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ORDOVICIAN AND SILURIAN REEFS IN THE BALTIC AREA

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Abstract - Coral, stromatoporoid and algal reefs were developed in the marginal part of the gulf-like Baltic cratonic basin in Gotland, north and central Estonia, and east to central Lithuania. They are situated at different stratigraphic levels from the middle Caradoc up to the lower Pridoli. Their appearance coincided with the transition of the Baltic Basin from an epicontinental to pericontinental phase of development, and with shifting from a temperate to the tropical climatic zone. Most of these reefs had a flat or lenticular shape, as they grew in conditions of relative tectonic and eustatic stillstand. Extensive progradation of the reef belt took place during general regression of the basin at these times. The role of stromatoporoids increased in frame building towards the end of the Silurian. Shoal-barrier type reef tracts, developed at different stratigraphic levels, were situated in the middle part of a broad carbonate shelf (platform) on the SW margin of the Baltic craton. This contrasts with Recent barrier reefs, usually located at the shelf edge of eastern margins of continents

1 INTRODUCTION

A comparatively complete sequence of Ordovician and Silurian rocks in the Baltic area shows development of reefs (carbonate buildups) over an interval of almost 40 million years, beginning in the middle Ordovician (mid-Caradoc), and ending in early Pridoli time.

Silurian reefs on the Swedish island of Gotland have been well known since first recorded by MURCHISON (1847). In the East Baltic area, reefs are less studied due to poor exposure in natural outcrops of Estonia and limited quarrying activity. Still lesser known are reefs from subsurface drill holes of the southern East Baltic, intensely studied in Lithuania by local petroleum geologists.

2. PREVIOUS STUDIES

Many papers have been published on the reefs of Gotland, recently reviewed by RIDING (1981) and by COPPER & BRUNTON (1991). The most complete list of the reef publications is found in an excursion guidebook by NEUMAN & KERSHAW (1991). In Estonia special investigations have been devoted to the reefs of the lower Wenlock (AALOE 1956, NESTOR 1990), middle Caradoc (MÄNNIL 1960; HINTS 1990), and lower Llandovery (AALOE & NESTOR 1977; NESTOR & NESTOR 1977). Additional information is available also in review papers on reefs (AALOE & EINASTO 1970, KLAAMANN & EINASTO 1982), as well as the bedrock geology of Estonia (KALJO 1970; RÔÔMUSOKS 1970). Subsurface Silurian reefs in Lithuania have been briefly treated by LAPINSKAS & CHEHAVICHIUS (1981), and LAPINSKAS (1987). A modern comprehensive summary on the Silurian geology of the Baltic Region with a detailed stratigraphic chart is included in the paper by BASSETT, KALJO & TELLER (1989).

3. GEOLOGICAL BACKGROUND

During the Ordovician and Silurian the Baltic area was part of a cratonic basin, which gradually evolved from a broad, level-bottom, shallow epicontinental sea to a bathymetrically more differentiated pericontinental sea opening south-west into the Rheic Ocean (NESTOR 1990). In the course of this process a deeper water axial depression was formed , referred to as the "Baltic Syneclise" It was characterized by argillaceous deposits (mudstones and marlstones) with planctic graptolites (see BASSETT, KALJO & TELLER 1989, Figs 119, 121 etc.). Along the margins of the

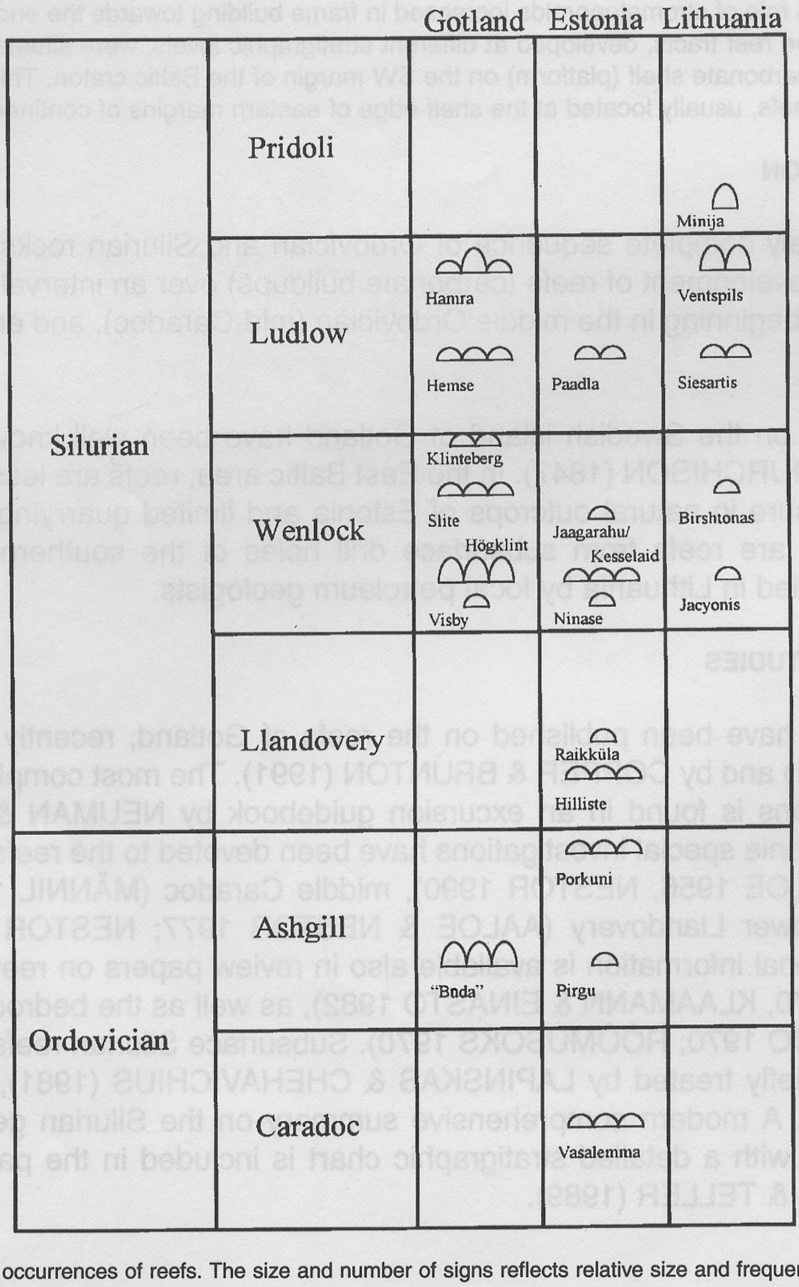

Fig.1 Stratigraphic occurrences of reefs. The size and number of signs reflects relative size and frequency of reefs in corresponding stratigraphic units.

basin, in Gotland district, north and central Estonia, and eastern Lithuania a wide belt of shallower-water carbonate sediments was developed with sporadic reefs or reef tracts. The appearance of reefs in the sequence roughly coincided with the transition from an epicontinental to pericontinental phase of basin development in Caradoc (NESTOR 1990). It also coincided with a suggested shift of the Baltica palaeocontinent from a temperate climatic zone into the tropics (see SCOTESE & McKERROW 1990, figs.8 and 9). During the late Ordovician and Silurian a generally regressive trend took place in the south-west direction, although it was cyclically interrupted by short transgressive episodes.

4. DISTRIBUTION

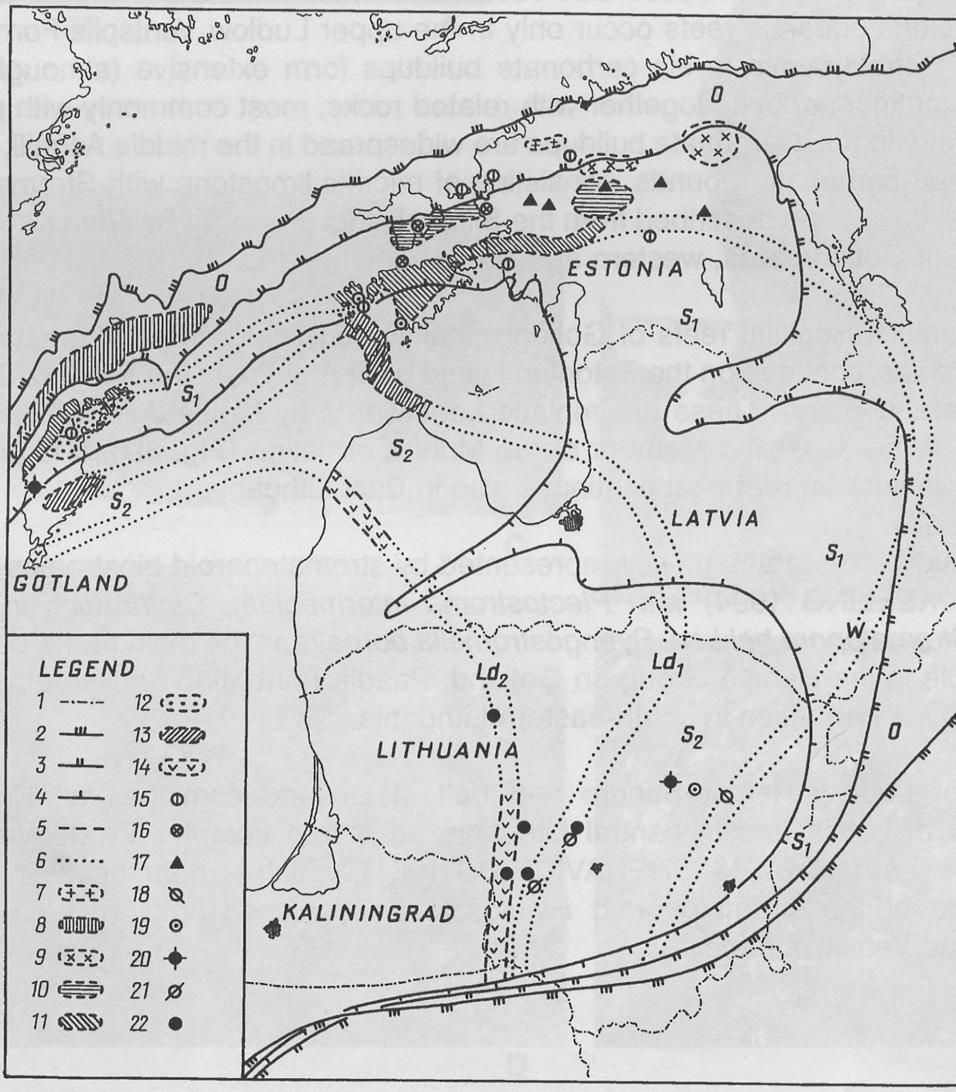

Fig.2. Distribution of reefs in the Baltic area. Legend: 1- frontier, 2- contour of the Ordovician rocks, 3- contour of the lower Silurian, 4- contour of the upper Silurian, 5- proved limit of a reef tract, 6- supposed limit; 7-14 reef areas: 7- Vasalemma, 8- "Boda" 9- Porkuni, 10- Juuru (Hilliste), 11- Högklint/ lower Jaagarahu/ Kesselaid, 12- Slite, 13- Hemse/ Paadla, 14- Hamra/ Sundre/ Ventspils; 15-22 single localities: 15- Pirgu, 16- Porkuni, 17- Raikküla, 18- Jacyonis, 19- middle Jaagarahu/ Birshtonas, 20- Klinteberg/ Siesartis, 21- Dubysa, 22-Minija.

The Baltic, Ordovician and Silurian reefs occur discontinuously at selected stratigraphic intervals from the middle Caradoc (Vasalemma Formation of the Keila and Oandu regional stages in Estonia) up to the lowermost Pridoli (Minija Formation of the Kaugatuma Stage in Lithuania) (Fig.1).In the Gotland area they occur in most of the stratigraphic units of the Wenlock and Ludlow, and also in subsurface sections of mid-Ashgill age ("B□da" carbonate mounds). The latter are also established by seismic reflection profiles below the sea-bed north of Gotland (Fig.2). In the Estonian sequence, reefs occur from the middle Caradoc up to the end of the Ludlow (Kuressaare Stage) with several interruptions in their stratigraphic succession (see KLAAMANN & EINASTO 1982). In Lithuania, reefs are well developed in the Ludlow and lower Pridoli sections in central Lithuania where they lie at a drillcore depth of 800 to 1200 m. Some records of reefs come also from the highly dolomitized Wenlockian rocks in subsurface sections of eastern Lithuania. In the deeper-water Latvian sequence reefs occur only in the upper Ludlow Ventspils Formation. At specific stratigraphic levels carbonate buildups form extensive (although, perhaps, discontinuous) belts together with related rocks, most commonly with pelmatozoan grainstones. Carbonate buildups are widespread in the middle Ashgill, where similar large carbonate mounds, consisting of micritic limestone with Stromatactis-structures, have been described from the Siljan district in central Sweden (JAANUSSON 1979), Gotland area, western and central Estonia (Fig. 2).

Lower Wenlock Högklint reefs of Gotland, mainly consisting of the stromatoporoid *Vikingia tenuis*, continue on the Estonian Island of Saaremaa in the Vilsandi Beds of the Jaagarahu Stage. These are replaced eastwards by highly dolomitized "mud-mounds" of the Kesselaid Member of the Muhu Formation (Fig. 3D). It is possible that this Wenlockian reef tract continues also in East Lithuania.

A lower Ludlow reef tract, mostly represented by stromatoporoid biostromes (KERSHAW & KEELING 1994) with *Plectostroma intermedium*, *Clathrodictyon mohicanum, Stromatopora bekkeri, Syringostromella borealis* as the main frame-builders, is traceable in the Hemse Group on Gotland, Paadla Formation on Saaremaa and in the Dubysa Formation in south-eastern Lithuania.

The upper Ludlow Hemse-Sundre reef belt of Gotland continues on Kurzeme Peninsula of Latvia and in central Lithuania as a reef complex in the Ventspils Formation (LAPINSKAS & CHEHAVICHIUS 1981), which is demonstrated by the abundance of the stromatoporoid *Plectostroma scaniense* both in the Hemse-Sundre and Ventspils reefs.

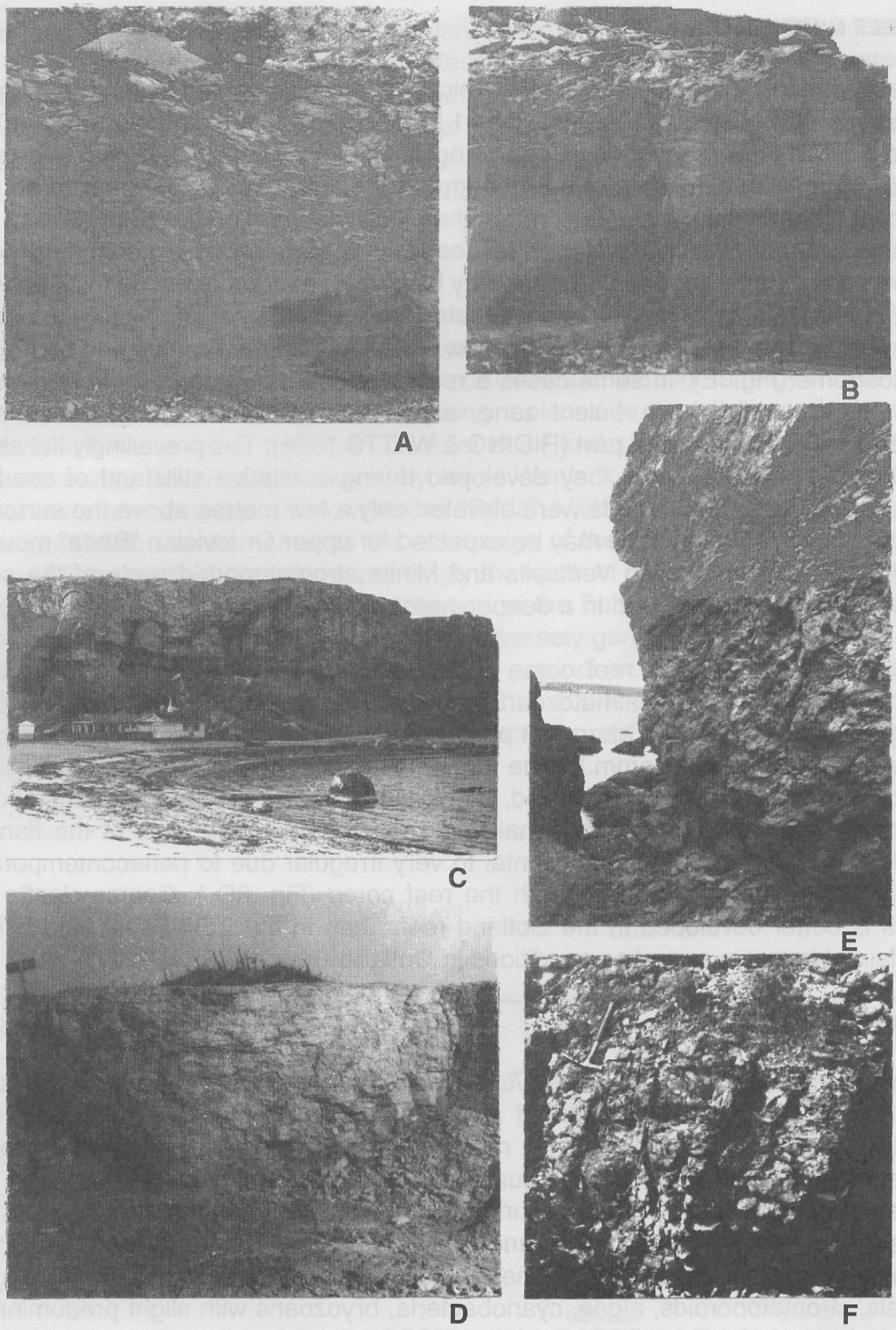

Fig.3. Examples of the early Palaeozoic carbonate buildups from the East Baltic area. A- middle Ordovician Vasalemma carbonate mound in an abandoned quarry at Vasalemma, Estonia; B- small bryozoan pioneer bioherm in pelmatozoan grainstones of the Ninase Member (lower Wenlock), Estonia, Saaremaa, Undva cliff; C- typical lenticular Högklint patch reef at Snäckgärdsbaden, Gotland; D- lower Wenlock Kesselaid “mudmound” Estonia, Muhu Island, Koguva quarry; E- lower Ludlow stromatoporoid biostrome, Hemse Group, Gotland, Kuppen; F- stromatoporoid framestone in a biostrome of the same age, Paadla Stage, Saaremaa, Riiumägi.

5. REEF MORPHOLOGY

Most commonly the Baltic early Palaeozoic reefs are represented by lenticular bodies of comparatively small sizes (thickness 1 to 10 m, horizontal diameter up to 50 m). Thickness of the largest reefs ("Boda", Högklint, Hamra, Ventspils, Minija) may reach 30 to 60 m, with diameters of 0.5 to 4 km. In the last case they appear to be coalescent biohermal agglomerates, rather than individual reef bodies. Bioherms or carbonate mounds, which developed in deeper-water argillaceous sediments below wave base ("Boda" mounds, Upper-Visby bioherms) may be about as thick as wide, or their thickness may exceed their diameter. More common are flat lenticular bodies, which developed in a high energy, shallow water environment whose end member is a biostrome (Fig.3E). In some cases a reef developed as a small pioneer bioherm and, growing into the turbulent zone, expanded sidewards rapidly, becoming a biostromal unit in its upper part (RIDING & WATTS 1991). The prevailingly flat shape of the reefs suggests that they developed during a relative stillstand of sea-level (Fig.3C). In general, flat reefs were elevated only a few metres above the surrounding sea floor A higher slope may be expected for upper Ordovician "Boda" mounds, and for the upper Silurian Ventspils and Minija stromatoporoid reefs of the south East-Baltic area, developed in a deeper-water environment on the outer shelf.

In most cases, massive reef cores were surrounded by flanking bioclastic limestones, prevailingly as pelmatozoan grain- and rudstones. Flanking rocks of the Högklint reefs contain an abundant pelletal component, especially in topmost parts (JAANUSSON, pers. comm.). The Lower Wenlock Kesselaid "mudmounds" of Estonia are enclosed by dolomitized, slightly kerogenous, argillaceous flagstones of probably restricted shelf or lagoonal origin (NESTOR 1990). Dips of the flanking beds may vary from almost horizontal to very irregular due to penecontemporaneously depressed strata underneath the reef cores (Fig. 3D). Coarse-clastic reef talus is better developed in the Gotland reefs than in the East-Baltic, and can be explained by more open-sea conditions in Gotland.

6. FRAME BUILDERS

The earliest, Ordovician buildups (Vasalemma and Boda mounds) consist mostly of micritic carbonate material without a visible skeletal frame (JAANUSSON 1979, HINTS 1990). Scattered skeletal remains of bryozoans, algae, pelmatozoans, corals, etc. occur in rather small quantities. Stromatoporoids are absent. The topmost Ordovician and lowermost Silurian (Hirnantian - Aeronian) small bioherms and biostromes in the Porkuni, Juuru and Raikküla regional stages of Estonia show a rather diverse assemblage of frame builders. These include tabulate and rugose corals, stromatoporoids, algae, cyanobacteria, bryozoans with slight predominance of tabulates (AALOE & NESTOR 1977; NESTOR & NESTOR 1977). In the Wenlock and Ludlow reefs, stromatoporoids gained dominance, particularly in the shallowest water biostromes (Fig. 3E-F). However, in deeper water (>10m) bioherms corals still prevailed. In the lower Wenlock of Estonia, small bryozoan bioherms have been described in the Ninase Member of the Jaani Formation (Fig.3B; AALOE & EINASTO 1970), and frameless dolomitized Kesselaid "mudmounds" (Fig.3D), laterally replacing Högklint-Jaagarahu coral-stromatoporoid reefs in eastern, more restricted marine sections of Estonia. Summing up, the increasing importance of stromatoporoids in frame-building was the most remarkable trend in the evolution of the reefs in the Baltic area. It was combined with a decrease in the diversity of frame-builders.

7. GENERAL ENVIRONMENTAL SETTINGS

A facies model worked out for the Baltic Silurian Basin (NESTOR & EINASTO 1977, NESTOR 1990) demonstrates that in most cases coral-stromatoporoid reefs and related rocks formed low shoal or barrier complexes in the high-energy middle part of a broad carbonate shelf (platform), being replaced in the offshore direction by biomicritic limestones of the open or outer shelf and shorewards by lagoonal or restricted-shelf dolomicritic rocks. Only lower Wenlock Kesselaid reefs in Estonia had a more shoreward position, whereas "Bɑda", Visby, Ventspils and Minija reefs were located seawards, nearer to the outer edge of the carbonate platform (Fig.4). The sea floor gradient, and correspondingly the width of the carbonate platform and facies belts, was different for different sectors of the Baltic Basin. Apparently, it was somewhat steeper in the Gotland area and extremely gently sloping in Estonia. This is indirectly demonstrated by the extent of the gradual progradation of the reef belt, which was about 200 km for Estonia and less than 100 km for Gotland (Fig.2). It also means that more open sea conditions, favourable for reef development, prevailed in the Gotland area.

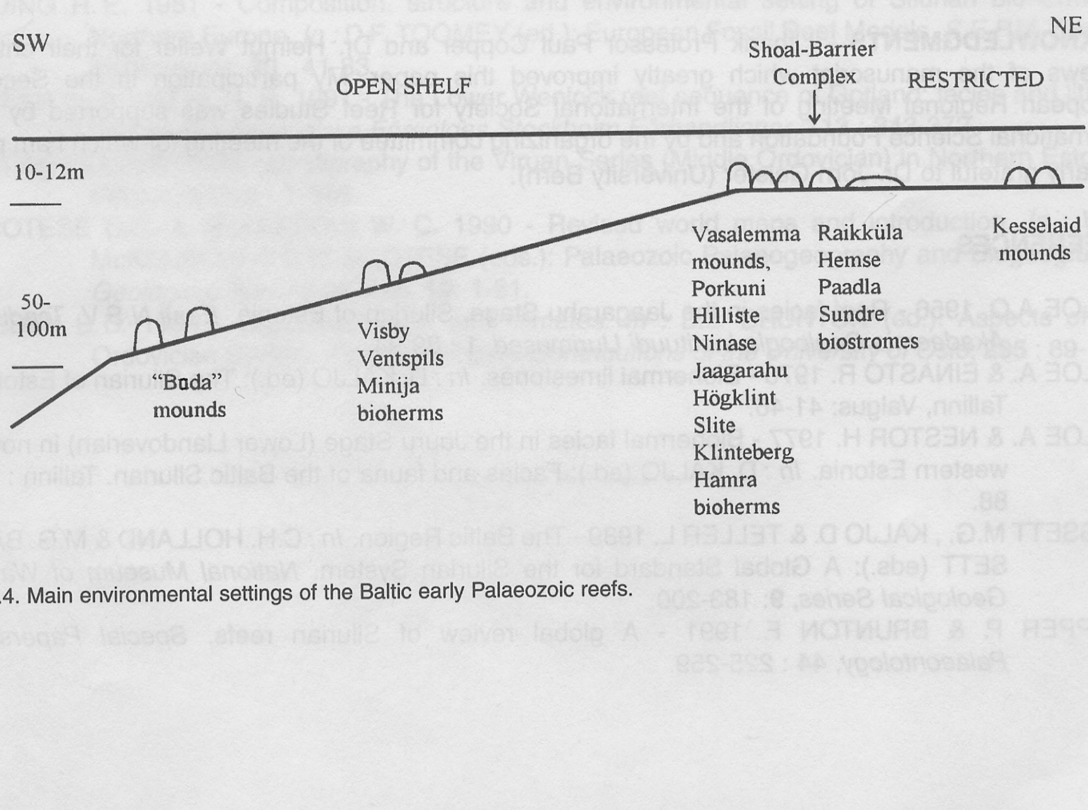

Fig.4. Main environmental settings of the Baltic early Palaeozoic reefs.

Judging from the gradual shifting of the reef tract, it becomes evident that no strong tectonic control of the reef development existed. Limited thickness of the individual reefs and reef complexes, often characterized by a shallowing up sequence (RIDING & WATTS 1991), as well as by extensive progradation of the reef tract, shows that reefs developed under the conditions of a general regression of the Baltic Basin, from time to time interrupted by short-living deepening events.

The Baltic Early Palaeozoic reefs, although forming extensive shoal-barrier complexes, developed in a different tectonic setting than the Great Barrier Reef of Australia, situated along the continental margin exposed to the trade currents. According to the most recent reconstructions (*e.g.* SCOTESE & McKERROW 1990), the Baltic Basin was located at the south-western margin of the Baltica Continent and reefs developed far away from the tectonic continental margin (Tornquist-Teisseyre Lineament). However, there are rather similar conditions for reef formation in the Gulf of Mexico.

8. CONCLUSIONS

The appearance of reefs in the Baltic area in the middle Caradoc coincided with the transition of the Baltic Basin from an epicontinental to the pericontinental phase of development, and with shift from temperate to tropical latitudes. A flat lenticular shape of many reefs suggests their development in the conditions of relative tectonic and eustatic stillstand. Extensive progradation of the reef belt took place due to general regression of the basin. The role of stromatoporoids increased in frame-building towards the end of the Silurian. Reefs were generally situated in the middle part of the broad carbonate shelf (platform) far away from the tectonical margin of the Baltica Continent.

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