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A Lithuanian–Swedish geotraverse study

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Cover: Microfossil residue of a sample taken from Pliensbachian beds, Lower Jurassic, Rya Formation at Katslösa, NW Scania (mostly foraminifers). Collector: Jan Rees, Department of Geology, Lund University. Photo: Yvonne Arremo, Swedish Museum of Natural History, Stockholm.

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CONTENTS

Abstract

In the southern Baltic Sea and framing land areas thick deposits of Jurassic age are preserved, mostly covered by younger sediments, but to a certain degree outcropping too. In the east area treated (Fig. 1) the northernmost finds of Jurassic rocks are located to southern Latvia, near the border to Lithuania. To the west Jurassic sediments occur along the margin of the Baltic Shield and further to the south and west (Fig. 1). The northernmost finds in Swedish territory are located to the Province of Scania and framing parts of the Öresund Strait and the Kattegat. The present publication describes the Jurassic succession of Lithuania, the South Baltic Basin, and Scania. The Jurassic stratigraphical representation is treated, as are biostratigraphical dating and correlation with the European standard chronostratigraphy. The foraminiferal faunas obtained from the areas in question have been used for biozonation. The faunas of Lithuania and adjacent areas are compared with those of Scania and framing sea areas as to taxonomic composition and representation. Similarities and major differences are commented on, and an attempt has been made to explain the major characteristics of depositional environments, palaeoecology and biogeography. According to our interpretation main differences between the two areas compared may be a closer contact between the Baltic–Polish Basin and the Tethyan Sea than between Scania and the Tethys. Southern Scandinavia, on the other hand was more influenced from the northwest through water gateways with the Arctic Basin than Lithuania. Such differences have caused discrepancies in salinity and water temperature between the western and eastern areas studied, which have had effects on faunal diversity, ecological conditions and, most likely migration trends. The publication is illustrated with 31 figures and 7 tables. Foraminiferal species are illustrated by scanning electron micrographs in 5 plates. The lithology and palaeogeography of the Jurassic Stages of northern and central Europe is illustrated by 12 coloured maps (Plates 6–17). In Index of foraminifera, page 63, their stratigraphical ranges in Lithuania, and in Sweden can be found.

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Introduction

In the north-western part of the East European Platform Jurassic sedimentary rocks cover a vast area in the southern Baltic Sea and framing land regions. The present study concerns mainly the Jurassic of Lithuania and southern Sweden, including offshore areas and the Jurassic of the Russian Kaliningrad Enclave (Fig. 1). In the East Baltic countries, an area including SW Latvia, Lithuania and the Russian Kaliningrad Enclave, the Jurassic deposits reach a maximum thickness of c. 240 m near the Lithuanian–Polish border. The total maximum thickness of the Jurassic in Sweden, restricted to the Province of Scania, is estimated to be of the order 700–800 m. In Lithuania, most of the Jurassic exposures are to be found in the valley of River Venta in the north-western part of the country. In southern Lithuania some exposures of Oxfordian deposits are located to the valley of River Merkys. In Lithuania, as well as in Scania, Jurassic outcrops are usually of minor dimensions. In Scania most of the exposures are to be found in the north-western and central parts of the province.

The stratigraphical and micropalaeontological presentations in the present monograph are based on previous studies, by the authors mainly, of strata visible in exposures and of subsurface sequences penetrated by borings. The core material, which has been at our disposal, originates from missions of various purposes; clay, coal, hydrocarbon and water prospecting, drillings made for scientific purposes etc. The stratigraphical representation of the Jurassic, viz. the presence of strata in terms of chronostratigraphical units, is different in Lithuania and Sweden. In Lithuania, the Lower Jurassic is missing in exposures, whereas in Scania this series forms the dominating part of the Jurassic rock surface. In subsurface core material from Lithuania and the SE part of the Baltic Sea, however, the upper part of the Lower Jurassic (the Pliensbachian and Toarcian Stages) has been recorded. The first marine influence in the East Baltic Jurassic seems to have occurred late in the Bathonian. During the Callovian a major marine transgression started, which is indicated e.g. by a rich ammonite fauna and a prolific microfauna, of which the foraminifers are paid special attention in this monograph. The marine upper Middle Jurassic and Upper Jurassic deposits have a fairly wide distribution in the eastern part of the Baltic region. In the west, in Scania, the first major marine transgression appeared in the Early Sinemurian. Thereafter, dominantly marine conditions lasted throughout the Early Jurassic. The Middle Jurassic of Sweden, known mainly from borings (and one outcrop only), is represented by continental and lagoonal deposits; sand and clays with coal-seams of Bajocian and Bathonian ages. At the very end of the Bathonian certain parts of western Scania were influenced by marine conditions, which progressively invaded wider areas during the Callovian and Oxfordian.

The marine microfaunas of Callovian and Oxfordian ages in Lithuania and Scania show similarities, as well as differences. During the Late Jurassic fully marine conditions lasted longer in the eastern Baltic region than in Scania and adjacent offshore areas. This is evident from the records of ammonites as well as foraminifers. In the following chapters, the Jurassic geology and stratigraphy will first be described from Lithuania and the south-eastern part of the Baltic Sea, then from Scania and adjacent offshore areas. The following chapters describe the composition of the foraminiferal faunas, and the biostratigraphy based on them, in the regions in question, followed by a comparison of the faunas. The final chapter concerns facies distribution, palaeo- and biogeography, and foraminiferal palaeoecology.

Acknowledgements. – This investigation was mainly carried out at the Lithuanian Institute of Geology in Vilnius, and at the Swedish Museum of Natural History, Department of Palaeozoology in Stockholm. The authors want to thank Dr. Valentinas Baltrūnas and Désirée Edmar, Directors of the Lithuanian institute and the Swedish museum respectively, and Professor Jan Bergström, head of the Department of Palaeozoology mentioned. For the scanning electron micrography of foraminifers, presented in this publication, equipment both at the Stockholm University, Department of Geology, and at the Swedish Museum of Natural History has been used. We are grateful to Emeritus Professor Maurits Lindström, Stockholm University for putting at our disposal the SEM microscope at his department, and to Dr Zhang Jianhua and Mrs Yvonne Arremo, assisting us at the electron microscopes of the University Department of Geology, and the Museum of Natural History. We will thank Mr Uno Samuelsson, Department of Palaeozoology, Swedish Museum of Natural History for careful dark-room work. Most of our draft illustrations were finally refined by Mr Algimantas Ručys, Institute of Geology in Vilnius, using the Corel Draw software, a fine work for which we are most grateful. Our sincere thanks go also to Professor Euan Clarkson, University of Edinburgh, who has corrected our English, and to Dr Anders Ahlberg, Lund University, who with his great experience in Jurassic geology and sedimentology, has contributed most constructive criticism. The mutual research visits in Lithuania and in Sweden have been sponsored by the Royal Swedish Academy of Sciences (KVA), and the Lithuanian Academy of Sciences. We want to thank the Research Exchange Secretaries, Mrs Sascha Edblad, KVA, and Mrs Nijolė Bulotaitė at the Lithuanian Academy for kind and ductile treatment of our applications, and the academies for giving us substantial economic support to this project. We are most grateful to Dr Hans-Jürgen Teschke, Berlin, Drs Franz Kockel and Thomas Schubert, Niedersächsisches Landesamt für Bodenforschung, Hannover, who have kindly supported us to get the copyright for printing 12 coloured maps, illustrating the lithology, palaeogeography and structural geology of the Jurassic System in northern Europe, maps compiled for the IGCP Project No. 86: East European Platform, SW Border. Warm thanks go also to the referee of the manuscript resulting in this publication, Dr Lars-Henrik Nielsen, Geological Survey of Denmark and Greenland (GEUS), Ministry of Environment and Energy, Copenhagen, for constructive criticism and improving corrections. We thank the Geological Survey of Sweden (SGU), Ministry of Studies and Science of Lithuania and the Royal Swedish Academy of Sciences for supporting the printing of this publication, and the SGU editors, Ms Agneta Ek and Mrs Jeanette Bergman Weihed for their fine editing and layout work.

Jurassic geology and stratigraphy of Lithuania and the SE part of the Baltic Sea

In Lithuania the marine Early Triassic was followed by a long continental period resulting in erosion and deposition of non-marine sediments with major stratigraphical gaps in Middle to Upper Triassic, as well as Lower and Middle Jurassic. Not until the Middle Callovian did major marine transgressions appear in Lithuania. Within the Lithuanian-Polish (Peribaltic) Syneclise marine basins predominated from Late Middle Jurassic times throughout the Cretaceous and into the Palaeogene (Grigelis & Kadūnas 1994). The south-western part of the syneclise is limited by a major tectonic lineament, viz. the Tornquist Zone, forming the boundary between the East European Platform and the area of subsidence in western Europe. In the Lithuanian–Polish Syneclise, Jurassic, Cretaceous and Palaeogene sedimentary successions are characterized by repeated facies shifts and great diversity in lithologies. The analyses of the sedimentary successions of the Mesozoic and Cenozoic geological systems show that various conditions prevailed, linked to changes in the depth of the basin. Differences in local environments may often have been caused by interaction between eustacy and synsedimentary tectonics.

MAINLAND LITHUANIA

Mesozoic and Palaeogene strata are restricted to SW Latvia, Lithuania and the Kaliningrad Enclave, whereas Estonia and the major part of Latvia are devoid of post-Palaeozoic deposits (Grigelis 1982b, Norling 1993). They include clastic as well as carbonate deposits of continental, lagoonal and marine origin. The stratigraphy of the Jurassic in Lithuania is illustrated in Table 1. Two lithofacies zones may be distinguished, though one lithostratigraphical unit relevant for both zones is regarded to be valid. The Jurassic rocks of SW Latvia, Lithuania, and the Kaliningrad Enclave gradually increase in thickness towards the south and west reaching a maximum of about 240 m near the Lithuanian–Polish border (Figs. 2–5 and Table 1). In mainland Lithuania Jurassic rocks usually rest upon the Triassic, but in minor areas on Permian or Devonian deposits too. In NW and Central Lithuania Callovian and Oxfordian strata form the rock surface beneath the Quaternary cover. Further towards the southwest Kimmeridgian and Volgian deposits are present, covered by successively younger pre-Quaternary strata, viz. Cretaceous and Tertiary (Grigelis 1982b). Since the 19th century outcropping Callovian and Oxfordian strata have been known from the vicinity of the little town of Papilė in NW Lithuania. The exposures are mainly found in the valley of River Venta and at nearby localities, e.g. at Papartinė and the Latvian village Nigrande. Callovian sands and sandstones can be studied in the Šaltiškės Pit, and in the slopes of River Vadakstis. In southern Lithuania, Oxfordian black clays are outcropping in the valley of River Merkys.

Lower Jurassic

No Hettangian or Sinemurian strata are documented from the Baltic area studied. The Pliensbachian and Toarcian Stages are represented by the Jotvingiai Group, which includes two formations, viz. the Neringa and Lava Formations (Grigelis 1994, Grigelis & Suveizdis 1993, Fig. 6 herein).

JOTVINGIAI GROUP

Neringa Formation (Upper Pliensbachian)

A core, the 535–567.5 m interval of drilling in the Vladimirov (Tarava) borehole, Kaliningrad Enclave, has been chosen as stratotype for this formation (Fig. 3). The Neringa Formation (Fig. 6) is composed of noncalcareous, light or yellowish grey and black sands and sandstones with blackish coal- and plant bearing interbeds. In some sections of the Neringa Formation, a basal conglomerate has been observed, resting on Lower or Upper Triassic deposits.

On the basis of palynological data, the Neringa Formation is referred to the Lower Jurassic by Vienožinskienė & Kisnėrius (1978). After a long Triassic–Early Jurassic break in sedimentation (or Early Jurassic denudation), strata representing the Neringa Formation were deposited in a freshwater lagoon, most likely in Late Pliensbachian time (Grigelis, Monkevich & Vishniakov 1985). The formation is present in a deeply submerged part of the Jurassic basin in SW Lithuania too. Its thickness may reach some 33 m.

Lava Formation (Toarcian)

The Lava Formation (Fig. 6), overlying the Neringa Formation, exhibits a similar lithology indicating a continuation of more or less the same depositional environment. The formation contains grey, greenish, and dark grey silt and clay with intercalations and lenses of fine-grained sand, pyritic concretions and plant remains (carbonised wood fragments).

The Lava Formation differs from the Neringa Formation in its high content of clay and in the composition of its spore and pollen flora (Vienožinskienė & Kisnėrius 1978). The formation has been correlated with the Cechocinek Beds in Poland and given a Toarcian age (Grigelis, Monkevich &

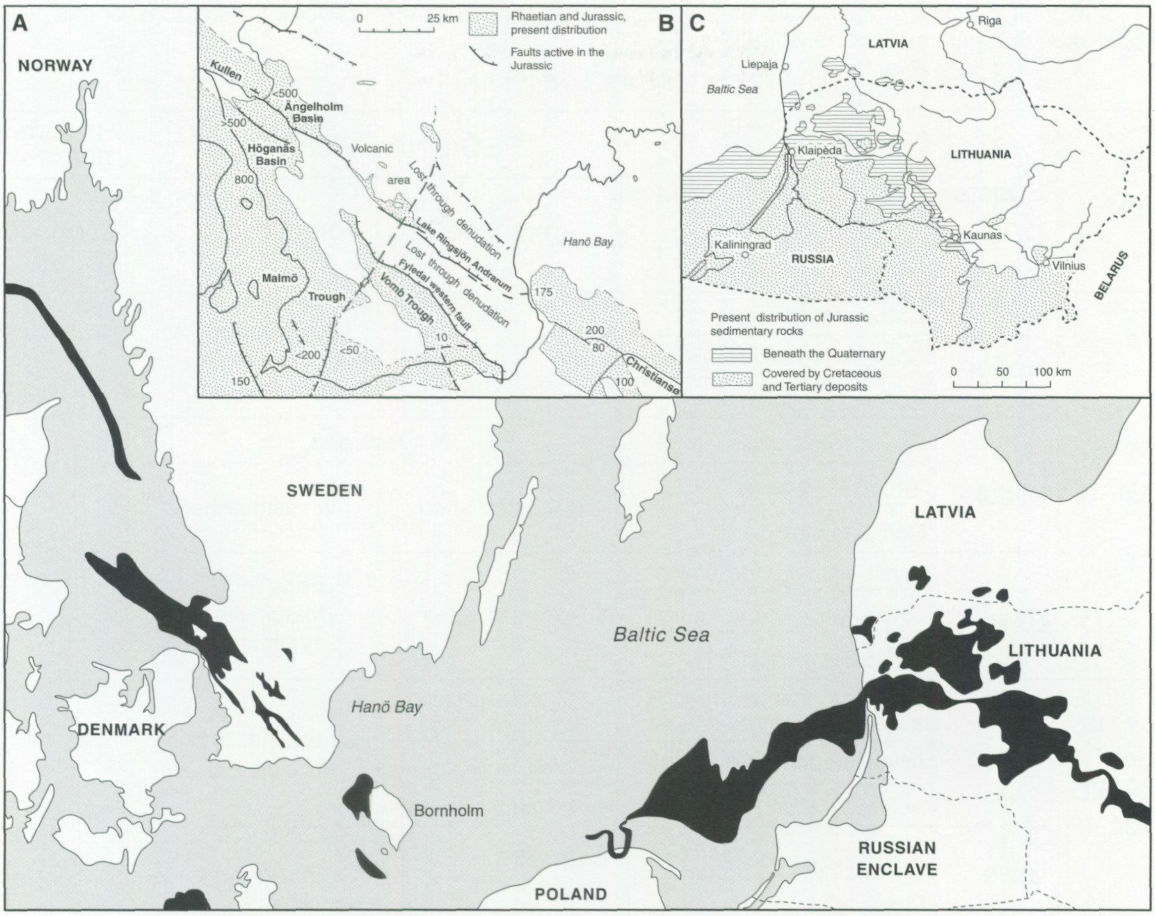

Fig. 1. A) Distribution of Jurassic rocks in the Baltic Sea area, Kattegat and Skagerak (at the base of the Quaternary. After Norling 1994). B) Distribution of the Rhaetian-Jurassic in Scania and adjacent waters (After Norling & Bergström 1987). C) Distribution of Jurassic deposits in the Baltic countries (after Norling & Grigelis 1996).

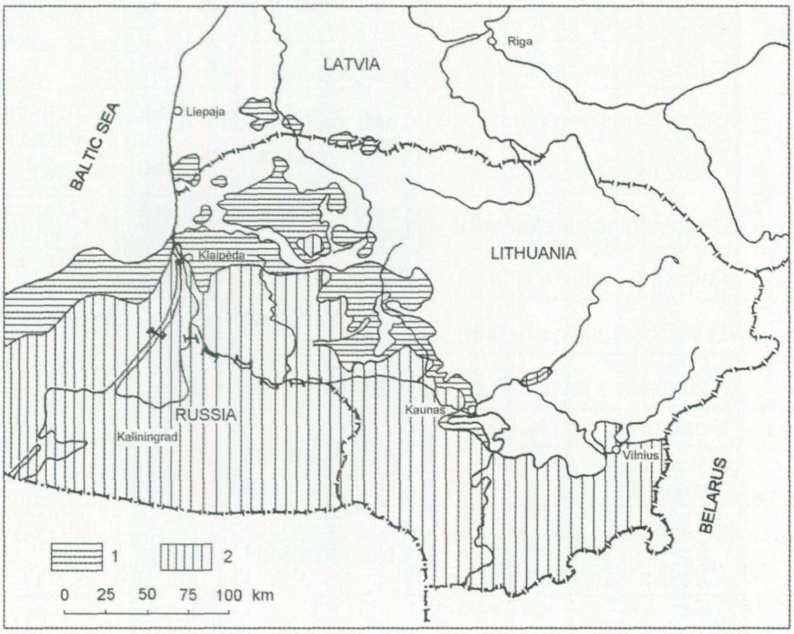

Fig. 2. Present distribution of Jurassic sedimentary rocks in SW Latvia, Lithuania and the Kaliningrad Enclave of Russia, including the SE Baltic Sea (after Grigelis 1985). Legend: 1) beneath the Quaternary, 2) covered by Cretaceous and Palaeogene deposits.

Table 1. Stratigraphical table of the Middle and Upper Jurassic in the Baltic countries (foraminiferal zonation after Grigelis 1985, ammonite zonation after Rotkytė 1987).

Stage	Substage	Standard ammonite zones	REGIONAL ZONATION: Ammonite	REGIONAL ZONATION: Foraminiferal	LITHOSTRATIGRAPHY: Formation
VOLGIAN	Upper	Craspedites notiger			
		Craspedites subditus			
		Kachpurites fulgens			
	Middle	Epivirgatites nikitini	Not recorded	Not recorded	Girdava
		Virgatites virgatus	Not established	Not established	
		Dorsoplanites panderi			
	Lower	Ilovaiskya pseudoscythica	Not established	Beds with Marginulina striatocostata	
		Ilovaiskya sokolovi			
		Ilovaiskya klimovi			
KIMMERIDGIAN	Upper	Aulacostephanus autisssiodorensis	Aulacostephanus autissiodorensis	Lenticulina illustris-Lenticulina daiva	Tarava
		Aulacostephanus eudoxus	Aulacostephanus eudoxus		
		Aulacostephanus mutabilis	Aulacostephanus mutabilis		
	Lower	Rasenia cymodoce	Beds with Amoeboceras kitchini	Lenticulina prussica-Lenticulina kuznetsovae	
		Pictonia baylei			
OXFORDIAN	Upper	Ringsteadia pseudocordata	Amoeboceras rosenkrantzi	Lenticulina quenstedti	Ąžuolija
		Decipia decipiens	Amoeboc. regulare Amoeboc. serratum		
		Perisphinctes cautisnigrae	Amoeboceras glosense		
	Middle	Gregoryceras transversarium	Cardioceras tenuiserratum	Ophthalmidium strumosum - Lenticulina brestica	
		Perisphinctes plicatilis	Cardioceras densiplicatum		
	Lower	Cardioceras cordatum	Cardioceras cordatum	Ophthalmidium sagittum - Lenticulina brueckmanni	
		Quenstedtoceras mariae	Vertumniceras mariae		
CALLOVIAN	Upper	Quenstedtoceras lamberti	Quenstedtoceras lamberti	Lenticulina tumida Lenticulina chmielewskii	Skinija
		Peltoceras athleta	Kosmoceras ornatum	Lenticulina paracultrata	
	Middle	Erymnoceras coronatum	Erymnoceras coronatum	Lentuculina cultratiformis Lenticulina cultratiformis	Papartinė
		Kosmoceras jason	Kosmoceras jason	Lenticulina pseudocrassa	
	Lower	Sigaloceras calloviense	Not recorded	Beds with Lenticulina okrojanzi	Papilė
		Macrocephalites macrocephalus			
BATHONIAN	Upper	Clydoniceras discus	Not recorded	Beds with Ophthalmidium infraoolithicum	Liepona
		"Oppelia" aspidoides			

Vishniakov 1985). The formation has a thickness of c. 45 m and a smaller distribution than the Neringa Formation. The two formations represent deposits laid down in fresh water and brackish basins, possibly lagoons or coastal plain lakes (Vienožinskienė & Kisnėrius 1978).

Middle Jurassic

Skalviai Group

The Middle Jurassic is represented by the Skalviai Group, which includes three formations; the Įsrutis, Liepona, and the Papilė Formations (Figs. 6, 7).

Įsrutis Formation (Bajocian – Lower Bathonian)

Localities of the Įsrutis Formation are known in the vicinity of Nida and Kybartai-Gumbinė, W and SW Lithuania (Fig. 3). Its stratotype is a cored sequence, 365.5–451.3 m, in Uljanov-3 (Kraupiškės) in the south-eastern part of the Kaliningrad Enclave (Šimkevičius 1973). The rich content of coal is characteristic of the formation, especially in the sandy-clayey parts. In some sections, up to 8 m thick lignitic beds have been recorded, in which the coal is evenly spread within the entire stratum (Fig. 6).

The Įsrutis Formation is referred to the Bajocian – Lower Bathonian. Its sedimentation took place in freshwater lakes after a long period of non-deposition, including Aalenian times. The formation rests on Triassic or Lower Jurassic rocks. Its thickness varies between 80 m and 140 m and it is recorded from rather deep depressions in the areas of Kuršiai and N Gumbinė-Kybartai (Figs. 3, 6). The distribution of the Įsrutis Formation is determined by tectonic faults. This is true of the 140 m thick coal-bearing deposits recorded from the Vepriai Graben (Slabada-201 borehole), NE Lithuania. Samples from this borehole have yielded a macroflora including plant fossils of the genera *Phlebopteris* and *Hausmannia, Pachypteris lanceolata* Brongiard, *Nilssonia acuminata* (Presl) Goeppert, *Gingkodium nathorstii* Yokoyama, and *Elatocladus* sp. (Vakhrameev, Grigelis & Mikhailov 1971).

Originally, the Įsrutis Formation most certainly had a wider distribution than it has today. The present distribution is affected by erosion, partly linked to Mid-Kimmerian tectonic fracturing and later inversion movements along the western margin of the East European Platform.

Liepona Formation (Upper Bathonian)

As stratotype of the Liepona Formation the 357–381 m interval of drilling in Kybartai-22 (Fig. 3), SW Lithuania has been chosen (Stirpeika 1968). The formation is composed of calcareous sands and sandstones with few finds of fossils. The sequence includes non-calcareous dark grey, laminated

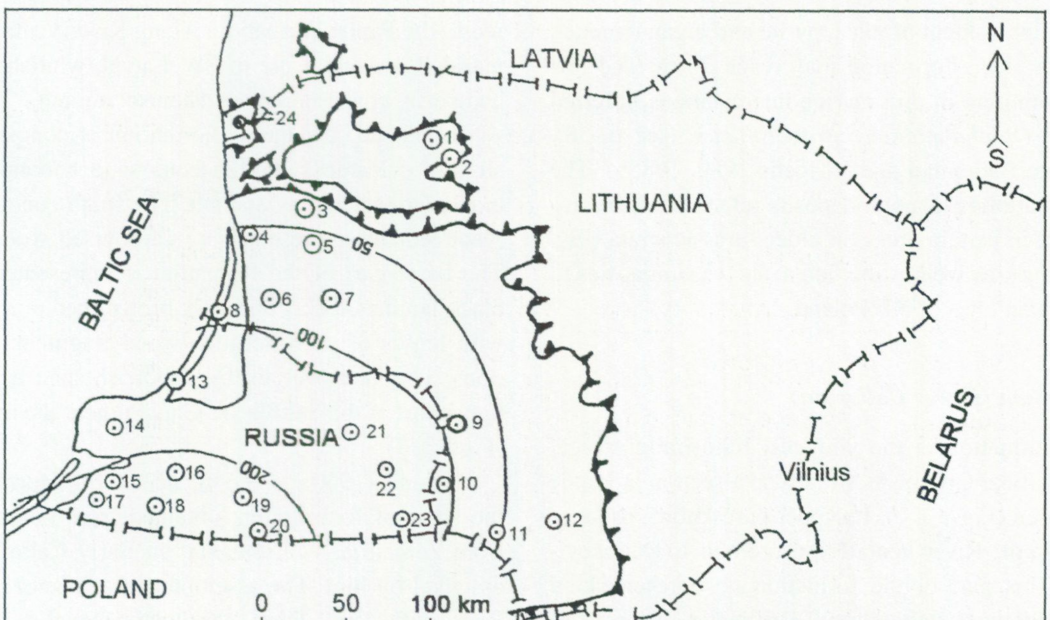

Fig. 3. Sketch map showing the location of Jurassic type sections in Lithuania and the Kaliningrad area, commented on in the text. 1) Papilė, 2) Papartinė, 3) Žadeikiai, 4) Dumpiai, 5) Stančaičiai, 6) Vilkyčiai, 7) Ąžuolija, 8) Nida, 9) Panoviai, 10) Kybartai, 11) Kalvarija, 12) Simnas, 13) Lesnoye, 14) Pereslavskoye, 15) Ladushkin, 16) Vladimirov, 17) Znamenka, 18) Gvardeiskoye, 19) Belyi Jar, 20) Zheleznodorozhnyi, 21) Ulyanovo, 22) Prioziorskoye, 23) Kutuzovo, 24) Rucava. Simplified isopachs of Jurassic deposits are shown in m.

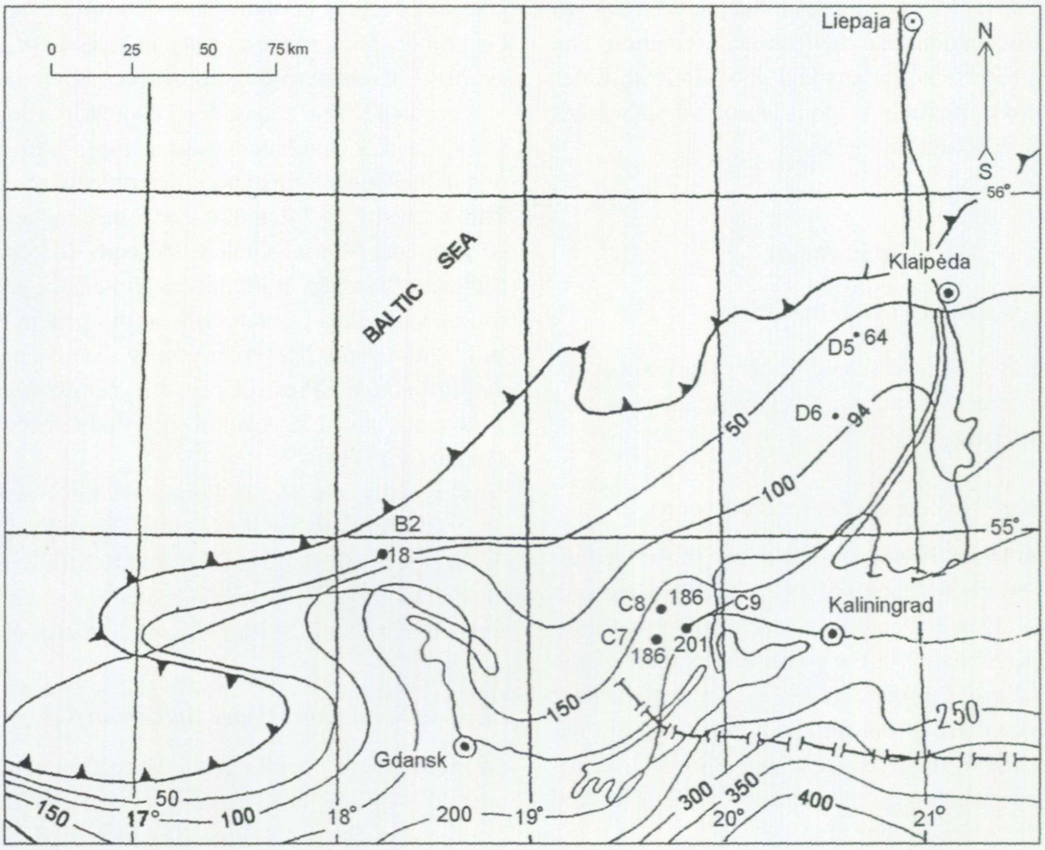

Fig. 4. Distribution and isopachs (in m) of Jurassic sedimentary rocks in the SE part of the Baltic Sea. Locations of borehole sections discussed in the text are given (after Kanev and Grigelis 1981).

clays with a high content of mica, pyrite and organic matter. The thickness of the formation may reach 70 m. The few finds of foraminifers in thin marine intercalations, referred to Beds with *Ophthalmidium infraoolithicum* (see p. 38), indicate a Late Bathonian age (Grigelis 1980, 1985b). The Łiepona Formation rests upon deposits referred to the Įsrutis Formation, in certain areas on older Jurassic strata (Fig. 6). The lithology, as well as the fauna, shows similarities to Upper Bathonian ones of NE Poland.

Papilė Formation (Lower Callovian)

The Papilė Formation is the youngest lithostratigraphical unit of the Skalviai Group. As stratotype a section at Papilė has been chosen (Figs. 3, 7). Its upper part, known as *layer h,* crops out in the River Venta Exposure No. 1 (Dalinkevičius 1926). This part of the formation is represented by 1.5 m of fine-grained, yellow sand. Drilling in the area has shown that 13 m of sandy, clayey deposits beneath known Middle Callovian strata and resting on Lower Triassic red clays, should be referred to the Papilė Formation (Fig. 7). In the Vadakstis Brook Valley, NW Lithuania small outcrops of coarse-grained, ferruginous sand and sandstone occur, referred to the Papilė Formation. Along River Venta, and its tributaries Luse and Zane in SW Latvia, whitish quartz sand, and partly coal-bearing sandstones crop out.

In general, the Papilė Formation is composed of grey, slightly calcareous, argillaceous sand and non-calcareous black, laminated clay and silt. The strata contain pyrite and plant remains represented by carbonised wood fragments. The basal part of the formation is represented by 5 m of black laminated clay and dark brown medium-grained sand with lenses of shell detritus, wood fragments and concretions. They are overlain by yellowish sand exposed in the upper part of the Šaltiškės-1 Clay Pit near the town of Papilė (Figs. 3, 7).

Grigelis (1960) coined the name of the formation and on the basis of foraminifers obtained from borehole samples from Žemaitija, W Lithuania, an Early Callovian age was assigned by him. The assemblage has been referred to the Beds with *Lenticulina okrojanzi* (Grigelis 1980, 1985b, p. 40 herein).

The present distribution of the Papilė Formation has an archipelagic pattern, including many small islands, resting either upon Lower Triassic, Permian or Devonian rocks. Its maximum thickness is of the order 30 m.

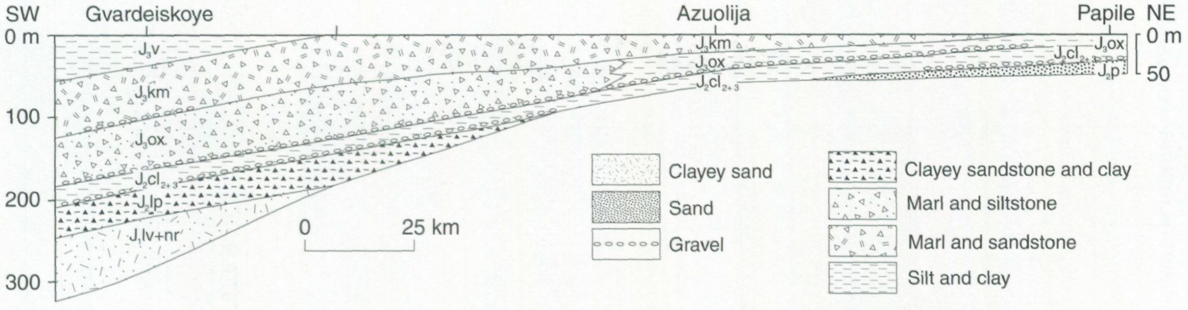

Fig. 5. A schematic SW-NE oriented cross section of the Jurassic in the Baltic Basin (After Grigelis 1994).

The Lower and Middle Jurassic Jotvingiai and Skalviai Groups are composed of subcontinental terrigenous, sometimes coal-bearing sediments. The Liepona and Papilė Formations represent marine ingressions and have yielded foraminifers and remnants of a macrofauna (Grigelis 1985b). At the end of the Middle Jurassic, from Mid-Callovian time, marine transgressions into a shelf basin formed the formations described in the following.

Papartinė Formation (Middle to Upper Callovian)

The name of this formation is derived from the Papartinė village situated near the little town of Papilė on the eastern side of River Venta in NW Lithuania (Fig. 3). The stratotype of the formation is located at Papilė and the reference section at Papartinė (Grigelis 1985b, 1993). In the Papilė stratotype section (Figs. 3, 7), originally described by Dalinkevičius (1934), the Papartinė Formation rests upon the Papilė Formation (Lower Callovian). Between the two formations a stratigraphical gap has been observed. The formation consists of greyish and brownish polymictic, fine-grained sands and sandstones measuring 6.20–6.25 m in thickness (Grigelis 1991b).

The Papartinė Formation has been dated to Middle to Late Callovian with the aid of foraminifers and ammonites (Pakuckas 1933, Grigelis 1985b, Rotkytė 1987). It is ascribed to the *Kosmoceras jason, Erymnoceras coronatum,* and the *Kosmoceras ornatum* Ammonite Zones (Middle Callovian to early Late Callovian). In terms of foraminiferal zones, established by Grigelis (1985b), the formation corresponds to the *Lenticulina cultratiformis* and *Lenticulina paracultrata* Zones (pp. 40, 41). In the stratotype section the formation is overlain by black clays of the Skinija Formation (Fig. 7).

In the parastratotype section of the Papartinė Formation, at present not accessible, the upper part of the formation is composed of oolitic marls and inaequigranular sands not exceeding 1.5 m in thickness.

The ammonite fauna obtained from Papilė-1, Papilė-2 and the Papartinė outcrops (Fig. 3) includes the following species: *Kosmoceras jason, K. castor, K. obductum, K. ornatum, K. aculeatum, K. transitionis, K.* cf . *compressum, K. gemmatum,* and *Peltoceras* ex gr. *athleta* (Authors' names are given in Index of Ammonites, p. 71). The best preserved ammonites are to be found in great number in concretions of calcareous sandstone from layer P3; *Erymnoceras coronatum, E. banksi, Kosmoceras pollucinum, K. duncani* should be mentioned (see Fig. 7). In the Papartinė outcrop, the lower and upper boundary beds of the Papartinė Formation have not been defined (Rotkytė 1987). At some levels within the *Kosmoceras jason* and *Erymnoceras coronatum* Zones brachiopods such as *Rhynchonelloidea varians popilanica, Zeilleria popilanica* and *Ptychothyris dorsoplicata lithuanica* are common. The most complete sections of the Papartinė Formation are located at the Žemaitjia Depression, western Lithuania (Fig. 8). In the Vilkyčiai and Šarkuva boreholes within this depression the formation is represented by yellow grey sands, oolitic sandstones and limestones reaching a thickness of 13 m (Figs. 3 and 8). Some sections of the formation, related to local structures, have been interpreted as condensed deposits not more than 0.5– 0.8 m thick.

In the Papilė area, the upper part of the Papartinė Formation, referred to the *Lenticulina paracultrata* foraminiferal zone, is composed of sandy deposits. Further towards the west and deeper into the basin the lithology changes gradually to greyish brown clays, referred to the Skinija Formation (Fig. 7). The upper boundary of the Papartinė Formation is diachronous.

Skinija Formation (Upper Callovian)

The stratotype section of the Skinija Formation is a core section of the Vilkyčiai-18 well in western Lithuania (Figs. 3, 8). Another section, documented by drilling, has been chosen as parastratotype, viz. Lesnoye-50 at Šarkuva, Curonian

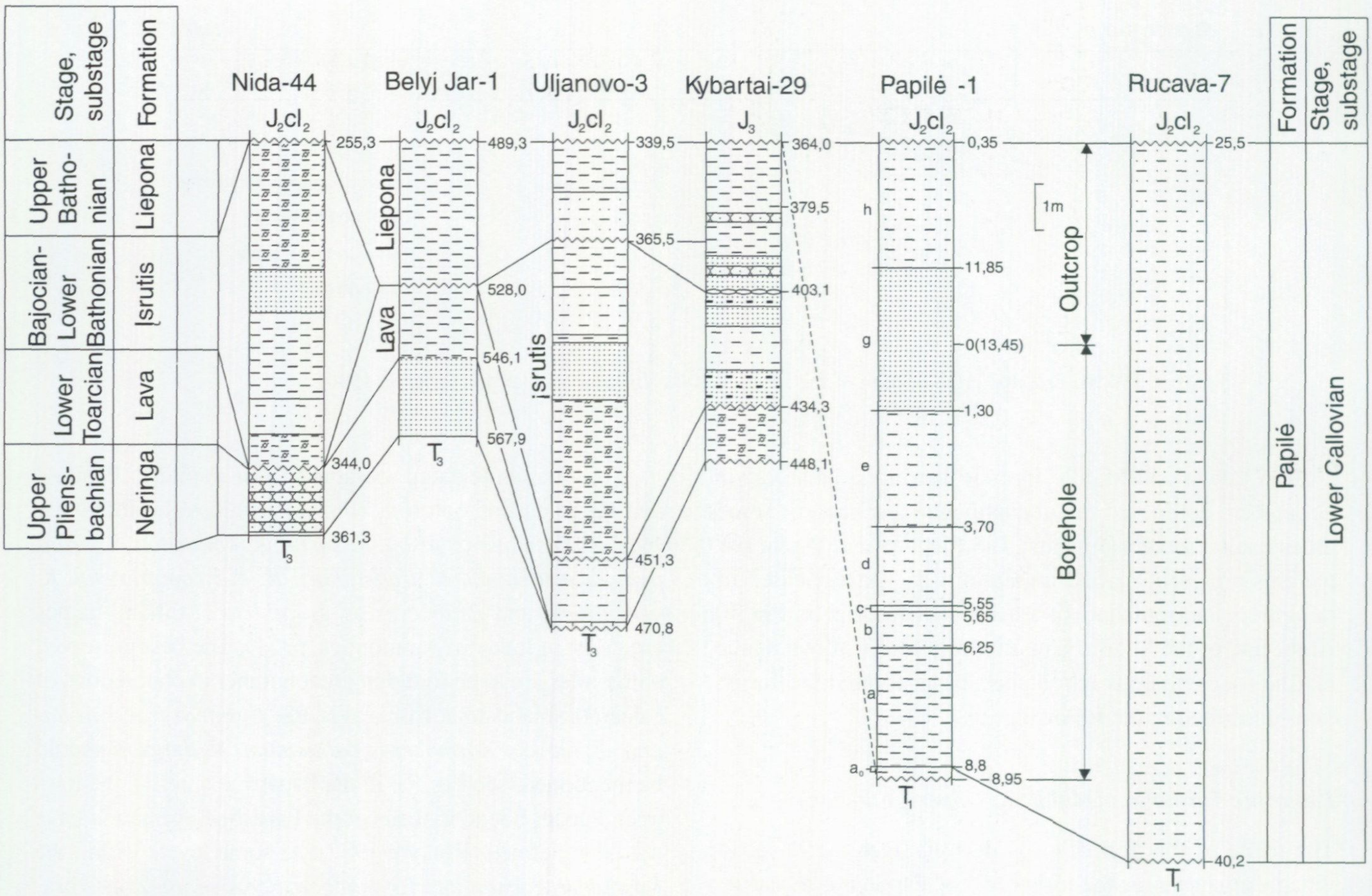

Fig. 6 a. Correlation of some lithological columns from the Lower and Middle Jurassic in Lithuania and the Kaliningrad Enclave (After Grigelis 1980, 1985).

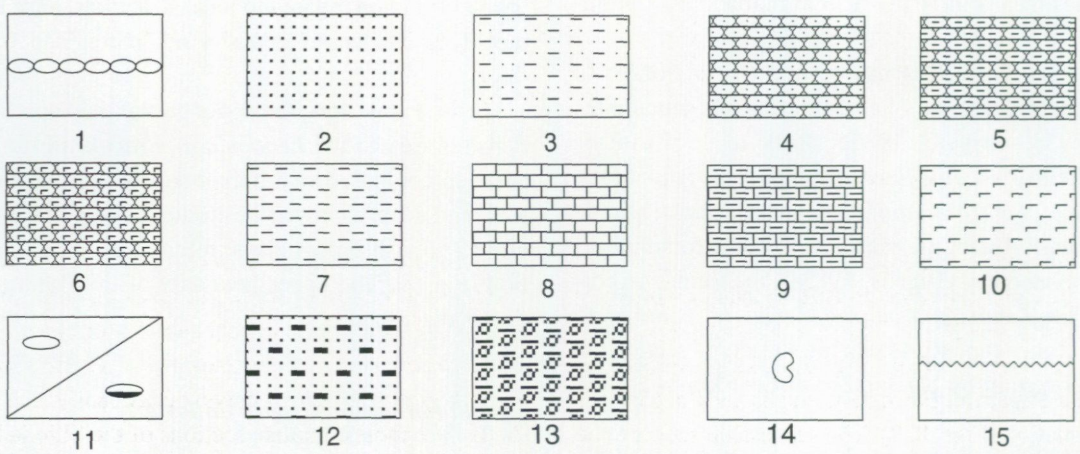

Fig. 6 b. Lithology legend for Figs. 6–10. 1) conglomerate, 2) sand, 3) clayish sand, 4) sandstone, 5) clayish sandstone, 6) marly sandstone, 7) silt, 8) limestone, 9) clayish limestone, 10) marl, 11) concretions (silicified, carbonaceous), 12) coal-bearing sediment, 13) plant-bearing, laminated clay, 14) fossiliferous beds, 15) hiatus.

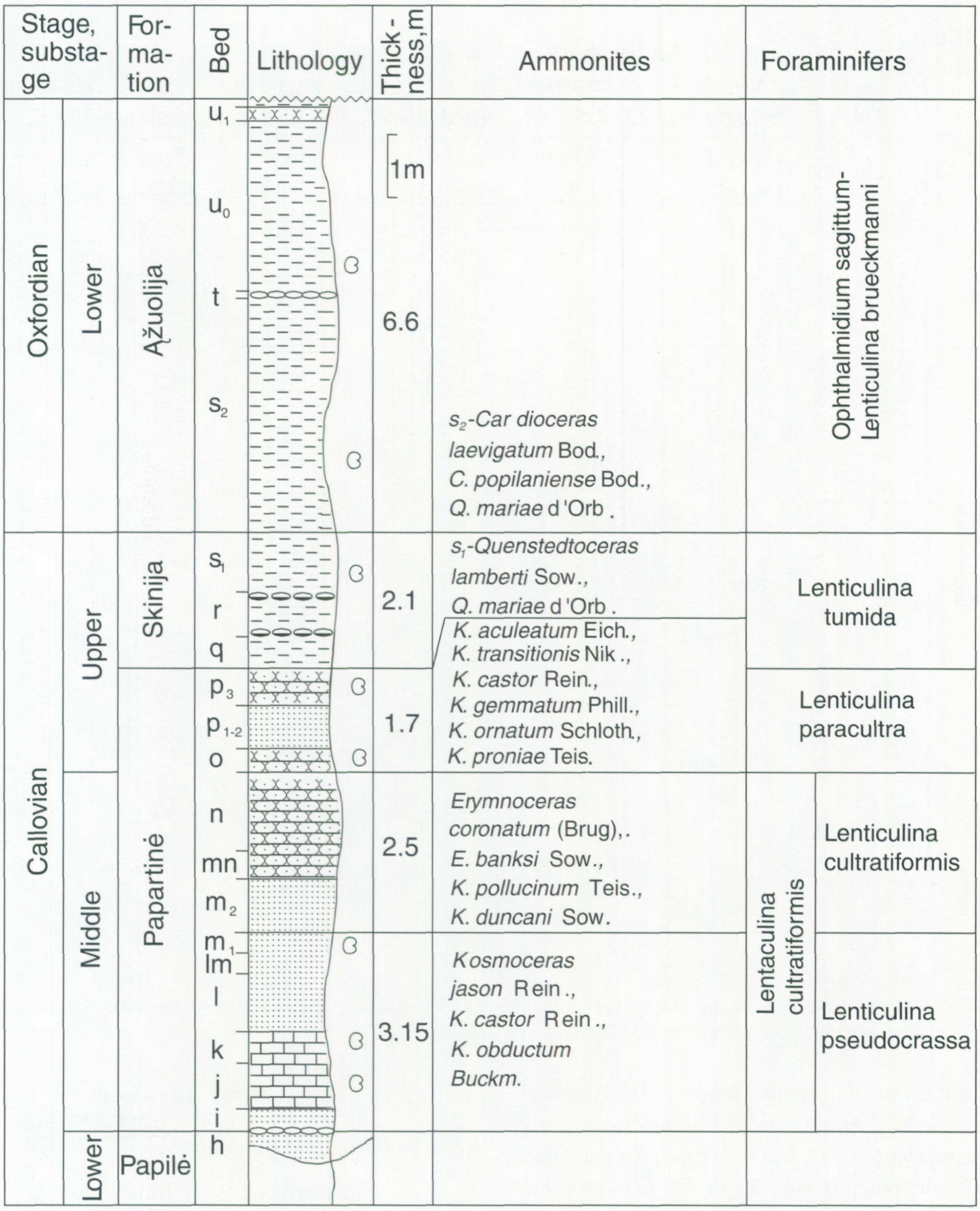

Fig. 7. The Papilė stratotype section, Papartinė Formation, Middle Callovian (after Grigelis 1985). Legend symbols are given in Fig. 6b.

Spit in the Kaliningrad Enclave (Fig. 8). The formation is named after the Skinija rivulet, an eastern tributary of River Minija (Pėteraitis 1992). In Vilkyčiai stratotype section, 117.1–159.2 m interval of drilling, the Skinija Formation rests upon the Papartinė Formation and is overlain by the Ąžuolija Formation (Figs. 8, 9). The succession seems to be stratigraphically complete and consists of homogenous black shales containing carbonate concretions. The equivalent Šarkuva section, the parastratotype, is found at a depth of 280.9–335.0 m in the Lesnoye-50 borehole (Fig. 8).

Throughout the Lithuanian–Polish Basin the Skinija Formation consists of clays, silt and siltstones. In the lower part of the formation the sequence is composed of greyish and brownish clays, whereas the upper part is characterized by dark grey to blackish clays, occasionally rich in *Astarte* shells. The most complete sections of the Skinija Formation have been found in the Žemaitija and Nivensk Depressions.

Foraminiferal studies by Grigelis (1985b) indicate that the Skinija Formation should be referred to the Upper Callovian, in terms of foraminiferal zones to the *Lenticulina*

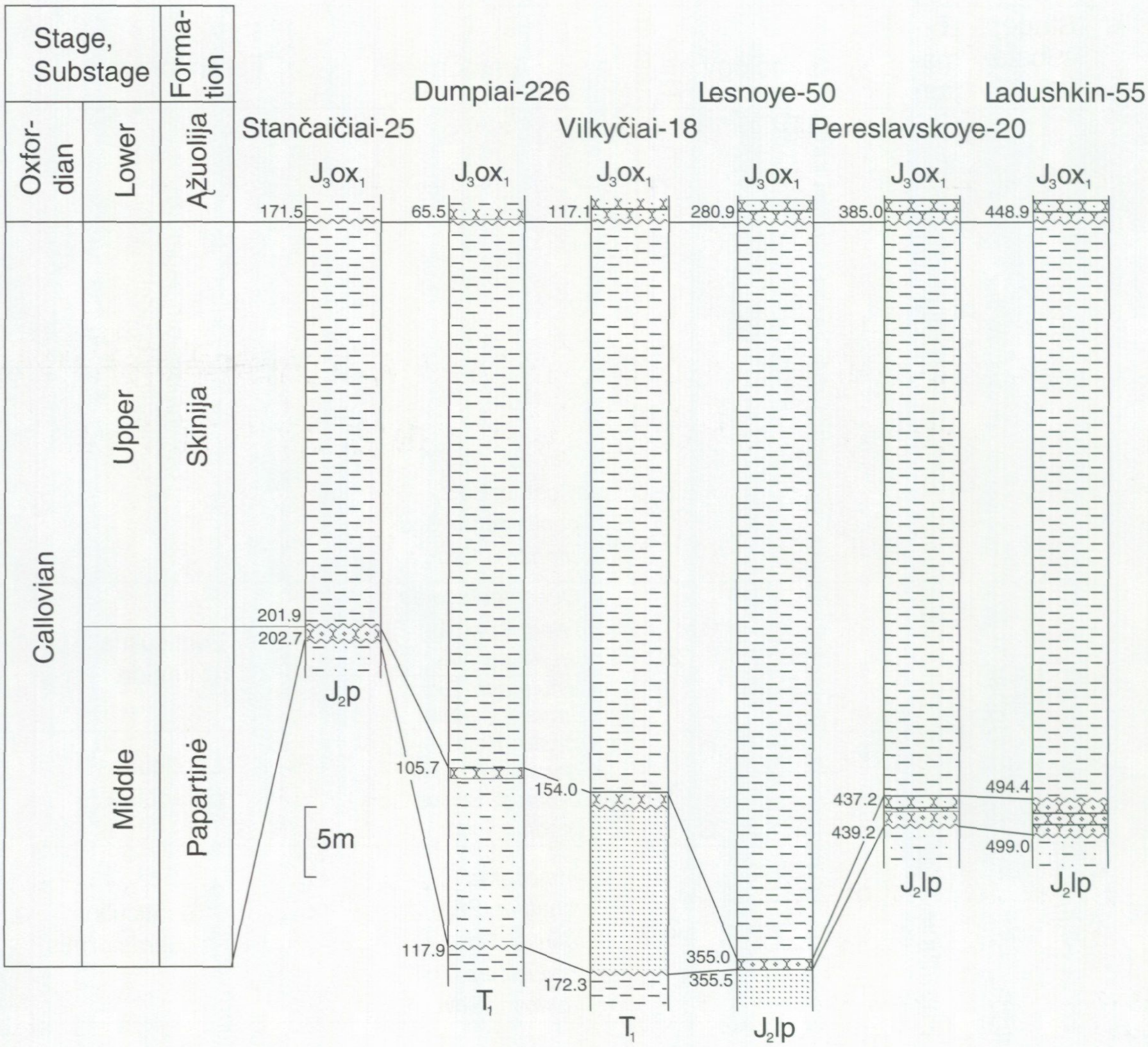

Fig. 8. Correlation of borehole sections in the Skinija Formation, Upper Callovian, Lithuania, including the Vilkyčiai-18 stratotype, and the Lesnoye-50 parastratotype sections. Legend to lithology is given in Fig. 6b.

paracultrata and *Lenticulina tumida* Zones (p. 41). Ammonites are rare. Rotkytė (1987) has recorded *Quenstedtoceras lamberti, Q. carinatum,* and *Q. leachi* in the upper part (Bed S1) of the Papilė outcrop No. 2 (to be found in the Jurakalnis gorge). In the Vilkyčiai-18 and Žadeikiai-27 wells (Figs. 8, 9) ammonites characteristic of the *Quenstedtoceras lamberti* Zone, including *Quenstedtoceras henryci,* have been obtained (Table 1, Fig. 3). The lower boundary of the Skinija Formation is diachronous, as mentioned before. At several sites the upper boundary is marked by a break in the sedimentation. Above this, oolitic sandstones of the Ąžuolija Formation follow. In the Papilė area the thickness of the Skinija Formation is about 2 m. In SW Lithuania, however, the formation may reach a thickness of about 55 m. In local structures of Central Lithuania and in the Suvalkai area of SW Lithuania, the Skinija Formation is missing. Here, the Ąžuolija Formation rests directly upon the Papartinė Formation.

Upper Jurassic

Ąžuolija Formation (Oxfordian)

The Ąžuolija village in western Lithuania (Fig. 3, p. 11) has given its name to this formation. A cored sequence in the Ladushkin-55 (Liudvigsortas) borehole in the Kaliningrad Enclave has been chosen as type stratum, whereas the parastratotype is defined in the Ąžuolija-20 borehole (Fig. 9). In the Ladushkin-55 stratotype, 369.8–448.9 m interval of drilling (Fig. 9), the Ąžuolija Formation overlies the Skinija Formation, which in turn is overlain by the Tarava Formation. Between the first two formations, a distinct break in the sedimentation has been observed. The stratotype, which is complete without stratigraphical gaps, is composed of clayey and marly, fairly homogenous deposits. At the base of the stratotype, an oolitic clayey sandstone occurs, 0.9 m thick. In general, the lower part of the stratotype consists of detritic, clayey limestones, 25 m , with abundant spongian spic-

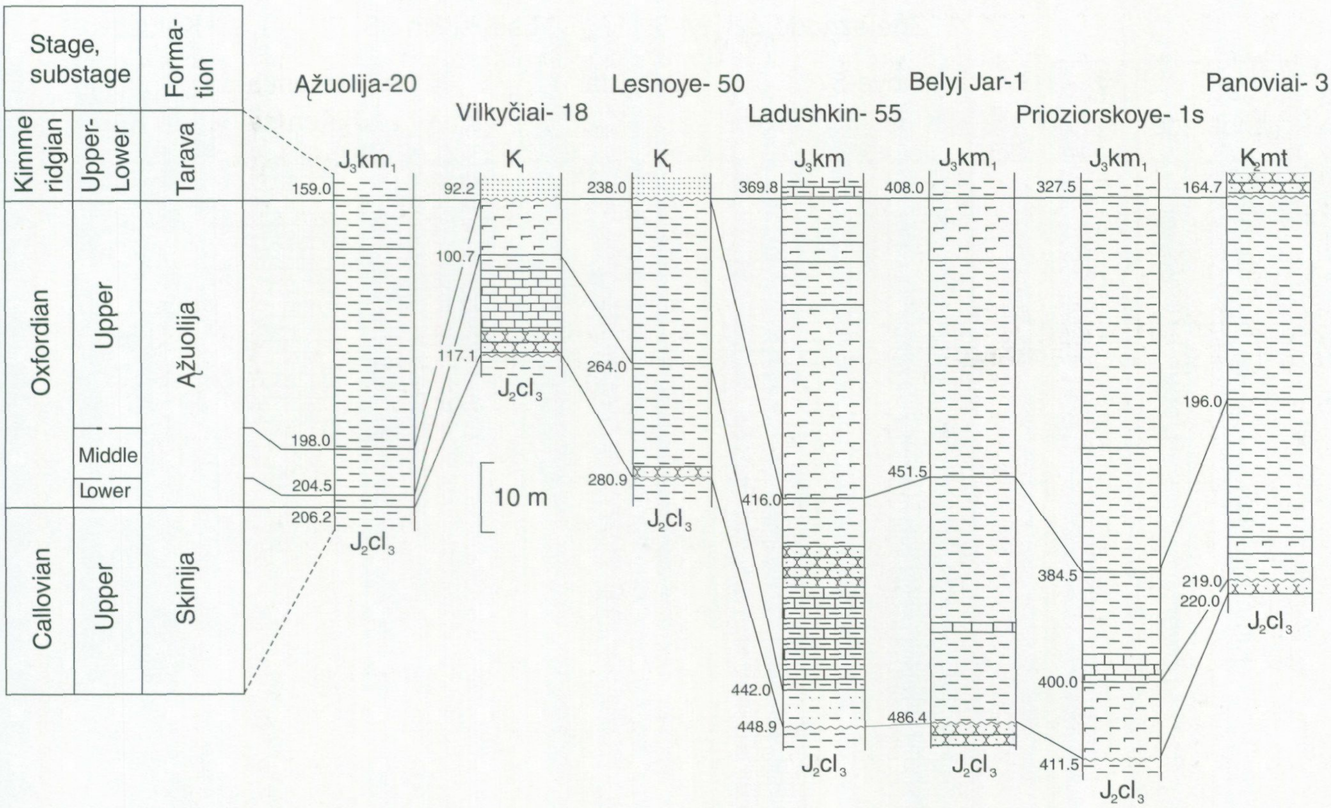

Fig. 9. Correlation of borehole sections in the Oxfordian Ąžuolija Formation of Lithuania, including the Ladushkin-55 stratotype, and the Ąžuolija parastratotype sections. Lithology legend is given in Fig. 6b.

ulae, whereas the upper part (47 m thick) is composed of interbedded marls and silt. In the parastratotype, 159.0–206.2 m in Ąžuolija-20, silty sediments are prevailing. In the Baltic Basin the Ąžuolija Formation, represented by grey micaceous, carbonaceous silt, clay and marl, has a more restricted distribution than the Skinija Formation. In some borehole sequences, viz. in Vilkyčiai-18, Simnas-3, and Kalvarija-2 (Fig. 3), carbonaceous detritic marls and limestones are found in 5 to 8 m thick bioherms. Foraminiferal data indicate a Middle Oxfordian age of the reef-like structures (Grigelis 1985b).

In the outcrops of the Lower Oxfordian in Lithuania ammonites are rare. From the Papilė-2 and Papilė-3 exposures *Vertumniceras mariae* and *Cardioceras laevigatum* have been recorded. Among Middle Oxfordian ammonites obtained from borehole sections *Cardioceras zenaidae, Cardioceras tenuistriatum* and non-specified forms of the "*tenuiserratum* group" may be mentioned. Upper Oxfordian ammonites, found along with foraminifers characterising the *Lenticulina quenstedti* Zone, belong to genus *Amoeboceras*. In the Ąžuolija-20 type section *Amoeboceras leucum* (found at a depth of 181.5 m), *Amoeboceras rosenkrantzi* (169.4 m), and some unidentified species of *Amoeboceras* have been found (Figs. 3, 9).

Foraminiferal, as well as ammonite finds, indicate an Oxfordian age of the Ąžuolija Formation. It seems as if the formation more or less corresponds to the entire Oxfordian Stage and the ammonite fauna has justified the following biostratigraphical subdivision (Rotkytė 1987, Grigelis 1985b):

Substages	**Ammonite zones**	**Foraminiferal zones**
Upper Oxfordian	*Amoeboceras rosenkrantzi* *A. regulare* *A. serratum* *A. glosense*	*Lenticulina quenstedti*
Middle Oxfordian	*Cardioceras densiplicatum*	*Ophthalmidium strumosum – Lenticulina brestica*
Lower Oxfordian	*Vertumniceras mariae* *Cardioceras cordatum*	*Ophthalmidium sagittum – Lenticulina brueckmanni*

As commented on before, the lower boundary of the Ąžuolija Formation is characterized by the shift from black clays of the Skinija Formation to the basal oolitic sandstone followed by grey, marly clays. The upper boundary of the

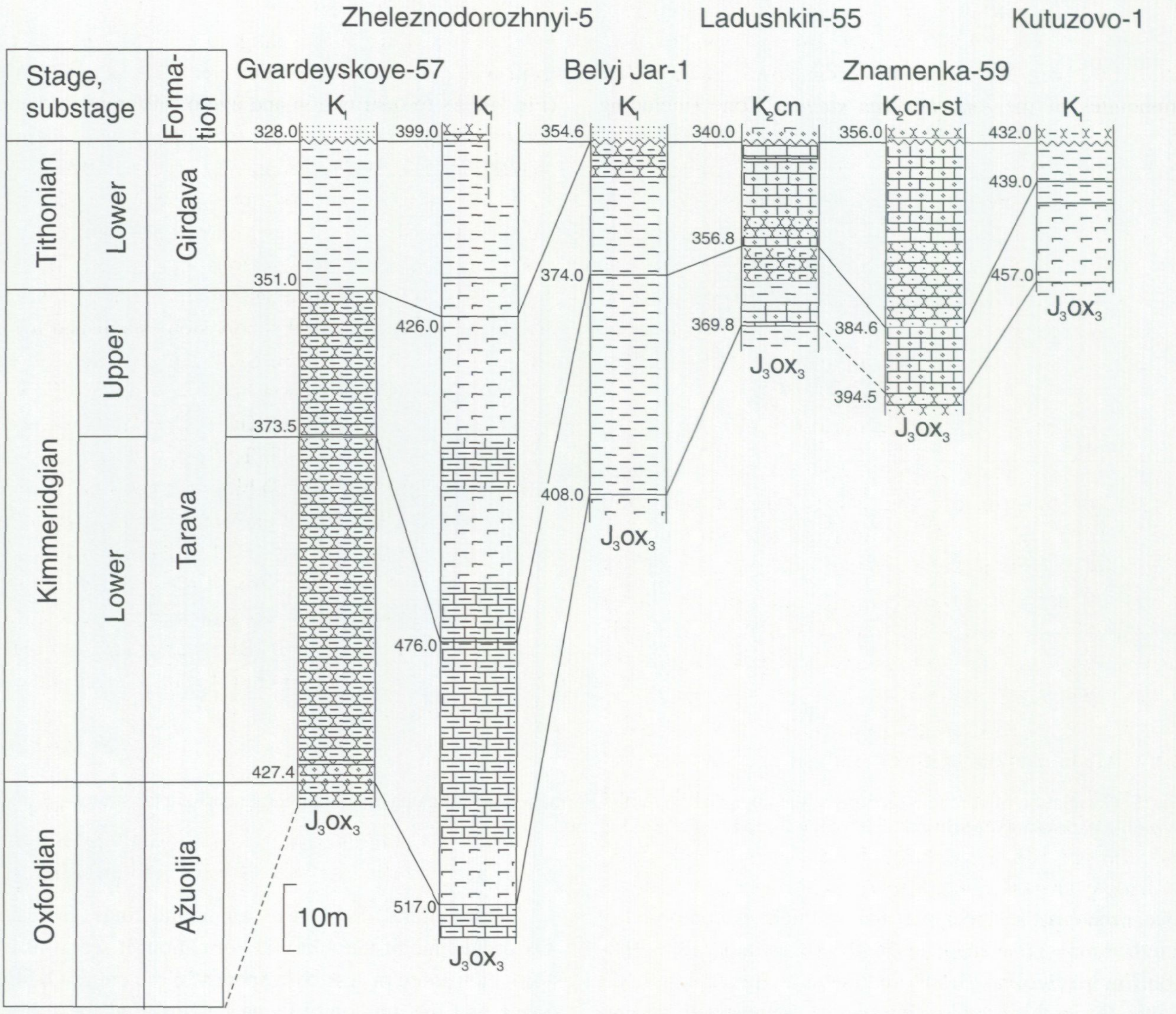

Fig. 10. Correlation of borehole sections from the Kimmeridgian Tarava Formation and the Lower Tithonian Girdava Formation, including the Gvardeyskoye-57 stratotype section (See Fig. 3). Lithology legend is given in Fig. 6b.

Ąžuolija Formation is less distinct; the grey, marly clays gradually turn into siltstones of the Tarava Formation.

The Ąžuolija Formation is the result of one of the most comprehensive marine transgressions into the Baltic Basin during the Jurassic. The thickness of the formation may reach 85 m. A detailed biostratigraphical subdivision of the Oxfordian in Lithuania, based on foraminifers, is given in p.41 (Grigelis 1985b).

Tarava Formation (Kimmeridgian)

As stratotype of the Tarava Formation the 351.0–427.4 m interval in the Gvardeiskoye-57 (Miulhauzenas) borehole has been chosen (Fig. 10). The name of the formation originates from the little town of Tarava (Vladimirov), which is situated in the ancient Notanga Land not far away from the Miulhauzenas village in the western part of the Kaliningrad Enclave (Šilas & Sambora 1990, Pėteraitis 1992, and Fig. 3 herein).

At its stratotype section, the Tarava Formation is composed of grey siltstones and claystones with interbeds of dark grey clay. It rests on the Ąžuolija Formation and is overlain by the Girdava Formation. The boundary between the siltstones of the Tarava Formation and the marls of the Ąžuolija Formation is gradual. The upper boundary of the Tarava Formation to the Girdava Formation is characterized by a transition from sandy siltstone to clayey silt. In some other sections of the Tarava Formation clayey sandstones, marls and biogenic limestones with spongian spiculae have also been found (Grigelis 1985b).

Foraminiferal and ammonite faunas of the Tarava Formation indicate a Kimmeridgian age (Grigelis 1985b, Rotkytė 1987). The foraminiferal zonation by Grigelis is presented on p. 43. A subdivision into substages and biozones has been made. Strata which have yielded a few ammonites of the *Amoeboceras kitchini* Zone (including *Rasenia evoluta, Amoeboceras kitchini and Rasenia* cf. *lepidula)* have been given an Early Kimmeridgian age (Table 1). From borehole sections the following Upper Kimmeridgian ammonites have been recorded: *Aulacostephanus* cf. *moeshi, A.* aff. *eudoxus, A. eulepidus* and *Amoeboceras* cf. *anglicum.* This Late Kimmeridgian ammonite fauna indicates the presence of the *Aulacostephanus mutabilis, A. eudoxus,* and *A. autissiodorensis* Zones (see Table 1, p. 10).

Girdava Formation (Lower Tithonian)

The stratotype section of the Girdava Formation has been chosen from the same borehole as for the Tarava Formation, at 328–351 m (Fig. 10). The Girdava Formation forms the uppermost part of the Jurassic succession in the East Baltic region. Its name is given after a little town, Girdava (at present officially named Zheleznodorozhniy), located in the ancient Barta Land in the southern part of the Kaliningrad Enclave (Šilas & Sambora 1990, Fig. 3 herein). The stratotype consists of 23 m of grey marl, clay and silt overlying the Tarava Formation. In its type section the upper boundary of the formation is erosional. With a great stratigraphical gap the Girdava Formation is overlain by greenish glauconitic sand of Albian age, belonging to the Jiesia Formation, indicating that the major part of the Lower Cretaceous is missing (Grigelis 1958b).

Based on foraminiferal analysis, e.g. by finds of *Marginulina striatocostata,* Grigelis (1985b) referred the Girdava Formation to the Lower Volgian. According to Rotkytė (1987) ammonites are rare in this formation. Species to be mentioned are *Pectinatites boidini* and *Pavlovia hypophantica,* indicating Early and Middle Volgian ages. According to the Jurassic chronostratigraphy, the Lower and Middle Volgian, being parts of the regional Volgian Stage of the East European Platform, may be equivalent to the Lower Tithonian. Consequently, the Girdava Formation can be referred to the latter substage (Grigelis & Suveizdis 1993).

SOUTH-EASTERN PART OF THE BALTIC SEA

In the south-eastern and southern parts of the Baltic Sea Mesozoic deposits are widely distributed (Figs. 2, 4, 5, 11). In this area they are affected by tectonic movements along the NW slope of the Lithuanian–Polish Syneclise, the formation of which started in Late Permian time. From the east towards the west in the SE part of the Baltic Sea, Mesozoic deposits cover Silurian, Devonian and Permian rocks discordantly (Grigelis 1991a, 1995).

In this area Jurassic stratigraphy is based on records from deep petroleum exploration wells drilled in 1980–1984 (Fig. 4). As to distribution and age of different formations, additional data were received from dredging and shallow well drilling in the Kuršių Marios Lagoon and offshore from Zelenogradsk (Krantz) during the years 1978 to 1985. The results achieved from offshore operations, including lithological analyses and foraminiferal studies, have been compared with corresponding data from mainland Lithuania. In this way the stratigraphical subdivision established for land areas was transferred to the SE Baltic Sea area (Grigelis 1991a). In the SE Baltic area Jurassic rocks are distributed within a narrow belt from Klaipėda south-westwards to Leba in Poland (Figs. 1, 4). The Jurassic is known from boreholes within the C and D blocks marked in Fig. 4. The presence of Lower, Middle and Upper Jurassic deposits is recorded. Up to the top of the Bathonian the sequence consists of continental deposits. From Callovian time to the end of the Jurassic marine conditions prevailed. The total thickness of the Jurassic in the SE Baltic area increases towards the southwest from about 64 m (D5-borehole) to more than 200 m (C9-borehole) (Fig. 4).

The Jurassic sedimentary rocks rest directly upon Lower Triassic reddish clays and siltstones and are succeeded by greenish glauconitic sand of the Lower Cretaceous. The foraminiferal biostratigraphy (p. 38) is based on analysis of drill cuttings. Lithologs have also been used for lithostratigraphical purposes.

Lower Jurassic

Rocks of Hettangian, Sinemurian and Early Pliensbachian ages have not been recorded from the offshore well material studied. The Upper Pliensbachian (Neringa Formation) and Toarcian strata (Lava Formation) consists of continental sand, sandstones and clays together referred to the Jotvingiai Group (p. 8). In the South Baltic (C8-borehole) the Neringa Formation has a thickness of some 15 m, whereas the Lava Formation measures 31 m (Figs. 4, 11).

Middle Jurassic

No Aalenian deposits have been recorded in borehole material studied. Bajocian, Bathonian and Lower Callovian strata, referred to the continental Skalviai Group, have been found in borehole samples from the C Block (Figs. 4, 11). No thorough dating of the Middle Jurassic Skalviai Group has yet been carried out. In the C8- and C9-boreholes the Skalviai Group is represented by clays and siltstones with interbeds of sand. In nearby land areas of Lithuania this group is subdivided into three lithostratigraphical units, viz.

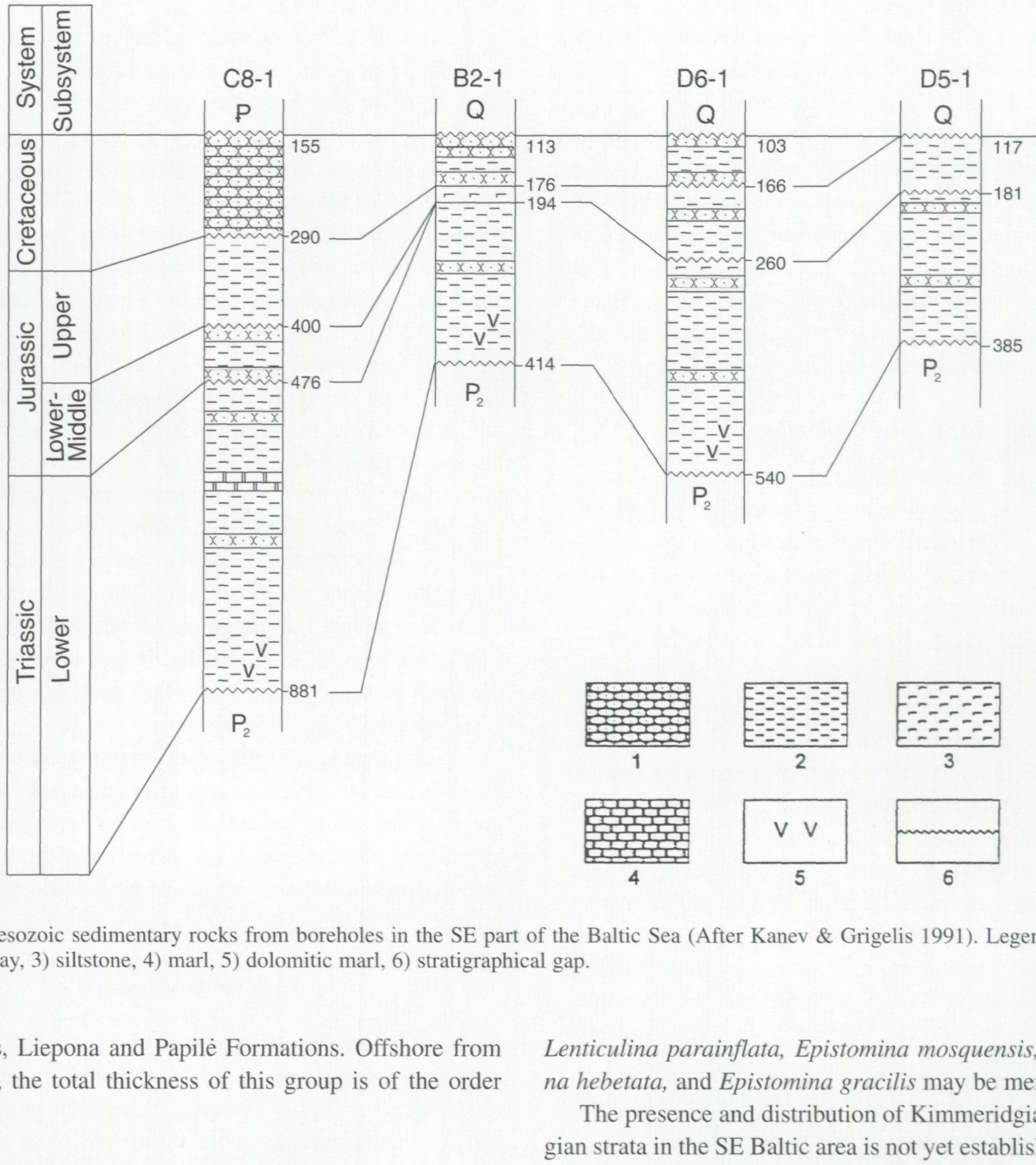

Fig. 11. Mesozoic sedimentary rocks from boreholes in the SE part of the Baltic Sea (After Kanev & Grigelis 1991). Legend: 1) sandstone, 2) clay, 3) siltstone, 4) marl, 5) dolomitic marl, 6) stratigraphical gap.

the Įsrutis, Liepona and Papilė Formations. Offshore from Lithuania, the total thickness of this group is of the order 50 m.

Middle and Upper Jurassic

From the Middle Callovian upwards in the Jurassic succession, the deposits are of marine origin. In the SE Baltic area the Callovian and Oxfordian Stages only have been identified. In the Gdańsk Basin deposits of these stages form the rock surface. They include sandstones, siltstones, clays, marls and limestones. Callovian strata may reach a thickness of 51 m, whereas Oxfordian deposits have been estimated to 85 m (C9-borehole).

From the Middle and Upper Jurassic the following lithostratigraphical units have been recognized: Papartinė Formation (Middle to Upper Callovian), Skinija Formation (Upper Callovian), and Ąžuolija Formation (Oxfordian), all known and well defined from mainland Lithuania (p. 13). As characteristic foraminifers of these offshore deposits *Lenticulina parainflata, Epistomina mosquensis, Lenticulina hebetata,* and *Epistomina gracilis* may be mentioned.

The presence and distribution of Kimmeridgian and Volgian strata in the SE Baltic area is not yet established. Rocks of these ages are found in borehole sections in onshore areas of SW Lithuania and the Kaliningrad region.

In the following, some information will be given from two offshore wells from the SE part of the Baltic Sea:

D6-3 Borehole (Figs. 4, 11)
Location: 55°19' N, 20°36' E

The 169–266 m interval (below sea level), penetrating Callovian and Oxfordian strata (undivided), shows dark grey clay with intercalations of limestones and sandstones. At the base of this sequence greenish grey marls occur, probably to be assigned to the Papartinė Formation. In this section foraminifers are rather common. Species recorded, such as *Lenticulina brestica, Epistomina gracilis, Lenticulina parainflata* and *Epistomina mosquensis* indicate Middle Callovian to Oxfordian ages.

TABLE 2. Foraminiferal species recorded from the Callovian and Oxfordian of the C8-1/82 borehole, SE Baltic Sea. For borehole location see Fig. 4.

Species	Upper Callovian				Lower Oxfordian					Ox-ford.
	Depth of samples, m									
	400	395	390	380	375	370	360	350	340	300
Epistomina porcellanea	o									
Citharinella schellwieni	•									
Ichthyolaria suprajurensis	•									
Lenticulina papillaecostata	•									
Trocholina klaipedica	•	•								
Epistomina elschankaensis	o	•								
Astacolus limataeformis	•		•							
Planularia limataeformis	•		•							
Pseudolamarckina rjasanensis	x		o							
Citharinella nikitini				•						
Lenticulina involvens		•	•							
Lenticulina uhligi				•		•	•	•		
Epistomina mosquensis	x	o	x	x						
Epistomina planiconvexa	xx	x	xx	x	o	o				
Marginulinopsis erucaeformis				•						
Lenticulina hoplites				•						
Lenticulina chmielewskii				•						
Lenticulina tumida	o		•	o	•	•				
Lenticulina polonica					•					
Epistomina nemunensis					o					
Lenticulina brueckmanni							•			
Epistomina volgensis							o			
Paulina furssenkoi							•			
Marginulinopsis folium							o	•		
Epistomina intermedia						x	xx	x		
Trocholina trasversarii							o	o	x	
Epistomina stelligeraeformis						o		•	o	
Epistomina gracilis					x	x	x		o	
Epistomina rjasanensis					x	x	x	x	x	
Epistomina uhligi						o	x		xx	
Astacolus dubius								•	•	
Citharina chanika									•	
Lenticulina hebetata					•	•	o	•	•	
Epistomina parastelligera							o		•	•
Lenticulina sp.										•

Number of specimens: •1-2, o 3-5, x 6-10, xx 10-30 shells.

C8-1 Borehole (Fig. 11, Table 2)
Location: 54°46' N, 19°43' E

The 290–375 m interval (b.s.l.), including dark grey marls, silty clays and siltstones, has been referred to the Oxfordian based on foraminifers. Species to be mentioned are: *Lenticulina hebetata, Epistomina rjasanensis, Epistomina gracilis and Trocholina transversarii.* The 375–400 m interval includes dark grey and grey calcareous clays. The fairly rich foraminiferal fauna includes species such as *Lenticulina tumida, L. polonica, Planularia deeckei, Epistomina mosquensis* and *E. planiconvexa* indicating Middle to Late Callovian ages.

Deeper intervals of the C8-1 borehole, i.e. 400–476 m, contain non-marine strata referred to the Lower and Middle Jurassic. Due to the lack of diagnostic fossils, no exact dating has been possible. The non-marine Middle Jurassic in the SE Baltic offshore areas is represented by dark, grey sandstones poor in calcareous content. They are referred to the Liepona Formation (Upper Bathonian), which is resting on top of Lower Jurassic strata (Toarcian), the latter being represented of kaolinized sandstones of the Lava Formation.

Jurassic geology and stratigraphy of Scania

After deposition of mainly continental to deltaic sediments in Late Triassic to Hettangian times, several marine transgressions invaded Scania during the Early Jurassic. Jurassic deposits cover the major part of western Scania and adjacent offshore areas. Minor faultbounded basins and small isolated inliers in central and north Scania indicate that the distribution of Jurassic deposits prior to denudation periods, was much wider and more continuous in the past than today (Fig. 12). Usually, Jurassic rocks rest upon Upper Triassic (Rhaetian) deposits. There are exceptions, however, mainly linked to tectonic (Kimmerian) activities during the Jurassic. In some parts of the Vomb Trough for instance (Fig. 12), Middle Jurassic strata rest directly on the Proterozoic crystalline basement. In other parts of Scania there may be major gaps within the Jurassic succession. In certain part of the Ängelholm Basin (Fig. 12. See also Guy-Ohlson & Norling 1988), the Upper Jurassic (Oxfordian) is overlying Pliensbachian strata. Many varieties of the stratigraphical representation could be exemplified. Even if the major part of Scania once was covered by Jurassic sediments, marine as well as non-marine, there were also land areas subjected to denudation, viz. landscapes characterized by freshwater sloughs, forests and, in Central Scania, high volcanic necks. As in the North Sea Graben System, Central Scania was subjected to volcanism from the Toarcian/Aalenian, the Middle Jurassic and onwards during the Jurassic period (Fig. 12 herein, Norling et al. 1993). In Central Scania more than 70 Mesozoic basaltic necks have been recorded (Bergström 1981). According to Klingspor (1976) most of the K-Ar datings of volcanic basalts group around 167 Ma and 108 Ma. Recent palaeomagnetic datings, however, have yielded older, Toarcian–Aalenian ages (Bylund & Halvorsen 1993).

Nowhere in Scania complete sections of the entire Jurassic can be studied in exposures. In outcrops the Lower Jurassic can best be studied in NW Scania, along the coast of Öresund, in quarries of the coal and clay mining district and in some road ditches, where the soil cover is thin or absent. At one outcrop only, the Eriksdal Sand and Clay Pit of south central Scania (Fig. 17), Middle and Upper Jurassic strata are visible. This is the most comprehensive section of the Swedish Jurassic, exposing Pliensbachian, Toarcian, Bajocian, Bathonian and Kimmeridgian strata (Erlström et al. 1991, Norling et al. 1993). From many boreholes, however, more or less complete Jurassic successions have been recorded.

Lower Jurassic

A fairly complete Lower Jurassic sequence occurs in Scania, which is referred to the Hettangian, Sinemurian, Pliensbachian and the Toarcian Stages with the aid of palynostratigraphy, ammonite, foraminiferal and ostracodal biostratigraphical datings and zonation (Fig. 14, p.26).

Höganäs Formation (Rhaetian – Hettangian)

The Höganäs Formation, subdivided into three members, is a unit some 250 m in thickness, spanning the Triassic–Jurassic boundary in W and NW Scania. It was originally described as the Höganäs Series by Troedsson (1947, 1951). For information on Lower Jurassic local stratotypes in Sweden see Sivhed (1984). Based on plant macrofossils and palynomorphs the formation has been dated to Rhaetian–Hettangian. The Rhaetian part of the Höganäs Formation, represented by the Vallåkra and Bjuv Members, has been assigned to the *Rhaetopollis – Limbosporites* Zone by Lund (1977) and Guy-Ohlson (1981).

Vallåkra Member (Rhaetian). The basal member of the Höganäs Formation, the Vallåkra Member, is regarded as forming a transition between the continental Kågeröd Formation (Norian?) and the deltaic, coal-bearing deposits of the Bjuv Member (Sivhed 1984). The Vallåkra Member includes grey and variegated clays with sphaerosiderite and greenish sandstone lenses. In the Helsingborg area (Fig. 12), the thickness of this member is estimated to about 30 m, according to records from boreholes (Erdmann 1915, Troedsson 1947, Sivhed & Wikman 1986). The clays of the Vallåkra Member have been used for facade bricks, drainpipes etc. (Norling et al. 1993).

Bjuv Member (Rhaetian). The following unit, the Bjuv Member, may be defined as the sedimentary sequence between and including the two main coal-seams of the Rhaetian. The lower seam (B-seam) forms the boundary to the Vallåkra Member. The upper seam (A-seam) has been chosen to mark the boundary to the Helsingborg Member and thus the lithostratigraphical boundary between the Triassic and the Jurassic (Fig. 13). The Rhaetian coal and fireclays have been mined for centuries in NW Scania, on a scale of national economic interest for more than 200 years. Though still mined in a few quarries, coal and clay exploitation is only of minor importance today. Between the two main coal-seams (in some areas split up into several seams), the Bjuv Member is represented by sandstones, siltstones, clay and claystones, characterized as palaeosols with underclays and autochthonous coal-seams followed by lenticularly bedded mudstone, sometimes rich in ripple marks and trace fossils, beds upwards grading into flaser bedded sandstones (Ahlberg 1994). Its thickness may be up to 25 m.

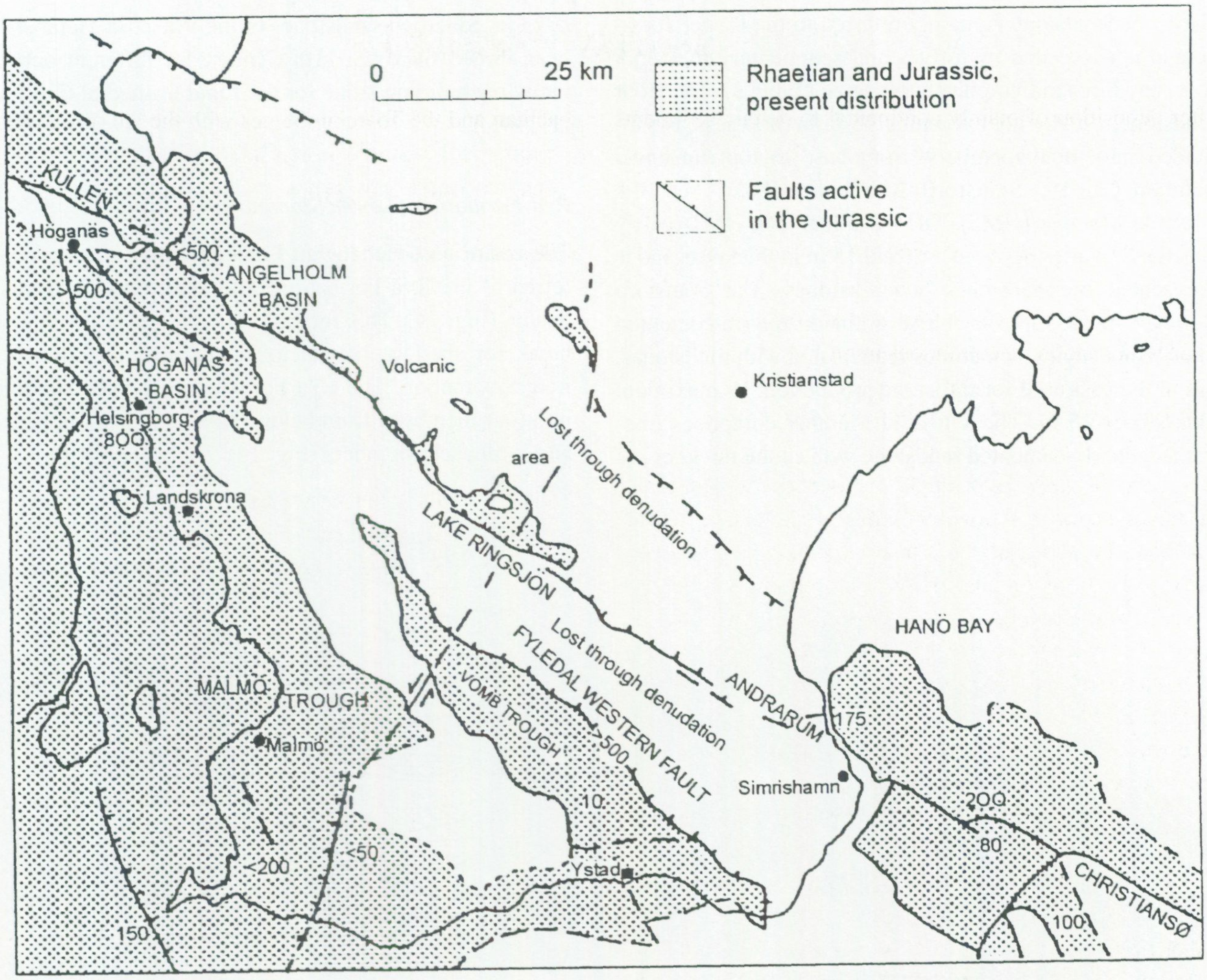

Fig. 12. Present distribution of Rhaetian and Jurassic rocks in Scania with adjacent areas together with faults. The volcanic activity (more than 70 basalt necks have been found in Central Scania), is dated as Jurassic and Crecaceous (after Bergström 1981, Norling and Bergström 1987).

Helsingborg Member (Hettangian). The Hettangian part of the Höganäs Formation is called the Helsingborg Member. It has a known thickness of 215 m and has been described by Troedsson (1947, 1951) among others. A brief presentation was given by Sivhed (1984), whereas Ahlberg (1994) and Pieńkowski (1991) presented sedimentological studies of this unit. Detailed descriptions from four localities are given by Ahlberg in Norling et al. (1993).

Lund (1977) established the *Pinuspollenites-Trachysporites* palynomorph assemblage zone for the Hettangian in Scania (Fig. 14). Finds of foraminifers in Hettangian strata (Helsingborg Member) are restricted to one locality only, the Välluf Viaduct Exposure (Norling 1972), some 7 km SSE of Helsingborg centre (Fig. 12). The faunal assemblage includes species such as *Ammodiscus asper* (Liassic), *Astacolus semireticulata* (Hettangian–L.Sinemurian), *Astacolus* ex gr. *varians* (Jurassic), *Marginulina lamellosa* (Hettangian–Pliensbachian), *Mesodentalina tenuistriata* (Hettangian–L. Toarcian), *Reophax horridus* (Rhaetian–Jurassic), and another five species previously described from Rhaetian strata only. Those species are: *Ichthyolaria intercostata, Pseudonodosaria holocostata, P. plumiricostata, Reophax eominutus,* and *Tetrataxis enflata*, all with Kristan-Tollmann (1957, 1964) as the author. The foraminiferal assemblage with Rhaetian and post-Rhaetian forms together may indicate presence of reworked Rhaetian microfossils in Hettangian strata, or that the microfauna recorded by Kristan-Tollmann in Rhaetian strata in fact has a Rhaetian–Hettangian range. The Hettangian age of the Helsingborg Member is based on palynomorphs, plant fossils and bivalves (Norling 1972).

Höör Sandstone Formation (Rhaetian? – Hettangian)

In Central Scania, Lower Jurassic (perhaps also Rhaetian) strata rest directly upon the weathered crystalline basement.

The Höör Sandstone is mainly referred to the Lower Jurassic and is succeeded by tuffites and sedimentary rocks not given any lithostratigraphical unit name (Table 3). The Höör Sandstone, usually not exceeding 55 m in thickness, is subdivided into three members, from base to top: unnamed member (HM1), Stanstorp Member (HM2), and the Vittseröd Member (HM3). The basal member, HM1 (partly Rhaetian?), varies between 1 m and 15 m in thickness and is represented by mudstones and siltstones. The Stanstorp Member, made up of coarse-grained, quartz-cemented arkosic sandstones, sometimes intercalated with mudstones, was in the past used for millstone production. Its maximum thickness is 15 m. The Vittseröd Member comprises fine-grained, quartz-cemented sandstone with a total thickness of c. 25 m. Silicified sandstones of the Vittseröd Member have been mined since the 11th Century for different purposes, including building stone for the Lund Cathedral (Norling et al. 1993).

Rya Formation (Lower Sinemurian – Toarcian)

The entire post-Hettangian Lower Jurassic sequence is referred to the Rya Formation in western and north-western Scania (Fig. 14). This formation is marine, but with a short break for shallow, littoral to deltaic sedimentation in the Late Sinemurian. The Rya Formation has been subdivided into four members, from below: Döshult, Pankarp, Katslösa and Rydebäck Members (Fig. 14).

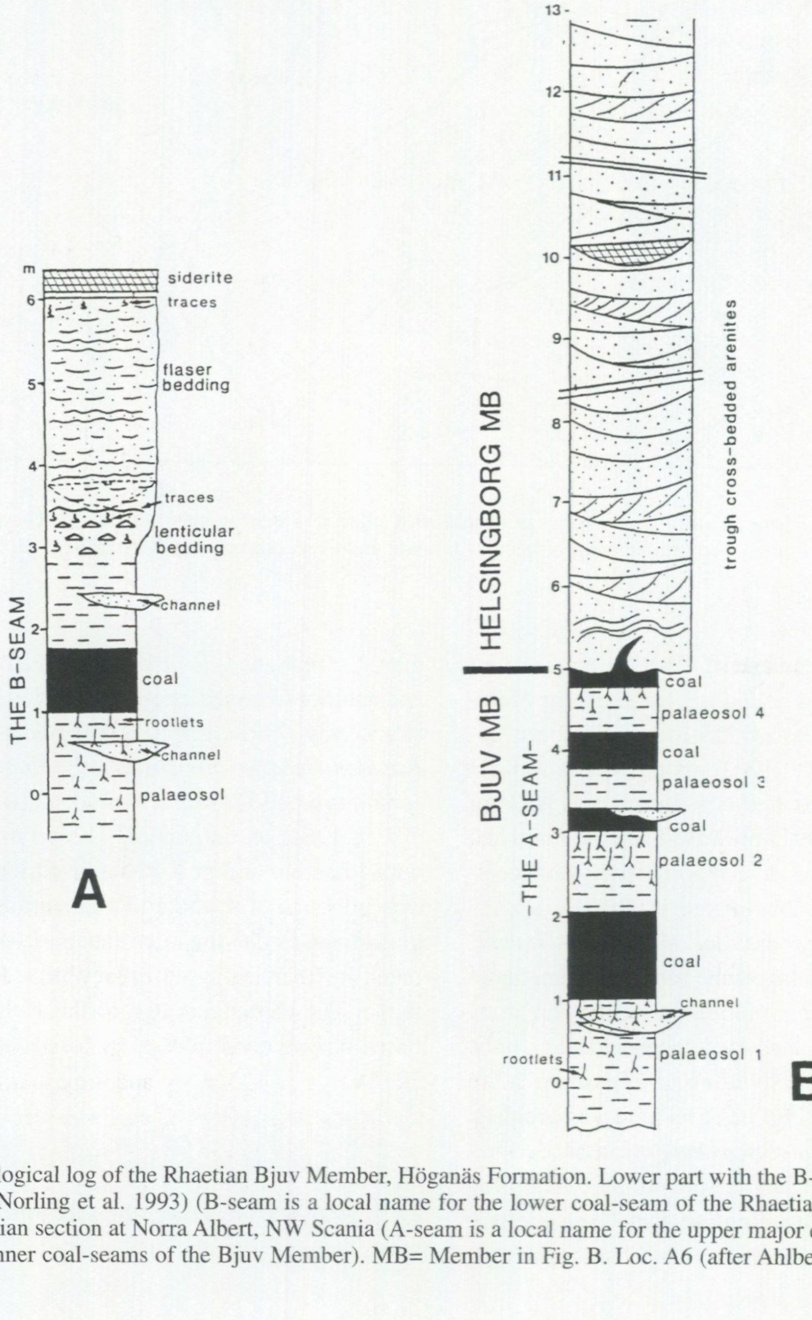

Fig. 13. A) Sedimentological log of the Rhaetian Bjuv Member, Höganäs Formation. Lower part with the B-seam, Rhaetian. Lunnom, Loc. A5 (After Ahlberg in Norling et al. 1993) (B-seam is a local name for the lower coal-seam of the Rhaetian). B) Sedimentological log of the Rhaetian - Hettangian section at Norra Albert, NW Scania (A-seam is a local name for the upper major coal-seam or, at some localities the upper series of thinner coal-seams of the Bjuv Member). MB= Member in Fig. B. Loc. A6 (after Ahlberg in Norling et al. 1993).

Table 3. Rhaeto-Liassic stratigraphy of Central Scania (after Sivhed *in* Norling et al. 1993).

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY	
		Formation	Member
JURASSIC	Sinemurian Hettangian	Höör Sandstone	Vittseröd (HM_3) Stanstorp (HM_2)
TRIASSIC	Rhaetian Norian		Unnamed (HM_1) member

Döshult Member (Lower Sinemurian). The Döshult Member represents the first major marine transgression in W and NW Scania and is referred to the Early Sinemurian, an age indicated by ammonites as well as foraminifers and ostracods. The member is characterized by coarse-grained, cross-bedded sandstones in the lower part and clays and marls in the upper part. A lateral change from coastal sandstones to sublittoral, more argillaceous, marly sediments is also observed. The type locality for the lower part of the member, named the Döshult sandstone, is an old sandstone quarry in the Höganäs Basin of NW Scania, some 4 km ESE of Viken church (Fig. 14.). The sandstone is devoid of fossils of any use in biostratigraphy. The marls, however, are rich in marine biota such as bivalves, ammonites, foraminifers and ostracods. Belemnites have also been recorded. Among the ammonites *Arietites bucklandi* and *Arnioceras semicostatum* may be mentioned. The fauna as the whole in the Döshult Marl Pit, near the type locality, indicates that the Döshult Member should be referred to the upper subzone of the *Arietites bucklandi* Zone and to the *Arnioceras semicostatum* Zone (Reyment 1959, Norling et al. 1993). As to the foraminiferal assemblages and zonation see p. 46 and Figs. 14, 27.

Pankarp Member (Upper Sinemurian). The Döshult Member is overlain by the Pankarp Member (Upper Sinemurian). Today this member is accessible in one locality only, the Gantofta Brick Pit some 9 km SE of Helsingborg centre (Figs. 12, 14, 15). A complete sequence of the Pankarp Member, known from boreholes, has a thickness of 60–75 m. The member has a threefold division into a lower part of variegated clays and shales, a middle, thin part of sand and sandstone with a rootlet bed, or a coal-seam, and an upper part of variegated clays and shales. With the aid of ammonites, foraminifers and ostracods the Pankarp Member is dated to the Late Sinemurian (Reyment 1959, 1969; Norling 1972; Sivhed 1980; Norling et al. 1993). At Gantofta the ammonite fauna indicates the presence of the *Asteroceras obtusum* Zone (on the Döshult Member/ Pankarp Member transition). In borehole material ammonite indications of the *Oxynoticeras oxynotum* Zone too have been recorded (Figs. 14, 15 B).

Katslösa Member (U. Sinemurian – L. Pliensbachian). The Katslösa Member consists of 30–40 m of greenish, brownish and dark grey claystones, siltstones and sandstones with a varying content of iron and carbonate. Thin beds of limestones and ferruginous oolites do also occur (Troedsson 1951, Norling 1972, Sivhed 1980). The ammonite fauna obtained, mainly from drill cores, indicates the presence of the *Uptonia jamesoni* and *Protodactyloceras davoei* Zones, which does not mean that the interjacent *Tragophylloceras ibex* Zone is missing (Hoffmann in Bölau 1959, Reyment 1959, 1969, Norling et al. 1993).

The ammonite and foraminiferal zonation of the Lower Jurassic of Sweden is illustrated in Fig. 14 (See also Figs. 27, 28). From the Pliensbachian throughout the Jurassic a palynomorph zonation has been established by Guy-Ohlson (1981, 1986, 1989, 1990) and Guy-Ohlson & Norling (1994), which especially has been of importance for the biostratigraphy of sedimentary intervals devoid of marine biota such as ammonites and foraminifers. For marine intervals the palynostratigraphy has confirmed the stratigraphy based on other organisms, and in general improved the relative datings of the Swedish Jurassic units.

Rydebäck Member (U. Pliensbachian – Aalenian). The uppermost part of the Rya Formation is referred to the Rydebäck Member, which spans across the Upper Pliensbachian, Toarcian and the Aalenian in part, according to biostratigraphical dating. The member, varying in thickness between 50 m and 100 m, is known from boreholes only. The unit includes sandy and silty, partly oolitic sediments with a varying content of clay and calcium carbonate. Intervals of variegated rocks occur, mainly with reddish, greenish and red-spotted blackish colours. The Upper Pliensbachian *Amaltheus margaritatus, Pleuroceras spinatum* and *Dactylioceras tenuicostatum* ammonite zones have been es-

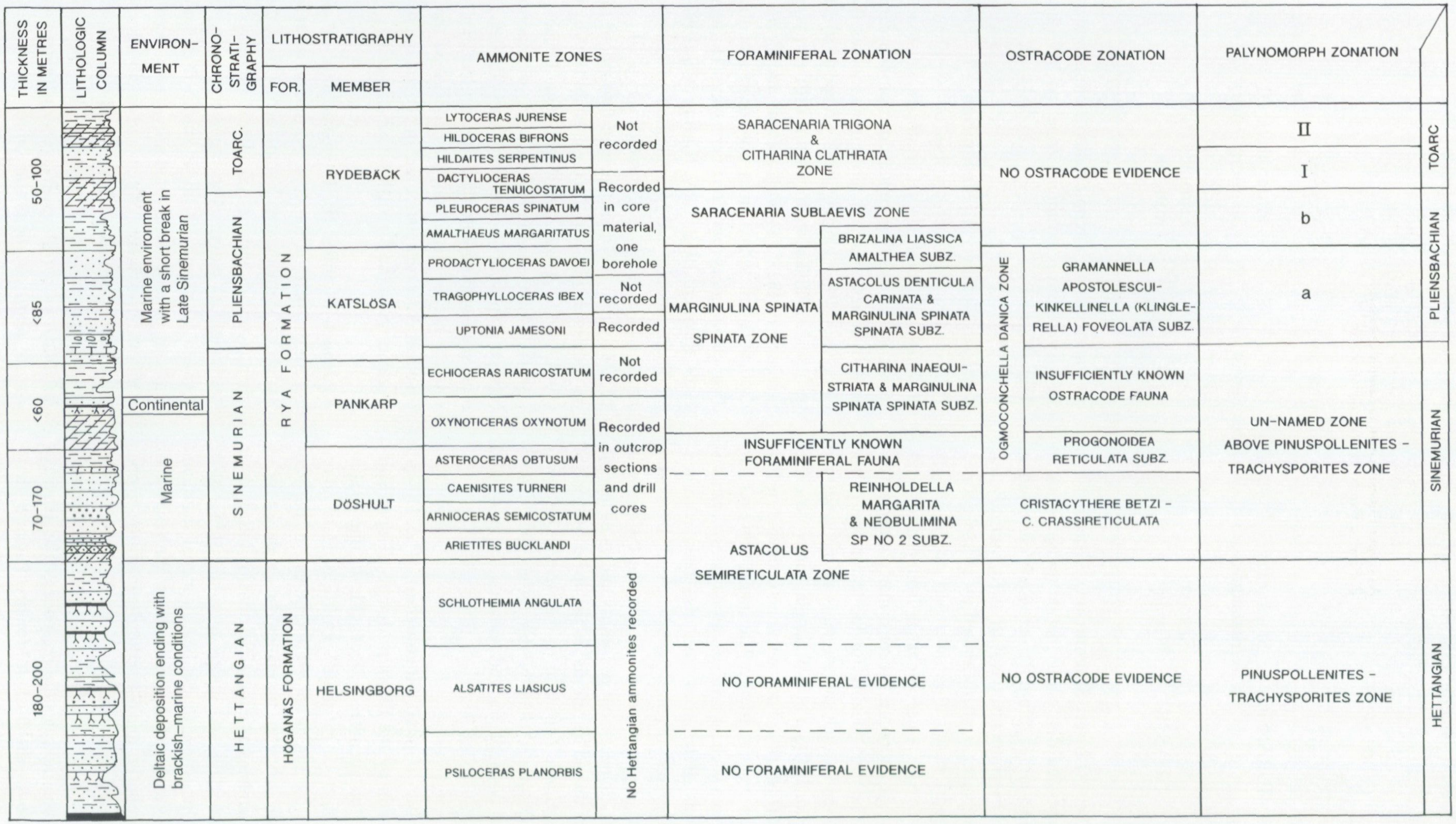

Fig. 14. Lower Jurassic chrono-, litho-, and biostratigraphy of Sweden (partly after Norling et al. 1993).

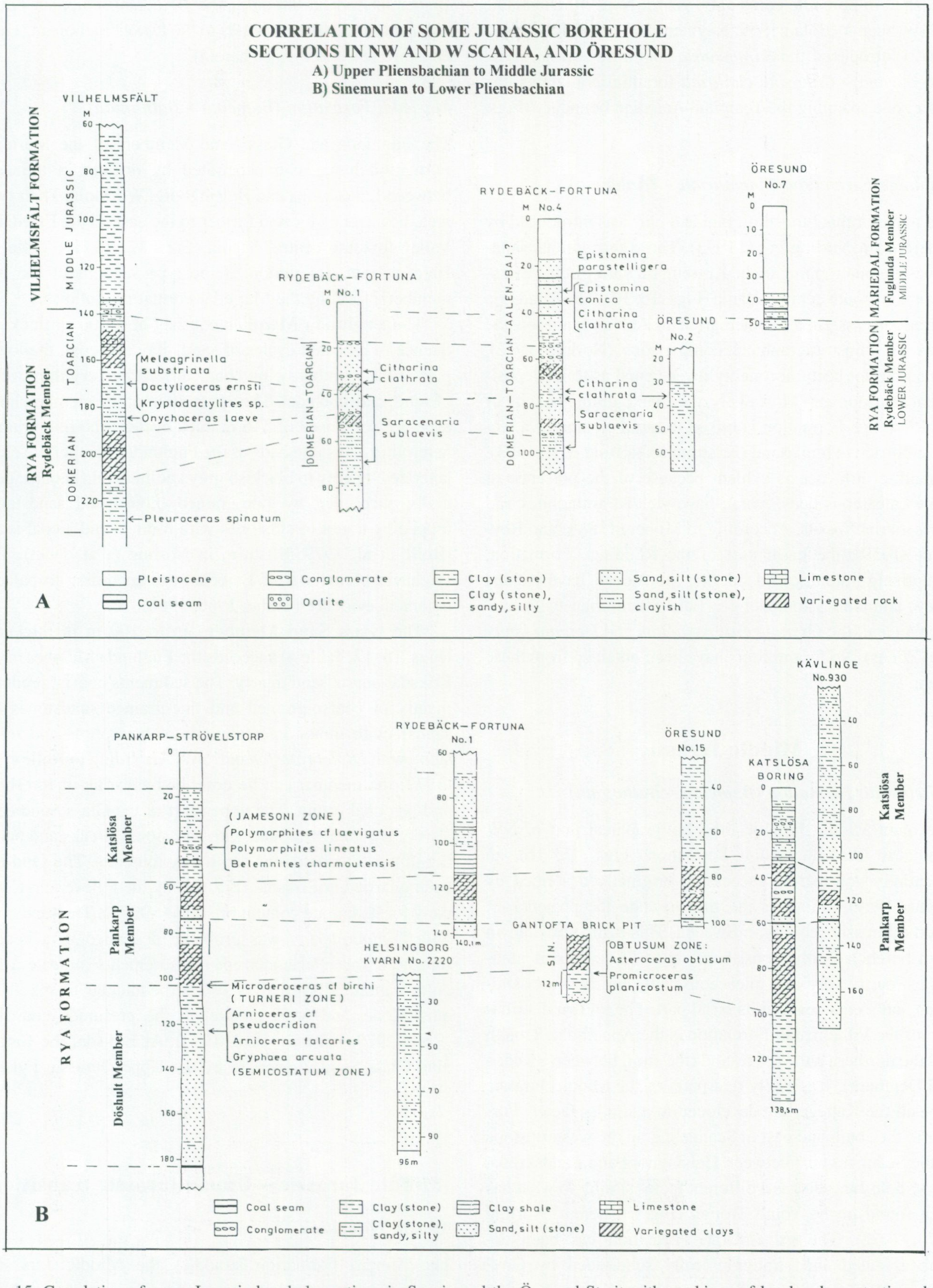

Fig. 15. Correlation of some Jurassic borehole sections in Scania and the Öresund Strait with markings of levels where stratigraphical index fossils (ammonites and foraminifers) have been found.

tablished in borehole cores only, viz. in Nya Vilhelmsfält-1 in NW Scania (Bölau 1959, Reyment 1959, 1969). Norling (1972) introduced the *Saracenaria sublaevis* and *Saracenaria trigona – Citharina clathrata* foraminiferal zones, the latter zone spanning the Toarcian–Aalenian boundary (Figs. 14, 16, 28).

Röddinge Formation (Sinemurian – ?Aalenian)

The name of this lithostratigraphical unit was introduced by Erlström (in Norling et al. 1993). These ferruginous sandstones are outcropping in the Kurremölla Valley in the Eriksdal area of south central Scania (Figs. 16, 17). The Röddinge Formation, assigned a Sinemurian to Aalenian age on the basis of lithostratigraphical comparisons (Norling 1972), has so far not been thoroughly investigated as to its depositional environment. Most likely, the coarse-grained nature of the Röddinge Formation is linked to rapid erosion of a tectonically active hinterland (Erlström in Norling et al. 1993). A marine influence is evident because of the presence of some calcareous beds, which have yielded ammonites and other marine fossils. According to Moberg (1888) and Reyment (1959), the basal part of the Röddinge Formation, comprising limonitic and sideritic sandstones, have yielded a few ammonites indicating a Late Sinemurian to Pliensbachian age (the *Oxynoticeras oxynotum* and *Uptonia jamesoni* Zones). No foraminifers have been obtained from these strata.

Middle Jurassic

Vilhelmsfält Formation (Bajocian – Bathonian)

The main Middle Jurassic lithostratigraphical unit of NW Scania is the Vilhelmsfält Formation (Figs. 15, 16), an essentially non-marine succession originally described by Bölau (1959), who was the first to state the presence of Middle Jurassic geology in Sweden. This formation, known from boreholes only, consists of up to 75 m of soft mudstones, partly silty and micaceous with thin beds of sandstone and a coal-seam in its basal part. The known distribution of the Vilhelmsfält Formation is the Ängelholm Trough and the northern part of Öresund (the strait between Sweden and Denmark). It is likely that parts of the Middle Jurassic beneath the Kattegat are developed in a similar facies. Further to the south and east in Scania, e.g. in the western slope of the Scanian uplift between Helsingborg and Landskrona, the Middle Jurassic has a different facies similar to what has been found in the Vomb Trough (Fig. 16 herein, Norling 1970, 1972). The Vilhelmsfält Formation has been described, dated and stratigraphically subdivided by Guy-Ohlson (1971, 1986, 1989). Zone 1 and Zone 2 of the Middle Jurassic palynomorph zonation, correspond to the Bajocian, Zone 3 straddles the Bajocian/Bathonian boundary, and Zone 4 corresponds to the Lower Bathonian (Guy-Ohlson 1989 and Fig. 16 herein).

Mariedal Formation (Bajocian – Bathonian)

The Fuglunda and Glass Sand Members of the Mariedal Formation have been penetrated by drilling in the area between Landskrona and Helsingborg, W Scania. Their type area, however, is located further to the east, to the Fyledalen Valley in south central Scania (Figs. 12, 16, 17, Table 4). Here, a brief description of the type sections of the two members, forming the Mariedal Formation, follows:

The **Fuglunda Member** consists of a 100 m thick sequence of repeated cycles of sand, clay and coal, the lower part of the member being characterized by very thin cycles of sand, clay and coal. The upper 40 m of the member, however, are composed of 5–6 m thick cycles. The fine-grained heterolitic claystone beds of the Fuglunda Member are characterized by grey to blackish grey kaolinitic claystones, generally succeeded by fine-grained bioturbated sandstones topped by a unit of siltstones with rootlets and a coal-seam (Rolle et al. 1979, Erlström in Norling et al. 1993). The Fuglunda Member is of Bajocian age according to palaeobotanical evidence (Tralau 1966, 1968).

The **Glass Sand Member**, up to 100 m in thickness (Figs. 16, 17, Table 4) succeeds the Fuglunda Member in the Eriksdal quartz sand quarry. The sediments consist predominantly of coarse-grained and fine-grained sandstones (or sands), with minor intercalations of heteroliths and mudstone with *Diplocraterion* burrows. According to Rolle et al. (1979) the member can be described as being of foreshore and lagoonal origin. The upper part of the Glass Sand consists of a pure quartz sand with occasional streaks and banding of pyrite concretions and heavy minerals. The sand has been quarried at Eriksdal (Fig. 17) by the Fyleverken Company for its unique content of silica (>99 %). The sandstone with *Diplocraterion* was probably deposited in a beach-foreshore area. Palaeocurrent measurements indicate a tripolar pattern; ENE and WSW, perpendicular to the Tornquist Zone, and SSE, parallel to the presumed coastline (Rolle 1979, Erlström et al. 1993). At Eriksdal the Bathonian Glass Sand is overlain by the Upper Jurassic Fyledal Clay.

Middle Jurassic – Upper Jurassic transition

Annero Formation

The Annero Formation straddles the Middle Jurassic–Upper Jurassic boundary. It is subdivided into 4 members, viz. Fortuna Marl (top Bathonian–Lower Oxfordian),

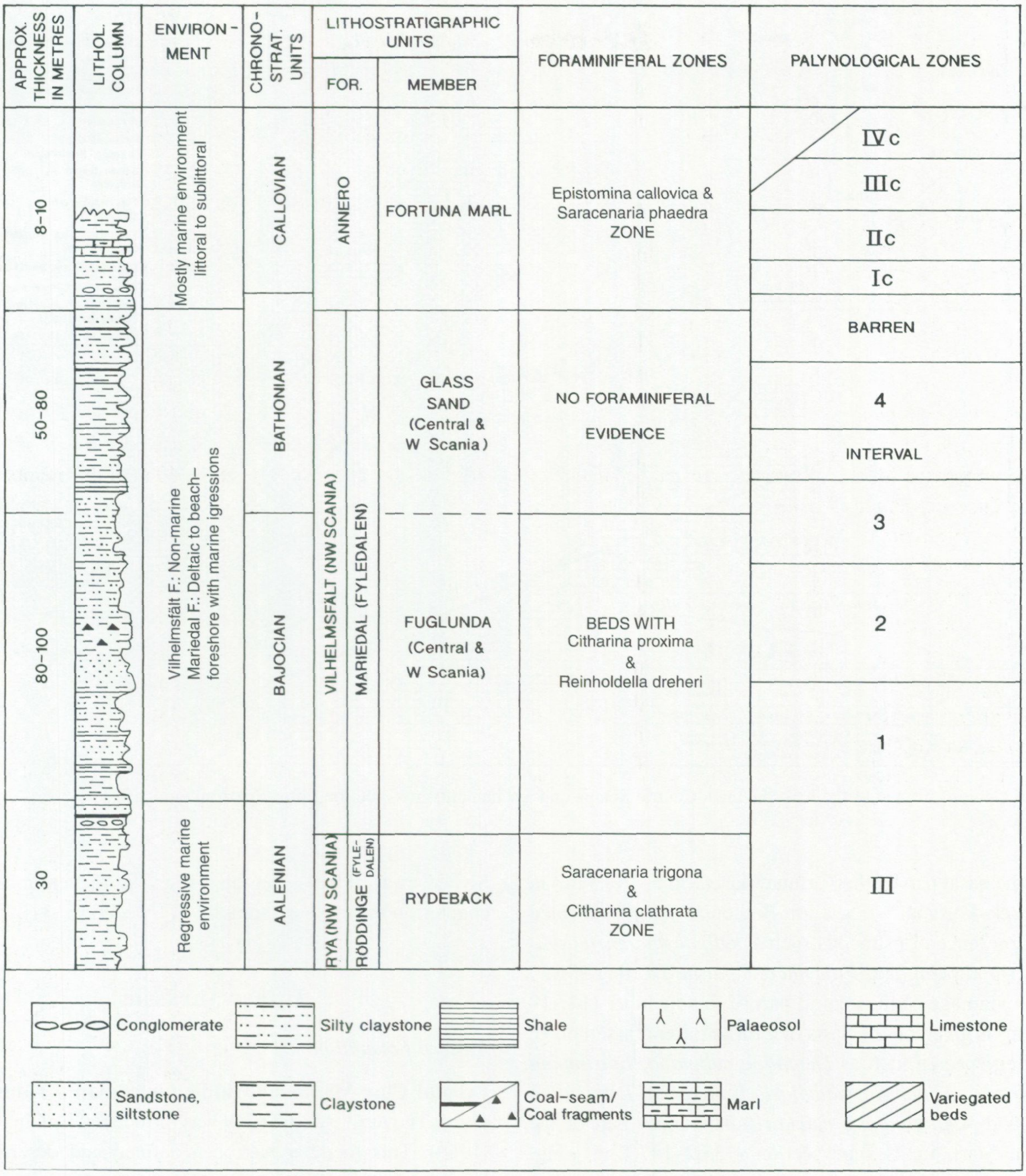

Fig. 16. Middle Jurassic chrono-, litho-, and biostratigraphy in Sweden, including legends to Figs. 14, 16, 19 (partly after Norling et al. 1993).

Fyledal Clay (Middle Oxfordian–Kimmeridgian), Nytorp Sand (Kimmeridgian–Tithonian), and Vitabäck Clays (Tithonian–Berriasian) (Figs. 16, 18).

Fortuna Marl Member (U. Bathonian – L. Oxfordian). This unit, forming the basal member of the Annero Formation, was first recorded from the Rydebäck–Fortuna borehole No. 5 in western Scania (Norling 1970, 1972). The type section, 135.2–161.3 m below surface (core length 26.1 m), consists of steeply dipping strata with an estimated true thickness of 9.7 m (Fig. 20 A). The section includes dark grey and brownish claystone, partly silty and calcareous, with thin layers of ferruginous claystone and silty limestone. At 160.1 m a conglomerate occurs. The sequence contains a fairly rich foraminiferal fauna, calcareous (dominating), as well as arenaceous forms. Based on this fauna the type section of the Fortuna Marl has been referred to the top Bathonian/Callovian–Lower Oxfordian (Norling 1972).

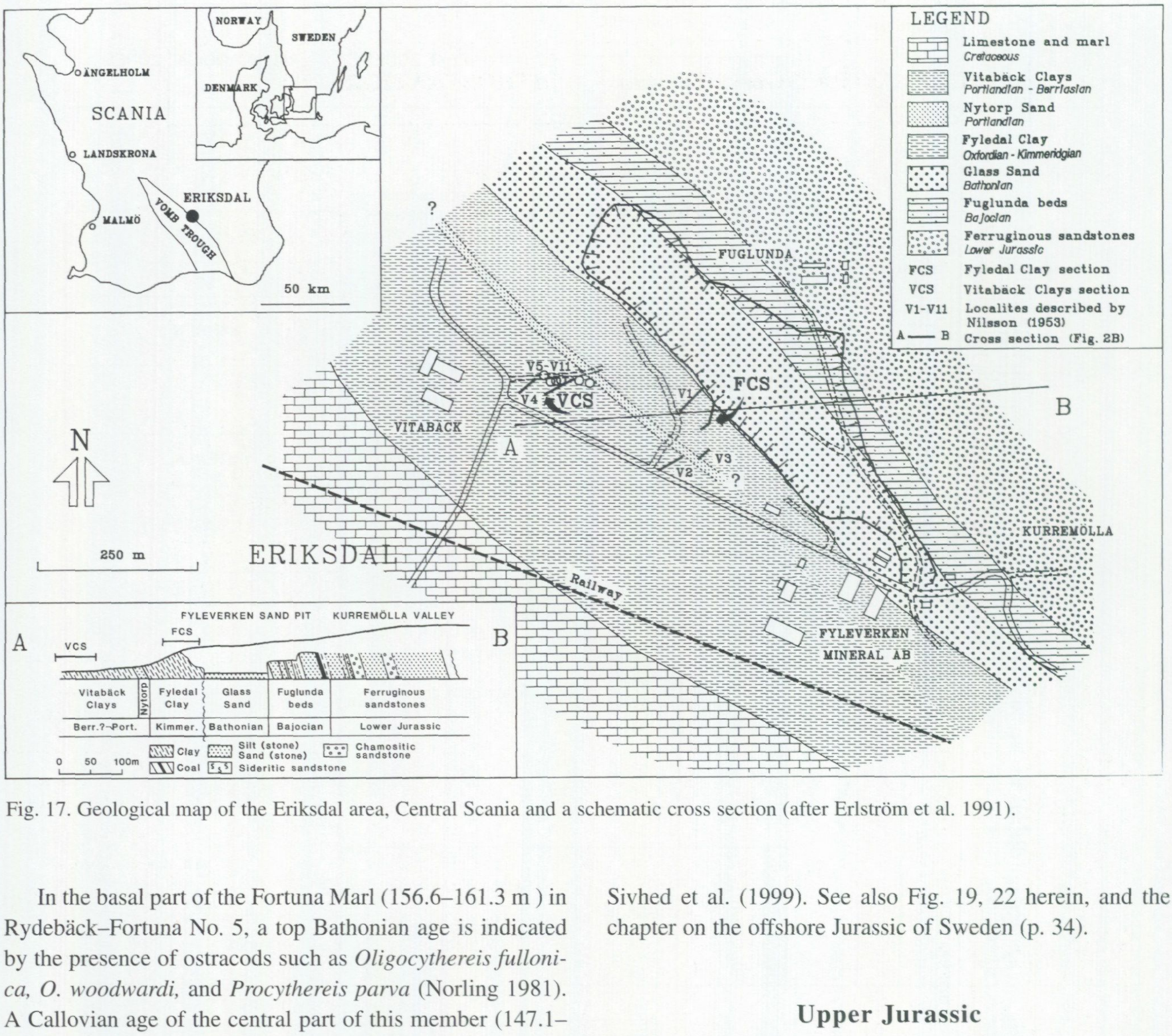

Fig. 17. Geological map of the Eriksdal area, Central Scania and a schematic cross section (after Erlström et al. 1991).

In the basal part of the Fortuna Marl (156.6–161.3 m) in Rydebäck–Fortuna No. 5, a top Bathonian age is indicated by the presence of ostracods such as *Oligocythereis fullonica, O. woodwardi,* and *Procythereis parva* (Norling 1981). A Callovian age of the central part of this member (147.1–156.6 m) is given on the basis of a foraminiferal assemblage including species such as *Dentalina subplana, Epistomina callovica, E. conica, Frondicularia franconica, Lenticulina fraasi* and *Vaginulinopsis epicharis.* The upper part of the Fortuna Marl, in its type section (135.2–147.1 m) (Fig. 20A), is referred to the Oxfordian. Among characteristic foraminiferal species obtained *Lenticulina brueckmanni, L. irretita, L. quenstedti var. evoluta, Marginulinopsis sculptilis* and *Epistomina volgensis* may be mentioned. The fauna is more thoroughly treated on page 50, Fig. 29.

Dominantly marine strata in Fortuna Marl facies are known from many boreholes in Scania, viz. Åstorp-20 of NW Scania (Fig. 20B), and Hammarlöv-1, Håslöv-1, Höllviksnäs-1 and Kungstorp-1, all deep wells in the southern part of the province, and from offshore wells SE of Scania (Hanö Bay 104/13-1 and 104/14-2, Fig. 19). These occurrences are documented by Norling (1972, 1981), Guy-Ohlson & Norling (1988), Norling & Skoglund (1977) and Sivhed et al. (1999). See also Fig. 19, 22 herein, and the chapter on the offshore Jurassic of Sweden (p. 34).

Upper Jurassic

Annero Formation

Fyledal Clay Member (Middle Oxfordian – Kimmeridgian). The term Fyledal Clay was introduced by Christensen (1969). This member has been defined and described by Norling (1972, 1981), Guy-Ohlson & Norling (1988), Erlström et al. (1991), and Norling et al. (1993). In NW Scania, the Fyledal Clay is represented by green, greenish blue and grey-brown to iron brown, greasy clays and claystones with a varying content of silt. According to available data, the thickness of the Fyledal Clay in NW Scania varies between 16 and 31 m. In its type area, at Eriksdal in the Fyledalen Valley (Fig. 17), the exposed part of the Fyledal Clay is less than 10 m. The occurrence of rootlet beds, lacustrine and brackish marine fossils, including ostracods, arenaceous and calcareous foraminifers, calcareous algae etc., caliche nodules, gypsum and organic-rich beds, verify deposition in shallow lakes, lagoons and marshes (mangroves)

Table 4. Jurassic stratigraphy of Eriksdal (after Erlström in Norling et al. 1993).

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY	
Series	**Stage**	**Formation**	**Member**
Upper Jurassic	Tithonian	Annero Formation	Vitabäck Clays
	Kimmeridgian		Nytorp Sand
	Oxfordian		Fyledal Clay
			Fortuna Marl
Middle Jurassic	Callovian		
	Bathonian	Mariedal Formation	Glass Sand
	Bajocian		Fuglunda
	Aalenian		
Lower Jurassic	Toarcian	Röddinge Formation	No defined members
	Pliensbachian		
	Sinemurian		
	Hettangian		

APPROX. THICKNESS IN METRES	LITHOL. COLUMN	ENVIRON-MENT	CHRONO-STRAT. UNITS	LITHOSTRATIGRAPHIC UNITS: FOR	LITHOSTRATIGRAPHIC UNITS: MEMBER	FORAMINIFERAL ZONATION	PALYNOLOGICAL ZONATION	SELECTED DIAGNOSTIC OSTRACODES
30–70		Similar to that of the Fyledal Clay	BERR. / TITHONIAN	ANNERO FORMATION	VITABÄCK CLAYS	BEDS WITH Lenticulina muendensis	C	Cypridea valdensis praecursor; Fabanella mediopunctata; Fabanella ornata; Klieana calyptroides; Macrodentina retirugata; Macrodentina transiens; Mantellina purbeckensis; Scabriculocypris trapetzoides
25–35		Coastal prograding sand barrier – strand-plain delta	TITHONIAN / KIMMERIDGIAN		NYTORP SAND	NO FORAMINIFERAL EVIDENCE	INTERVAL ZONE	
15–70		Lacustrine–brackish-marine environment with restricted marine influence in quiet waters	KIMMERIDGIAN / OXFORDIAN		FYLEDAL CLAY	BEDS WITH Verneuilinoides meentzeni	B	Cytheropteron decoratum; Damonella pygmaea; Klieana alata; Klieana calyptroides; Macrodentina rudis; Rhinocypris jurassica; Rhinocypris rasilis
						BEDS WITH Reophax suprajurassica	A	
8–10		Mostly marine	OXFORDIAN		FORTUNA MARL	Saracenaria oxfordiana & Lenticulina brueckmanni ZONE	Oxfordian part of the Fortuna Marl not investigated	

Fig. 18. Upper Jurassic chrono-, litho- and biostratigraphy of Sweden For legend explanation see Fig. 16 (partly after Norling et al. 1993).

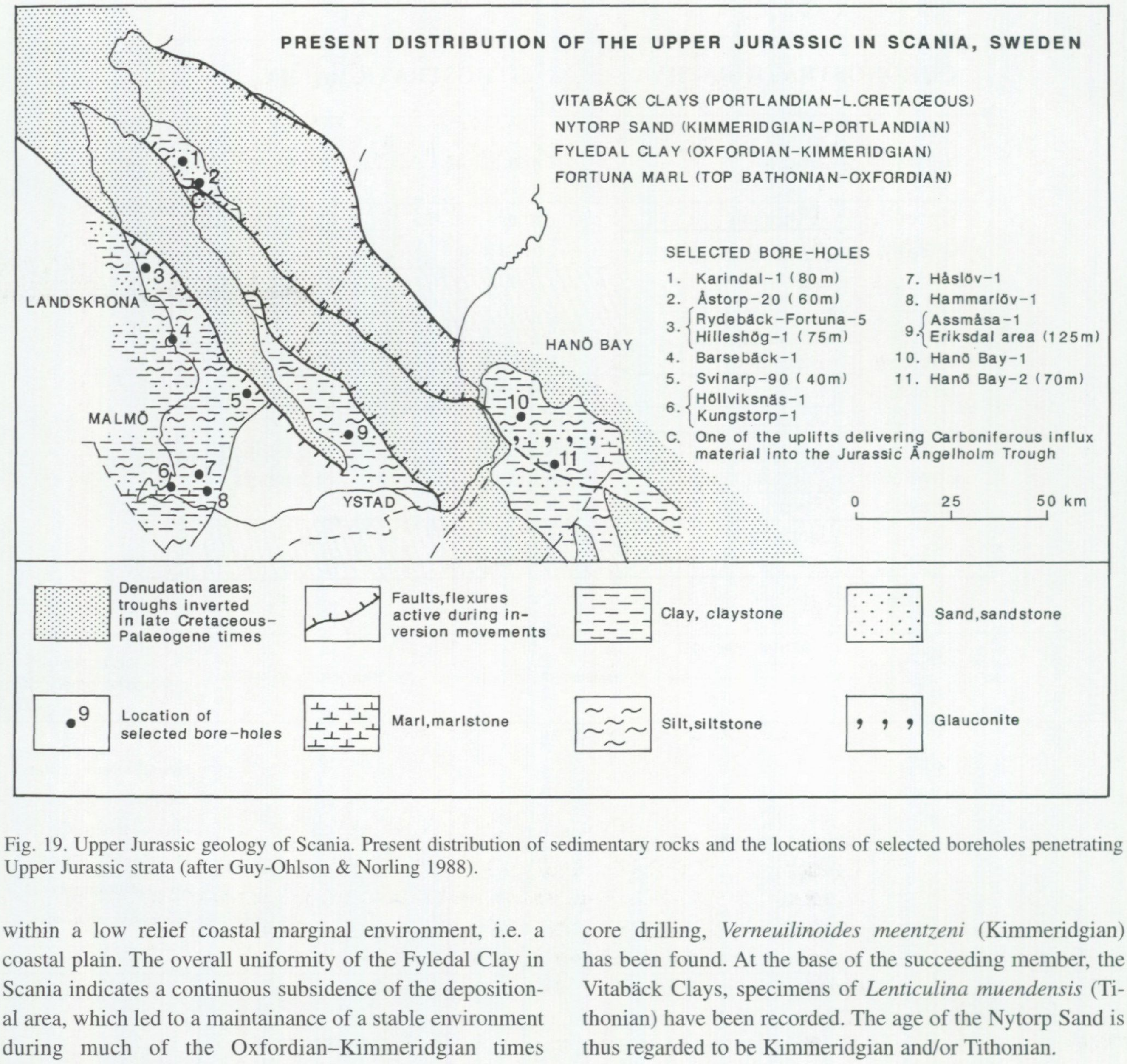

Fig. 19. Upper Jurassic geology of Scania. Present distribution of sedimentary rocks and the locations of selected boreholes penetrating Upper Jurassic strata (after Guy-Ohlson & Norling 1988).

within a low relief coastal marginal environment, i.e. a coastal plain. The overall uniformity of the Fyledal Clay in Scania indicates a continuous subsidence of the depositional area, which led to a maintainance of a stable environment during much of the Oxfordian–Kimmeridgian times (Erlström et al. 1991).

Based on foraminifer and ostracod biostratigraphy the Fyledal Clay is referred to the Oxfordian and Kimmeridgian, a dating which is supported by palynostratigraphy (Guy-Ohlson 1985, Guy-Ohlson & Norling 1988). Foraminiferal assemblages and zonation are commented on in page 46. See also Figs. 18, 29).

Nytorp Sand Member (Kimmeridgian – Tithonian). The Nytorp Sand, characterized by whitish, greyish and brownish (ferruginous), partly clayey, coarse and fine-grained sandstones, uncemented sands, silts and siltstones, is known from boreholes only. The thickness of this member, originally described by Norling (1970, 1972), ranges from 18 to 35 m. The unit is devoid of fossils. A few metres below the base of the Nytorp Sand type section in Rydebäck–Fortuna No. 5 core drilling, *Verneuilinoides meentzeni* (Kimmeridgian) has been found. At the base of the succeeding member, the Vitabäck Clays, specimens of *Lenticulina muendensis* (Tithonian) have been recorded. The age of the Nytorp Sand is thus regarded to be Kimmeridgian and/or Tithonian.

Upper Jurassic – Lower Cretaceous Transition

Annero Formation

Vitabäck Clays Member (Tithonian – Berriasian). The uppermost lithostratigraphical unit of the Annero Formation is called the Vitabäck Clays after a farm named Vitabäck near Eriksdal in the Fyledalen Valley (Fig. 17). The Vitabäck Clays were formed in a depositional environment similar to that of the Fyledal Clay. The Vitabäck Clays are known from ditch sections in the Eriksdal area and from many boreholes in NW Scania (Figs. 17, 18, 19). Today, the unit is not exposed. The member is composed of a heterogenous sequence of differently coloured, argillaceous beds with a

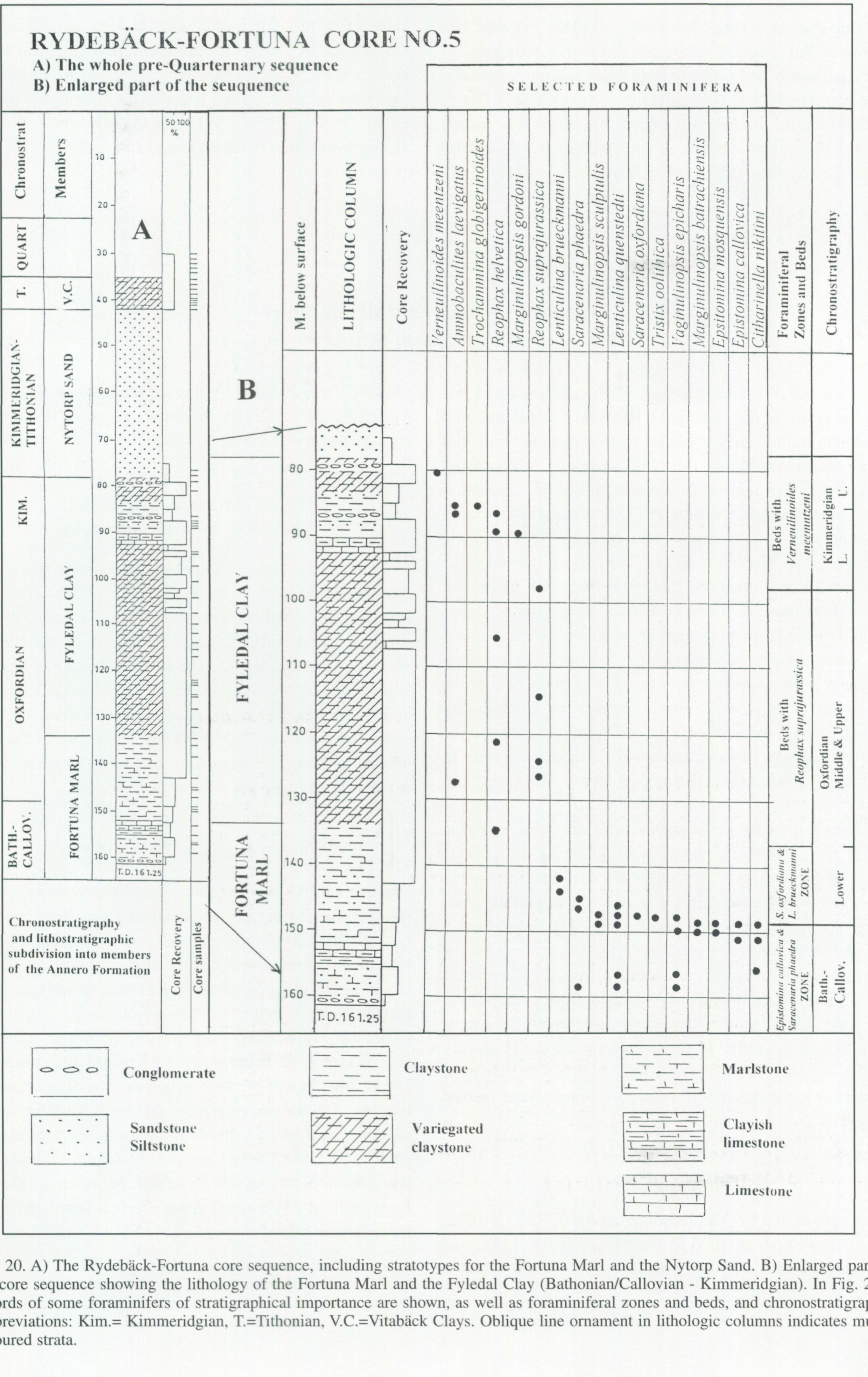

Fig. 20. A) The Rydebäck-Fortuna core sequence, including stratotypes for the Fortuna Marl and the Nytorp Sand. B) Enlarged part of the core sequence showing the lithology of the Fortuna Marl and the Fyledal Clay (Bathonian/Callovian - Kimmeridgian). In Fig. 20B records of some foraminifers of stratigraphical importance are shown, as well as foraminiferal zones and beds, and chronostratigraphy. Abbreviations: Kim.= Kimmeridgian, T.=Tithonian, V.C.=Vitabäck Clays. Oblique line ornament in lithologic columns indicates multi-coloured strata.

varying content of silt. When compared to the Fyledal Clay, however, the Vitabäck Clays show a higher frequency of silty and sandy beds. The unit includes several palaeosols. The petrography and biostratigraphy of the Vitabäck Clays, which span the Jurassic–Cretaceous boundary, was treated by Erlström et al. (1991). A well preserved palynoflora, described by Guy-Ohlson (in Erlström et al. 1991), indicates a Tithonian–Berriasian age. The foraminiferal fauna is meagre, but some species are of biostratigraphical value, such as *Lenticulina muendensis* (Tithonian) and epistominids of the *caracolla* group (Berriasian or younger), recorded by Norling (1972, 1981) and Guy-Ohlson & Norling (1988, 1994) from borehole material.

Jurassic geology and stratigraphy offshore from Scania

The Province of Scania is framed by the sea in all directions but the north; to the east by the Hanö Bay, to the south by the South Baltic Sea, to the west by the Öresund Strait, and to the northwest by the Kattegat. According to data from seismic surveys and offshore wells drilled in connection with oil prospecting (Norling 1973, Talbacka 1974, Norling & Skoglund 1977, Kumpas 1980, Norling 1981), Jurassic deposits of the Hanö Bay east of Scania are restricted to the Linderödsåsen–Christiansø fault zone in the SW part of the bay, where they are found beneath a thick cover of Cretaceous–Palaeogene and Quaternary sediments (Fig. 19).

South and west of Scania too the Jurassic rocks are mostly found at rather great depths, covered by younger deposits (Erlström et al. 1997). From the area of Landskrona–Helsingborg in the northern part of Öresund to the southern part of Kattegat, Jurassic deposits form the rock surface to be found beneath a Quaternary cover up to c. 100 m in thickness (Fig. 21).

The offshore drillings include three deeper wells in the Hanö Bay, and two deep wells drilled for hydrocarbons south of Scania (Fig. 19). In northern Öresund Strait some shallow boreholes were drilled in connection with the planning of a tunnel or bridge between Sweden and Denmark (Larsen et al. 1968).

Jurassic strata have been recorded from the deep wells Falsterborev-1 and Smygehuk-1 offshore from south Scania. No foraminiferal studies have been made on cuttings sampled from these wells. Material from two of the Hanö Bay wells , viz. Nos. 104/13-1 and 104/14-2, however, have been studied at some detail with regard to foraminiferal faunas. (Fig. 22).

HANÖ BAY 104/13-1

This well, drilled by Oljeprospektering AB (OPAB) in 1973, has a total depth of 1026 m (below sea bottom). The sequence penetrated includes Triassic (1026–939 m), Jurassic (939–831 m), Jurassic–Cretaceous transitional beds (831–810 m), Cretaceous (810–161 m), Palaeogene (161–135 m), and Quaternary deposits.

Upper Triassic (Rhaetian) (981–939 m subsea depth)

In general, the Rhaetian sequence in Scania is represented by non-marine beds. In the Hanö Bay wells, however, this stage includes marine strata, which are indicated by the lithology; glauconitic, calcareous clays and siltstones, as well as by the microfauna. The fauna includes a.o. *Scabriculocypris sp. No. 844* Wicher 1957 (Rhaetian ostracod), and the foraminifers *Eoguttulina kuhni* (Rhaetian–L. Jurassic), *Gaudryina triadica, Variostoma coclea*, *Variostoma coniforme* (Rhaetian), *Glomospira gordialis* (Rhaetian–Jurassic) and *Tetrataxis inflata* (Rhaetian) (See Fig. 22).

Lower Jurassic (939–893 m)

The interval 939–893 m has been referred to the Lower Jurassic partly on lithostratigraphical grounds, partly based on microfossil finds (foraminifers and ostracods). The tentative boundary between the Triassic and the Jurassic Systems is based on the uppermost finds of Rhaetian foraminifers such as *Gaudryina triadica, Variostoma* cf. *coclea, Variostoma coniforme, Glomospira gordialis*, and *Tetrataxis inflata*, all described from the Eastern Alps by Kristan-Tollmann (1957, 1964). The Lower Jurassic sequence is characterized by interbeds of clay and claystone, argillaceous sandstone and siltstone, partly with calcareous cement and traces of glauconite and pyrite. Certain parts of the sequence show similarity to the Katslösa and Rydebäck Members of the Rya Formation (p. 25), a comparison which is supported by the foraminiferal assemblages (Figs. 14, 22).

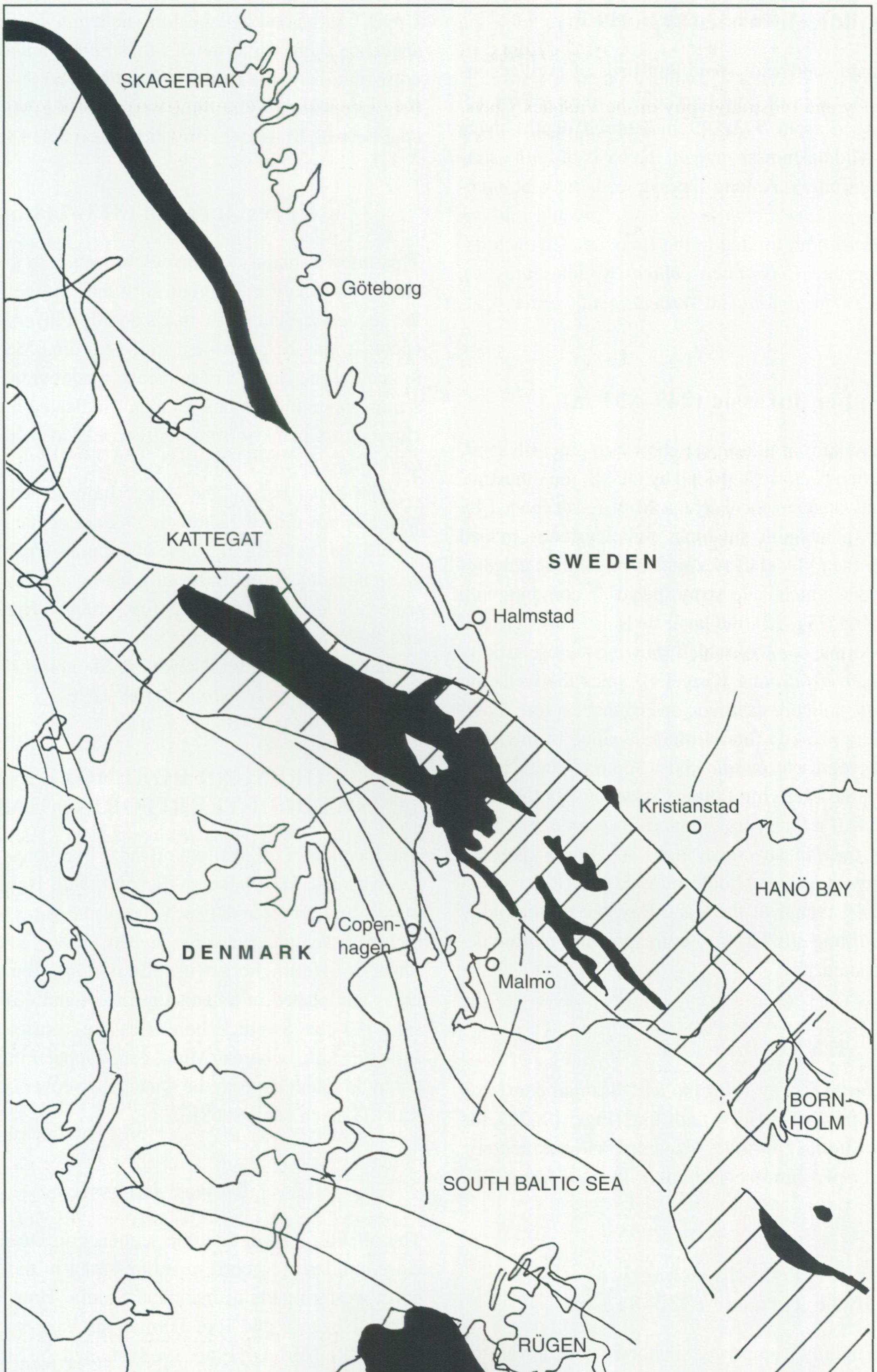

Fig. 21. Sketch map of southern Sweden and surrounding sea areas; Skagerrak, Kattegat, and the South Baltic Sea, showing the distribution of Jurassic rocks (black) beneath the Quaternary cover (after Norling, SNA 1994).

Middle Jurassic (893–849 m)

The uncemented sand with some thin beds of argillaceous sandstone with traces of coal overlying a more clayey sequence, recorded from 893–849 m (subsea depth), have been given a Middle Jurassic age on the basis of both ostracods and foraminifers. Among the ostracods may be mentioned *Fuhrbergella (Praefuhrbergella) sauzei* and *Ljubimovella piriformis,* both limited to the Bajocian. Characteristic foraminifers are *Epistomina conica* (Middle Jurassic), *Trochammina* ex. gr. *inflata* and *Verneuilinoides fusca* (Callovian).

Upper Jurassic (849–831 m)

The interval contains argillaceous, greyish to greenish sandstones. In the two deep wells drilled by OPAB, the lithostratigraphical equivalent to the Fortuna Marl is succeeded by purely marine, glauconitic siltstones and claystones, indeed different from the Fyledal Clay. Apart from benthic calcareous foraminifers, which have many species in common with the Fortuna Marl (Fig. 22), the latter beds have also yielded tiny planktic forms, some of which showing a close affinity to *Globuligerina oxfordiana* (Grigelis). Since the wells are rotary drillings, not core drillings, one cannot be sure, however, that all the planktic foraminifers obtained from Upper Jurassic strata represent *in situ* finds. Some of them might originate from the overlying Lower Cretaceous. In the Hanö Bay it seems as if a Late Jurassic marine episode may have lasted longer than in any other parts of Scania (Norling 1981). Not only the upper Middle Jurassic and Upper Jurassic foraminiferal faunas of the Hanö Bay, but the lithology too, show a striking similarity to corresponding marine deposits of Lithuania.

HANÖ BAY 104/14-2

In this well, further away from the east Scanian coast and closer to the Christiansø Horst fault line (Figs. 19, 22), the Rhaetian to Middle Jurassic sequence is rudimentary, whereas the Upper Jurassic is thicker than in Hanö Bay 104/13-1.

Upper Triassic (Rhaetian) – Lower Jurassic (822–813 m)

This interval mainly comprises siltstones with a varying content of grey, calcareous clay. Trench samples from this interval have yielded a mixture of Rhaetian, Lower Liassic (pre-Pliensbachian), and Upper Jurassic foraminifers. The microfossils in these beds may be reworked. According to the microfauna (and supported by the lithology), Middle to Upper Liassic and Middle Jurassic strata are missing in the sequence. Thus, in terms of lithostratigraphical units, strata correponding to the Pankarp, Katslösa, and Rydebäck Members are missing. The same is true of the Middle Jurassic coal-bearing Mariedal Formation. (See Fig. 14).

Upper Jurassic (813–744 m)

This interval mainly comprises brownish to greyish, partly clayey and shaly, calcareous siltstones. In the lower part of the sequence glauconitic marls and thin layers of limestone occur. It may be equivalent to the Fortuna Marl (p.29), but in general the Hanö Bay sequence was obviously formed in a more open marine environment, indicated a.o. by the occurrence of planktic foraminifers related to *Globuligerina oxfordiana.*

The upper part of the Upper Jurassic sequence in this well has not the characteristic colours of the Fyledal Clay (p. 30), but has a similar type of foraminiferal fauna (mainly arenaceous forms indicating a low salinity and/or cold water). Selected foraminifers from the two Hanö Bay wells, and their stratigraphical ranges, are listed in Fig. 22. (For further information see Norling & Skoglund 1977, Kumpas 1980, Norling 1981, Norling et al. 1993.)

ÖRESUND BOREHOLES IN SWEDISH TERRITORIAL WATERS

The location of 14 shallow offshore boreholes in the Jurassic between Helsingborg (Scania) and Helsingör (Denmark), and the boundaries between the Jurassic series and members are presented by Sivhed (1986, geological map Sheet 3C Helsingborg with description). Ten of the boreholes are located in Swedish territory, and 4 on the Danish side. All the Swedish boreholes are restricted to Lower Jurassic strata, whereas Middle and Upper Jurassic deposits are to be found beneath the Quaternary cover on Danish territory (Larsen et al. 1968)

Lower Jurassic

The offshore Lower Jurassic sequence in Öresund shows a close similarity to corresponding strata in the western and north-western parts of mainland Scania. Thus, all members of the Höganäs and Rya Formations have been identified (see p. 22). Norling (1966, 1968) studied the Sinemurian foraminiferal fauna from one of the offshore boreholes, viz. Öresund 01 (N 56° 4´32“, E 12° 39´30“) from a biostratigraphical view as well as the characteristics of the wall structures in the nodosariid foraminiferal fauna. The core sequence has yielded 25 species of calcareous foraminifera,

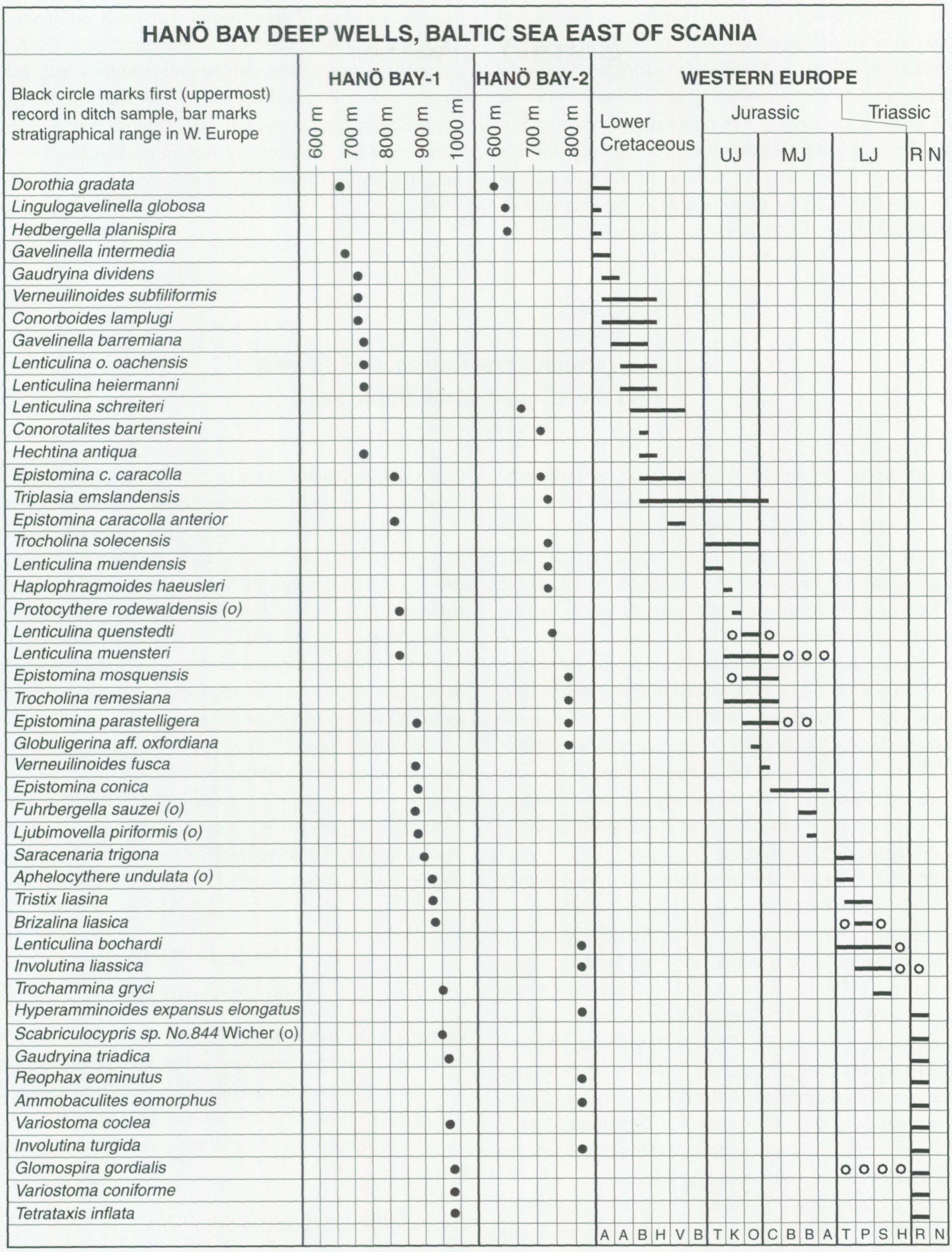

Fig. 22. Records of selected Triassic to Lower Cretaceous foraminifers, and a few ostracod species, from the Hanö Bay wells, Baltic Sea east of Scania, and their stratigraphical ranges.
Abbreviations: LJ= Lower Jurassic, MJ= Middle Jurassic, UJ= Upper Jurassic. Chronostratigraphical stages from older to younger: N= Norian, R= Rhaetian, H= Hettangian, S= Sinemurian, P= Pliensbachian, T= Toarcian, A= Aalenian, B= Bajocian, B= Bathonian, C= Callovian, O= Oxfordian, K= Kimmeridgian, T= Tithonian, B= Berriasian, V= Valanginian, H=Hauterivian, B= Barremian, A= Aptian, A= Albian.

most of them nodosariids restricted to the Sinemurian and Pliensbachian Stages. Species such as *Nodosaria kuhni, Marginulina undulata, Vaginulinopsis exarata, Nodosaria columnaris* and *Paralingulina tenera* ssp. *pupoides,* indicate that the whole interval should be referred to the Lower Sinemurian. From a lithostratigraphical point of view this sequence belongs to the Döshult Member of the Rya Formation (Norling 1968). In the same year Bang (in Larsen et al. 1968), presented the foraminiferal faunas obtained from the Jurassic in other offshore wells. Larsen et al. mainly presents the lithostratigraphy and sedimentology, the foraminiferal biostratigraphy, and the ostracod biostratigraphy of the Jurassic in Öresund between Sweden and Denmark. The paper commented on, was of great value in the planning and location of the five core drillings in the Rydebäck–Fortuna area, the results of which were presented by Norling (1970, 1972).

Jurassic foraminiferal faunas of Lithuania and the SE part of the Baltic Sea

Fossils are frequently found in the Jurassic of Lithuania. Sedimentary rocks of Early and Middle Jurassic ages (Jotvingiai and Skalviai Groups) contain palynomorphs (pollen and spores). Not until Late Bathonian–Early Callovian times foraminifers, marine bivalves and ostracods seem to appear in the Jurassic of Lithuania, all finds obtained from marine ingressional strata. From the Middle Callovian onwards in the Jurassic succession (Callovian–Volgian), prolific foraminiferal faunas occur, as well as invertebrate fossils such as ammonites, belemnites, bivalves and brachiopods (Brückmann 1904, Pakuckas 1933, Grigelis 1985a, Rotkytė 1987). The biostratigraphy of the marine Jurassic in the East Baltic region is mainly based on ammonites and foraminifers. The biozonation and the lithostratigraphical subdivision is presented in Table 1, p. 10.

As mentioned before, the Jurassic foraminiferal faunas of Lithuania are rich and some 300 species have been recorded (Grigelis 1985a). In the East Baltic region the foraminiferal fauna is of a boreal shelf sea type in which representatives of Nodosariidae, Lenticulinidae and Epistominidae dominate (Fig. 23). The superfamily Nodosariacea contributes with 140 species (59%) to the fauna, whereas Ceratobuliminacea has 50 species (22% of the fauna). Other taxa such as Astrorhizacea and Ammodiscacea (5 species), Textulariacea (5), Miliolacea (15), Spirillinacea (13) and Globigerinacea (1 species) form together 19% of the fauna (Grigelis 1980b, 1985a and Fig. 24 herein).

With few exceptions the classification by Loeblich & Tappan (1988) has been followed. One exception, favoured by one of us (Grigelis), is the subdivision of the family Nodosariidae (sensu Loeblich & Tappan) into three families, viz. Nodosariidae Ehrenberg 1838, Lenticulinidae Chapman, Parr & Collins 1934, and Vaginulinidae Reuss 1860. In total, 20 foraminiferal families have been recorded from the Baltic Jurassic (Grigelis 1978, 1985a, Grigelis & Gorbatchik 1980). A change in the number of genera shows that the most drastic renewal in the systematic composition of the fauna took place in Late Callovian and Early Kimmeridgian times (Fig. 24). The changes can be explained by major marine transgressions into the Baltic Basin. The foraminiferal studies have been based on material from outcrops as well as boreholes (Grigelis 1985b). For precise establishment of biozone boundaries, several sections of the same age have been studied. Biozones of the Baltic Jurassic, based on selected foraminifers, are shown in Fig. 25.

The foraminiferal zones established fulfil the demands for assemblage zones (Grigelis 1980a). Every zone is characterized by diagnostic foraminiferal species. The zonation is correlated with the ammonite stratigraphy proposed by Rotkytė (1987). Biostratigraphy based on vertical ranges of foraminifers is illustrated by Fig. 26.

Middle Jurassic

Upper Bathonian

Certain marine ingressions of Late Bathonian and Early Callovian ages have yielded foraminifers, but no biozones have been established for this stratigraphical interval. Correlation of various sections from this interval has mainly been based on lithostratigraphical features and a few foraminiferal species.

Beds with Ophthalmidium infraoolithicum
(Figs. 6, 25; Plate 3:1)

In the Baltic area the oldest Jurassic strata which have yielded foraminifers belong to the Liepona Formation of Middle Jurassic age. In this formation finds of calcareous foraminifers, bivalves and gastropods are restricted to a few marine ingressional layers. Within the Beds with *Ophthalmidium*

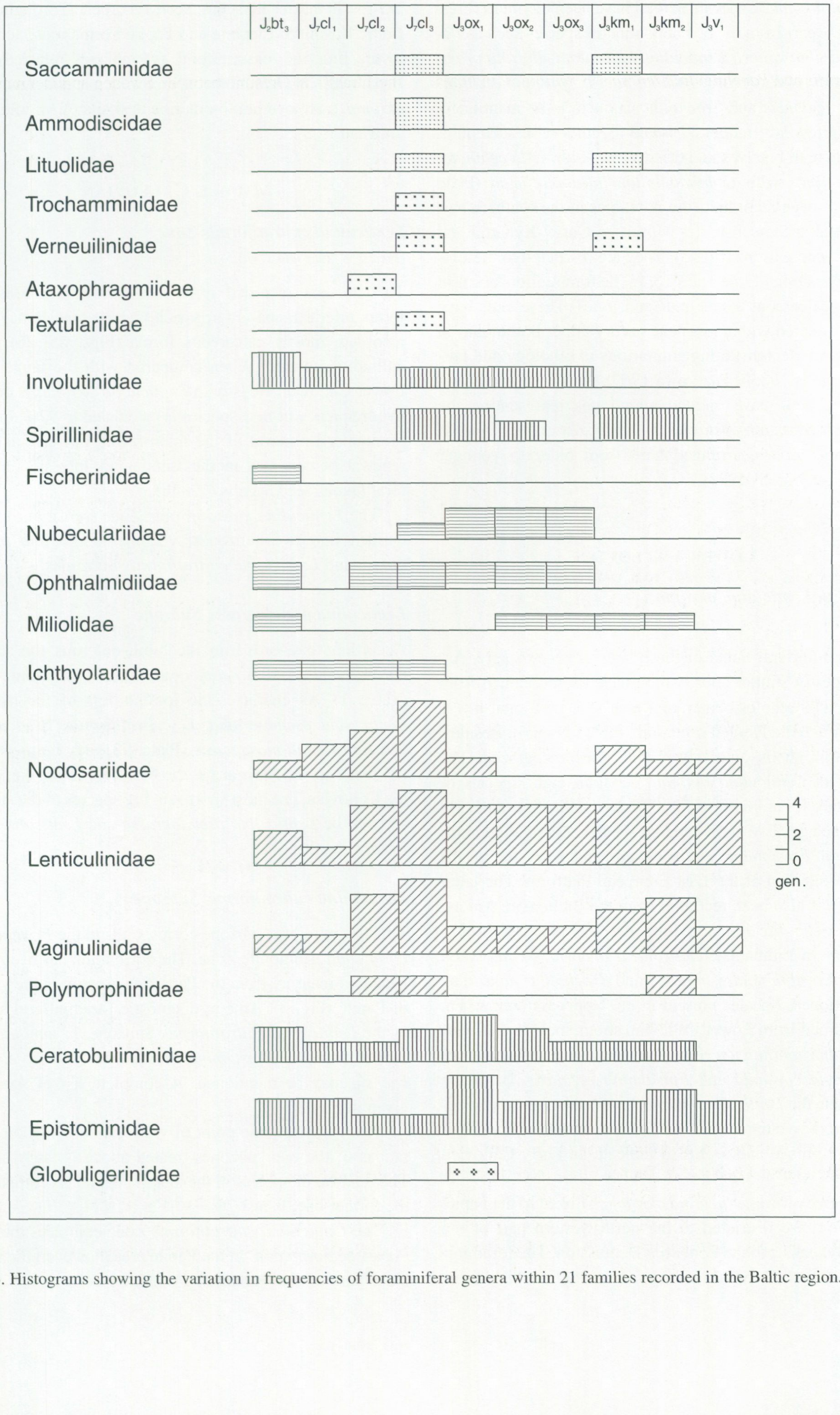

Fig. 23. Histograms showing the variation in frequencies of foraminiferal genera within 21 families recorded in the Baltic region.

infraoolithicum 22 species in total have been recorded (Figs. 24, 25). Apart from the bed denominator species such as *Palaeomiliolina kanevi, Lenticulina labecula, Citharina proxima, Reinholdella crebra, Paulina paula, Epistomina coronata, E. regularis* and *Trocholina nana* may be mentioned. Foraminifers are frequently found together with accumulations of small bivalves identified as *Meleagrinella echinata*.

The Beds with *Ophthalmidium infraoolithicum* (Plate 3:1) have been recorded from boreholes in the southern part of the Baltic Syneclise, i.e. within the Gusev-Kybartai and Nivensk depressions (Fig. 3). They are restricted to the Liepona Formation (Table 1, Fig. 6,). The foraminifers occur in slightly calcareous sands and sandstones. These beds have been correlated with equivalent strata (Upper Bathonian) in NE Poland, demonstrating similarities in lithology and faunas (Grigelis 1985b, Pazdrowa 1969). In NE Poland corresponding beds have yielded ammonites representing the *Oecotraustes heterocostatus, O. paradoxus* and *Clydoniceras discus* Zones, arranged here from older to younger (Marek & Grigelis 1998).

Lower Callovian

Beds with Lenticulina okrojanzi

(Figs. 6, 26)

The foraminiferal fauna of these beds is very meagre. Assemblages of similar composition have been obtained from some few boreholes penetrating marine ingressional layers belonging to the Papilė Formation (Table 1, Fig. 6). Besides, small, thin shells of bivalves have been recognized. The Beds with *Lenticulina okrojanzi* contain eight species of calcareous foraminifers (Figs. 25, 26), indicating an Early Callovian age. Two short-ranging species, *Lenticulina okrojanzi* and *Epistomina callovica* are characteristic of the Lower Callovian of the East European Platform. The latter species has also been recorded from the Bathonian. Among characteristic species straddling the Bathonian–Callovian boundary in Lithuania, *Ichthyolaria distorta, Reinholdella crebra, Epistominoides minutus* and *Trocholina nana* may be mentioned. Species present in the Upper Bathonian, but not recorded from Lower Callovian strata, include *Ophthalmidium infraoolithicum* (Plate 3:1), *Palaeomiliolina kanevi, Epistomina coronata* and *Epistomina regularis.* Based on these facts the *Lenticulina okrojanzi* assemblage may be regarded to be younger than the *Ophthalmidium infraoolithicum* assemblage and seems to indicate an Early Callovian age.

The Beds with *Lenticulina okrojanzi*, linked to the Papilė Formation, are restricted to the north-western part of the Baltic Syneclise, to the Žemaitija Depression. The foraminifers are found in slightly calcareous, sandy and silty beds. No fossil macrofauna has been recorded. Throughout the Baltic Basin the Liepona and Papilė Formations, according to the finds of foraminiferal assemblages referred to the Beds with *Opthalmidium infraoolithicum* and *Lenticulina okrojanzi,* are overlain by marine deposits of Middle Callovian age.

Middle Callovian

Lenticulina cultratiformis Zone

(Figs. 7, 8, 26; Plate 3:3, 3:5)

This zone is recorded from the entire Baltic Basin. Its foraminiferal fauna is fairly rich and 39 species have been recorded, mostly calcareous forms (Figs. 25, 26). Lenticulinids dominate. When compared with the fauna of the Lower Callovian Beds with *Lenticulina okrojanzi*, the relative frequency of new species is calculated to 97%, indeed a pronounced renewal of the microfauna. For calculation of renewal percentages in the Lithuanian Jurassic foraminiferal faunas see Grigelis (1985b).

The *Lenticulina cultratiformis* Zone (sensu lato) is subdivided into two subzones, viz. the *Lenticulina pseudocrassa* and *Lenticulina cultratiformis* Subzones.

Lenticulina pseudocrassa Subzone

According to records from the Papilė outcrops, this subzone corresponds to the *Kosmoceras jason* Ammonite Zone (Table 1). As characteristic foraminifers of this subzone *Lenticulina pseudocrassa, L. cultratiformis, L. eichwaldi,* and *Epistomina mosquensis* (Plate 4:3) may be mentioned. All these species appear for the first time in the early Middle Callovian.The most short-ranging species of the subzone seem to be *Lenticulina pseudocrassa* and *Lenticulina eichwaldi* (Fig. 26).

Lenticulina cultratiformis Subzone

This foraminiferal subzone corresponds to the *Erymnoceras coronatum* Ammonite Zone. The correlation has been established on material from the Papartinė outcrop in the vicinity of Papilė (Fig. 3). Among diagnostic foraminiferal species of the *Lenticulina cultratiformis* Subzone, *L. tumida, Planularia flexuosa, Epistomina mosquensis* and *E. elschankaensis* may be mentioned. A complete list of species is given in Fig. 26.

From a systematic point of view the composition of the faunas of the two subzones treated above is fairly similar. The renewal of species in the latter subzone, as compared to the former one, is just 7%.

The *Lenticulina cultratiformis* Zone embraces the entire Papartinė Formation. In the Papilė area, however, the uppermost part of the Papartinė Formation corresponds to the

Lenticulina tumida Zone (early Late Callovian). Sands, sandstones and oolitic limestones represent the main lithologies of the *Lenticulina cultratiformis* Zone. At the base a detritic conglomerate occurs.

The foraminiferal assemblage of the Middle Callovian *Lenticulina cultratiformis* Zone of the SE Baltic region shows great similarity to assemblages elsewhere within the East European Platform; the Dnepr-Donets, Pechora and the Mangyshlak regions to be mentioned (Grigelis 1983, 1985b).

Upper Callovian

Lenticulina tumida Zone

(Figs. 7, 8, 26; Plate 3:4, 6,9, 10, 11, 13, 14, 16, Plate 4:2, 3, Plate 5:2)

The foraminiferal fauna of this zone contains 67 species. Lenticulinids and epistominids predominate. Arenaceous foraminifers occur also (Figs. 23, 24). In relation to the *Lenticulina cultratiformis* Zone, the present zone shows a renewal of foraminiferal species calculated to 59%. The *Lenticulina tumida* Zone is subdivided into two subzones, described in the following.

Lenticulina paracultrata Subzone

This subzone corresponds to the *Kosmoceras ornatum* Ammonite Zone established by Rotkytė (1987) for the type stratum of the Papilė outcrop. In terms of standard zonation, the latter zone corresponds to the *Peltoceras athleta* Zone. Among diagnostic foraminiferal species of the *Lenticulina paracultrata* Subzone, the denominator itself and *Lenticulina tumida, L. catascopium, L. subtilis, Epistomina mosquensis* (Plate 4:3) and *E. elschankaensis* may be mentioned. A complete list of foraminiferal species of the *Lenticulina tumida* Zone is given in Fig. 26, as well as their stratigraphical ranges.

Lenticulina chmielewskii Subzone

The subzone given this name has been correlated with the *Quenstedtoceras lamberti* Ammonite Zone established in the Papilė-2 outcrop and some boreholes in western Lithuania (Rotkytė 1987). In the Papilė area the subzone is condensed (< 2.1 m thick). Eight foraminiferal species only have been recorded. Deeper in the basin, a prolific fauna has been obtained with 56 species identified from boreholes. When compared with the fauna of the *Lenticulina paracultrata* Subzone, the foraminiferal fauna of the *Lenticulina chmielewskii* Subzone shows a renewal percentage of 18%. The entire foraminiferal fauna of the subzone is given in Fig. 26.

The entire assemblage of the *Lenticulina chmielewskii* Subzone is characteristic and easy to recognize in various sections.

In most parts of the SE Baltic Basin, the *Lenticulina tumida* Zone corresponds to the Skinija Formation. One exception to be mentioned is the Papilė area (Fig. 3), where the lower part of this zone, viz. the *Lenticulina paracultrata* Subzone, belongs to the Papartinė Formation. The foraminiferal assemblages of the Upper Callovian *Lenticulina tumida* Zone show great similarity to assemblages elsewhere in the Baltic area and in the Dnepr-Donets and Mangyschlak regions within the East European Platform. One exception is the Pechora region, where assemblages of corresponding age show differences (Grigelis 1983).

Upper Jurassic

Lower Oxfordian

Ophthalmidium sagittum – Lenticulina brueckmanni Zone

(Figs. 9, 26; Plate 3:2, 7, 8, Plate 4:1, 4, 5, 7, Plate 5:1, 4)

This zone corresponds to the initial part of the Lower Oxfordian sequence, which is widely distributed in the Baltic Basin as a result of a major Late Jurassic marine transgression. From this zone a foraminiferal fauna of 52 species has been recorded. Epistominids and lenticulinids dominate. Ophthalmidiids and spirillinids are common too. When compared with the *Lenticulina tumida* Zone, the present zone show a renewal of species of about 86%.

The *Ophthalmidium sagittum – Lenticulina brueckmanni* Zone corresponds to the *Vertumniceras mariae* and *Cardioceras cordatum* Ammonite Zones of the Lower Oxfordian. Among foraminiferal species of diagnostic importance within the zone *Ophthalmidium sagittum* (Plate 3:2), *Lenticulina brueckmanni* (Plate 3:7), *L. belorussica, L. hebetata, Epistomina intermedia, Epistomina volgensis* (Plate 4:4) and *Globuligerina oxfordiana* (Plate 5:4–8) should be mentioned. A full list of foraminiferal species of the zone and their stratigraphical ranges is given in Fig. 26.

In terms of lithostratigraphical units the *Ophthalmidium sagittum – Lenticulina brueckmanni* Zone corresponds to the lower part of the Ąžuolija Formation of the Baltic Basin. Within these deposits, mainly of clay and marl, the distribution of foraminifers is continuous without any breaks.

Middle Oxfordian

Ophthalmidium strumosum – Lenticulina brestica Zone

(Figs. 9, 26; Plate 5:3)

In the Oxfordian, strata of this zone are represented by clayey and marly, fairly homogenous deposits. This zone has yielded 42 foraminiferal species, mainly lenticulinids and

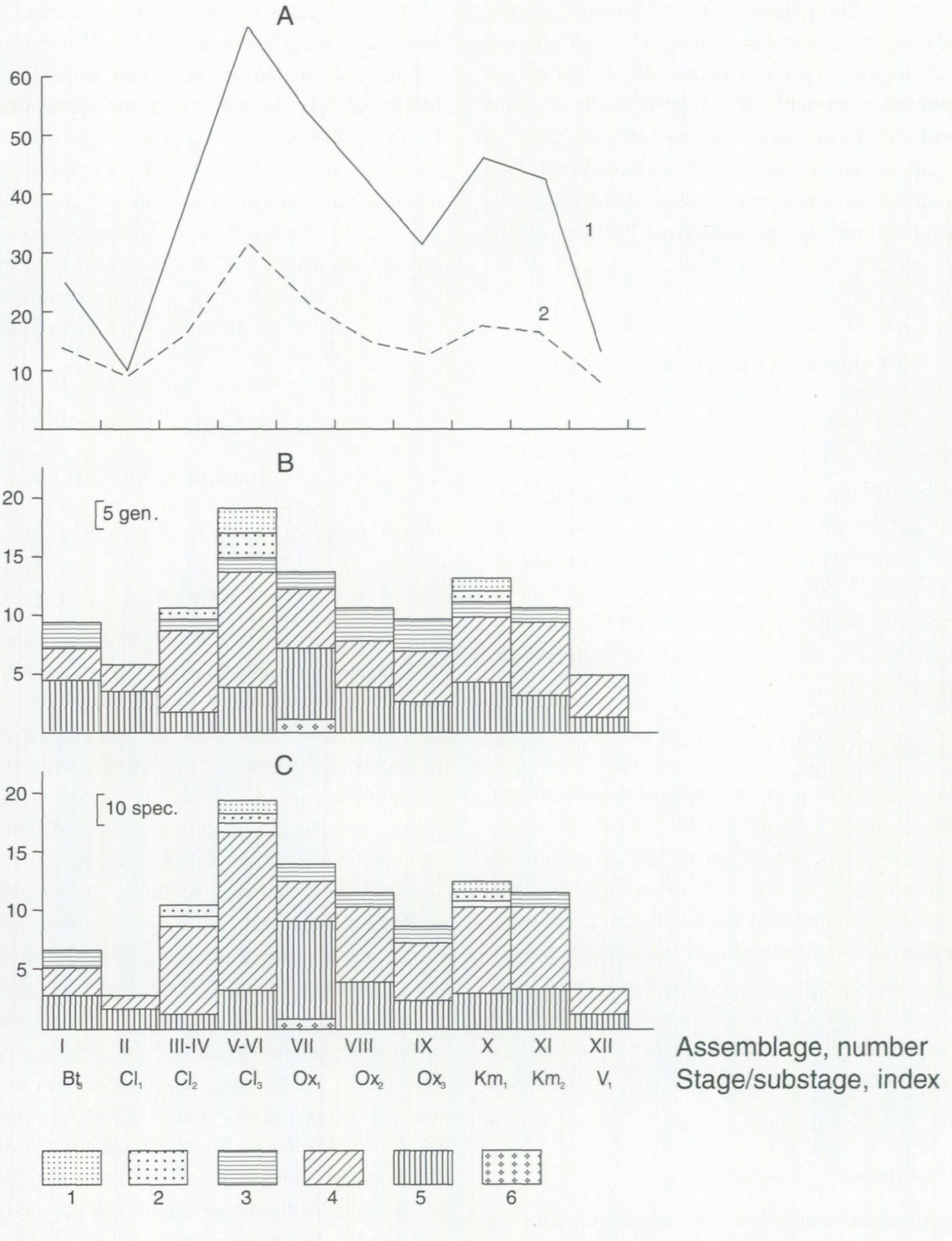

Fig. 24. Curves and histograms showing the systematic composition of Jurassic foraminifera of the Baltic (After Grigelis 1985). A) Number of species (1) and genera (2); B) Relative frequency histograms of genera within the superfamilies listed below. C) Relative frequencies of species within the same superfamilies. Legend: 1) Astrorizacea & Ammodiscacea, 2) Textulariacea, 3) Miliolacea, 4) Nodosariacea, 5) Rotaliacea, 6) Globigerinacea. Abbreviations: Bt_3=Upper Bathonian, Cl_1 = Lower Callovian, Cl_2= Middle Callovian, Cl_3= Upper Callovian, Ox_1= Lower Oxfordian, Ox_2= Middle Oxfordian, Ox_3= Upper Oxfordian, Km_1= Lower Kimmeridgian, Km_2= Upper Kimmeridgian, V_1= Lower Volgian.

epistominids. The renewal percentage of species of the assemblage is about 24%, indicating a rather close similarity to the Lower Oxfordian foraminiferal association (Figs. 23, 24).

The *Ophthalmidium strumosum – Lenticulina brestica* Zone corresponds to the *Cardioceras densiplicatum* and *Cardioceras tenuiserratum* Ammonite Zones. Among diagnostic foraminifers of this zone the zonal denominators and *Lenticulina hebetata* (Plate 3:8), *L. sublenticularis, Pseudolamarckina suvalkensis, Paulina furssenkoi* (Plate 5:1), *Epistomina uhligi, E. parastelligera* (Plate 4:5) and *Trocholina transversarii* (Plate 5:3), *Lenticulina nostra* and *Episto-*

mina perfidiosa may be mentioned. The last two mentioned species are short-ranging. The total foraminiferal fauna and stratigraphical ranges of species are given in Fig. 26.

The organogenic, possibly reef-related marls in some borehole sections in SW Lithuania contain a stenofacial, lenticulinid association of foraminifers. In the Vilkyčiai-18 well (at 92.2–100.7 m) for example, the following lenticulinids have been found (Fig. 9, p. 17):

Lenticulina hebetata
Lenticulina simplex
Lenticulina compressaeformis
Lenticulina attenuata
Lenticulina bulbiformis
Lenticulina nostra
Lenticulina aff. *brestica*
Marginulinopsis primaformis

In the Baltic area this association corresponds to the Middle Oxfordian *Ophthalmidium strumosum – Lenticulina brestica* Zone (Grigelis 1985b). In the Baltic Basin the *Ophthalmidium strumosum – Lenticulina brestica* Zone occupies the middle part of the Ąžuolija Formation. Throughout the East European Platform the foraminiferal assemblages of this zone seem to be rather similar.

Upper Oxfordian

Lenticulina quenstedti Zone

(Figs. 9, 25, 26, Plate 2:4)

The foraminiferal fauna of this zone is not as rich as those of the Lower and Middle Oxfordian, and the Lower Kimmeridgian of Lithuania. The *Lenticulina quenstedti* Zone has yielded 31 species, most of them being lenticulinids and epistominids. The renewal percentage of the fauna is as low as 16%. This zone corresponds to four ammonite zones of the Upper Oxfordian, viz. the *Amoeboceras glossense, A. serratum, A. regulare* and *A. rosenkrantzi* Zones. Apart from the zonal denominator, characteristic foraminifers of the zone are species such as *Lenticulina sublenticularis, Sigmoilina milioliniforme, Astacolus russiensis, Epistomina nemunensis, E. parastelligera* (Plate 4:5) and *E. uhligi* (Fig. 26).

In the Baltic Basin the zonal denominator, *Lenticulina quenstedti* (Plate 2:4) is a short-ranging species. More rare, but short-ranging too are species such as *Ophthalmidium stuifense* and *Planularia laminosa. Sigmoilina milioliniforme, Epistomina uhligi, E. parastelligera* (Plate 4:5) and *E. nemunensis* disappear within this zone, whereas *Lenticulina sublenticularis* and *Astacolus russiensis* occur in the Early Kimmeridgian too.

In the Baltic Basin the *Lenticulina quenstedti* Zone corresponds to the upper part of the Ąžuolija Formation. The Baltic *Lenticulina quenstedti* Zone corresponds to the *Epistomina uhligi – Astacolus russiensis* Zone of the eastern part of the East European Platform (Grigelis 1982a).

Lower Kimmeridgian

Lenticulina prussica – Lenticulina kuznetsovae Zone

(Figs. 10, 26; Plate 3:12, 15, Plate 4:6)

In Kimmeridgian time the Baltic Basin decreased in size. There are, however, marine Kimmeridgian calcareous clays, which have yielded a rich foraminiferal fauna. 42 species have been recorded from this zone with lenticulinids and vaginulinids as dominating (Figs. 23). Characteristic is also an almost complete renewal, 83% in comparison with the Upper Oxfordian fauna. To be noted, however, is that most of the Oxfordian taxa continue into the Kimmeridgian (Grigelis 1985b). This zone corresponds to the Lower Kimmeridgian Beds with *Amoeboceras kitchini*. Diagnostic foraminifers are species such as *Lenticulina sublenticularis, L. prussica, L. kuznetsovae, L. undosa, Planularia kostromensis, Marginulinopsis crepidulaeformis* and *Epistomina arkelli*. Less common, but characteristic for the zone, are other species listed in Fig. 26.

As seen in Table 1, p. 10, the present foraminiferal zone corresponds to the lower part of the Tarava Formation in the Baltic Basin. In the Baltic Basin the composition of the foraminiferal fauna of the zone in question shows a noticeable similarity to faunas from corresponding strata in the central part of the Volga Province.

Upper Kimmeridgian

Lenticulina illustris – Lenticulina daiva Zone

(Figs. 10, 25, 26)

This zone has yielded 42 species of foraminifers showing a predominance of epistominids, lenticulinids and vaginulinids (Figs. 23). A correlation of this zone has been made with the following Upper Kimmeridgian Ammonite Zones, from below: *Aulacostephanus mutabilis, A. eudoxus* and *A. autissiodorensis*. The renewal percentage of the foraminiferal species in this zone is about 64% by comparison with the fauna of the preceding zone. Apart from the zonal denominators, the following species may be mentioned as diagnostic forms: *Lenticulina vistulae, Marginulina buskensis, Epistomina stellicostata, E. praereticulata* and *Mironovella mjatliukae* and *M. foveata*. Further information is given in Fig. 25, 26.

The *Lenticulina illustris – Lenticulina daiva* Zone corre-

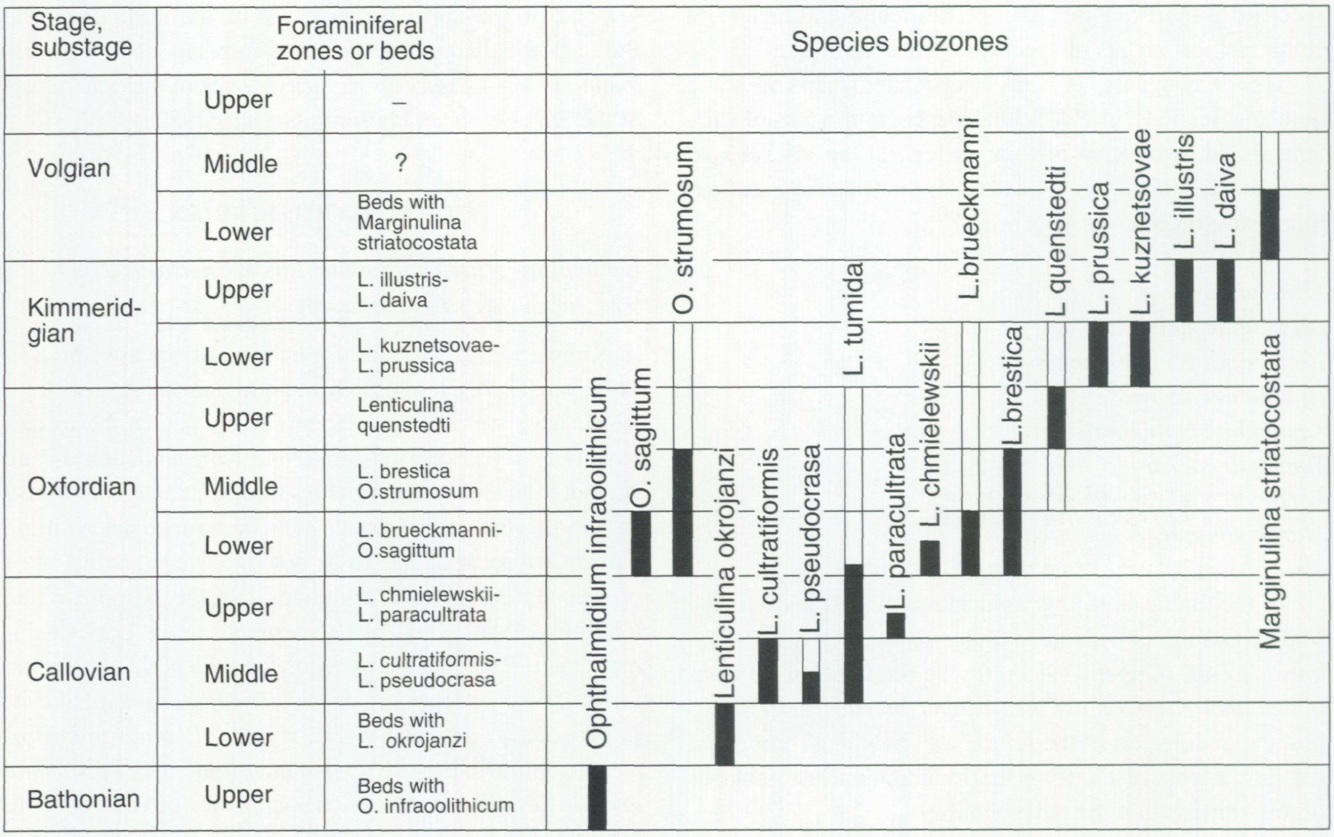

Fig. 25. Biozones of selected foraminifera from the Jurassic of the Baltic region. Black bar = stratigraphical range in the Baltic, open bar = stratigraphical range elsewhere in Europe.

sponds to the upper part of the Tarava Formation in the Baltic Basin (see Table 1, o. 10). The foraminiferal assemblage of the zone shows close similarity to the assemblages of the *Pseudolamarckina pseudorjasanensis* Zone of the Central Volga Region in Russia, and to corresponding zone in Poland and Great Britain as well (Grigelis 1982a).

Lower Volgian

Beds with Marginulina striatocostata

(Figs. 10, 25, 26)

These beds represent the uppermost Jurassic deposits in the Baltic Basin, which have yielded foraminifers. The fauna is not rich, but some of the 13 species recorded, mainly vaginulinids and epistominids, justify a dating to the Early Volgian. Among diagnostic foraminifers *Marginulinopsis striatocostata, Saracenaria pravoslavlevi* and *Mironovella gemina* may be mentioned (see Table 1, Fig. 10). Other species to be noted are *Citharina zaglobensis, C. raricostata, Epistomina praereticulata* and *E. gorodistchensis.* These species have stratigraphical ranges from the Upper Kimmeridgian to the Lower Volgian.

Amongst the few ammonites obtained from the Lower Volgian strata *Pectinatites boidini* and *Pavlovia hypophantica* may be mentioned. The foraminifers found, co-occurring with these ammonites, were too badly preserved to allow any specific determinations.

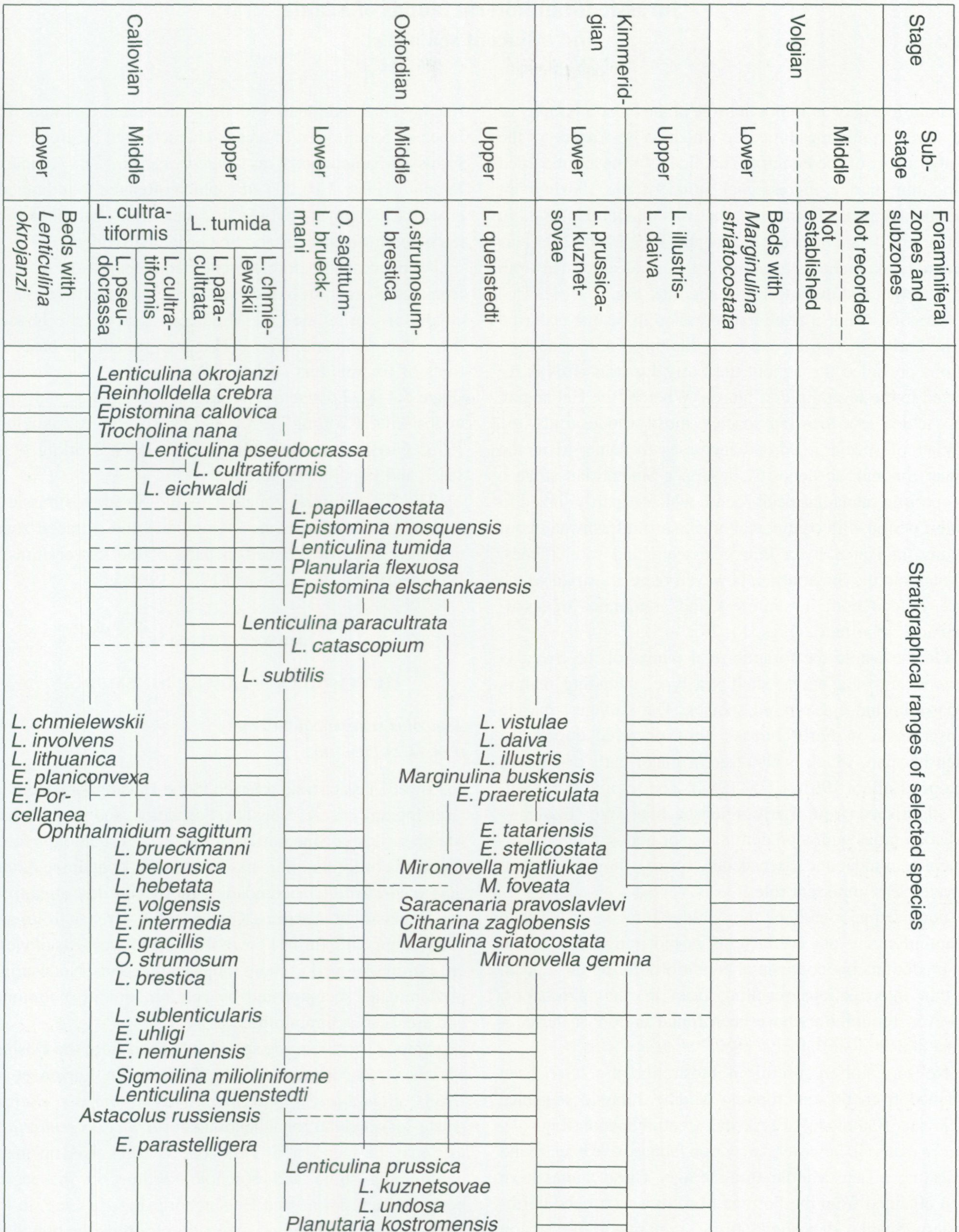

Fig. 26. Middle and Upper Jurassic foraminiferal zones and assemblages of the East Baltic region.

Jurassic foraminiferal faunas of Scania and adjacent sea areas

Foraminifers play an important role in the biostratigraphy of the Swedish marine Jurassic, which is restricted to the southern part of the country. The oldest forms are recorded from thin marine ingressional strata of the Helsingborg Member, Höganäs Formation, that was mainly deposited in deltaic and freshwater environments (Fig. 14, p. 26). This meagre fauna includes foraminiferal species described from the Rhaetian and the lowermost Jurassic (Fig. 27).

The first major marine transgression in Scania occurred in the Early Sinemurian and from this time on, marine conditions prevailed throughout the Early Jurassic. This is reflected in the foraminiferal faunas. Whereas the Hettangian has yielded less than ten species, mostly nodosariids, the number of species recorded increases to some 40 in the Lower Sinemurian deposits. In Upper Sinemurian strata a less prolific fauna has been found, which is partly linked to a short period with continental brackish and freshwater conditions, indicated by a thin coal-seam and rootlet beds. Throughout the Sinemurian, however, there are strata which have yielded both foraminifers and ammonites of stratigraphical importance (Figs. 14, 27).

On the whole the foraminiferal faunas of the Swedish Jurassic are of a boreal shelf sea type, including mainly nodosariid and epistominid species. The strongest marine transgression in Early Jurassic time occurred during the Pliensbachian, which is also true of major parts of western Europe (Hallam 1961, 1975, 1987). The foraminiferal faunas flourished from Early Pliensbachian into Toarcian–Aalenian times with a predominance of nodosariids, whereas epistominids and arenaceous forms, though present, played a less important role.

For the major part of the Middle Jurassic of Sweden foraminifers are not useful tools in biostratigraphy due to the predominating continental conditions during this epoch. In thin intercalations resulting from marine ingressions, however, foraminifers have been found in core material, a fauna indicating a Bajocian age.

No foraminifers useful in biostratigraphy have been obtained from the outcropping Middle Jurassic sequence (Bajocian–Bathonian) at Eriksdal, Central Scania (Fig. 17). In core material, however, fairly rich faunas have been found indicating a Late Middle Jurassic age. These faunas have been obtained from the Fortuna Marl in western and northwestern Scania, deposited during a marine transgression starting in Late Bathonian and prevailing into the Oxfordian (Norling 1972, 1981; Guy-Ohlson & Norling 1988, 1994; Norling et al., 1993). The major part of the Upper Jurassic deposits in mainland Scania is interpreted as brackish marine lagoonal sediments with thin marine intercalations. The brackish foraminiferal fauna is characterized by arenaceous forms of genera such as *Ammobaculites, Trochammina, Reophax* (Plate 2:10, 11) etc., which often are found together with Charophyta oogones (in recent time charophytes are restricted to freshwater and brackish environments).

As mentioned before, samples from deep wells offshore from east Scania, from the Hanö Bay, indicate more marine conditions during the Late Middle Jurassic to Late Jurassic times than mainland Scania. This interpretation is based on finds of foraminifers such as *Globuligerina cf. oxfordiana* (Plate 5:4–8), *Epistomina mosquensis* (Plate 4:3) and some nodosariids (Norling 1970, 1972; Norling & Skoglund 1977; Guy-Ohlson & Norling 1988, 1994; Norling et al. 1993, and Figs. 22, 29 herein).

The foraminiferal zonation of the Swedish Jurassic is based on assemblage zones. Ammonite and ostracod zonation have been established in parts of the Lower Jurassic (Reyment 1959, 1969; Sivhed 1980, 1984).

Lower Jurassic

Hettangian – Lower Sinemurian

Astacolus semireticulata Zone

(Figs. 14, 28, Plate 1:10)

In Lower Liassic strata referred to the Helsingborg Member (Hettangian) of the Höganäs Formation and the Döshult Member (Lower Sinemurian) of the Rya Formation, a fairly rich fauna of foraminifers has been found, containing *Astacolus semireticulata* accompanied by species described from the Rhaetian of Austria (Kristan 1957, Kristan-Tollmann 1964) along with forms known from the Lower Lias of western Europe, as well as more long-ranging ones. Nodosariids predominate, accompanied by ceratobuliminid, buliminid, and arenaceous foraminifers.

Among short-ranging species obtained from the Döshult Member, *Neobulimina* sp. No. 2 (Bang in Larsen et al. 1968), *Reinholdella margarita, Vaginulinopsis exarata* (Plate 1:7), and the zonal denominator *Astacolus semireticulata* may be mentioned. This zone is recognized in many outcropping strata and borehole sections in the region between Landskrona and Helsingborg (Fig. 12), e.g. in the western slope of the giant monocline forming the boundary between the Tornquist Zone and the Danish Subbasin (Norling 1970, 1972; Norling et al. 1993; Guy-Ohlson & Norling 1994). The entire foraminiferal fauna of the *Astacolus semireticulata* Zone, and their stratigraphical ranges, are given in Fig. 27. Author names of all the species listed and/or commented on are given in Index of foraminiferal genera and species, p. 63.

Upper Sinemurian – Lower Pliensbachian

Marginulina spinata spinata Zone

(Figs. 14, 27, 28)

This zone is correlated with the Upper Sinemurian and the Lower Pliensbachian and covers the major part of the Pankarp and Katslösa Members of the Rya Formation (p. 25). The correlation with international stages is based not only on foraminifers, but on ammonites too, such as *Asteroceras obtusum* and *Uptonia jamesoni* (Norling 1972, Fig. 14 herein).

In the lower part of this zone the foraminiferal fauna is rather scarce, including species such as *Citharina inaequistrata* (Plate 1:12), *Vaginulina listi* (Plate 1:9), *Mesodentalina haeusleri* (Plate 1:17), *Astacolus neoradiata*, *Trochammina gryci* and *Paralingulina tenera* (ssp. *tenuistriata, pupoides* and *praepupa*). The co-occurrence of *Marginulina spinata spinata* and *Citharina inaequistriata,* found i.e. in the lower part of the type section of the Katslösa Member is of importance for an approximate location of the Sinemurian–Pliensbachian boundary (Norling 1972). These two foraminiferal species have therefore been chosen to characterize a narrow foraminiferal subzone including the uppermost part of the Pankarp Member and the lowermost part of the Katslösa Member in Scania (Upper Sinemurian, p. 25).

In the upper part of the *Marginulina spinata spinata* Zone the foraminiferal fauna becomes richer, including mainly Lower Pliensbachian forms, apart from more long-ranging ones (Fig. 28). One of the most characteristic species within the upper part of the zone is *Astacolus denticulacarinata* (Plate 1:20), a species occurring in the lowermost part of Upper Pliensbachian too. Besides, species such as *Ichthyolaria mesoliassica, I. frankei, Prodentalina insignis, Paralingulina* ssp. *subprismatica* and *pupa, Marginulina prima rugosa* and *Astacolus quadricostata* are typical.

According to the ammonite finds at the Gantofta Brick Pit (Figs. 14, 15) and the Katslösa Member type section (Troedsson 1951, Reyment 1959, 1969), the *Marginulina spinata spinata* Zone corresponds to the Lower Liassic interval including at least the *Asteroceras obtusum* and *Uptonia jamesoni* Zones and probably still younger Early Pliensbachian ammonite zones (Norling 1972).

The main part of the Katslösa Member is characterized by the co-occurrence of *Astacolus denticulacarinata* (Plate 1:20) and *Marginulina spinata spinata,* a pair of foraminiferal species which have been chosen as subzonal denominators. This subzone roughly corresponds to the Carixian Substage. The sequence embraced by the *Marginulina spinata spinata* Zone (Fig. 27) includes variegated clays and claystones, calcareous, mainly dark claystone and shale, and some light-coloured calcareous siltstones as well.

Upper Pliensbachian

Saracenaria sublaevis Zone

(Figs. 14, 28)

This zone mainly embraces the lower part of the Rydebäck Member of the Rya Formation. The foraminiferal fauna of this zone is rather rich, especially in its lower part, including some species indicating a Late Pliensbachian age. The whole fauna and the stratigraphical range of various species are given in Fig. 28.

In the basal part of the zone, a short-ranging subspecies of *Brizalina liasica* has been found, spanning the Carixian-Domerian boundary in western Europe, viz. *Brizalina liasica amalthaea* (Plate 1:14). This foraminifer is chosen as subzonal denominator (Fig. 14). The foraminiferal assemblage characterizing the *Saracenaria sublaevis* Zone includes species such as *Marginulina spinata interrupta, Paralingulina tenera* ssp. *carinata, Tristix liasina* (Plate 1:8, 13), *Ichthyolaria terquemi, I. major, Marginulina prima prima, Lenticulina acutiangulata, L. turbiniformis* and *Vaginulina spuria.* The rocks of the zone are characterized by grey, partly greenish and reddish brown, calcareous siltstones with intervals of banded claystone, ferruginous claystones and conglomerates.

Toarcian – Aalenian

Saracenaria trigona – Citharina clathrata Zone

(Figs. 14, 16, 28)

This zone corresponds to the upper part of the Rydebäck Member of the Rya Formation and the lower part of the Fuglunda Member (thin marine ingressional layers only) of the Mariedal Formation (Fig. 16). This is true of drill core sequences in western Scania only. In the type sections of the Fuglunda Member and the Mariedal Formation no foraminifers have yet been found (Norling et al. 1993). Marine influence of the basal Middle Jurassic seems to be restricted to western Scania. Apart from *Citharina clathrata*, foraminifers such as *Anomalina liassica, Tristix liasina* (Plate 1:8, 13), *Ichthyolaria terquemi, Saracenaria trigona, Marginulina reversa, Lenticulina vetusta* and *Citharina deslongschampsi* characterize this zone. The zone has been identified in the Rydebäck–Fortuna cores Nos. 1 and 4 in western Scania. The sequence mainly consists of dark, partly variegated siltstones, with a varying content of clay, ferruginous oolites and conglomerates in the lower part, and clayey, mainly light, uncemented silt and sand in the upper part.

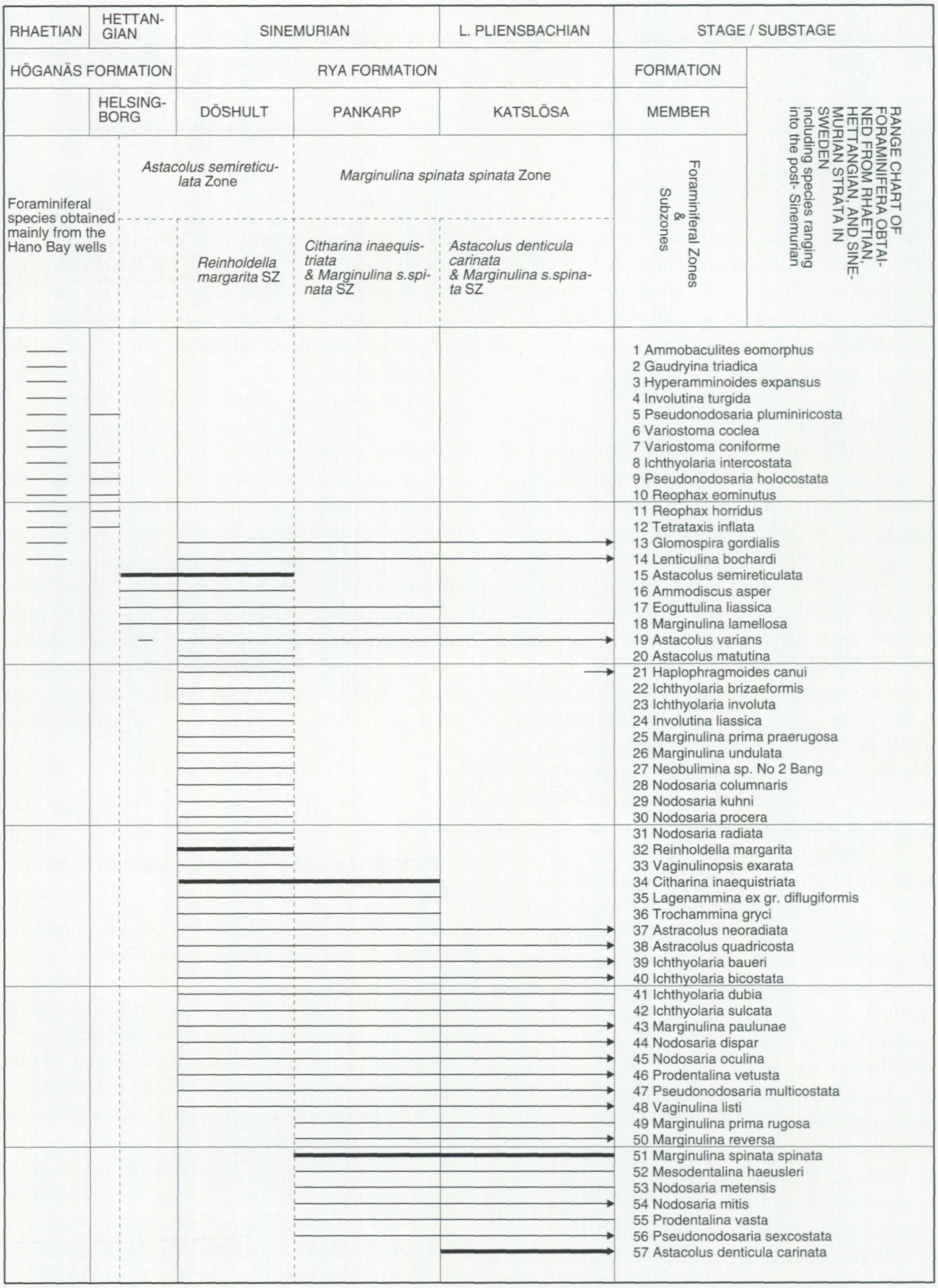

Fig. 27. Range chart of foraminifera from Rhaetian, Hettangian, and Sinemurian strata in Sweden, including species ranging into the post-Sinemurian.

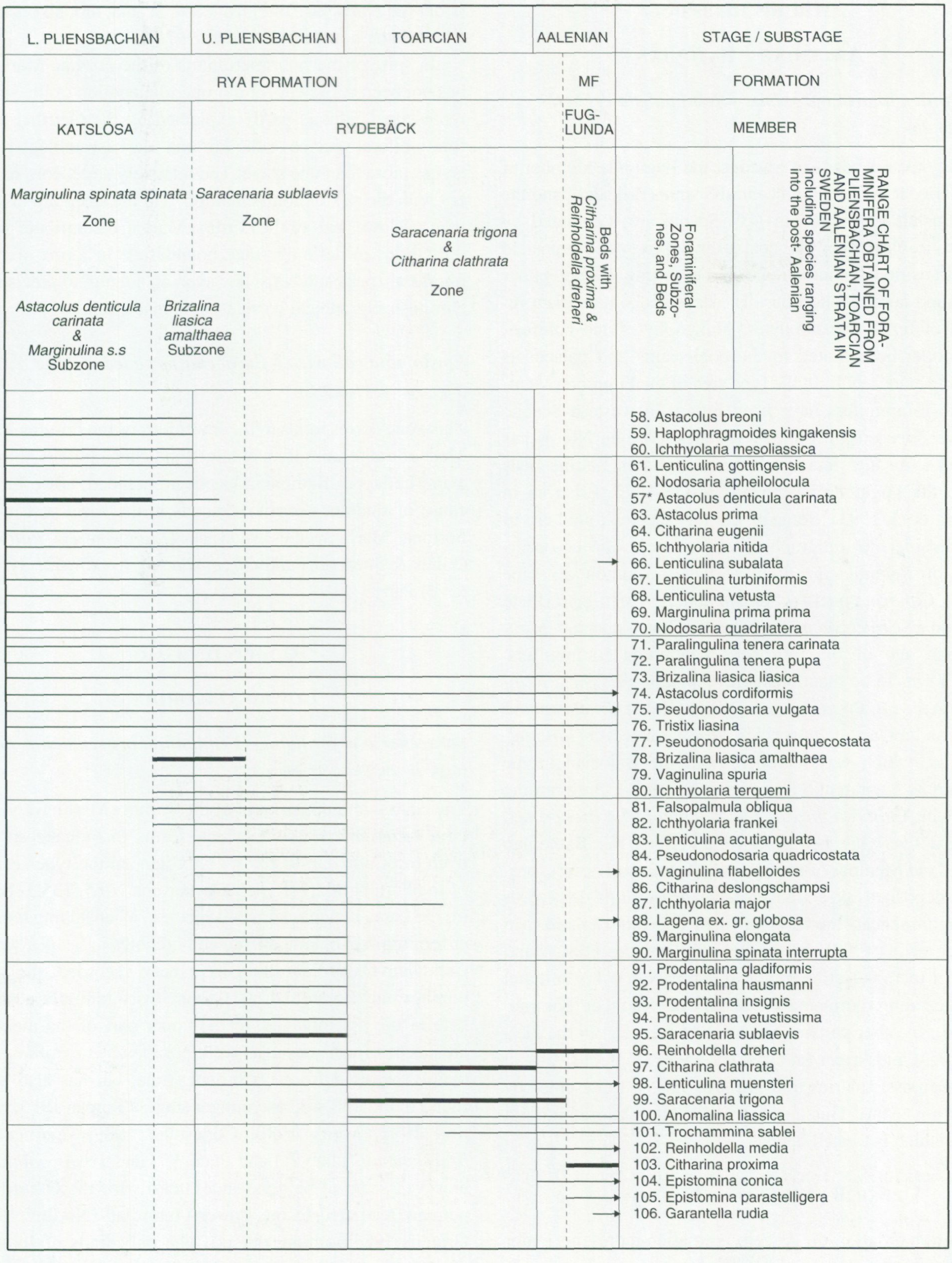

Fig. 28. Range chart of foraminifera from Pliensbachian, Toarcian, and Aalenian strata of Sweden, including species ranging into the post-Aalenian. MF=Mariedal Formation.

Middle Jurassic

Aalenian / Bajocian

Beds with Citharina proxima – Reinholdella dreheri

(Figs. 16, 28)

The Bajocian deposits of Sweden, the Fuglunda Member of the Mariedal Formation in central Scania (Eriksdal), and the Vilhelmsfält Formation in NW Scania are dominated by sandstone, claystones and coal arranged in cycles deposited in a transitional continental-marine setting during rather warm and humid conditions. The deposits contain plant remains of ferns, cycadophytes, ginkgophytes and conifers, and rootlet beds linked to the coal-seams and palaeosols (Norling et al. 1993). In the type area of the Fuglunda Member, no foraminifers have been found. In western Scania, however, one core drilling, Rydebäck–Fortuna No. 4, has yielded a meagre fauna in thin ingressional marine beds within the Fuglunda Member (Norling 1972, Erlström in Norling et al. 1993). Some of the few species found are of considerable biostratigraphical importance. The co-occurrence of *Reinholdella dreheri* (fairly common at some levels), *Citharina proxima, Epistomina parastelligera* (Plate 4:5) and *E. conica* seems to indicate a Late Aalenian–Early Bajocian age of the thin beds containing foraminifers. Other forms to be mentioned are *Anomalina liassica, Reinholdella media, Brizalina liasica* (Plate 1:14), *Trochammina sablei* and a *Garantella* species closely related to *Garantella rudia,* which was recorded from the Bajocian in the Ukraine by Kaptarenko-Chernoussova (1956). Between the Beds with *Citharina proxima* and *Reinholdella dreheri* and the next overlying bed with foraminifers, the Bathonian Glass Sand Member of the Mariedal Formation occurs, probably deposited as a transgressive prograding delta over tidally influenced lower delta plain deposits (Erlström in Norling et al. 1993). In the type area of the Glass Sand Member there is a stratigraphical gap between this unit and the succeeding rudimentary Fyledal Clay Member (Kimmeridgian). In other parts of Scania, however, e.g. in the Helsingborg–Landskrona and Åstorp areas (Figs. 12, 20), a Middle Jurassic marine transgressive pulse is represented by the Fortuna Marl. This unit has yielded a rich foraminiferal fauna, which is treated below.

Upper Bathonian – Callovian

The Fortuna Marl of the Annero Formation represents major marine transgressions from late Middle Jurassic to early Late Jurassic times, affecting NW Scania and the Hanö Bay east of the province as well. This is indicated by finds of a prolific foraminiferal fauna. Of interest in this connection are also finds of excellently preserved Callovian ammonites (from the *Lamberti* Zone) from SW Scania, though obtained from erratic boulders (Reyment 1971).

In spite of the rich microfauna of the Fortuna Marl this has not been sufficient for a proper delineation of the stages represented. This is partly explained by the fact that most foraminiferal species of the Fortuna Marl assemblage range across more than one stage. The relatively small core recovery with the risk of contamination, and the steep dip of strata in the lower part of the Fortuna Marl also contribute to the difficulties in defining stage boundaries. In terms of foraminiferal zones and beds, however, an attempt to precise the chronostratigraphical correlation is made here.

Epistomina callovica – Saracenaria phaedra Zone

(Figs. 16, 29; Plate 2:1)

This zone corresponds to the lower part of the Fortuna Marl. Most of the foraminifers obtained indicate a post-Bathonian age. The Upper Bathonian has been included, however, because of finds of certain ostracods in the basal part of the Fortuna Marl, species such as *Oligocythereis fullonica* (Jones & Sherborn) and *Oligocythereis woodwardi* Sylvester-Bradely.

Upper Jurassic

Lower Oxfordian

Saracenaria oxfordiana – Lenticulina brueckmanni Zone

(Figs. 18, 29; Plate 2:3, Plate 3:7)

The central and upper parts of the Fortuna Marl have yielded a foraminiferal fauna which seems to indicate an age from top Callovian to Early Oxfordian. In the type section of the Fortuna Marl (Rydebäck–Fortuna No.5, 135.2–161.3 m) the fauna includes some 40 species. When adding together foraminifers obtained from all boreholes in Scania, where Callovian–Oxfordian strata have been recorded, the total number may be around 60. Calcareous foraminifers dominate in the assemblages. In the upper part of the member arenaceous forms occur as well. *Saracenaria oxfordiana* is mainly reported from Oxfordian strata, but has also been found in older as well as younger stages (Tappan 1955, Norling 1972, Munk 1980, Copestake 1989). *Lenticulina brueckmanni* (Plate 2:3 and Plate 3:7) and *Tristix oolithica,* however, seem to be good index fossils for the Oxfordian, perhaps restricted to the Lower Oxfordian (Norling 1972, Grigelis 1985b among others). The only finds of Jurassic planktic foraminifers in Sweden, are limited to Oxfordian deposits of the Hanö Bay (p. 34). Along with characteristic Callovian–Oxfordian benthic foraminifers there are records of several small planktic forms showing affinity to *Globuligeina oxfordiana* (Plate 5:4–8)

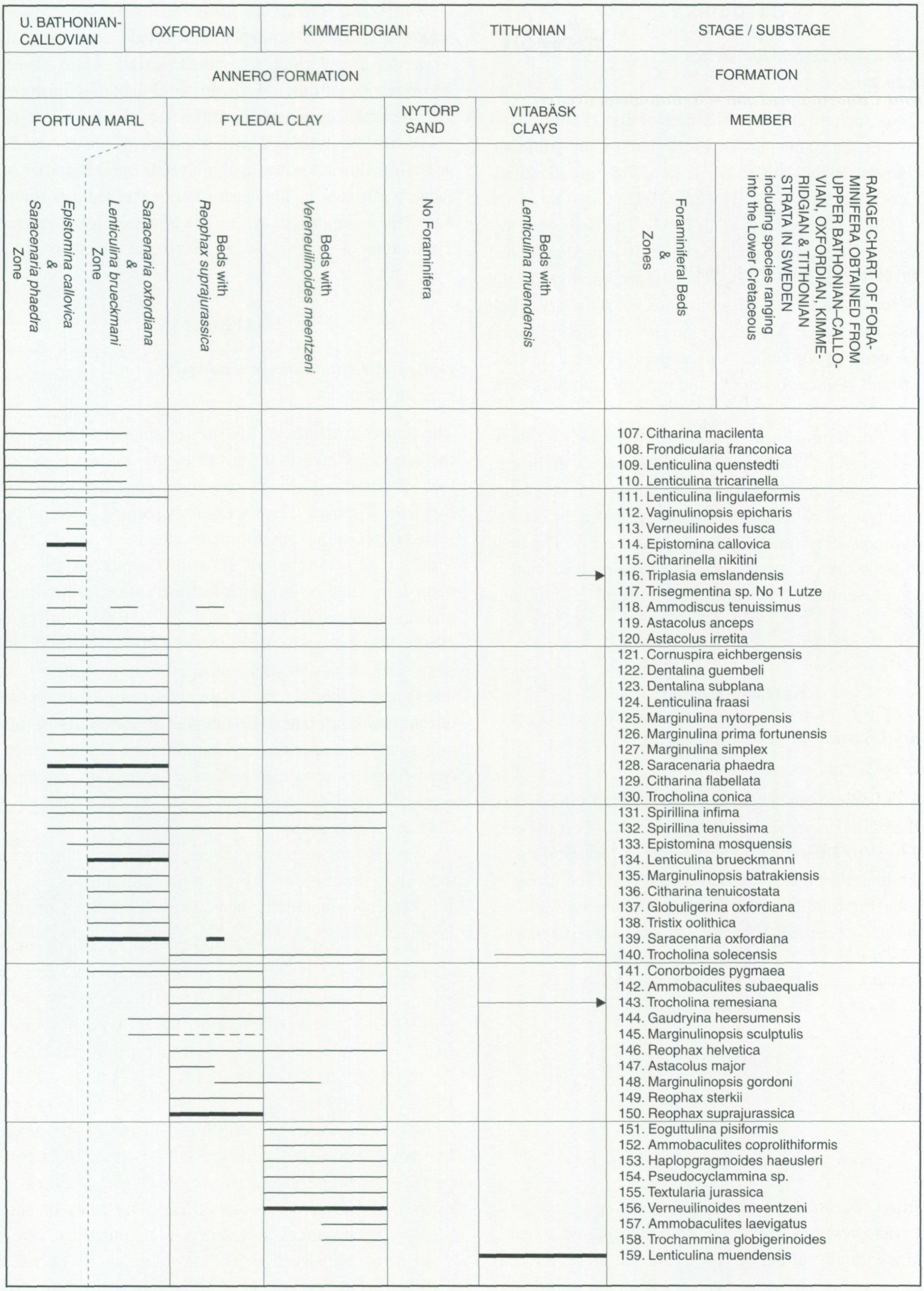

Fig. 29. Range chart of foraminifera from the Upper Bathonian, Callovian, Oxfordian, Kimmeridgian, and Tithonian of Sweden, including a couple of species ranging into the Lower Cretaceous.

Oxfordian

Beds with Reophax suprajurassica

(Figs. 18, 20, 29)

These beds include the topmost part of the Fortuna Marl Member and the main part of the Fyledal Clay Member, both belonging to the Annero Formation. They are identified in drill core material only (Norling 1972, Guy-Ohlson & Norling 1988, 1993, Norling et al. 1993). The Beds with *Reophax suprajurassica* are characterized by a predominance of arenaceous foraminifers, especially representatives of the genera *Ammobaculites, Haplophragmoides, Reophax* (Plate 2:10) and *Textularia*. A scarce fauna of calcareous forms does also occur, *Lenticulina brueckmanni* (Plate 2:3, Plate 3:7), *L. fraasi, Astacolus anceps* and rare epistominids to be mentioned.

The bed denominator, *Reophax suprajurassica,* is abundant at some levels. The lithology of the sequence embraced by these foraminiferal beds is mainly variegated clays and claystones (greenish-bluish) with some intervals of brownish, ferruginous claystones, and some silty layers. The beds fall within the Oxfordian according to the European ranges of the representatives of the foraminiferal assemblage (Fig. 29).

Kimmeridgian

Beds with Verneuilinoides meentzeni

(Figs. 18, 20, 29)

These beds embrace the uppermost part of the Fyledal Clay, as this member is represented in the Rydebäck–Fortuna core No. 5 (Fig. 20). The rather meagre fauna of foraminifers includes both arenaceous and calcareous forms. The group of arenaceous foraminifers is represented by *Ammobaculites subaequalis, A. coprolithiformis, A. laevigatus, Reophax helvetica* and *Textularia jurassica* along with *Verneuilinoides meentzeni.* Among characteristic calcareous forms *Astacolus cordiformis, Marginulinopsis gordoni, Lenticulina fraasi, Eoguttulina pisiformis*, and scattered epistominids may be mentioned (see Fig. 29).

Above the Fyledal Clay a sequence of uncemented sand and silt follows, known as the Nytorp Sand Member of the Annero Formation. This unit has not yielded any foraminifers. The member falls within the Kimmeridgian and /or the Tithonian.

Tithonian

Beds with Lenticulina muendensis

(Figs. 18, 22, 29, 30)

The uppermost Jurassic lithostratigraphical unit in Sweden, the Vitabäck Clays, is still insufficiently known as to its content of foraminifers. As the underlying unit, the Nytorp Sand, the Vitabäck Clays are mainly formed in slightly more varied depositional environments than the Fyledal Clay. The Vitabäck Clays represent Jurassic–Cretaceous transitional beds dominated by brackish to freshwater strata with some marine influence (Erlström et al. 1991, 1993; Norling et al. 1993). These deposits are composed of partly cyclic successions with clays and silts deposited in quiet waters (coastal lakes) and lagoons, which is evident from the composition of the molluscan fauna (Erlström et al. 1991). As to foraminifers only one species of biostratigraphical importance has been found in core material, viz. *Lenticulina muendensis*, originally recorded from the Middle Münder Marl of West Germany (Tithonian).

It is obvious that ostracods and palynomorphs are better tools than foraminifers for the biostratigraphy of the Jurassic/Cretaceous boundary beds in Sweden (see Christensen 1968, Erlström et al.1991, 1994, Vajda-Santivanez, 1998).

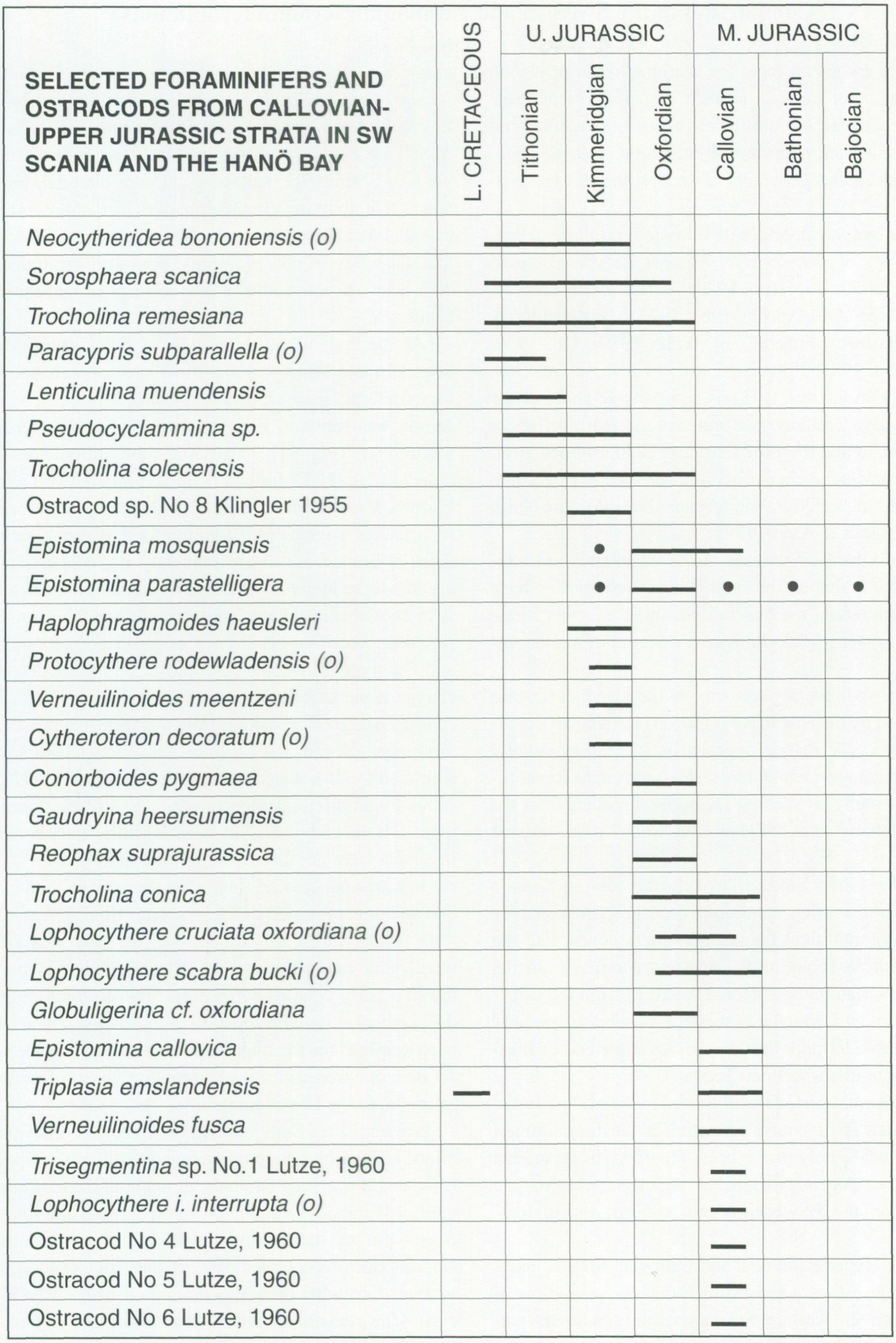

Fig. 30. Stratigraphical ranges of selected foraminifers and ostracods from Callovian–Upper Jurassic strata in SW Scania and the Hanö Bay. Ostracods are marked with (o).

Comparison of the Swedish and Lithuanian foraminiferal faunas

Foraminifers are useful tools for stratigraphical correlation and comparison of Jurassic basins. Comparison of different basins can be carried out when areas of foraminiferal species distribution, pathways of migration, palaeobiogeographical and palaeogeographical reconstructions are considered.

The stratigraphical ranges of Jurassic foraminiferal species are fairly well-known in Western Europe (Barnard 1950, 1952, 1953, Copestake 1989, Gordon 1970, Johnson, Morris & Shipp 1989, Norling 1968, 1972 to be mentioned), and in Eastern Europe as well (Bielecka 1960, Grigelis 1958, 1981, 1985, Kuznetsova 1979, Pazdro 1969, Piatkova & Permiakova 1978). A comparative study of the Jurassic–Early Cretaceous foraminifers from offshore Eastern Canada and the East European Platform, has given important knowledge about directions of species migration, especially during Late Jurassic times in the area of the North Atlantic (Grigelis & Ascoli 1995).

A major difference between the Swedish and the Lithuanian Jurassic is that all the Jurassic series of Sweden have yielded foraminifers, whereas in Lithuania the Lower Jurassic and the Lower Middle Jurassic are devoid of marine microfossils.

The basal sedimentary sequence of the Swedish Jurassic is represented by the Höganäs Formation (Hettangian), characterized by cyclic deltaic deposits (p. 22), an essentially continental sequence which has yielded a meagre foraminiferal fauna (totally 14 species, including 5 species from the Rhaetian–Hettangian of the Hanö Bay wells) in thin marine ingressional beds (Fig. 27).

From the Early Sinemurian onwards during Liassic times, however, marine conditions prevailed, indicated by the richest foraminiferal fauna of Sweden, concerning the Jurassic, with 38 foraminiferal species recorded from the Lower Sinemurian transgressional strata, 28 from the Upper Sinemurian and 45 from the Lower Pliensbachian, a number which increased to more than 50 species at the end of Liassic times (Late Pliensbachian–Toarcian).

The continental period that followed in the Middle Jurassic of Sweden is of course reflected in the foraminiferal fauna; 9 species only have been recorded from marine ingressions in Aalenian–Bajocian deposits, whereas the Lower Bathonian of Sweden seems to be devoid of foraminifers.

As to the Upper Bathonian and Callovian Stages, major marine transgressions appeared in Lithuania, as well as in south Sweden. In western Scania marine conditions prevailed from Late Bathonian time into the Oxfordian. During this time interval marls, limestones and calcareous siltstones referred to the Fortuna Marl were deposited, a lithostratigraphical unit, which has yielded some forty foraminiferal species. East of Scania, borehole material from the Hanö Bay indicates a longer period with open marine conditions from Late Middle Jurassic into the Late Jurassic than in western Scania. The lack of good core material, however, means that no reliable estimation of the foraminiferal faunal extent and range can be made. Nevertheless, the lithology of the Hanö Bay Middle Jurassic–Upper Jurassic transitional beds bear a close resemblance to corresponding sequence in Lithuania.

At the end of the deposition of the Fortuna Marl in Scania in late Mid-Oxfordian time, a drastic change in the foraminiferal fauna happened. A fauna dominated by nodosariids was replaced by a fauna very rich in arenaceous foraminifers (Fig. 31). This is still more pronounced in the Fyledal Clay (U. Oxfordian–Kimmeridgian), overlaying the Fortuna Marl. When compared with present-day foraminiferal faunas it seems as if foraminiferal assemblages dominated by arenaceous forms frequently are indicative of conditions where secretion of calcium carbonate is difficult, that is in cool-water or low salinity conditions (Gordon 1970). Based on noted co-occurrence of arenaceous foraminifera and Charophyta oogones, the cause for the sudden faunal change in the Late Oxfordian of western Scania is interpreted as a change of deposition from a marine to a brackish environment (Norling 1972). In recent waters Charophyta are restricted to fresh water and brackish conditions, and arenaceous foraminifers mainly to marine and brackish environments. At the end of the Jurassic the sedimentary conditions in Scania were not favourable to foraminifers.

In Lithuania, marine conditions started later than in Sweden and thus prevailed during a shorter time. The foraminiferal faunas during this time, however, were very rich, as were other marine organisms. These conditions have allowed a fairly detailed correlation between foraminifer and the classical ammonite zonation, a correlation which has not been possible for the upper Middle Jurassic and the Upper Jurassic of Sweden. Jurassic ammonite finds in Sweden are restricted to the Lower Jurassic.

Not until Late Bathonian–Early Callovian times foraminifers, along with other marine organisms, seem to appear in Lithuania. From then onwards, throughout the major part of the Late Jurassic, foraminifers formed a rich and important constituent of the marine fauna. In all the superfamily Nodosariacea represented 59% of the fauna (140 species), whereas Ceratobuliminacea contributed with 22% (50 species). The remaining part of the foraminiferal fauna belonged to Astrorhizacea, Ammodiscacea, Textulariacea, Miliolacea, Spirillinacea, and Globigerinacea (Figs. 24, 31).

The only stratigraphical part of the Jurassic within which

TABLE 5. Number of foraminiferal species in Jurassic Stages of Sweden and Lithuania.

Stages	Sweden	Lithuania
Rhatian-Hettangian	19	
L. Sinemurian	38	
U. Sinemurian	18	
L. Pliensbachian	45	
U. Pliensbachian-Toarc.	52	
Aalenian-Bajocian	9	
Bathonian		22
L. Callovian		8
M. Callovian	28 (Bathonian – L. Oxfordian)	39
U. Callovian		67
L. Oxfordian		52
M. Oxfordian	37 (M. Oxfordian – U. Kimmeridgian)	42
U. Oxfordian		31
L. Kimmeridgian		42
U. Kimmeridgian		42
Tithonian	5	13

foraminiferal faunas in Lithuania and Sweden can be compared is the Late Bathonian–Kimmeridgian interval, because the pre-Late Bathonian Jurassic of Lithuania is devoid of foraminifers, and from the Tithonian (Volgian) in Sweden five foraminiferal species only have been recorded.

For a general comparison of the Jurassic foraminiferal faunas in the SE Baltic area with those of Scania, the faunas have been subdivided into four main groups, vis. Nodosariacea, Ceratobuliminacea, other calcareous foraminifera, and arenaceous foraminifera. Such a comparison is valid for the Upper Bathonian, Callovian, Oxfordian, and the Kimmeridgian Stages. As to these four major groups of foraminifera, the relative frequencies of species show a similar pattern in both the areas for the main part of the upper Middle Jurassic. One difference is the high percentage of ceratobuliminacean foraminifera in the Upper Bathonian (35%) and Lower Callovian (37.5%) of the SE Baltic area (Fig. 31). Throughout the foraminifer-bearing succession of the Lithuanian Jurassic Ceratobuliminacea plays a much more important

TABLE 6. Nodocariacean, ceratobuliminacean, other calcareous, and arenaceous foraminifera in the Jurassic of Lithuania and Sweden.

Group of Foraminifera	Number of species in: Kimmeridgian U	Kimmeridgian L	Oxfordian U	Oxfordian M	Oxfordian L	Callovian U	Callovian M	Callovian L	Upper Bathon.
Lithuania									
Nodosariacea	25	31	19	24	19	55	31	3	6
Cerato-buliminacea	15	8	9	11	16	12	3	3	7
Other calcareous foraminifera	4	3	5	6	11	6	2	1	6
Arenaceous foraminifera	1	2	0	0	0	9	2	1	1
TOTAL	45	44	33	41	46	82	38	8	20
Sweden									
Nodosariacea	4		3	25	21	23	28	10	5
Cerato-buliminacea	1		1	3	3	4	3	1	1
Other calcareous foraminifera	4		1	2	2	2	2	2	2
Arenaceous foraminifera	11		6	2	1	2	2	1	0
TOTAL	20		11	32	27	31	35	14	8

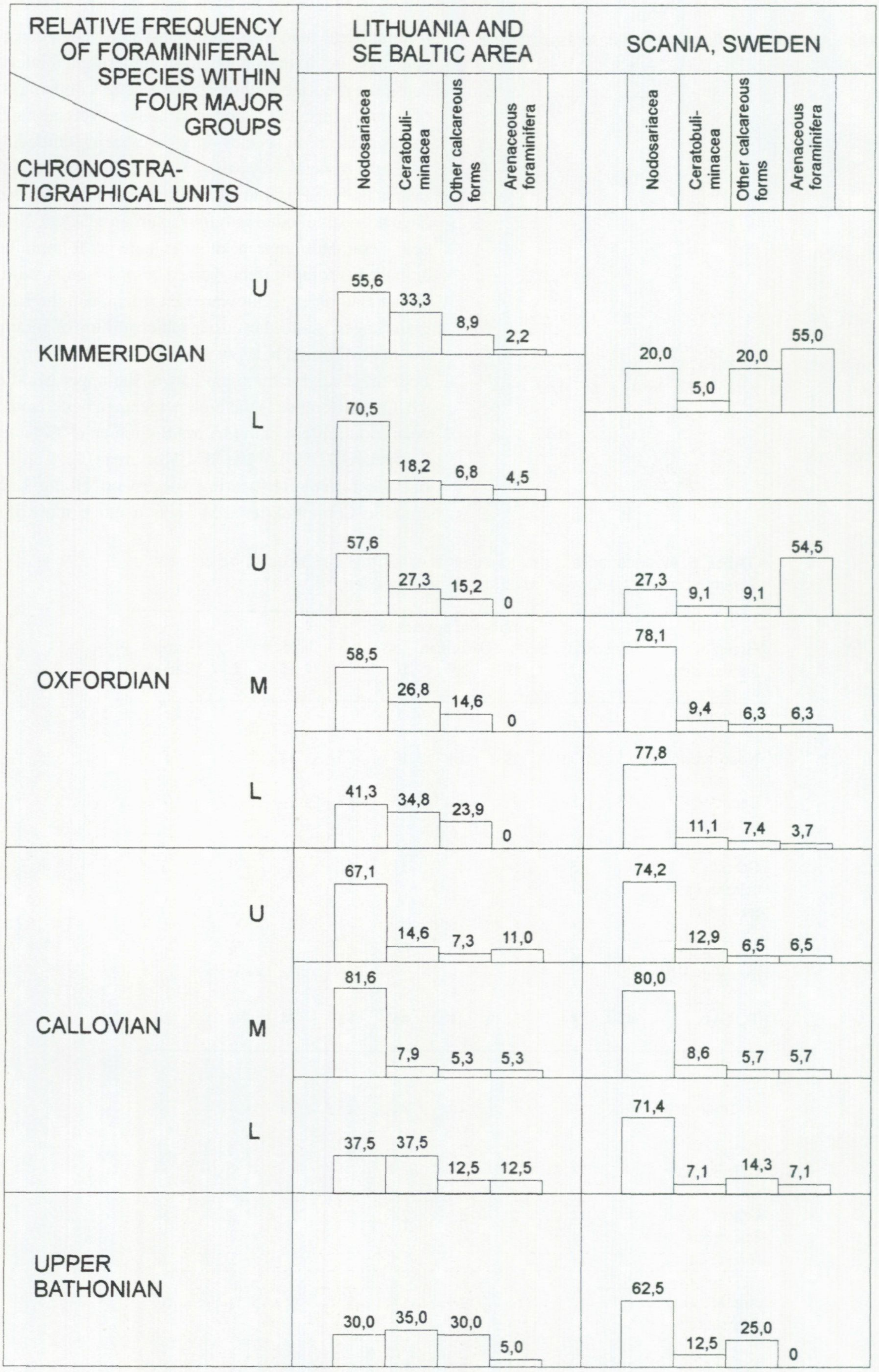

Fig. 31. Comparative histograms showing relative frequencies of foraminiferal species within four major groups in Lithuania and the SE Baltic region, and in Sweden.

TABLE 7. Foraminiferal genera from the Jurassic of Lithuania and Sweden listed in alphabetical order.

Genus	Number of species in Lithuania	Number of species in Sweden
Ammobaculites	2	3
Ammodiscus	2	2
Ammovertella	1	0
Anomalina	0	2
Astacolus	15	11
Brizalina	0	2
Ceratolamarckina	2	0
Citharina	11	8
Citharinella	4	1
Conicospirillina	2	0
Cornuspira	1	1
Cyclogyra	1	0
Denatlina	5	2
Eoguttulina	1	2
Epistomina	35	5
Epistominita	2	1
Epistominoides	3	0
Falsopalmula	2	1
Frondicularia	1	1
Garantella	0	1
Globulina	2	0
Globuligerina	1	1
Glomospirella	1	0
Haplophragmoides	1	3
Ichthyolaria	5	11
Lagena	1	3
Lagenammina	0	1
Lenticulina	52	14
Marginulina	7	10
Marginulinopsis	13	2
Marsonella	1	0
Mesodentalina	0	4
Miliospirella	2	0
Mironovella	3	0
Neobulimina	0	1
Nodobacularia	1	0
Nodosaria	2	9
Nubeculinella (Vinelloidea?)	1	0
Ophthalmidium	8	1
Orthella	1	0
Paleogaudryina	2	0
Paleomiliolina	2	0
Paralingulina	0	1*
Paulina	5	0
Planularia	14	0
Prodentalina	0	6
Pseudocyclammina	0	1
Pseudolamarckina	4	0
Pseudonodosaria	0	7
Quinqueloculina	1	0
Ramulina	1	0
Rectoepistominoides	1	0
Reinholdella	3	2
Reophax	1	5
Saccammina	1	1
Saracenaria	8	6
Sigmoilina	1	0
Sorosphaera	0	1
Spirillina	5	1
Tertataxis	0	2
Textularia	1	1
Tristix	3	2
Trochammina	1	3
Trocholina	4	1
Trochospirillina	1	0
Vaginulina	3	2
Vaginulinopsis	2	2
Verneuilinoides	0	2

* Many subspecies of *Paralingulina tenera*

role than in corresponding strata of Sweden. This does not only concern the number of species, but the number of genera too. The Lithuanian Jurassic has yielded genera such as *Ceratolamarckina, Epistomina, Epistominita, Epistominoides, Mironovella, Paulina, Pseudolamarckina, Rectoepistominoides* and *Reinholdella*. In corresponding stratal units of Sweden, two ceratobuliminacean genera only, *Epistomina* and *Epistominita,* have been recorded. It has also been noted that the epistominid specimens recorded in the Swedish Jurassic usually are in a bad state of preservation, whereas aragonite forms in the Lithuanian Jurassic seem to be excellently preserved.

From the Middle Callovian to the Middle Oxfordian nodosariacean foraminifers dominated in both regions. In the Late Oxfordian, as mentioned before, a drastic change of the faunal composition occurred in Sweden. From then and throughout the Kimmeridgian arenaceous foraminifers were dominant, represented by many different genera, whereas in Lithuania and adjacent areas the faunas of corresponding strata continued to have a dominance of nodosariacean foraminifera. Further comparisons can be made by studying the histograms in Fig. 31 (see also Table 6).

In the Jurassic of Sweden and Lithuania, and adjacent offshore areas, some 70 foraminiferal genera have been identified, but some foraminifers recorded remain unidentified as to genus. Of these genera 55 are recorded from Lithuania and 45 from Sweden (Table 7). The ratio arenaceous/calcareous foraminifera of the entire Jurassic faunas is about the same in both areas, viz. 1/3. At different stratigraphical levels, however, there are in part very great differences, as can be seen in Fig. 31.

The number of species within various genera gives an important characteristic of similarities and differences in the faunas. In Lithuania many more species have been identified than in Sweden. With regard to the number of species the six dominating genera in the Jurassic of Lithuania are: *Lenticulina* (52), *Epistomina* (35), *Astacolus* (15), *Planularia* (14), *Marginulinopsis* (13) and *Citharina* (11). In Sweden the following 6 genera dominate: *Lenticulina* (14), *Ichthyolaria* (11), *Astacolus* (11), *Marginulina* (10), *Citharina* (8) and *Pseudonodosaria* (7). A similarity between Lithuania + SE Baltic, and Scania is thus a dominance of species within *Lenticulina, Astacolus* and *Citharina,* all nodosariacean foraminifers. Major differences are reflected e.g. in the number of *Epistomina* species (35) in Lithuania, whereas 5 species only have been recorded in the Swedish Jurassic (Table 7).

Facies distribution, palaeogeography and palaeoecology

During the Jurassic the sedimentary basins of Western and Central Europe continued to subside along patterns established in the Triassic. Throughout this area a gradual overstepping of the Late Triassic basin edges is evident (Ziegler 1990). This may be related to a cyclical rise of sea level, not least as noted in Lower Jurassic deposits along the SW margin of the East European Platform, e.g. in Scania (Troedsson 1951, Vossmerbäumer 1970, Norling 1972, Haq et al.1988, Norling et al. 1993, Ahlberg 1994).

In Rhaetian and Hettangian times renewed transgressions of the Tethyan Sea occurred in Western Europe (Plate 6). During the Rhaetian, a connection may have been established for the first time between the Arctic and the Tethys seas via the Irish Sea and the Rockall-Faroe Rift (Ziegler 1982). Tethys-derived marine incursions reached also into the Polish Trough via the East Carpathian Gateway during the Rhaetian (Senkowiczowa & Szyperko-Sliwczynska 1975).

In Western and Central Europe post-Hettangian Lower Jurassic facies patterns were strongly influenced by the interference of the colder, lower salinity Arctic and the warmer, higher salinity Tethys waters, as well as the influx of clastics from eastern sources (Plates 7, 8). At the same time the rising sea level induced an overstepping of the basin margin. In principle, three facies provinces are visible, viz. (1) the clastic-dominated Baltic–Polish Province, (2) the open marine colder water North Sea–North German Shale Basin, and (3) the warmer water, carbonate-shale dominated basins of south-western Europe (Ziegler 1990).

During the Rhaetian–Lower Jurassic Lithuania formed a part of the Baltic–Polish Province (1), also named the Eastern Clastic Province, whereas Scania during the same time interval demonstrates facies characteristic of both the Eastern Clastic Province and the North Sea–North German Shale Basin (1 and 2).

In the Baltic–Polish Province sedimentation during Aalenian time was restricted to the Polish Basin, where continental clastics were deposited initially (Plate 9). In Late Aalenian time the Tethyan Sea advanced north-westwards resulting in deposition of shallow marine shales in the southern and central parts of the Polish Basin, and accumulation of sandy, shaly successions in its northern part, including parts of Scania, whereas no Aalenian deposits have been recorded in Lithuania (Grigelis et al. 1985, Norling 1972, Ziegler 1990, Norling & Grigelis 1996).

In Bajocian time a regression caused a renewed restriction of marine environments to the axial zones of the Polish Trough (Dadlez et al. 1973). This was followed by a Late Bajocian transgression, which invaded much of the platform areas in Poland and persisted throughout the Bathonian (Plates 10, 11). Along the northern margin of the Baltic–Polish Province, however, in an area including both Lithuania and Scania, thin marine ingressional beds of Bajocian and Bathonian age only have been recorded (pp. 11, 28, 38).

Within the Baltic–Polish Province an Early Callovian regression was followed by a gradual transgression that peaked during the Early Oxfordian (Plates 12, 13, 14). In the Early Callovian sedimentation was mostly restricted to the axial parts of the Polish Trough, which were occupied by a shallow sea arm connected with the Tethyan shelves. This embayment was separated from the North German Basin by a land mass connecting the Lusatian High with the Pompeckj Uplift and the eastern parts of the Ringköbing–Fyn High. During the Late Callovian this barrier was transgraded by the sea (Ziegler 1990). At the same time much of Eastern Europe became inundated resulting in marine connections with the Lvov–Lublin and the Moscow Basins (Grigelis et al. 1992). By the Early Oxfordian boreal faunas migrated via the North Danish Basin into the Baltic–Polish Province, and in its southern parts mixed with Tethyan related taxa. This connection with the Arctic and Tethyan faunal provinces was maintained during the Kimmeridgian and Tithonian and was interrupted during the latest Tithonian only (Plates 15, 16). In the axial parts of the Danish–Polish Basin, sedimentation was more or less continuous during the Tithonian and Berriasian (Ziegler 1990). Within the Fennoscandian Border Zone and further to the east into the Baltic region, however, Late Kimmerian tectonic movements resulted in gaps in sedimentation (Guy-Ohlson & Norling 1988, Grigelis et al. 1992, Marek & Grigelis 1998; Plate 17 herein).

LITHUANIA

In the eastern Baltic, sedimentation during the Jurassic period resulted in thick deposits with various fossils. From a lithological and genetic point of view, these deposits can, in general, be subdivided into two major successions, the older one having an alluvial to lacustrine character, the younger one being marine. The Lower and Middle Jurassic succession of the Eastern Baltic has yielded plant remains and palynomorphs, some of them being useful for relative dating and biostratigraphy. The marine Callovian and Upper Jurassic strata contain a rich and varied fauna. Ammonites and foraminifers have been the most important groups for the dating and biozonation of the strata. The thickness of the Jurassic in Lithuania and adjacent areas varies from some few metres in northern Lithuania to c. 240–250 metres at the Polish border.

In the Early and Middle Jurassic, into the Middle Callovian, a continental regime prevailed in the Eastern Clastic Province. Now and then slow subsidence resulted in minor basins that were filled with sand and clay deposits, in places rich in plant fossils. Certain beds rich in plant debris were transformed to seams of brown coal. During the Middle Jurassic the first indices of marine influence appeared. The oldest marine ingressional beds recorded in Lithuania are of Late Bathonian age, beds which have yielded a poor foraminiferal fauna and a few lamellibranchs.

In the beginning of Callovian time the entire Lithuanian area, with the exception of its north-eastern part, was submerged by the sea transgressing from the south (Plate 12). A marine period lasted then almost to the very end of the Jurassic. Thus, at the end of the Middle Jurassic, in Mid-Callovian time, palaeogeographical conditions changed greatly. Wide transgressions of the North German and Polish basins started from the southwest. From Callovian time throughout the Late Jurassic sandy, and clayey calcareous sediments were deposited. The sea was rich in various protozoans and invertebrate organisms. Ammonites were living in the sea, and the first planktic foraminifers appeared (Grigelis 1958), indicating open marine conditions. The sea bottom was occupied by various brachiopods, echinoids and crinoids. During the Oxfordian reef-forming corals and bryozoans were characteristic of the fauna. Occasionally, siliceous sponges appeared indicating cold water influence.

The prolific fauna obtained indicates that the marine basin was of shelf type, with normal salinity, oxygen and rich in calcium carbonates. As characteristic features of the marine Jurassic succession (Callovian–Upper Jurassic) in Lithuania may be mentioned: dark grey to blackish, calcareous, argillaceous, fossiliferous sediments, deposited in a sea much warmer than the present day climate in the area. The basin formed a part of the North German–Polish Basin with connection to the Tethyan Sea.

Relative dating and correlation of pre-Callovian Jurassic units in Lithuania are mainly based on lithostratigraphical criteria. The dating and correlation of Middle Callovian and younger units are based mainly on ammonite and foraminiferal zonation, which allow this part of the Lithuanian Jurassic to be widely correlated within the boreal palaeogeographical realm.

Within the marine sedimentary sequence of the Lithuanian Jurassic the Callovian, Oxfordian, Kimmeridgian and Volgian Stages have been established. They are divided into lithostratigraphical and biostratigraphical units. Major parts of the sequence can be seen in the Papilė region of NW Lithuania (Fig. 3), where 15 exposures are known. The Jurassic sequence of the Papilė region is a reference section of the Jurassic in the East European Platform. It also represents the stratotype section of the Middle and Upper Callovian and the Lower Oxfordian of the South Baltic area.

SWEDEN

In Scania and offshore, a mainly non-marine Upper Triassic-Hettangian sequence is followed by a marine comprising the remaining part of the Lower Jurassic (Plates 6, 7, 8). Then a non-marine sequence followed, representing the major part of the Middle Jurassic (Plates 9, 10, 11). From top Bathonian throughout the Callovian and the main part of the Oxfordian, marine sediments were deposited in western Scania and in the Hanö Bay, whereas the central part of Scania is devoid of strata from this time interval. The same is true of the north-western part of Scania (Helsingborg–Höganäs area, the Ängelholm Trough excluded), where post-Liassic sediments, once deposited, were eroded away during Cretaceous–Tertiary inversion movements. Upper Oxfordian, Kimmeridgian and Tithonian strata of Scania were deposited in brackish-marine and freshwater environments such as lagoons and coastal plains.

The Rhaetian to Early Jurassic transgressions of the Tethys, which reached northwards into the Central Graben of the North Sea and the northern part of the Danish Embayment did not affect Scania until Hettangian time (Norling & Bergström 1987). There seems to be one exception, the Hanö Bay east of Scania, where finds of Rhaetian foraminifers indicate the presence of marine sediments (Norling & Skoglund 1977, Norling et al. 1993, and present paper, Fig. 12, p. 23). The first major transgression in South Sweden appeared in the Early Sinemurian. From then on marine conditions prevailed throughout the Early Jurassic with the exception of a short break in Late Sinemurian (see p. 25).

The deposition of Jurassic sediments in Sweden was strongly influenced by tectonic activities within the Tornquist Zone. The sedimentary record is reflected by numerous provenance shifts, disconformities and evidence of transgressions and regressions. In addition, the climate was a major factor controlling weathering, erosion and deposition (Ahlberg in Norling et al. 1993).

During Bajocian–Bathonian times the marine influence decreased in Scania as a result of renewed faulting at the margin of the East European Platform. The tectonic uplift led to a general regression over vast areas and the development of sedimentary facies similar to the Rhaetian deposits. A narrow depositional area across Scania acted as a communicating link between the Norwegian–Danish Basin and the Central European Basin (Plates 10, 11). To the west, the Ringköbing-Fyn High existed as a vast denudation area. In Scania, the depositional environments were dominated by non-marine (alluvial, lacustrine) and sea-margin (lagoonal, intertidal) settings. The same is true of the Norwegian–Danish Basin and the Central Graben of the North Sea (Norling et al. 1993). At that time shallow marine conditions were limited to the Central European Basin (Jubitz et al. 1988).

As in the North Sea Graben system, areas within the Scanian part of the Tornquist Zone were subjected to volcanism from the Middle Jurassic and onwards. In Central Scania, which is dominated by gneiss and a patchy thin Jurassic sedimentary cover, at least 70 Mesozoic basaltic necks have been recorded (Norin 1933, 1934, Bergström 1981, Norling & Bergström 1987, Norling et al. 1993, Bylund & Halvorsen 1993). The bulk of volcanics in the Central North Sea is dated to the Bajocian and Bathonian on the basis of biostratigraphical criteria. Radiometric age determinations, however, yield a wider range, which may be a function of secondary alteration of the analysed rocks (Ritchie et al. 1988, Latin et al. 1989, Ziegler 1990).

In Callovian time sedimentation in Scania was again influenced by marine conditions. This is recorded in borehole sections in western Scania and the Hanö Bay east of the province. In the Vomb Trough of Central Scania, however, Callovian strata are missing.

In Late Jurassic times an increasing influence of marine conditions led to the formation of shallow marine clays and silts over vast areas in the Central European Basin, as well as in the Norwegian–Danish Basin. A narrow pathway between the Fennoscandian Shield and the Ringköbing–Fyn High linked the two basins, but was still influenced by brackish conditions during most of the Late Jurassic (Plates 13–16).

The Rhaetian and Hettangian deposits of Sweden have yielded a fairly rich, well-preserved macrofossil plant flora, which, along with pollen and spores, has been of great importance for correlation and dating. The same is true of the Middle Jurassic non-marine deposits. The Early Jurassic marine conditions in Sweden resulted in fairly rich macro- and microfaunas, of which ammonites, foraminifers and ostracods have been used for zonation, correlation and dating. Other organisms such as brachiopods, belemnites and bivalves are also important representatives of the Early Jurassic marine faunas, but these groups have not yet been studied in detail. The most useful tools for dating the Middle Jurassic non-marine deposits have been pollen and spores. For the Bajocian, plant macrofossils too have been of importance. The mostly marine deposits of top Bathonian to Oxfordian ages have yielded fairly rich foraminiferal faunas, as described above, whereas no ammonites of use in biostratigraphy have been recorded. Kimmeridgian and Tithonian deposits of Scania have also yielded foraminiferal faunas, mainly of brackish-marine character. For these two stages, however, ostracods and palynomorphs have been the most reliable tools in biostratigraphy.

Foraminiferal biogeography and palaeoecology

The boreal realm occupied the northern part of the Northern Hemisphere (Hallam 1975). The Jurassic foraminiferal faunas of Lithuania and Scania lived in shelf sea environments favourable to benthic foraminifers. In both the areas nodosariacean taxa dominated the fauna most of the time. Though there are great similarities between the faunas there are also differences. One difference between the foraminiferal faunas of Late Middle Jurassic and Late Jurassic ages in Lithuania and Sweden is the following: Though there is no major difference in the number of genera in the two regions, the Lithuanian fauna seems to be much more diversified at a specific level. The differences may be due to a provinciality related to tectonic plate movements and more of the influx of warm water from the Tethyan Sea via the Polish Basin into the Eastern Baltic area, than to Scania. The Scanian waters on the other hand had more connections with Arctic waters than the Lithuanian basins. All the major faunal changes during the Jurassic can be related to changes in the environments of deposition.

During the Early Jurassic an overall progressive increase in diversity of the foraminiferal associations happened throughout Western Europe, which was related to the marine transgressions starting in the Late Triassic (Rhaetian). In general, transgressions generated new appearances of taxa and regressions resulted in species extinctions. Well documented transgressions in the Jurassic of Sweden mark the arrival of new species and subspecies as a result of evolutionary appearances and/or migration, whereas regressions and time of lowered sea level appear to equate to extinctions (Norling 1968, 1972, Hallam 1961, 1987, Copestake 1989). Throughout the Early Jurassic the foraminiferal assemblages were dominated by nodosariacean taxa.

A characteristic feature of the Aalenian in northern Europe is the widespread development of strongly regressive facies, which concerns deposition in both onshore and offshore basins.

Characteristic foraminiferal associations were more mixed than in the Early Jurassic and included species such as *Citharina proxima, Citharina clathrata, Reinholdella dreheri, Lenticulina varians* and *Trochammina sablei* (Norling 1972, Morris & Coleman 1989). At certain horizons within the Aalenian–Bajocian of Scania the meagre fauna of calcareous benthic foraminifers, other than nodosariaceans, dominated, e.g. *Epistomina, Garantella* and *Reinholdella* species. When occurring alone the genus *Reinholdella* may indicate waters with low oxygen content (Murray 1989). This is for instance the case at certain levels, representing short marine incursions within the essentially non-marine Fuglunda Member, which spans the Aalenian–Bajocian boundary in W Scania.

In both Lithuania and Sweden the top Bathonian–Callovian stratigraphical interval is characterized by a transgressive sequence, which is also the case of the North Sea (Morris & Coleman 1989, Grigelis & Norling herein).

The foraminiferal assemblage of this stratigraphical interval in western Scania (see Fig. 29) has much in common with the foraminiferal fauna in the Bathonian–Callovian boundary beds in the Inner Moray Firth of Scotland (Beatrice Field area), with species in common such as *Epistomina parastelligera, Frondicularia franconica, Lenticulina muensteri,* and *Marginulinopsis batrakiensis.* In both areas sediments as well as the faunas indicate marginal to shallow marine environments. At the margin of the marine Heather Formation in the Inner Moray Firth the continental Brora Coal Formation is present. In Scania the onshore Bathonian deposits are represented by the sub-continental Glass Sand of the Mariedal Formation. Open marine connections east of Scotland and the Mid North Sea High via northern Denmark to Scania and further eastwards seem to be obvious (Morris & Coleman 1989, Grigelis & Norling herein).

Deposits of corresponding age in Lithuania and the southern part of the Baltic Syneclise, Beds with *Ophthalmidium infraoolithicum* and *Lenticulina okrojanzi* contain a more varied nodosariacean fauna than those further to the west, together with other foraminiferal genera such as *Ophthalmidium* and several ceratubuliminaceans such as *Epistomina, Epistominoides, Reinholdella* and *Paulina*. The greater variety of nodosariaceans in the Baltic Basin suggests a more stable marine environment than in Scania. The fairly rich ceratobuliminacean fauna may indicate open marine shelf conditions. A closer connection with the Tethyan Sea via the Polish Basin may also be a reason for the difference between Lithuania and South Sweden, as to foraminiferal faunas at that time. According to Oravecz-Scheffer (1987), species of *Ophthalmidium* show a preference for protected micritic cavities within reef bodies. He & Norling (1991) arrived at a similar conclusion as to the presence of *Ophthalmidium* in Upper Triassic shelf sea environments in Sichuan, China.

During the Middle and Late Callovian the foraminiferal faunas in Lithuania and Sweden showed close similarities as to the representation of nodosariacean foraminifers, ceratobuliminaceans, other calcareous foraminifers and arenaceous forms (see Fig. 31). During the Oxfordian, however, a remarkable increase of ceratobuliminacean foraminifers occurred in Lithuania and the SE Baltic Basin, parallel to a dominating nodosariacean fauna, a combination interpreted as indicating open high-marine conditions, still more pronounced by the appearance of planktic foraminifers (Grigelis 1958). Jurassic planktic foraminifers probably spread from the Tethys only in times of unusually favourable temparature conditions (Gordon 1970) .

In the Oxfordian of South Sweden, on the other hand, the nodosariacean and ceratobuliminacean foraminifera gradually decreased, whereas arenaceous foraminifers increased to constitute more than fifty per cent of the fauna in the Late Oxfordian (Fig. 31). The difference in faunal composition between Lithuania and Scania became still more pronounced in the Kimmeridgian. The Late Jurassic faunal change in South Sweden is interpreted as a change from marine to brackish-marine conditions, indicated by the occurrence of an arenacean foraminiferal fauna together with Charophyta oogones at some levels. A cold water influence on the Swedish Upper Jurassic environments from the Arctic Sea in the north is most likely to have had an effect on the foraminiferal fauna too. Arenaceous foraminifers as indicators of reduced salinity, and in certain cases deeper water conditions, have been commented on by several students, including Gordon (1970), Norling (1972), Barnard et al. (1981), Shipp (1989) and Gregory (1989).

During the Tithonian regressions in both Lithuania and South Sweden caused a drastic decrease in the foraminiferal fauna and reduced connections to open marine basins.

As to the biogeography of Jurassic foraminifera a delineation of provinces, similar to those distinguished for ammonites and belemnites, is difficult. Regarding the northern hemisphere, a distinction can be made instead, between faunal assemblages characteristic of the Boreal–Atlantic region, and the Tethyan Sea (e.g. Gordon 1970, Grigelis & Ascoli 1995). In the South Baltic area treated in the present paper, the marine microfaunas now and then show indications of influence both from the Tethyan Sea (e.g. spread of planktic assemblages to restricted parts of the Boreal Realm) and from Arctic waters in connection with the initial opening of the Atlantic.

The lithologic–palaeogeographical maps

In the years 1975 to 1986 the present authors were involved in the IGCP Project Accession No. 86, entitled: "East European Platform, SW Border" with the brief key title "Project Tornquist". Apart from some 900 publications, Project Tornquist resulted in an atlas of geological maps of northern and central Europe, mostly lithologic-palaeogeographical maps, but also maps of structural geology.

Project Tornquist, with Professor K.B. Jubitz, Zentralinstitut für Physik der Erde, Berlin as the international leader, engaged geologists from 10 countries, viz. Czechoslovakia, England, Denmark, German Democratic Republic (GDR), the Netherlands, Poland, Roumania, Sweden, the Soviet Republics of Estonia, Latvia, Lithuania, Belorussia, Ukraine, Moldavia, and Western Germany (FRG). The head maps of the atlas produced, two sheets for each stratigraphical level, covering the main part of northern Europe from 15 selected horizons of the Phanerozoic, are on the scale 1: 1.5 Mill. Every sheet couple has smaller inset maps, on the scale 1:10 000 000, illustrating the lithology and palaeogeography of various stratigraphical stages or, concerning certain maps, of stratigraphical series.

Most of the maps were printed and sent to the national compilators of each country involved in Project Tornquist before the fall of the Berlin wall and the reunion of Eastern and Western Germany. Because of the dissolution of various institutes, including geological ones, and printing offices of former GDR, the complete geological atlas with the many maps, resulting from Project Tornquist, was never printed and distributed widely as originally planned.

For the present publication we have singled out 12 maps, previously published as inset maps covering the Jurassic System. To all these maps, both of us have contributed with the basic information from Sweden, Lithuania, the Russian Enclave of Kaliningrad, and offshore regions of our countries.

The maps of the Hettangian–Sinemurian, Pliensbachian, Toarcian, Aalenian, Bajocian and the Bathonian (Plates 6–11) are inset maps on the head map of the Pliensbachian (2 sheets). The international compilator of those maps has been Professor Ryszard Dadlez, Instytut Geologiczny, Warsaw, Poland.

The maps of the Callovian, Oxfordian, generalized Oxfordian thicknesses, Kimmeridgian, Portlandian, and Jurassic structural units (Plate 12–17), are inset maps on the head map of the Oxfordian (2 sheets), having Professor Olaf Michelsen, Aarhus University, Denmark, as the international compilator.

Index of foraminiferal genera and species
Including stratigraphical ranges of species (L: in Lithuania, S: in Sweden)

R

S

T

U

V

W

Z

Index of ammonites

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Plate 1. Lower Jurassic foraminifera from Scania, Sweden

1. *Ichthyolaria sulcata* (Bornemann, 1854). Side view. Katslösa Exposure, 762 m. Rya Formation, Lower Sinemurian-Upper Sinemurian transitional beds. EN 972:5. 80 X.

2. *Nodosaria metensis* terquem, 1864. Side view. Öresund B1, 33.5-33.8 m, Döshult Member, Rya Formation, Lower Sinemurian. EN 971:5. 65 X.

3. *Nodosaria mitis* (Terquem & Berthelin, 1875). Örby E6 Viaduct Exposure, sample 5, Döshult Member, Rya Formation, Lower Sinemurian. EN 35:2. 110 X.

4. *Nodosaria dispar* Franke, 1936. Side view of specimen with broken apertural neck. Öresund B1, 21.8 m, Döshult Member, Rya Formation, Lower Sinemurian. EN 971:8. 80 X.

5. *Paralingulina tenera* (Bornemann, 1854) ssp. *substriata* Nørvang, 1957. Side view. Örby E6 Viaduct Exposure, sample 6. Döshult Member, Rya Formation, Lower Sinemurian. EN 971:7, 100 X.

6. *Mesodentalina matutina* (D´Orbigny, 1849). Side view. Katslösa Exposure, 762 m. Base Pankarp Member, Rya Formation, Upper Sinemurian. EN 972:20. 57 X.

7. *Vaginulinopsis exarata* (Terquem, 1866). Side view. Katslösa Exposure, 782 m. Pankarp Member, Rya Formation, basal Upper Sinemurian. EN 972:9. 65 X.

8. *Tristix liasina* (Berthelin, 1879). Side view. Rydebäck-Fortuna-1, 65 m. Rydebäck Member, Rya Formation, Upper Pliensbachian. EN 972:3. 160 X.

9. *Vaginulina listi* (Bornemann, 1854). Side view. Kävlinge-930, 31-32 m, Rydebäck Member, Rya Formation, Pliensbachian. EN 972:19. 80 X.

10. *Astacolus semireticulata* (Fuchs, 1970) emended Norling, 1972. Side view. Örby E6 Viaduct Exposure, sample 6. Döshult Member, Rya Formation, Lower Sinemurian. EN SEM 49:1. 100 X.

11. *Mesodentalina matutina* (D´Orbigny, 1849). Side view of microspheric speciemen. Katslösa Exposure, 762 m, base Pankarp Member, Rya Formation, Upper Sinemurian. EN 973:8. 40 X.
12. *Citharina inaequistriata* (Terquem, 1863). Side view. Gantofta Brick Pit, top Döshult Member, Rya Formation, Lower Sinemurian. EN 87:1. 72 X.

13. *Tristix liasina* (Berthelin, 1879). Side view. Rydebäck-Fortuna-1, 40.5 m, Rydebäck Member, Rya Formation, Upper Pliensbachian. EN 973:4. 160 X.

14. *Brizalina liasica* (Terquem, 1858) ssp. *amalthea* Brand, 1937. Side view. Kävlinge-928, 67.3 m, Rydebäck Member, Rya Formation, Pliensbachian (Carixian/Domerian boundary). EN 97:1. 195 X.

15. *Nodosaria aphaeilolocula* Tappan, 1955. Micrograph of isolated chamber showing a hispid chamber wall and a smooth, broken, interlocular tube. Kävlinge-930, 65.4-66.3 m. Katslösa Member, Rya Formation, Lower Pliensbachian. EN 37:2. 205 X.

16. Subspherical form referreble to *Saccammina* Carpenter, 1869 or *Thurammina* Brady, 1879. Side view. Fredriksberg E6 Viaduct Exposure, Helsingborg Member, Höganäs Formation, Hettangian. EN 98:3, 40 X.

17. *Mesodentalina haeusleri* (Schick, 1903). Side view of broken specimen. Katslösa Exposure, 774 m. Pankarp Member, Rya Formation, Upper Sinemurian. EN 92: 6. 74 X.

18. *Marginulina prima* D´Orbigny, 1849 ssp. *praerugosa* Nørvang, 1957. Side view. Örby E6 Viaduct Exposure, sample 10. Döshult Member, Rya Formation, Lower Sinemurian. EN 971:4. 65 X.

19. *Marginulina prima* D´Orbigny, 1849 ssp. *praerugosa* Nørvang, 1957. Side view. Örby E6 Viaduct Exposure, sample 6. Döshult Member, Rya Formation, Lower Sinemurian. EN 971:1. 95 X.

20. *Astacolus denticulacarinata* (Franke, 1936). Side view. Kävlinge-930, 44-45 m. Katslösa Member, Rya Formation, Lower Pliens--bachian. EN 96:1. 100 X.

21. *Marginulinopsis radiata* (Terquem, 1864). Side view. Kävlinge-930, 44-45 m. Katslösa Member, Rya Formation, Lower Pleinsbachian. EN 971:13. 160 X.

PLATE 1

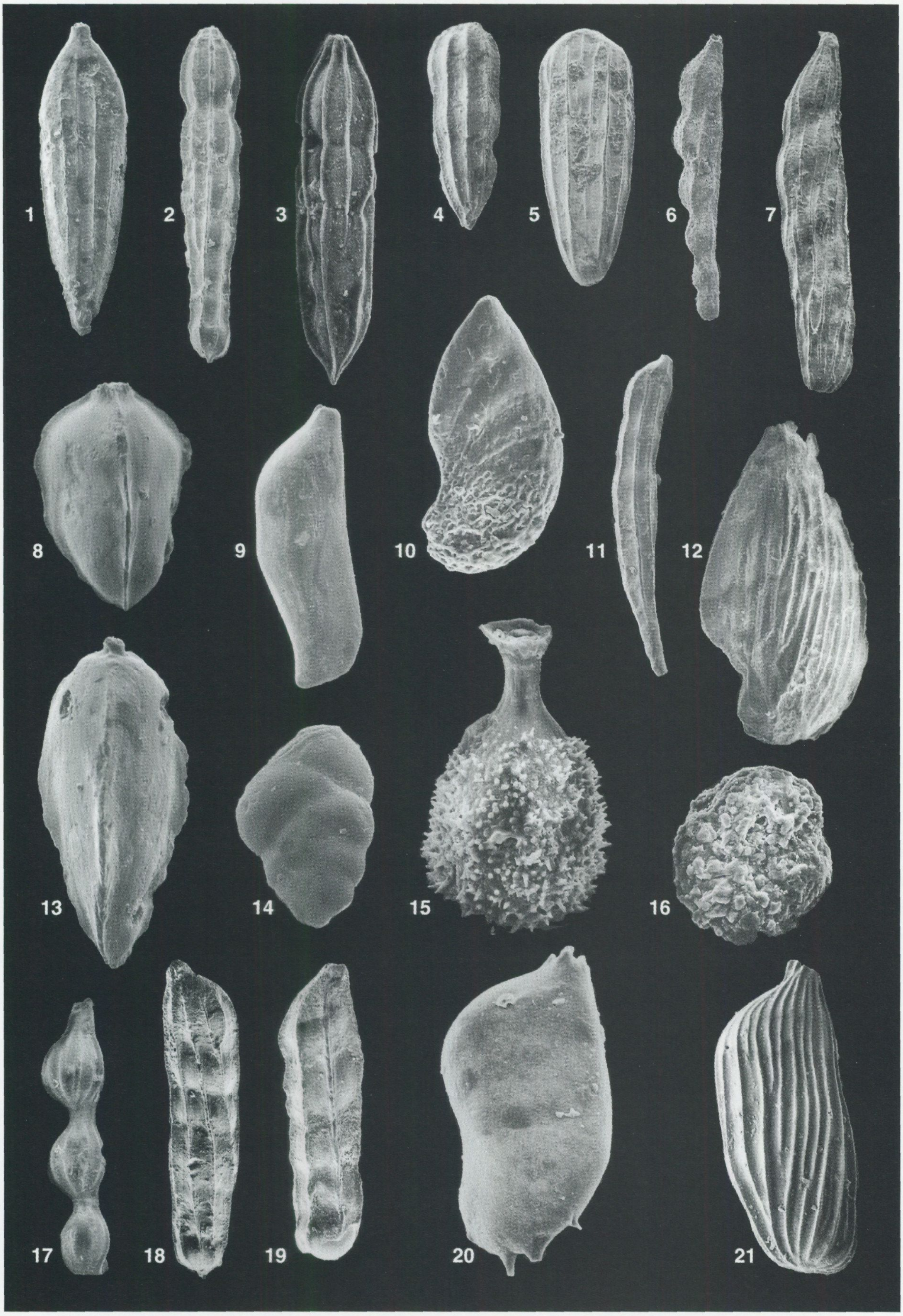


Plate 2. Middle and Upper Jurassic foraminifera from Sweden

1. *Saracenaria phaedra* Tappan, 1955. Side view. Rydebäck-Fortuna-5, 157 m. Fortuna Marl, Annero Formation, Upper Bathonian/Callovian. EN 105:5. 144 X.

2. *Lenticulina attenuata* (Kübler & Zwingli, 1870). Side view. Rydebäck-Fortuna-5, 147 m. Fortuna Marl, Annero Formation, Lower Oxfordian). EN 973:27. 90 X.

3. *Lenticulina brueckmanni* (Mjatliuk, 1939). Side veiw of slightly corroded specimen. Rydebäck-Fortuna-5, 147 m. Fortuna Marl, Annero Formation, Lower Oxfordian. EN 973:28. 70 X.

4. *Lenticulina quenstedti* (Gümbel, 1862) var. *evoluta* Paalzow, 1917. Oblique apertural view. Rydebäck-Fortuna-5, 147 m. Fortuna Marl, Annero Formation, Lower Oxfordian. EN 11:8. 180 X.

5. *Astacolus colligatum* (Brückmann, 1904). Side view. Rydebäck-Fortuna-5, 150 m, Fortuna Marl, Annero Formation, Callovian. EN 973:15. 120 X.

6. *Lenticulina tricarinella* (Reuss, 1863). Oblique dorsal view. Rydebäck-Fortuna-5, 149.5 m, Fortuna Marl, Annero Formation, Lower Oxfordian. EN 30:4. 105 X.

7. *Lenticulina tricarinella* (Ruess, 1863). Ventral view. Woodham Quarry, Dorset, UK. Mariae Zone, Lower Oxfordian. EN 30:5. 110 X.

8. *Marginulina nytorpensis* Norling, 1972. Rydebäck-Fortuna-5, 157 m, Fortuna Marl, Annero Formation, Upper Bathonian/Callovian. EN 973:30. 95 X.

9. *Haplophragmoides kingakensis* Tappan, 1955. Side view. Kävlinge-928, 30 m. Katslösa Member, Rya Formation, Lower Pliensbachian. EN 99:6. 205 X.

10. *Reophax helvetica* (Haeusler, 1881). Rydebäck-Fortuna-5, 138.5 m. Top Fortuna Marl, Annero Formation, Middle Oxfordian. EN 973: 11. 110 X.

11. Ditto, from the same sample. EN 973:12. 110 X.

12. *Saracenaria cornucopiae* (Schwager, 1865). Side view. Rydebäck-Fortuna-5, 147 m. Fortuna Marl, Annero Formation, Lower Oxfordian. EN 40:2. 240 X.

13. *Citharinella nikitini* (Uhlig, 1883). Side view. Rydebäck-Fortuna-5, 157 m. Fortuna Marl, Annero Formation, Upper Bathonian/ Callovian. EN 40:3. 70 X.

14. *Citharina macilenta* (Terquem, 1868). Side view. Rydebäck-Fortuna-5, 148 m, Fortuna Marl, Annero Formation, Lower Oxfordian. EN 28:2. 60 X.

15. *Epistomina volgensis* Mjatliuk, 1939. Dorsal view, Rydebäck-Fortuna-5, 147 m. Fortuna Marl, Annero Formation, Lower Oxfordian. EN 41:3. 80 X.

16. *Paralingulina* ex.gr. *lingulaeformis* (Schwager, 1865). Side view. Rydebäck-Fortuna-5, 157 m, Fortuna Marl, Annero Formation, Upper Bathonian/Callovian. EN 105:3. 200 X.

PLATE 2

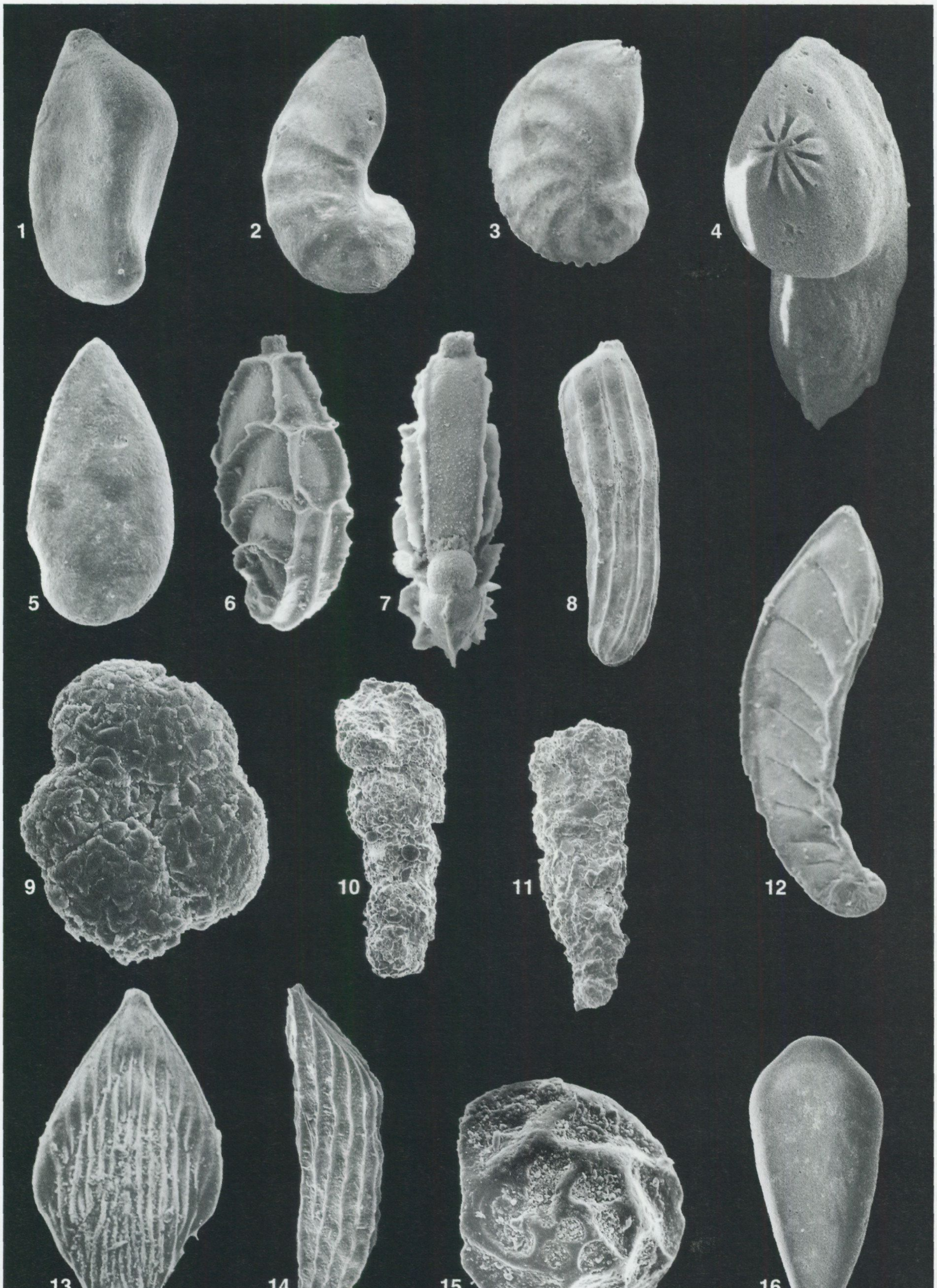


Plate 3. Middle and Upper Jurassic foraminifera from Lithuania, the Kaliningrad Enclave, and the SE part of the Baltic Sea

1. *Ophthalmidium infraoolithicum* (Terquem, 1874). Side view. Kybartai-29, 391.5 m, sample 152. Liepona Formation, Upper Bathonian, SW Lithuania. AG SEM 0509. 75 X.

2. *Ophthalmidium sagittum* (Bykova, 1948). Side view. Jotija borehole, 148.8 m, sample 12. Ąžuolija Formation. Lower Oxfordian, SW Lithuania. AG SEM 0508. 120 X.

3. *Ichthyolaria suprajurensis* (Mjatliuk, 1961). Side view. Papilė-1 Outcrop, *layer k*, 8.25-8.30 m. Papartinė Formation, *Erymnoceras coronatum* Zone, Middle Callovian, NW Lithuania. AG SEM 0510. 55 X.

4. *Lenticulina papillaecostata* Bielecka & Styk, 1981. Side view. Ladushkin-55, 466.5 m, sample 16. Skinija Formation, Upper Callovian. SW part of the Kaliningrad Enclave. AG SEM 0506. 47 X.

5. *Lenticulina polonica* (Wisniowski, 1890). Side view. Nida-2k, 246.7-250.6 m, sample 30. Papartinė Formation, Middle Callovian, W Lithuania. AG SEM 0511. 93 X.

6. *Lenticulina involvens* (Wisniowski, 1890). Nida-2k, 216 m, sample 25. Skinija Formation, Upper Callovian, W Lithuania. AG SEM 0512. 96 X.

7. *Lenticulina brueckmanni* (Mjatliuk, 1939). A) Side view; B) Oblique apertural view. Žalgiriai-1, 158.6 m, sample 283/81- Ąžuolija Formation, Lower Oxfordian, W Lithuania. AG SEM 0520 and 0522. 47 X.

8. *Lenticulina hebetata* (Schwager, 1865). Side view. C 8-1/82 borehole, sample 26. Ąžuolija Formation, Lower Oxfordian, SE Baltic Sea. AG SEM 0501. 93 X.

9. *Saracenaria cornucopiae* (Schwager, 1865). Side view. Smiltynė-3P borehole, 97 m, sample 105. Skinija Formation, Upper Callovian, W Lithuania. AG SEM 0521. 80 X.

10. *Planularia deeckei* (Wisniowski, 1890). Side view. Ladushkin-55, 487.2 m. Skinija Formation, Upper Callovian, Kaliningrad Enclave. AG SEM 0528. 87 X.

11. *Citharina mosquensis* (Uhlig, 1883). Side view. C8-1/82 borehole, 400 m, sample 35, Skinija Formation, Upper Callovian, SE Baltic Sea. AG SEM 0527. 86 X.

12. *Citharina parallella* (Bielecka & Styk, 1954). Side view. Oziorsk-1, 444.1 m, sample 29, Tarava Formation, Lower Kimmeridgian, SE Kaliningrad Enclave. AG SEM 0524. 50 X.

13. *Citharinella schellwieni* (Brückmann, 1904). Side view. C8-1/82 borehole, 400 m, sample 35, Skinija Formation, Upper Callovian, SE Baltic Sea. AG SEM 0504. 53 X.

14. *Marginulinopsis batrakiensis* (Mjatliuk, 1939). Side view. Dauglaukis-8, 179 m, sample 16, Skinija Formation, Upper Callovian, W Lithuania. AG SEM 0513. 130 X.

15. *Marginulinopsis gordoni* (Norling, 1972). Side view. Oziorsk-1, 444.1 m, sample 29. Tarava Formation, Lower Kimmeridgian. AG SEM 0525. 45 X.

16. *Pseudolamarckina rjasanensis* (Uhlig, 1883). A) Dorsal view; B) Ventral view. Stoniškiai-1k borehole, 227-230.4 m, sample 39. Skinija Formation, Upper Callovian. AG SEM 0503. 80 X.

PLATE 3

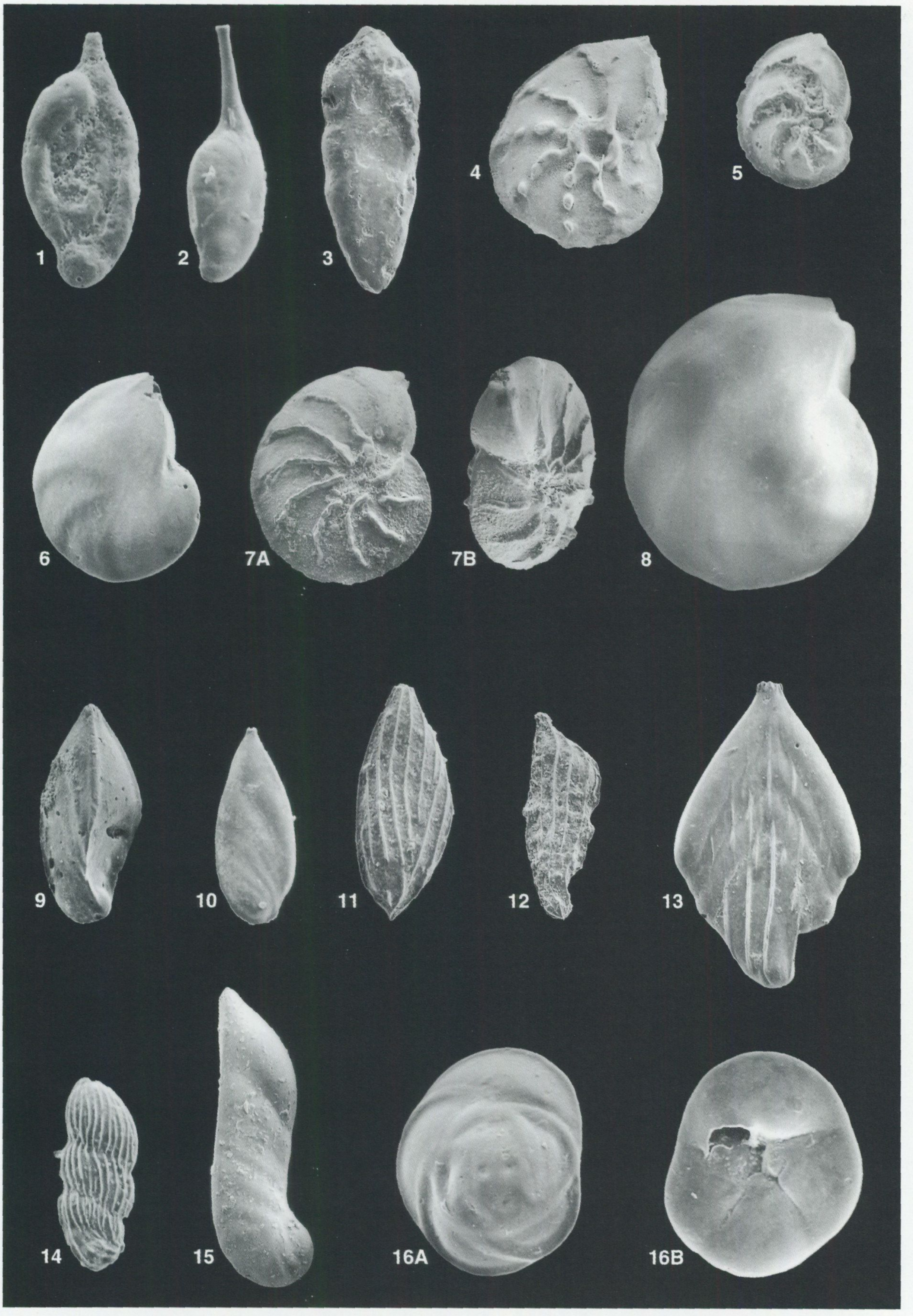


Plate 4. Middle and Upper Jurassic foraminifera from Lithuania, the Kaliningrad Enclave, and the SE Baltic Sea

1. *Epistomina planiconvexa* Bielecka & Styk, 1981. A) Dorsal view; B) Ventral view. C 8-1/82 borehole, 375 m, sample 30, Ąžuolija Formation, Lower Oxfordian, SE Baltic Sea. AG SEM 0502 and 05022. 85 X.

2. *Epistomina porcellanea* Brückmann, 1904. A) Dorsal view; B) Ventral view. C 8-1/82 borehole, 400 m, sample 35, Skinija Formation, Upper Callovian, SE Baltic Sea. AG SEM 0505 and 05052. 80 X.

3. *Epistomina mosquensis* Uhlig, 1883. A) Dorsal view; B) Ventral view. C 8-1/82 borehole, 415 m, sample 38, Skinija Formation, Upper Callovian, SE Baltic Sea. AG SEM 0507 and 05072. 100 X.

4. *Epistomina volgensis* Mjatliuk, 1953. A) Dorsal view; B) Ventral view. Jotija borehole, 148.8 m, sample 12, Ąžuolija Formation, Lower Oxfordian, SW Lithuania. AG SEM 0515 and 05152. 85 X.

5. *Epistomina parastelligera* (Hofker, 1954). A) Dorsal view; B) Ventral view. Stoniškiai-1k borehole, 206.4-207.9 m, sample 34, Ąžuolija Formation, Lower Oxfordian, W Lithuania. AG SEM 0516 and 05162. 90 X.

6. *Epistomina ventriosa* Espitalié & Sigal, 1963. A) Dorsal view; B) Ventral view. Majakovskoye-2 borehole, 355 m, sample 3, Tarava Formation, Lower Kimmeridgian, SE Kaliningrad Enclave. AG SEM 0526 and 05262. 70 X.

7. *Spirillina tenuissima* (Gümbel, 1862). Side view. Jotija borehole, 132.3 m, sample 6, Ąžuolija Formation, Lower Oxfordian, SW Lithuania. AG SEM 0517. 130 X.

PLATE 4

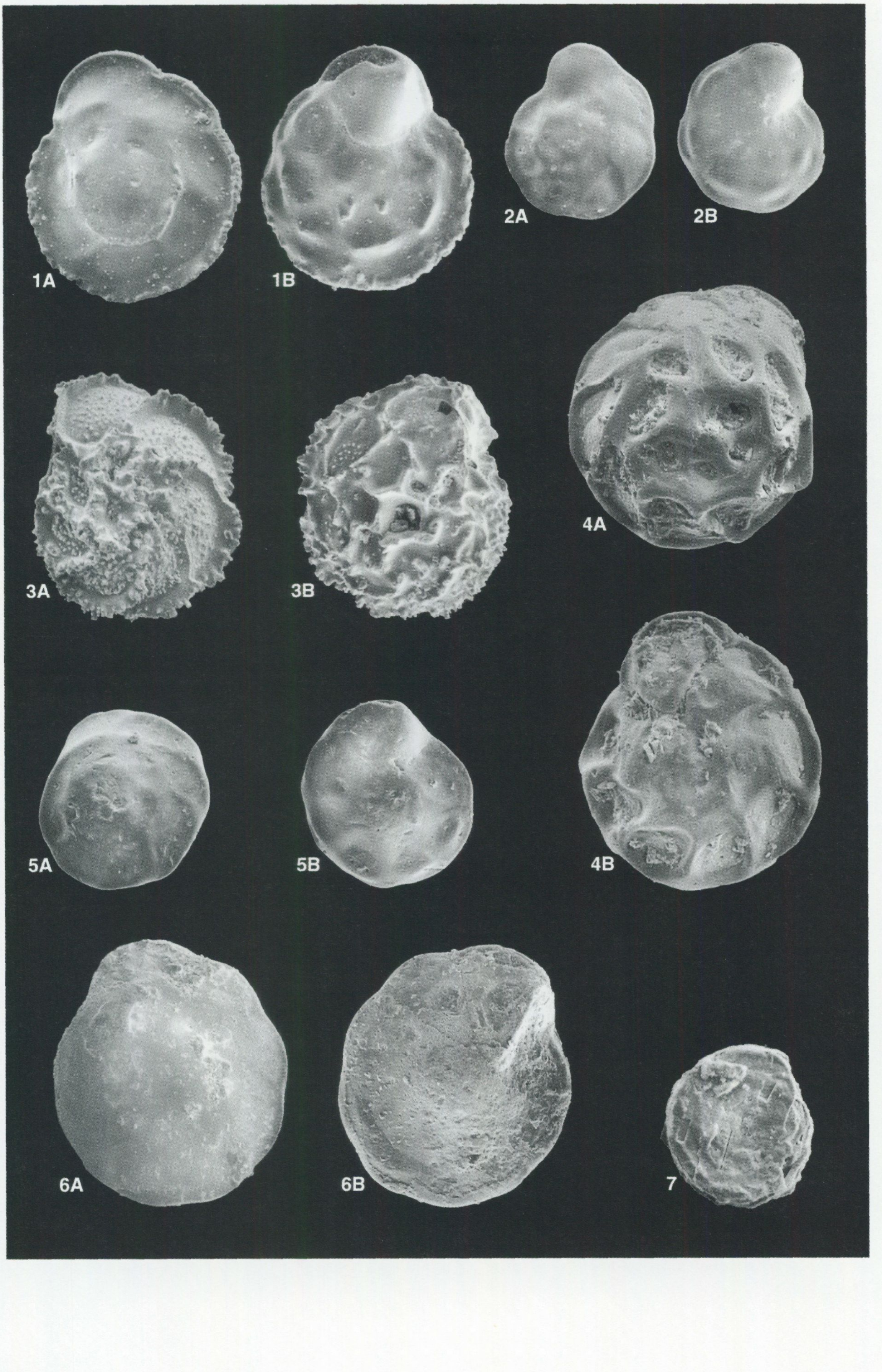


Plate 5. Callovian and Oxfordian foraminifera from Lithuania and Sweden

1. *Paulina furssenkoi* Grigelis, 1977. A) Dorsal view; B) Ventral view. Jotija borehole, 132.3 m, sample 6, Lower Oxfordian, SW Lithuania. AG SEM 514. 100 X.

2. *Trocholina klaipedica* Grigelis, 1985. A) Dorsal view; B) Ventral view. Vilkyčiai-18, 157.7 m, sample 193. Upper Callovian, W Lithuania. AG SEM 519. 100 X.

3. *Trocholina transversarii* Paalzow, 1932. A) Dorsal view; B) Ventral view. Stoniškiai-1k, 187.3 m, Middle Oxfordian, W Lithuania. AG SEM 518. 85X.

4. *Globuligerina oxfordiana* (Grigelis, 1958). Topotype. Dorsal view. Jotija borehole, 143 m, sample 10. Lower Oxfordian, SW Lithuania. AG SEM 522. 250 X

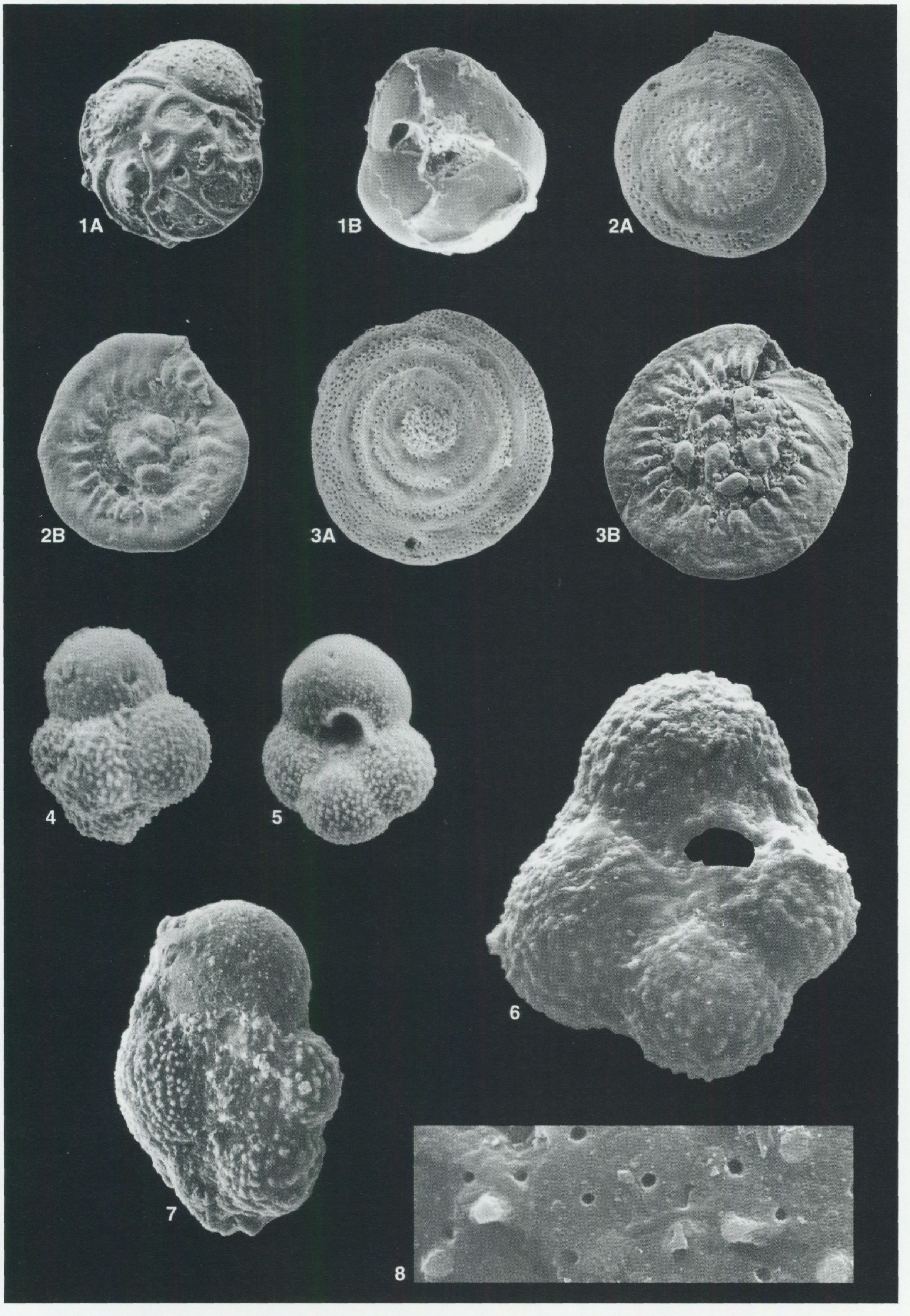
5. Ditto. Ventral view. Shatrishche-2, sample 801, Middle to Upper Oxfordian, Rjasan, Central Russia. AG SEM 523. 250 X.

6. *Globuligerina* cf. *oxfordiana* (Grigelis, 1958). Ventral view. Hanö Bay 104/14-2, 790 m, Oxfordian. Hanö Bay, E Scania. EN 195 b. 400 X.

7. Ditto. Oblique dorsal view. EN 195 a 380 X.

8. *Globuligerina* cf. *oxfordiana* (Grigelis, 1958). Part of surface enlarged to show nonperforate pustules and scattered pores. EN 195 a. 2 400 X.

PLATE 5



Plates 6–11

Lithologic-palaeogeographical maps produced for the International Geological Correaltion Programme, IGCP Project No. 86 SOUTH-WEST BORDER OF THE EAST EUROPEAN PLATFORM

Editorial Board: K.-B. Jubitz, former German Democratic Republic, GDR (Project leader),
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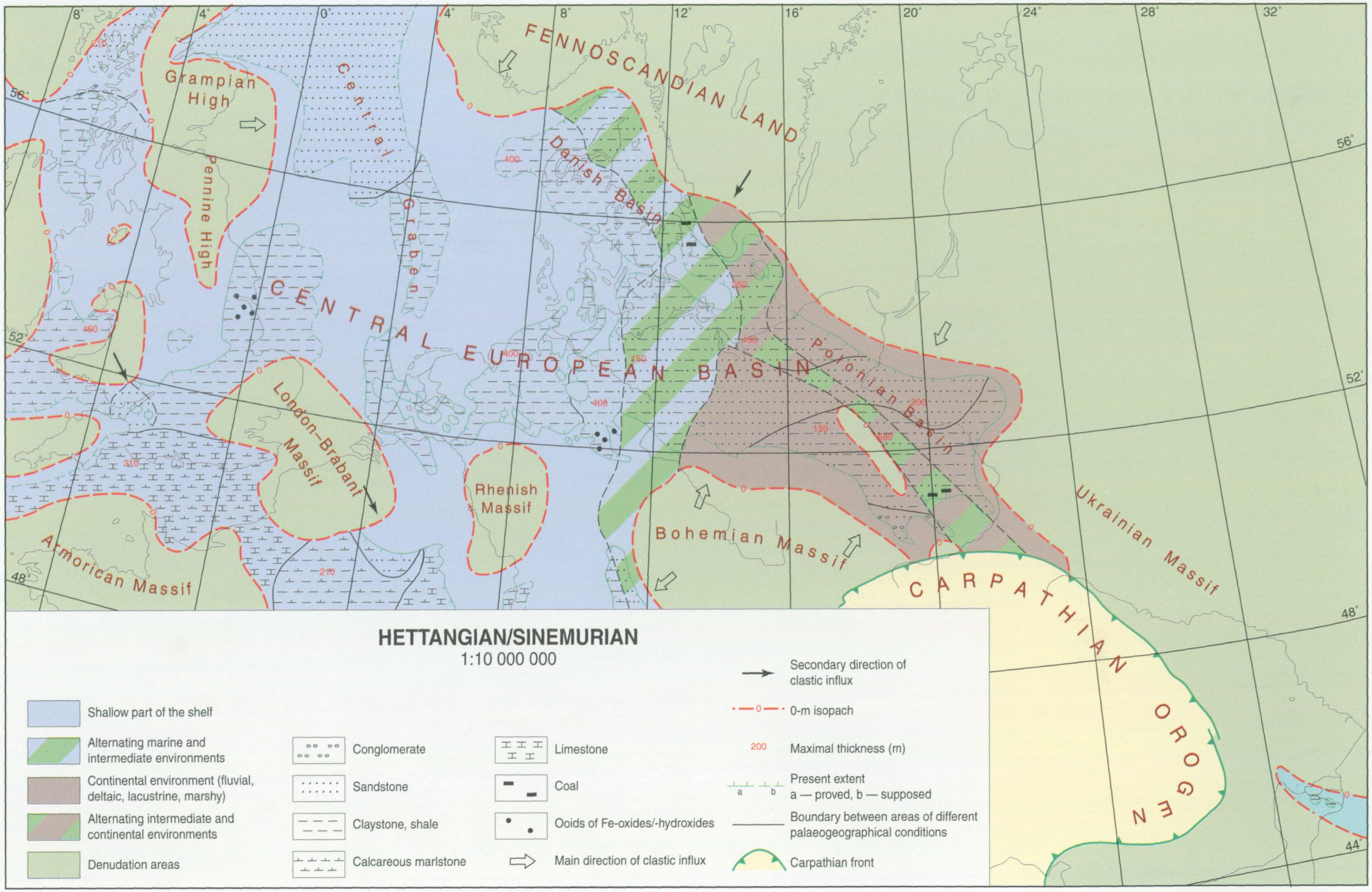
All the maps are inset maps on the scale 1:10 000 000 linked to the head map of the Pliensbachian 1: 1 500 000.
Plate 6. Hettangian – Sinemurian, Lower Jurassic
Plate 7. Pliensbachian, Lower Jurassic
Plate 8. Toarcian, Lower Jurassic
Plate 9. Aalenian, Middle Jurassic
Plate 10. Bajocian, Middle Jurassic
Plate 11. Bathonian, Middle Jurassic

PLATE 6


FENNOSCANDIAN LAND
Grampian High
Pennine High
Central Graben
Danish Basin
CENTRAL EUROPEAN BASIN
Polonian Basin
London-Brabant Massif
Rhenish Massif
Bohemian Massif
Armorican Massif
Ukrainian Massif
CARPATHIAN OROGEN
HETTANGIAN/SINEMURIAN
1:10 000 000
Shallow part of the shelf
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic, lacustrine, marshy)
Alternating intermediate and continental environments
Denudation areas
Conglomerate
Sandstone
Claystone, shale
Calcareous marlstone
Limestone
Coal
Ooids of Fe-oxides/-hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
200
Maximal thickness (m)
Present extent
a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front

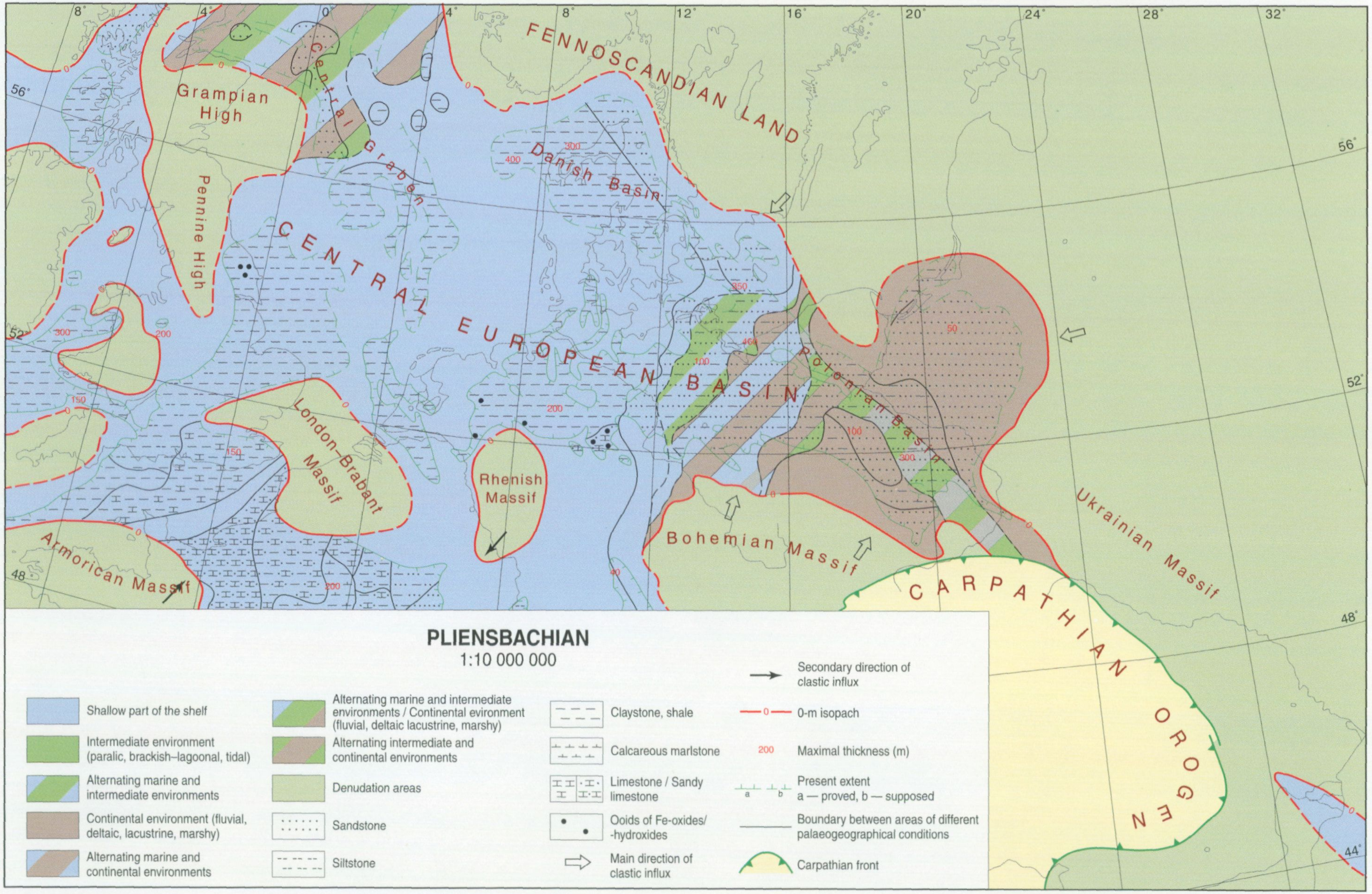
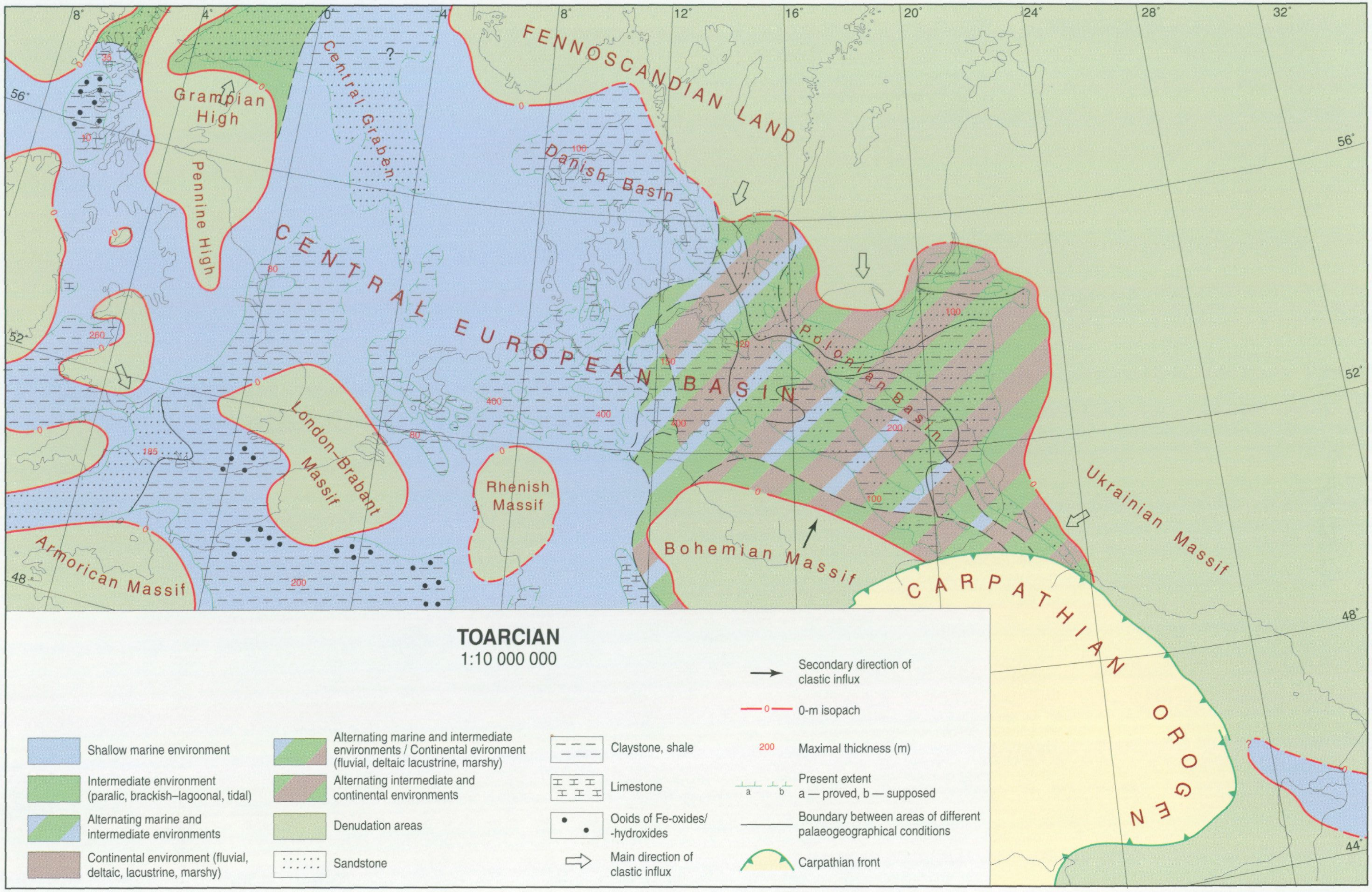
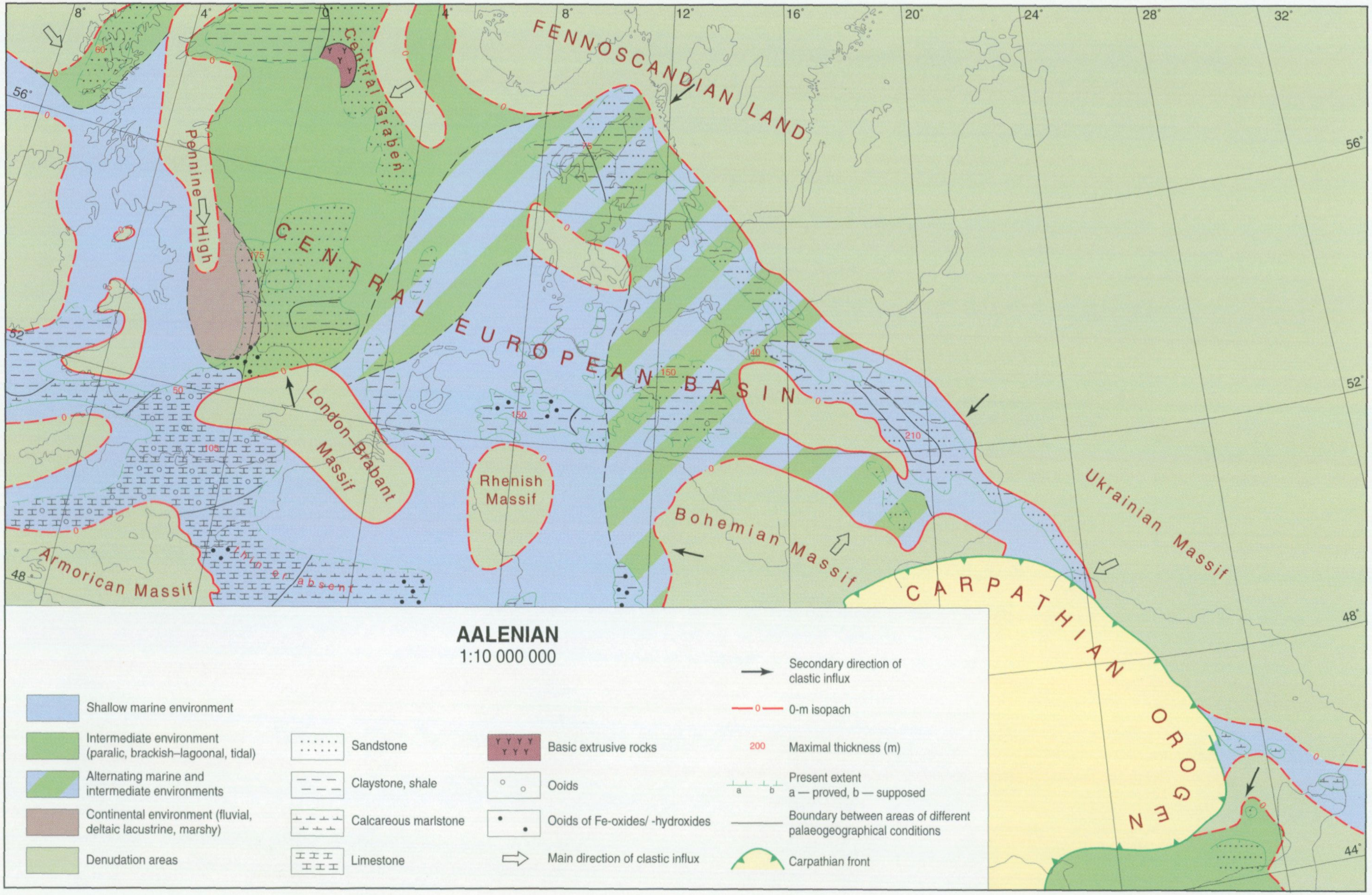
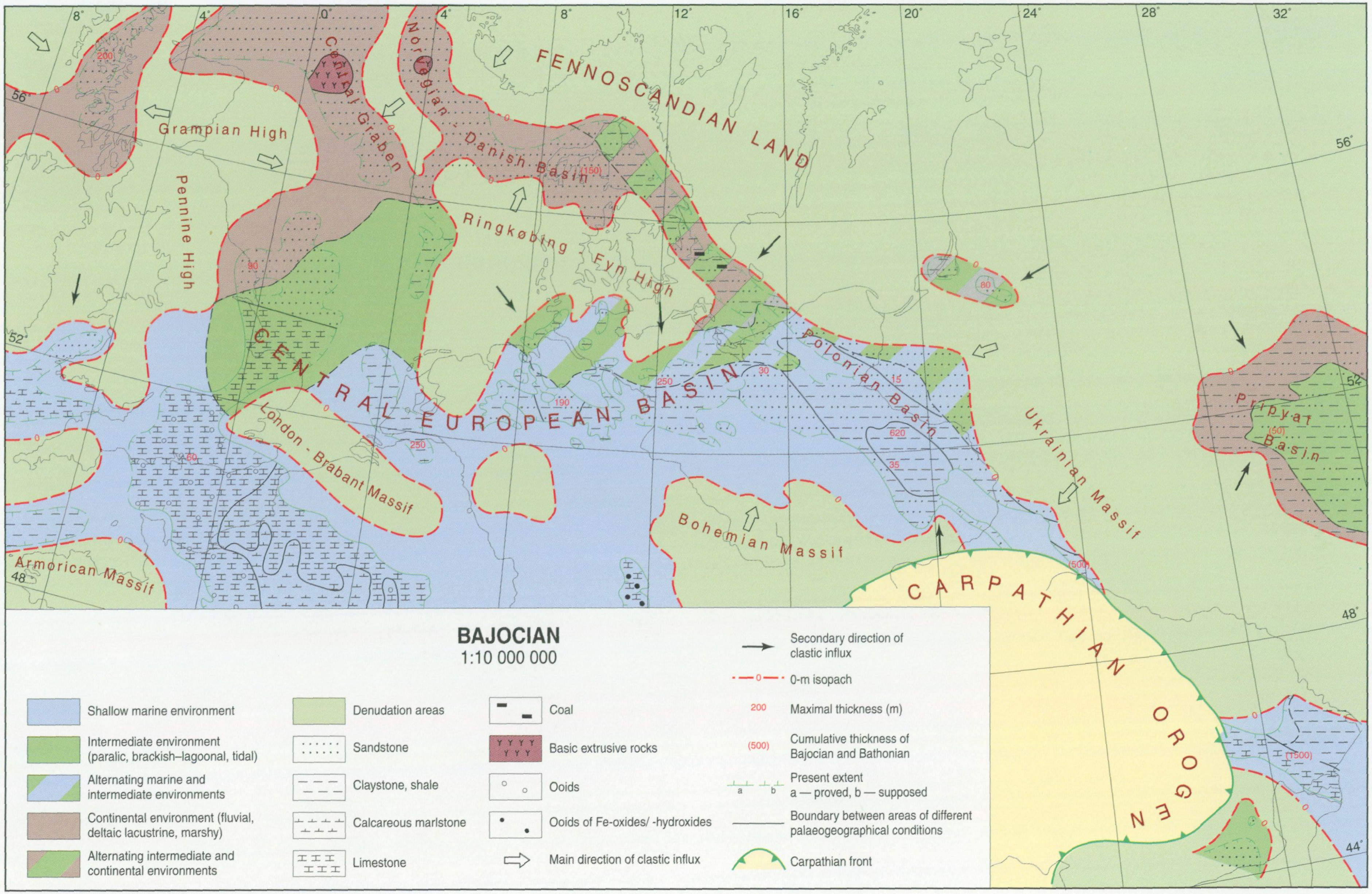

FENNOSCANDIAN LAND
Grampian High
Central Graben
Danish Basin
Pennine High
CENTRAL EUROPEAN BASIN
London–Brabant Massif
Rhenish Massif
Polonian Basin
Bohemian Massif
Ukrainian Massif
Armorican Massif
CARPATHIAN OROGEN
PLIENSBACHIAN
1:10 000 000
Shallow part of the shelf
Intermediate environment (paralic, brackish–lagoonal, tidal)
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic, lacustrine, marshy)
Alternating marine and continental environments
Alternating marine and intermediate environments / Continental evironment (fluvial, deltaic lacustrine, marshy)
Alternating intermediate and continental environments
Denudation areas
Sandstone
Siltstone
Claystone, shale
Calcareous marlstone
Limestone / Sandy limestone
Ooids of Fe-oxides/ -hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
200 Maximal thickness (m)
Present extent a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front

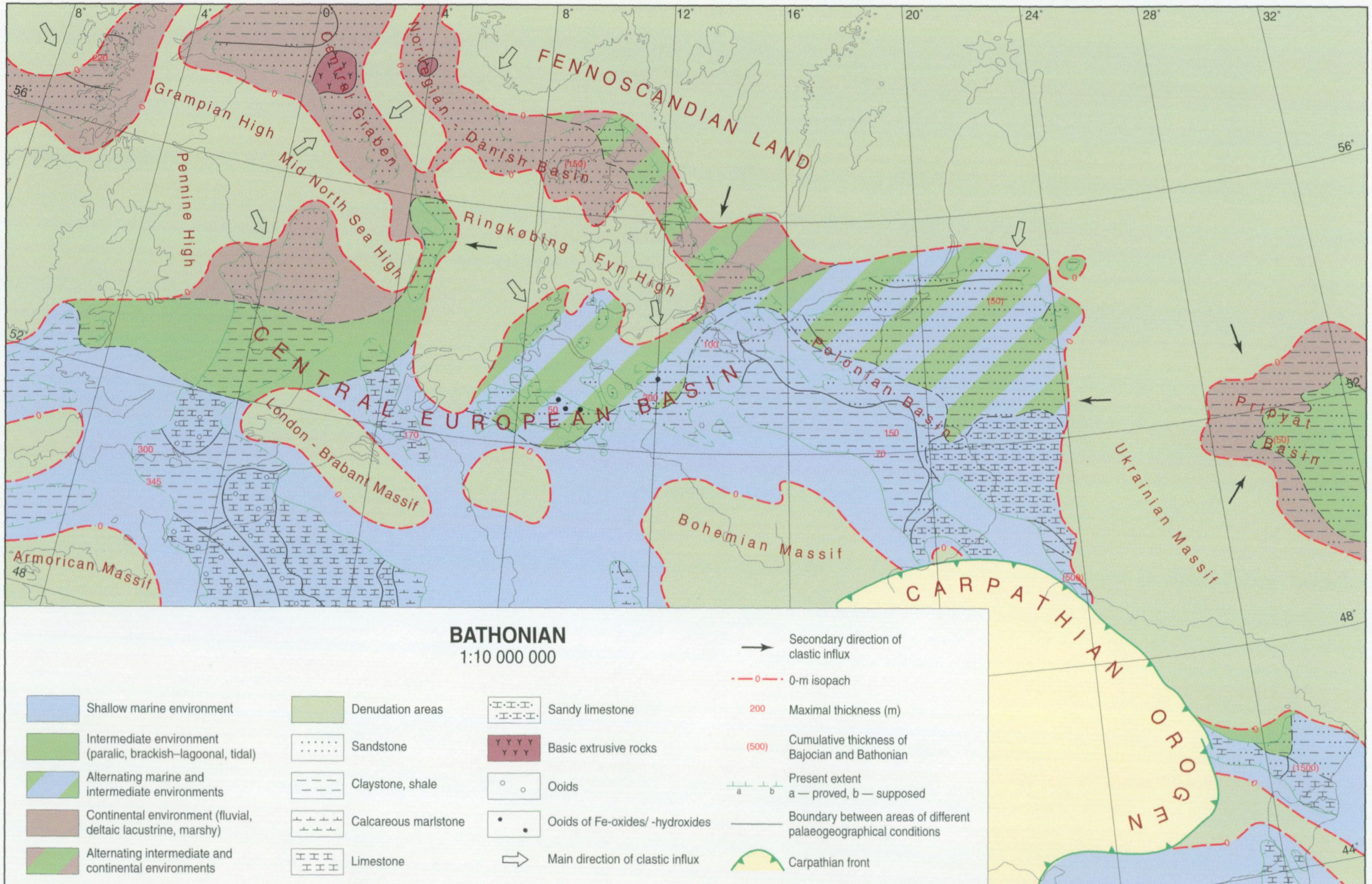
PLATE 8


FENNOSCANDIAN LAND
Grampian High
Pennine High
Central Graben
Danish Basin
CENTRAL EUROPEAN BASIN
Polonian Basin
London–Brabant Massif
Rhenish Massif
Armorican Massif
Bohemian Massif
Ukrainian Massif
CARPATHIAN OROGEN
TOARCIAN
1:10 000 000
Shallow marine environment
Intermediate environment (paralic, brackish–lagoonal, tidal)
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic, lacustrine, marshy)
Alternating marine and intermediate environments / Continental environment (fluvial, deltaic lacustrine, marshy)
Alternating intermediate and continental environments
Denudation areas
Sandstone
Claystone, shale
Limestone
Ooids of Fe-oxides/ -hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
Maximal thickness (m)
Present extent a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front



AALENIAN
1:10 000 000
FENNOSCANDIAN LAND
CENTRAL EUROPEAN BASIN
Central Graben
Pennine High
London–Brabant Massif
Rhenish Massif
Bohemian Massif
Armorican Massif
Ukrainian Massif
CARPATHIAN OROGEN
Shallow marine environment
Intermediate environment (paralic, brackish–lagoonal, tidal)
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic lacustrine, marshy)
Denudation areas
Sandstone
Claystone, shale
Calcareous marlstone
Limestone
Basic extrusive rocks
Ooids
Ooids of Fe-oxides/ -hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
200 Maximal thickness (m)
Present extent a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front


FENNOSCANDIAN LAND
Grampian High
Central Graben
Norwegian - Danish Basin
Ringkøbing - Fyn High
Pennine High
CENTRAL EUROPEAN BASIN
London - Brabant Massif
Polonian Basin
Ukrainian Massif
Pripyat Basin
Bohemian Massif
Armorican Massif
CARPATHIAN OROGEN
BAJOCIAN
1:10 000 000
Shallow marine environment
Intermediate environment (paralic, brackish–lagoonal, tidal)
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic lacustrine, marshy)
Alternating intermediate and continental environments
Denudation areas
Sandstone
Claystone, shale
Calcareous marlstone
Limestone
Coal
Basic extrusive rocks
Ooids
Ooids of Fe-oxides/ -hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
200 Maximal thickness (m)
(500) Cumulative thickness of Bajocian and Bathonian
Present extent a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front



FENNOSCANDIAN LAND
Grampian High
Central Graben
Norwegian - Danish Basin
Mid North Sea High
Pennine High
Ringkøbing - Fyn High
CENTRAL EUROPEAN BASIN
Polonian Basin
London - Brabant Massif
Bohemian Massif
Armorican Massif
Ukrainian Massif
Pripyat Basin
CARPATHIAN OROGEN
BATHONIAN
1:10 000 000
Shallow marine environment
Intermediate environment (paralic, brackish–lagoonal, tidal)
Alternating marine and intermediate environments
Continental environment (fluvial, deltaic lacustrine, marshy)
Alternating intermediate and continental environments
Denudation areas
Sandstone
Claystone, shale
Calcareous marlstone
Limestone
Sandy limestone
Basic extrusive rocks
Ooids
Ooids of Fe-oxides/ -hydroxides
Main direction of clastic influx
Secondary direction of clastic influx
0-m isopach
Maximal thickness (m)
Cumulative thickness of Bajocian and Bathonian
Present extent a — proved, b — supposed
Boundary between areas of different palaeogeographical conditions
Carpathian front

PLATE 11

Plates 12–17

Lithologic-palaeogeographical maps, thickness map, and map of Jurassic structural units produced for the International Geological Correlation Programme, IGCP Project No. 86 SOUTH-WEST BORDER OF THE EAST EUROPEAN PLATFORM

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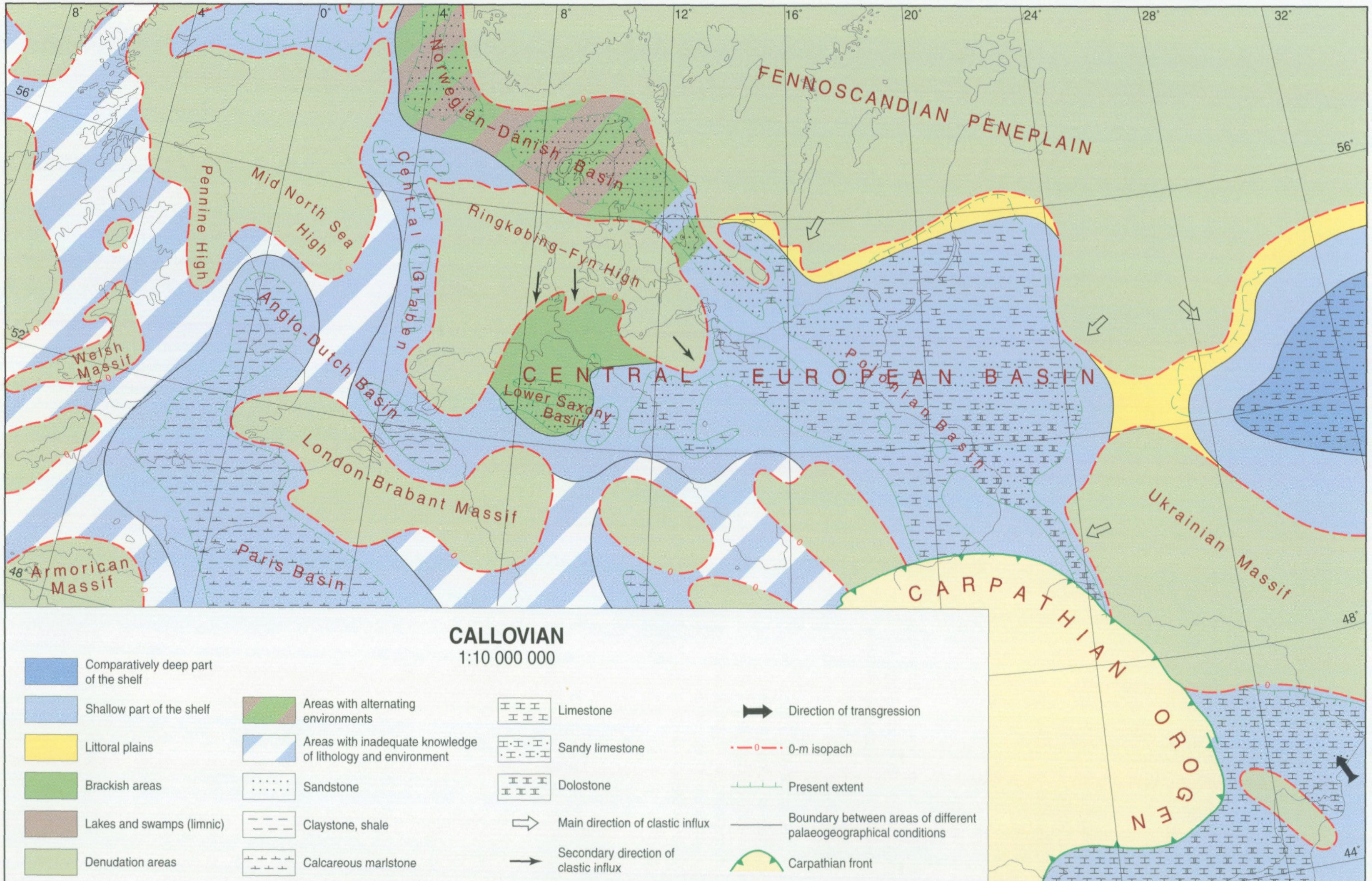
All the maps are inset maps on the scale 1:10 000 000 linked to the head map of the Oxfordian 1:1 500 000.
Plate 12. Callovian, Middle Jurassic
Plate 13. Oxfordian, Upper Jurassic
Plate 14. Generalized Oxfordian thicknesses, Upper Jurassic
Plate 15. Kimmeridgian, Upper Jurassic
Plate 16. Portlandian, Upper Jurassic
Plate 17. Jurassic structural units



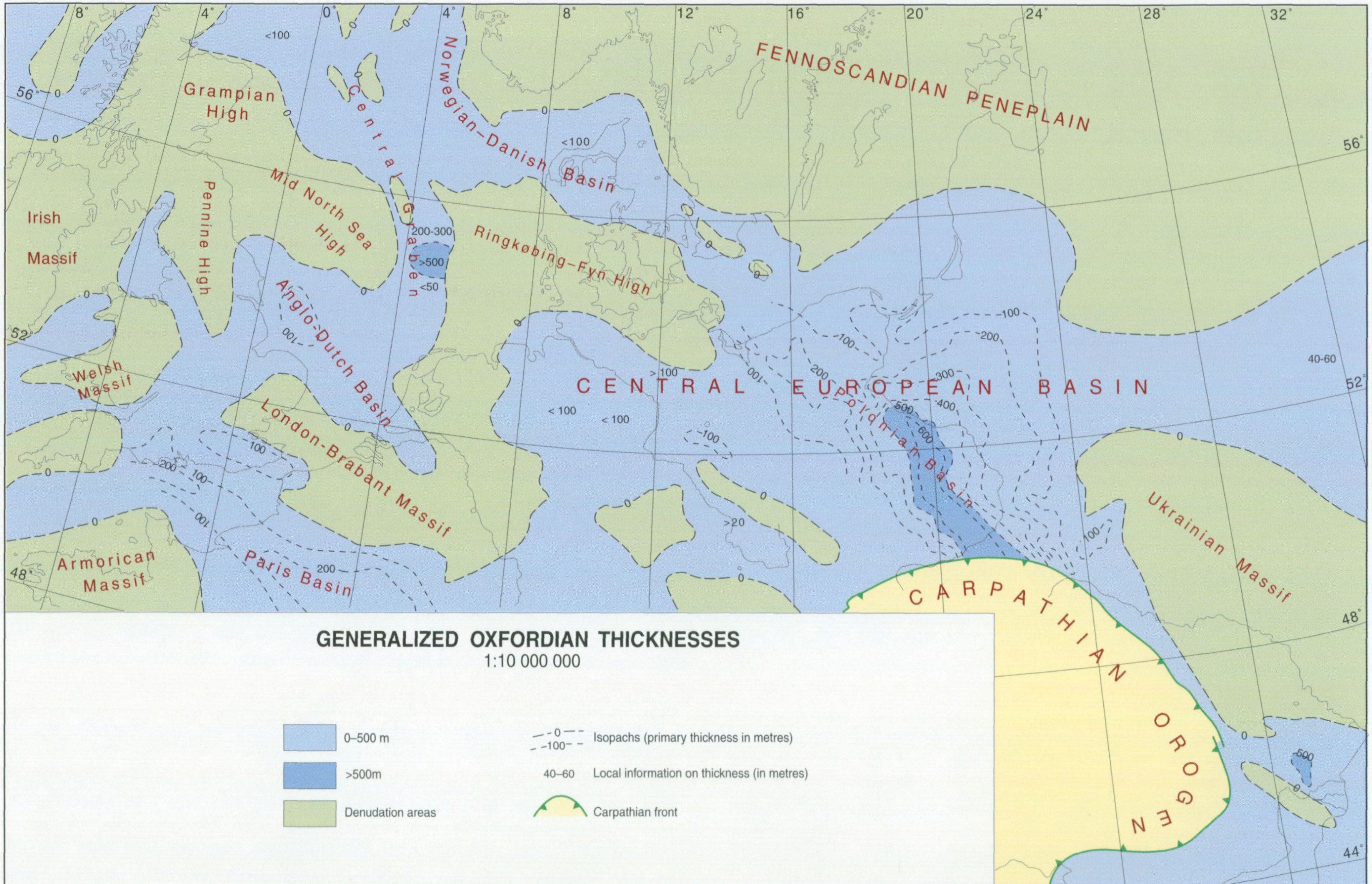
CALLOVIAN
1:10 000 000
FENNOSCANDIAN PENEPLAIN
Norwegian-Danish Basin
Central Graben
Ringkøbing-Fyn High
Mid North Sea High
Pennine High
Welsh Massif
Anglo-Dutch Basin
CENTRAL EUROPEAN BASIN
Lower Saxony Basin
Polish Basin
London-Brabant Massif
Paris Basin
Armorican Massif
Ukrainian Massif
CARPATHIAN OROGEN
8°
4°
0°
4°
8°
12°
16°
20°
24°
28°
32°
56°
52°
48°
44°
Comparatively deep part of the shelf
Shallow part of the shelf
Littoral plains
Brackish areas
Lakes and swamps (limnic)
Denudation areas
Areas with alternating environments
Areas with inadequate knowledge of lithology and environment
Sandstone
Claystone, shale
Calcareous marlstone
Limestone
Sandy limestone
Dolostone
Main direction of clastic influx
Secondary direction of clastic influx
Direction of transgression
0-m isopach
Present extent
Boundary between areas of different palaeogeographical conditions
Carpathian front

PLATE 13

OXFORDIAN
1:10 000 000
FENNOSCANDIAN PENEPLAIN
Grampian High
Central Graben
Norwegian-Danish Basin
Mid North Sea High
Irish Massif
Pennine High
Ringkøbing-Fyn High
Anglo-Dutch Basin
Welsh Massif
London-Brabant Massif
CENTRAL EUROPEAN BASIN
Polish Basin
Ukrainian Massif
Armorican Massif
Paris Basin
CARPATHIAN OROGEN
8°
4°
0°
4°
8°
12°
16°
20°
24°
28°
32°
56°
52°
48°
44°
Comparatively deep part of the shelf
Shallow part of the shelf
Littoral plains
Brackish areas
Lakes and swamps (limnic)
Denudation areas
Volcanic areas
Areas with alternating environments
Areas with inadequate knowledge of lithology and environment
Conglomerate
Sandstone
Claystone, shale
Calcareous marlstone
Limestone/Dolostone
Sandy limestone
Oolitic limestone
Basic extrusive rocks
Anhydrite, gypsum
Synsedimentary fault
Main direction of clastic influx
Secondary direction of clastic influx
Direction of transgression
0-m isopach
Present extent
Boundary between areas of different palaeogeographical conditions
Carpathian front

A. GRIGELIS AND E. NORLING

PLATE 14

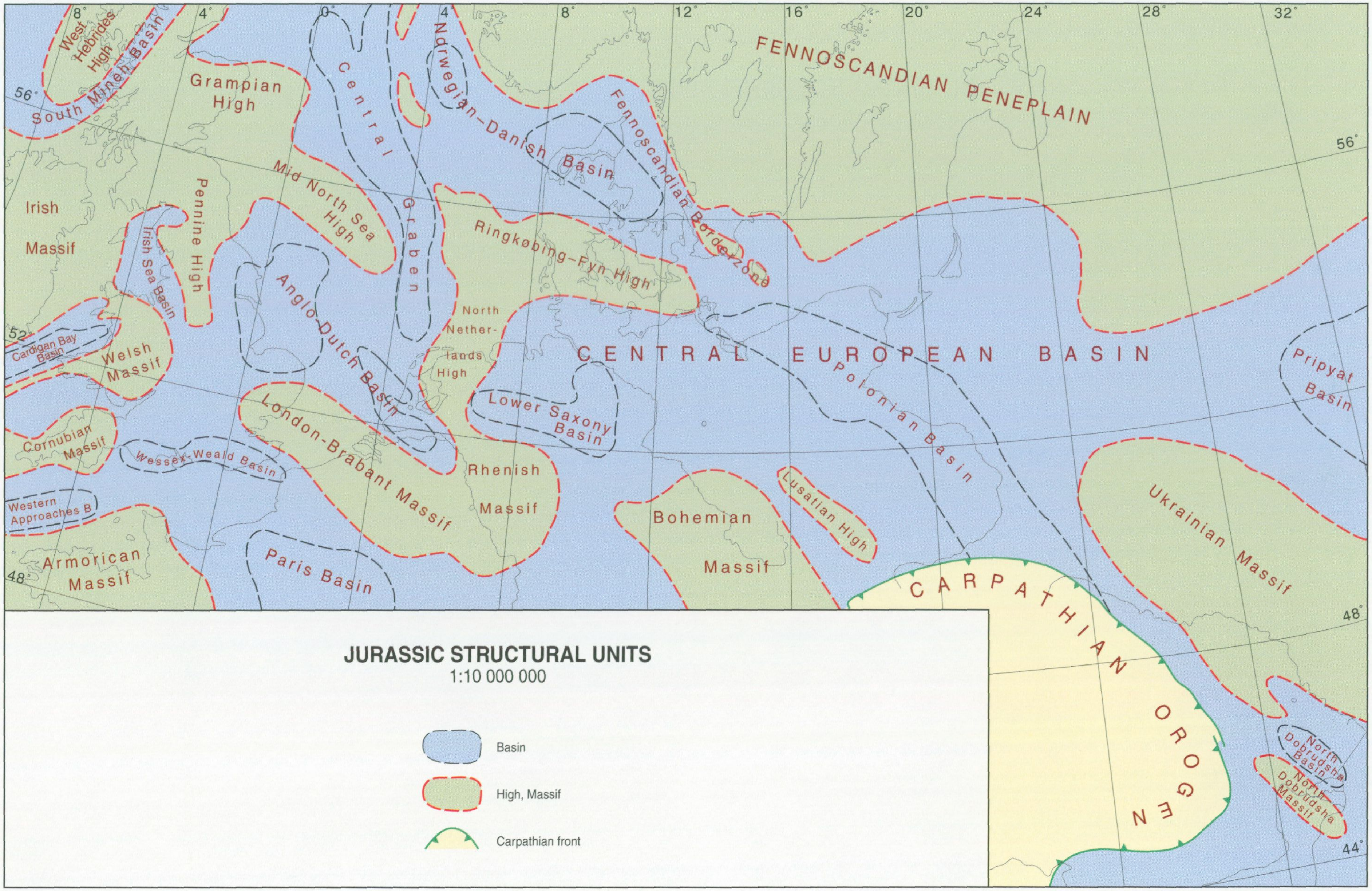


GENERALIZED OXFORDIAN THICKNESSES
1:10 000 000


KIMMERIDGIAN
1:10 000 000
FENNOSCANDIAN PENEPLAIN
Norwegian–Danish Basin
Central Graben
Pennine High
Ringkobing–Fyn High
Anglo-Dutch Basin
London-Brabant Massif
CENTRAL EUROPEAN BASIN
Lower Saxony Basin
Polonian Basin
Ukrainian Massif
Armorican Massif
Paris Basin
CARPATHIAN OROGEN
North Dobrudsha Massif
8°
4°
0°
4°
8°
12°
16°
20°
24°
28°
32°
56°
52°
48°
44°
100
400
200
50
Comparatively deep part of the shelf
Shallow part of the shelf
Littoral plains
Brackish areas
Denudation areas
Areas with inadequate knowledge of lithology and environment
Sandstone
Siltstone
Claystone, shale
Calcareous marlstone
Limestone / Dolostone
Anhydrite, gypsum
Main direction of clastic influx
Secondary direction of clastic influx
Direction of transgression
0-m isopach
400
Maximal thickness (m)
Present extent
Boundary between areas of different palaeogeographical conditions
Carpathian front

PORTLANDIAN
1:10 000 000
Grampian High
Central Graben
Norwegian-Danish Basin
FENNOSCANDIAN PENEPLAIN
Ringkøbing-Fyn High
Pennine High
Anglo-Dutch Basin
London-Brabant Massif
Lower Saxony Basin
Polish Basin
Bohemian Massif
Ukrainian Massif
Armorican Massif
Paris Basin
CARPATHIAN OROGEN
Shallow part of the shelf
Littoral plains
Brackish areas
Epeiric sea, bays and lagoons partly of high salinity
Lakes and swamps (limnic)
Denudation areas
Areas with alternating environments
Areas with inadequate knowledge of lithology and environment
Sandstone / Claystone, shale
Calcareous marlstone / Limestone
Oolitic limestone
Sandy limestone
Dolostone
Anhydrite, gypsum / Halite
Main direction of clastic influx
Secondary direction of clastic influx
Direction of transgression
0-m isopach
Maximal thickness (m)
Present extent
Boundary between areas of different palaeogeographical conditions
Carpathian front

PLATE 17


JURASSIC STRUCTURAL UNITS
1:10 000 000
Basin
High, Massif
Carpathian front
West Hebrides High
South Minch Basin
Grampian High
Central Graben
Norwegian-Danish Basin
Fennoscandian Border Zone
FENNOSCANDIAN PENEPLAIN
Irish Massif
Irish Sea Basin
Pennine High
Mid North Sea High
Ringkøbing-Fyn High
Anglo-Dutch Basin
North Netherlands High
Cardigan Bay Basin
Welsh Massif
CENTRAL EUROPEAN BASIN
Pripyat Basin
Polonian Basin
Lower Saxony Basin
London-Brabant Massif
Cornubian Massif
Wessex-Weald Basin
Western Approaches B
Rhenish Massif
Armorican Massif
Paris Basin
Bohemian Massif
Lusatian High
Ukrainian Massif
CARPATHIAN OROGEN
North Dobrudsha Basin
North Dobrudsha Massif
8°
4°
0°
4°
8°
12°
16°
20°
24°
28°
32°
56°
56°
52°
48°
48°
44°