THELODONTS FROM THE UPPER SILURIAN OF RINGERIKE, NORWAY

PETER TURNER & SUSAN TURNER

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The thelodont fauna of the Sundvollen Formation (upper Silurian) of Ringerike is described. Several horizons throughout this formation have yielded thelodont scales which are of Baltic and Scottish type unlike those in the English Silurian. Additional information on the thelodonts from the 9g beds is also given. Sedimentological study has enabled an environmental interpretation to be made and compared with that of the well-known Rudstangen fauna. The vertebrates from this latter locality lived in a marginal marine, probably lagoonal environment whilst the thelodonts described here lived in a more open marine environment, probably on a sub-tidal platform. The succession in the Ringerike area from the 9g beds to the top of the Sundvollen Formation is thought to range from upper Wenlock to lower or middle Ludlow age.

P. Turner, Department of Geophysics, The University, Newcastle-upon-Tyne NE1 7RU, England. S. Turner, Hancock Museum, Newcastle-upon-Tyne NE2 4PT, England.

A study has been made of the rocks in the Ringerike area by one of us (PT) over the past few years which has yielded new sedimentary and faunal evidence on the nature of the red bed sequence which Kiær (1911) designated Stage 10. This study has involved stratigraphic revision, and Stage 10, formerly known as the Ringerike Sandstone Series has been renamed the Ringerike Group. In the type area of Ringerike it can be divided into a lower Sundvollen Formation (500 m) and an upper Stubbdal Formation (700 m). The Sundvollen Formation, which this study concentrates on, lies conformably on thinly bedded limestones and shales of Stage 9 and consists mostly of unfossiliferous sandstones and siltstones of fluviatile origin. Also, at several horizons there occur thin calcarenitic limestones of marine origin, and it is in these that the thelodonts are found (Fig. 1).

Thelodont material

Several horizons within the Sundvollen Formation have yielded thelodont scales (Fig. 2). These all come from the limestones which are red, reddish-green and grey calcarenites which are mostly of fossiliferous intrasparite composition. The calcarenites are medium to coarse grained, well-rounded and fairly well sorted. The beds are 0.10 to 1.00 metres thick, usually cross-stratified and associated with fine grained sandstones. The thinner beds are often lensoid but the thicker ones may be laterally persistent for distances up to 2

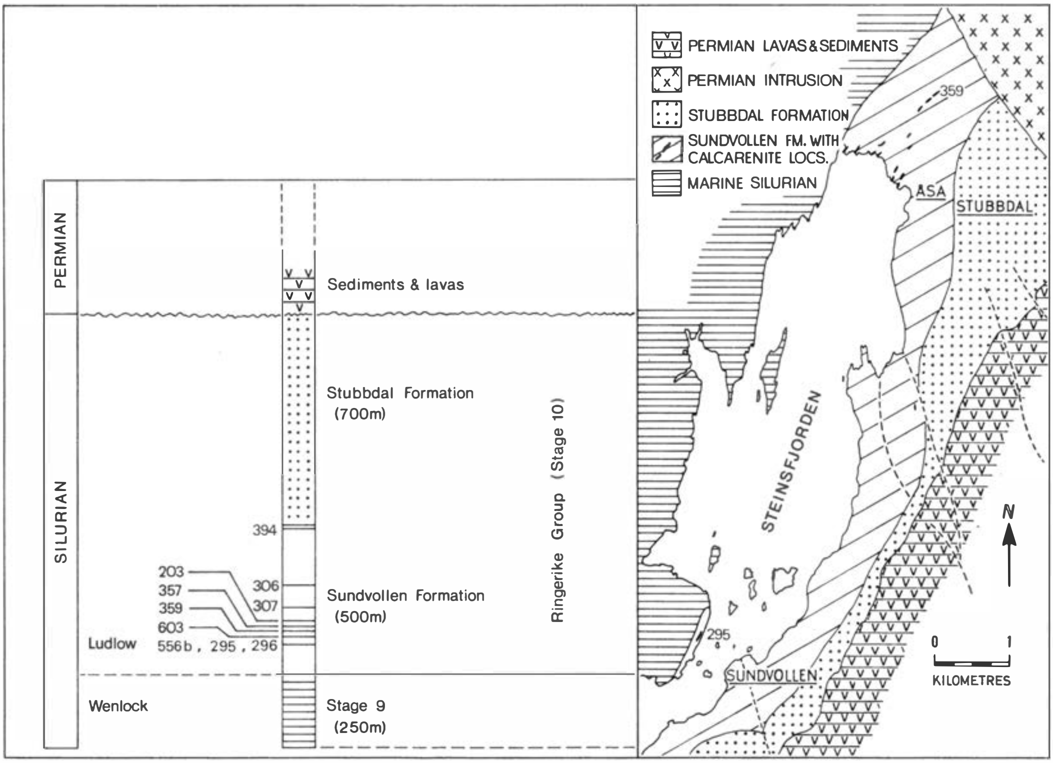


Fig. 1. Geology of the northern part of the outcrop of the Ringerike Group, Ringerike, 25 km NW. of Oslo, southern Norway. The stratigraphic and geographic distribution of thelodont bearing calcarenites is shown.

kilometres. Further thelodont material has been obtained from thinly bedded peloidal limestones in the 9g beds.

The scales from Ringerike are mainly small, less than 1 mm in length, and grey in colour. They are often pyritised which makes histological identification very difficult, but most are only slightly waterworn, if at all. About 100 scales have been examined and these are lodged at the University of Leicester Geology Department (Accession No. 65700-65799).

Thelodont fauna

Kiær (1924) first noted the presence of thelodont scales in the Ringerike succession in his Stage 10, both at Rudstangen and higher up in pockets of fossiliferous limestone, and he presumed they belonged to *Thelodus scoticus* Traquair and were therefore Downtonian. Now it is known that *Logania scotica* comes from Llandoverian and Wenlockian rocks (Halstead & Turner 1973).

In 1954, Størmer reported that Spjeldnæs had found *Thelodus parvidens* Ag. and *T. scoticus* at one horizon in Stage 10 (loc. 295 in Fig. 2) and that this might therefore be equivalent to the Ludlow Bonebed. There were in fact *T. laevis* (Pander) and *L. taiti*. The first full account of thelodonts in the Ringerike succession came from Gross (1967) who identified the scales from the 9g beds at Ringerike. The scales come from a dark limestone fish band. He noted *T. laevis* (Pander), *T. schmidti* (Pander), *Logania martinssoni* Gross, and possible *Logania cuneata* (Gross). Later in 1968 studying scales found by A. Martinsson, he revised his identification of the latter as body scales of *T. schmidti* and compared this fauna with the Wenlockian Halla Beds of Gotland.

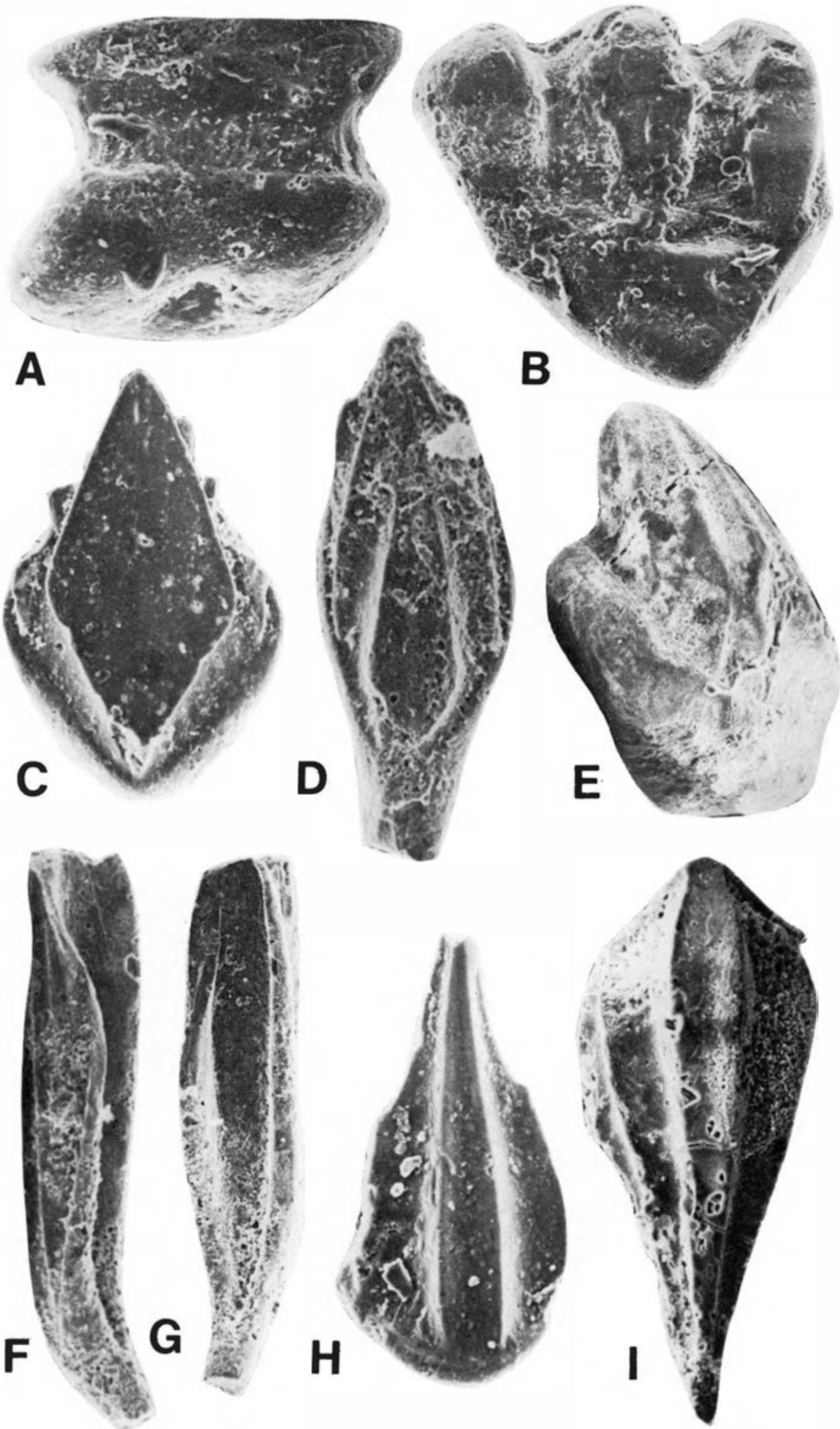
Ritchie (1963) noted the similarity of the Scottish to Norwegian thelodont remains, especially *Logania taiti* (Stetson) of the upper fish bands of Hagshaw and Lesmahagow, now thought to be upper Wenlock or lower Ludlow age, and he has collected good articulated thelodont remains from Ringerike which seem to confirm this identification (Ritchie pers. comm. 1973).

No detailed study of the thelodonts from a succession of beds in the Ringerike area has previously been made. This study covers rocks from the 9g beds almost to the top of the Sundvollen Formation with the aim of studying the stratigraphical and environmental implications of the thelodont remains.

In the 9g beds, apart from those species recognized by Gross, there are scales of *Logania taiti*, head, body and transitional scales (Fig. 3). The head scales do resemble those of *L. martinssoni* and these are typical of head scales in the genus *Logania*. Some of the body scales resemble those of *Turinia pagei* (Powrie) but are much smaller in size and have the *Logania* type histology (Gross 1967). New occurrences in the 9g horizon are the small numbers of scales of *Thelodus trilobatus* (Hoppe) and *Phlebolepis elegans* Pander (Fig. 3D, F, G).

	9g	SUNDVOLLEN FORMATION							
		295 296 556b	603	359	357	203	307	306	394
Thelodus laevis (Pander)	X	X	X	X	X	X	X	X	X
Thelodus schmidti (Pander)	X	X				X			
Thelodus trilobatus (Hoppe)	X								
Logania martinssoni (Gross)	X	X	X		X?				X
Logania taiti (Stetson)	X	X	X	X	X	X	X	X	
Phlebolepis elegans Pander	X	X							

Fig. 2. Stratigraphic distribution of thelodont species.


A
B
C
D
E
F
G
H
I

The thelodont fauna in the Sundvollen Formation is essentially no different from that in the 9g beds, though in some samples the scales are more waterworn, and there are fewer, i.e. in 306, 307, 357, 359 and 394.

Thelodus laevis (Pander, 1856)

Gross (1967, 1968) has described the scales of this species in detail. Most specimens are slightly waterworn and although the range of scale shapes, and the neck ridges are found, the reticulated pattern on the crown surface is not common (Fig. 3A).

Thelodus schmidti (Pander, 1856)

Body scales of this species are particularly abundant at loc. 295 (and also locs. 296 and 556b which are at the same horizon) and loc. 203 (Fig. 3E, H, I). These were first described by Gross (1968). They resemble scales of *Logania cuneata* (Gross) but have a *Thelodus* type histology. Not many typical head scales have been found.

Logania martinssoni (Gross, 1968)

Head, transitional and body scales have been found. These are generally very small scales, around 0.5 mm and less (Figs. 3B, C; 4C). Stratigraphically they have a wide range from the 9g beds, to near the top of the Sundvollen Formation (loc. 394).

Logania taiti (Stetson, 1931)

Similarly, head, body and transitional scales have been found (Fig. 4). The head scales are small and rounded with crenulated edges, resembling those of *L. martinssoni*. The transitional scales are more oak-leaf like in shape and become more diamond shaped with side notches anteriorly, resembling small

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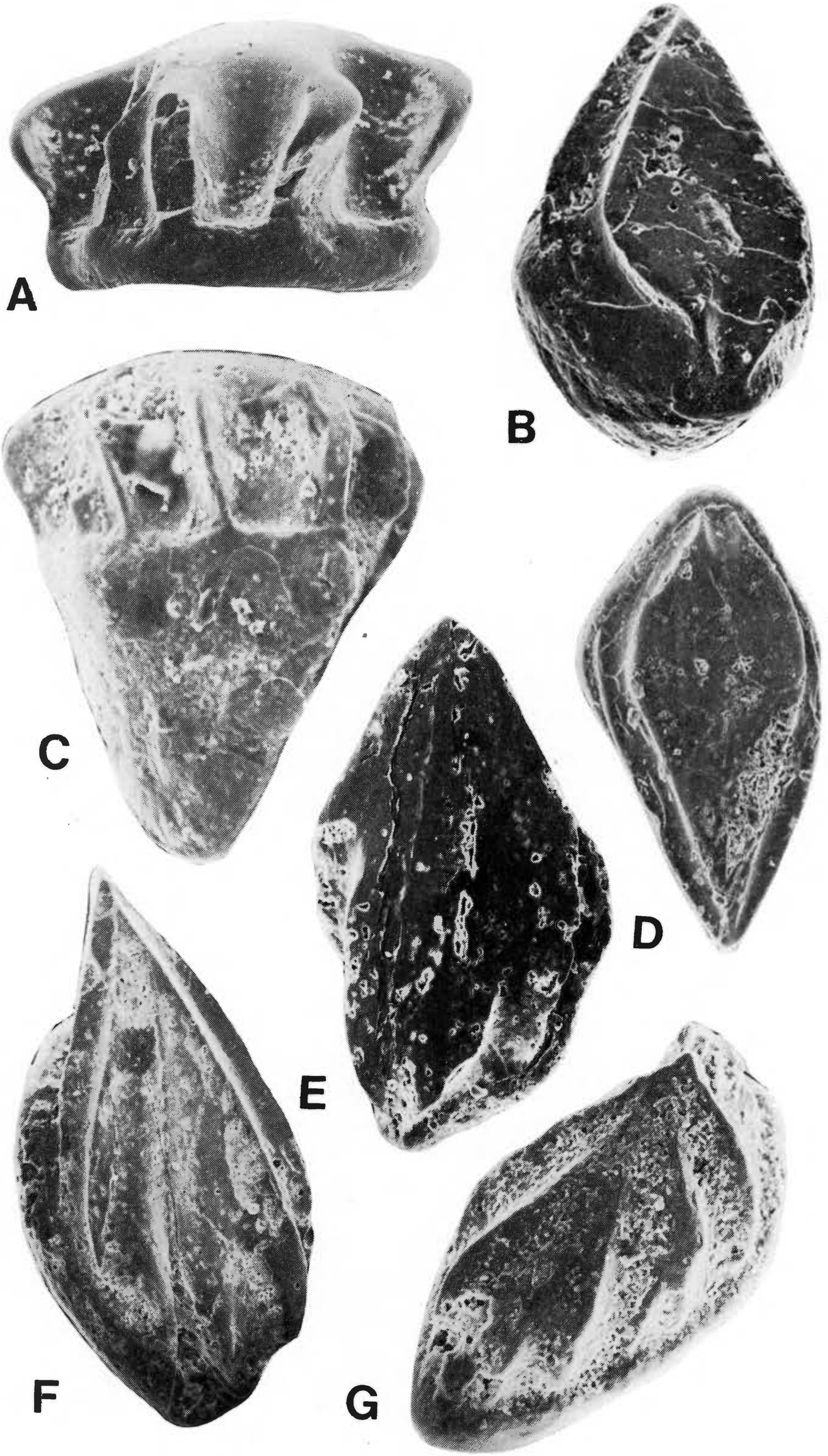
Fig. 3. A. *Thelodus laevis* (Pander), 603–12, lateral view, 270 mu; B. *Thelodus schmidti* (Pander)?, 295–19, dorsal view of head scale of '*goebeli*' type, 350 mu; C. *Logania martinssoni* Gross, 603–2, dorsal view of body scale, 375 mu; D. *Thelodus trilobatus* (Hoppe), 9g-5, dorsal view of body scale, 375 mu; E. *T. schmidti,* 556b–3, lateral view of transitional scale, 750 mu; F. *Phlebolepis elegans* Pander, 9g–2, lateral view, 300 mu; G. *P. elegans,* 9g–2, dorsal view: H. *T. schmidti,* 203–8, dorsal view of body scales, 525 mu; I. *T. schmidti,* 9g–1, dorsal view of body scale, 475 mu; Scanning electron microscope photographs. (Size shown is of longest diameter.)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scales of *Katoporus* species or *Logania kummerowi* Gross (Gross 1967). The body scales, as noted, can resemble those of *Tu. pagei*, and some are like those of *L. cuneata*. The rather specialised scales found on the articulated specimens from Scotland, with up to five posterior spines (Stetson 1931) have not been found. Probably they were too delicate and broke up easily.

Associated fauna

The Rudstangen vertebrate fauna, which occurs about 10 m above the base of the Sundvollen Formation is associated with arthropods, crustacea and eurypterids (Kiær 1911, Størmer 1954) including *Dictyocaris slimoni* Salt., *Hughmilleria norvegica* Kiær, *H. lata* Størmer, *Xiphosura, Bunodes,* and *Kiæra*. There is a rich fish fauna, mostly known from articulated specimens from Rudstangen, Kroksund and Jeløya. The anaspids are *Pharyngolepis oblongus* Kiær, *P. heintzi* Ritchie, *Pterolepis nitidus* Kiær and *Rhyncholepis parvulus* Kiær with cephalaspids *Ateleaspis robustus* Kiær, *Ateleaspis spp, Hirella gracilis* Kiær and other species, *H. denisoni* Heintz and *Tyriaspis whitei* Heintz. *Hemicyclaspis kiæri* Heintz and acanthodian spines have been found at Jeløya from a horizon near the top of the Ringerike Group, well above that of the Sundvollen Formation.

This association of animals is similar to that found throughout the middle to upper Silurian (including Downtonian) of western Europe (Halstead & Turner 1973). There are close similarities with the fauna of the upper fish band of Scotland, which have *Logania taiti, Ateleaspis tessellata* Traquair, cephalaspids, eurypterids and other arthropods. A similar fauna of arthropods, cephalaspids and an anaspid has been found at Stonehaven, Cowie Harbour in lower Downtonian rocks (Westoll 1945).

Age and correlation

Heintz (1969) argued convincingly that the Rudstangen and Kroksund Faunas were lower Ludlovian in age and the evidence from this study supports this view. Säve-Söderbergh (1941) hoped that ostracodes would help make a definite determination of the age of the uppermost marine beds (Zone 9g) at Ringerike. The ostracode faunas from 9g, as described by Henningsmoen (1954) are different in many respects from those of other areas. Revision of

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Fig. 4. A. *Logania taiti* (Stetson), 556b–6, lateral view of head scale, 325 mu; B. *L. taiti*, 296–8, dorsal view of body scale, 450 mu; C. *Logania martinssoni* Gross, 603–3, lateral view of head scale, 300 mu; D. *L. taiti*, 296–1, dorsal view of body scale, 690 mu; E. *L. taiti*, 296–11, dorsal view of transitional scale, 480 mu; F. *L. taiti*, 556b–1, dorsal view, 500 mu; G. *L. taiti*, 556b–5, dorsal view, 350 mu.

this fauna by Martinsson (1969) has shown that the 9g beds as well as the Halla Beds and parts of the Kaarma Beds should be placed in the same faunizone at the Wenlockian-Ludlovian transition.

The 9g fauna except for the ostracodes links up with that in the upper fish bands of Scotland of upper Wenlock to lower Ludlow age (Ritchie 1967), the J_2-K_1 Stages of Saaremaa (Mark-Kurik & Noppel 1970) and the transition beds of Prince of Wales Island, North-West Territories (Dixon, Williams & Turner 1972) and, as noted above the Halla Beds of Gotland. This suggests that 9g is of upper Wenlock age and it must be that the whole of Stage 9 is Wenlockian rather than Ludlovian as was previously thought (Bassett & Rickards 1971). The Rudstangen fauna at the base of the Sundvollen Formation can be similarly correlated with these areas and Heintz's (1969) suggestion that it was lower Ludlovian in age, along with the fauna from Kroksund, although there are some associations with the lower Downtonian in one locality only (Westoll 1945), would seem to be correct.

The thelodonts throughout the Sundvollen Formation, however, are of Baltic type comparable with the K_1-K_4 Stages of Saaremaa and the Ludlovian of Scotland. The presence of *L. taiti* which is only known from the lower Ludlovian upper-fish bands of Lesmahagow and Hagshaw is an indication that the lowest beds at least of the Sundvollen Formation are in the Ludlovian. The implication of this is that the boundary between the carbonate sequence of Stage 9, and the clastic red bed sequence of the Sundvollen Formation (Stage 10), must approximate very closely to the Wenlock-Ludlow boundary in this area.

Palaeoecology

The environment of the Rudstangen fauna has been discussed by Denison (1956). Most of this material came from a thin (3 cm) lens of greenish-grey fine grained sandstone about 10 m above the base of the Sundvollen Formation. Denison (1956), recognizing the fluviatile nature of most of the Sundvollen Formation, and the absence of marine forms, suggested that the deposit was fresh-water. Recent sedimentological analysis, however, has shown that marine inter-tidal and tidal-flat conditions prevailed for about the lowest 15 m of the Sundvollen Formation. Moreover the presence of articulated specimens must indicate that these beds were not fresh-water since the fish are found in truely marine conditions elsewhere. For example, in the lower Downtonian of England (Allen & Tarlo 1963), and the fish beds of Scotland little transport occurred and the fauna and sediments indicate lagoonal or estuarine conditions. The rest of the fauna of eurypterids and ceratiocarids are not known to be truely marine or fresh-water. In all, the evidence suggests that the Rudstangen fauna was deposited in very quiet, near-shore marine (probably lagoonal) conditions.

The environment of the new thelodont horizons described in this paper can be determined precisely due to sedimentological analysis. The calcarenites in which the thelodonts occur are of intrasparite and fossiliferous intrasparite composition, are medium-coarse grained, well-rounded and moderately well sorted. They occur in thin beds, averaging about 0.5 m in thickness and contrast sharply with the fine grained clastics which make up the bulk of the Sundvollen Formation. Analysis of cross-stratification dip azimuths has yielded a bi-polar distribution characteristic of shallow marine tidal deposits. P. Turner (1974) suggested that the calcarenites may be laterally equivalent to fluviatile clastics in the north (Sundvollen Formation) and sub-tidal carbonates (Stage 9) in the south and that the boundary between Stage 9 and 10 is diachronous (Spjeldnæs 1966). The fragmental marine fauna associated with the thelodonts includes: ostracodes, echinoderms, trilobites, bryozoa, algae and molluscs. This fauna and the carbonate sand which went to make up the calcarenites was presumably derived from this sub-tidal platform to the south. It is here, in a sub-tidal carbonate shelf environment in which the thelodonts are thought to have lived.

Palaeogeography

The very close association of the fauna of the Ringerike Group from Wenlock to Downtonian times with that of Scotland and the Baltic indicates and confirms the concept of the closure of the proto-Atlantic at this time (Turner 1970, 1973, Halstead & Turner 1973, McKerrow & Ziegler 1972). This fauna is quite unlike that found in England or the southern Baltic area, which gave rise to the north German Beyrichienkalk erratics, or western Canada. However, by early Downtonian times these regions were close enough for some migration of *Hemicyclaspis* to take place. Some barrier must have separated Ringerike from Ramsåsa in southern Sweden, which has a different (English type) thelodont fauna during Ludlovian times (S. Turner 1973).

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