

Stratigraphy of Ordovician limestones, Lower Allochthon, Scandinavian Caledonides

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Rasmussen, J. A. & Bruton, D. L.: Stratigraphy of Ordovician limestones, Lower Allochthon, Scandinavian Caledonides. *Norsk Geologisk Tidsskrift*, pp. 199–212. Oslo 1994. ISSN 0029-196X.

The Lower Allochthon Osen–Røa Nappe Complex in Norway and the Jemtlandian Nappes of Sweden, contain Ordovician limestones shown to be deeper water equivalents of the Huk Formation (= 'Orthoceras' Limestone, Orthoceratite Limestone) of the autochthon and younger. They are redefined as the Stein Formation (Arenig–Llanvirn) and the newly named Elvdal Formation (Llandeilo–?Caradoc). The Stein Formation, consisting of the Herram Member and Steinsholmen Member (new name), is 40–50 m thick but thins towards the basin in the west and is replaced by the Ørnberget formation at Etnedal, Norway and the Föllinge Formation west of Andersön–Norderön, Jämtland, Sweden. The Stein Formation contains 2–5 times less magnesium (Mg) than that recorded from the Huk Formation. The Elvdal Formation, estimated to be 14 m thick, is thrust between Precambrian units in central east Norway, south of Lake Femunden. Although lithologically similar to the Stein Formation, its contained conodonts are distinctly younger (*P. anserinus* Zone). The Stein Formation yields Baltoscandian conodonts together with deeper water elements known from Western Newfoundland and Spitsbergen. The Elvdal Formation contains more than twice the amount of manganese (3000–5000 ppm Mn) recorded from the Stein Formation.

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Introduction

Baltic Realm Ordovician rocks of pre-Caradoc age are well developed within the autochthonous–parautochthonous platform successions of Sweden and Norway and also occur within the Lower Allochthon of the Scandinavian Caledonides (Bruton & Harper 1988; Bruton et al. 1989). Of particular interest for the time interval in question is the apparent shale-limestone cyclicity of units across a broad shelf area extending from the Baltic area in the east and beyond what today is the margin of the Baltic Shield represented by the present west coast of Norway. Nystuen (1981) has estimated that parts of the Lower Allochthon may have been translated 200–400 km southeastwards, the latter figure being for the Osen–Røa Nappe Complex containing some of the units discussed below. These include limestones previously thought to be equivalent to the 'Orthoceras Limestone' (Arenig–Llanvirn) of the platform but now shown, on the basis of their contained conodont faunas, to be either deeper water equivalents or even younger (Llandeilo–?lowest Caradoc). Detailed study of the rocks and their contained conodont faunas (Rasmussen & Stouge 1988, 1989; Rasmussen 1994, in prep.), has led to the need for the new lithostratigraphic and biostratigraphic classification outlined below. This forms a basis for discussions on the depositional environment and also adds to our understanding of the Ordovician palaeogeography of the western Baltic Shield (Bruton 1989).

Geological setting

Ordovician rocks of the Parautochthon and Lower Allochthon of the Scandinavian Caledonides were deposited in a variety of environments on and adjacent to the western edge of the Baltoscandian Platform (Bruton & Harper 1988; Jaanusson 1982, fig. 3), whilst those of the Oslo Region occupy an intermediate position between the developing Caledonides and the Autochthon of the more stable Baltic Platform where successions are thinner and characterized by distinctive limestones and mudstones deposited in well-defined confacies belts (Jaanusson 1976). Among the limestones of the central Baltoscandian confacies belt are those formerly known as the Orthoceras or Orthoceratite Limestone of Arenig–Llanvirn age. This unit has been redefined as the Huk Formation in the Oslo Region (Owen et al. 1990) whilst Jaanusson (1982) and Karis (1982) informally introduced the name Isö Limestone for a tongue of the limestone representing a maximum westward extension of the central Baltoscandian confacies belt now found in the Lower Allochthon of Jämtland. According to the model outlined by Jaanusson (1973, 1982), sediment input was from two sources, a carbonate one in the east developed at the margins of an area of low relief where supply of terrigenous material was slight, whilst in the west the greater influx of siliciclastic sediments and mud has been ascribed to sources within the rising Caledonides. The Tøyen Shale Formation (Owen et al. 1990) represents such an event and underlies the 'Orthoceras

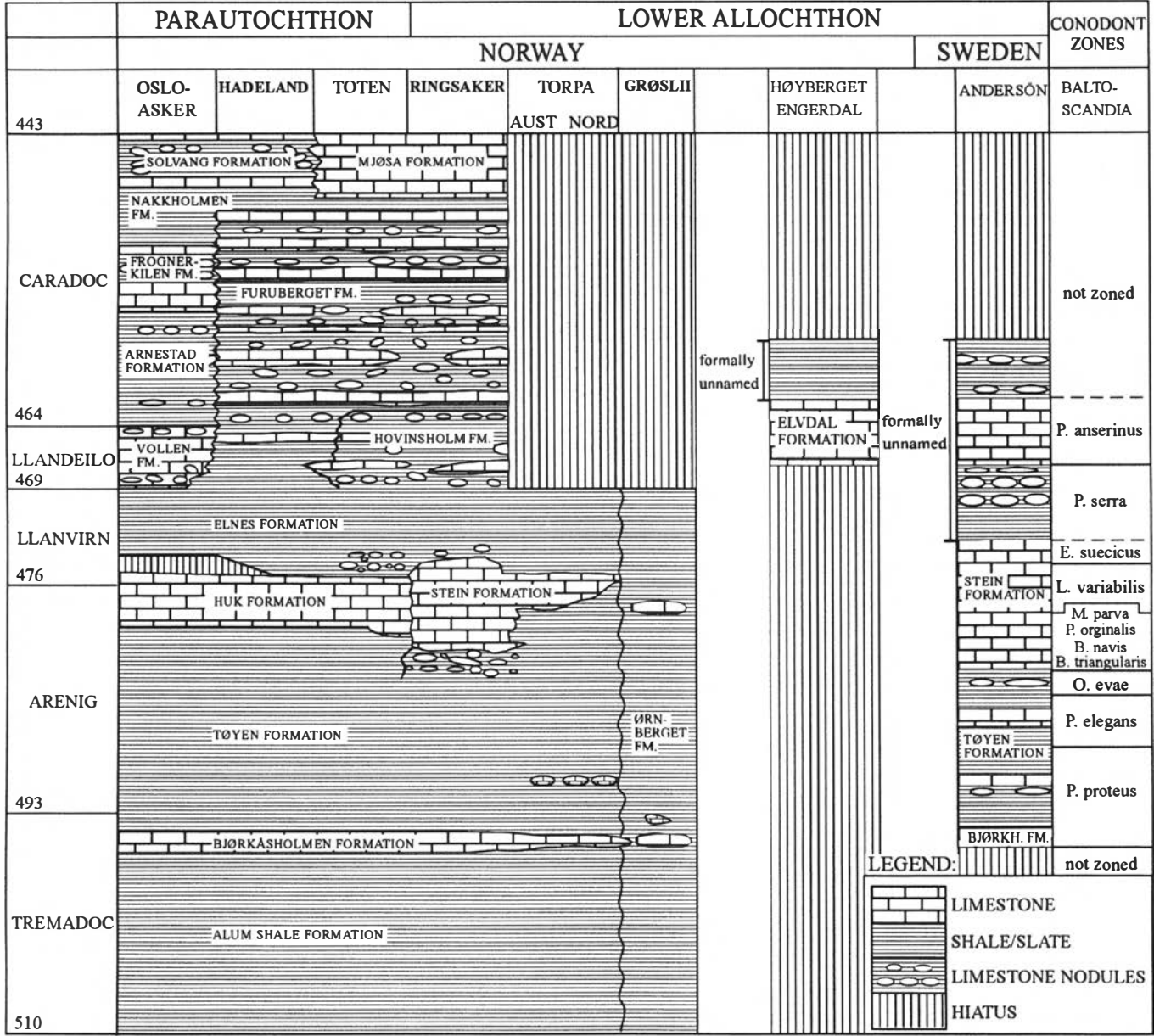


Fig. 1. Stratigraphy of the Lower and Middle Ordovician limestone units of the Scandinavian Caledonides. The lithological division of the parautochthon is after Owen et al. (1990).

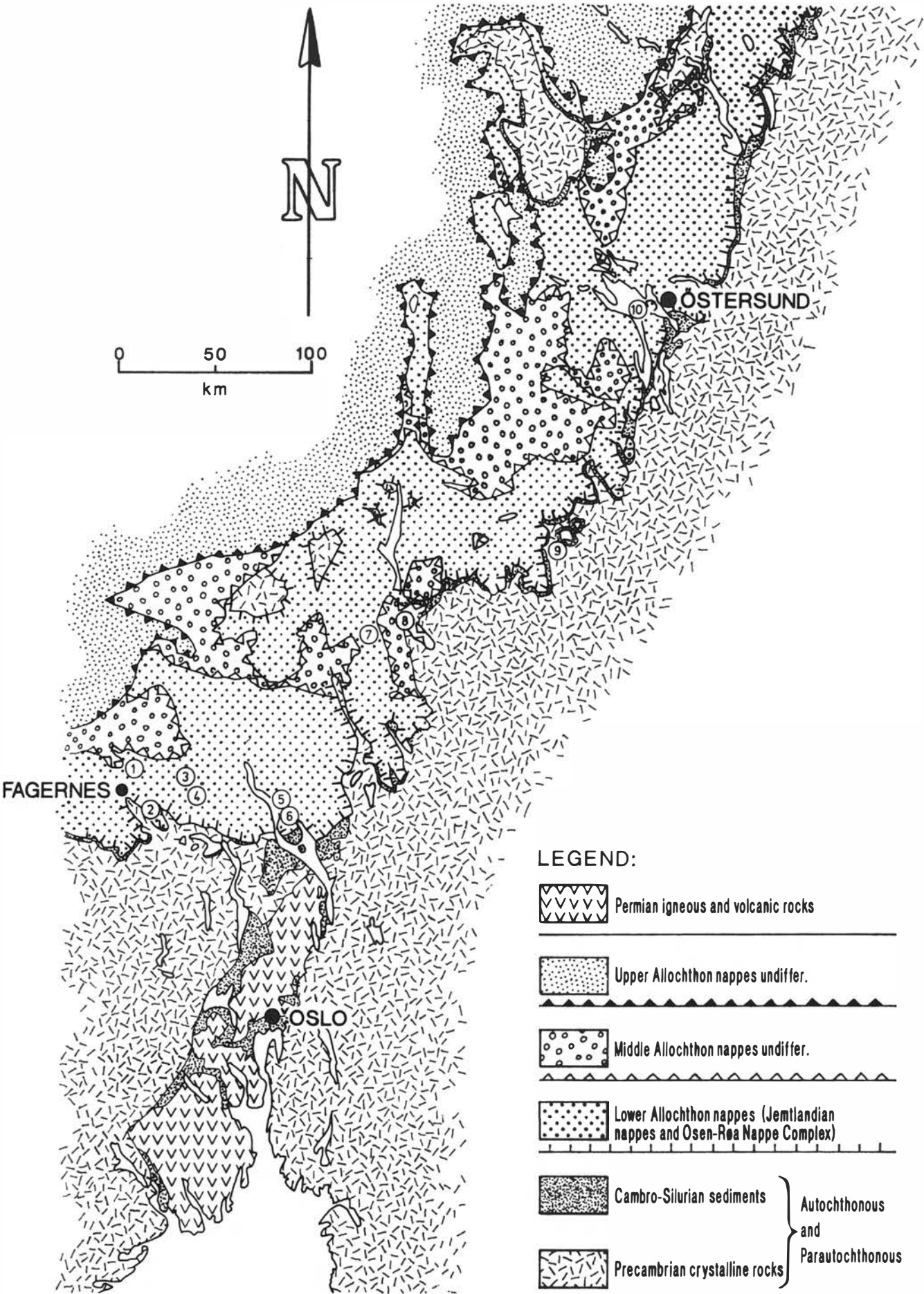
Limestone' wherever this outcrops and together they are among the most extensive Ordovician units in Baltoscandia. Within the Parautochthon and Lower Allochthon the limestone units are readily identified but their contained macrofossils are either poorly preserved or too wide-ranging for accurate dating. Owen et al. (1990, fig. 8) attempted to correlate the Huk Formation and its constituent members with the Baltoscandian chrono- and biostratigraphical units based on the conodont information available at that time. This information has since been improved by one of us (JAR) and indicates the diachronous nature of the Lower and Middle Ordovician limestones of the Lower Allochthon in Sweden and Norway. Such diachroneity is not surprising considering

that we are dealing with platform to slope environments with concomitant facies changes along the active Caledonian front. For this reason a revised lithostratigraphic classification is provided (Fig. 1) which takes this into account.

The former 'Orthoceras Limestone' of the Scandinavian Caledonides is situated along the Caledonian front from Etneidal and Torpa in the west (close to the southeastern slopes of Valdres), through Ringsaker and the Engerdal-Drevsjø area in central East Norway, to Jämtland in northern Sweden (Fig. 2).

It occurs in the Osen-Røa Nappe Complex in Norway (Nystuen 1981; Hossack et al. 1985, with earlier references), and in the Jemtlandian Nappes in Sweden

Fig. 2. Location map (modified from Gee et al. 1985 and Bockelie & Nystuen 1985). 1: Grøslil, 2: Hestekinn, 3: Jørnli, 4: Røste, 5: Steinsodden, 6: Herram, 7: Høyberget, 8: Røskdalssknappen, 9: Glöte, 10: Andersön.



(Asklund 1960; Gee 1975; Gee et al. 1985). Bockelie & Nystuen (1985) and Gee et al. (1985) summarized the stratigraphy and structural geology of the investigated area. The westernmost section is at Hestekinn, Bruflat (Strand 1954) but Strand (1938, p. 23) mentioned the presence of loose blocks of 'typical *Orthoceras* Limestone' (translated from Norwegian) at the road near the stream Åfeta, which is about 7 km east of lake Steinsetfjorden (Valdres) and 15 km ENE of Fagernes. However, he did not mention the precise location of the erratics.

Equivalent limestones, the Bjørnaskalle Formation (Andresen 1978), occur on Hardangervidda some 200 km further southwest, and contain a shelly fauna which correlates with the uppermost Arenig–lowest Llanvirn interval (Bruton et al. 1985, 1989). In the following account we discuss the former 'Orthoceras Limestone' of the Scandinavian Caledonides in terms of the Stein Formation, (with Herram Member and Steinsholmen Member; (new name) and Elvdal Formation (new name).

Stratigraphy

Stein Formation (Skjeseth 1963)

Previously termed '3c' (Brøgger 1882, table 6; Münster 1891, 1900 followed by several authors), *Orthoceras* Limestone (Münster 1891, 1900 followed by several authors), Stein Limestone (Skjeseth 1963), Stein Formation (Høy & Bjørlykke 1980), Isö Limestone (Karis 1982). The Stein Limestone of Skjeseth (1963) was included as

the Stein Member of the Huk Formation by Owen et al. (1990).

Lithology. – The Stein Formation is dominated by grey, massive, biomicritic limestone which may be classified as predominantly mud- and wackestone following Dunham (1962). Skeletal debris of trilobites, brachiopods and, more rarely, gastropods is visible in thin sections from the Stein Formation at Steinsodden. The formation is characterized by beds of argillaceous limestone alternating with beds of more pure limestone. Distinct bedding planes are rare. Thickness of the single beds is usually 10–30 cm. Clastic silt beds become progressively more common towards the west. Pressure dissolution seams containing residual clay are common. The calcium carbonate content ranges from an average of 81% at Andersön through 71% at Steinsodden to 56% at Hestekinn (Table 1), measured by atomic absorption spectro photometry. The gradual increase in clastic material west of Lake Mjøsa, already observed by Münster (1900) and Strand (1929), is connected with deepening of the platform in this direction. The manganese content of the Stein Formation has an average of 1300–2200 ppm which is considerably less than that found in the younger, but lithologically similar, Elvdal Formation.

The CaCO₃ content at localities west of Mjøsa varies from an average of 66% at Røste to 56% at Hestekinn and 63% at Jøronlia (Fig. 2, Table 1).

Basal stratotype. – Moelv (Ringsaker): Steinsodden (map Gjøvik 1816, 1; NN919539).

Table 1. Geochemical data of the Stein Formation from six localities along the Caledonian Front (see Fig. 2). n = number of samples, avg. = average value (sum/n), min. = minimum value, max. = maximum value, st. dev. = standard deviation. Data from the Huk Formation at Slemmestad are included for comparison (Rasmussen unpublished). Elemental concentrations were determined with an Atomic Absorption Spectrophotometer.

	Steinsodden	Andersön-A	Andersön-B	Røste	Hestekinn	Jøronlia	Slemmestad (Huk Fm)
CaCO ₃ %							
n	25	18	18	5	4	4	18
avg.	71.4	81.1	80.4	66.3	56.1	62.9	58.8
max	90.0	94.6	90.1	81.9	69.4	71.6	79.8
min.	36.1	60.9	67.4	45.2	45.0	43.2	27.6
st. dev.	13.5	8.0	7.5	13.7	11.1	13.5	17.1
Mn ppm							
n	25	18	18	5	4	4	18
avg.	1570	1708	2167	2024	1338	1820	918
max.	2120	2380	3250	2890	1460	2100	2250
min.	1060	1150	1260	1230	1210	1280	460
st. dev.	363	457	559	613	136	368	479
Mg ppm							
n	25	18	18	5	4	4	18
avg.	4881	2076	2500	2700	2200	3128	14997
max.	11100	2500	3500	3500	2500	3800	29500
min.	2770	1800	1900	2300	2000	2500	4840
st. dev.	2365	228	417	495	245	538	7740
Sr ppm							
n	25	18	18	5	4	4	18
avg.	397	245	277	462	293	600	1103
max.	641	380	530	890	330	800	1640
min.	284	160	160	210	260	432	810
st. dev.	100	57	86	269	33	152	218

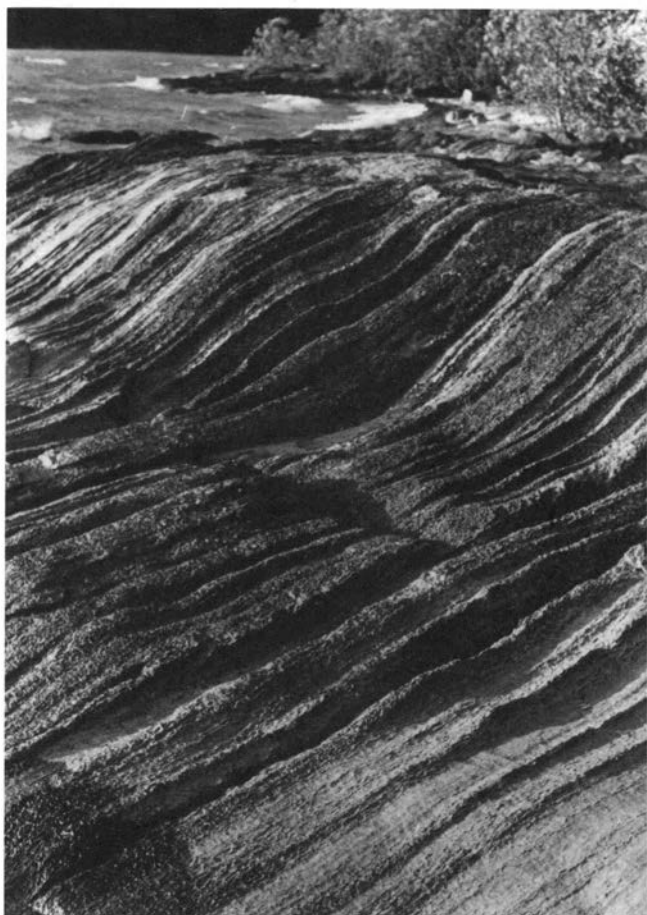


Fig. 3. Middle part of the Steinsholmen Member at Steinsodden. The strike is WNW-ESE and the dip is vertical.

Hypostratotypes. – Norway: Herram (map sheet Hamar 1916 IV; NN989485), Jøronlia (Bruflat 1716 I, NN505617), Hestekinn (Bruflat 1716 I, NN323498), Røste (Dokka) 1816 IV; NN614583).

Sweden: Andersön A (Östersund 193B, 14307E 70074N), Andersön B (Östersund 193B, 14297E 70066N).

Thickness variation. – Norway: Steinsodden, Ringsaker, 45 m (Figs. 3 & 8); Herram, Ringsaker 2.7 m (Fig. 4, Herram Member and basal part of Steinsholmen Member); Lyshaug, Dokka (Dokka 1816 IV; NN627462) + 8 m; Aust-Torpa, Røste 7 m (Fig. 5); Nord-Torpa, Jøronlia 5.8 m; Hestekinn, Bruflat, +4.3 m. Sweden: Andersön A, 29 m (Fig. 6, upper part missing); Andersön B, 28.7 m (Fig. 7, middle part missing), Föllinge, about 35 m (section partly covered).

Definition and boundaries. – The Stein Formation is characterized by a typical reticulate pattern when weathered (Fig. 3). Distinct bedding planes and discontinuity surfaces are infrequent, especially in the Norwegian sections. The magnesium content averages 2000–5000 ppm Mg (Table 1).

Wiman (1893, p. 266), noted the lithological similarity between the Stein Formation at Lake Mjøsa, Norway and Andersön-Frösön-Norderön in Jämtland, Sweden.

Surface weathering is rather similar to that of the Middle Ordovician Elvdal Formation (see below), which is why the two formations have been confused earlier.

The Stein Formation overlies the dark shales of the Tøyen Formation and in all areas except Ringsaker and Andersön, there is an abrupt lithological change between them. In Ringsaker, the Stein Formation comprises two members. The lower member, formerly named ‘Heramb Shale and Limestone’ by Skjeseth (1963), was renamed Herram Member by Owen et al. (1990). The nodular Herram Member (Fig. 4), forms a gradual transition between the typical shales of the underlying Tøyen Formation and the upper member of the Stein Formation

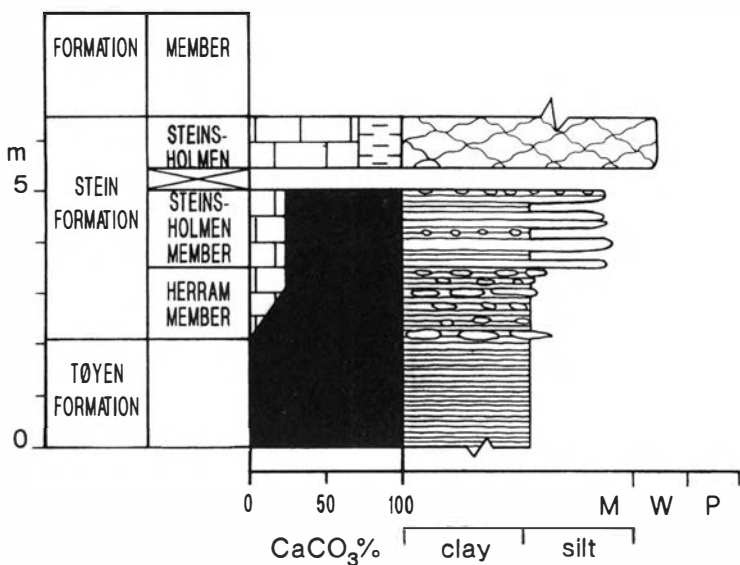
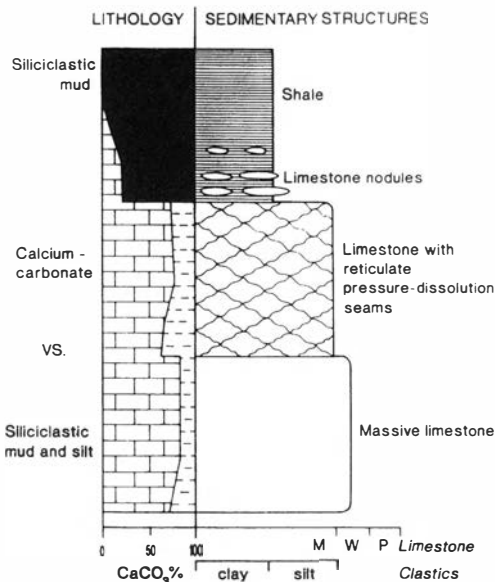


Fig. 4. The Herram Member of the Lower Ordovician Stein Formation at Herram, Ringsaker.

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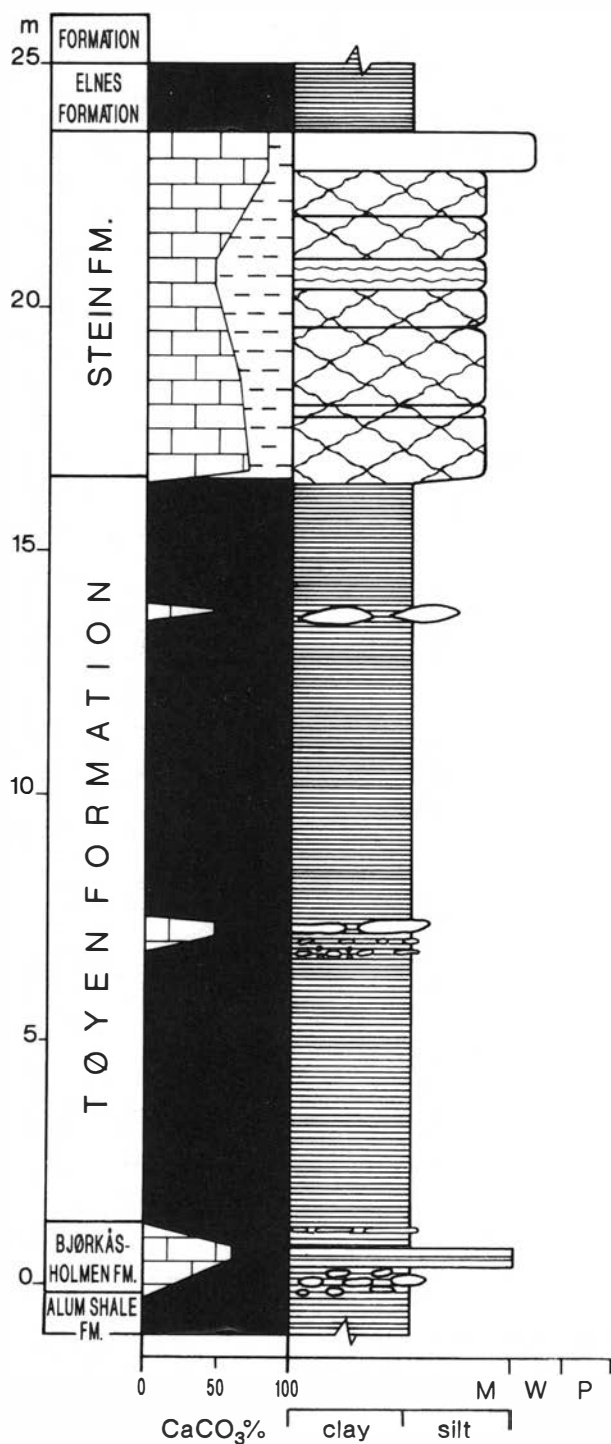


Fig. 5. The Stein Formation at Røste. Legend as in Fig. 4.

for which we introduce the new name, Steinsholmen Member (see below). A. Bjørlykke (1979) noted that the nodular Herram Member is also present in Snertingdal and at Austsinni, 2 km north of Dokka. At Andersön in Sweden, the Stein Formation overlies a succession of dark shales, interbedded limestone nodules, and continuous limestone beds, traditionally assigned to the Tøyen Formation (=Lower *Didymograptus* shale of Hadding 1912; Tjernvik 1956; Tøyen Shale of Karis 1982). The Stein Formation is overlain by dark graptolitic shales. In

the Ringsaker–Torpa–Dokka area, these shales belong to the Elnes Formation although here the unit is more clastic than in the type area of the Oslo region (Münster 1900, p. 31; Owen et al 1990). At the roadcut one kilometre south of the Røste section (Fig. 5), the clastic mud, silt and sand beds alternate in a rhythmic, distal turbidite-like manner. At Andersön the Stein Formation is succeeded by a dark grey graptolitic shale unit interbedded with sandstone layers with a thickness of about 5 cm (Thorslund 1937, p. 10). The unit has been termed 'Andersö Shale' (Karis 1982). It becomes progressively sandier west of Andersön (Thorslund 1940, p. 106).

Discussion. – We have chosen to introduce the name Steinsholmen Member (*nomen novum*) for the upper part of the Stein Limestone (*sensu* Skjeseth 1963; Stein Member of Owen et al. 1990). This and the underlying Herram Member were assigned to the Huk Formation by Owen et al. 1990. Subsequent investigations, however, have revealed that the Huk Formation of the Oslo Region is different both lithologically and palaeontologically from similar units within the Lower Allochthon of the Scandinavian Caledonides. Because the Name *Stein Limestone* is well known in the literature and the unit has already been given formational status, albeit informally, on the geological map HAMAR 1916, 4 (Høy & Bjørlykke 1980), we prefer to formalize it here. By doing this we avoid having to introduce a new formation name for the Herram and Stein members of Owen et al. (1990).

Fauna and biostratigraphy. – Macrofossils reported from the Stein Formation are few in number and generally poorly preserved. Some importance has been attached to specimens of *Cycloendoceras* and related cephalopods, but these unfortunately have limited biostratigraphical value.

Skjeseth (1952) recorded trilobites and graptolites from the Herram Member at Herram Farm, Ringsaker, Norway, and correlated the unit with the Billingen *Phyllograptus densus* and *Phyllograptus angustifolius elongata* graptolite zones. However, Dr. Kristina Lindholm, Lund, (pers. comm. 1992) informs us that her work with the graptolites suggests that the Herram Member more likely correlates with the Volkhovian *Didymograptus hirundo* Zone. This is confirmed by the conodonts indicative of the *Baltoniodus navis* Zone (Kohut 1972; Rasmussen 1989, 1994).

Unlike the Stein Formation, the succeeding Elnes Formation is rich in macrofossils. *Ogygiocaris dilatata* (Brünnich), *Didymograptus geminus* (Hisinger) and *Pseudoclimacograptus scharenbergi* (Lapworth) were listed from the Elnes Formation ('4a') at Ringsaker (Holtedahl 1909; Strand 1929; Skjeseth 1963) whereas *Ogygiocaris* sp. and *Hustedograptus teretiusculus* have been reported from several localities west of Lake Mjøsa (Münster 1900). A. Bjørlykke (1979) recorded *Ogygiocaris* sp. and *Diplograptus* sp. from Snartumelva, eastern Snertingdal,

and Flåmyra (Aust-Torpa). None of this material was figured. Holtedahl (1909, p. 13) studied fossils from limestone nodules of the Elnes Formation ('4a') at Stokbækken, Vest-Torpa, collected by Münster (1900) and recorded *O. sarsi* Angelin, *Trinucleus foveolatus* Angelin, *Cheirurus* sp., *Climacograptus* sp. and *Diplograptus* (possibly *Hustedograptus*) sp.

D. geminus, *P. scharenbergi*, *H. teretiusculus* and *Climacograptus* spp. are all common in the Elnes Formation at Slemmestad, Oslo-Asker (Berry 1964).

In Sweden only a few macrofossils have been recorded from the Stein Formation in Jämtland. The trilobites *Pseudasaphus tecticaudatus* (Steinhart) and *Trinucleus coscinorhinus* Angelin (*Botrioides* sp. ?) were reported by Hadding (1912, tab. 7a: loc. 1) from the Andersön B section, but they were not accurately located. Tjernvik (1956) listed *Megistaspis* sp. from about 0.5 m above the base of the formation at Andersön (the Andersön A section herein), whilst Tjernvik & Johansson (1980, p. 197) recorded *Megistaspis* (*M.*) *lata* (Törnquist) from the lowermost part of the Stein Formation. Karis (1982) recorded *Asaphus* (*A.*) *expansus* (Linnaeus) 5 m above the base and *Paraceraurus exsul* (Beyrich) and *Pseudomegalaspis patagiata* (Törnquist) from the uppermost 2 m of the formation (possibly the Andersön B section herein). Based on this, Karis (1982) correlated the top of the formation with the Lasnamägian Folkeslunda Limestone (upper Llanvirn). However, this conflicts with the conodont data. Conodonts from the top of the formation are indicative of the *Eoplacognathus suecicus* Zone (the zonal species is identified within the upper 2 m of the section), thus indicating correlation with the Upper Kunda Stage which correlates with the middle Llanvirn Series (Fig. 1). This means that either the conodont-trilobite-graptolite correlation scheme for the distal parts of the Baltoscandian platform is different from the standard Baltoscandian correlation scheme (e.g. Jaanusson 1982, fig. 2) or that the macrofauna of the Stein Formation is in need of revision.

Graptolites and trilobites are relatively common in the contiguous shale units. Hadding (1912) and Tjernvik (1956) correlated the underlying shale unit with the Tøyen Formation ('Lower *Didymograptus* Shale') from Oslo and Scania. The Tøyen Formation-Stein Formation boundary is well exposed at the Andersön A profile (locality 8 of Hadding 1912). Tjernvik (1956) did not record fossils from the uppermost part of the Tøyen Formation at this locality, but found *Didymograptus validus* Törnquist from a level about 1 m below the top and correlated this level with the *D. balticus* graptolite Zone. Limestone nodules 0.30 m below the base of the Stein Formation (Fig. 6) yielded the following conodont fauna: *Microzarkodina flabellum* (Lindström), *Baltoniodus* sp., *Paroistodus originalis* (Sergeeva), *Drepanoistodus forceps* (Lindström) and *Protopanderodus rectus* (Lindström) indicative of the *B. navis* Zone (Volkhov). The Stein Formation is succeeded by a dark shale unit which is about 6 m thick at Andersön, Jämtland (Fig. 7),

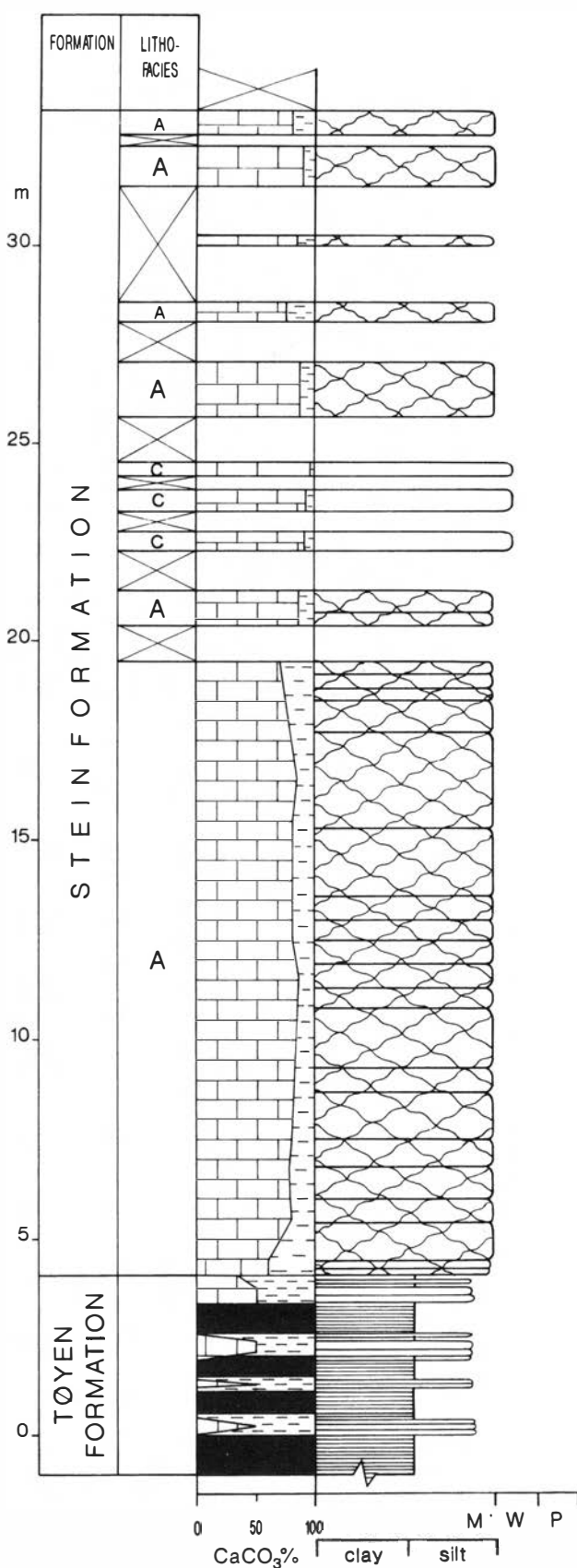


Fig. 6. The Stein Formation at the Andersön A section (northern Andersön). Legend as in Fig. 4.

though the contact is a faulted one. This is followed by the 1.5 m thick 'Biseriata Limestone' which is overlain by more than 5 m dark shales. These three units, collectively

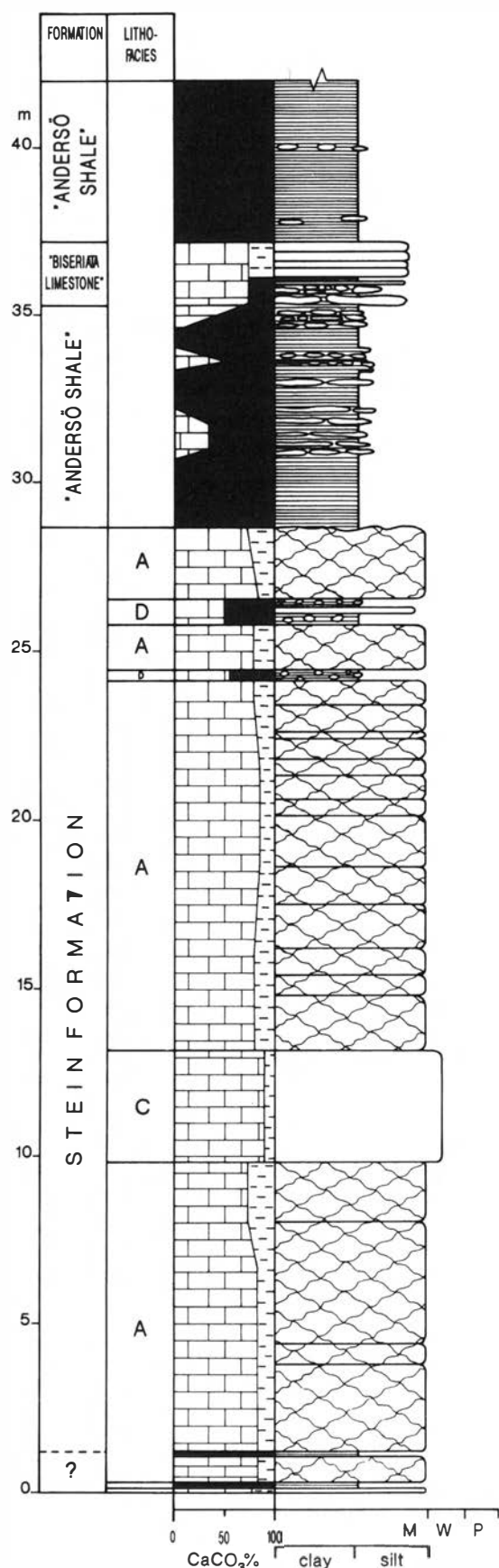


Fig. 7. The Stein Formation at the Andersön B section (northwestern Andersön). Legend as in Fig. 4.

called *Ogygia* shale or *Ogygiocaris* shale (e.g. Wiman 1893; Thorslund 1960), were informally named the Andersö Shale by Karis (1982). The shale unit contains *Ogygiocaris sarsi* Angelin, *Pseudoclimacograptus scharenbergi* (Lapworth), *Hustedograptus teretiusculus* and *Nemagraptus gracilis* Hall (Linnarsson 1872; Wiman 1893; 1897; Hadding 1912; Thorslund & Asklund 1935; Thorslund 1960; Karis 1982) indicating a Llanvirn to Lower Caradoc age. This corresponds well with the occurrence of *Pygodus serra* and *P. anserinus* Zone conodonts within the 'Biseriata Limestone' (Bergström in Bergström, Riva & Kay 1974, table 10; and Rasmussen, unpublished). Hadding (1912, p. 594) reported *N. gracilis* and *Dicranograptus clingani* Carruthers from black, nodular shales 200 m north of the Andersön B profile. However, the presence of *clingani* Zone strata at Andersön, has not been confirmed by subsequent studies (Stig Bergström, pers. comm. 1992).

Conodont zonation. – Conodonts are fairly abundant in the Stein Formation (Kohut 1972; Rasmussen 1994) thus allowing correlation with the Baltoscandian stratigraphical scheme introduced by Lindström (1971) and later refined by Löfgren (1978). In addition, the conodont fauna of the Stein Formation contains several taxa which are rare or unknown in Baltoscandia but are common in North America, e.g. *Histiodella holodentata* Ethington & Clark, *H. kristinae* Stouge, *Fahraeusodus* sp. and several species of *Periodon* Hadding. This makes the Stein Formation an effective agent for biostratigraphic correlations across the Iapetus Ocean (Rasmussen & Stouge 1988; Rasmussen 1994). The conodont fauna also differs from the faunas that typify the more proximal, undeformed Baltoscandian platform, with respect to stratigraphic ranges and relative abundances. This is especially distinct within the upper Arenig–lower Llanvirn time interval, where a new conodont zonation has been established (Rasmussen 1994, in prep.). However, it is possible to correlate the faunal succession of the Stein Formation with the Baltoscandian standard zones, and intervals correlating with the following conodont zones have been recognized at Steinsodden and Andersön: *B. navis*, *P. originalis*, *M. parva*, *L. variabilis* and *E. suecicus* (Fig. 1). A sample from the very top of the Stein Formation at Andersön yielded *Eoplacognathus suecicus* Bergström together with *Panderodus sulcatus* (Fåhræus) and *Scalpellodus gracilis* (Sergeeva). Thus at Andersön and in Ringsaker the Stein Formation correlates with the Baltoscandian Volkhov (possibly also the uppermost Billingen?), Kunda and Aseri stages corresponding to the Fennian–lower–Upper Llanvirn of the British standard.

At the westernmost localities, Røste, Jøronlia and Hestekinn, west of Snertingdalen, Norway, the formation seems to be less extensive being restricted to the uppermost Arenig and lower Llanvirn (lower–middle Kunda), portion of the *L. variabilis* Zone (Fig. 1). The conodont fauna is dominated by Gen. et sp. nov. A, *Polonodus* spp., *Periodon aculeatus* spp. A Rasmussen, 1991 and

Protopanderodus rectus (Lindström), *P. robustus* (Hadding), *P. cf. varicostatus* (Sweet & Bergström) and *Ansella jemtlandica* (Löfgren). The above described diachronism is thought to be related to the platform-deepening towards the west and northwest. Palaeoecological studies of the conodont fauna from Steinsodden have revealed that a major regression occurred around the *L. variabilis*–*M. parva*/*L. variabilis*–*M. ozarkodella* subzonal boundary (middle Kundan) (Rasmussen 1994), and it seems likely that it was this regression which initiated limestone deposition (although impure) also on the shale-dominated deeper parts of the platform.

Depositional environment. – The Stein Formation is the deeper lateral equivalent of the Huk Formation described by Owen et al. (1990). Conodonts from the Stein Formation include those which have been described from the outer platform or slope environments of the Table Head and Cow Head Groups of Western Newfoundland (Stouge 1984) and the Valhelfonna Formation of Spitsbergen (Fortey & Barnes 1977). The most important taxa are *Periodon* spp., '*Walliserodus*' spp., *Ansella jemtlandica* (Löfgren), *Paroistodus horridus* (Barnes & Poplawski), *Histiodela holodentata*, *H. kristinae* and Gen. et sp. nov. A, all rare or missing from contemporary strata in the more proximal parts of the Baltoscandian Platform such as the Oslo Region (Kohut 1972; Rasmussen 1991), the autochthon of Jämtland (Löfgren 1978), Glöte, Härjedalen, central Sweden (Fig. 2; Rasmussen unpublished), the south Bothnian Bay (Löfgren 1985), Öland (Stouge & Bagnoli 1990) and the Baltic (Viira 1967, 1974).

Preliminary studies of the phosphatic microbrachiopod biofacies of the Stein Formation have shown that *Numericoma* dominates at Dalarna, Västergötland and Andersön, *Scaphelasma* at Snertingdalen (near Røste). *Hisingerella* is the main constituent at Grøslia (Harper & Rasmussen 1994). Accordingly, there is strong palaeontological evidence from conodonts and brachiopods to suggest that the Stein Formation was deposited in a deeper environment along the platform margin and that the palaeo-depth increased from Andersön through Ringsaker and Aust-Torpa (Røste) to Nord-Torpa (Jørnolia). Sedimentological observations including thin-section studies also favour this interpretation, whereas the environmental significance of the geochemical data (Tables 1–3) is more uncertain.

Lithologically, the Stein Formation becomes gradually thinner and more silty towards the west and northwest of Lake Mjøsa, and is replaced laterally by the grey slates of the Solheim Member of the Ørnberget Formation in the succeeding Synnøfjell duplex at Valdres (Strand 1938; Hossack et al. 1985; Nickelsen et al. 1985; Bruton 1989; Bruton et al. 1989). The successively higher tectonic units of East Jotunheimen (Aurdal duplex–Synnøfjell duplex–Valdres thrust sheets) contain gradually more sandstones and greywackes which indicate slope-basin depositional environments (Bruton & Harper 1988, p. 261). A similar

development can be seen in the southwestern Storsjön area of Jämtland where the Stein Formation ('Isö Limestone') thins rapidly from 12 m to about 1 m near Kläppe about 10 km southwest of Andersön (Karis 1982, p. 57). Further towards the west the formation is replaced by the Föllinge Greywacke Formation.

The magnesium content of the Stein Formation is commonly 2–5 times less than that of the contemporary Huk Formation. K. Bjørlykke (1974a; 1974b, p. 38) showed that 13 samples of the Huk Formation ('3c') from throughout the Oslo Region averaged 1.78% MgO = 10,800 ppm Mg. Magnesium measurements of 18 samples through the Huk Formation at Slemmestad (Oslo–Asker) gave an average of 15,000 ppm Mg, which is in accordance with the trend (Rasmussen, unpublished data; Table 1). Our preliminary studies of the geochemical parameters indicate that the higher magnesium content within the Huk Formation compared to that in the Stein Formation, probably results from a higher degree of dolomitization in the Oslo Region *sensu stricto* than in the areas which today form part of the Lower Allochthon.

Herram Member

See Owen et al. 1990 for complete description.

Steinsholmen Member (new member, Fig. 8)

Previously termed the Stein Limestone (Skjeseth 1963) and the Stein Member of the Huk Formation (Owen et al. 1990).

Lithology. – Mainly bedded, biogenic, argillaceous lime mud- and wackestone. The Steinsholmen Member is subdivided into three or four lithofacies at Ringsaker and Andersön, whereas it is restricted to only one principal lithofacies west of Lake Mjøsa.

Lithofacies A consists of bedded biogenic argillaceous lime mudstone and wackestone with a characteristic irregular reticulate weathered surface. The CaCO₃ content averages 73% at Steinsodden and 80% at Andersön (Table 2).

Lithofacies B consists of bedded biogenic argillaceous lime mudstone and wackestone interlayered with more regular (commonly horizontal) clastic mud and silt seams. An almost nodular fabric may occur. This lithofacies occurs at Steinsodden, where the CaCO₃ content averages 65%.

Lithofacies C is characterized by massive bedded skeletal lime wackestone. The CaCO₃ content averages 86% at Steinsodden and 90% at Andersön.

Lithofacies D consists of nodular biogenic lime mudstone interbedded with clastic mud- and siltstone. This lithofacies is common in the upper part of the Stein Formation, particularly at Steinsodden. The CaCO₃ content of the limestone nodules averages 57%.

Exposures of the Stein Formation west of Lake Mjøsa are of Lithofacies A, except that mudstone is the domi-

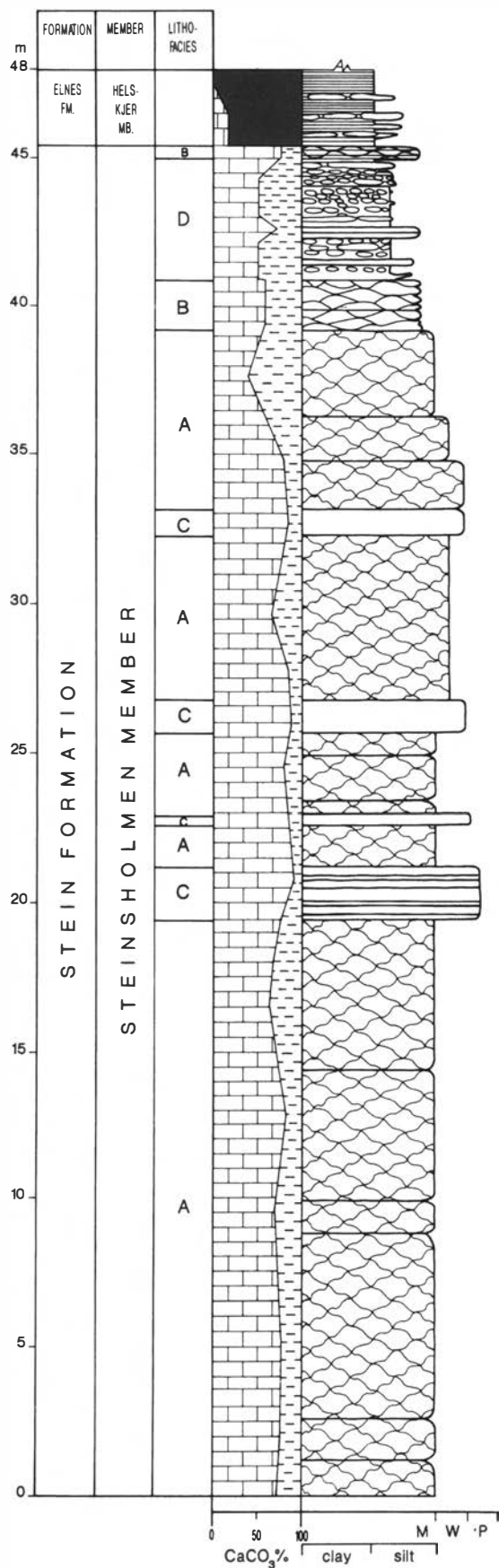


Fig. 8. The Steinsholmen Member of the Stein Formation at Steinsodden, Ringsaker. See text for description of lithofacies. Legend as in Fig. 4.

Table 2. Geochemical data from the four lithofacies of the Steinsholmen Member at Steinsodden. Abbreviations as in Table 1.

	Facies A	Facies B	Facies C	Facies D
CaCO ₃ %				
n	14	3	4	4
avg.	72.9	64.8	85.8	56.6
max.	84.6	76.0	90.0	71.8
min.	36.1	58.7	80.8	47.1
st. dev.	12.2	9.7	4.2	10.6
Mn ppm				
n	14	3	4	4
avg.	1454	1820	1653	1708
max.	2120	1940	2080	2080
min.	1060	1760	1140	1350
st. dev.	373	104	436	309
Mg ppm				
n	14	3	4	4
avg.	4103	6403	3058	8288
max.	9830	6660	3300	11100
min.	2900	6170	2770	4800
st. dev.	1718	246	236	2607
Sr ppm				
n	14	3	4	4
avg.	360	489	358	493
max.	640	641	443	557
min.	290	410	284	436
st. dev.	86	132	72	53

nating depositional texture, the clastic content is greater, and interbedded silt layers are more common. Nodular limestone occurs in some levels.

Basal stratotype. – Moelv (Ringsaker): Steinsodden (map sheet Gjøvik 1816 I; NN919539).

Thickness variation. – Mjøsa (Ringsaker): Steinsodden, 45 m.

Definition and boundaries. – The Steinsholmen Member is named after the small island of Steinsholmen (map Gjøvik 1816 I; NN918538) about 100 m west of Steinsodden. Here the lower 30 m is exposed, the base being the first of the continuous limestone horizons above the nodular Herram Member (Skjeseth 1963; Owen et al. 1990). The top of the unit is the base of the succeeding dark graptolitic shales of the Elnes Formation. The uppermost continuous bed is 0.35 m thick at Steinsodden. Limestone beds and nodules are interlayered with grey clastic mudstones of Lithofacies D in the upper 5 m of the member (Fig. 8). It only has been possible to divide the Stein Formation into the Herram and Steinsholmen members in Ringsaker and probably also east Snertingdal and Dokka (A. Bjørlykke 1979). Elsewhere in Norway the Stein Formation consists of only one lithostratigraphic unit consisting of mainly massive, argillaceous limestone with interlayered silt and mud beds. At Andersön in Sweden, the Stein Formation succeeds a more than 4 m-thick succession of dark shales with interlayered limestone nodules and thin continuous limestone beds, which traditionally has been referred to

as the Tøyen Formation (previously the ‘Lower Didymograptus Shale’) (Hadding 1912; Tjernvik 1956; Karis 1982).

Discussion. – See discussion of the Stein Formation above.

Fauna and biostratigraphy. – The relatively abundant Steinsodden conodont fauna is indicative of the *B. navis*, *P. originalis*, *M. parva* and *L. variabilis* Zones and the *E. suecicus*–*S. gracilis* Subzone. This correlates with the Volkhov and Kundan (except for the uppermost Kundan) stages. For details of the fauna, see the description of the Stein Formation.

Elvdal Formation (new formation)

Previously termed: Orthoceras Limestone (Meinich 1881, succeeded by several authors), 3c (Størmer 1967), Høgberg Formation (Spjeldnæs 1985), Limestone at Høyberget (Rasmussen & Stouge 1989).

Lithology. – The Elvdal Formation consists of medium grey, weakly bedded, biogenic, argillaceous lime mudstone with a characteristic irregular, reticulate weathered surface, similar to that of the Stein Formation, which is why the two formations have been confused previously. The CaCO₃ content is commonly about 80% at Høyberget (formerly Høgberget), Røskdalsknappen and Sorken (Table 3; Høltedahl 1920, p. 29). One sample from Høyberget contained about 50% CaCO₃.

Table 3. Geochemical data from the Elvdal Formation. For comparison, data are included from the contemporaneous ‘Biseriata Limestone’ at Andersön. Abbreviations as in Table 1.

	Høyberget	Røskdalsknappen	Sorken	*Andersön ("Biseriata Limestone")
CaCO ₃ %				
n	1	3	1	2
avg.	50.2	85.2	79.2	75.8
max.	—	89.9	—	76.9
min.	—	82.2	—	74.7
st. dev.	—	3.7	—	1.6
Mn ppm				
n	1	3	1	2
avg.	5300	4847	4360	8100
max.	—	6000	—	9200
min.	—	4230	—	7000
st. dev.	—	1000	—	1556
Mg ppm				
n	1	3	1	2
avg.	3600	2067	1700	3250
max.	—	2200	—	3300
min.	—	2000	—	3200
st. dev.	—	115	—	71
Sr ppm				
n	1	3	1	2
avg.	150	280	190	530
max.	—	310	—	620
min.	—	260	—	440
st. dev.	—	26	—	127

The manganese content varies between 4300 ppm and 5300 ppm in the Elvdal Formation (Table 3), which is considerably higher than in the Stein Formation (1300–2200 ppm Mn in average; Table 1). The gradual increase in manganese may be related to the erosion of existing island arcs, which may be already obducted, or present within an advancing nappe system during the Middle Ordovician (K. Bjørlykke 1974c).

Basal stratotype. – Elvdal, Høyberget (Elvdal 2018 III; PP452441).

The Høyberget area was described by Meinich (1881), Schiøtz (1883), K. O. Bjørlykke (1905) and mapped by Høltedahl (1921) and Nystuen (1975).

Hypostratotype. – Engerdal, Røskdalsknappen (Engerdal 2018 I; UJ424569).

Thickness variation. – The exact thickness is difficult to obtain because of faulting and overburden at all sections studied. At the stratotype locality at least 5–6 m of the upper part crops out in the small stream to the north east above the road. Below the road one metre crops out just above the Vardal Sandstone of the Vangsås Formation. The estimated thickness at Høyberget is about 14 m which is more than the 5–10 m estimated by Høltedahl (1921, p. 37) and Meinich (1881, p. 24), whose estimated the thickness at Rømundjellet (Elvdal 2018 III; PP476361) 7 km south of Høyberget to ‘30–40 Norwegian feet’, which corresponds to about 10 m.

At Røskdalsknappen the vertical distance between the uppermost and the lowermost limestone blocks is about 30 m along the small valley at the northern slope. One significant exposure (about 5 × 2 × 1 m) was oriented 18/36 NW but erratic blocks dominate throughout the small valley. At Sorken (Engerdal 2018 I; PP562768) close to the eastern shore of Lake Femunden, large erratic blocks (diameter more than 1 m) of the Elvdal Formation occur at the eastern side of the road. The thickness is unknown.

Definition and boundaries. – The Elvdal Formation is named after the village of Elvdal about 3 km SE of the stratotype at Høyberget. Spjeldnæs (1985) chose the name Høberg Formation for the unit but this name was already in use having been chosen by Nystuen (1980) for a much older Upper Proterozoic unit, the Høyberg Formation.

The Elvdal Formation is succeeded by a black, poorly fossiliferous shale unit which is about 20 m thick at Høyberget (K. O. Bjørlykke 1905). This unnamed shale unit, is exposed at Røskdalsknappen, but here it is impossible to estimate the thickness because of overburden. The shale unit is probably one of the youngest known (? early Caradoc) lithological units of the Lower Allochthon of the southeastern Norwegian Caledonides, with the exception of the Bruflat Formation (Silurian) of the Ringsaker area (Skjeseth 1963; Worsley et al. 1983).

Upper Proterozoic clastic deposits of the Hedmark Group are situated below the Ordovician at Røskdalsknappen and Høyberget and are included in the Lower Allochthon of the Osen–Røa Nappe Complex (Nystuen 1982; Bockelie & Nystuen 1985). At both Høyberget and Røskdalsknappen clastic sediments from the Vendian Engerdalen Group of the Kvitvola Nappe (Middle Allochthon) have been thrust onto the two Ordovician units (Nystuen 1980).

Discussion. – Skjeseth (1962) summarized the stratigraphy of two drill cores from the area between Røskdalsknappen and Drevsjø (nos. 4 and 5 of Skjeseth) and three drillcores at Vurrusjøen some 7 km east of Drevsjø (nos. 1, 2 and 3). Skjeseth (1962, fig. 3) correlated the limestones of drillcores 1, 2 and 3 with the '3c' limestone of the Oslo Region (the Huk Formation of Owen et al. 1990), but based the correlation on lithological rather than palaeontological evidence. According to his lithological log, the limestone is more than 25 m thick at this site. He (Skjeseth 1962, fig. 3) also measured a ca. 13 m-thick limestone unit at Løvbekken on the eastern slope of Røskdalsknappen. No fossils were detected from the limestone unit, but the Llanvirnian trilobite *Ogygiocaris dilatata* was recorded from the overlying black shale unit with interlayered limestone nodules. This, together with the tectonic interpretations of the area (Nystuen 1974, 1975) indicates that the limestone exposure at Løvbekken and probably also the limestone unit occurring in drill cores 1, 2 and 3 may be autochthonous equivalents to the Lower Ordovician Huk Formation of the Oslo Region, and not the Elvdal Formation. However, further palaeontological investigations are needed to confirm this.

The Elvdal Formation correlates with the upper part of the *Pygodus serra* and *P. anserinus* bearing 1.5 m-thick 'Biseriata Limestone' (Bergström in Bergström et al. 1974, table 10; Rasmussen unpublished) which is exposed in the eastern Storsjön area of Jämtland (Fig. 7). The 'Biseriata Limestone' may represent the north-eastern extension of the Elvdal Formation but it lacks the typical reticulate pattern and has more distinct bedding planes.

Fauna and biostratigraphy. – Fossils from the Elvdal Formation include nautiloid cephalopods and gastropods (Kjerulf 1863), trilobites (Schjötz 1874), brachiopods, ostracods and echinoderms (Henningsmoen 1979). Spjeldnæs (1985) noted that some of the nautiloids have annulate siphuncles, and belong to the genus *Ormoceras* Stokes. The recorded macrofossils give no precise dating of the unit. However, as shown by Rasmussen & Stouge (1989), the contained conodonts indicate a Llandeilo–early Caradoc age. The fauna includes *Pygodus anserinus* Lamont & Lindström and *Baltoniodus variabilis* (Bergström) which correlates with the upper part of the *P. anserinus* and the lower part of the *A. tvaerensis* conodont zones of Bergström (1971). A similar conodont

fauna has been obtained from the Elvdal Formation at Røskdalsknappen.

Fossils from the succeeding black shale unit include asaphid trilobites (Holtedahl 1921), brachiopods (Henningsmoen 1979), cephalopods (Holtedahl 1921), echinoderms (Schjötz 1874; Bjørlykke 1905), and gastropods (Schjötz 1874; Bjørlykke 1905; Holtedahl 1921) but are too poorly preserved for precise correlation.

Depositional environment. – The Elvdal Formation contains a conodont fauna dominated by *Periodon aculeatus* Hadding and *Scabbardella altipes* (Henningsmoen). Species of *Periodon* are known from deeper platform and slope facies elsewhere (Stouge 1984) and it seems likely that the Elvdal Formation, like the Stein Formation, was deposited in a relatively deep environment on the gently sloping Baltoscandian ramp. The marked change from limestone to black shale might well represent the Llandeilo regressive/transgressive turnover (Rasmussen & Stouge 1989, p. 108).

Acknowledgements. – We are indebted to Anita Löfgren, Markes Johnson and Alan Owen who reviewed the manuscript and made helpful suggestions. We thank Birgit Damgård for her assistance with the geochemical analysis, Tage Rasmussen for field assistance, Jan Ove Ebbestad for computer help and Svend Stouge for helpful discussions on Ordovician stratigraphy. Financial support from the Faculty of Science, University of Copenhagen and Nordisk Ministerråd is gratefully acknowledged.

Manuscript received December 1993

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