
A total of 15,955 identifiable conodont elements were extracted from the Orthoceras Limestone and its lateral equivalents in the Oslo graben, Norway. The Lower Ordovician conodont zonation devised by M. Lindström in 1971 for the eastern Baltic is, for the most part, recognizable in the Norwegian section. In gross aspect, the following equivalencies are noted: Megistaspis Limestone (3ca)/lower Stein Limestone and zone of Paroistodus originalis (BII(B); uppermost Asaphus Shale (3cB)/compact limestone of the Endoceras Limestone (3cy)/lower upper Stein Limestone and the lower part of the zone of Amorphognathus variabilis (BIII(A)).

Hence, the Orthoceras Limestone, with the possible exception of the transition beds, Helskjær Shale and Limestone, and uppermost Stein Limestone, are within the upper part of the graptolite zone of Didymograptus hirundo (upper Volkhov/lowermost Kunda). At Rognstrand, the Arenigian-Llanvirnian boundary is placed within the lower half meter of transition beds.

The Orthoceras Limestone, a Lower Ordovician lithologic unit designated 3c in the time-stratigraphic framework of Norway, crops out in various districts of the Oslo region. Subjacent to the Orthoceras Limestone is the Lower Didymograptus Shale (3b), the upper layers of which contain the graptolite species Didymograptus hirundo, first reported by Monsen (1937) at Galgeberg, Oslo. A similar occurrence at Slemmestad, Asker, was reported by Spjeldnæs (1953), who equated the Norwegian find with that of the lower part of the D. hirundo zone of Great Britain. The known range of D. hirundo beneath the Orthoceras Limestone in the Oslo-Asker district has been designated 3be; that is, the uppermost zone of the Lower Didymograptus Shale (Størmer 1953).

Black graptolite shale, the Upper Didymograptus Shale (4aa), also overlies the Orthoceras Limestone. According to Størmer (1953), the lowermost part of this shale (4aaa1) contains graptolite species suggestive of the zone of Didymograptus bifidus, the graptolite zone succeeding that of D. hirundo, according to the British zonation. Størmer drew the D. hirundo-D. bifidus boundary at the top of the Orthoceras Limestone, thus correlating the entire Orthoceras Limestone with somewhat less than the entire zone of D. hirundo. Skevington (1963), however, contended that the evidence is inconclusive and that the D. hirundo-D. bifidus boundary may be within or at the base of the
Orthoceras Limestone. On the basis of trilobite-graptolite zonal relationships discovered by him in Öland, Sweden, Skevington concluded that the zonal boundary must be at the contact between the Asaphus Shale (3ca) and Endoceras Limestone (3cy) members of the Norwegian Orthoceras Limestone.

Berry (1964) placed a further restriction on the age of the Orthoceras Limestone. In his study of the graptolites of the Upper Didymograptus Shale, Berry failed to find Didymograptus bifidus in 4aε1 strata. He noted that in general aspect the graptolite fauna of 4aε1 resembles that of overlying 4aε5 strata and concluded that the lowermost Upper Didymograptus Shale belongs to the D. murchisoni zone, the zone superjacent to that of D. bifidus. However, Berry (1968) maintained that the lower part of the D. murchisoni zone, as recognized in the Oslo region, is correlative with the upper D. bifidus zone in Great Britain. Assuming that the interpretations of Skevington and Berry are correct, the base of the D. bifidus zone must be within or coincide with the base of the Endoceras Limestone (3cy), uppermost member of the Orthoceras Limestone.

It is evident that age determinations of the Orthoceras Limestone have been based primarily on graptolite evidence outside the unit proper; the unit itself, unfortunately, has revealed no diagnostic graptolite forms. With this in mind, Professor L. Størmer of the University of Oslo suggested that an internal faunal component of the Orthoceras Limestone, specifically conodonts, be investigated. Hopefully, the conodont fauna would elucidate the problems of the D. hirundo-D. bifidus boundary and the position of the Arenigian-Llanvirnian boundary in relation to the Orthoceras Limestone. Størmer’s suggestion was founded on a discovery of György Hamar (unpublished data) that conodonts are present, and at some levels abundant, within the Orthoceras Limestone. Modern conodont studies initiated in Sweden by Lindström (1954), in the Leningrad district in U.S.S.R. by Sergeeva (1962), in Norway by Hamar (1964), and in Estonia by Viira (1966) proved promising for potential biostratigraphic correlation. Various conodont zonations devised by these authors have been discussed in the literature, most recently by Viira (1970) for the Baltic provinces and by Lindström (1971) for the entire central and eastern Balto-Scandinavian region.

The major objective of this study then is to fix the age of the Orthoceras Limestone, primarily by correlation with the conodont zonation by Lindström (1971). An ancillary objective is to demonstrate via conodonts the time-stratigraphic relationship between the Orthoceras Limestone and its northern equivalent, the Stein Limestone.

Stratigraphy

The Oslo region of this report is as defined and subdivided by Størmer (1953). Conodont material was collected from three formations: Orthoceras Limestone, Stein Limestone, and Heramb Shale and Limestone (Fig. 1).

The Orthoceras Limestone is a tripartite unit whose members are litho-
logically recognizable (Brøgger 1882), and thereby represent rock-stratigraphic units, although they are named for characteristically contained fossils. Detailed stratigraphic studies may upset the present correspondence between rock-stratigraphic and time-stratigraphic boundaries. The stratigraphic nomenclature as modified by Størmer (1953) is adopted here, and the following discussion is in large part a condensation of his review of the Orthoceras Limestone.

The Megistaspis Limestone (3ca) is the lowest member of the Orthoceras Limestone. It ranges from 1 to 2 m in thickness throughout the Oslo region, except in the Langesund-Gjerpen district and most of the Sandsvær-Eiker district where it is absent. An important index fossil, *Megistaspis limbata*, is found here as well as in the overlying Asaphus Shale. The Asaphus Shale (3cβ), medial member of the Orthoceras Limestone, varies from about 1 m in thickness in the north (Nes-Hamar district) to about 6 m in the south (Sandsvær-Eiker district). However, it is absent in the Langesund-Gjerpen district, where the upper Orthoceras Limestone lies unconformably on the Alum Shale (Cambrian). The 3cβ lithology is also variable, from an essentially nodular limestone in the north to a dark grey shale with very little limestone in the south. The Asaphus Shale is marked by asaphids throughout and by *Asaphus expansus*, particularly within the uppermost meter.

The Endoceras Limestone (3cγ), upper member of the Orthoceras Limestone, is composed of two basically different lithologies, a lower compact limestone, 1–4 m thick, and upper transition beds with quite a variable lithology and thickness throughout the Oslo region. The compact limestone
contains numerous endoceratids, of which *Endoceras* is an uncommon though diagnostic member. The transition beds contain various megistaspids, succeeded by *Megistaspis* cf. *gigas*. In the Mjøsa district, where the transition beds tend to be thickest and best developed, they are known as the Helskjør Shale and Limestone (Skjeseth 1963). The Helskjør Shale and Limestone is progressively less calcareous upsection, so that only scattered limestone lenses are found in its upper reaches.

The Stein Limestone (found only in the Mjøsa district) has been recognized for some time as the northern facies of the Orthoceras Limestone (Strand 1929, Størmer 1953). It is a bedded compact limestone with a characteristic reticulate surface due to differential weathering between arenaceous seams and less resistant limestone. The Stein Limestone is as much as 40 m thick in the Ringsaker district, but because megafossils are scarce zonation is difficult. From one locality to another the Helskjør Shale and Limestone may or may not overlie the Stein Limestone. There is a question whether the upper Stein Limestone at its type section is equivalent to the Helskjør Shale and Limestone. In the Ringsaker district the Stein Limestone is underlain by grey shale and limestone, the latter becoming more prominent upsection. This unit, first described by Skjeseth (1952) and named the Heramb Shale and Limestone by him (1963), is considered to be equivalent to the upper two subzones of the Lower Didymograptus Shale.

**Collecting localities**

Seventy-seven samples collected from 11 geographically disparate sections yielded 15,955 disjunct conodont elements. The sections are more or less parallel to the axis of the Oslo graben from the southernmost exposure of Orthoceras Limestone in the Langesund-Gjerpen district to its northernmost facies, the Stein Limestone, in the Ringsaker district, a distance of some 220 km (Fig. 2). Each section was sampled at roughly regular intervals. However, the pattern was varied to permit collection adjacent to formation and member contacts. Because of the necessity for relatively large rock samples, the conodonts of each sample may represent strata as much as 10 cm above and below the cited level for most samples within each section. Near rock-stratigraphic contacts, care was exercised to sample only one or the other unit. The location of each sample taken within each section investigated is shown in Fig. 3.

Two to 4-kilogram samples were processed for conodonts by standard laboratory techniques (Collinson 1963). The conodonts were segregated from acid-resistant residues with bromoform, and identifiable elements were classified and counted. Conodont-element yield per sample varied radically as a function of the unit sampled. Excluding sample 4 taken at Rognstrand (locality 1, Fig. 2), the transition beds and Helskjør Shale and Limestone account for only about 0.5 per cent of the total number of elements collected. Approximately 1 per cent was extracted from the Asaphus Shale. Poor acid
Fig. 2. Outline map of the Oslo region showing Ordovician outcrops and collecting sites.
digestion and resultant small residues, as well as possible sampling bias, are probably the primary factors for the small yield of the above units. One sample taken from the Heramb Shale and Limestone (locality 10, Fig. 2) and one from the ‘Planilimbata’ Limestone bench (locality 3, Fig. 2) accounted for 3 per cent of the total yield; the great majority of elements came from the former sample. Approximately 0.5 per cent of the total came from sample 5, from the uppermost bed of the transition beds at Rognstrand. The rest of the elements, that is about 95 per cent, came from the Megistaspis Limestone and compact limestone of the Endoceras and Stein Limestones. The correspondence between conodont yield and lithology has, of course, an important impact on the limits of detailed biostratigraphic correlation. All conodonts collected are on repository at Paleontologisk Museum, Oslo.

The following summary of collecting localities gives section names, laboratory/sample catalog designations (for example, 67KD), descriptive notes, references to published sections, and number of samples and conodont yield of each lithologic unit sampled.

**Locality 1: Rognstrand, Molleklev (Langesund-Gjerpen district), 67KN**
Described by Brøgger (1883, pp. 278–279). The Orthoceras Limestone is 2.5–3.5 m thick and is probably all Endoceras Limestone (Størmer 1953). Gunnar Henningsmoen (unpublished field-trip notes) puts the thickness of the transition beds at about 1 m. These beds are considerably more calcareous than elsewhere in the Oslo region. The uppermost bed is characterized by an abundant transitional fauna containing *Megistaspis curvispina* and *M. cf. gigas*. Sample 5, collected 0.7 m above the base of the transition beds, yielded 820 conodont elements; sample 4 from the top of the compact limestone, 399 conodont elements.

**Locality 2: Krekling (Sandsvær-Eiker district), 67KP**
About 3 m of black shale, Asaphus Shale (basal part unexposed), and approximately 3.5 m of Endoceras Limestone, 3.25 m compact and 10 cm transitional (upper part truncated by erosion), crop out in a minor anticlinal structure along the county road northeast of Krekling (Kongsberg quadrangle: 44.5, 16.2). The Cambrian-Silurian section at Krekling has been described and figured by Brøgger (1879, p. 20). Four samples (3–6) collected from the compact limestone yielded a total of 767 conodont elements; sample 7 taken from the transition beds produced 11 conodont elements.

**Locality 3: Kårtveibekken (Sandsvær-Eiker district), 67KJ**
An 0.8 m thick limestone bench occurs within the upper Lower Didymograptus Shale (Kongsberg quadrangle: 43.3, 14.8). This unit was described.
by Brøgger (1879, p. 19; 1886, p. 41) and more recently discussed by Skjeseth (1952, p. 151), who equates it with the 'Planilimbata' Limestone of Sweden. Sample 2 from the upper part of the bed yielded 41 conodont elements.

**Locality 4: Vestfossen (Sandsvær-Eiker district), 67KK**
A complete section of Orthoceras Limestone is exposed in a roadcut along route 10 about 1.1 km due west of the center of Vestfossen (Kongsberg quadrangle: 47.8, 22.3). Two samples (1, 2) taken from the base and top of the Megistaspis Limestone yielded 299 conodont elements.

**Locality 5: Slemmestad (Oslo-Asker district), 67KD**
Entire section of Orthoceras Limestone exposed in roadcut at loading dock of Eternite Factory across the inlet from Bjerkåsholmen (Størmer 1966). Three samples (1–3) from the Megistaspis Limestone yielded 1,013 conodont elements: three samples (4, 6, 8) from the Asaphus Shale, 123 conodont elements; and three samples (9–11) from the compact limestone of the Endoceras Limestone, 2,588 conodont elements.

**Locality 6: Killingen, NW (Oslo-Asker district), 67KA**
A complete section of almost vertically dipping Orthoceras Limestone is exposed along the northern half of the island on the western shore (Brøgger 1882, pp. 178–183). Two samples (1, 2) from the Megistaspis Limestone yielded 1,304 conodont elements; samples (3–6) from the Asaphus Shale, 75 conodont elements; samples (7–9) from the compact limestone facies of the Endoceras Limestone, 1,489 conodont elements; and samples (10, 11) from the transition beds, 9 conodont elements.

**Locality 7: Hovodden (Hadeland district), 67KB**
A section of essentially vertically dipping upper Orthoceras Limestone crops out along the eastern shore of the Randsfjord (Størmer 1953, pp. 88–89). Roughly 4 m of compact Endoceras Limestone is overlain by 2 m of bedded limestone and 9 m of shale and limestone of the transition facies. Three samples (1–3) from the compact limestone yielded 51 conodont elements; six samples (4–9) from the transition beds, 6 conodont elements.

**Locality 8: Helskjær, Helgøya (Nes-Hamar district), 67KI**
Type section of the Helskjær Shale and Limestone (Skjeseth 1963, p. 63). A complete section of Orthoceras Limestone is exposed in both flanks of a west-trending, slightly overturned anticline (Holtedahl 1909, p. 6). Samples from the southern limb processed for conodonts by G. Hamar (unpublished data). Sample 1 from the Megistaspis Limestone yielded 784 conodont elements; sample 2 from the Endoceras Limestone, 243 conodont elements; and five samples (3–7) from the Helskjær Shale and Limestone, 56 conodont elements.
Locality 9: Raufoss (Toten district), 67KG
Incomplete section of Stein Limestone (upper 14 m untectonized) and 2 m of Helskjær Shale and Limestone (upper part unexposed) in roadcut along Raufoss-Østvold road about 0.7 km east of intersection with Raufoss-Eina road (Eina quadrangle: 88.8, 33.5). Six samples (1-6) from the Stein Limestone yielded 660 conodont elements; three samples (7-9) from the Helskjær Shale and Limestone, 3 conodont elements.

Locality 10: Heramb (Ringsaker district), 67KF
Type section of the Heramb Shale and Limestone (Skjeseth 1963, p. 71). In this exposure, first described by Skjeseth (1952), is 1.5 m of grey shale with fossiliferous limestone lenses (3be) underlain by 0.3 m of Lower Didymograptus Shale. Above is a thin nodular limestone considered to be 3c. Sample 1 from about 1 m below the base of the Stein Limestone yielded 400 conodont elements.

Locality 11: Steinsodden (Ringsaker district), 67KE
Type section of the Stein Limestone (Skjeseth 1963, p. 71). Twenty-one samples (1-21) from the approximately 40 m of Stein Limestone yielded 4,765 conodont elements.

Biostratigraphic correlation
In Lindström's conodont zonation (1971), each conodont zone is related to time-stratigraphic units well established in the eastern Baltic (Fig. 4). The present study represents an attempt at equating a select interval of the Norwegian time-stratigraphic framework with that of the Balto-Scandian scheme. The correlation is, of course, from west to east across the uppermost Lower Ordovician Balto-Scandinavian biogeographic province. The conodont nomenclature followed here is patterned after that proposed by Lindström for multielement species. On the basis of this study the author can see little to refute the multielement models of Lindström. In fact, conodont distribution in the Norwegian material seems to corroborate the natural species recognized by Lindström elsewhere in the Baltic region. A complete taxonomic study of the Orthoceras Limestone/Stein Limestone conodont fauna will be the topic of a complementary paper. Only stratigraphically significant conodont species are discussed herein.

In general, the conodont zonation devised by Lindström (1971) for the eastern Baltic is applicable to the Oslo region (Fig. 4). A major exception is the zone of Microzarkodina parva which is unrecognizable in the Norwegian section. The zonal limits as recognized in the Oslo region rest mainly on the vertical ranges of only a few salient forms. The uppermost find of Paroistodus originalis in every section is taken as the upper known extent of the zone of the same name (= upper 'Limbata' Limestone, BIIIβ). The first appearance of Amorphognathus variabilis in abundance defines the lowermost known
Fig. 4. Conodont zonation in relation to graptolite zones and Balto-Scandian time-stratigraphic framework (from Lindström 1971).

Extent of the zone bearing its name and is interpreted as the base of the Kunda Stage (BIII). According to Lindström, *Microzarkodina ozarkodella* evolved from *Microzarkodella parva*. Furthermore, *M. ozarkodella* is unknown below the Valaste substage (BIIIβ). Co-occurrence of *A. variabilis* and *M. parva* is, therefore, taken to mark the known limits of strata equivalent to the Hunderum substage (BIIIα). The sample with *Microzarkodina ozarkodella* belongs either to the Valaste (BIIIβ) or Aluoja (BIIIγ) substage.

Final correlations and stage/substage assignments will have to depend on zonations based on many fossil groups, not just conodonts. It is the contention here, however, that it would be useful in the long term to show correlations suggested by the conodont evidence. The assumption is, of course, made that the relationship between the conodont zonation and Balto-Scandian time-stratigraphic sequence in the eastern Baltic holds true in the Oslo region.

Conodont zones within the interval studied are for the most part equivalent to entire stages or substages in vertical range (Fig. 4). This equivalence is particularly true within the Oslo region where it is impossible with the material collected to make a distinction between the zone of *Baltoniodus triangularis* and *B. navis*. The Balto-Scandian alphanumeric nomenclature

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<th>Graptolite zonation</th>
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<td>Kunda</td>
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<td>Aluoja</td>
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<td>Billingen</td>
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<td><em>Prioniodus elegans</em></td>
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has, therefore, been used to designate each zone (= substage/stage) in Fig. 3, and a detailed description of the correlation is given below. No attempt was made to extrapolate zonal boundaries beyond the available evidence in any of the sections in the Oslo region. Hence, shaded areas in Fig. 3 represent positions in the profiles where conodonts typical for the various zones occur. Upper and lower limits may, but are not intended to, indicate the total vertical extent of each zone. For this reason, dotted lines are used to bound areas known to contain assemblages characteristic of each zone. Unsampled intervals and samples that failed to produce diagnostic forms are left unsigned. Discrepancies in vertical numbering sequences are due to unprocessed samples.

Strictly on the conodont evidence, the oldest unit investigated is that of sample 1 collected at Kårtveitbekken (locality 3, Fig. 3). The conodont fauna is transitional in one important respect; that is, equal numbers of *Paroistodus originalis* and its progenitor *Paroistodus parallelus* were found. In Sweden, the latter is found in great abundance in the lower part of the *Prioniodus evae* zone (= upper Billingen substage, B1β), and the former appears abundantly at the base of the *P. originalis* zone (= upper ‘Limbata’ Limestone, B1α). The *Paroistodus*-population is obviously an intermediate one and probably corresponds to strata no lower than the upper part of the Billingen Substage and no higher than the lowermost ‘Limbata’ Limestone (B1α). The presence of *Drepanoistodus forteps* (though only one diagnostic oistodiform element was found) and apparent absence of *Drepanoistodus basiivalis* supports a correlation with beds older than those of the upper ‘Limbata’ Limestone. Unfortunately, no other stratigraphically important elements, especially those of the genera *Prioniodus* or *Baltoniodus*, were found.

The problem of a ‘mixed fauna’ is even more complex in the sample from the Heramb Shale and Limestone (locality 10, Fig. 3) where indicators of no less than three conodont zones co-occur. The most striking feature of the fauna is the great abundance of *Paroistodus originalis*, a feature diagnostic of basal upper ‘Limbata’ Limestone (B1β) in the eastern and central Baltic. However, the presence of a few fragmented prioniodiform elements of *Baltoniodus navis* (possibly *Baltoniodus triangularis*) and absence of *Baltoniodus prevariabilis* indicates a B1α designation (lower ‘Limbata’ Limestone). The foregoing data lead one to postulate a stratigraphic position very close to the B1α–B1β time-stratigraphic boundary; that is, mid-‘Limbata’ Limestone. However, another anomaly complicates the situation. All element types of *Prioniodus evae* are represented, as well as a few elements of *Periodon flagellum*, *Stolodus stola*, and the form-species *Paracordylodus gracilis*, *Oistodus selene*, and *Oistodus triangularis*. In addition, these elements persist in the lowermost bed, represented by sample 1 of the Stein Limestone at Steinsodden (locality 11, Fig. 3), which is faunally identical with the sample from Heramb. None of the forms have previously been reported from strata higher than the Billingen Substage. It is necessary to point out, however, that the Billingen forms at Heramb and Steinsodden are a minor component (0.5 per
cent) of the total conodont fauna in terms of numbers of elements. They might have been missed entirely had the samples not yielded so great an abundance of elements (2,690).

Although 805 drepanodiform elements of *Paroistodus* were collected, no *Paroistodus* other than *P. originalis* is evident in the two samples from Heramb and Steinsodden. At least the uppermost meter of the Heramb Shale and Limestone is, therefore, younger than the limestone bench sampled at Kårtveitbekken. In fact, the overwhelming abundance of *P. originalis* suggests a level equivalent to lower Bn1β, a determination supported by the occurrence of *Scandodus brevibasis*, another form characteristic of the upper ‘Limbata’ Limestone. On the other hand, the prioniodiform elements of *Baltoniodus* militate against a level higher or lower than the lower ‘Limbata’ Limestone. The Bn1α determination gains credence from the dominance of *Drepanoistodus forceps* over its descendant, *Drepanoistodus basiovalis*, in the sample from Heramb; though both are uncommon here as at Steinsodden. In the latter sample they occur in approximately equal numbers. One may postulate, therefore, that there is an overlapping of two conodont zones here, *Baltoniodus navis* and *Paroistodus originalis*. In this case, at least the uppermost meter of Heramb Shale and Limestone through lowermost bed of Stein Limestone at Steinsodden represent an interval perhaps absent in the sections studied in Sweden. As noted by Lindström (1971), the Bn1α–Bn1β boundary may be marked by a discontinuity or a complex of discontinuities. The hypothesis proposed above may be only one of several that would explain the distinct zonation in Sweden in contrast to the mixed character of the fauna near the Heramb Shale and Limestone-Stein Limestone boundary in Ringsaker.

Given as a working hypothesis the Bn1α–Bn1β correlation, the problem of the Billingen forms remains. There are at least two obvious possibilities:

Billingen forms simply existed longer in Norway than in the eastern Baltic (though with presumably free communication within the Ordovician Baltic sea this alternative is unexpected).

The Billingen material was reworked from older deposits (through there is no good evidence of reworking).

Moreover, other common Billingen forms such as *Paroistodus parallelus* are missing. Despite an adequate explanation for the ‘mixed fauna’ the author is inclined to place the weight of evidence on evolutionary considerations – *Paroistodus originalis* from *Paroistodus parallelus*, *Baltoniodus prevariabilis* from *Baltoniodus navis*, and *Drepanoistodus basiovalis* from *Drepanoistodus forceps* – rather than on the presence or absence of other diagnostic forms. Hence, a position near the Bn1α–Bn1β boundary is proposed.

Sample 1 collected by G. Hamar from the lowermost bed of the Orthoceras Limestone at Helskjær (locality 8, Fig. 3) is less problematic than the foregoing. *Drepanoistodus forceps* is very abundant (125 oistodiform elements) with the exclusion of *Drepanoistodus basiovalis*. *Paroistodus originalis*, though
the only *Paroistodus* present, is a minor faunal component. One prioniodid fragment, probably from *Baltoniodus navis*, was found. Solely on the basis of conodont evidence, the lowest bed of the Orthoceras Limestone on Helgøya appears to belong to the zone of *Baltoniodus navis*, upper B_{IIIa}. It may be older than the sample from Heramb and lowest bed of Stein Limestone at Steinsodden, but it is definitely younger than the sample at Kårtveitbekken.

The only diagnostic element identifiable from sample 2 (locality 11), collected 1 m above the base of the Stein Limestone at its type section, is *Drepanoistodus basiovalis* (four oistodiform elements). Although this is suggestive of B_{IIb}, the correlation remains uncertain. Sample 3, however, reveals a conodont fauna quite diagnostic of the *Paroistodus originalis* zone. *P. originalis* is by far the dominant species, an indication of the basal part of the zone. Also present are the diagnostic species *Scandodus brevibasis*, *Baltoniodus prevariabilis*, and *Drepanoistodus basiovalis*, which is more abundant than *Drepanodus forceps*. There is such faunistic similarity between this sample and those assigned elsewhere to the *P. originalis* zone that there is little doubt that the B_{IIa}–B_{IIb} boundary is below a level 3 m above the base of the Stein Limestone at its type locality.

Similarly, samples from the basal unit of the Megistaspis Limestone at Killingen Island (locality 6), Slemmestad (locality 5), and Vestfossen (locality 4) are considered basal *Paroistodus originalis*-zone; that is, lower upper 'Limbata' Limestone. The B_{IIa}–B_{IIb} boundary presumably is at, or just below, the contact between the Lower Didymograptus Shale and Orthoceras Limestone in these sections. Within the Megistaspis Limestone of these three sections and the lower part of the Stein Limestone at Steinsodden there is a radical decrease in abundance of the index fossil, *Paroistodus originalis*, upsection.

The zone of *Paroistodus originalis* is followed by that of *Microzarkodina parva*, (= Langevoja substage, B_{IY}), recognized mainly by the coexistence of *M. parva*, *Scandodus brevibasis*, and *Protopanderodus cornuformis* (Lindström 1971). During the time interval equivalent to B_{IIb}, *M. parva* supposedly evolved from *Microzarkodina flabellum*, from which it is differentiated by the relative height of the cusp and denticles of the posterior process. Unfortunately, the Norwegian material is for the most part poorly preserved. The vulnerable cusp and denticles are almost invariably broken so that it is difficult, if not impossible, to make a clear-cut distinction between the two species. Because *S. brevibasis* occurs in the preceding zone it, by itself, is not a definitive form. Finally, in Norway *Protopanderodus* cf. *P. cornuformis* (= *P. cornuformis*, Lindström 1971) first appears in league with forms typical of the next higher zone. The problem is compounded by the failure of the Asaphus Shale, within which the zone of *M. parva* should lie, to produce many conodont elements. In short, the zone of *M. parva* as defined by Lindström is unrecognizable in the Norwegian sections studied.

On the other hand, *Paroistodus originalis* has not been reported above the 'Limbata' Limestone. The upper occurrence of *P. originalis* in each section is, therefore, taken as the known upper extent of B_{IIb} (Fig. 3). Sample 9
taken 16 m above the base of the Stein Limestone at Steinsodden and sample 1 from Raufoss (locality 9) contain one element of *P. originalis*, the uppermost known occurrence in these two sections. One element was also found in sample 3 at Slemmestad (locality 5) and two elements in sample 2 from Vestfossen (locality 4), both taken from the top of the Megistaspis Limestone. At Killingen, the uppermost find of *P. originalis* is also from the topmost unit of Megistaspis Limestone, but its abundance is considerably greater, 48 elements from sample 2. Apparently a level about 16 m above the base of the Stein Limestone at Steinsodden is biostratigraphically equivalent to a level about 14.5 m below the top of the Stein Limestone at Raufoss (locality 9, Fig. 3). This is within, of course, the tolerance of error dictated by the sampling interval. It appears that this level is either equivalent to the top of the Megistaspis Limestone to the south or possibly is within the Asaphus Shale at some indeterminate level, probably near its base.

Just as the last occurrence of *Paroistodus originalis* is taken as the upper known extent of B[m][n][b], so the first appearance of the characteristic species of the zone of *Amorphognathus variabilis* is taken as the lowest known extent of B[m][n][a] (= Kunda Stage). Although *A. variabilis* ranges downward into the Langevoja (B[m][n][y]), it is very rarely found below B[m][n][a], and its occurrence in most samples suggests an age at least as young as the Kunda (Lindström 1971, Viira 1970). In the Norwegian sequence *A. variabilis* first appears rather suddenly, generally in substantial numbers, and consistently from sample to sample upsection.

At Steinsodden, amorphognathids are found in sample 11, 20 m below the top of the Stein Limestone, midway between the top and bottom of the formation. At Raufoss (locality 9), first occurrence is in sample 4, 6.5 m below the top of the Stein Limestone. Sample 3 from the uppermost compact Endoceras Limestone at Helskjær (locality 8) yields amorphognathids and marks the lowest known extent of the Knuda here. At Hadeland (locality 7), *Amorphognathus variabilis* ranges throughout the compact limestone of the Endoceras Limestone and at least as high as sample 4 from the base of the transition beds. At Killingen, *A. variabilis* is found in sample 6, collected from immediately below the contact between the Asaphus Shale and Endoceras Limestone. At Slemmestad, the first appearance is in sample 6, about 3 m below the same lithologic contact. Despite the fact that only one specimen was found, the sample produced so few elements that it is unlikely that an amorphognathid would be detected if it did not represent a significant proportion of the population sampled. On the other hand, the presence of only one actual specimen prompts the author to extend the *A. variabilis* zone downward to include sample 6 with reservation (Fig. 3). To the south, *A. variabilis* is known as low as 1.3 m above the base of the Endoceras Limestone at Krekling (locality 2) and from a sample of uppermost compact limestone of the Endoceras Limestone at Rognstrand (locality 1). *A. variabilis* almost certainly ranges lower than shown in these two sections, but lack of diagnostic elements and processed samples preclude a definite statement.
As noted above, co-occurrence of *Amorphognathus variabilis* and *Microzarkodina parva* is taken as indicative of the Hunderum substage (Bma). These forms commonly co-occur almost everywhere within the compact limestone of the Endoceras Limestone (3cy). *M. parva* is poorly represented in the lower upper Stein Limestone and absent from the uppermost part. At Hadeland the upper Endoceras Limestone (samples 2–4) produced few conodont elements. Of these, *A. variabilis* was found in each sample, but no ozarkodinids were found. On the basis of the age of the Endoceras Limestone everywhere else, its age here is probably Bma. All that can be said with certainty, however, is that the interval above sample 1 through sample 4 is Kundan (BIII). Similarly, the uppermost Stein Limestone at Raufoss (locality 9, samples 6, 7) and Ringsaker (samples 8–12), and lowermost transition beds at Krekling (sample 7) and Helgøya (locality 8, sample 3) yielded *A. variabilis* without any ozarkodinids. They are given no finer than a BIII assignment.

Elements of the form-species *Lenodus clarus*, first described by Sergeeva (1963), are sometimes, albeit always in small numbers, found in samples taken from the *Amorphognathus variabilis* zone as recognized in the Oslo region. This form-species is unknown below Kundan strata in the Baltic provinces (Sergeeva 1963, Viira 1970), thereby verifying a Kunda age assignment based on the presence of *A. variabilis*. First appearance of *L. clarus* coincides with that of *A. variabilis* at Ringsaker (sample 7) and Helgøya (locality 8, sample 3). In contrast to the eastern Baltic, however, *Protopanderodus* cf. *P. cornuformis* (= *P. cornuformis*, Lindstrøm 1971) almost invariably first appears in association with *Amorphognathus variabilis*. Only in two sections does this general rule not apply. At Raufoss, *P. cf. P. cornuformis* ranges at least 3 m below the first appearance of *A. variabilis* and at Slemmestad, about 1.5 m above. In both cases, particularly the latter, the inconsistency may well be a function of sample size. Two element types, a scolopodiform (= form-species *Scolopodus* aff. *S. quadriplicatus*, Branson & Mehl 1933) and distacodiform (= form-species *Distacodus* sp.) are similar to, and perhaps related on a subspecific level to, *P. cf. P. cornuformis* with which they invariably occur. The scolopodiform element type tends to coincide with the first appearance of *P. cf. P. cornuformis*. Its range is rather short and in none of the sections studied overlaps that of the distacodiform elements which first appear upsection. This relationship is particularly evident at Steinsodden, Killingen, Slemmestad, and Krekling, and may be of value for detailed local correlation.

The Hunderum substage, BIIIα, is set off from the overlying Valaste (BIIIβ) and Aluoja (BIIIγ) substages by essentially negative conodont evidence; that is, the absence of *Drepanoistodus venustus* (= *Drepanoistodus* cf. *D. venustus*, Lindström 1960), *Protopanderodus graeai* (Hamar) (= *Protopanderodon-
dus triangulatus (Fåhræus of Lindström 1971), and Microzarkodina ozarkodella from the Hunderum substage. However, in the Oslo region, D. venustus ranges downward to a level roughly midway between the last occurrence of Paroistodus originalis and the first appearance of Amorphognathus variabilis. Thus, the lower range of D. venustus is considerably extended; that is, to a level below BIIIα. This extension is especially evident in the Stein Limestone of Steinsodden and Raufoss.

Protopanderodus graeai, distinguished by the form-species Acodus graeai of Hamar (1966), is known from only two samples: samples 21 from within the upper meter of Stein Limestone at Steinsodden and sample 5 from the transition beds at Rognstrand (locality 1). Unfortunately, sample 19 from Steinsodden produced only a few nondiagnostic elements, and sample 20 was barren. Therefore, the range of P. graeai at Steinsodden may in reality be lower by as much as 6 m or so. The presence of P. graeai at Steinsodden suggests a Llanvirnian Age for at least the upper meter of Stein Limestone here, but this proposition lacks confirmation because of the absence of Microzarkodina ozarkodella. It appears that the uppermost Stein Limestone at Steinsodden is near, perhaps above, the BIIIα–BIIIβ boundary.

Microzarkodina in the form of the species M. ozarkodella does, however, co-occur with Protopanderodus graeai at Rognstrand. According to Lindström (1960), M. ozarkodella evolved from Microzarkodina parva by the progressive addition of denticles anterior to the single anterior denticle of the ozarkodiniform element of M. parva. The Rognstrand forms have equal numbers of denticles anterior and posterior to the cusp, suggesting a fully developed form of M. ozarkodella. The upper transition beds at Rognstrand must, therefore, be no older than strata equivalent to the Valaste substage. Because M. ozarkodella typifies the Aluoja substage as well, no finer distinction than BIIIβ or BIIIγ can be made with the evidence given. Sample 4 from the same section contains only M. parva. Apparently, the Arenigian-Llanvirnian boundary is within the lower half meter of transition beds above the top of the compact limestone of the Endoceras Limestone at Rognstrand. The boundary cannot be delimited in the other sections because of the consistent failure of the transition beds and Helskjær Shale and Limestone to produce any diagnostic conodonts.

Summary and conclusions

A correlation based on the distribution of all faunal groups will be undertaken at the conclusion of the Ordovician project initiated by Størmer (1953). Consequently, the following biostratigraphic conclusions, based solely on conodonts, are tentative.

It appears that the bulk of the sections studied comprise only two identifiable zones of Lindström's zonation, Paroistodus originalis and Amorphognathus variabilis. The former, equivalent to the upper 'Limbata' Limestone substage (BIIIβ), approximates the interval of the Megistaspis Limestone (3ca).
The exact limits of the zone are not precisely defined, but the lower boundary must be at or just below the base of the Orthoceras Limestone. The upper limit of the zone is at the top of the Megistaspis Limestone or within the lower Asaphus Shale (3cβ). Biostratigraphically, the Megistaspis Limestone is roughly equivalent to the lower 16 m of Stein Limestone at Steinsodden, except for perhaps the lower 2 m or so.

All the compact limestone of the Endoceras Limestone (3cγ) is within the lower part of the zone of Amorphognathus variabilis, Hunderum substage (BIIIα). Also within BIIIα is the lower upper Stein Limestone and perhaps the uppermost Asaphus Shale (3cβ). The zone of Microzarkodina parva, Lange­voja substage (BIIIγ), is unrecognizable in the Oslo region. In Sweden it is expressed within only 1 m of section (Lindström 1971) and, if of equivalent magnitude in Norway, may have been missed either because of sampling interval or failure of the Asaphus Shale to produce many diagnostic forms. If present, the Microzarkodina parva zone must be restricted to some part of the Asaphus Shale, to within 16–20 m above the base of the Stein Limestone at Steinsodden, and within 6.5–14.5 m below the top of the Stein Limestone at Raufoss.

Except for the section at Rognstrand, little can be said regarding time-stratigraphic subdivision of the transition beds, Helskjær Shale and Limestone and uppermost Stein Limestone. At least the upper strata of the transition beds at Rognstrand, however, are no older than strata of the Valaste substage (BIIIβ).

Exceptions to the general time-stratigraphic equivalencies summarized above occur in the lower reaches of the sections at Helskjær and Steinsodden. At Helskjær, material collected by G. Hamar from the lowermost bed of the Orthoceras Limestone produced an abundant conodont fauna typical of the lower ‘Limbata’ Limestone (BIIα), thereby indicating earlier deposition of limestone here than in the other sections studied. The lowermost bed at Steinsodden revealed a transitional fauna between that of the zone of Baltoniodus navis, lower ‘Limbata’ Limestone (BIIα), and Paroistodus originalis, upper ‘Limbata’ Limestone (BIIβ). As in the upper Heramb Shale and Limestone, a minor contribution of forms typical of the Prioniodus evae zone, Billingen substage (BIIβ), is admixed with the transitional fauna.

The Hunderum substage (BIIα) is purportedly equivalent to the upper Didymograptus hirundo zone, and the Valaste (BIIβ) and Aluoja (BIIIγ) substages, coincident with the zone of Didymograptus bifidus (Skevington 1963). Moreover, Microzarkodina ozarkodella distinguishes the Valaste and Aluoja from the underlying Hunderum substage where it is absent (Lindström 1960, 1971). In terms of the standard Ordovician graptolite succession then, the Orthoceras Limestone, with the possible exception of the transition beds, is within the zone of D. hirundo. Similarly, the Stein Limestone, with the possible exception of the uppermost part, belongs to the D. hirundo zone. At Rognstrand, the boundary between the Arenigian and Llanvirnian is present somewhere within the lower half meter of the transition beds.
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