The Middle Ordovician of the Oslo Region, Norway, 28. Lithostratigraphy of the Steinvika Limestone Formation, Langesund-Skien district

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The conspicuous massive limestone at the top of the Middle Ordovician sequence in the Langesund-Skien district is named the Steinvika Limestone Formation, with stratotype locality at Steinvika, south of Langesund. The Formation, which is equivalent to the 'Encrinite Limestone' of previous workers, is approximately 40 m thick and is divided into four distinct members: the Bunæs, Åsstranda, Langesundstangen, and Skavråker Members. Each member is described in detail. In addition, a new stratotype for the overlying Venstøp Shale Formation is proposed.

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The present study focusses on the conspicuous massive limestone unit present at the top of the Middle Ordovician sequence in the Langesund-Skien district, which is the southernmost of the Oslo Region (Fig. 1). Early studies in this district were undertaken by Dahll (1857) and Brøgger (1884), whilst more recent summaries include Størmer (1953) and Henningsmoen (1960). The history of stratigraphical terminology of the Middle and Upper Ordovician sequence in the Langesund-Skien district is presented in Table 1, together with the units proposed and followed in this account. The units proposed below are based solely upon lithological character and, other than the broad correlation included in summary, detailed correlation with units outside the Langesund-Skien district is deferred until more detailed biostratigraphic work is completed.

The new lithostratigraphical unit here formally proposed is the Steinvika Limestone Formation. This formation corresponds to the 'Encrinitenkalk' of Brøgger (1884) and subsequent workers, and is renamed to conform with modern stratigraphical practice (Hedberg 1976). The formation is thus named after the designated stratotype locality of Steinvika, which is situated south of Langesund (Fig. 2). In addition, a new stratotype is proposed for the Venstøp Shale Formation, which overlies the Steinvika Limestone Formation throughout the Langesund-Skien district. The Venstøp Shale Forma-

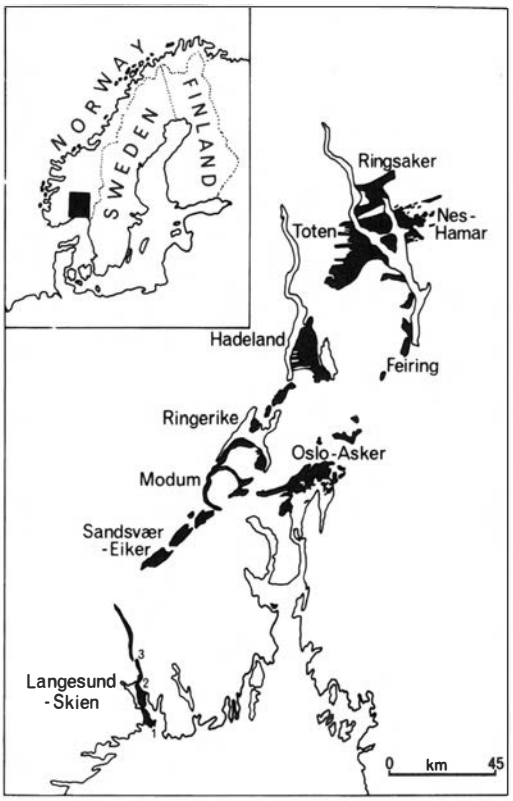

Figure 1. Geographical districts of the Oslo Region with the Ordovician outcrop shaded (after Størmer 1953). 1 = Langesund, 2 = Porsgrunn, 3 = Skien.

Table 1. Summary of stratigraphic terminology applied to the upper Middle Ordovician rocks in the Langesund-Skien district together with the units designated here.

<table>
<tr><th colspan="2">Dahll 1857</th><th>Brøgger 1884</th><th>Størmer 1953</th><th colspan="2">Henningsmoen 1960</th><th>Harland here</th></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="2">Kalksandstein 5b-d</td><td>Kalksandstein 5</td><td rowspan="3">not covered</td><td colspan="2">Calcareous sandstone formation 5b</td><td>Calcareous sandstone</td></tr>
<tr><td colspan="2" rowspan="2">Venstøb oder (or) Herø-Kalkstein 5a</td><td>Gastropodenkalk 4h</td><td>Gastropod limestone</td><td rowspan="3">Herøy limestone 4cβ-5a</td><td rowspan="3">Herøy Limestone</td></tr>
<tr><td>Isoteluskalk 4g</td><td>Isotelus beds</td></tr>
<tr><td rowspan="3">Fossum Gruppe</td><td>Upper Tretaspis beds</td></tr>
<tr><td>Venstøb-Schiefer 4b</td><td>Trinucleus-schiefer 4f</td><td colspan="2">Lower Tretaspis Shale 4cα</td><td>VENSTØP SHALE FORMATION</td></tr>
<tr><td rowspan="3">Fossum Kalkstein 4a</td><td>Encrinitenkalk 4e</td><td>Encrinite Limestone 4bδ</td><td colspan="2">Encrinite Limestone 4bδ</td><td>STEINVIKA LIMESTONE FORMATION</td></tr>
<tr><td rowspan="2">Chasmopskalk und Schiefer 4b-d</td><td rowspan="2">Mastopora-Coelosphaeridium zone
Bryozoan zone, 4bδ̃-γ
Echinosphaerites zone</td><td>Coelosphaeridium Mastopora beds ?4bγ</td><td rowspan="3">undifferentiated shales & irregular limestones</td></tr>
<tr><td>Bryozoan beds ?4bβ
Echinosphaerites beds ?4bα</td></tr>
<tr><td>Ampyxzone</td><td>Ampyx limestone 4aβ</td><td colspan="2">Ampyx limestone 4aβ</td></tr>
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tion corresponds to the Venstøb-Schiefer of Dahll (1857) and the Trinucleusschiefer (Brøgger 1884) or Lower Tretaspis Shale (Henningsmoen 1960) of more recent workers (Table 1). Although Dahll's original name is reinstated, a new stratotype designation is necessary as the original exposures around Venstøp, north of Skien (Fig. 2) are now poor and do not provide a satisfactory section. The stratotype is selected as the section at the southern tip of Langesundstangen (Fig. 2), where it overlies that of the Steinvika Limestone Formation.

Place names and geographical locations mentioned in the text are taken from Norge 1:50,000 Blad 1712I (Langesund) and Blad 1713II (Porsgrunn) and a locality map of this main part of the district is included here (Fig. 2). The area around and to the north of Skien is best covered by Omlandskart 1:25,000 Blad II (Skien) (see Inset, Fig. 2).

Stratigraphy

Steinvika Limestone Formation

The Steinvika Limestone Formation is well exposed between Langesundstangen and Porsgrunn where numerous quarries, road cuttings, and several natural exposures are present along the outcrop belt. North of Porsgrunn, however, exposures are limited and poor due to agricultural, urban, and industrial development. The formation is lithologically diverse and is defined as comprising four distinct members, viz. the Bunæs, Åsstranda, Langesundstangen, and Skavråker Members (Fig. 3). The formational stratotype is selected as the extensive cliff and shore exposures along the west coast of Langesundstangen around Steinvika (Map reference: 58°59′00″N, 9°44′55″E), south of Langesund. (*Note:* Part of the exposures at Steinvika lie within the military precinct occupying the southern end of Langesundstangen and permission to visit these is required. Applications for permission can be made at the sentry gate on the main road south from Langesund centre. Otherwise, complete sections through the Steinvika Limestone Formation, including the Langesundstangen Member, and the Venstøp Shale Formation are freely available in the public area at Steinvika, especially immediately next to the perimeter of the military precinct.) The base of the formation is defined by the contact between the dark coloured, thickly bedded bioclastic limestone and the paler argillaceous mudstones with thin calcareous sandstones and fine limestone layers below. Lithologically this boundary is slightly transitional but can be easily and accurately placed by the sharp colour

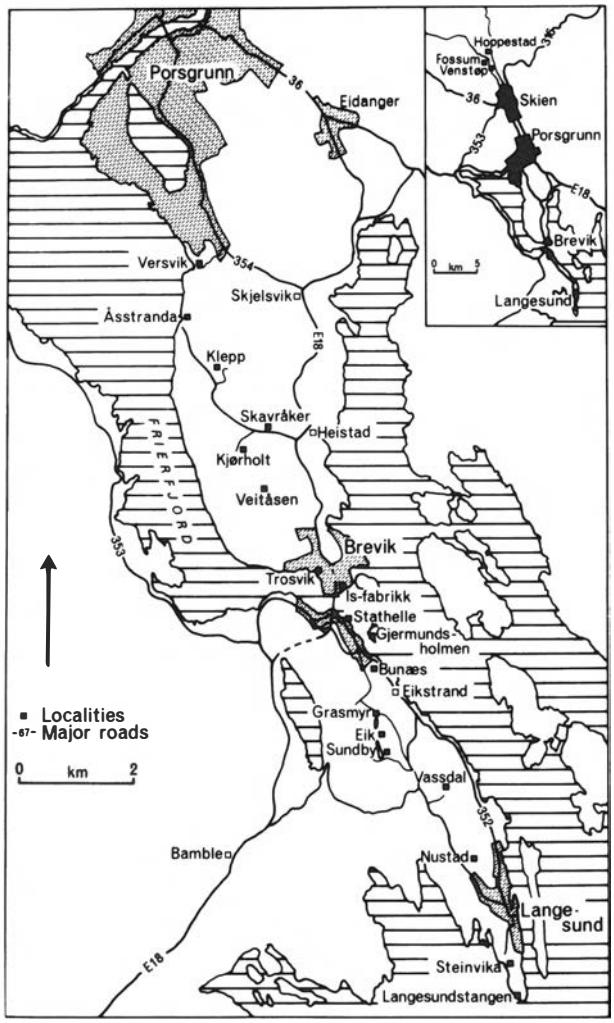

Fig. 2. Map of the Langesund-Skien district showing all localities mentioned in the text.

change. The upper boundary of the formation is also marked by a colour change between the pale coloured calcilutites and argillaceous mudstones below and the iron-stained dark shales of the Venstøp Shale Formation above. The total thickness of the Steinvika Limestone Formation at the stratotype locality is 41.4 m and the complete stratotype sequence is illustrated in Figure 4, where it is seen that the lower parts are dominated by thickly bedded limestones and the upper parts consist of more thinly bedded limestones interbedded with argillaceous mudstones. In order to provide a complete and exact description of the formation, stratotypes have been selected for each of the four component members. The Åsstranda Member does not occur at Steinvika and is only present at the more northerly localities, where its stratotype is selected as the section at Åsstranda (Map reference: 59°05′45 ″N, 9°39′00 ″E) along the coast of Frierfjorden (Fig. 2). The remaining members are all present at Steinvika but, although it would have been convenient to have selected each stratotype there, it is considered better to select the localities where each member exhibits its fullest and most characteristic development. Thus the stratotypes of the Bunæs and Skavråker Members are selected as the sections exposed at Bunæs (59°02′35 ″N, 9°42′30 ″E) and Skavråker (59°04′35 ″N, 9°40′45 ″E) respectively

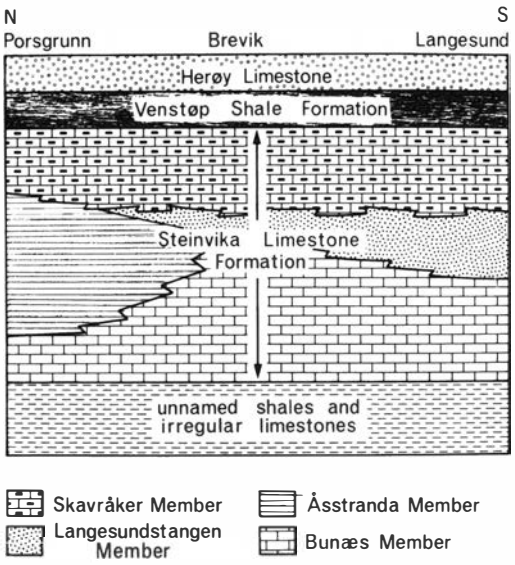

Fig. 3. Stratigraphical profile of the Steinvika Limestone Formation, with its four component members, and adjacent rocks between Porsgrunn and Langesund.

(Fig. 2), whilst the stratotype of the Langesundstangen Member is selected at Steinvika where it forms part of the formational stratotype. Each member is described below.

The Bunæs Member – This member consists of a sequence of thickly bedded, dark coloured bioclastic limestones with scattered small patch reefs. The member is present throughout the district (Fig. 3) and its base coincides with that of the Steinvika Limestone Formation. At Bunæs, the characteristic well-marked colour change and rapid lithological transition of this lower boundary can be seen on the northern side of the footpath along the quarry floor. The upper boundary of the Bunæs Member is well-marked at Bunæs, where the thickly bedded bioclastic limestones are overlain by thinly interbedded fossiliferous limestones and silty mudstones of the Langesundstangen Member. The stratotype sequence at Bunæs is 21.9 m thick (Fig. 5). South of Brevik (Fig. 2), where the same fossiliferous facies overlies the Bunæs Member, the member is fairly uniform in thickness, thinning southwards from 23.0 m at Trosvik (Fig. 2) to 17.2 m at Steinvika (Fig. 3). Northwards from Brevik the Bunæs Member thins considerably and is overlain by massive calcilutites of the Åsstranda Member (Fig. 3). The upper contact in this northern area is poorly exposed but where seen, for example south of the inland quarry at Åsstranda, it is more transitional than in the south.

The Bunæs Member is dominated by thickly bedded, dark bioclastic limestones. Typically, the limestones are composed primarily of whole and broken pelmatozoan ossicles together with other diverse bioclasts. Generally the character of the limestones changes vertically and several lateral variations are also present. Throughout the district the lower beds are poorly sorted, indistinctly cross-stratified bioclastic limestones containing considerable admixtures of mud. Laterally discontinuous thin, irregular layers of brown argillaceous mudstone occur in these lower parts. The higher beds of the member consist of coarse pelmatozoan-rich bioclastic limestones which are usually well-sorted and have grainstone textures. Large-scale cross-stratification is characteristic. At Bunæs, Eik and other central localities (Fig. 2) these higher parts contain few argillaceous mudstone beds whilst further south, for example at Steinvika, thick (10–50 cm) cross-stratified bioclastic limestone beds are separated by 2–8 cm thick argillaceous mudstone beds. Intraclasts, micritized bioclasts, ellipsoidal micrite grains (?faecal pellets), and oncolites are present locally and are abundant at several horizons. Further local variations include the presence of shallow, steep- or vertical-sided erosional scours in the uppermost parts of the member, particularly at Steinvika. The scours cut into both low angle cross-stratified limestones and interbedded thin argillaceous mudstones and are infilled by coarse, intraclast-rich bioclastic limestones. The intraclasts are generally 1–4 cm in diameter, though larger examples, up to 12 cm, are present at scour edges. Both limestone and mudstone intraclasts are common.

Several small patch reefs (4–6 m thick and 30–35 m in lateral extent) are present in the lower parts of the Bunæs Member. These consist largely of calcareous algae, stromatoporoids, the corals *Eofletcheria irregularis, Lyopora favosa,* and *Tryplasma basaltiforme,* and pelmatozoan holdfasts, together with a diverse accessory fauna of gastropods, bryozoa, orthocone nautiloids, brachiopods, and occasional trilobites. Coarse bioclastic debris, consisting of abundant pelmatozoan stem and cup ossicles, immediately surrounds the reefs and is usually poorly bedded and badly sorted. Outside the reefs, fossil preservation in the Bunæs Member

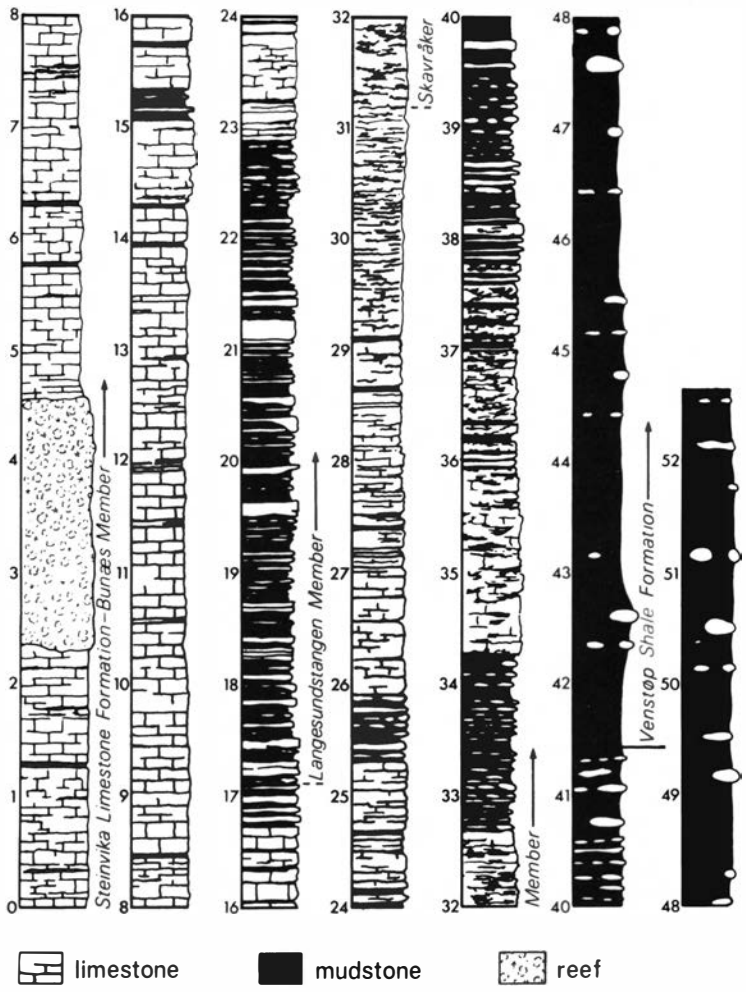

Fig. 4. Stratigraphic section showing the complete sequence through the Steinvika Limestone and Venstøp Shale Formations at their stratotype locality, logged in metres.

is extremely poor. However, two common assemblages can be distinguished. *Strophomena* cf. *steinari* is typically found scattered on bedding planes with a diverse gastropod fauna, including particularly *Liospira* sp., and orthocone nautiloids. The second assemblage consists of more diverse clusters which include *Vellamo* sp., *Platystrophia dentata, Zygospira* sp., *Triplesia?* sp., *Parastrophina?* sp., bryozoa, *Stenopareia glaber,* and *Toxochasmops extensus*.

The Åsstranda Member. – The Åsstranda Member consists of pale blue-grey massive calcilutites, laminated calcilutites, and laminated quartz-siltstones, and is present only in the northern parts of the district. The basal parts of the member are a transition from the coarse bioclastic limestones of the underlying Bunæs Member into the pale calcilutites, whilst the upper boundary is placed at the sharp contact between the calcilutites below and the interbedded shaley argillaceous mudstone and fine limestones of the Skavråker Member above. The Åsstranda Member is 24 m thick at the stratotype locality (Fig. 6) but thins rapidly southwards towards Kjørholt (Fig. 2) and is absent from all southerly localities (Fig. 3).

Pale bluish-grey massive calcilutites occur at several levels in the Åsstranda Member but are particularly characteristic of the lower and upper parts. These calcilutites are typically homogeneous although some vaguely mottled horizons are present. Immediately overlying the Bunæs

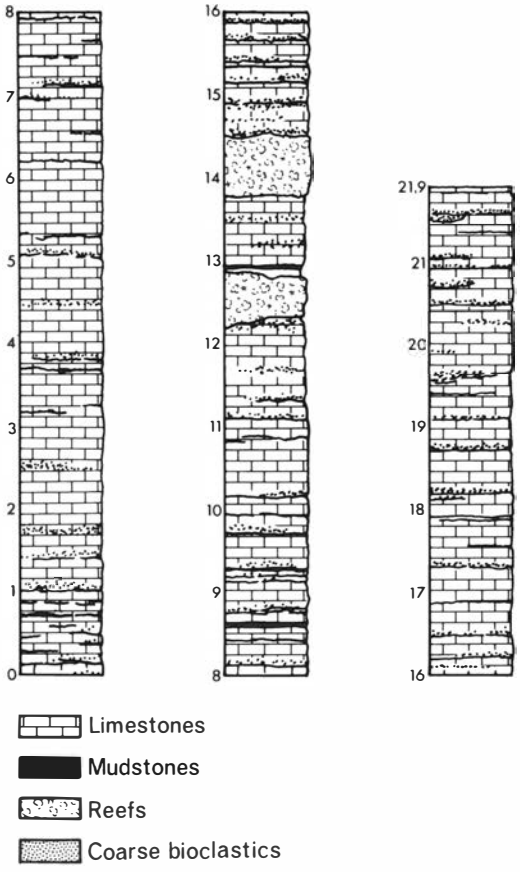

Fig. 5. Detailed stratigraphic section through the Bunæs Member at the stratotype locality of Bunæs, logged in metres. The majority of limestones are cross-stratified or indistinctly cross-stratified (see text).

Member the calcilutites are rich in scattered bioclasts and several thin bioclastic horizons are present. The bioclasts are mainly small, abraided pelmatozoan fragments together with less frequent mollusc, brachiopod, and bryozoa fragments. Elsewhere similar bioclasts also occur but are more sparsely and irregularly distributed. Laminated calcilutites predominate in the middle parts of the member (Fig. 6) and are well-exposed at the stratotype locality where the characteristic laminated nature can be studied on smooth water-worn surfaces. Small-scale symmetrical and, less frequently, asymmetrical ripple marks are exposed on several bedding surfaces, and many other bedding surfaces exhibit very well-developed polygonal systems of desiccation cracks. At several horizons, mud-flake conglomerates are present and these occasionally have a slight imbrication. Associated with the laminated calcilutites are thin (10–90 cm thick) units of laminated quartz-siltstones within which desiccation cracks are also common. Stylolites are abundant throughout the Åsstranda Member, which, apart from the scattered bioclasts, is totally unfossiliferous.

The Langesundstangen Member. – This member consists of a variable sequence of fossiliferous bioclastic limestones, skeletal limestones, and argillaceous mudstones. At the stratotype locality of Steinvika the Langesundstangen Member is 14.1 m thick (Fig. 7) and it thins northwards towards Skavråker (Fig. 3), where a thin lateral equivalent of the upper beds at Steinvika is present. At Skavråker the Langesundstangen Member transitionally overlies pale calcilutites of the Åsstranda Member, but elsewhere the lower boundary is sharp and is placed at the contact between the dark, cross-stratified

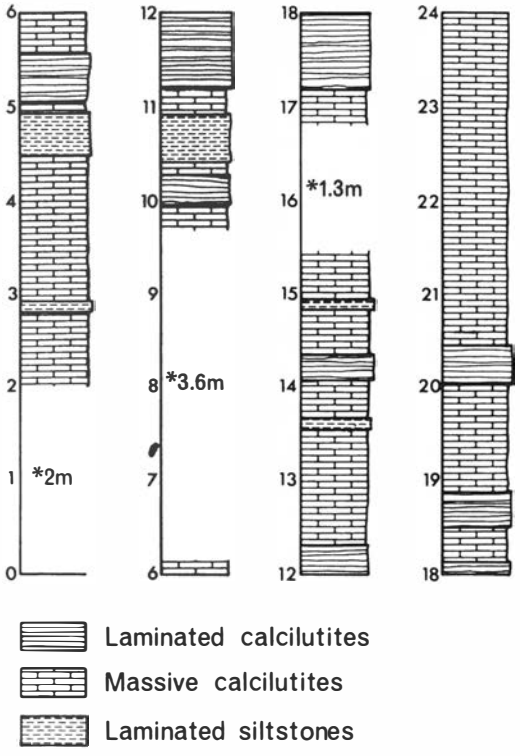

Fig. 6. Detailed stratigraphic section through the Åsstranda Member at the stratotype locality of Åsstranda, logged in metres (*indicates strata not present in the coastal section but which can be examined in the adjacent quarry).

and scoured bioclastic limestones of the Bunæs Member below and the overlying thinly interbedded fossiliferous limestones and argillaceous mudstones. The upper boundary is well-marked at all localities and is placed at the contact between the skeletal limestones and thin argillaceous mudstones below and the overlying paler coloured fossiliferous calcilutites of the Skavråker Member.

At Steinvika the lowermost 5.15 m of the Langesundstangen Member consist of variable wavy and lenticular bedded limestones (2–10 cm beds) and bioturbated silty mudstones (1–8 cm beds). The limestones are commonly cross-stratified or ripple-laminated and a crude grading from highly fossiliferous bases to finer bioclastic tops is characteristic. Although only well-developed at the more southerly localities, these beds can be recognised by their faunal content as far north as Trosvik (Fig. 2). Unispecific clusters are common though mixed assemblages are more typical. *Dinorthis* cf. *flabellulum, Strophomena keilhaui, Sowerbyella sericea* and small disc-like bryozoa are each abundant and occur with less common *Cyclospira* sp., *Zygospira* sp., *Platystrophia dentata,* stick-like bryozoa, *Toxochasmops extensus, Encrinurus* sp., and calymenids. The upper parts of the Langesundstangen Member are dominated by dark skeletal limestone beds ranging between 4 and 25 cm in thickness and interbedded with thin (1–2 cm), blocky argillaceous mudstone beds. Ripple marks are fairly common particularly in the lower horizons where asymmetrical varieties occur on several bedding surfaces. Bioturbation increases upwards through these beds, being typically limited to the thin mudstones in the lower parts but obscuring stratification at the tops of limestone beds in the higher parts. In addition to the thin beds of argillaceous mudstone present throughout, the Langesundstangen Member also includes two thin units of almost pure argillaceous mudstone. In the stratotype section at Steinvika (Fig. 7) the lower of these units is 80 cm thick with its base 5.15 m above the base of the member, whilst the upper unit is 65 cm thick with its base 8.3 m above the base of the member. Both units are very similar in development and lack primary sedimentary features but are highly bioturbated.

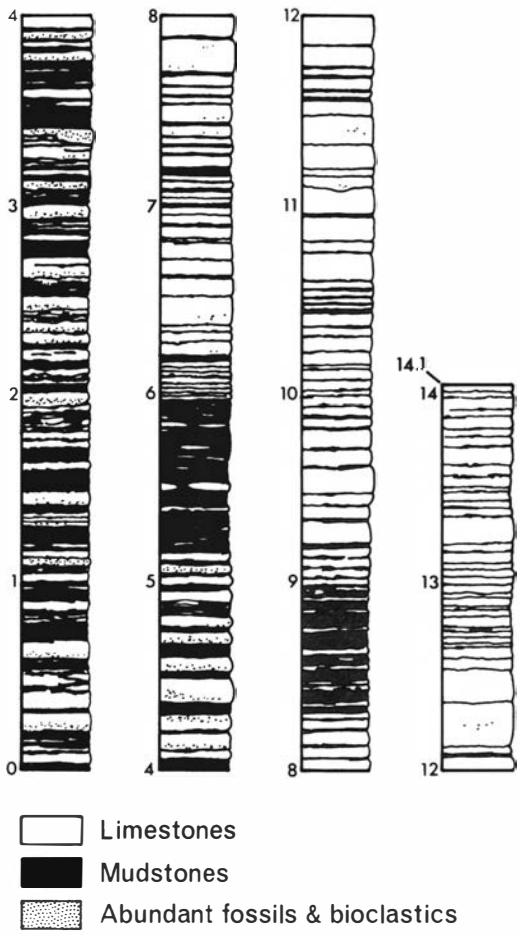

Fig. 7. Detailed stratigraphic section through the Langesundstangen Member at the stratotype locality of Steinvika, logged in metres. The majority of limestones are cross-stratified or ripple-laminated (see text).

The Skavråker Member. – This member is present throughout the Langesund-Skien district and consists of a uniform sequence of thinly interbedded bioturbated calcilutites and argillaceous mudstones. In contrast to the other members of the Steinvika Limestone Formation, which are markedly diachronous, the Skavråker Member is relatively constant in thickness (Fig. 3). At the stratotype locality of Skavråker the member is 12.45 m thick (Fig. 8) and elsewhere varies between 8.3 m and 10.9 m. The member overlies either the Åsstranda or Langesundstangen Members (Fig. 3). In both cases the lower boundary is sharp and is placed at the contact between the fossiliferous calcilutites above and the underlying massive calcilutites or dark skeletal limestones respectively. The upper boundary of the Skavråker Member coincides

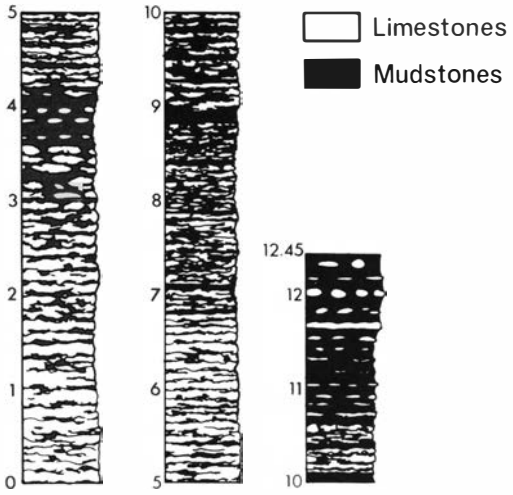

Figure 8. Detailed stratigraphic section through the Skavråker Member at the stratotype locality of Skavråker, logged in metres.

with the formational boundary and has been defined above.

At Skavråker the lowermost 3.6 m of the member consist of pale calcilutites with subordinate argillaceous mudstones. The latter occur as thin, wispy, and discontinuous laminae and impart a reticulate aspect to the pale calcilutites. These lower beds are present throughout the district with only slight variation in thickness and contain a well-preserved fauna of *Dolerorthis* cf. *duftonensis, Howellites* sp., *Diplotrypa* sp., *Echinosphærites* aff. *grandis, Haplosphaeronis* sp., and large pelmatozoan ossicles. A thin unit of argillaceous mudstone overlies these fossiliferous calcilutites across the whole of the district. At Skavråker this mudstone is 50 cm thick (Fig. 8) and varies between a minimum of 30 cm at Åsstranda and a maximum of 60 cm at Gjermundsholmen (Fig. 2). The mudstone is highly bioturbated and contains a sparse fauna including *Howellites* sp., *Leptaena* sp., and *Toxochasmops extensus*. Above this mudstone are the highly bioturbated horizons which typify the Skavråker Member. Bedding is irregular due to the intense bioturbation and is small-scale, usually 2–4 cm calcilutite separated by 1–8 cm argillaceous mudstone. Each exposed bedding surface is covered with systems of *Chondrites* burrows, which, in the absence of other trace fossils, appear responsible for all the bioturbation seen. Generally there is a decrease in the proportion of calcilutite upwards through these beds culminating in the preponderance of the darker argillaceous mudstones in the upper one to two metres of the member. With the exception of the lower beds of the member, faunas are scarce but include *Skenidioides* sp., *Glyptorthis* sp., *Howellites* sp., *Heliocrinites* sp., and *Toxochasmops extensus*. The uppermost beds are very poorly fossiliferous.

Venstøp Shale Formation

As stated earlier, this characteristic rock unit was first studied by Dahll (1857) in the vicinity of Venstøp, north of Skien (Fig. 2) and although these exposures are now poor and a new stratotype is designated here, Dahll's original name is reinstated in preference to terms such as the Lower Tretaspis Shale which have been applied to the unit more recently. The new stratotype is selected as the section occurring at the southern tip of Langesundstangen (Map reference: 58°59′15″N, 9°45′10″E), where an excellent exposure is readily accessible and both lower and upper boundaries are immediately apparent (see note, p. 270). This stratotype thus overlies that of the Steinvika Limestone Formation and its lower boundary has been defined above. As is the case with the lower boundary, the upper boundary of the Venstøp Shale Formation is sharp and marked by a significant colour change from the very dark shales below to the pale coloured compact nodular fine limestones of the Herøy Limestone above. The thickness (11.1 m at the stratotype locality) and character of the Venstøp Shale Formation are constant throughout the Langesund-Skien district and it consists entirely of very dark, almost black shales with horizons of widely spaced calcareous concretions (Fig. 4). The concretionary nature of the latter is undoubted as several weathered examples show well-developed septarian structures. Beds of sandstone, siltstone, and limestone are totally absent. The shales are heavily iron-stained and are often dark red on outcrop surfaces, reflecting the abundant pyrite which is disseminated through them. The Venstøp Shale Formation is exceptionally fossiliferous at certain horizons, though preservation is poor due to pyritization and subsequent oxidation. The faunas occur in two ways. Scattered individuals of *Flexicalymene?* sp., *Primaspis* cf. *evoluta,* and tretaspids occur throughout and orthocone nautiloids also occur in this manner but are confined to the lower

Table 2. Summary of the newly designated formations in the Langesund-Skien district.

Lithostratigraphic unit	Stratotype locality	Thickness	Geographic extent	Facies
VENSTØP SHALE FORMATION	Southern tip of Langesundstangen	11-11.5 m	throughout	black shales
STEINVIKA LIMESTONE FORMATION	Steinvika	c.41 m	throughout	see members
Skavråker Member	Skavråker	8.5-12.5 m	throughout	1.fossiliferous calcilutites 2.argillaceous mudstones 3.bioturbated calcilutites and argillaceous mudstones
Åsstranda Member	Åsstranda	0-24 m	only north of Veitåsen	1.massive calcilutites 2.laminated calcilutites 3.laminated siltstones
Langesundstangen Member	Langesundstangen	0-14 m	only south of Skavråker	1.thinly interbedded fossiliferous limestones and silty argillaceous mudstones 2.skeletal limestones 3.argillaceous mudstones
Bunæs Member	Bunæs	5-23 m	throughout	1.dark bioclastic limestones 2.patch reefs and associated facies 3.channelled facies

beds. Several horizons contain scattered, poorly preserved graptolites, including *Climacograptus styloideus, Dicellograptus morrisi, Dicellograptus pumilis?, Leptograptus* sp., and *Orthograptus truncatus*. However, the most striking assemblages are dense bedding plane clusters with abundant *Onniella argentea* and *Hisingerella nitens,* together with *Sericoidea* sp., *Dalmanella* sp., and linguloids, which occur at several levels.

Summary

The lithostratigraphical units proposed and described herein are summarised in Table 2, together with their included lithofacies. The wide variety of lithofacies included in the Steinvika Limestone Formation and the shallow water and very shallow water origin of many of them are unusual in the Ordovician sequences of the Oslo Region, which more usually consist of monotonous shales and shales with irregular limestone layers and lenses. Briefly, the facies distribution within the Steinvika Limestone Formation shows that the sediments initially developed during a regressive phase when the coarse skeletal sands of the Bunæs Member were deposited in an offshore, high energy shoaling environment whilst the calcilutites of the Åsstranda Member were deposited in an inshore, low energy lagoonal environment behind the shoals. Maximum shallowing is marked by the desiccation-cracked laminated calcilutites and siltstones of the Åsstranda Member and the lithification and scouring of skeletal sands at the top of the Bunæs Member. Following this, renewed transgression resulted in the deposition of the overlapping sequence of progressively offshore sediments of the Langesundstangen Member. Ultimately, the offshore mixed lime and argillaceous mudstones of the Skavråker Member were deposited across the whole district before restrictions in circulation led to the development of a euxinic environment and deposition of the black pyritic shales of the Venstøp Shale Formation.

The sparse though widespread occurrence of the trilobite *Toxochasmops extensus* shows that the Steinvika Limestone Formation is a lateral equivalent of the Upper Chasmops Limestone of the Oslo-Asker district. Other members of the diverse fauna present in the Steinvika Limestone Formation appear to be of little use in correlation at the present time, although a high number of taxa present – particularly the corals, bryozoa, and brachiopods – also occur in the Mjøsa Limestone of the Toten and Nes-Hamar districts (Fig. 1) which is also considered to be a lateral equivalent of the Upper Chasmops Limestone. The graptolites recovered from the Venstøp Shale Formation are a firm indication of the zone of *Pleurograptus linearis* (D. Skeving-

ton, pers. comm. 1975) and an equivalence with the Lower Tretaspis Shale of the Oslo-Asker district. Despite these broad equivalents, more precise correlation is not possible at the present time but may be achieved by more detailed biostratigraphical studies, particularly with respect to the trilobites which are proving useful elsewhere in the Oslo Region (Owen 1978, D. L. Bruton, pers. comm. 1978).

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