lineages (Williams 1951, Ziegler 1966, Rubel 1977, Johnson 1979 and Mørk 1981). 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 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 "Etage" system we could, for example, retain these units, either by redefinition and adjustment of their boundaries or by recognition and tabulation of their informal and diachronous nature. However, we consider that such procedures would merely exacerbate 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 an interim period, especially prior to forthcoming detailed descriptions, where Kiær's minor subdivisions (e.g. 6bβ) may still have to be used within our formational framework: these should then be used only as local and informal descriptive terms and have no intraregional correlative significance.

In most districts the maps of Kiær (1908) provide an adequate basis for tracing our formational boundaries and so we do not present new geological maps showing the areal distribution of our formations throughout the region. Although we here redefine and 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. We therefore define in each case the equivalence of our formations to Kiær's numerical units in each district. An exception is the northern districts where Silurian exposures were only briefly described and not mapped by Kiær. In these districts we accept the proposals and summary map of Skjeseth (1963) and subsequent detailed mapping carried out by M.P.A.H. validates our approach.

Geographical nomenclature

Størmer (1953) divided the Oslo Region into eleven districts in his description of Ordovician stratigraphy and his terminology has been generally accepted in subsequent publications. Silurian outcrops are common in seven of these districts and we mainly adhere to Størmer's district boundaries. However, Størmer's "Oslo-Asker" district is here divided into the Oslo and Asker (i.e. Asker and Bærum) districts with boundaries defined by the respective local government areas (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 with no implicit facies connotations. This is explicitly stated here since Kiær discussed palaeogeographical relationships in terms of "eastern", "western" and "mixed" facies developments; our work indicates the inadequacy of such a simple palaeogeographical zonation.

Place 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 the NGO maps. The most important localities referred to in the text for the definition and description of our units are shown in Figs. 2 and 3.

New lithostratigraphical units

We here propose and describe eight new formations in the marine sequence studied; 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 (see p. 44) we also propose the establishment of the Bærum and Hole groups to embrace the entire complex of marine facies described below. The formational scheme proposed is presented in Figs. 4 and 5, which show both regional correlations and facies and thickness variations observed throughout the region. In Fig. 4 we also compare our units with Kiær's (1908) stratigraphical scheme in each district. Individual lithostratigraphical units are defined and described below. We also 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 largely reflects the present state of research. Future refinements will result in the definition of additional members to characterize the total facies mosaic present. Our synthesis is based on an examination of all districts within the region, but we should note that more detailed studies are required in the Skien district and in the Wenlock succession of Holmestrand. Closer inspection of small and often highly metamorphosed exposures in the Eiker and Lier districts should also give extra data to augment the depositional models we present here.

Brief and generalized environmental interpretations are presented for each formation. The use of benthic faunas in the environmental analysis of Silurian sequences was pioneered by Ziegler (1965) and Ziegler et al. (1968) who defined five brachiopod dominated "communities" with distributions which apparently parallelled the Llandovery coastlines of central England and Wales. Each was named after a typically occurring genus: - (from proximal to distal) the _Lingula_, _Eocoelia_, _Pentamerus_, _Stricklandia_ and _Clorinda_ "communities". Successors of these Llandovery faunal assemblages have subsequently been defined in the Wenlock and Ludlow of Britain (Calef & Hancock 1974, Hurst 1976 and Watkins 1979). A major point of debate has been the direct palaeobathymetrical significance of such recurring benthic assemblages. Some authors (e.g. McKerrow 1979) assert a direct relationship between "community" development and water depth, but detailed sedimentological studies suggest that varying faunal mosaics may be expected in different depositional regimes. Works by Anderson (1971, 1974) and Bridges (1976) suggest that the fivefold division originally proposed by Ziegler (1965) reflects the linear barred coastline developed in the Welsh Borderlands during the Upper Llandovery, the _Lingula_ and _Eocoelia_ "communities" inhabiting tidal and lagoonal environments behind pentamerid colonized banks and shoals; the _Stricklandia_ and _Clorinda_ "communities" were then developed in progressively lower energy shoreface and offshore shelf environments. In other situations, e.g. on a shelf influenced by a prograding deltaic coastline, a different benthic fauna mosaic may be expected. In each case, ecological structure and faunal distribution will reflect all limiting factors affecting a particular habitat. These factors, together with ecological interplay between individual species (and not only the single limiting factor of depth), will determine the structure of the resultant benthic faunas. Another serious weakness of the "community" concept which is commonly used for Silurian benthic faunas is that the "communities" described by many workers are larger units than those which most modern ecologists would term a community and Boucot (1975) proposed the term "Benthic Assemblage" which we consider useful to group the various communities (_sensu strictu_) which are found in a spectrum of proximal to distal marine situations from intertidal (B.A.1) to dominantly pelagic (B.A.6) environments. We will here adhere to Boucot's scheme prior to the completion of more detailed palaeoecological analyses which we hope will enable the definition of recognizable palaeocommunities in the sense of Kauffmann & Scott (1976).

The dating of each formation is only briefly discussed here using key faunal elements. Appreciable refinements of our correlations will result from biostratigraphical studies based on more detailed systematic sampling within each unit and district. In our comparisons with other areas within the Anglo-Baltic province we have found it natural to correlate our units with the standard stratigraphical scheme for the British Silurian sequence (Fig. 4, see Cocks, Holland, Rickards & Strachan 1971). Stages for the Wenlock Series which we use here were first proposed by Bassett, Cocks, Holland, Rickards & Warren (1975) and these have now been formally accepted as international standards (Martinsson et al. 1981). The status of the Llandovery stages proposed by Cocks, Toghill & Ziegler (1970) has not yet been formalised internationally but we find it useful to correlate our units with these local British divisions of the Llandovery Series.

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 are here assigned 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 earlier definitions of the lowermost occurrence of "Etage" 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 Formation on Hovedøya, Oslo district (p. 12) where it is conformable with the underlying rocks. In other districts the group's base corresponds to the base of our Sælabonn Formation. The base of the group in these latter districts is locally 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 area (Fig. 5). 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 "Etage" 8b and 8c as defined by Kiær (1908). As discussed later (p. 35), 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, becoming younger 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 "Etage" 6 of Kiær (1908) in the Oslo, Asker and Holmestrand districts. The Solvik Formation is characterized by dominant shales with very thin to thin* siltstone and limestone intercalations. All quantitative terms for describing bedding used herein follow the scheme of Ingram (1954). Variation in these components (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 stratotype for the base 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 on the east (NM988380) and west (NM981377) coasts of Malmøya respectively; the top of the formation is seen in the latter section at Solvik.

\- * All references to bed thicknesses used herein follow the scheme proposed by Ingram (1954).

The formation is thought to be approximately 190 m thick in its type area, but faulting makes an exact determination impossible.

The lower boundary is defined by the sharp contact between underlying calcareous sandstones of the Langøyene Sandstone Formation (Brenchley and Newall 1975, equivalent to 5b of Kiær 1897 and 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. 7). 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 6aβ and 6bα 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 malmoeyensis* characterize 6bα and 6bβ respectively (Worsley 1971).

The Padda Member corresponds in general to 6c of Kiær (1908) in the Malmøya area. Its name is derived from a small island northwest 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 calcareous interbeds above the highly shaly upper parts of the Myren Member. Characteristic faunal elements of the Padda Member are both in situ and reworked populations of *Stricklandia lens*; bryozans, corals and stromatoporoids are also relatively common.

The upper boundary of the Solvik Formation is gradational over about 2 m, but it is easily mappable in the type area. The dominantly shaly Padda Member grades rapidly into the thinly interbedded limestones and shales (in approximately equal proportions) of the overlying Rytteråker Formation (Fig. 6); the junction is taken at the first appearance of finely "nodular" limestone horizons assigned to the Rytteråker Formation. Bedding plane exposures show that most 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 at Spirodden (NM840338) contain both Stricklandia lens, abundant tabulate corals and stromatoporoids; these beds should be assigned to a new, as yet undefined unit with member status (B.G. Baarli pers. comm.). The significance of benthic algae in this unit at Spirodden was commented upon by Lauritzen & Worsley (1974) and Mørk & Worsley (1980). Kiær (1908) defined 6cβ in Asker as a 10 m thick shaly sequence which he assumed to be directly overlain by the limestones of "Etage" 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 "6cα" 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 (B.G. Baarli pers. comm.).

Only the uppermost 25 m of the Solvik Formation 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 which we assign to the Solvik Formation. Exposures through the uppermost parts of the Solvik Formation on Bjørkøya show similar shales and siltstones to those seen in the upper parts of the formation in Asker.

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 here of shallower environments with intermittent periods of both current and wave reworking of the sea floor. The storm generated siltstones seen "in 6cβ" 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

Rare graptolites and abundant brachiopods form the basis for our dating (Fig. 4). The nodular horizon which defines the base of the formation contains a sparse shelly fauna with Hirnantian aspects (Cocks in press). This passes up into shales with very sparse and non-diagnostic 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 is therefore immediately below the Ordovician/ Silurian boundary as taken at the base of the persculptus Biozone. Occurrence of subspecies of Stricklandia lens in the Asker district indicate that the top of the formation here approximates to the Idwian/Fronian transition (B.G. Baarli pers. comm.).

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 "Etage" 6 of Kiær (1908) in the Ringerike, Skien, Hadeland, Toten, Hamar and Ringsaker districts. Our definition incorporates the Helgøya Quartzite of Skjeseth (1963) as a local member in the two latter districts. The formation is approximately 110 m thick in the Sælabonn area, where it is characterized by varying proportions of sandstone, siltstone and shale. Sandstones dominate the middle part of the unit and lithological variation was apparently the main reason for Kiær's (1908) tripartite subdivision (6a, 6b, and 6c). Formal proposals for subdivision into three members approximately equivalent to Kiær's units will probably result from work in progress in the Ringerike area. (E. Thomsen pers. comm.).

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 also are exposed (Fig. 8). A reference section through the middle of the unit is exposed around Sandvika (NM696606) and its upper parts are well displayed in the basal stratotype for the overlying Rytteråker Formation at Limovnstangen (p. 19). The base of the Sælabonn Formation is defined on Store Svartøya at the sharp contact between crinoidal biosparites of 5b (with a karstic upper surface) and the silty shales with minor thin limestones and siltstones of the lower part of the Sælabonn Formation (Fig. 8). This 20 m thick development 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 uppermost 5b (Rønning 1979). Exposures north of Skien at Jønnevall in Gjerpendalen (NL 321708) 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).

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 "Etagen" 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. Although present exposures do not display the precise contact between these units, 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 his unit show a tripartite development similar to that of the Sælabonn Formation in the adjacent Ringerike 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 Ringerike.

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 here defined in a disused quarry at Vestby near Gjøvik (NN921379). The member is 9 m thick here (Fig. 10). The lower 5 m consist of medium to thickly bedded sandstones 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 Brumunddalen (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 an essentially similar depositional history to that of the type area. 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 regional 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 (E. Thomsen pers.comm.) and conodonts (R.J. Aldridge pers. comm.). 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 an equivalent of "Etage" 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 the name "Pentamerus Limestone" in a sense which conforms to our Rytteråker Formation, Kiær used the terms "Borealis and "Pentamerus" Limestones" to those restricted parts of our Rytteråker and overlying Vik formations which contain abundant pentamerids. This varying usage and the inherent nomenclatural confusion of bio- and lithostratigraphical properties prompt our rejection of the name "Pentamerus Limestone". The informal "Engen Limestone" proposed by Owen (1978) in the Hadeland district is here assigned to the Rytteråker Formation. Limestones assigned to the formation are approximately 50 m thick in the type area; Kiær's tripartite division (7a, 7bα, 7bβ) 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 in the basal stratotype of the overlying Vik Formation on the northern limb of a small syncline whose axis defines the northern coast of Limovnstangen (NM695596).

The basal stratotype shows a gradational development: interbedded thin to medium siltstones and shales here assigned to the Sælabonn Formation show increasingly common intercalations of limestone beds upwards. The base of the Rytteråker Formation is defined at the quantitative dominance of limestone contra siltstone intercalations (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 (7bα 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 (Kiær 1908, Hanken, Olaussen & Worsley 1979). The uppermost 17 m of the formation (7bβ of Kiær 1908) consist of planar limestone beds and well-bedded calcareous nodules with interbedded shales; the shale content increases towards the contact with the overlying Vik Formation.

Other occurrences

Although the character and content of the carbonates in the Rytteråker Formation vary from district to district, the unit can be traced throughout the Oslo Region. The formation thins markedly to the NE of the type area (Fig. 5); thickening to the ESE and S results in maximum observed thicknesses of 65 m in the Oslo and Asker districts and 80 m in the Skien district.

Exposures in the Hadeland district show a gradational base from 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. 24). 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.

The Rytteråker Formation shows somewhat similar developments in the Asker, Oslo, Holmestrand and Skien districts. 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 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 biosparite units seen in 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 these shoals' highly mobile substrates. Other districts show somewhat 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

The occurrence of the pentamerids Borealis and Pentamerus suggests a somewhat diachronous base for the Rytteråker Formation, ranging from the middle to late Idwian in the Ringerike and Hadeland districts to the late Idwian or early Fronian in the central and southern districts of the Oslo region (Mørk 1981). The transition to the Vik and Ek formations is dated by graptolite and brachiopod faunas in these overlying units (p. 25 and 27).

THE VIK FORMATION

Definition

The development of this formation is best demonstrated in widespread but discontinuous exposures throughout the Ringerike district. The most easily accessible sections are seen in roadside cuttings immediately east of Vik (NM715609), prompting our use of this formational name. The formation is generally synonymous with "Etage" 7c of Kiær (1908) in the Ringerike, Oslo, Holmestrand and Skien districts and with Kiær's 7bβ 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 7cα, 7cβ and 7cγ and 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 NW of Rytteråker Farm (NM695596). This section is marked by 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 transition from limestone to shale dominance 4 m below the lowermost occurrence of red shales.

- * "Red" units, referred to both 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 5GY6/1 of the same chart.

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 (NM6958). 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 articulated crinoid stems, 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 exposures in the road section near Garntangen display 19 bentonitic horizons which vary from a few mm to 12 cm thick (Fig. 12, 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 Pentameroides sp. 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. 12).

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 7cβ or the "Upper Pentamerus Limestone" by Kiær (1908). In the Skien district a 10 m thick shale sequence (Kiær's 7cα) passes up into nodular limestones and greenish grey marls; these are directly overlain by shales which we assign to the Skinnerbukta Formation (8a/b of Kiær 1908).

Exposures assigned to the Vik Formation on Malmøya consist of irregularly varying proportions of greenish grey shales and marls with finely nodular limestones. A notable feature is the widespread 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 7bβ 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 colouration of shales in the formation is developed only in the Ringerike and Asker districts. However, the apparent absence of both red colouration and bentonites in the Holmestrand and Skien districts may result from Permian contact metamorphism of the exposures in these areas.

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 formation in the Ringerike, Holmestrand and Skien districts 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 in the type area. A comparable unit in Holmestrand comprises a bioclastic shoal rich in pentamerid and coral debris. Several interpretations have been presented by previous workers to explain the local red colouration of the Vik Formation's shales. These will be discussed further below (p. 52).

Age

Our correlation of the unit is based both upon occurrences of the brachiopods Pentameroides and Costistricklandia and on conodonts (Aldridge pers. comm.). These brachiopods suggest that the Garntangen Member may be equivalent to low C_5 of the British sequence and the conodonts suggest a slightly older (C_4) age for the base of the Vik Formation. A markedly diachronous top is suggested, ranging from mid C_5 equivalent in Ringerike to late C_6 on Malmøya (Fig. 4).

THE EK FORMATION

Definition

This 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 graptolitiferous) shales. We consider the Ek Formation to comprise all units assigned by Kiær (1908) to "Etage" 7c in the Hadeland, Toten, Hamar and Ringsaker districts and we retain Skjeseth's (1963) concept of the formation. Exposures in the Hadeland district show a transitional development to the Vik Formation of Ringerike 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 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 shales with bentonites appear to have been secondarily reddened, probably during Permian times. Small exposures of dark grey graptoliferous shales are also seen in railway cuttings in the Toten district around Bruflat (NM875238 and NM877257).

The base of the unit was exposed in 1977 in a temporary exposure in a trench at Stor-Kyset (NM907297), 2.5 km east of Reinsvoll in Toten. The top of the Rytteråker Formation was marked there by a 55 cm thick red nodular limestone; this was overlain by a 20 cm thick bentonite, followed by greenish grey shales and bentonites with some graptolite horizons. Exposures in Hadeland (railway cuttings at Netberg, NM842851 and Gunnstad, NM787844) indicate a similar thickness to that seen in the type area and a basal hypostratotype is defined at the former (Fig. 13). The base of the formation there is marked by red shales (7c of Kiær) overlying grey nodular limestones of the Rytteråker Formation. The lower part of the Ek Formation consists of alternating greenish grey and reddish shales with occasional bentonitic horizons, sparse shelly fossils and occasional thin black graptoliferous horizons. The remainder of the formation consists of greenish grey and red shales with finely nodular limestone horizons.

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

Well preserved graptolites indicate a maximus Biozone age for the base of the Ek Formation in its hypostratotype in Hadeland. A good turriculatus Biozone fauna is seen 5 m above the base of the formation. Two poorer faunas 3 and 3,5 m above the base suggest a probable correlation with the maximus Biozone. A basal crenulata Biozone age is suggested by graptolites from the top of the unit in Hadeland; sparse shelly faunas support this conclusion, indicating an equivalence to the C_5/C_6 transition. The base appears to be progressively younger and the top progressively older northwards (Fig. 4) through the Toten and Hamar districts.

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 the

Toten, Hamar and Ringsaker districts, with its name derived from Bruflat (NN877256) in the Toten district. Kiær (1922) introduced the term "Mariendal Series" for rocks which we assign to this unit in the Ringsaker district; however, that term has never been widely used, whereas the Bruflat Formation is now generally accepted. The informal term 'Marienberg Beds' was used by Ramberg and 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 the Ringerike and Hadeland districts.

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 where various parts of the unit are exposed. 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 in the order of 400-550 m is suggested (Fig. 14). The formation is characterized 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. At the top of the formation there is a gradational contact with red shales here assigned to the Reinsvoll Formation in an exposure on the western margin of the type area, (see p. 31).

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-PN0758)). At Bjørgeberget (PN0555) reddened shales uppermost in the Bruflat Formation yield a fauna with Cyrtia exporrecta (Kiær 1922). In Hadeland approximately 125 m of the formation are exposed; neither the top of this unit nor any younger units are preserved in this district. However, comparison with the adjacent Ringerike district 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 demonstrate an attenuated development of the Bruflat Formation in this district. A composite reference section can be studied on the islands of Purkøya and Storøya. The base is seen on the NW coast of Purkøya (NM688571), the middle parts in good but discontinuous exposures on Storøya (NM691571 to NM690574) and the top is exposed at Vintergututangen, 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 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 graptolitic 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).

In the Ringerike district the formation shows a similar coarsening (and shallowing) upwards trend to that seen in the type area. Stormgenerated 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 uppermost beds still contain these marine faunas and the erosive contact with the overlying Braksøya Formation is noteworthy. Clasts of the underlying 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 "Etagen" 8 and 9 of more southerly areas and subsequent workers (e.g. Størmer 1967, Bjørlykke 1974) 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 Zone). 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 at the same stratigraphical level. It is now clear that the cyrtograptids did not originate from this locality, and graptolites found in 8a and 8b at Ringerike (Monograptus vomerina vomerina and M. parapriodon) suggest correlation with the crenulata Zone (Rickards 1976). Aldridge (1974) described an amorphognathoides assemblage of conodonts from 8b in Ringerike; this conodont assemblage ranges into the early

Wenlock, but the associated occurrence of the brachiopods Costistricklandia lirata lirata, Cyphomenoidea wisgoriensis, Protomegastrophia walmstedtii and of the rugose coral Palaeocyclus porpita suggest a Telychian age.

Both conodont and brachiopod shelly faunas now 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 "Cyrtia 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 has only been identified with certainty 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-porphyry lavas and by the Brumunddal Sandstone (Kiær 1922, Rosendahl 1929) of probable Permo-Triassic age. The junction, seen at several places on Bjørgeberget (PN05555) 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 NW coast of Malmøya in the Oslo district. The Skinnerbukta Formation corresponds to "Etagen" 8a and 8b of Kiær (1908) in the Oslo, Asker, Modum, Holmestrand and Skien districts. 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. The nodules are larger and the limestone beds thicker than those usually seen in the Vik Formation, but these beds are here assigned to that formation. The overlying dark grey shales of the Skinnerbukta Formation contain occasional very 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 (see below). 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 individuals of Eoplectodonta transversalis.

Other occurrences

The formation is also exposed at several localities in the Asker, Holmestrand and Skien districts. Exposures at Bærum in the Asker district (Øverland, NM876449, Jong 846404 and Gjettum NM850022) suggest a thickness of 90 m; shales there contain both graptolites and low diversity benthic faunas. Exposures on Kommersøya (NL750990) and at Sando (NM740013) in the Holmestrand district are metamorphosed, but a more diverse benthic fauna with several taxa of both brachiopods and trilobites are seen, while graptolites are rare. Exposures in the Skien district (e.g. around Kapitelberget, NL 367628) mark the continuation of this sedimentological and ecological gradient; limestones are more common, and form distinct horizons (often bioclastic lenses) in the upper part of the unit. Benthic faunas here show a moderate diversity and approach an ecological structure similar to that seen in the upper parts of the Bruflat Formation of Ringerike. However, the absence of coarse clastic material leads to the assignment of this sequence to the Skinnerbukta, rather than to the Bruflat Formation.

Depositional environments

In its type area, the Skinnerbukta Formation was 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 in Skien 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 become 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 and its upper parts may 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 mckenzii).

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 and comprises the carbonate-dominated sequences found in 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 "Etage" 8c of Kiær (1908). In the Ringerike, Modum and Skien districts this corresponds to the base of our Braksøya Formation and the boundary stratotype for the base of the Hole Group is that defined below for the Braksøya Formation on Braksøya in the Ringerike district. The junction with the 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 and 240 m respectively in the Ringerike and Asker districts, thinning southwards to 120 m and 170 m in the Holmestrand and Skien districts. 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 "Etagen" 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 a large-scale regional diachronism for the junction between the Hole Group and the overlying Ringerike Group (e.g. Spjeldnæs 1967, Bjørlykke 1974 and Ramberg & Spjeldnæs 1978). We still lack adequate biostratigraphic documentation of such a relationship (see p. 40).

THE BRAKSØYA FORMATION

Definition

The formation is best demonstrated on the west coast of Braksøya (NM727610) in the Ringerike district, 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 "Etagen" 8c and 8d of Kiær (1908) in the Ringerike, Modum and Skien districts. We provisionally subdivide the formation into two informal members, pending the results of work in progress by S.O. and N.M. Hanken.

The base of the Braksøya Formation in its type section is defined immediately above the clearly-defined eroded top surface of the Bruflat Formation. Small sandstone and shale clasts are seen in the basal limestone development of the Braksøya Formation. The lower biohermal member is 17 m thick and is characterized 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 elements in the reefs' structure (Hanken, Olaussen & 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 sulphate pseudomorphs after celestite or gypsum are also seen in the marly sequence. The upper part of this member consists of a 3.5 m thick, black, bituminous shale with *in situ* tabulate corals and stromatoporoids; individual colonies over 1 m^3 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 reef and marl components of the lower member of the formation show variable local developments, and in some exposures this member consists of only one of these components.

Exposures in the Modum and Skien districts are provisionally included in the Braksøya Formation. A lower biohermal member is well developed in both districts (especially at Kapitelberget, NL 367628 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 periodical 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 here 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 the Holmestrand and central districts (Fig. 5).

THE MALMØYA FORMATION

Kjerulf (1857) introduced the term "Malmøya Limestone and Shale" (his Etage 8) for exposures on Malmøya in the Oslo district. Kiær (1908) assigned the lower (more shaly) part of Kjerulf's unit to "Etage" 8c and the upper massive limestones to "Etage" 8d; he applied the term "Malmøkalk" both to the latter limestones and to units which he assigned to 8d in the Bærum, Holmestrand and Skien districts. 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 (1857) original designation; both Kiær's (1908) term "Malmøkalk" and subsequent application of this term only to the upper part of Kjerulf's unit are therefore rejected. Our use of the Malmøya Formation corresponds to "Etagen" 8c and 8d of Kiær (1908) in the Oslo, Asker, Eiker and Holmestrand districts.

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 hypostratotype 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 slightly 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 horizons, all with interbedded shales. These grade up into thickly to massively bedded biosparitic limestones and the faunal diversity increases with increasing limestone content. 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 biosparrudites 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, the unit shows a grading up from interbedded limestones and shales into thickly bedded limestones with coral biostromes and biosparrudites.

Depositional environments

Thinly-bedded limestones in the lower parts of the formation are interpreted as storm-generated units deposited distally to carbonate shoals 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 the progradation of these carbonate shoals over the basinal 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 on Malmøya is younger than the *riccartonensis* (possibly early *rigidus*) Biozone upper graptolitic shales of the underlying Skinnerbukta Formation. Faunal elements within the Malmøya Formation have a general, but nondiagnostic Wenlock aspect; conodonts found in Kiær's 8d may however make more detailed correlations possible (R.J. Aldridge pers. comm.). The brachiopod *Eocoelia angelini* occurs in the lower parts of the formation (8c) at Gjettum 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 (Kiær's 8c) are considered to be time equivalents of the upper parts of the Braksøya Formation of Skien (Kiær's 8d) and the basal unit of the Steinsfjorden Formation in Ringerike (Kiær's 9a). The basal units of the Malmøya Formation on Malmøya are somewhat younger and are correlated with Kiær's 8d in Holmestrand and Asker, 9a in Skien and 9b in Ringerike. The age of the transition between the Malmøya and Steinsfjorden formations in the Asker and Holmestrand districts 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 Loretangen (NM728637) and representative sections through the formation are seen northwards along the coast to Brattstad (NM3668) and on Herøya (NM7363). The upper 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 grey-green shales and marls, red dolomitic shales, dolomites and limestones. Variation in these components forms the basis of a subdivision into three members proposed by Olaussen (1978). The formation corresponds to "Etage" 9 of Kiær (1908) throughout the Oslo Region, and we here assign outcrops preserved in the Ringerike, Asker, Eiker, Modum, Holmestrand and Skien districts to this unit.

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. Olaussen (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 limestones are common; the fauna shows a low diversity, with a high proportion of euryhaline elements and often high individual abundance. A noteworthy eurypterid fauna (Størmer 1934, 1938) occurs together with algae (Höeg & 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 ripplemarks. 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 40 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 the Asker, Modum and Skien districts. The biostromal "Favosites Limestone" of Kiær (1908) can be found in all these districts in the upper part of the formation.

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 are marked by the deposition of thin biostromal banks. The presence of early diagenetic dolomite and celestite suggests arid conditions in the type area (Olaussen 1978 & 1981b). The lower and upper parts of the formation in other districts were deposited in similar peritidal environments, but the unit's middle parts suggest more open subtidal environments 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, which for a short time resulted in normal marine conditions throughout the Oslo Region, prior to a regional regression which culminated in the deposition of the overlying red beds of the Ringerike Group.

Age

The units 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 Steinsfjorden Formation becomes younger progressively from Ringerike through Holmestrand and Skien to the Asker district (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 the Asker district and of the upper parts of the Malmøya and Braksøya formations in the Holmestrand and Skien districts 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 prep.) 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 (9d) have a Sheinwoodian character, and faunas elsewhere have a general Wenlock aspect. We have therefore no biostratigraphic data to test the sedimentological models of Spjeldnæs (1966) and Bjørlykke (1974) which suggest a regionally diachronous contact with the overlying Ringerike Group, becoming younger from Ringerike towards the ESE and S; work now in progress on thelodonts from the Asker district (S. Turner pers. comm.) may resolve this question.

THE RINGERIKE GROUP

We will here summarize the development of the nonmarine red beds which overlie the Steinsfjorden Formation in the Ringerike, Asker, Holmestrand, Eiker and Skien districts. In all these districts the red beds assigned to the Ringerike group have a conformable and gradational contact with the Steinsfjorden Formation. The Ringerike Group is uncomformably overlain by sediments (the Asker Group of Dons & Györy 1967, Henningsmoen 1978), or lavas generally thought to be of Permian age, although fusulines found recently in the Asker Group have a late Carboniferous aspect (Olaussen 1981a).

Kiær (1908) assigned the red beds of Ringerike to "Etage" 10 and suggested a Devonian age. There is a "Downtonian" fauna of agnathans, crustaceans and eurypterids in the lower parts of this red bed sequence (Kiær 1911, Kiær 1924, Hanken & Størmer 1975). Agnathans have also been described from similar red beds on Jeløya on the eastern side of outer Oslofjord in the Holmestrand district (Kiær 1931, Heintz 1974). The entire red bed development was for many years assigned to "Etage" or stage 10 in most works (e.g. see review of Henningsmoen 1960), but later workers have assigned the sequence either to the "Ringerike Formation" (Spjeldnæs 1966), the "Ringerike Sandstone Series" (Whitaker 1966) or to the "Ringerike Sandstone" (Heintz 1969). Studies of various aspects of this red bed development have been presented by Whitaker (1964, 1965, 1966, 1980), Turner (1974a, b, c) and Turner & Whitaker (1976). These studies have been chiefly directed towards the Ringerike district, although Turner (1974a) and Turner & Whitaker (1976) also presented information on the Asker and Holmestrand districts.

Turner (1974a) proposed the Ringerike Group to embrace all red bed units earlier assigned to "Etage" 10 in the original sense of Kiær (1908). The group comprises a 1,250 m thick sequence of red siltstones and sandstones in its type area in the Ringerike district. Turner (1974a) also defined the Sundvollen (lower 500 m) and Stubdal, (sic, 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, interpreted by Turner as deposited in estuarine and coastal alluvial plain environments. The Stubdal Formation's type section in Stuvdal (NM 7766) is dominated by sandstones (with intra-formational conglomerates), reflecting deposition by braided stream systems prograding over the more fine-grained deposits of the underlying formation. Both palaeocurrent indicators and the petrology of sandstones in both formations suggest drainage systems with sources to the N and NW of the present Ringerike district in the developing Caledonides (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 increasing pre-Permocarboniferous 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 is only 500 m. The Sundvollen Formation is 100 m thick and consists of siltstones and mudstones with minor sandstones. The Stubdal Formation consists of finergrained sandstones than those seen in its type area, although the mineralogical content is similar both in Ringerike and Asker.

The Holmestrand Formation of Turner (1974a) is exposed on both the east (on Jeløya) and west (around Holmestrand) coasts of outer Oslofjord in the Holmestrand district. Turner defined the type section of the formation between Engenes and Smørstein (NL723999) in the Holmestrand area, and assigned all pre-Permocarboniferous red bed units in the area to this formation. 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, both clast composition and sandstone mineralogy suggesting the erosion of Pre-Cambrian basement complexes to the east of the Oslo graben. This interpretation contrasts with the results of other workers (F. Andreasen pers. comm.) which suggest deposition of the Holmestrand Formation on coastal floodplains with palaeocurrent directions from the NW. A further complication is that recent studies of the junction between the Ringerike and Asker groups (Espejord 1979, Olaussen 1981a) suggest that some of the red beds previously assigned to the Ringerike Group in the Holmestrand district may be of Permocarboniferous age. We note here that late Carboniferous fusulines have been found recently at Jeløya in a limestone clast from beds earlier assigned to the upper part of the Holmestrand Formation (Olaussen 1981a) so that more detailed work is clearly necessary. Studies of the metamorphosed exposures of a 300 m thick sequence generally assigned to the Ringerike Group in the Eiker and Skien districts 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 considered to indicate a nassa Biozone age, these lowermost red beds could be of Wenlock age. Turner (1974a: 111) considered the Holmestrand Formation of the Holmestrand district to be age equivalent to the Stubdal Formation of Ringerike. 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 G. Henningsmoen contains a plectambonitacean brachiopod and a single poorly preserved chitinozoan with "a general Ludlow aspect" (S. Laufeld pers. comm.). Agnathans found on Jeløya (NL953923) suggest an early Downtonian age (Heintz 1974), but these finds are from the upper parts of the Holmestrand Formation. The combined 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).

3. SYNTHESIS

Our correlations and environmental interpretations of the proposed formational units permit a synthesis 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 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 rather reflect glacioeustatic 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 and 1979, Rønningen 1979). The central districts show a complex of NE-SW trending sandy and oolitic shoals (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 the 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 district), 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 (1974b) envisaged this area as consisting of a positive arch with sand shoals separating the Oslo Region's syneclise from the geosynclinal development to the west. Brenchley et al. (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 syneclise, with the Ashgill regression producing progradation over both the western and eastern margins of the depositional basin.

The early Silurian transgression of the Oslo region

The 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 immediately over the formational contact; this transgression may be related to the melting of the Gondwanaland ice-cap at this time (Brenchley & Newall 1980). Graptolites suggest that this 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 1974) 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. 4) suggests that the early Rhuddanian transgression rapidly established marine depositional environments in all but the northernmost districts of the region, with coastal deposits of the Sælabonn Formation in western and southern 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 the early Silurian transgression of the Oslo Region can be fully interpreted.

Rhuddanian and early Idwian

Most districts of the Oslo Region were inundated during the early Rhuddanian, producing a regionally coherent facies mosaic with marginal marine deposits of the Sælabonn Formation grading into the more distal shales of the Solvik Formation. The development of the Sælabonn 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 the Ringerike and Skien districts; this transgression resulted in in 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 over all of the Oslo Region supports this conclusion as this 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 development 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 shallowing 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 stabilization of these mobile bodies in the mid-Fronian. 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 seen in the northernmost districts suggests distal depositional environments throughout the Rytteråker Formation; the of elevation of the northern districts in the late Ordovician and early Silurian was now ended, presaging the more 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 turriculatus 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 marl and shale facies, with both faunas and sedimentary structures suggesting more moderate depths of deposition.

Bentonites are found in both the Ek and Vik 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 suggests that the bentonites rather represent a prolonged period of intermittent volcanic activity throughout the turriculatus and crispus zones. The local red colouration of the Vik Formation's shales has earlier been interpreted as a result of deposition in continental environments (Hagemann 1966), an interpretation which cannot be supported by our faunal and sediment-ological data. Whitaker (1965, 1977) interpreted these marine deposits as the weathering products of lateritic earths resulting from basaltic eruptions in the 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 produced the preservation of primary red colouration. Franke & Paul (1980) note that marine red shales always contain > 2% Fe_2O_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 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), while Silurian red shales in the Baltic area are found with Clorinda community representatives in outer shelf environments (Bassett 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 and Vik formations to overlying units is diachronous and Malmøya in the Oslo district is the only locality where the top of either of these units approximates to the Llandovery/Wenlock boundary. In Ringerike and northern districts we date the transition to the Bruflat Formation as lower C6 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 in the Ringsaker district. 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 (1974:27) 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 suggest rather that an initial rapid progradation with high sedimentational rates was followed by stabilization and the establishment of a wave dominated clastic shelf environment and 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, and 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 and 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 junction with the overlying Skinnerbukta Formation (penecontemporaneous with the Vik/Bruflat Formation 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, the 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 throughout most of the Telychian, with no signs of shallowing or break in deposition in the uppermost Llandovery. In contrast, the Llandovery/ Wenlock boundary there is marked by continued deepening, and deposition of the graptolitic shales of the Skinnerbukta Formation.

In summary, the Telychian was marked by subsidence throughout the depositional basin, with the 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 to 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 Brüflat 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

Earlier 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" then. Subsequent authors (e.g. Bjørlykke 1974, Ramberg & Spjeldnæs 1978) considered the Bruflat Formation as representing the initiation of a continuing southwards deltaic progradation which culminated in the deposition of "Old Red type" 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 with the restricted shallow subtidal to supratidal facies sequences now preserved in Ringerike, while the Asker and Oslo districts 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 probable 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 Holmestrand area apparently emerged as a result of progradation from the eastern margin of the depositional basin (Turner & Whitaker

1976). Fish occurrences on Jeløya, used previously to support a gradual southerly progradation, occur in the upper parts of the red bed sequence and their Downtonian age gives only an upper limit to the age of the transition from marine to continental deposition in this area.

The Wenlock development of the Oslo Region was therefore not marked by continuous regression and red-bed 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 drop 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 because of local uplift in this segment of the Caledonides so that the entire depositional basin became the site of terrestrial sedimentation.

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FIGURES

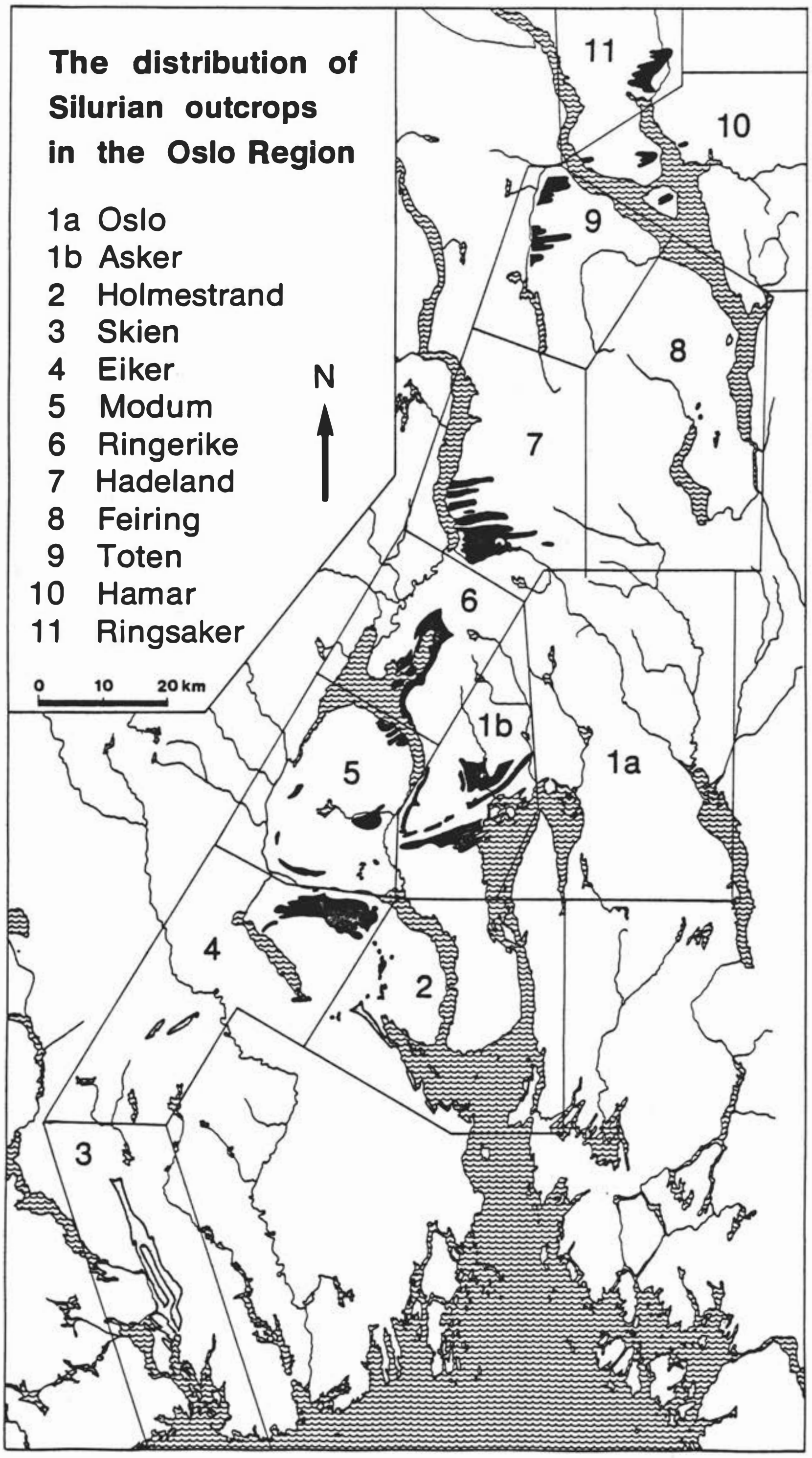
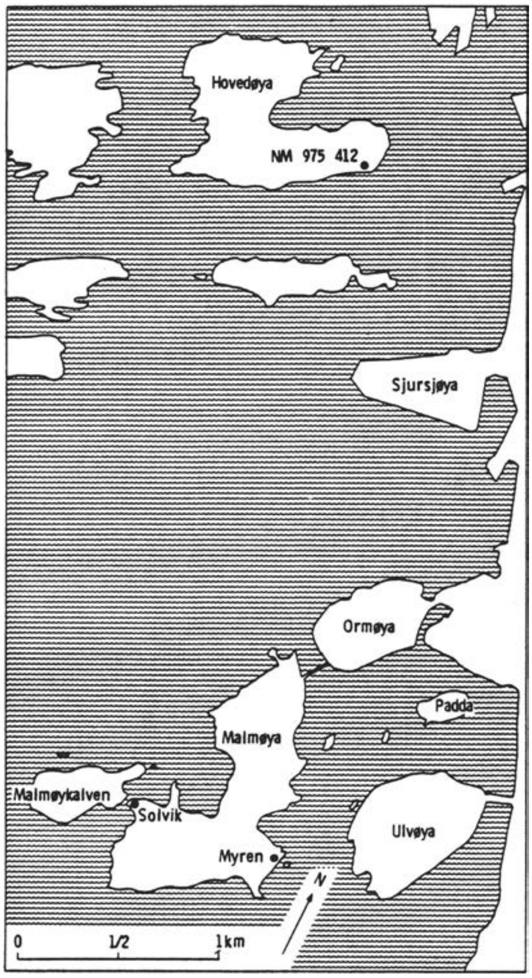


Fig. 1 Silurian outcrops of the Oslo Region showing the districts referred to herein (modified from Størmer, 1953). Progressively paler shadings reflect decreasing deformation southwards.



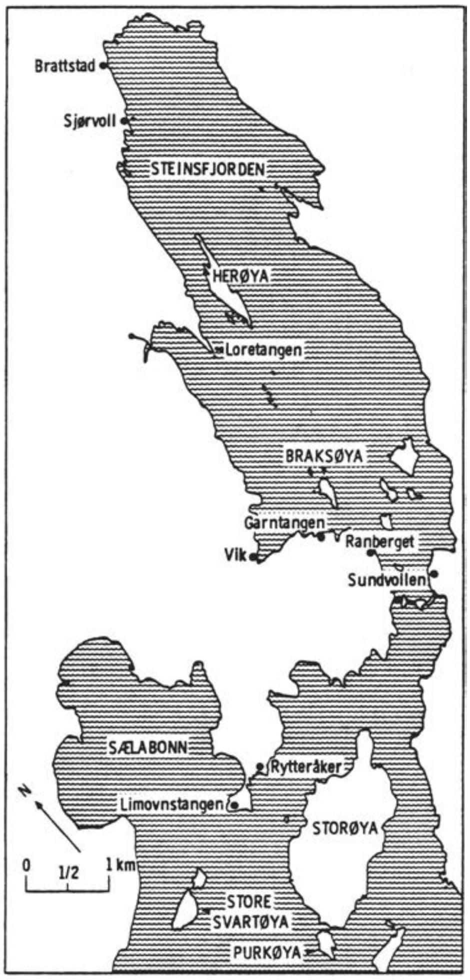


Fig. 2 a, b Maps showing key locations of exposures in the Oslo and Ringerike districts.

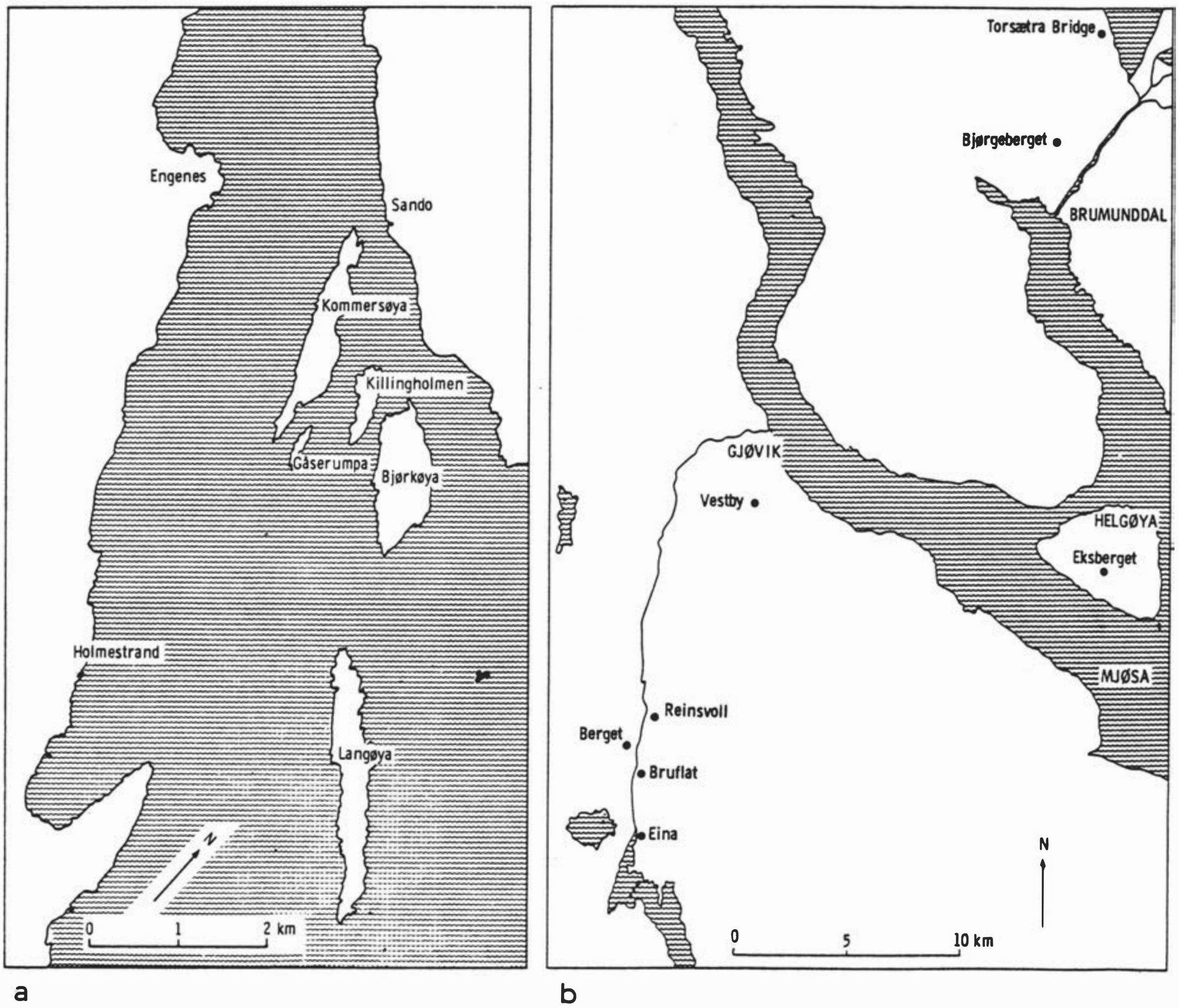
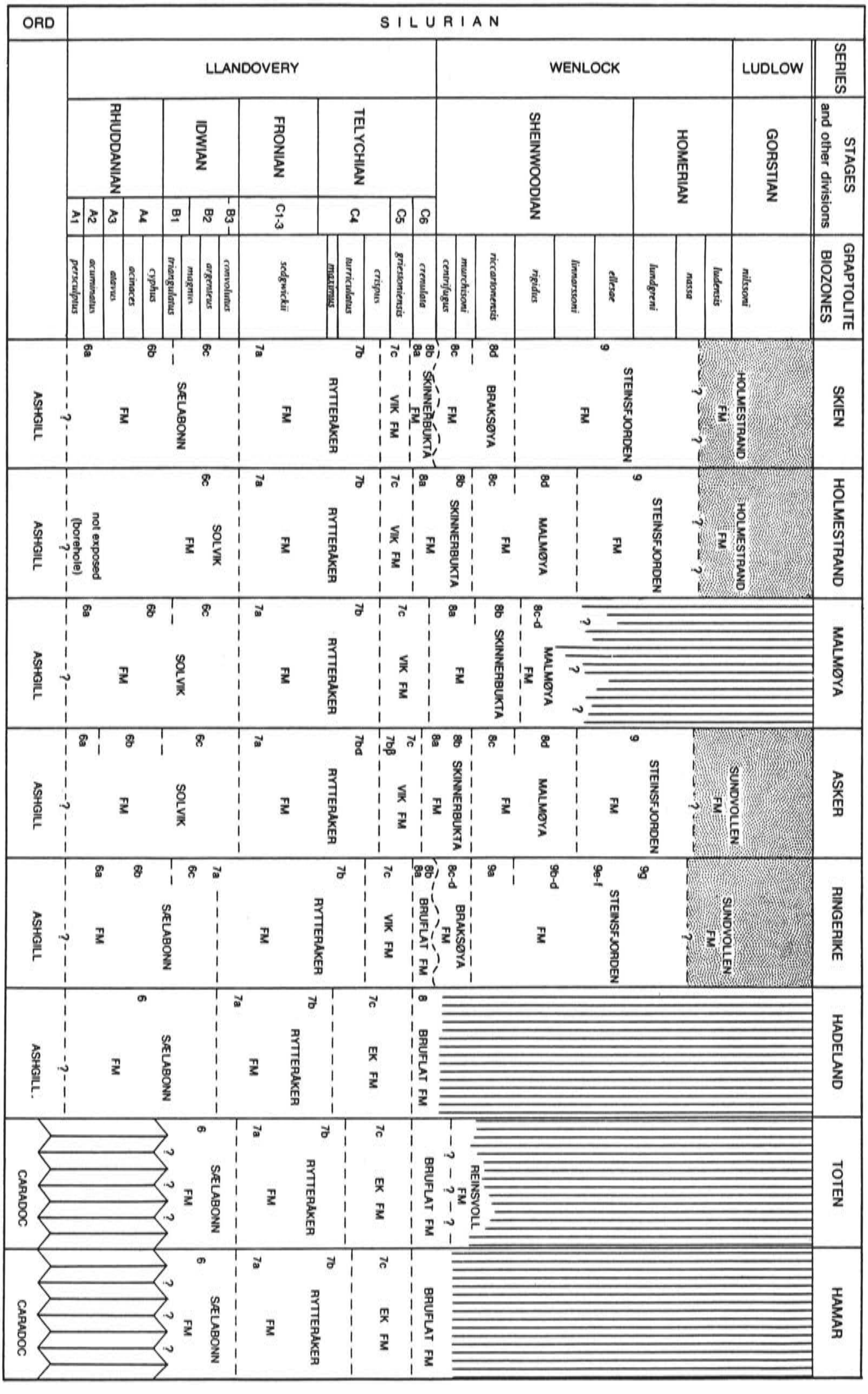
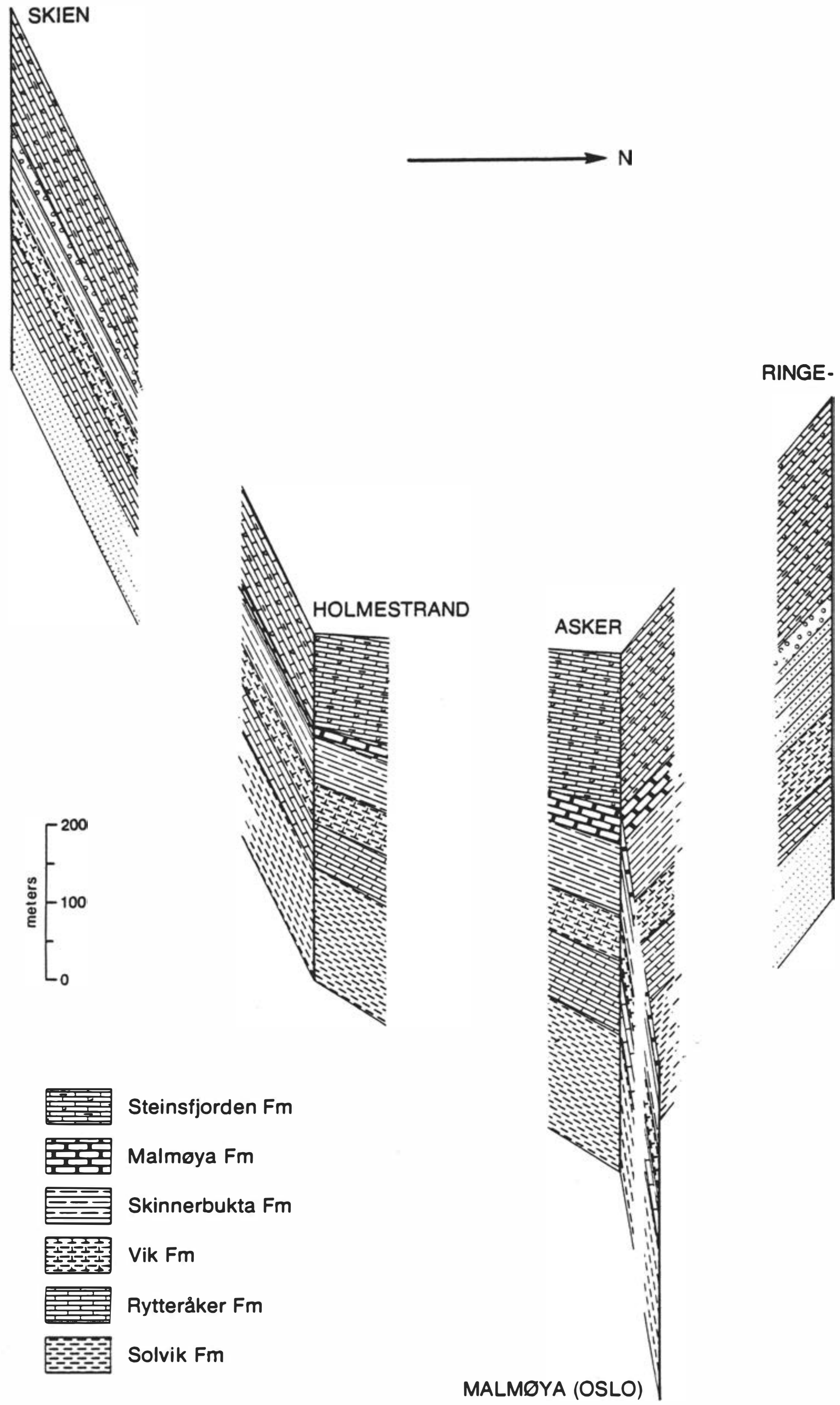


Fig. 3 a, b Maps showing key locations of exposures in the Holmestrand and northern districts.

Fig. 4 A regional correlation of the formational units proposed here; comparisons with the previous numerically-based units are presented for each district.


ORD
SILURIAN
SERIES
LLANDOVERY
WENLOCK
LUDLOW
STAGES and other divisions
RHUDDANIAN
IDWIAN
FRONIAN
TELYCHIAN
SHEINWOODIAN
HOMERIAN
GORSTIAN
A1
A2
A3
A4
B1
B2
B3
C1-3
C4
C5
C6
GRAPTOLITE BIOZONES
persculptus
acuminatus
atavus
acinaces
cyphus
triangulatus
magnus
argenteus
convolutus
sedgwickii
maximus
turriculatus
crispus
griestoniensis
crenulata
centrifugus
murchisoni
riccartonensis
rigidus
linnarssoni
ellesae
lundgreni
nassa
ludensis
nilssoni
SKIEN
HOLMESTRAND
MALMØYA
ASKER
RINGERIKE
HADELAND
TOTEN
HAMAR
SÆLABONN FM
RYTTERÅKER FM
VIK FM
SKINNERBUKTA FM
BRAKSØYA FM
STEINSFJORDEN FM
HOLMESTRAND FM
not exposed (borehole)
SOLVIK FM
MALMØYA FM
SUNDVOLLEN FM
BRUFLAT FM
EK FM
REINSVOLL FM
ASHGILL
CARADOC


SKIEN
N
RINGE-
HOLMESTRAND
ASKER
200
meters
100
0
Steinsfjorden Fm
Malmøya Fm
Skinnerbukta Fm
Vik Fm
Rytteråker Fm
Solvik Fm
MALMØYA (OSLO)

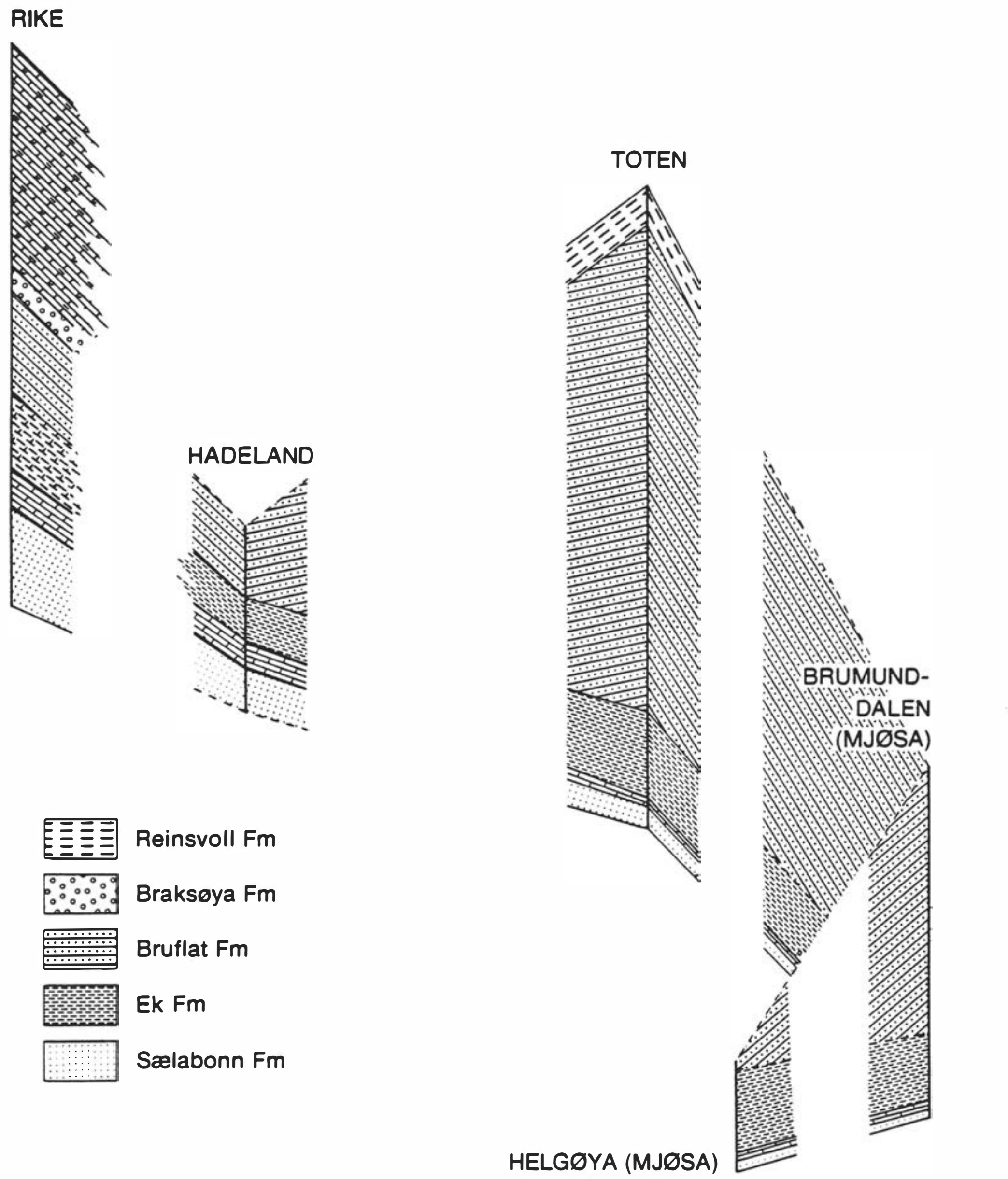


Fig. 5 A fence diagram displaying thickness variations of the marine Silurian succession throughout the Oslo Region.

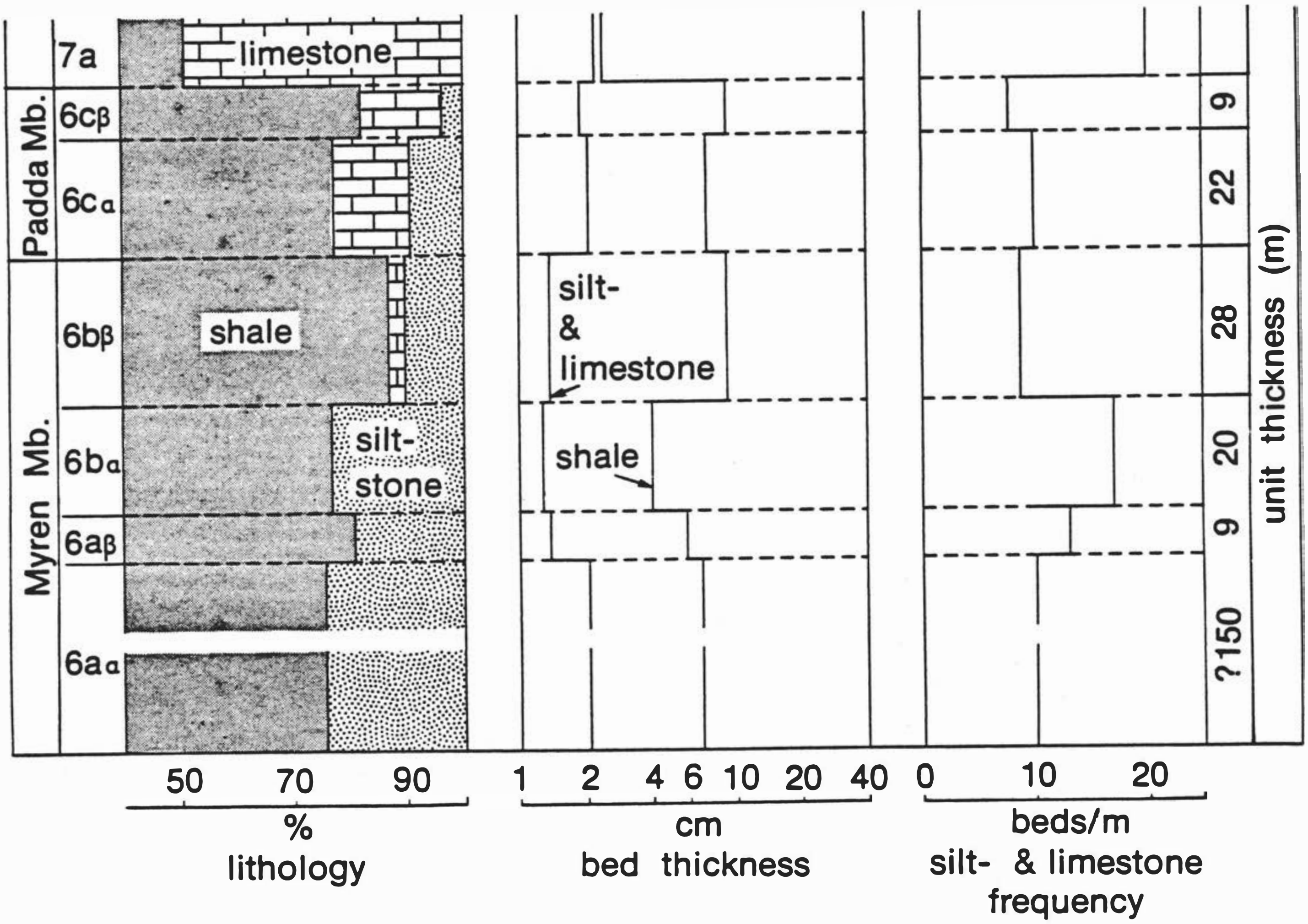
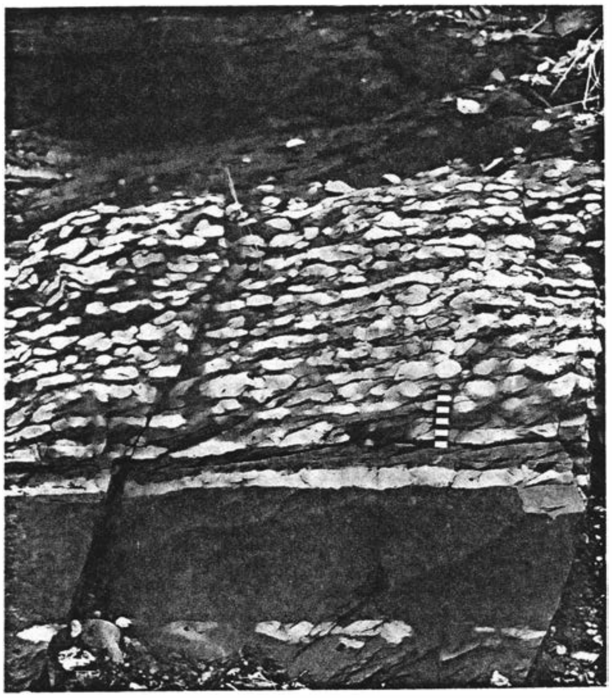
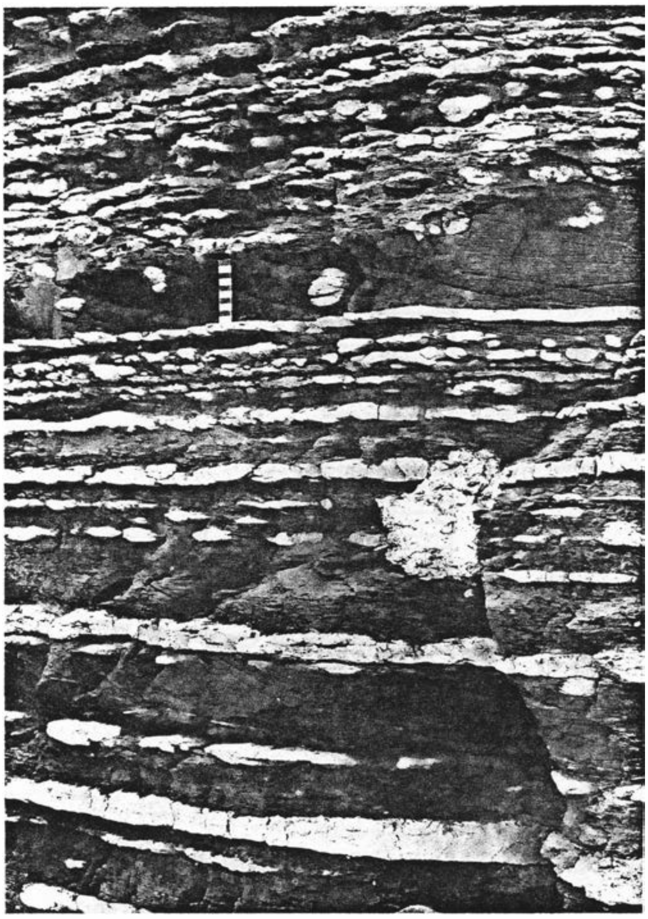


Fig. 6 A schematic log through the Solvik Formation on Malmøya (Oslo district) showing lithological variation and member boundaries.



a



b

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

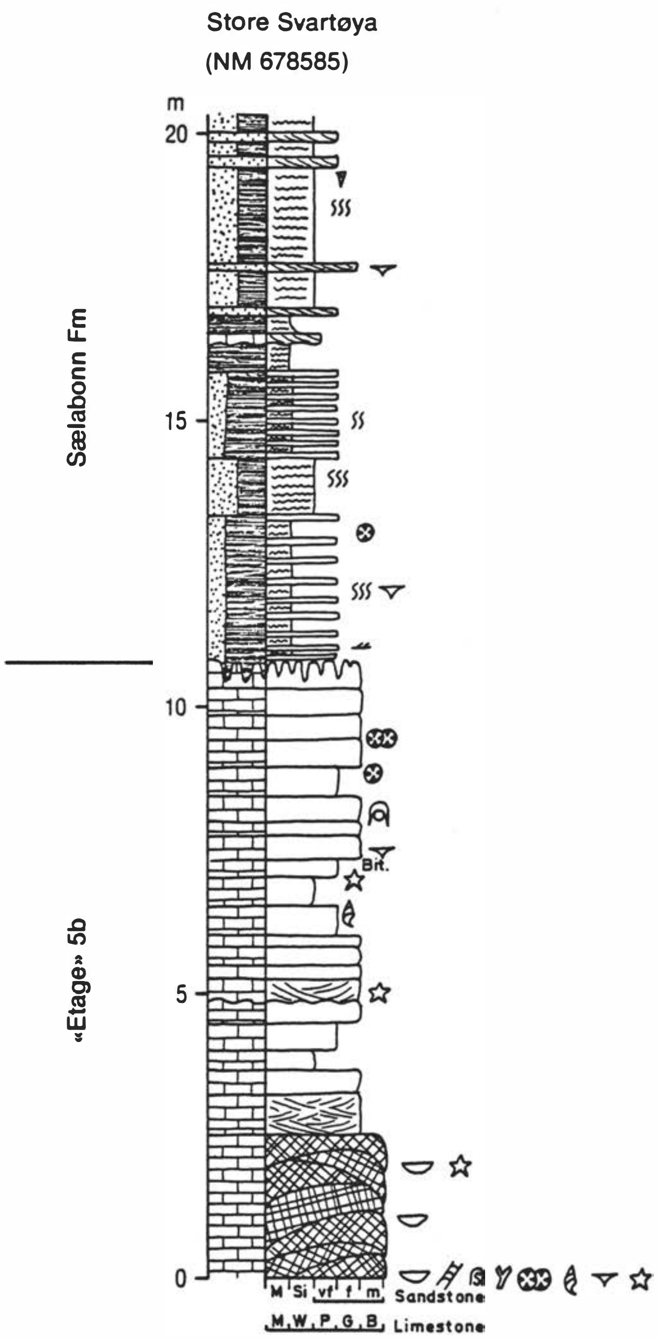


Fig. 8 A schematic section of the boundary stratotype for the base of the Sælabonn Formation, Store Svartøya, Ringerike.

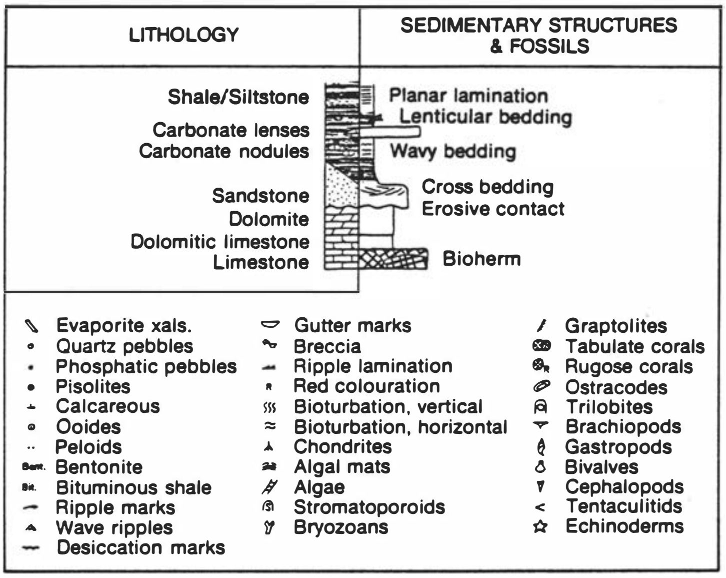


Fig. 9 Symbols used in the stratigraphic sections presented herein.

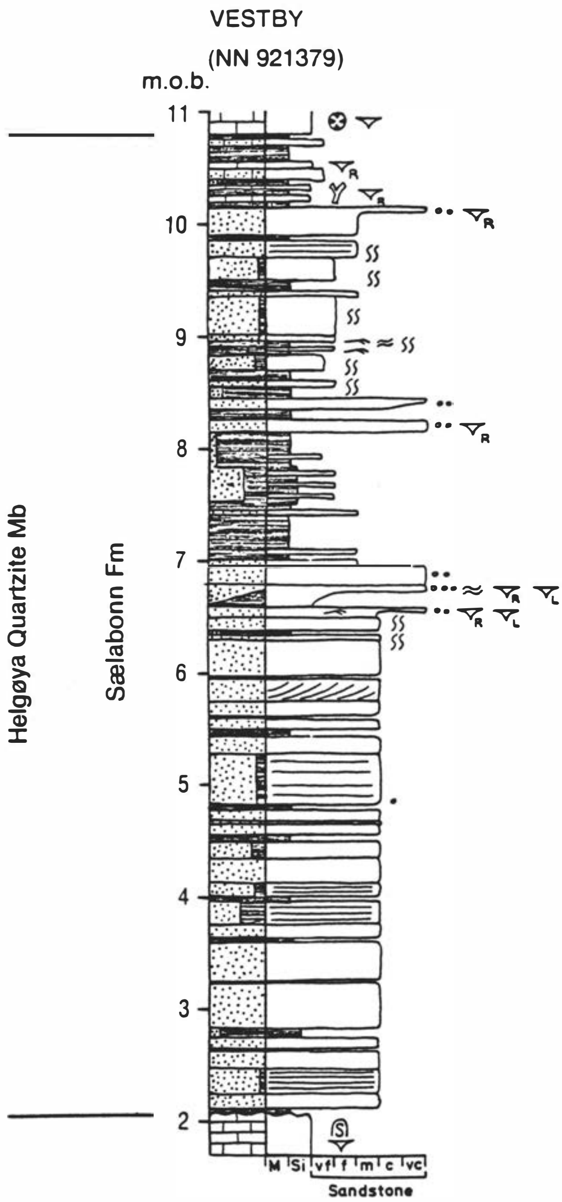


Fig. 10 Hypostratotype through the Helgøya Quartzite Member of the Sælabonn Formation at Vestby (Toten district).

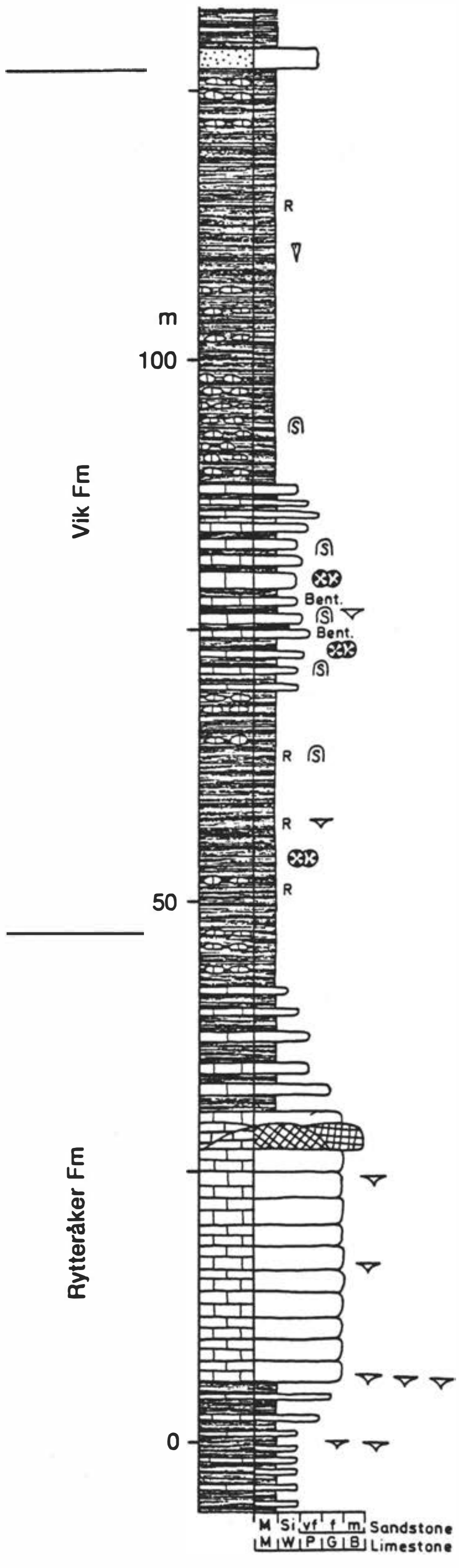


Fig. 11 A general section through the composite stratotypes of the Rytteråker and Vik formations in Ringerike.

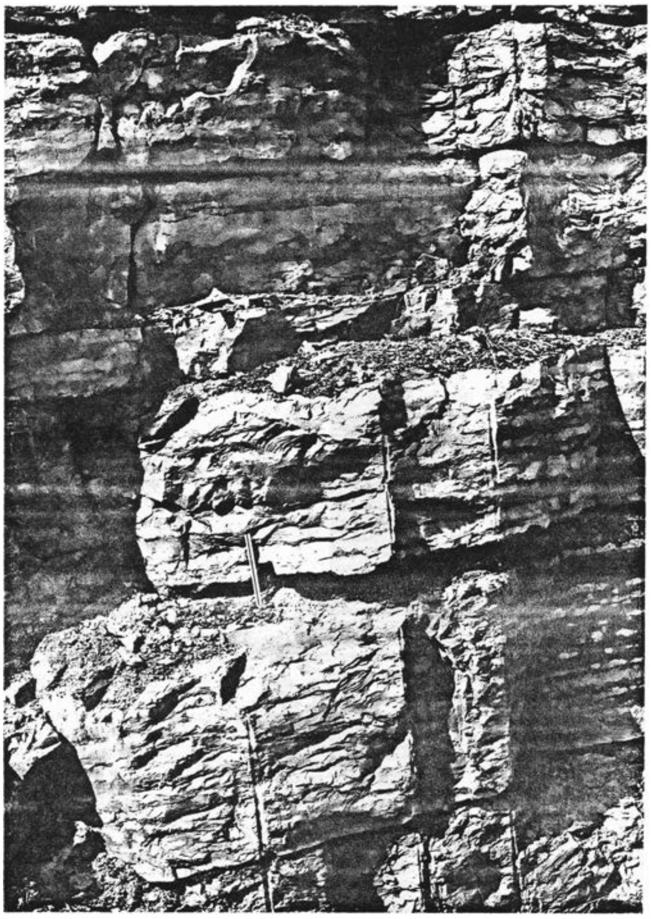
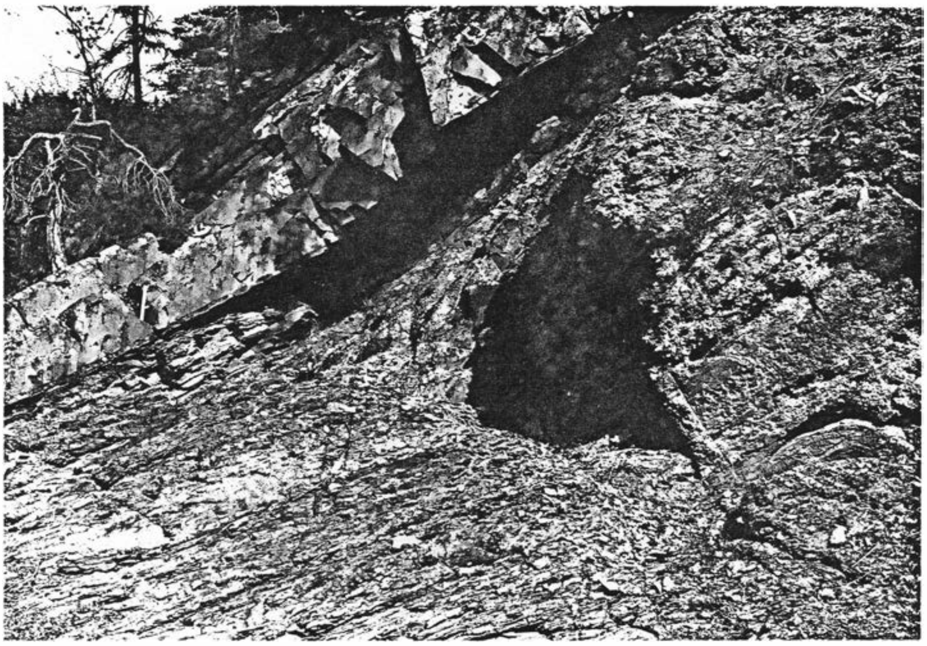


Fig. 12 a) Vik Formation, bentonites at Vik (Ringerike). Photo.



b) Junction between the Vik and Bruflat formations in Ringerike. Photo.

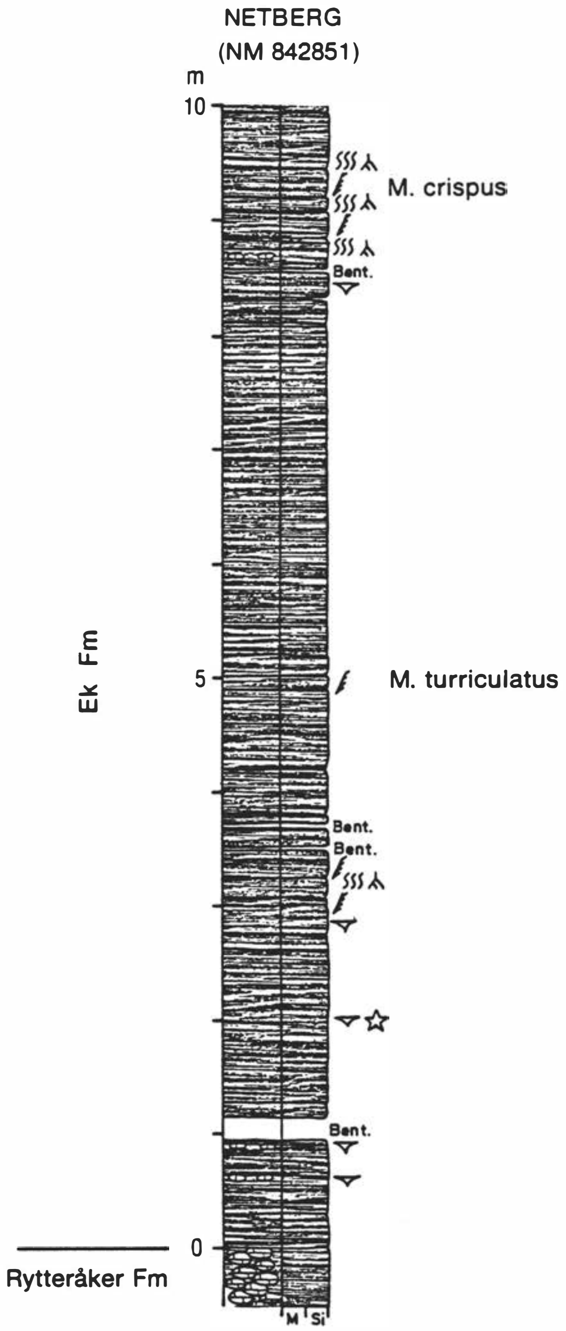


Fig. 13 Hypostratotype for the base of the Ek Formation in Hadeland.

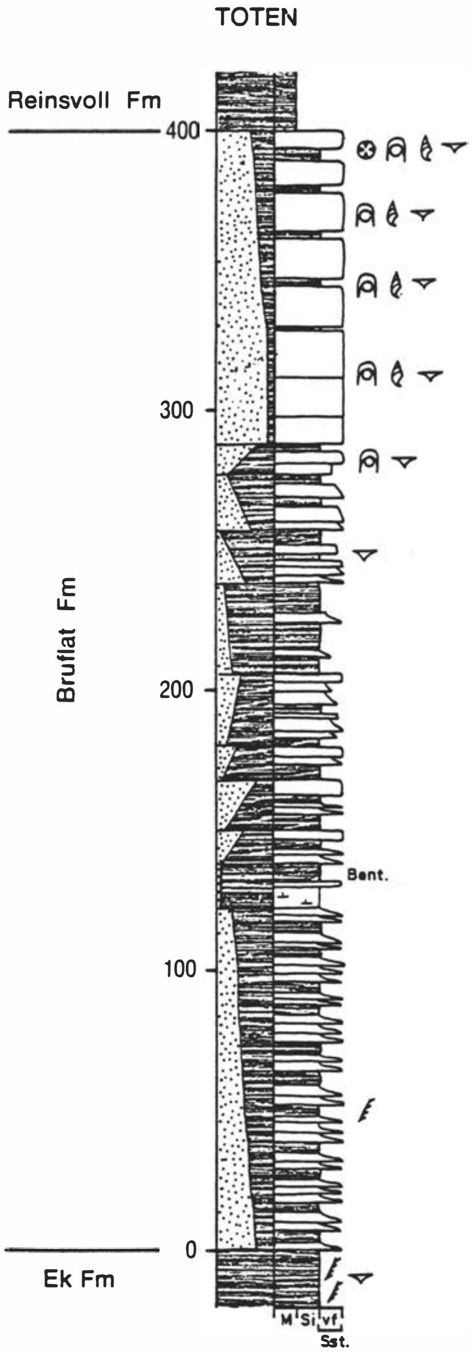


Fig. 14 Schematic section through the Bruflat Formation at Bruflat (Toten).

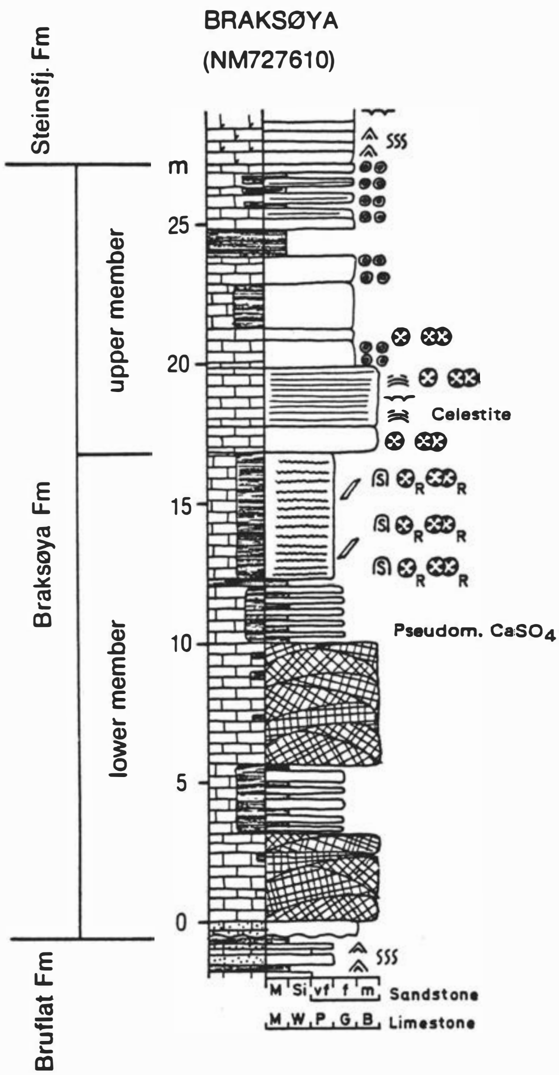


Fig. 15 The type section of the Braksøya formation, Ringerike.

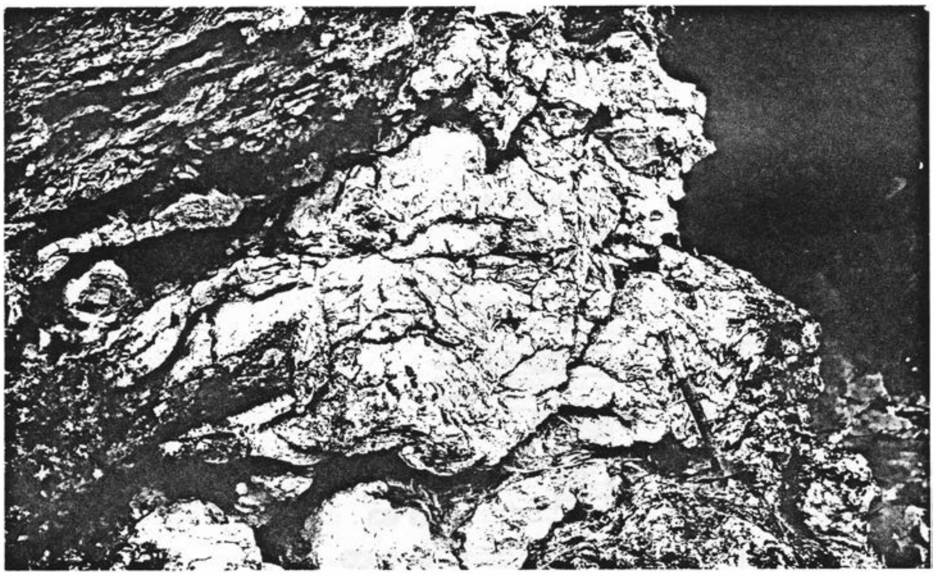
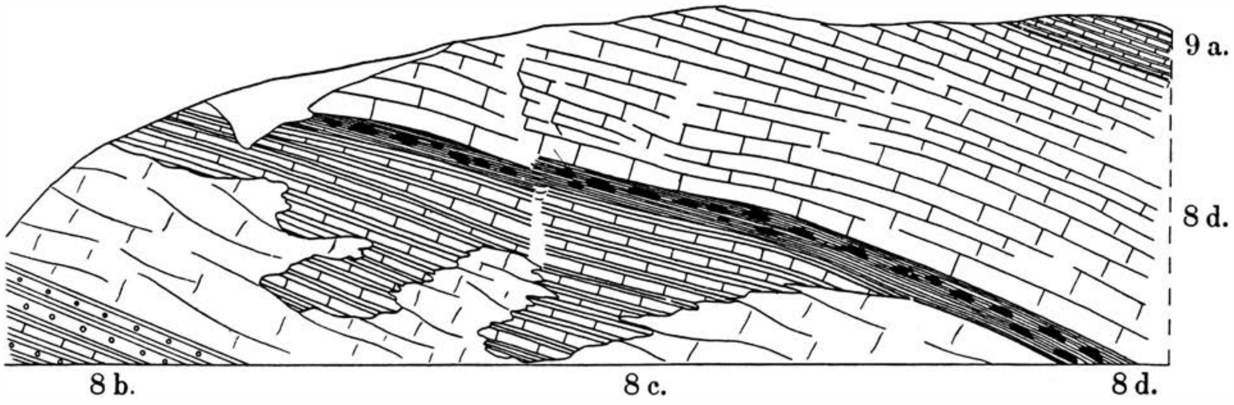


Fig. 16 Biohermal developments in the Braksøya Formation at Braksøya, Ringerike (photo).



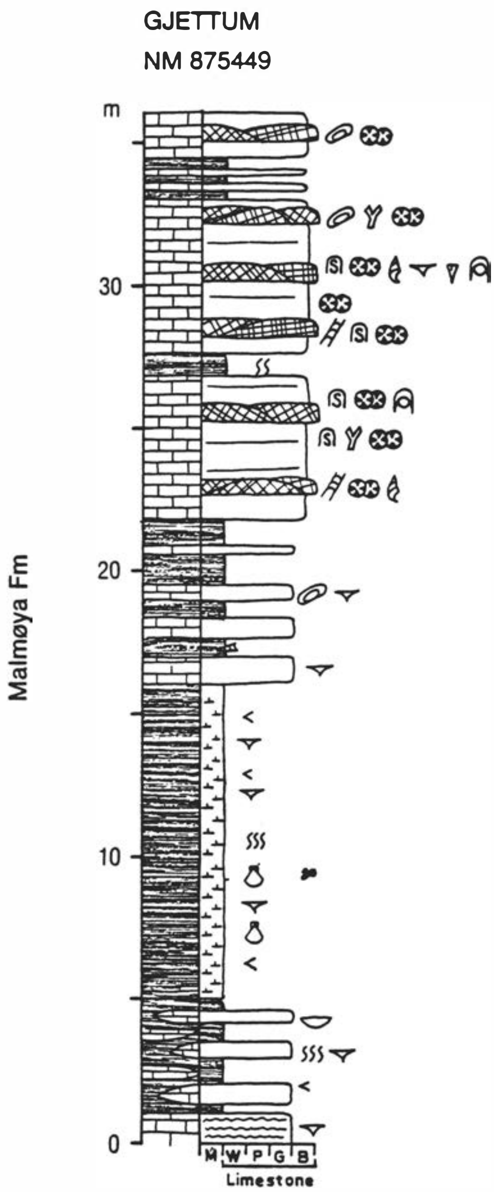


Fig. 17 Hypostratotype of the Malmøya Formation at Gjettum (Asker district).

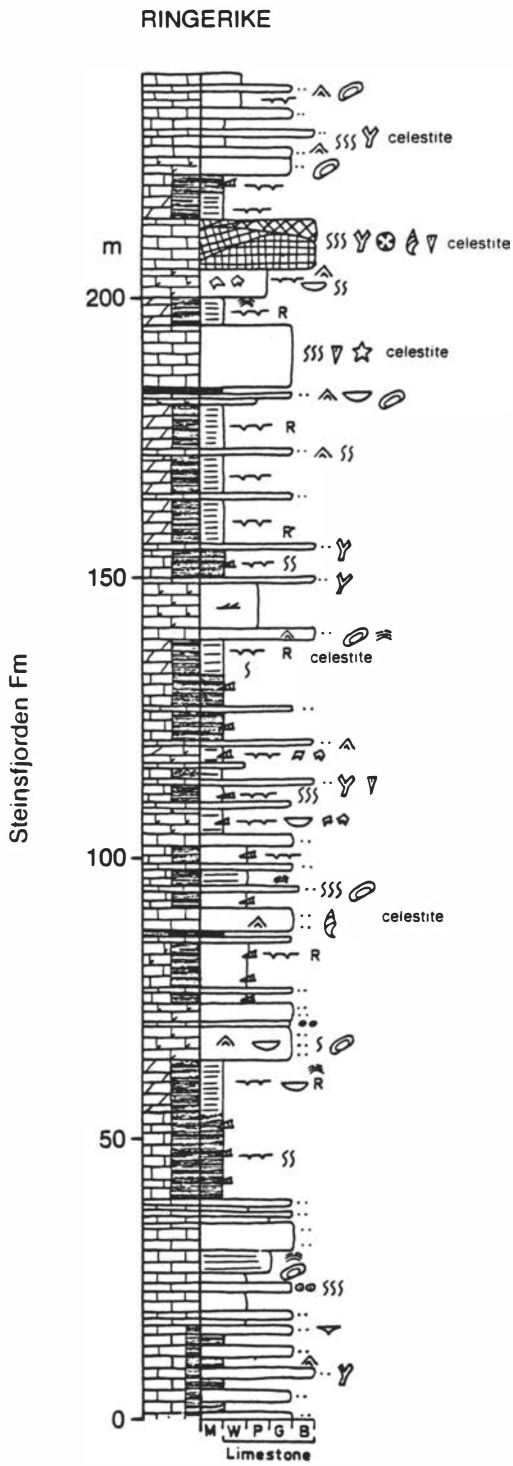
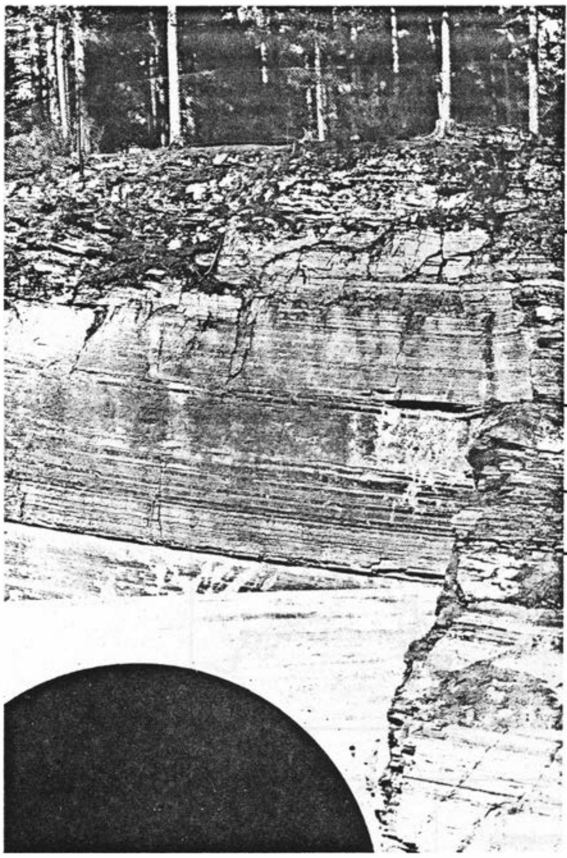


Fig. 18 A composite section through the Steinsfjorden Formation, Ringerike.

Fig. 19a. A transgressive sequence in the upper part of the Brattstad Limestone Member of the Steinsfjorden Formation. Thickness from prominent bentonite to cliff-top approx. 5,5 m.



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.

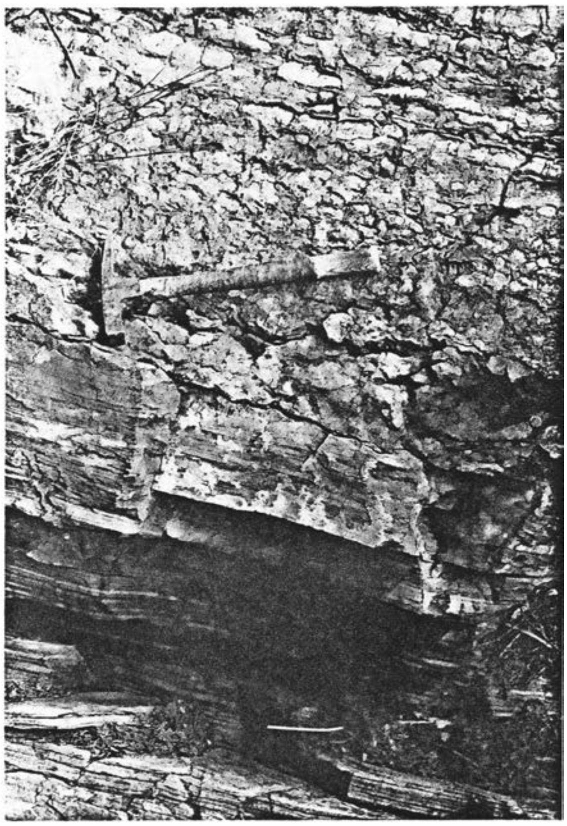
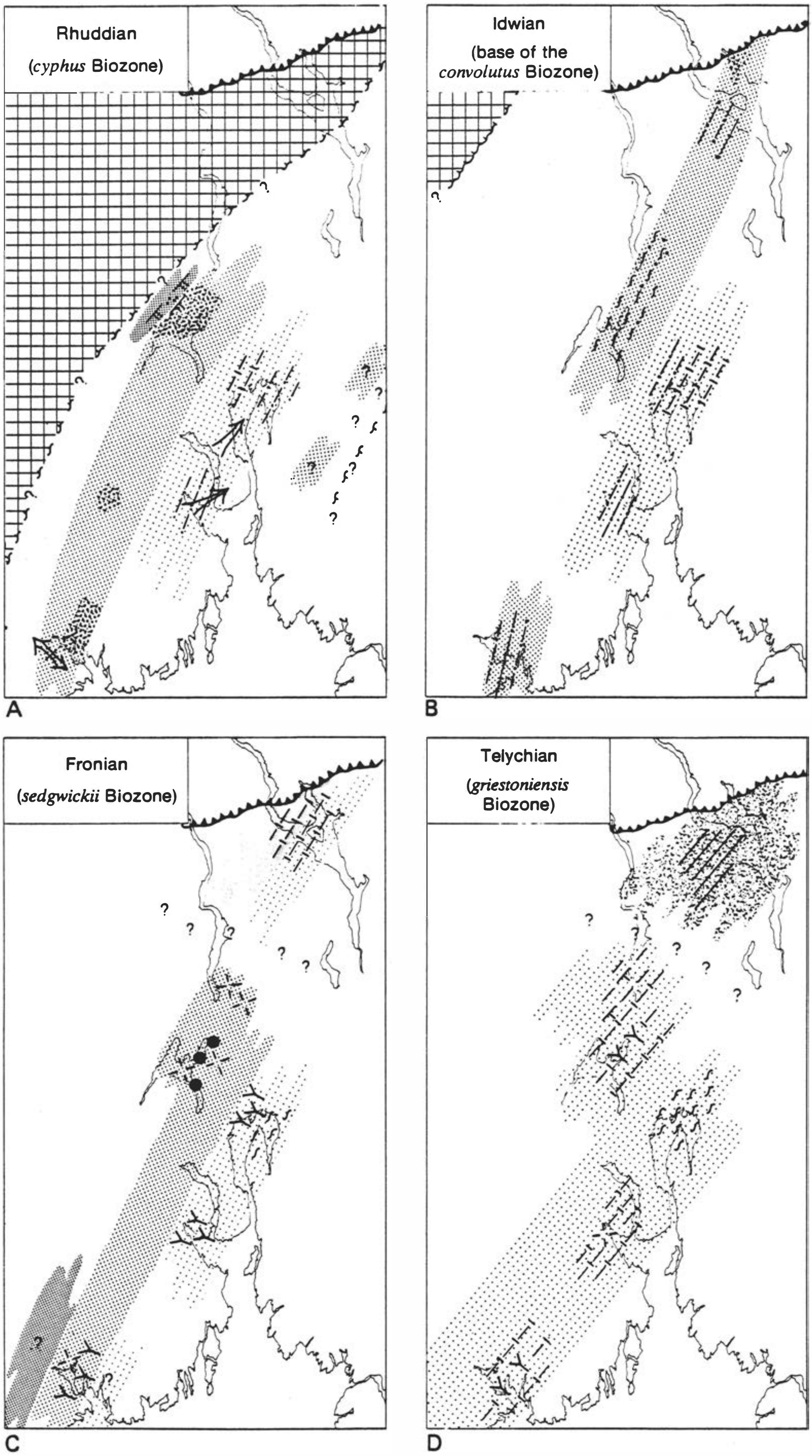


Fig. 19b.
Thinly bedded to thickly laminated pelsparite and micrite passing up into ?algal laminated dolomitic limestone (intertidal), erosively overlain mid-picture by subtidal oncolitic limestone and nodular biosparite. Hammer is 35 m long. Steinsfjorden Formation, Gjettum, Asker district.


Rhuddian
(*cyphus* Biozone)
A
Idwian
(base of the *convolutus* Biozone)
B
Fronian
(*sedgwickii* Biozone)
C
Telychian
(*griestoniensis* Biozone)
D

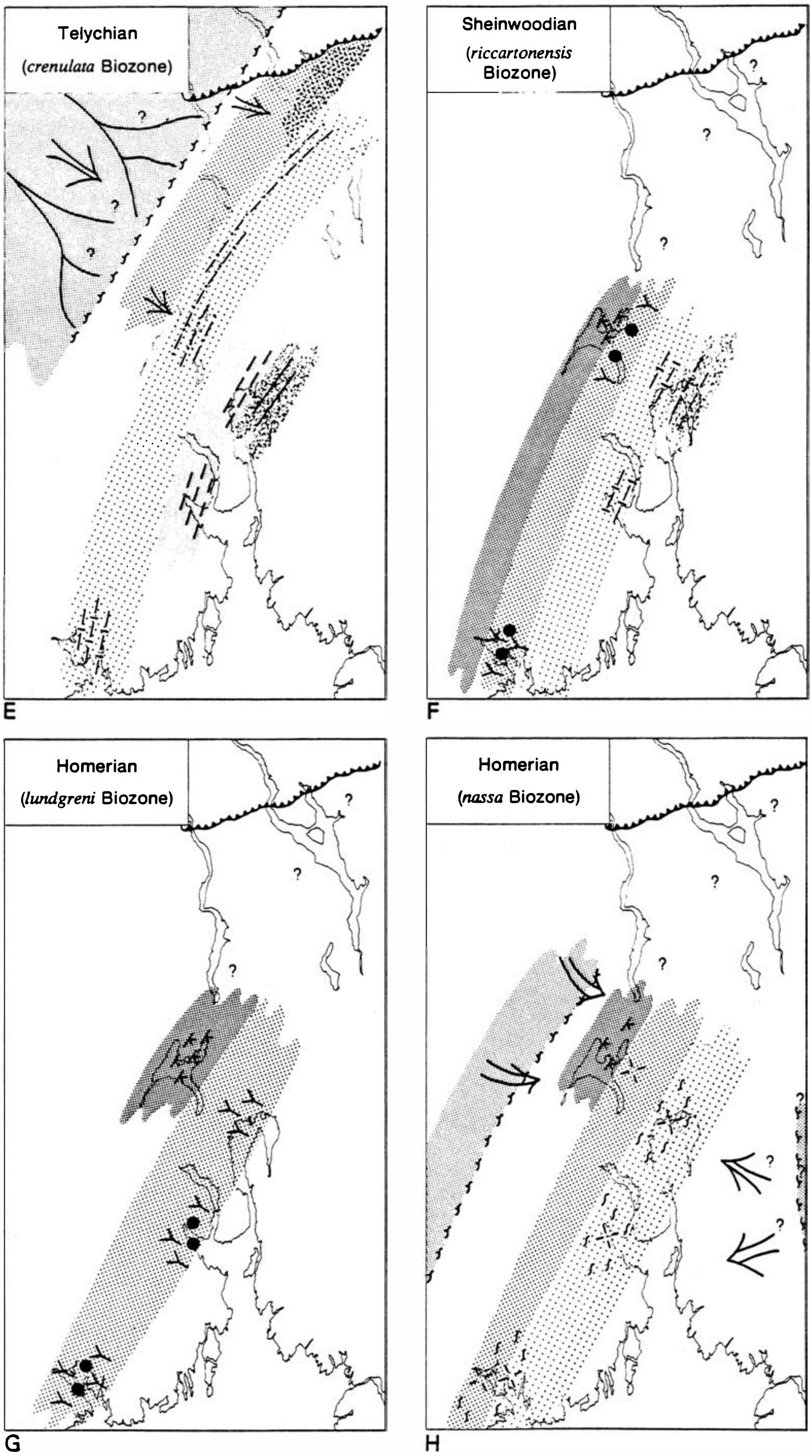


Fig. 20, a-h "Time-slice" maps showing lithofacies distributions, near stage boundaries within the Llandovery and Wenlock.

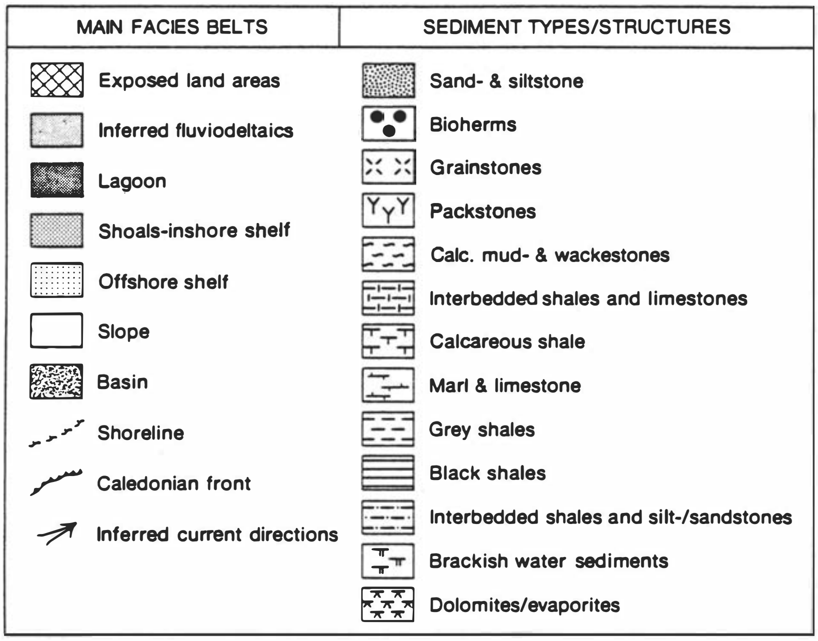


Fig. 21 Symbols used in Fig. 20.