Biostratigraphy of key brachiopod lineages from the Llandovery Series (Lower Silurian) of the Oslo Region

B. GUDVEIG BAARLI & MARKES E. JOHNSON

The biostratigraphic ranges of three important brachiopod lineages are described from the central and southern Oslo region. Transitions between the various subspecies of Stricklandia, between Stricklandia and Costistricklandia, and between Pentamerus and Pentameroides are refined in several districts. The transition between Borealis and Pentamerus is redefined in the Asker District. The occurrence of Eocoelia in the Skien District is recorded for the first time. Most of the biostratigraphic changes in correlation involve the Rytteråker Formation.

B. G. Baarli & M. E. Johnson, Department of Geology, Williams College, Williamstown, Massachusetts, U.S.A.

The cosmopolitan lineages of Stricklandia–Costistricklandia, Borealis – Pentamerus – Pentameroides and Eocoelia are among the most biostratigraphically useful brachiopods diagnostic of Llandovery to earliest Wenlock (Silurian) time units. The first two lineages are well represented in the Oslo region where the record is probably the most complete to be found anywhere. An overview of the stratigraphic ranges of stricklandiid and pentamerid brachiopods was given originally by Baarli & Johnson (1982). Supplementary information was added later by Worsley et al. (1983a), Baarli (1986), and Baarli (in press). This contribution summarizes previous knowledge on the biostratigraphy of these important brachiopods in the central and southern Oslo region, provides new data, and offers necessary revisions. The most significant new information regards the transitions between Stricklandia and Costistricklandia and between Pentamerus and Pentameroides. These transitions are now known to occur within a few meters of each other in four districts of the Oslo region. This paper also includes data and figured specimens from two districts (Modum & Skien) not considered by Baarli & Johnson (1982). Material of Eocoelia, from Skien is figured for the first time.

Stricklandiid biostratigraphy

Stricklandiid brachiopods achieved a widespread distribution during the Early Silurian. The whole or extraneous parts of the Stricklandia–Costistricklandia lineage have been reported from Wales (Williams 1951), Estonia (Rubel 1977; Nestor, Nestor & Rubel 1978), Australia (Jenkins 1977), North America (Johnson 1979), China (Rong & Yang 1981), and Norway (Baarli 1986). The Norwegian paleontologist Johan Kjær (Kjær 1908) was the first to suggest the existence of this lineage. His collections were later figured and described by St. Joseph (1938). Williams (1951) confirmed the lineage from the Llandovery area of Wales. Recently, Baarli (1986) biometrically defined the Stricklandia part of the lineage, based on extensive new collections from Norway as supplemented by previous collections from Estonia and Wales.

Elements of the Stricklandia–Costistricklandia lineage are well represented in several districts of the central to southern Oslo Region (Fig. 1). A stratigraphic key and detailed composite sections from these districts are given in Figs. 2–7. The lineage seems to have evolved gradually and the limits between the subspecies of Stricklandia are therefore arbitrarily defined. In Baarli & Johnson (1982), these limits for the Norwegian examples of the subspecies were suggested on the basis of a preliminary review of type material from Wales. Later (Baarli 1986), a biometric evaluation and comparison of the type material made possible a less subjective determination of these limits. The new positions are shown for the Asker District in
Changes in stratigraphic position are mainly seen for the transition between *Stricklandia lens intermedia* Williams and *S. lens progressa* Williams. The results found for the *Stricklandia lens* (J. de C. Sowerby) to *S. laevis* (J. de C. Sowerby) transition in the Asker and Oslo (Malmøya) districts are shown in Figs. 3 and 4. Occurrence of the *Stricklandia lens* lineage in the Modum District near Sylling is shown in Fig. 5 (based on Baarli, in press). No new discoveries of stricklandiid material have been made in the Ringerike District (Fig. 6), but there is a new find of *S. lens progressa* 37 m above the base of the Rytteråker Formation in Skien (Figs. 7 & 8).

The occurrence of stricklandiids at the base of the Vik Formation at Sandvika (Fig. 3) has been redesignated as a pure population of *Stricklandia laevis* (see Baarli 1986). Previously a mixture of *S. lens progressa* and *S. laevis* was identified, based on fragmentary shells. The reason for confusion was the presence of cardinalia belonging...
to the stricklandiid, *Kolumella* sp. (Fig. 8Q). *Stricklandia laevis* is also found at the base of the Vik Formation at Sylling in the Modum District (Fig. 8F & G) and at Malmøya in the Oslo District (Fig. 8C & D). In the Oslo District, *S. laevis* occurs rarely, generally as very small specimens from 1.5 m to 18 m above the base of the Vik Formation (Fig. 4). *Stricklandia laevis* is the only stricklandiid which may have reduced outer plates (Rubel 1977). Although identification of the other *Stricklandia* taxa should be based preferably on a collection of at least 10 specimens, one specimen lacking outer plates ensures a positive identification of *S. laevis*. Very small fragmentary specimens where ribbing cannot be observed, however, may be confused with *Costistricklandia*.

Six specimens of *Costistricklandia lirata* (J. de C. Sowerby) in Kjær's collections from Skien are marked as coming from etage 7b (or the Rytteråker Formation). This is the only possible occurrence of *C. lirata* in the Rytteråker Formation. Thus, the transition between *Stricklandia laevis* and *Costistricklandia lirata* may lie somewhere near the top of the Rytteråker...
Fig. 4. Composite stratigraphic section for the Lower Silurian of the Oslo District (Malmøya area), showing the ranges of stricklandiid and pentamerid brachiopods. The localities include: Malmøya (grid ref. NM 9837) and Malmøykalven (NM 9737).

Formation. These finds, however, are not mentioned by Kiær (1908) and we have not been able to find similar specimens in the area. Costistricklandia lirata occurs with certainty upward from the base of the Vik Formation in Skien. In all other districts it lies within the Vik Formation. Costistricklandia lirata ranges into the upper part of the Skinnerbukta Formation in Skien. Moulds and latex casts of C. lirata are figured herein (Fig. 8A, B & E) to show their similarity with Stricklandia laevis (Fig. 8C & D, F–I).

Pentamerid biostratigraphy

Kiær (1908) was the first to propose a lineage from Pentamerus borealis (Eichwald) through Pentamerus oblongus J. de C. Sowerby and ending with what he called Pentamerus gothlandicus. (=Pentameroides subrectus Hall & Clarke). In current taxonomic terms, this is the lineage from Borealis borealis (elevated to genus status by Boucot et al. 1971) through Pentamerus to Pentameroides subrectus (see below). St. Joseph (1938) also described and illustrated the pentamerid material collected by Kiær (1908), and the Borealis to Pentamerus transition has been recently discussed by Mørk (1981). Apart from Norway, Borealis occurs widely throughout the Baltic, Novaya Zemlya, Ural, and Siberian regions of the U.S.S.R. (Boucot et al. 1971) and in South China (Rong & Yang 1981). Pentamerus is reported widely by Boucot & Johnson (1979) throughout the eastern parts of the U.S.A. and Canada, as well as the British Isles, Scandinavia, Podolia, and much of Asia. The genus is also known from New South Wales, Australia (Jenkins 1977). Pentameroides has a more restricted range, occurring in north-central and western U.S.A., eastern Canada, England, and Norway (Boucot & Johnson 1979). The transition between Pentamerus and Pentameroides in North America has been described by Johnson (1979) and Johnson & Colville (1982).
In Norway *Borealis* first appears very near the base of the Leangen Member of the Solvik Formation (or etage 6cβ of Kiær 1908) at Vettre in Asker (grid ref. NM 83433) and through the first 8 m of the Leangen Member at Skytterveien nearby (Fig. 91). Mørk (1981) noted the occurrence of this genus at Sandvika in the Solvik Formation 8 to 16 m below the base of the Rytteråker Formation. This particular observation was based on erroneous data provided by Baarli. Re-examination of the original material, together with a cast of the cardinalia indicates an abnormal occurrence of *Stricklandia lens* (Fig. 9K & L). As noted below, this revision has major consequences for local biostratigraphy beyond a precise identification of the transition between *Borealis* and *Pentamerus*.

*Pentamerus oblongus* is the most abundant fossil in the Rytteråker Formation and it occurs in all of the five districts treated herein (Figs. 3–7). Mass occurrences are also found at a few horizons within the Vik Formation at Sandvika and on Malmøya (Fig. 4). A single specimen from Kiær’s collection (PMO 40410) is marked as coming from etage 6c (or the upper part of the Solvik Formation) on Malmøya. This is the only known representative from the Solvik Formation. In the Ringerike District (Fig. 6), a single specimen (PMO 108.259) is reported from the lower part of the Vik Formation. Otherwise, *Pentamerus* is common between 3–12 m above the base of the Gamtangen Member on Purkøya (the base of this member is approximately 20 m above the base of the Vik Formation). As previously observed (Baarli & Johnson 1982), *Pentamerus* occurs together with the first *Pentameroides* on a bedding plane at the 12 m horizon on Purkøya. Near Syl ling (Fig. 5), the Vik Formation is represented by only about 6 m of strata and *Pentamerus* occurs there throughout. At Sandvika in the Asker District (Fig. 3), *Pentamerus* occurs intermittently throughout the first 30 m of Vik Formation. On Malmøya in the Oslo District (Fig. 4), *Pentamerus* occurs sparsely through the Vik Formation up to

---

**Fig. 5.** Stratigraphic section for the Lower Silurian near Syl ling (Modum District, grid ref. NM 747435), showing the ranges of stricklandiid and pentamerid brachiopods.
Fig. 6. Composite stratigraphic section for the Lower Silurian of the Ringerike District, showing the ranges of stricklandiid and pentamerid brachiopods. The localities include: Limovnstangen (grid ref. NM 691591 and NM 695596), Purkøya (NM 687568), Storsøya (NM 691574), and Vintergututangen (NM 709586).
Brachiopods from the Llandovery, Oslo Region

265

Fig. 7. Composite stratigraphic section for the Lower Silurian of the Skien District (grid ref. NM 3763), showing the ranges of stricklandiid, pentamerid, and eocoeliid brachiopods.

a level at least 24 m above the base of the formation. Pentamerus does not range into the Vik Formation in Skien, where Pentameroides (and Costistricklandia) are found throughout the first 10 m (etage 7ca of Kiær 1908).

As in North America (Johnson 1979; Johnson & Colville 1982), the transition from Pentamerus to Pentameroides in Norway is anticipated by a gradual reduction in the space separating the outer plates of Pentamerus. Note the difference between the older Pentamerus (Fig. 9H) with widely spaced, divergent outer plates from the Rytteråker Formation in Skien in contrast to younger specimens of Pentamerus (Fig. 9G & J) with more closely spaced, parallel outer plates from the Vik Formation of the Asker District (at Sandvika). The age difference between these forms is corroborated by the fact that Stricklandia progressa co-occurs with the Pentamerus in Skien in contrast to its descendant S. laevis is found both together and stratigraphically below the last Pentamerus at Sandvika. In Pentameroides the outer plates are fused anteriorly into an elevated cruralium. This feature is clearly shown by the latex casts in Fig. 9B. Bassett & Cocks (1974, p. 23) confirmed that the so-called Pentamerus gotlandicus Lebedev occurring on Gotland, Sweden is a true Pentamerus of Wenlock age. This means that some forms of Pentamerus survived the transition giving rise to Pentameroides, and thus were coeval with Pentameroides.

Pentameroides subrectus is restricted to the Vik Formation in Norway. It occurs in Skien (Fig. 7) at the base of the Vik Formation and at Sandvika (Figs. 3 & 9A–C) 43 m above the base of the formation. As mentioned above, Pentamerus and Pentameroides are found on the same bedding plane about 32 m above the base of the Vik Formation in the Ringerike District. Occurrences of P. subrectus alone are continuous from 2–6 m above this horizon. On Malmøya, Nakrem (1986, p. 123) erroneously reported Pentameroides in life position at a level 20 m above the base of the Vik Formation. Re-examination of field photos reveals the clear separation of outer plates diagnostic for Pentamerus. A true specimen of Pentameroides, however, has been found between 35 and 40 m above the base of the Vik Formation on Malmøya (Worsley et al. 1983a, p. 31).

Eocoelia biostratigraphy

The Eocoelia lineage has a more restricted geographic range than those described above. It
Fig. 8. Llandovery stricklandiids from the central and southern Oslo region. These and subsequent specimens are deposited in the Paleontologisk Museum, Oslo (PMO).

A: Costistricklandia lirata, PMO89167. Internal mould of brachial valve from the Vik Formation. Old Quarry near the 'Storm' club house, Skien. ×2.

B, E: Costistricklandia lirata, PMO89162. Internal mould ×2 and latex cast of brachial valve ×3, Vik Formation, Old Quarry near 'Storm' club house, Skien.

C, D: Stricklandia laevis, PMO116009. Internal mould and latex cast of brachial valve. Vik Formation, 18 m above the base, west side of Malmøykalven, ×3.

F, G: Stricklandia laevis, PMO116004. Internal mould and latex cast of brachial valve. Vik Formation, 3 m above the base, road cut east of Holsfjorden, Sylling, ×3.
occurs abundantly in the Llandovery type sections in Wales (Ziegler 1966), and also occurs in England, Norway, Sweden, North America (Nova Scotia, Michigan, Ohio, New York and Maryland), and Siberia (Ziegler et al. 1977, p. 39). *Eoecolia* is not common in Norway. Until recently, the only known occurrences were of *E. angelini* (Lindstrom) from the Braksøy Formation in Skien and the Steinsfjorden Formation in Ringerike (Bassett & Rickards 1971; Worsley et al. 1983b). In 1982 the authors discovered abundant *E. hemisphaerica* (J. de C. Sowerby) at Skien in a thin shale bed 37 m above the base of the Rytteråker Formation (Fig. 7). Unfortunately, preservation is poor and few specimens clearly reveal the umbonal chambers lateral to the dental lamellae typical of this species (Fig. 9D & E). Since *E. intermedia* (Hall) consists of mixed populations both with and without this feature, it is possible that *E. intermedia* may be represented. A re-examination of Kiær’s collections revealed three specimens of *E. hemisphaerica* from the base of the Rytteråker Formation (top of etage 7a, or lower 10 m of the Rytteråker Formation) at Skien. One of them is illustrated in Fig. 9F.

Co-occurrences of stricklandiids and pentamerids in Norway

Elements of the two lineages occur mostly alone or otherwise in relationships where one representative is strongly dominant. They do, however, co-occur at various levels throughout the Llandovery succession. Specimens of *Borealis borealis* are found with the first sparse appearance of *Stricklandia lens intermedia* in the Asker District (directly overlying beds with *S. lens lens*). Probably there is a diastem just below this level, so this occurrence of *Borealis* may correspond to a somewhat higher position in the range of *S. lens intermedia* (Baarli 1986). No specimens of Pentamerus have been found as yet together with *S. lens intermedia* in the Oslo region. In the Modum, Asker, and Oslo districts, Pentamerus oblongus has its first appearance in the Rytteråker Formation close after *S. lens progressa* in the Solvik Formation. At Ringerike, strata with *B. borealis* are directly overlain by strata bearing *P. oblongus*. Stricklandiids identifiable to the sub-species level have not been found in the Salabonn or Rytteråker formations in Ringerike. In Skien, *P. oblongus* ranges from the bottom of the Rytteråker Formation to a horizon 37 m above the base of the formation (Fig. 9H), where it is found together with *S. lens progressa* (Fig. 8J & N) as well as *Eoecolia hemisphaerica* (Fig. 9D & E). Pentamerus oblongus and *E. hemisphaerica* also co-occur lower in the section (10 m above the base of the Rytteråker Formation) in Skien. In the central districts (Modum, Asker, and Oslo), *P. oblongus* and *S. laevis* are found together in the first few meters of the Vik Formation. In the Oslo District, they continue to co-occur until at least 18 m above the base of the formation.

*Pentamerus oblongus* always occurs stratigraphically below *Costistricklandia* in the Oslo region, as elsewhere in the world. *Pentameroides subrectus* and *Costistricklandia lirata*, on the other hand, typically occur in interfingering strata but they are seldom found together in the same stratum. At Ringerike, *C. lirata* first appears 7 m above the earliest occurrence of *P. subrectus*. The highest stratigraphic position of *C. lirata* is at the top of the Bruflat Formation. In Skien, both *C. lirata* and *P. subrectus* are very abundant in the Vik Formation and they sometimes co-occur. At Sandvika (Asker District), rare specimens of *P. subrectus* and *C. lirata* are found separately towards the top of the Vik Formation. The lowest stratigraphic level with *P. subrectus* is still 13 m above the highest level with *P. oblongus*.

Fig. 9. Llandovery pentamerids and stricklandiids from the central and southern Oslo Region.

B, C: PM011027. Latex cast and internal mould of brachial valve. Vik Formation 43 m above base, Kampebråten, Sandvika. ×2.
D, E: *Eocoeola hemisphaerica* D: PM0116014 and E: PM0116013. Internal moulds of pedicle and brachial valves respectively. Rytteråker Formation, 37 m above base, Klamra, Skien. ×3.
F: *Eocoeola hemisphaerica* PM051069. Mould of pedicle valve, 5–10 m above the base of the Rytteråker Formation, Klamra, Skien. ×3.
Co-occurrences with other important taxa in Norway

The Llandovery District of Wales was confirmed as the type area for the first series in the Silurian System (Bassett 1985). Although unsuccessful, the candidacy of the Oslo region for an alternative type area stimulated interest in a variety of other biostratigraphically useful groups besides brachiopods. Much work remains to be done in Norway, but the groundwork has been laid for studies on graptolites (Howe 1982), conodonts (Aldridge & Mohamed 1982; Mohamed 1984; Nakrem 1986), as well as acritarchs (Smelror 1987). At least one rugose coral seems to be biostratigraphically significant (Neuman 1988). Each of these groups is reviewed briefly below, with particular reference to co-occurrences involving members of the brachiopod lineages.

Graptolites

Graptolites are found scattered throughout the Llandovery section in the Oslo region. *Borealis* and *S. lens intermedia* are found together with *Orthograptus obutii* Rickards & Koren and *Rhaphidograptus toernquisti* Elles & Wood at the base of the Leangen Member of the Solvik Formation in the Asker District. *O. obutii* has been found in the Urals in beds probably of *Coronograptus cyphus* (Lapworth) age (Rickards & Koren 1974). *R. toernquisti* is a long-ranging species from the *Atavograptus atavus* Zone of the United Kingdom (Aldridge 1982). The Rytteråker Formation yields few conodonts of any biostratigraphic importance. One exception is *Pterosphatodus cel­ loni* (Walliser), which occurs at the top of the overlying Vik Formation.

Costistricklandia. At Ringerike, however, graptolites are found in Kiær's etage 8a and 8b at localities nearby sections containing *Pentameroides* and *Costistricklandia*. The identification and interpretation of these graptolite finds are uncertain (Howe 1988), but they suggest a transition from the Llandovery to the Wenlock series. Graptolites in the Asker, Oslo, and Skien districts are found in the Skinnerbukta Formation directly overlying the Vik Formation. These graptolites indicate that the Llandovery-Wenlock boundary lies in the lowermost beds of the Skinnerbukta Formation in the Oslo and Asker districts (Bassett & Rickards 1971), although possibly somewhat higher in the Asker District (Howe 1982).

Conodonts

A conodont fauna consistent with the *Distomodus kentuckyensis* Zone occurs throughout the Solvik Formation in Asker. In the uppermost meters (235 m above base) of the Solvik Formation, however, *'Amorphognathus' tenuis* Aldridge occurs together with *S. lens progressa*. This species is also found at the bottom of the Rytteråker Formation at Malmøya and Ringerike and it is commonly correlated with the *Monograptus argenteus* Zone in mid-M. *sedgwickii* graptolite zones. *Distomodus aff. D. stauognathoides* (Walliser) occurs 243 m above the base of the Solvik Formation (=topmost meter). Specimens similar to the latter conodont are recorded in the *M. sedgwickii* graptolite Zone of the United Kingdom (Aldridge & Mohamed 1982). The Rytteråker Formation yields few conodonts of any biostratigraphic importance. One exception is *Pterosphatodus celloni* (Walliser), which occurs at the top of the formation in Skien (Aldridge & Mohamed 1982). This is found immediately below the first occurrences of *Costistricklandia lirata* and *Penta­ meroides subrectus* in the overlying Vik Formation.

In the Ringerike District, the transition from *Pentamerus* to *Pentameroides* is within the *Ptero-
### Correlation Scheme for the Silurian (Llandovery-earliest Wenlock) of the Central and Southern Oslo Region

<table>
<thead>
<tr>
<th>Stage</th>
<th>Rhuddanian</th>
<th>Aeronian</th>
<th>Telychian</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Llandover</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhuddanian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Orthograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Orthograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Lagagrapthus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Corongrapthus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Distomodas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Monograptus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**
- **A** shows stage divisions, standard graptolite zones (A), brachiopod lineages for *Stricklandia* (C) and *Eocoelia* (F), and acritarch zones (E), all after Cocks et al. (1984, fig. 69). Column B shows the brachiopod lineage *Borealis-Pentamerus-Pentameroides* (Baarli & Johnson, herein). Column D shows the conodont zones after Aldridge (1975, Nakrem (1986), and Baarli & Johnson (herein). Column E shows the brachiopod lineage *Borealis-Pentamerus-Pentameroides* (Baarli & Johnson, herein). Column F shows the brachiopod lineage *Borealis-Pentamerus-Pentameroides* (Baarli & Johnson, herein).

**Right-hand side** gives the lithostratigraphy and local correlation. Asterisks mark the first or last occurrence of fossils in metres above base of formation where available. Numbers and letters refer to taxa in the relevant column on the left-hand side.
sphatodus celloni Zone (Worsley et al. 1983a). Outcrops of the Vik Formation at Sandvika (Asker District) and at Malmøya (Oslo District) were sampled extensively for conodonts by Nakrem (1986). The first occurrence of *P. celloni* in the Asker District is found at 22 m above the base of the Vik Formation in a conodont association that indicates a position high in the Zone. This is 8 m below the last known occurrence of *Pentamerus oblongus*. At Malmøya, the same first occurrence is found 32 m above the base of the Vik Formation. This is 8 m above the last occurrence of *P. oblongus*, and thus also very near the transition from *Pentamerus* to *Pentameroides*. In Skien, the *P. celloni* Zone corresponds to the uppermost Ryteråker Formation and extends through the 45 m-thick Vik Formation (Aldridge & Mohamed 1982) together with *P. subrectus*.

The next zone, the *Pterospathodus amorphognathoides* Zone, is very well defined in the Oslo region mainly due to the recent work of Nakrem (1986). The first occurrences are found at 69 m and 45 m above the base of the Vik Formation at Sandvika (Asker District) and Malmøya (Oslo District), respectively. Both these horizons are about 10 m above beds bearing *Pentameroides subrectus*. At Ringerike, this zone is found at least through the topmost 30 m of the Bruflat Formation (Worsley et al. 1983a). In Skien, *P. amorphognathoides* Walliser is found near the base of the Skinnerbukta Formation.

**Acritarchs**

Smelror (1987) studied acritarchs from the Llandovery section at Ringerike and found that the Rhuddanian–Aeronian transition may occur in the upper part of the Sælabonn Formation (6c). This is well below the transition between *Borealis* and *Pentamerus*, as found in the lower part of the Ryteråker Formation. Acritarchs from near the top of the Ryteråker Formation may correlate with the base of acritarch Zone 3a of Hill & Dorning (1984) in the Llandovery type area of Wales (corresponding to the base of the *Monograptus sedgwickii* Zone).

**Rugose corals**

*Paleocyclus porpita*, (Linnaeus), which generally indicates a late Llandovery to early Wenlock age (Neuman 1988), occurs widely through the uppermost range of *Costistricklandia lirata* at Ringerike (top of Bruflat and base of Braksøya formations), the Asker District (top of the Vik Formation), and at Skien (top of the Skinnerbukta Formation).

**Inter-regional correlation**

Here we discuss briefly those co-occurrences from elsewhere around the world which more sharply delimit or contradict the transitional ages within the three brachiopod lineages presently defined in the Oslo region. In Estonia *Borealis borealis* is found together or interbedded with *Stricklandia lens intermedia* (Rubel 1977). Specimens previously attributed to *Pentamerus* cf. *oblongus* in Estonia, however, correspond to *B. borealis* osloensis Mørk and they are interbedded with *S. laevis* (Rubel, pers. comm., 1988).

The earliest *Pentamerus oblongus* associated with a stricklandiid, *S. l. intermedia*, is reported from the Newland Formation at Girvan (Cocks & Toghill 1973). This association is overlain by strata bearing graptolites indicative of the *Monograptus gregarius* Zone. Therefore, the first known occurrences of *Pentamerus* are of variable ages in different parts of northern Europe. Awaiting publication of the Estonian data and a better understanding of the possible co-occurrences of *Borealis* and *Pentamerus*, we follow Cocks & Toghill (1973) and set the first occurrence of *Pentamerus oblongus* within the range of *S. lens intermedia*.

Cocks et al. (1984) correlate the upper limits of *S. lens intermedia* (Williams 1951) and the uppermost *Monograptus convolutus* Zone. In the Asker District the uppermost clear population of *S. lens intermedia* is found at 192 m above the base of the Solvik Formation and the lowermost clear population of *S. lens progressa* is found at 230 m above the base. The populations found between these levels are difficult to assign to one or the other of the subspecies. Baarli (1986) made the transition arbitrary at 202 m above the formalional base. Poorly preserved graptolites from Asker near this level indicate an age no younger than the *M. gregarius* Zone. Thus, there is the possibility of a considerable difference in age assignment involving at minimum the entire *M. convolutus* Zone. These factors justify placement of a higher boundary definition in Norway.

Several biostratigraphic refinements have been
suggested based on recent work in the Llandovery type district of Wales (Cocks et al. 1984). Eocoelia is common, but first occurs at a level just below the Monograptus sedgwickii Zone. Presently, it is unknown from older strata anywhere else in the world. A closer correlation between Stricklandia lens progressa and Eocoelia intermedia confines the latter to the uppermost range of the former. The transition between Stricklandia laevis and Eocoelia intermedia is set just above the base of the Monograptus turriculatus Zone and the range of the latter brachiopod is extended up to the middle of the Monoclimacus griestoniensis Zone.

Cocks et al. (1984) did not consider the evolving lineage of pentamerid brachiopods. Ziegler et al. (1974) set the Pentamerus/Pentameroides transition at the mid-Monograptus turriculatus Zone slightly below the transition between Stricklandia and Costistricklandia. The transition between Stricklandia laevis and Costistricklandia lirata was moved as high up as possible in the mid-Monoclimacus griestoniensis Zone by Cocks et al. (1984). The Norwegian evidence with (1) a relatively long co-occurrence of Stricklandia laevis, Pterospathodus celloni, and Pentamerus oblongus, (2) no co-occurrence of Costistricklandia and Pentamerus, and (3) the first occurrence of Costistricklandia just a few meters above the Pentamerus/Pentameroides transition would justify moving the pentamerid transition up to about the same level as the stricklandiid transition.

The base of the Pterospathodus celloni condond Zone is set at the base of the Monograptus crispus graptolite Zone (or base of earlier C5 beds) by Aldridge (1975), who again based his correlation on Cocks (1971). After the revisions of Cocks et al. (1984), however, the base of the Cefin Formation (earlier base of C5 beds) is now near the base of the Monograptus turriculatus Zone which defines the base of the Telychian Series. The base of the P. celloni Zone should be adjusted in accordance, pending more precise data. P. celloni ranges nearly to the top of the Llandovery but the base of the succeeding P. amorphognathoides Zone, appears 1 m below the Llandovery–Wenlock boundary in the type Wenlock area (Aldridge & Mohamed 1982).

Summary and conclusions

The above information is summarized in the correlation chart given in Fig. 10. Mutual relationship ship of the brachiopods belonging to the Stricklandia–Costistricklandia, Borealis–Pentamerus–Pentameroides, and Eocoelia lineages, provide much of the basic temporal framework necessary for interpretation of facies distribution and sea-level events in the Lower Silurian of the central and southern parts of the Oslo region. The main differences from the correlation chart of Worsley et al. (1983a and b) and found in the Ryternaker Formation: (1) The Ryternaker Formation of the central districts was synchronously deposited during the time interval spanned by the Monograptus sedgwickii graptolite Zone. (2) As pointed out by Möller (1987), the base of the Ryternaker Formation has a locally diachronous history with a much earlier onset in the Ringerike District relative to the central districts. (3) The top of the Ryternaker Formation in the Ringerike District is also older than anywhere else. (4) In the Skien District, the base of the Ryternaker Formation is only slightly diachronous (e.g. with a slightly older base than in the central districts). (5) The top of the Ryternaker Formation in Skien departs from the other districts in being much younger than anywhere else.

Acknowledgements. – Baarli is grateful for support from the Norwegian Research Council for Science and the Humanities (NAVF) during the period 1982–1984. Johnson acknowledges the Royal Norwegian Council for Scientific and Industrial Research (NTNF), the U.S. Education Foundation in Norway (Fulbright Program), and Williams College for support in 1981–1982 during his stay at the Paleontologisk Museum (University of Oslo), as well as continuing support from the latter two organizations in 1987–1988 during his stay at the Institutt for Geologi (University of Oslo). The authors also thank David Worsley (Saga Petroleum a.s.) for encouraging this contribution.

References


