Ordovician stratigraphy of the Kovel-1 well (Volkhov–Haljala) in the Volynia region, northwestern Ukraine

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The Ordovician succession of the Kovel-1 well in the Volynia region, northwestern Ukraine is composed of a basal 0.6 m thick siliciclastic unit succeeded by 24.7 m Lower and lower Middle Ordovician carbonate sediments. The carbonate rocks are divided into 13 informal lithologic units. The carbonate sediments accumulated in marine shallow water open shelf and shoal or turbulent environs.

Biostratigraphically, the succession is referred to seven chitinozoan zones and 12 conodont biozones. Integration, chronostratigraphic position and correlation of the proposed biozones with those from Baltoscandia are briefly discussed.

Four major unconformities are recognized within the succession: 1) the Pakerort(?)–Volkhov unconformity, 2) the mid Volkhov unconformity, 3) the early Kunda unconformity and 4) the early Mid Ordovician hiatus. The latter straddles the Oeland–Viru regional Series boundary in the well. The early Mid Ordovician unconformity is prominent and the corresponding hiatus spans the Aseri and Lasnamägi regional stages (= upper Darriwilian).

A complex of cyclic transgressive–regressive depositional pattern prevailed and the whole succession is referred to three major depositional cycles. The major depositional cycles are related to global eustatic sea-level cycles in general and hypothetic way to tectonic events caused by collisions of Peri-Gondwanan microcontinents with Baltica.

Keywords: Ordovician, Kovel-1 core, Ukraine, sedimentology, facies analysis, biostratigraphy, cyclostratigraphy and sea-level curve.

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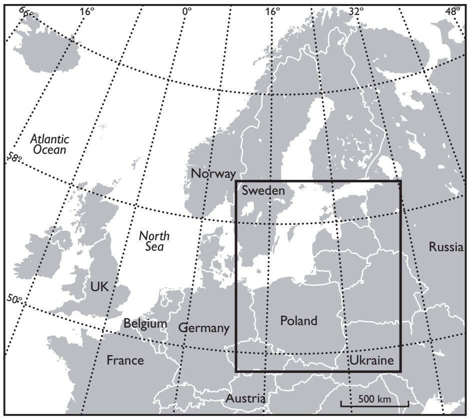
The Volynia region in Ukraine represents the south-western-most extension of the Baltic Basin (or Baltic Syneclise) framed by the Ukraine Massif east of Volynia and the Lublin and Lviv Troughs to the west and southwest respectively. The Lublin and the Lviv Troughs are incorporated in the Teisseire-Tornquist Zone (T-TZ; Pharaoh 1999; Pharaoh *et al*. 1997; Fig. 1).

Ordovician sedimentary rocks in the Ukraine have been penetrated by several wells in the Lviv and Volynia regions (Ginda 1986; Männil & Meidla 1994). One of them is the Kovel-1 well, northwestern Ukraine (Fig. 1) and is the target of this paper. The preliminary micropalaeontological investigation on the core proved that the sediments were productive for microfossils (Stouge & Saadre 1997). The following investigation of the stratigraphy, microfauna and -flora of the Ordovician succession of the Kovel-1 core allowed for the recognition of laterally correlative horizons into the Baltic Basin (Saadre *et al*. 2001).

This paper presents the results of the stratigraphical, sedimentological and micropaleontological analysis of the fossiliferous Lower , Middle and lower Upper Ordovician strata recorded from the Kovel-1 core (Fig. 1). The interdisciplinary investigation places the succession into the frame of second and third order cycles, which are comparable with those established for the Ordovician sedimentary basin of the East European Platform (Einasto 1986, 1995; Laškovas 2000).

The aim of the study is: 1) to describe the lithostratigraphy in detail, 2) to provide a chitinozoan and a conodont biostratigraphy serving as a basis for a precise definition of the Lower to lower Upper Ordo-



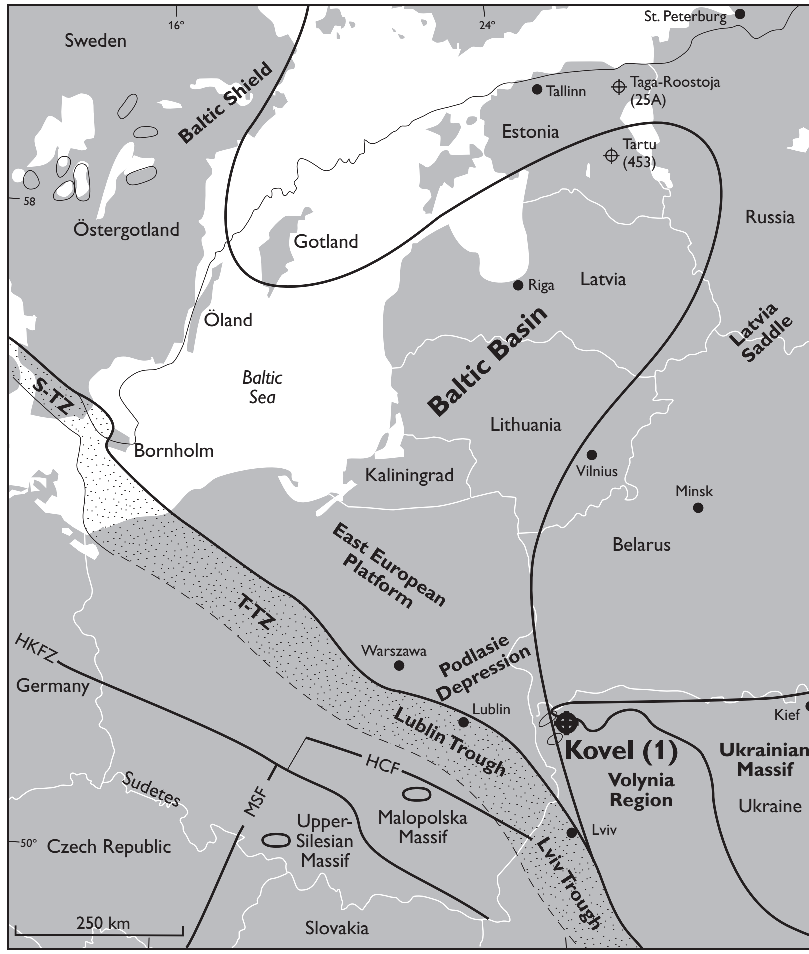


Fig. 1. Location map, the Kovel-1 well is located in western Ukraine.
T-TZ = Teisseire-Tornquist Zone;
S-TZ = Sorgenfrei-Tornquist Zone;
HKFZ = Hamburg-Kraków Fault Zone;
HCF = Holy Cross Fault;
MSF = Moravian-Silesian Fracture.

vician succession in this part of Ukraine and facilitating interregional correlation of the Ukrainian strata and 3) to give the significance of the prominent hiatuses recorded in the succession.

Study area and regional setting

The Kovel-1 well was drilled in western Volynia, northwestern Ukraine in the late 1980's. Cretaceous sediments cover the area. The region is transected by tectonic faults. The Ordovician strata are known only from the subsurface and the succession is not completely preserved in the region.

The Kovel-1 well is located in an area that is transitional between two stratigraphical regions i.e. southwestern Belarussia (Podlasie-Brest Trough) and western Volynia (Männil 1984, 1986; Männil & Meidla 1994; Fig. 1). The Ukrainian Massif bounds the area to the east and the Lublin and Lviv Trough successions are near the west and south boundaries.

Stratigraphical Framework

Only the Lower, Middle and lower Upper Ordovician i.e. from the Pakerort regional Stage to the Haljala regional Stage, which corresponds to the time slices 1a–5b of Webby *et al*. (2004), is preserved by the Kovel-1 core (Stouge & Saadre 1997; Saadre *et al*. 2001; this paper). The Ordovician succession in the Kovel-1 well spans the depth interval from 255.4 m to 280.7 m,

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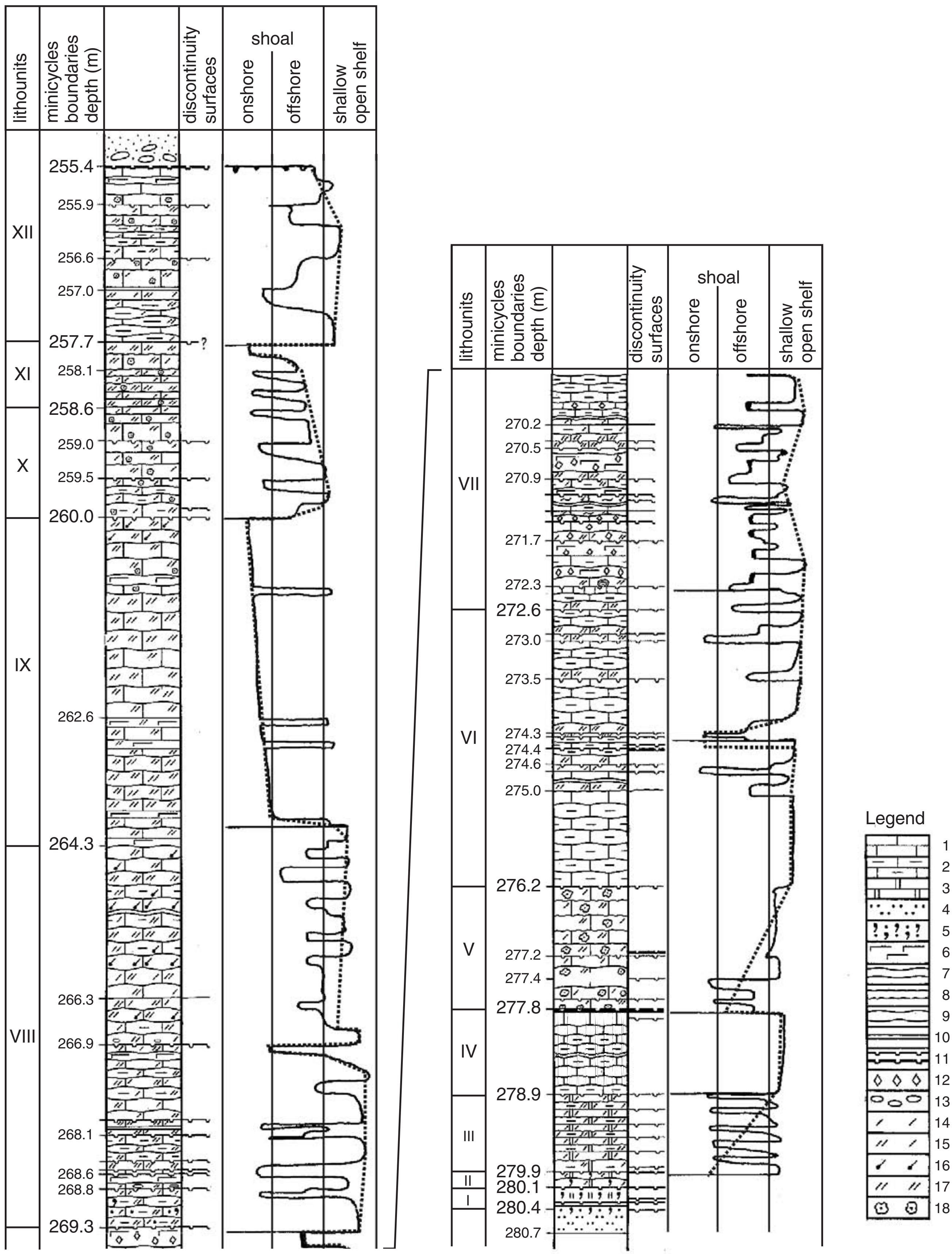
Fig. 2. Lithological log of the Ordovician succession; distribution of facies and DS's in the Kovel-1 core. Sea-level curve and based on facies analysis is shown in the right column. Explanation to the legend: 1. Limestone; 2. Argillaceous limestone; 3. Dolostone; 4. Sand and siltstone; 5. Glauconitic sandstone; 6. Marlstone; 7. Wavy bedding; 8. Horisontal bedding; 9. Nodular texture; 10. Interbeds of marlstone; 11. Phosphatised and pytitised discontinuity surfaces (=DS); 12. Breccia; 13. Conglomerate; 14. Fine biodetritus; 15. Unsorted biodetritus; 16. Pyritised biodetritus; 17. Corase-grained detritus; 18. Ooids and pseudo-ooids.



lithounits
minicycles boundaries depth (m)
discontinuity surfaces
shoal
onshore
offshore
shallow open shelf
XII
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
255.4
255.9
256.6
257.0
257.7
258.1
258.6
259.0
259.5
260.0
262.6
264.3
266.3
266.9
268.1
268.6
268.8
269.3
270.2
270.5
270.9
271.7
272.3
272.6
273.0
273.5
274.3
274.4
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275.0
276.2
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277.8
278.9
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which means it is only 25.3 m thick (Fig. 2). The lowermost 0.6 m is composed of quartzitic siltstone (0.3m+) succeeded by glauconitic sandstone (0.3 m). The remaining part of the succession consists of limestone with marl interbeds and films. The thickness of the beds is small throughout the section and discontinuity surfaces (= DS's; Saadre 1992, 1996) are frequent. The most extensive stratigraphic hiatuses occur in the Lower Ordovician portion of the section.

The basal Ordovician strata overlie Cambrian quartzitic siltstone. The Ordovician carbonates are overlain unconformably by a basal conglomerate of Early Cretaceous age. The Cretaceous basal conglomerate is polymict and 0.1 m thick. It rests on the smooth denudation surface that forms the top of the Lower Palaeozoic succession. The sediments from the upper part of the Ordovician have been removed, probably during various times, when the succession became exposed and up to the Early Cretaceous, when the succession became covered.

The Kovel-1 succession cannot precisely be allocated to the local stratigraphy of the western Volynia region (Pomjanovskaja & Hiznjakov 1967; Chegelnjuk 1980; Männil & Meidla 1994) and hence references to informal units are used here. The lower part of the Ordovician strata in Kovel-1 corresponds to the Vyzhivka (unit I), Podgorodny (unit II), Ishov (unit III) and Lyubokhin formations (units IV and V) of the western Volynia region. The upper informal units VI–XII of the Kovel-1 succession correspond to the formally described Ordovician Novoselki Formation of the southwestern Belarussian region (Pushkin 1981; Ropot & Pushkin 1987; Männil & Meidla 1994).

Material and methods

The drill core with a diametre of 8 cm was cut in half and the material from the one half was used for analysis whereas the second half is kept as reference. Bed-by-bed macrolithological characteristics of the sequence were composed using the polished surface of the reference drill core, complemented with 50 thin sections and 10 chemical (carbonate) analyses. Facies analysis was carried out and an empirical transgression-regression curve was constructed on the basis of the distribution of facies.

A total of 24 samples were studied for chitinozoans using a standard preparation technique and a weak acetic acid was used. The sample size, collected at 1m intervals varied from 0.5 to 0.7 kg of limestone except the lowermost one, which was smaller in size. Chitinozoans were extracted from the residue of the samples before the residues were searched for conodonts in the case where the two microfossil groups were obtained from the same sample.

58 samples were collected for conodont examination throughout the succession. In the lowermost condensed part of the succession the samples were collected bed-by-bed. In the higher part of the succession the samples represent intervals of 1 m. After being dissolved in weak acetic acid the conodont samples were washed using a 0.063 mm sieve.

Lithostratigraphy

The preserved, 25.3 m thick Ordovician succession is here subdivided into 13 informal lithological units (i.e. siltstone unit and the informal units I–XII; Fig. 2). The succession is composed of clastic sediments (quartzitic siltstone and glauconitic sandstone) in the basal part (siltstone unit and unit I) succeeded by carbonates and mixed siliciclastic carbonates in the higher parts (units II–XII; Fig. 2). The following lithological units are distinguished:

Siltstone unit. 280.7–280.4 m
This 0.3 m thick unit is grey and consists of well-sorted silt with fine biodetritus composed of inarticulate brachiopods (Fig. 3A).

Unit I. 280.4–280.1 m
Unit I consists of green glauconitic sandstone interbedded with 1–2 cm thick silty clay (Fig. 3B). It is 0.3 m thick.

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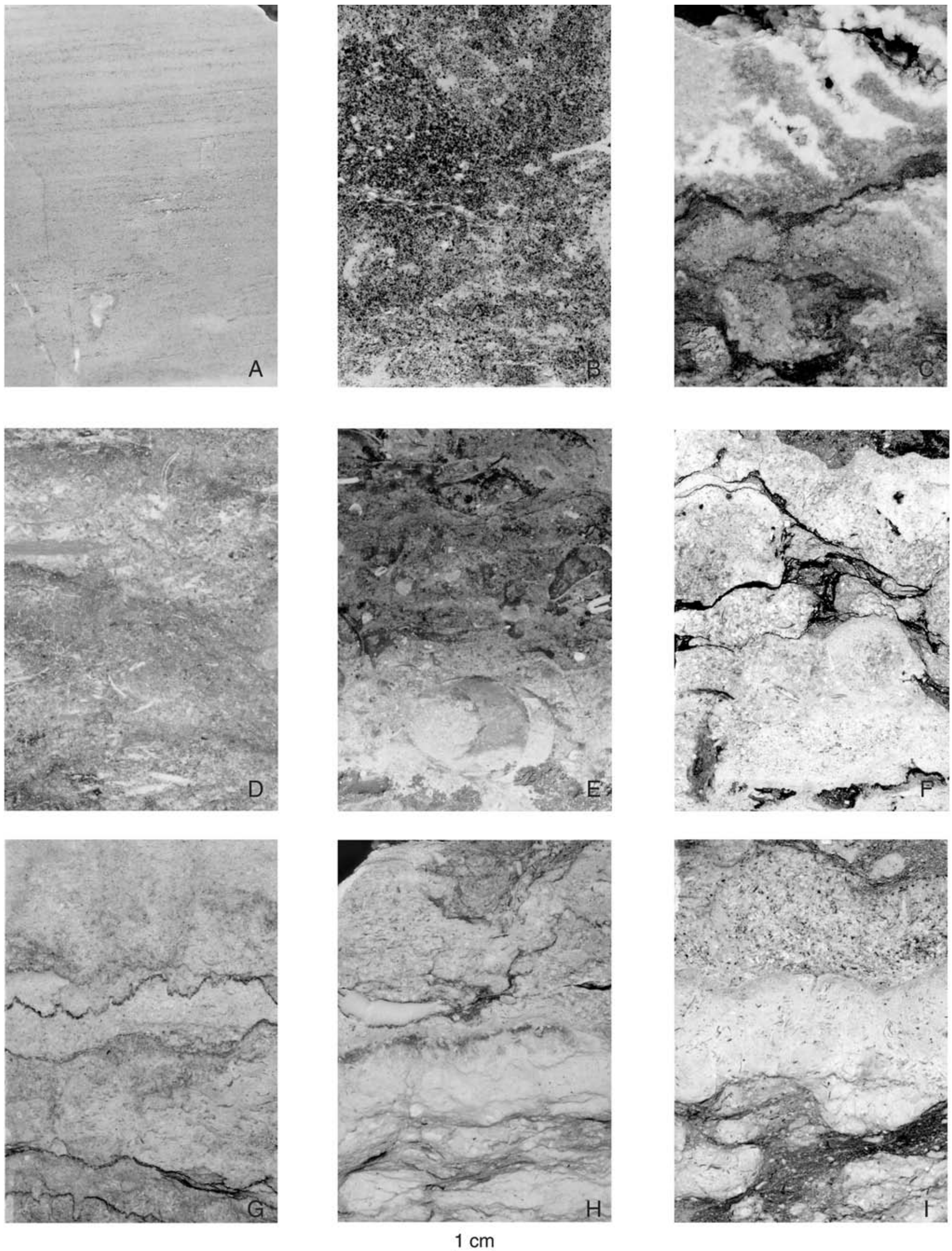
Fig. 3. Macrophotos of polished core samples.
A. Grey quartzose siltstone (280.5 m).
B. Green glauconitic sandstone. Unit I (280.3 m).
C. Greenish-grey glauconitic dolostone with lenses of dark-grey dolomitic marl with a druse of dolomite. Unit II (280.0 m).
D. Red-coloured packstone (dolostone) with intercalations of rare films of greenish-grey dolomitic marl. Unit III (279.7 m).
E. Red-coloured packstone (limestone). Nautiloids and fragments of shelly fauna are present. Unit IV (277.9 m).
F. Light-grey moderately sorted polydetrital packstone with lenses of grainstone and marl films. Note two distinct phosphatic DS's. Unit V (277.1 m).
G. Yellowish-grey to light-grey packstone to grainstone. The grain material is represented by polydetrite (mostly crinoidal) and Fe-coated grains. Note frequent stylolitic surfaces. Unit V (276.5 m).
H–I. Contact between light-grey seminodular wackestone with wavy marl beds and dark-grey grainstone. The grain component is mainly polydetrital, partly pyritised. The phosphatic and pyritic DS's are distinct. Unit VII (270.5; 274.4 m).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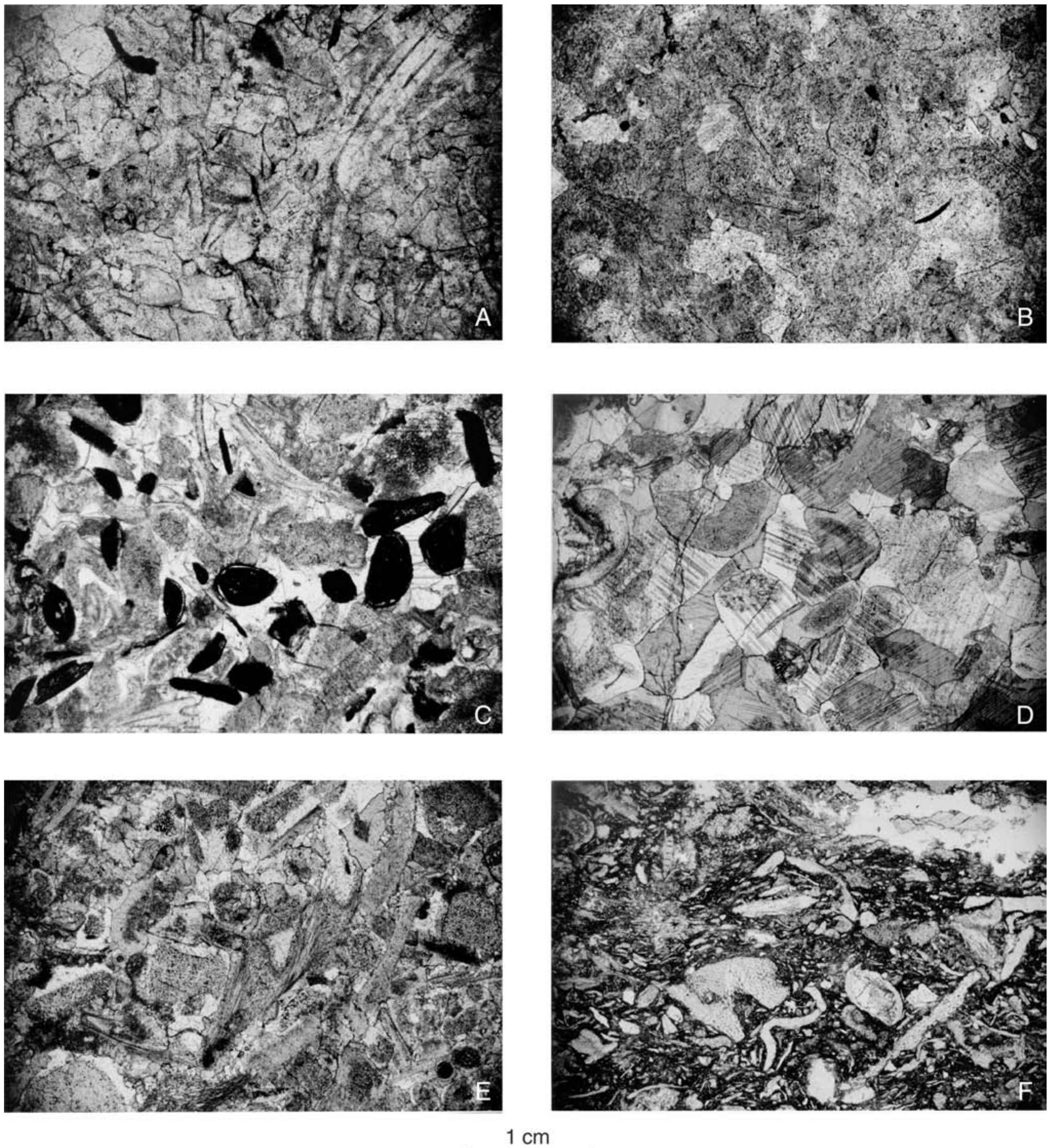


Fig. 4. Photos of thin sections
A. Doloumite (recrystallized crinoidal grainstone). Unit III (279.6 m).
B. Glaucomite dolostone with limonitized coated grains (recrystallized biodetrital packstone (?)). Unit III (279.1 m).
C. Polydetrital (predominantly crinoidal) grainstone with frequent pyritised coated grains (Fe-pseudooids). Basal part of a microcycle. Unit V (277.4 m).
D. Well-sorted crinoidal grainstone from the basal bed of a mesocyclite. Unit VI (274.1 m).
E. Poorly sorted polydetrital (predominantly crinoidal) grainstone. Unit VI (272.6 m).
F. Unsorted polydetrital argillaceous packstone, basal bed of a mesocycle. Unit VIII (268.8 m).

Unit II. 280.1–279.9 m
Unit II is 0.2 m thick and consists of green-grey glauconitic dolomite with 3 mm thick lenses of dark-grey dolomite marl (Fig. 3C).

Unit III. 279.9–278.9 m
Unit III is red-colored wackestone and packstone (dolomite) intercalated with rare beds of green-grey dolomite marl. This unit is 1.0 m thick.

The content and degree of sorting of the biodetritus vary considerably (Fig. 3D, Fig. 4A, B). Nautiloids are present and are most frequent in the basal part of the unit. Six weak discontinuity surfaces (DS's) are recorded in the unit, including the upper boundary of the unit.

Unit IV. 278.9–277.8 m
Unit IV is 1.1 m thick. The lowermost 10 cm is yellowish-grey and the rest is red-colored. It is composed of semi-nodular wackestone and packstone (limestone). The middle part of the unit is nodular and slightly argillaceous. Nautiloids become frequent in the topmost part (Fig. 3E). A clear pyritized DS is recorded at the depth of 277.9 m. The upper boundary of the unit is developed as an erosion surface indicating a continuous sedimentary break in the succession.

Unit V. 277.8–276.2 m
Unit V is composed of yellowish-grey wackestone to grainstone with wavy films of marl (Fig. 3G). The unit is 1.6 m thick.

The grain material consists of abundant Fe-pseudo-ooids (Fig. 4C) and very poorly sorted biodetritus (coarse in the lower, fine in the upper part) and rare pebbles. Four weak DS's are registered in the lower part and stylolites are frequent in the upper part of the unit. A distinct phosphatised DS is recorded at its upper boundary.

Unit VI. 276.2–272.6 m
Unit VI is a light-grey nodular wackestone to packstone. It is 2.6 m thick.

Bioturbated grainstone forms the basal part of the five sedimentary cycles that are distinguished in unit VI. The biodetritus is unsorted in some levels. It is coarse, mostly crinoidal (Fig. 4D, E). The eleven DS's recorded in the unit are mostly weak and are concentrated to the middle part of the unit. A weak DS marks the upper boundary of the unit.

Unit VII. 272.6–269.3 m
Unit VII is a 3.3 m thick succession composed of gray nodular to semi-nodular slightly argillaceous bioturbated wackestone to packstone. Interbeds of biodetrital grainstones and marl beds containing brecciate particles of different limestones are frequent (Fig. 3H, I; Fig. 5A, B). The biodetritus in the limestone and marl is moderately sorted and partly pyritised. Nine weak phosphatic DS's are recorded; most of them occur in the middle part of the unit. The upper boundary is an non-impregnated DS and is developed as an erosion surface.

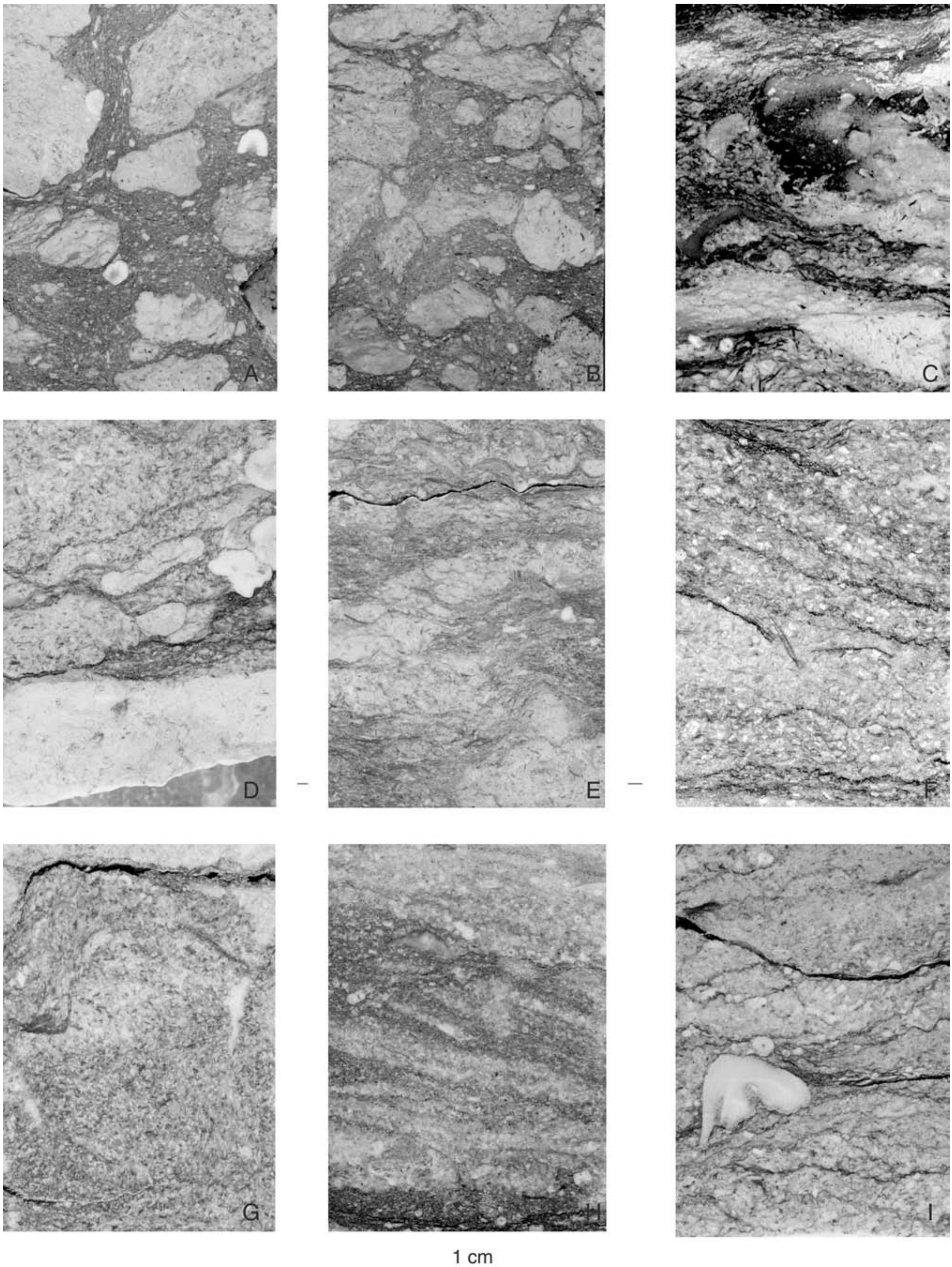
Unit VIII. 269.3–264.3 m
Unit VIII is 5.0 m thick. It is composed of an intercalation of semi-nodular to nodular bioturbated, slightly argillaceous wackestone, pure and non-argillaceous packstone, where biodetritus is mainly pyritised and biodetrital marl beds (Fig. 4F; Fig. 5C–E; Fig. 6A–D). The pyritised biodetritus consists predominantly of trilobites, brachiopods, ostracodes and crinoids. Seven, weak DS's are present in the lower part of the unit. Fine grains of glauconitic and silty quartz are present in the basal 0.5 m. Rounded pebbles and fragments of bryozoans occur at the depths of 268.8 and 266.9 m and immediately above distinct phosphate DS's (Fig. 5D). The boundary between the units VIII and IX is gradual.

Unit IX. 264.3–260.0 m
Unit IX consists mainly of light- to dark-gray grainstone interbedded with bioturbated packstone. It is 4.3 m thick. Light crinoidal detritus dominates in the upper and lower parts, pyritised detritus in the middle part (Fig. 5F, G). The bedding of the sequence is mainly inclined. Fe-pseudo-ooids occur in the interval 261.0–260.65 m. The beds in unit IX are cyclic and four biodetrital marl beds, each about 20 cm in thickness, occur in the basal parts of the cycles. A distinct DS marks the upper boundary of the unit.

Unit X. 260.0–258.6 m
Unit X is 1.4 m thick. It is composed of brownish wackestone to packstone with Fe-ooids and pseudo-ooids (Figs 5H, 6E). The bedding is horizontal to inclined. Four weakly developed DS's occur in the unit and the uppermost one is the upper boundary of unit X.

Unit XI. 258.6–257.7 m
Unit XI consists of light- to dark-gray grainstone and packstone with Fe-ooids and pseudo-ooids. Unit XI is 0.9 m thick.

In the basal part the biodetritus is dominantly poorly sorted and coarse and well sorted and fine-grained in the upper part. Four cycles are recognized within the unit. The upper boundary of unit XI is developed as a distinct DS.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Unit XII. 257.7–255.4 m

Unit XII is a light- to dark-gray packstone intercalated by marl and grainstone (Figs 5I, 6F). It is 2.3 m thick. Irregularly dispersed pseudo-ooids occur in the middle and upper parts of the unit. Two weak DS's are present in the middle part of the unit. The upper boundary is a very distinct erosion surface, marking the end of the Lower Palaeozoic succession.

Sedimentary facies and environmental interpretation

The lithological characteristics of the section indicate that sedimentation occurred in a narrow open-shelf environment and marginal to the Ukraine Massif in the east. The facies model proposed for the Baltic basin (Nestor & Einasto 1977; Einasto 1986, 1995; Nestor 1990) is used here. The facies analysis shows that the sediments identified in Kovel-1 accumulated in the shallow water open shelf and shoal or turbulent environments. Open shelf rocks predominate in units III–VIII; shoal sediments prevail in the lowermost units I and II and units IX–XI in the upper part of the section (Fig. 2).

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Fig. 5. Macrophotos of polished core samples.

A, B. Sedimentary breccia consisting of slightly sorted light-grey packstone and moderately sorted grey grainstone. Brecciated particles are surrounded by bidetrital bioturbated marl (dm 3–5 cm, 30–50 % of the total amount). Unit VII (269.5 m; 272.0 m).

C. A distinct intensely pyritised DS in the light-grey unsorted packstone. Unit VIII (268.1 m).

D. A distinct phosphatic DS between light-grey slightly sorted packstone and grey moderately sorted grainstone with some pebbles and rounded bryozoa. The shelly detritus is partly pyritised. Unit VIII (266.9 m).

E. Light-grey bioturbated nodular packstone with wavy greenish-grey biodetrital marlbeds. The biodetritus is poorly sorted. Note the interbed of coquina. Unit VIII (265.0 m).

F. Light-grey, moderately sorted predominantly crinoidal grainstone. The bedding is inclined, with frequent stylolitic surfaces. Unit IX (262.3).

G. Contact between dark- and light-grey well-sorted polydetrital grainstone. Unit IX (260.5 m).

H. Crinoidal grainstone with frequent Fe-pseudoolites and oolites – the basal bed of a macrocycle. Unit X (259.6 m).

I. Crinoidal grainstone with stylolitic surfaces. The grain size of biodetritus and sorting varies from bed to bed. Note the inclined bedding and the slightly rounded bryozoa. Unit XII (depth 256.0 m).

Facies 1. Shoal limestones

The shoal limestones are represented by the units I, II, IX, XI and occur as interbeds in the units VI and XII. They can be subdivided into two distinct groups: 1) poorly sorted polydetrital limestones (with muddy additive), and 2) well sorted monodetrital crinoidal limestones (with calcite cement).

1. Poorly sorted polydetrital shoal limestones

The limestones of the first group consist predominantly of poorly sorted skeletal detritus: brachiopods, trilobites, molluscs (in several levels micro-gastropods prevail), ostracodes, echinoderms, bryozoans and calcareous algae (Fig. 6D–E). In the groundmass muddy calcite material can be found in various amounts. The clay content is low, reaching rarely above 3–5%. Only in marl inter-beds the insoluble residue may reach 30%. Coarser encrusted shell material is usually oriented parallel to the bedding plane. Units VII and VIII of the middle part of the Kukruse Stage have moderately sorted detritus, which is partly pyritized (Fig. 5C, 5F).

2. Well sorted monodetrital crinoidal limestones

Limestones of the second group consist almost exclusively of echinoderm skeleton detritus, with a small addition of shell detritus, which has undergone some sorting and wear. Coarse detritus is prevailing.

Facies 2. Open shelf facies

The open shelf limestones, which are dolomitised in unit III, are predominantly represented by packstones and - more rarely - by wackestones. The packstones are mostly unsorted and polydetrital (Fig. 3E; Fig. 5E); the wackestones are characterised by trilobites and brachiopods, with molluscs, echinoderms, ostracodes and bryozoans being less common.

Facies 3. Breccia interlayers

Breccia interlayers occur in the lower part of the Kukruse Stage, in the interval 272.3–269.3 m, and constitutes a distinct lithostratigraphical unit i.e. unit VIII. The facies is represented by bioturbated wackestones and packstones, which contain nine thicker (5–20 cm) and several thinner (2–3 cm) interbeds of breccia. The matrix of the breccia is bioclastic marl containing angular or slightly rounded isometric or elongated

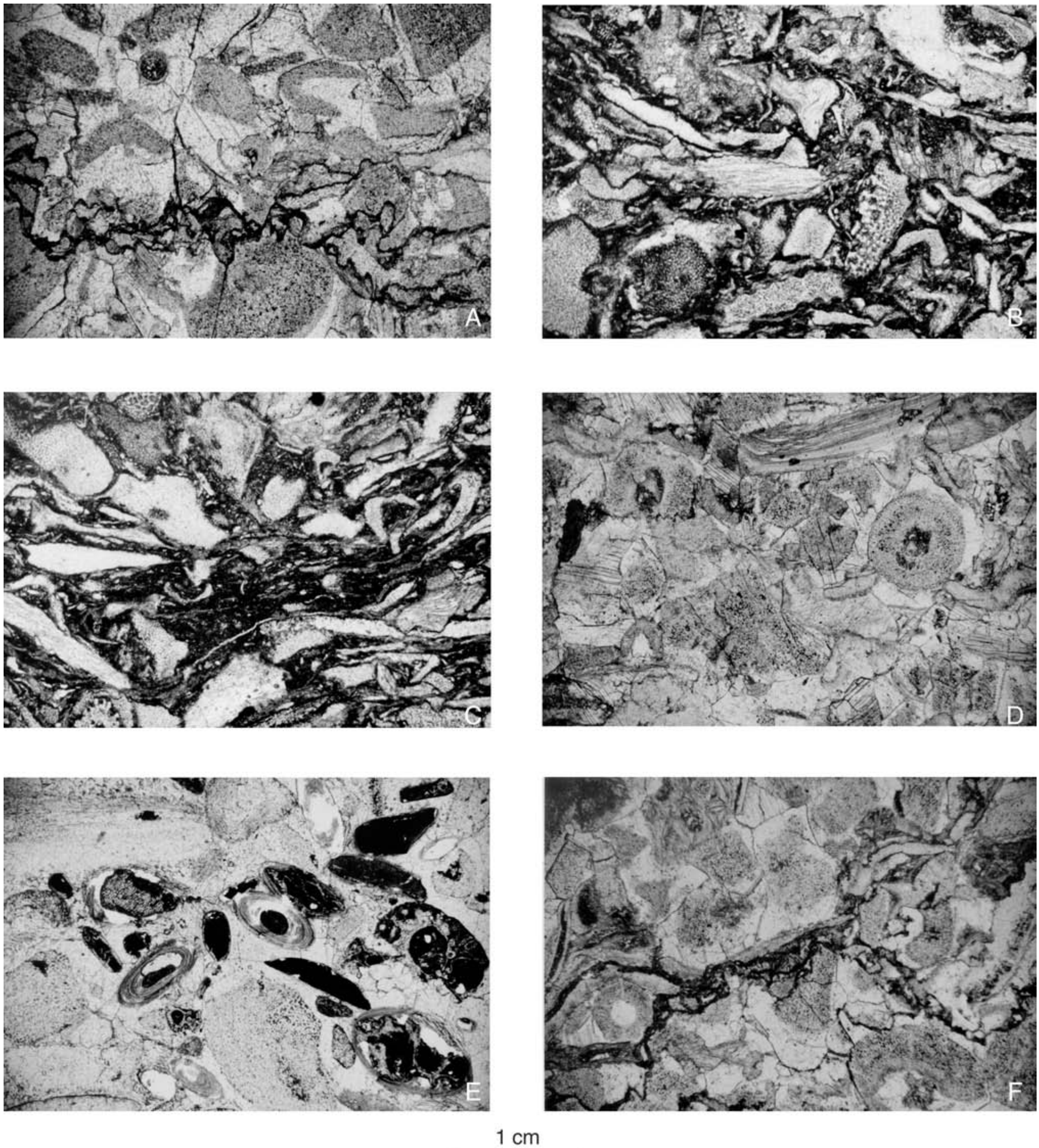

Fig. 6. Photos of thin section
A. Mainly coarse crinoidal grainstone. Note the stylolitic surface. Unit VIII (266.2 m).
B–C. Unsorted polydetrital grainstone. Unit VIII (265.0 m).
D. Moderately sorted crinoidal grainstone. Unit VIII (262.8 m).
E. Crinoidal grainstone with frequent Fe-oolites and pseudoolites – basal bed of a macrocycle. Unit X (259.6 m).
F. Crinoidal moderately sorted grainstone. Note the stylolitic surface. Unit XII (256.4 m).

intraclasts (lithoclasts) (Fig. 5A, B) of bioturbated wackestone and packstone; the former type is prevailing. The breccia interlayers are either clast-supported (rudstone) or matrix-supported (floatstone); the latter type of interlayer is the most frequent.

There is no trace of sorted or graded lithoclasts and this excludes tempestite or turbidite origin of breccia interlayers. Traces of noteworthy transportation are missing i.e. in places the pebbles are not fully separated from the underlying bed.

Discontinuity surfaces (DS's)

The most distinct discontinuity surfaces mark stratigraphical breaks at the depths of 279.9, 277.8 and 255.4 m (Fig. 2). The DS's at the depths of 278.9, 276.2, and 274.2 m are the boundaries of sedimentary fourth and third order cycles. The surfaces bear clear evidence of denudation and the uppermost regressive part of the underlying cycle is eroded away. Therefore, the depositional sedimentary cycle of unit IV, the topmost part of the depositional sedimentary cycle of unit V (277.2–276.2 m) and the lowermost part of the depositional sedimentary cycle of unit VI (276.2–275.0 m) do not show any facies changes. At the same time, the surfaces show traces of polishing and scattered pebbles occur above the DS's in the core. The DS's are indistinct and discontinuous. Only tops of the rugged surface, covered with phosphate impregnation, are observable while the grooves of the microrelief are nearly indiscernible. Such indistinct DS's are frequent in the intervals 275.0–274.5, 271.7– 270.9 and 268.8–268.1 m. Only a few DS's on the levels 279.9 m, 277.8 m, 274.4 m, 268.1 m (Fig. 5C) and 255.4 m have a rather strong pyrite impregnation, but there is no direct correlation between the intensity of pyritisation and the rank of the depositional sedimentary cycle.

In the Baltic area, the phosphatised DS's developed in deposits of the mid-shelf environment. Both in onshore and offshore direction they were replaced by pyritised DS's (Saadre 1992). It is possible that the same regularity is valid for the Volynia area.

Most of the DS's in the Kovel core are connected with pelmatozoan and polydetrital grainstone interlayers and occur on their lower or upper bedding planes. Most of the grainstone interbeds mark boundaries of bed-scale rhythms and cycles (e.g. Einsele *et al*. 1991) and may represent storm layers (tempestites).

Biostratigraphy

The Lower, Middle and lower Upper Ordovician succession of Kovel-1 core is divided into seven chitinozoan zones and subzones (Ch1–Ch7) and 13 conodont zones (C1–C13). The first occurrences (FO) of the chitinozoan and conodont index species have been used for precise definition of zonal boundaries (Figs 7–9).

The regional chronostratigraphy in the Kovel-1 well is established on the distribution of conodonts in the lower portion of the well and up to 277.80 m. Above that level it is based also on the distribution of chitinozoans and their correlation to the Baltoscandian successions (Nõlvak & Grahn 1993; Bauert & Bauert 1998; Nõlvak 1999a, b).

Distribution of chitinozoans in the Kovel-1 well

As a rule, chitinozoans are regarded as relatively independent of facies variations, but they are absent in red limestones and dolomites. Also the degree of metamorphism of organic matter has to be low and heating of sediments should not exceed 200–250o C. Above this temperature the use of these organic-walled microfossils becomes irrelevant.

Metamorphism has not been registered in the rocks of the section, but the red limestone and dolomite beds of units II–IV put a limit to the preservation of the organic walled microfossils. As a result all samples below 277.8 m were completely barren of chitinozoans in the Kovel-1 core.

The chitinozoan specimens are rather well preserved and 47 different chitinozoan taxa have been distinguished (Fig. 7). The stratigraphic distribution of the chitinozoan species compares with the chitinozoan succession reported from the Estonian core sections Tartu (453) (Bauert & Bauert 1998; Fig. 1) and Taga-Roostoja (25A) (Nõlvak 1999b; Fig. 1). Hence, the chitinozoan succession from Kovel-1 can be referred to the biozonal schemes established by Nõlvak & Grahn (1993) and Nõlvak (1999a).

Just above the level of disappearance of the barren red beds at a depth of 277.8 m a relatively diversified association of chitinozoans appeared, among others the stratigraphically important *Conochitina clavaherculi* Eisenack and *C. tuberculata* Eisenack. By definition, these taxa provide two successive subzones, however, in some very rare cases they can also be found together (Nõlvak & Grahn 1993; see also Nõlvak 1999b) as it is the case in the Kovel-1 section.

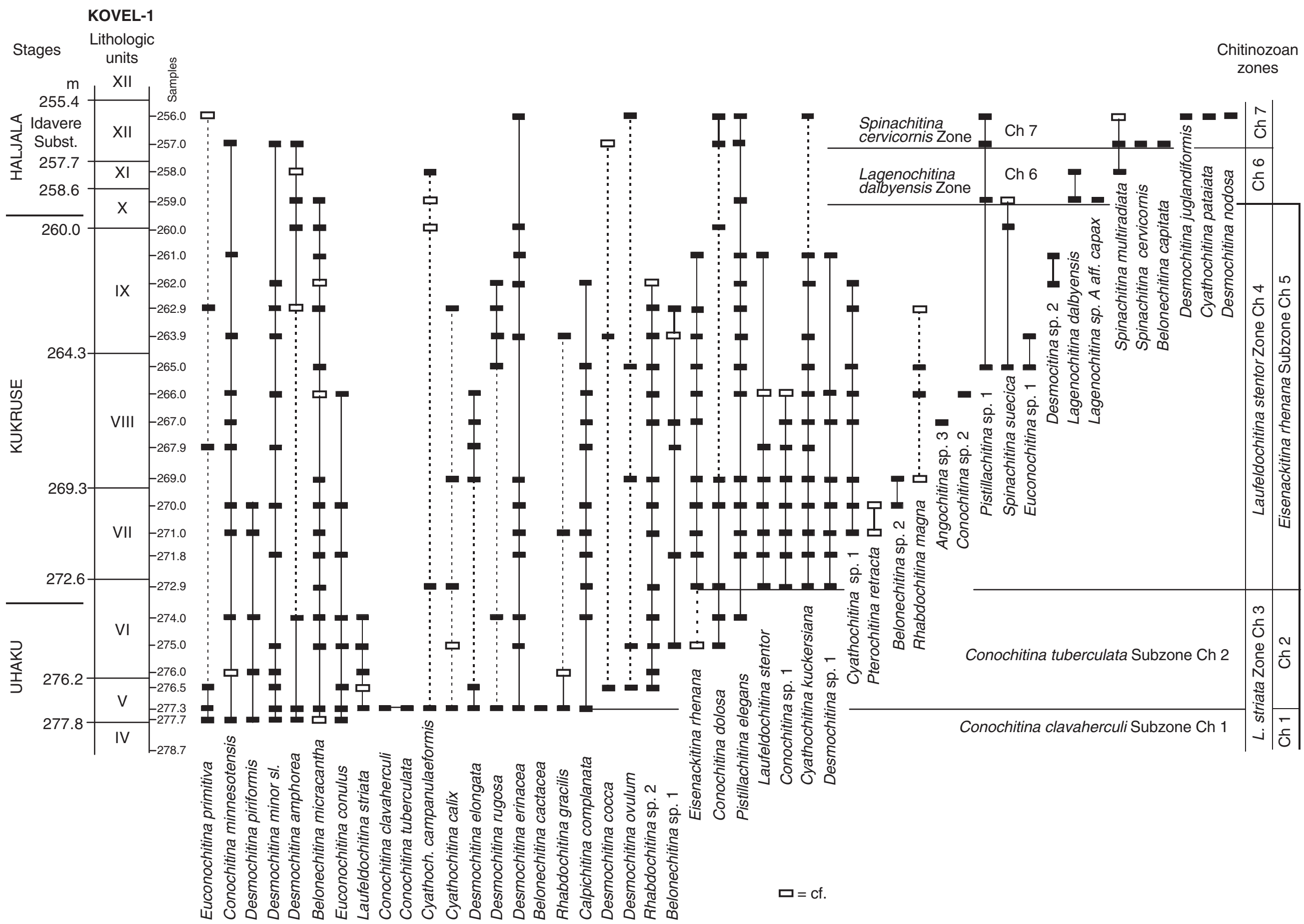

Fig. 7. Ranges of Chitinozoan species in the Kovel-1 core.

Ch1. *Conochitina clavaherculi* Subzone
Interval: 277.7–277.3 m
Age: Uhaku

The *Conochitina clavaherculi* Subzone of the Uhaku Stage is the oldest chitinozoan subzone identified in the Kovel section. It encompasses the lower half of the non-red limestones of unit V with many discontinuity surfaces in the interval 277.2–277.8 m.

Ch2. *Conochitina tuberculata* Subzone
Interval: 277.3–272.9 m.
Age: Late Uhaku

The subzone is defined as the interval between the FO (first occurrence) of the index species and the first continuous occurrence of *Eisenackitina rhenana* (Eisenack). It must be noted that a single specimen of *E. rhenana* is recorded in sample 275.0 m about 2 m lower. The lower boundary of *Conochitina tuberculata* Subzone lies within the middle part of the Uhaku Stage in the North-Estonian sections. The subzone embraces limestones from the upper part of the unit VI.

Ch3. *Laufeldochitina striata* Zone
Interval: 277.7–272.9 m
Age: Uhaku

This zone represents the lowermost chitinozoan zone in the Kovel-1 section and encompasses Unit V entirely and almost the whole Unit VI.

Ch4. *Laufeldochitina stentor* Zone
Interval: 272.9–259.0 m
Age: Kukruse

The *Laufeldochitina stentor* (Eisenack) Zone embraces almost all the beds represented by the units VII–IX and these are referred to the Kukruse Stage. The species *Conochitina* sp. 1 and 2 (= *C. savalaensis* nomen nudum and *C. viruana* nomen nudum *in* Männil 1986, fig. 2.1.1) and *Conochitina* n. sp. A and B (*sensu* Bauert & Bauert 1998) have been found only from the beds of this age, and the former only from the kukersite-bearing beds in the stratotype area (Nõlvak 1999b).

Ch5. *Eisenackitina rhenana* Subzone
Interval: 272.9–259.0 m
Age: Kukruse
This subzone coincides almost exactly with the stratigraphical extent of the Kukruse Stage in many North-Estonian sections (Bauert & Bauert 1998; Nõlvak 1999b). However, the sample 260.0 m from the topmost part of unit IX in the Kovel-1 well does not contain any specific taxa, and the corresponding beds here are tentatively assigned to the Kukruse Stage. This conclusion is also supported by the appearance of abundant acritarch *Leiosphaeridia* sp. in the next higher sample at 259.0 m, which is a very good index species showing the lower boundary of the Idavere Substage of the Haljala regional Stage in the North-Estonian sections and the Fjäcka section in Dalarna, Sweden (Nõlvak *et al*. 1999).

Ch6. *Lagenochitina dalbyensis* Zone
Interval: 259.0–257.0 m
Age: Early Haljala (Idavere)
The zone is defined here as a range zone. According to the data available, *Lagenochitina dalbyensis* (Laufeld) is a very common species throughout its short range and in the whole Baltoscandia. Although the two oldest, but also very short-ranging zones (*Armoricochitina granulifera* and *Angochitina curvata*, see Nõlvak & Grahn 1993; Nõlvak *et al*. 1999) are absent, the appearance level of *L. dalbyensis* can be used as one of the main criteria for the Idavere Substage of the

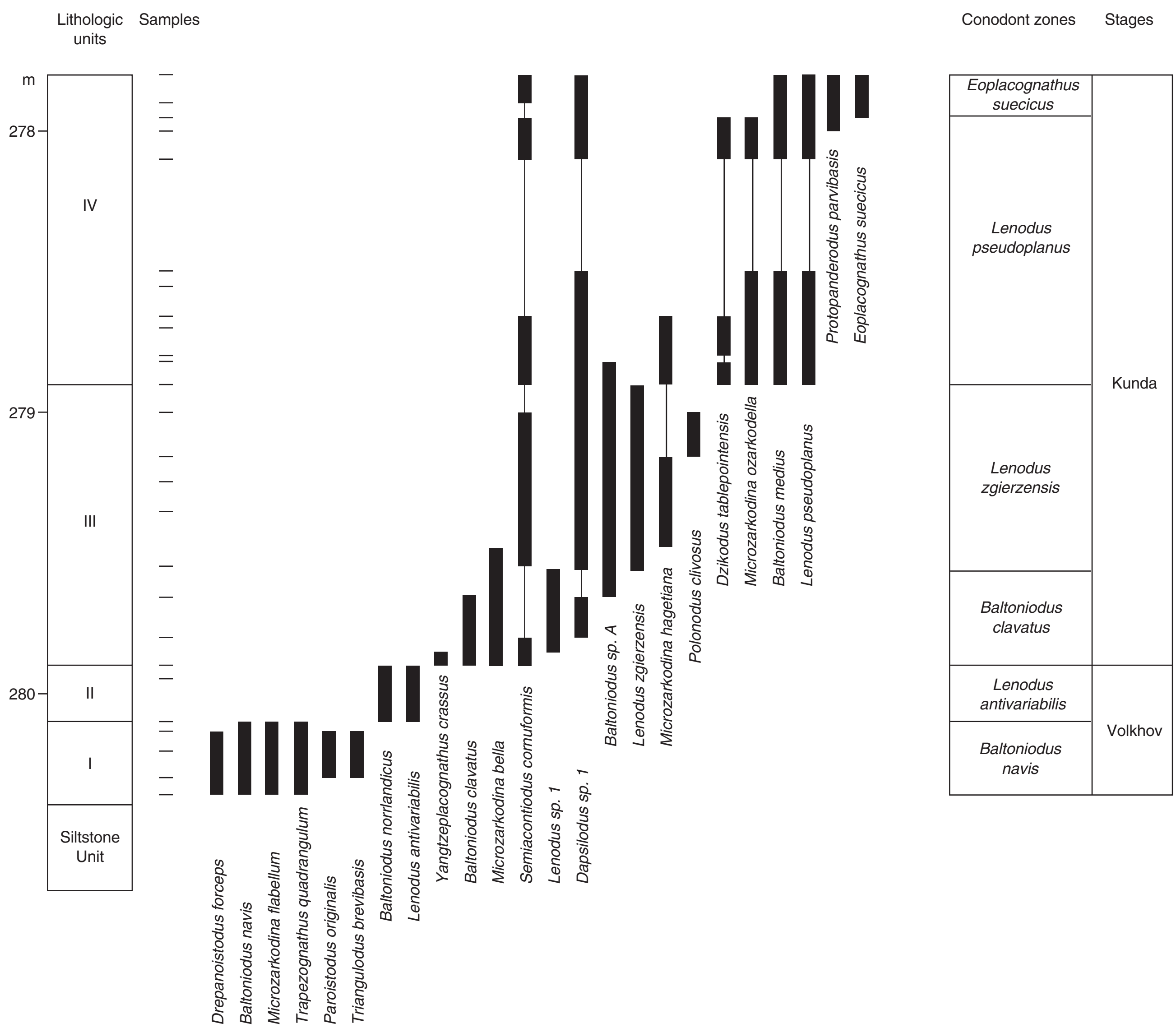

Fig. 8. Conodont ranges of selected species for the Volkhov–Kundan succession in the Kovel-1 core.

Haljala Stage. *Spinachitina multiradiata* (Eisenack) appears within this zone and it is also characteristic to this part of the succession in North Estonia and Sweden (see Nõlvak 1999b; Nõlvak *et al*. 1999, fig. 3).

Ch 7. *Spinachitina cervicornis* Zone
Interval: 257.0–256.0 m
Age: Haljala (Idavere)
This zone is defined here as the FO of *Spinachitina cervicornis* (Eisenack) and encompasses the topmost part of the Kovel-1 section. Most probably, the short-ranging *Belonechitina hirsuta* Zone is absent (see Nõlvak *et al*. 1999, fig. 3), or this part of the section needs more precise sampling.

Among the chitinozoans, there are no indications on the presence of the younger Jõhvi Substage or Keila Stage in the Kovel-1 section.

Conodont zonation of the Kovel-1 well

The Lower Ordovician conodont succession and composition of the fauna in Kovel-1 are clearly of Baltoscandian affinity. Thus, the conodonts from this lower interval are easily comparable with the known Baltoscandic conodonts published by Bergström (1971, 1983), Lindström (1971), Viira (1974), Löfgren (1978, 1985, 1994, 2000), Stouge (1989, 1998), Männik & Viira (1990), Bagnoli & Stouge (1997), Zhang (1998), Rasmussen (2001) and Viira *et al*. (2001). Precise correlation to levels of the Baltoscandian succession is possible with the exception that the Kovel-1 succession is incomplete. The conodont biostratigraphy of this specific outlying district of the Baltoscandian Ordovician Basin gives some new information to the existing conodont zonation and allows for a more precise subdivision.

The lower Middle Ordovician Kovel-1 conodont fauna demonstrates strong links with the conodont succession described from the Holy Cross Mountains in Poland (Dzik 1976, 1994). Here, the appearance of *Sagittodontina kielcensis* and *Phragmodus polonicus* in the Kovel-1 well compares with the Holy Cross Mountains conodont succession (Dzik 1994).

C1. *Baltoniodus navis* Zone
Interval: 280.40–280.10 m
Age: Early–Middle Volkhov
The FO of *Baltoniodus navis* is at 280.40 m and defines the lower boundary of the biozone. The FO of *Baltoniodus norrlandicus* and *Lenodus antivariabilis* marks the upper boundary of the biozone in the Kovel-1 core. Representative species of the genera *Microzarkodina*, *Paroistodus*, *Triangulodus* and *Trapezognathus* are recorded from this zone (Fig. 8).

The interval is referred to the lower and middle Volkhov regional Stage and is the oldest conodont zone identified in the Kovel-1 well. It encompasses all the strata referred to unit I. Some reworked specimens belonging to *Drepanodus arcuatus* and *Drepanoistodus forceps* occur in the zone; possibly these taxa indicate that older Volkhov strata or strata older than the Volkhov are present in the area.

Baltoniodus navis occurs together with several species characteristic of the *Baltoniodus navis* and *Paroistodus originalis* zones (*sensu* Lindström 1971; Löfgren 1978, 1985, 1994; Stouge 1989; Bagnoli & Stouge 1997) and the *Microzarkodina flabellum* – *Drepanoistodus forceps* Zone of Rasmussen (2001) suggesting correlation with these Baltoscandian zones.

C2. *Lenodus antivariabilis* Zone
Interval: 280.10–279.90 m
Age: Late Volkhov
This Volkhov biozone is defined by the interval from the FO of *Lenodus antivariabilis* (Bagnoli & Stouge 1997) to the FO of *Baltoniodus clavatus* . The index species appears at 280.10 m and the biozone encompasses unit II. The fauna is of low diversity. The other conodont species found within this part of the succession are *Drepanodus arcuatus* and *Drepanoistodus basiovalis*.

C3. *Baltoniodus clavatus* Zone
Interval: 279.90–279.55 m.
Age: Valastean (middle Kundan Substage)
The zone is defined as the interval between the FO of *Baltoniodus clavatus* and FO of *Lenodus zgierzensis*. *Baltoniodus clavatus* appears at 279.90 m in the Kovel-1 core. It encompasses the lower part of unit III and marks the beginning of the Valastean Substage of the Kunda regional Stage in the succession (see Stouge & Nielsen 2003). Other species present in the zone are referred to *Drepanodus*, *Drepanoistodus* and *Protopanderodus*.

The presence in one sample of *Yangtzeplacognathus crassus* suggests that part of *Y. crassus* Zone of Zhang (1998) is contained in the *Baltoniodus clavatus* Zone of this study (Fig. 8).

C4. *Lenodus zgierzensis* Zone
Interval: 279.55–278.90 m
Age: Mid Kunda
The FO of *Lenodus zgierzensis* defines the base of the zone. The index species appears at 279.55 m in the Kovel-1 well and the biozone comprises the upper part of unit III. The biozone largely corresponds to the middle part of the Kunda Stage. Most common associated species are given on Figure 8.

C5. *Lenodus pseudoplanus* Zone
Interval: 278.90–277.95 m.
Age: Mid – late Kunda
The FO of *Lenodus pseudoplanus* defines the base of the biozone. In the Kovel-1 core, *Lenodus pseudoplanus* appears together with *Baltoniodus medius* and *Microzarkodina ozarkodella* at 278.90 m, where they are associated with *Dzikodus tablepointensis*. *Microzardina ozarkodella* is abundant. The biozone encompasses the lower portion of unit IV and common associated taxa are given in Figure 8.

The biozone is widely spread across the East European Platform. It corresponds to the *Eoplacognathus*? *variabilis* – *Microzarkodina ozarkodella* Subzone (Löfgren 1978) from Sweden, the *Microzarkodina ozarkodella* Subzone of the *Eoplacognathus pseudoplanus* Zone (*sensu* Zhang 1998) and *Baltoniodus medius* – *Histiodella holodontata* Zone from the platform margin of Scandinavian Caledonides (Rasmussen 2001). The zone is contained in the upper, but not the uppermost part of the Kunda regional Stage.

C6. *Eoplacognathus suecicus* Zone
Interval: 277.95–277.80 m
Age: Latest Kunda
The FO of *Eoplacognathus suecicus* defines the base of the biozone. The upper boundary cannot be defined due to the development of a major hiatus (see below). In the Kovel-1 core *Protopanderodus parvibasis* is the most frequent associate taxon. *Microzarkodina ozarkodella* is present in the zone but upwards it becomes rare to absent. The zone is recorded from the uppermost beds of unit IV.

C7. *Baltoniodus prevariabilis* Zone
Interval: 277.80–276.00 m
Age: Uhaku
The zone is the interval from the FO of the index species to the FO of *Baltoniodus variabilis*. *Baltoniodus prevariabilis* appears together with *Sagittodontina kielcensis* at 277.80 m in the Kovel-1 core. The zone starts from the base of unit V. It corresponds to the lower half of the Uhaku Stage.

In the lower part of the *Baltoniodus prevariabilis* Zone several species characteristic of the international *Pygodus serra* Zone are recorded and the *Baltoplacognathus reclinatus* and *B. robustus* subzones (Bergström 1971, 1983) are present (Fig. 9). This is probably an indirect indication of the *Pygodus serra* Zone in the Kovel-1 core, despite the absence of the zonal index. *Sagittodontina kielcencis* is common within the zone.

C8. *Baltoniodus variabilis* Zone
Interval: 276.00–274.00 m
Age: Uhaku
The zone is defined by the appearance of *Baltoniodus variabilis* and up to the FO of *Amorphognathus inaequalis. Sagittondontina kielcensis* (advanced form and cf. on Fig. 9) is a common associate of the *B. variabilis* fauna. The zone is present in the lower half of unit VI and is referred to the upper part of Uhaku Stage.

The appearance of *Pygodus anserinus* at 276 m in the *Baltoniodus variabilis* Zone suggests equivalence (*partim*) between the *Pygodus anserinus* Zone (*sensu* Bergström 1971, 1983) and the *Baltoniodus variabilis* Zone of this study.

C9: *Amorphognathus inaequalis* Zone
Interval: 274.00–269.00 m
Age: Late Uhaku – Early Kukruse
The zone is defined as the interval from the FO of *Amorphognathus inaequalis*, which follows *Amorphognathus* sp. A. at 274.00 m, to the FO of *Amorphognathus tvaerensis* at 269.00 m. The biozone encompasses the upper part of unit VI and all of unit VII. It is contained within the uppermost part of the Uhaku Stage and extends into the Kukruse Stage.

C8: *Amorphognathus tvaerensis* Zone
Interval: 269.00–262.00 m
Age: Kukruse
The *Amorphognathus tvaerensis* Zone is here defined as the interval from the FO of *A. tvaerensis* to the FO of *Amorphognathus* cf. *tvaerensis.* The zone begins at 269.00 m at the base of unit VIII and extends into the higher part of unit IX. The zone comprises the middle part of the Kukruse Stage.

Bergström (1971, 1983) originally defined the *Amorphognathus tvaerensis* Zone by the FO of the index species to the FO of *Amorphognathus superbus*. *A. superbus* has not been recorded in this study and *Amorphognathus* cf. *tvaerensis* represents an evolutionary stage, which is more advanced than considered typical for *A. tvaerensis* (see Dzik 1994; Stouge 1998). Defined in this way, the *Amorphognathus tvaerensis* Zone is less comprehensive than originally intended by Bergström (1971).

C9. *Amorphognathus* cf. *tvaerensis* Zone
Interval: 262.00–260.00 m
Age: Kukruse
The *Amorphognathus* cf. *tvaerensis* Zone is defined by the local range of *Amorphognathus* cf. *tvaerensis*. *Amorphognathus* cf. *tvaerensis* appears at 262.00 m. The *Amorphognathus* cf. *tvaerensis* Zone is typically low in diversity and associated taxa characteristic of the zone

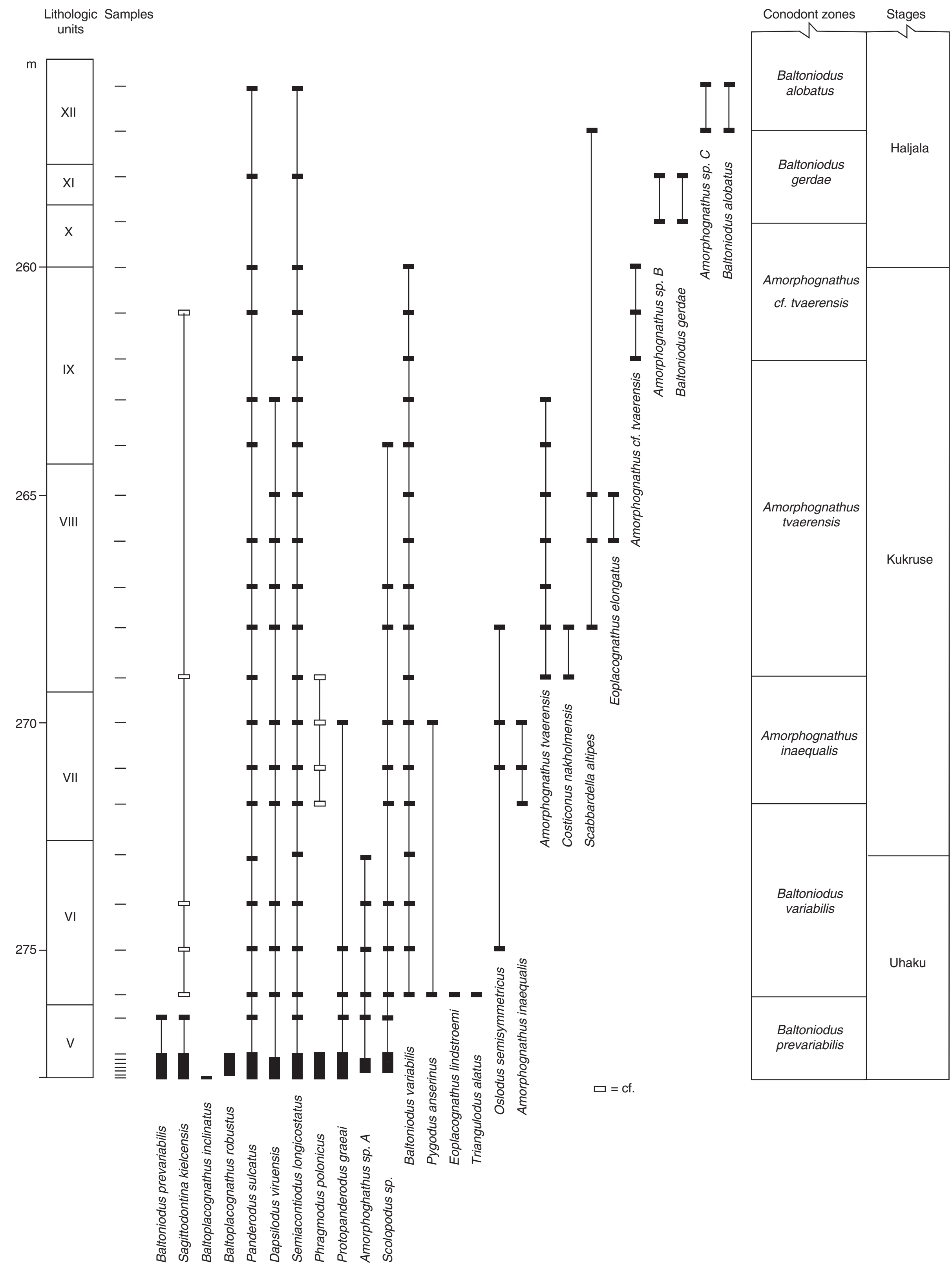

Fig. 9. Conodont ranges of selected species for the Middle Ordovician in the Kovel-1 core.

are not obvious. The few associated species given in Figure 9 are all long ranging species. The zone covers the uppermost part of unit IX.

C10. *Baltoniodus gerdae* Zone
Interval: 260.00–257.00 m
Age: Kukruse(?)–Haljala
Baltoniodus gerdae Zone is defined by the FO of the index species to the FO of *Baltoniodus alobatus*. *Amorphognathus* sp. B appears together with *B. gerdae*. *Baltoniodus gerdae* Zone characterises the units X and XI in the Kovel-1 well. The zone may be assigned to the Idavere Substage of the Haljala regional Stage.

The *Baltoniodus gerdae* Zone in this study corresponds to the *B. gerdae* Subzone of the comprehensive *Amorphognathus tvaerensis* Zone of Bergström (1971, 1983; see also Dzik 1978, 1994; Stouge 1998).

C11. *Baltoniodus alobatus* Zone
Interval: 257.00–256.00 m.
Age: Haljala
The *Baltoniodus alobatus* Zone is defined by the FO of *Baltoniodus alobatus* and *Amorphognathus* sp. C. The top of the zone is not recorded in the Kovel-1 core as the index species ranges up to the top of the investigated sequence. *Amorphognathus* sp. C is an intermediate between *Amorphognathus tvaerensis* and *Amorphognathus superbus* (see also discussion in Dzik 1994 and Stouge 1998). The yield and faunal diversity of this interval is very low. The *Baltoniodus alobatus* Zone is recorded from unit XII in the Kovel-1 core.

Baltoniodus alobatus Zone is the youngest conodont zone recorded here. Drygant (1974) described the conodont species *Semiacontiodus longicostatus* and *Complexodus pugonifer* from North-Western Volynia, Ukraine. *Semiacontiodus longicostatus* is a long ranging species and it is also recorded from the Middle Ordovician strata in the Kovel-1 core. *Complexodus pugonifer* however is known from strata that are younger than those found in Kovel-1 (Dzik 1994).

Unconformities in the Kovel-1 core

The chitinozoan and conodont biostratigraphy investigated here provide significant constraints for the age and nature of the unconformities in the Kovel-1 core (Fig. 10). These are developed at levels of lithological changes and are associated with discontinuity surfaces. Additional and perhaps minor unconformities may well be present in the succession but these are not well constrained perhaps due to the large sample intervals and perhaps also the lack of resolution caused by small changes in diversity of the two microfossil groups.

The Pakerort(?)–Volkhov unconformity

The boundary between the basal siltstone unit and unit I at the depth of 280.40 m reflects a hiatus spanning the interval from the Pakerort(?) regional Stage and into the basal part of the Volkhovian Stage as the lowermost Volkhovian *Baltoniodus*? *triangularis* conodont zone is missing in the Kovel-1 core.

The mid Volkhov unconformity

The mid Volkhov unconformity is documented by the lack of the *Microzarkodina parva* Zone as it is redefined by Bagnoli & Stouge (1997) and the *Baltoniodus norrlandicus* Zone (*sensu* Stouge 1989); the hiatus corresponds to Rasmussen's (2001) *Protopanderodus rectus* – *Microzarkodina parva* Zone. The unconformity is developed as a discontinuity surface at the lithological boundary between units I and II at the depth of 280.10 m.

The early Kunda unconformity

The unconformity is developed as a distinct discontinuity surface marking the boundary between the lithological units II and III. The faunal change from unit II to unit III is marked by the distinct change from the *Lenodus antivariabilis* Zone (upper Volkhov) to the *Baltoniodus clavatus* Zone (Kunda). The *Lenodus variabilis* and the *Yangtzeplacognathus crassus* (of Zhang 1998) Zones (lower Kunda) are not represented in the Kovel-1 succession suggesting that the hiatus covers at least the Hunderumian Substage of the Kunda Stage.

The early Mid Ordovician unconformity

The lithological change from unit IV to unit V is distinct. The boundary is marked by a prominent discontinuity surface showing traces of denudation at the depth of 277.80 m. The faunal change is equally abrupt and the appearance of *Baltoniodus prevariabilis* and *Sagittodontina kielciensis* - the latter in abundance - after the last presence of *Eoplacognathus suecicus* is prominent. The *Eoplacognathus suecicus* and the *Eoplacognathus foliaceus* subzones of Bergström (1971, 1983) are missing and the hiatus encompasses the Aseri and Lasnamägi regional Stages. The top of the hiatus is constrained by the appearance of the *Laufel-*

Chronostratigraphy			Lithologic units	Conodont zones	Chitinozoan zones	
VIRU	KURMA	Haljala	XII	*Baltoniodus alobatus*	*S. cervicornis*	(not subdivided)
			XI	*Baltoniodus gerdae*	*L. dalbyensis*	
			X	*Amorphognathus cf. tvaerensis*	*L. stentor*	*E. rhenana*
	PURTSE	Kukruse	IX			
			VIII	*Amorphognathus tvaerensis*		
			VII	*Amorphognathus inaequalis*		
		Uhaku	VI	*Baltoniodus variabilis*	*L. striata*	*C. tuberculatus*
			V	*Baltoniodus prevariabilis*		*C. clavaherculi*
		Lasnamägi	**early Mid Ordovician unconformity**		No data	
		Aseri				
OELAND	ONTIKA	Kunda	IV	*Eoplacognathus suecicus*		
				Lenodus pseudoplanus		
			III	*Lenodus zgierzensis*		
				Baltoniodus clavatus		
			early Kunda unconformity			
		Volkhov	II	*Lenodus antivariabilis*		
			mid Volkhov unconformity			
			I	*Baltoniodus navis*		
		Latorp	**Pakerort(?)-Volkhov unconformity**			
	IRU	Varangu				
		Pakerort	Siltstone Unit	(not zoned)		

Fig. 10. Major unconformities in the Kovel-1 core.

dochitina striata (Ch 3) chitinozoan Zone at the depth at 277.70 m and the *Baltoniodus prevariabilis* conodont Zone (Uhaku Stage).

Sea-level fluctuations and ranks of cyclicity

The deposits in the Kovel-1 reflect sea-level changes and cyclic deposition at various ranks. The cycles are characterised by 1) alteration of sediments of different facies, and their periodical or non-periodical reoccurrence; 2) occurrence of discontinuity surfaces (DS's), marking gaps in sedimentation and boundaries of cycles at various levels; 3) gradual directed alternation of the facial character of the rocks.

The DS's in the Kovel-1 succession (Fig. 2) as a rule represent cycle boundaries (Fig. 11). The most indistinct DS's are predominantly connected with high frequency interbeds and belong to low rank or bed-scale rhythms and cycles (e.g. Einsele *et al*. 1991) and are here referred to as micro or short term cycles (Fig. 11). Intermediate rank cycles or fourth and third order cycles are present, but only the sediments that accumulated during a considerable highstand of the sea are preserved in the succession (Figs 2, 11).

Three macro-scale cyclic sequences (MTS) can be distinguished in the section primarily on the specific characteristics of the basal beds. The lower MTS lies on the DS that marks a gap in the succession and sediments of the Varangu and Latorp regional stages are missing. Lithologically, its basal part resembles the Arenig transgression typical of the whole Baltic basin i.e. it is characterised by glauconitic sands and sandstones. The basal beds of the following middle- and upper MTS's contain dispersed Fe-ooids (mostly goethitic) and pseudooids (i.e. coated grains), which are missing at other levels.

The lower MTS (units I–IV)

The lower MTS corresponds to the Ontika Subseries of the Oeland regional Series (Männil & Meidla 1994; Webby 1998) and to the timeslices 1c–4b of Webby *et al*. (2004). In general, the trend of the preserved sediments of the lower MTS is transgressive and characterised by a general increase in water depth. This is indicated by the basal units I-II of the MTS, which consists of shoal sediments, succeeded in the middle part (i.e. unit III) by alternating shoal and open-shelf sediments and the upper part of the lower MTS or unit IV is composed of sediments typically of the open-shelf. The uppermost part of the MTS is missing and has been eroded away. A distinct DS occurs at this level.

The middle MTS (units V–IX)

The middle MTS corresponds to the Purtse Subseries of the Viru regional Series (Rõõmusoks 1970; Männil & Meidla 1994) and to timeslices 4c–5a (Webby *et al*. 2004). It is the only completely preserved macro-scale cycle in the Kovel section. The basal part of the macro-scale cycle is unit V and it represents the initial transgression. Open shelf limestones are represented by the part of unit VI that is below the depth of 275.0 m and this is the maximum flooding of the transgression. The upper regressive part (i.e. the upper part of unit VI and units VII and VIII) is the most extensive portion of the middle MTS. This upper portion of the middle MTS is developed as bed-scale cycles alternating between open shelf and shoaly limestones. The topmost part of the middle MTS is unit IX and it consists almost exclusively of crinoidal limestones. The middle MTS comprises three 3rd order cycles.

The upper MTS (units X–XII)

The upper MTS (= timeslice 5b of Webby *et al*. 2004) is incomplete in the Kovel section and only the basal transgressive part is preserved. The pre-Cretaceous erosion has cut out the upper strata of the upper macro-scale cycle. The basal transgressive part of this macro-scale cycle is subdivided into two 3rd order sedimentary cycles. The lower sedimentary cycle comprises units X and XI and the upper sedimentary cycle is unit XII.

Comparison with eustatic and regional sea-level curves

Models for a global sea-level curve in the Ordovician are few and are not fully accepted (Vail *et al*. 1977; Fortey 1984; Nielsen 1992a, b, 2003; Ross & Ross 1992, 1995). Despite this drawback the proposed sea-level

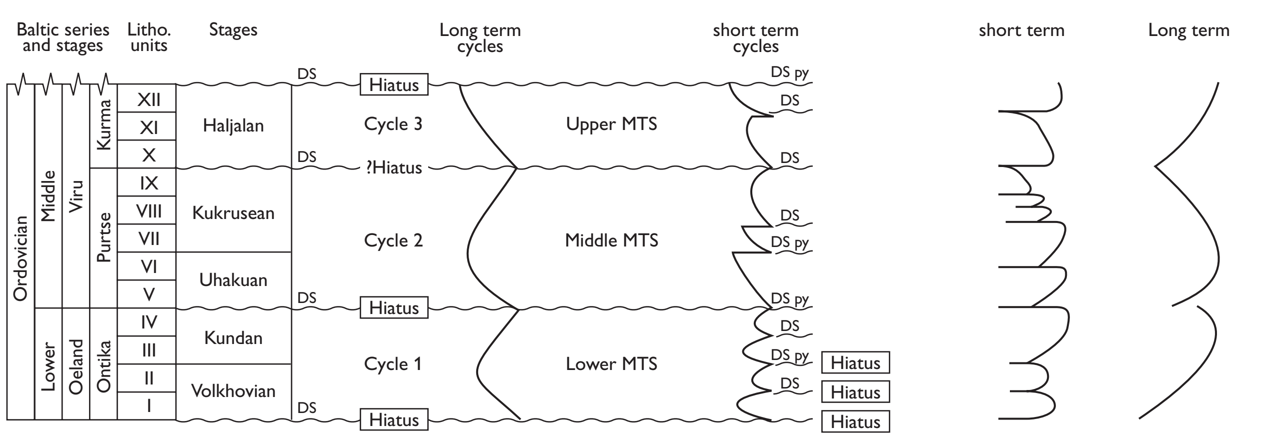

Fig. 11. Mega- and micro-cycles in the Kovel-1 core. Comparison of shortterm and longterm sea-level curves for the Early – Middle Ordovician time interval and the interpreted sea-level curve of the Kovel-1 core section. ?Hiatus at boundary between units IX and X indicate the possible presence of a hiatus. This hiatus however has not been detected by the microfossils in this paper. Based on data in this study (Kovel-1, Ukraine), Vail *et al*. (1977), Ross & Ross (1992, 1995), Nielsen (1992a, b; 2003), Einasto (1995), Laškovas (2000) and Dronov & Holmer (1999) (East European Platform).

changes are generally interpreted and accepted as being somehow eustatic.

Correspondance with the various global sea-level curves (Vail *et al*. 1977; Nielsen 1992a, 2003; Ross & Ross 1992, 1995) is not yet certain. The extensive early Mid Ordovician unconformity at the base of the middle MTS is presented in the global eustatic sea-level curves (Vail *et al*. 1977; Ross & Ross 1992, 1995).

The sea-level changes based on the facies and cyclostratigraphic interpretation of the Kovel-1 succession can be tied into Baltic chronostratigraphy and allow refinement of the existing regional sea-level curves for the Lower and Middle Ordovician of the East European Platform of Baltica.

The large scale sea-level changes recorded in the Kovel-1 succession corresponding with the three megacycles fits well with the sea-level curves produced from the East European Platform (Einasto 1995; Laškovas 2000). The reconstructed sea-level changes also correspond rather well with the reconstructed regional sea-level curve for the East European Platform and based on sequence stratigraphic interpretation (Dronov & Holmer 1999).

Detailed information from within the lower MTS suggests a sea-level rise and highstand in the early Volkhov (*B. navis* Zone of this study) and a sea-level fall during the mid Volkhov (*B. norrlandicus* Zone), a late Volkhov rise (*Lenodus antivariabilis* Zone) and an early Kunda fall. This is followed by the Kunda sea-level rise in early Kunda (*B. clavatus* Zone) and with a highstand in late Kunda (*Lenodus pseudoplanus* Zone) followed by a sea-level fall during latest Kunda (*Eoplacognathuus suecicus* Zone). These changes matches well with some but not all of the proposed sea-level curves for the East European Platform (Einasto 1995; Nielsen 1992a, 2003; Dronov & Holmer 1999; Laškovas 2000) and the Baltoscandian margin areas (Rasmussen & Stouge 1995).

The middle MTS suggests a sea-level rise in early Uhaku (*L. striata* Zone (*C. clavaherculi*-*C. tuberculata* Subzones) -*B. prevariabilis* Zone) with a maximum flooding in early middle Uhaku (*C. tuberculata* Subzone (*partim*) -*B. variabilis* Zone), a highstand to a sea-level fall from the earlier highstand is recorded for the Kukruse Stage (*L. stentor* Zone-*A. inaequalis*, *A. tvaerensis* and *A*. cf. *tvaerensis* zones).

The preserved part of the upper MTS in Kovel-1 well is mainly transgressive with a sea-level rise followed by a minor sea-level fall in the early Haljala Stage (*L. dalbyensis* Zone-*B. gerdae* Zone). This is succeeded by another sea-level rise comprising the higher part of the Haljala Stage (*cervicornis* Zone-*B. alobatus* Zone). The Haljala part of the sea-level curve matches the sea-level curve of Einasto (1995), Dronov & Holmer (1999), Laškovas (2000) and Nielsen (2003).

Summary and Conclusions

The Kovel-1 well was selected as a microfossil-based bio- and cyclostratigraphic reference section for the Lower, Middle to lower Upper Ordovician succession of northwestern Ukraine. The result of the integrated analysis is given in Figure 11.

Probably the most specific feature of the Ordovician in the Kovel-1 drill core section is the condensed thickness of the sediments. The total thickness of the preserved Ordovician succession is merely 25.3 m. The small thickness is caused, on the one hand, by the incompleteness of the succession. Several extensive gaps are recorded. On the other hand the reduced thickness is due to the low sedimentation or accumulation rate. The 16 m of the Kukruse Stage are the exception or the contrast to this picture and this thickness is remarkable – even when compared to the Baltic region – as it forms 1/2–2/3 of the whole succession.

The Ordovician succession in the Kovel-1 well is also characterised by the presence of abundant, mostly weakly or inconspicuously developed, discontinuity surfaces. The discontinuity surfaces mark a break in the sedimentation and the succession is composed of multiple high frequency rhythms and cycles.

The Kovel-1 limestones accumulated alternately in shallow shelf and shoal facies environment up through the vertical succession. The shoal facies is characterised by having a great proportion of pelmatozoan debris. Specific breccia interlayers occur in the interval 272.3–269.3 m within the lower part of the Kukruse Stage. These were formed possibly by disturbances caused by earth-quakes occurring during the early phase of the Taconic Orogeny. At this time the Peri-Gondowanan Avalonia palaeocontinent and the adjacent Malopolska, Sudetes and Czech Massifs terranes approached Baltica (Tomczyk 1964; Torsvik *et al*. 1992; Dzik & Pisera 1994).

In Ukraine the vertical distribution and diversity of chitinozoans in the beds within the depth interval 256.0–277.7 m are in general the same as recorded in the previously investigated sections from different confacies belts of Baltoscandia. Similarly, first occurrences of conodonts compare well with the Lower Ordovician conodont appearences in the Baltoscandian region and the Lower to Middle Ordovician succession of the Kovel-1 section resembles that of the Mójcza Limestone in Holy Cross Mountain region, Poland (Dzik 1994).

The biostratigraphic analyses demonstrate the presence of several extensive stratigraphical gaps (hiatuses) especially in the lower part of the succession.

The boundaries of the recognized macro-scale cycles (MTS) coincide with the recognized extensive unconformities and documented extensive hiatuses in the succession. The lower boundary of the lower MTS is at the Pakerort(?)–Volkhov unconformity and the hiatus covers the Varangu and Latorp stages. Within the lower MTS the mid Volkhov unconformity and the early Kunda unconformity including the Hunderum Substage of the Kunda Stage are distinguished. The early Mid Ordovician unconformity lies at the base of the middle MTS and the hiatus covers the Aseri and Lasnamägi stages. The MTS boundaries can be traced along the margin of the East European Craton, into the Baltic palaeobasin (Kõrts *et al*. 1991) and to the Holy Cross Mountain region (Tomczyk 1964; Dzik & Pisera 1994) and at the same stratigraphical levels.

Comparison with proposed eustatic sea-level curves suggests that the Varangu–Latorp hiatus that developed in the latest part of the Tremadoc and the beginning of the Arenig series is recorded as being eustatic. The early Kunda hiatus reflect eustatic sea-level changes rather than autocyclic shallowing. For instance, it is recognised as a major regressive event in the Baltoscandian outer platform areas of Norway and Sweden (Rasmussen & Stouge 1995)

The extensive hiatus at the base of the Viru Series (Middle Ordovician; Kunda–Aseri boundary beds) is significant in the region and does match the existing eustatic sea-level curves (Vail *et al*. 1977; Ross & Ross 1992, 1995; Nielsen 2003). Regionally however, this early Mid Ordovician unconformity has been documented from Kinnekulle, Billingen and in Scania, southwestern Sweden (Bergström 1982; Jaanusson 1982; Zhang 1998), on Bornholm, Denmark (Poulsen 1966), in several wells in northwestern Poland (Tomczyk & Turnau-Morawska 1967; Bednarczyk 1998) and southwestern Poland (Modlinski 1982, 1991; Modlinski & Nehring-Lefeld 1994; Modlinski *et al*. 1994) and in the Holy Cross Mountains, Poland (Dzik 1994). The early Mid Ordovician unconformity is developed mostly at locations situated along the western margin of the East European Platform of the Baltica palaeocontinent. Hence, the recognised hiatus probably represents an important response to tectonic events that occurred next to the margin of the East-European Platform (Modlinski 1982; Dzik & Pisera 1994). These early tectonic movements of the Taconic Orogeny may be related to the initial collision of Baltica with several micro-continents of Peri-Gondwanan terranes and the Avalonia palaeocontinent (Dzik & Pisera 1994; Modlinski 1982; Modlinski *et al*. 1994).

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