EESTI NSV TEADUSTE AKADEEMIA TOIMETISED. GEOLOOGIA
ИЗВЕСТИЯ АКАДЕМИИ НАУК ЭСТОНСКОЙ ССР. ГЕОЛОГИЯ
PROCEEDINGS OF THE ACADEMY OF SCIENCES OF THE ESTONIAN SSR. GEOLOGY

1986, 35, 3

https://doi.org/10.3176/geol.1986.3.01

УДК 551.732/733.1(470.23+474.2)

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THE CAMBRIAN-ORDOVICIAN BOUNDARY IN THE BALTIC-LADOGA CLINT AREA (NORTH ESTONIA AND LENINGRAD REGION, USSR)

The Baltic-Ladoga clint area extends over the whole of northern Estonia and the Leningrad Region, from the Pakri Islands in the west as far as Lake Ladoga in the east (Fig. 1). The numerous good outcrops (sections) enabling detailed studies of the structure of the boundary beds (Fig. 2) are situated on the clint and in the river valleys crossing it. Seven of these sections are figured and discussed below (Fig. 3), although, of course, all others are also taken into consideration in the discussion.

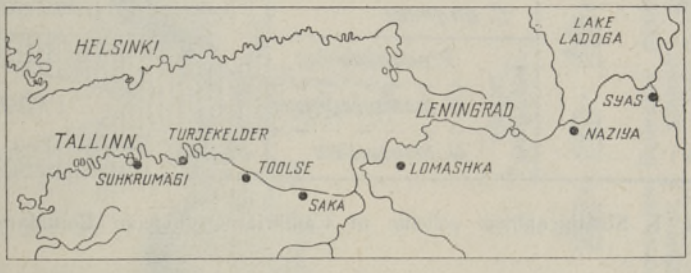


Fig. 1. Location map showing sections (black points) given in Fig. 3.

As a general rule in the East Baltic, the Cambrian-Ordovician Boundary has been drawn at the base of the so-called Obolus Sandstone which overlies Cambrian arenites of different ages; this is the base of the Pakerort Regional Stage, taken as an equivalent of the Lower Tremadoc in Great Britain and Scandinavia. Such a correlation was motivated mostly by finds of different species and subspecies of the *Dictyonema* (= *Rhabdinopora*) *flabelliforme* (Eichwald) group of graptolites from the so-called Dictyonema Shale constituting the upper part of the Pakerort Regional Stage, as well as from shale interbeds in the Obolus Sandstone (in some sections, e. g. Kalvi and Aseri, from almost the lowermost beds). The established graptolite succession shows the presence of deposits through an interval from the D. sociale Subzone up to the Upper Tremadoc Clonograptus-Didymograptus Zone (Кальо, Кивимяги, 1970, 1976).

Data obtained recently on the micropaleontology of Cambrian-Ordovician strata (Боровко, Сергеева, 1981; Волкова, 1980; Хазанович и др., 1984) have established a problem in attributing a part of the Obolus Sandstone to the Cambrian. In 1952 A. Öpik already regarded the

lowermost beds of the Pakerort Regional Stage, the Acrotreta Zone (now called the Ülgase Formation), as Upper Cambrian. Results of lithological investigations of the East Baltic sections (N. Borovko, H. Heinsalu, K. Khazanovich, K. Mens) together with data on brachiopods (L. Popov), conodonts (V. Viira, S. Sergeyeva) and graptolites (D. Kaljo, R. Sobolevskaya) are also significant in contributing to the solution of the general problem of the Cambrian-Ordovician Boundary, which is now under discussion in a corresponding IUGS working group. Accordingly, the main subjects of this paper are the succession of conodont zones and their relations with graptolite zones, together with a concrete definition of this boundary in the sections of the study area.

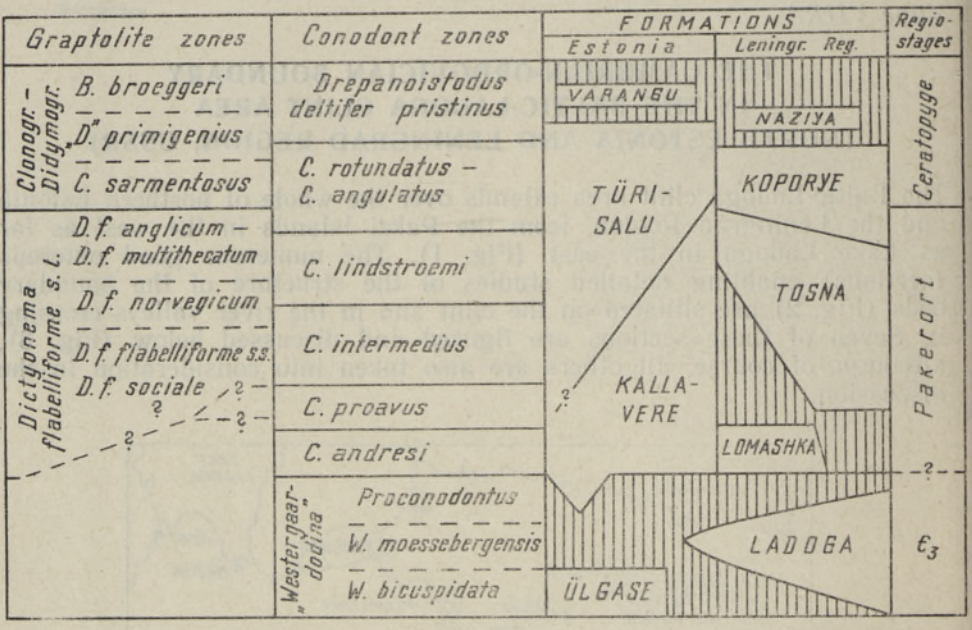


Table 1. Stratigraphical scheme of Cambrian-Ordovician Boundary beds.

A general stratigraphical scheme is given in Table 1, and relations between the formations distinguished along the clint line are shown in Fig. 2. Brief characteristics of the sections are given below.

Lithology and lithostratigraphy

The Pakerort Regional Stage is underlain by an entirely terrigenous sequence of different-aged Cambrian rocks, revealing the recurrent and complicated nature of sedimentation and denudation processes.

Tiskre Formation (Lower Cambrian). This division is represented mainly by oligomineralic sandy siltstones; it crops out in Estonia and at Koporye High in the Leningrad Region (Fig. 2) (see Менс, Пиррус, 1977). Denudation has reached down to the Lükati Formation (Schmidtiellus mickwitzi Zone) only at the centre of this dome structure.

Sablinka Formation (Middle Cambrian). The mature silty sandstones of this formation crop out mostly in the western part of the Leningrad Region where they form the top of the pre-Ordovician rocks. On the basis of scarce finds of inarticulate brachiopods, bradoriids and acritarchs, the beds are assigned conditionally to the Paradoxides paradoxissimus and P. forchhammeri Zones.

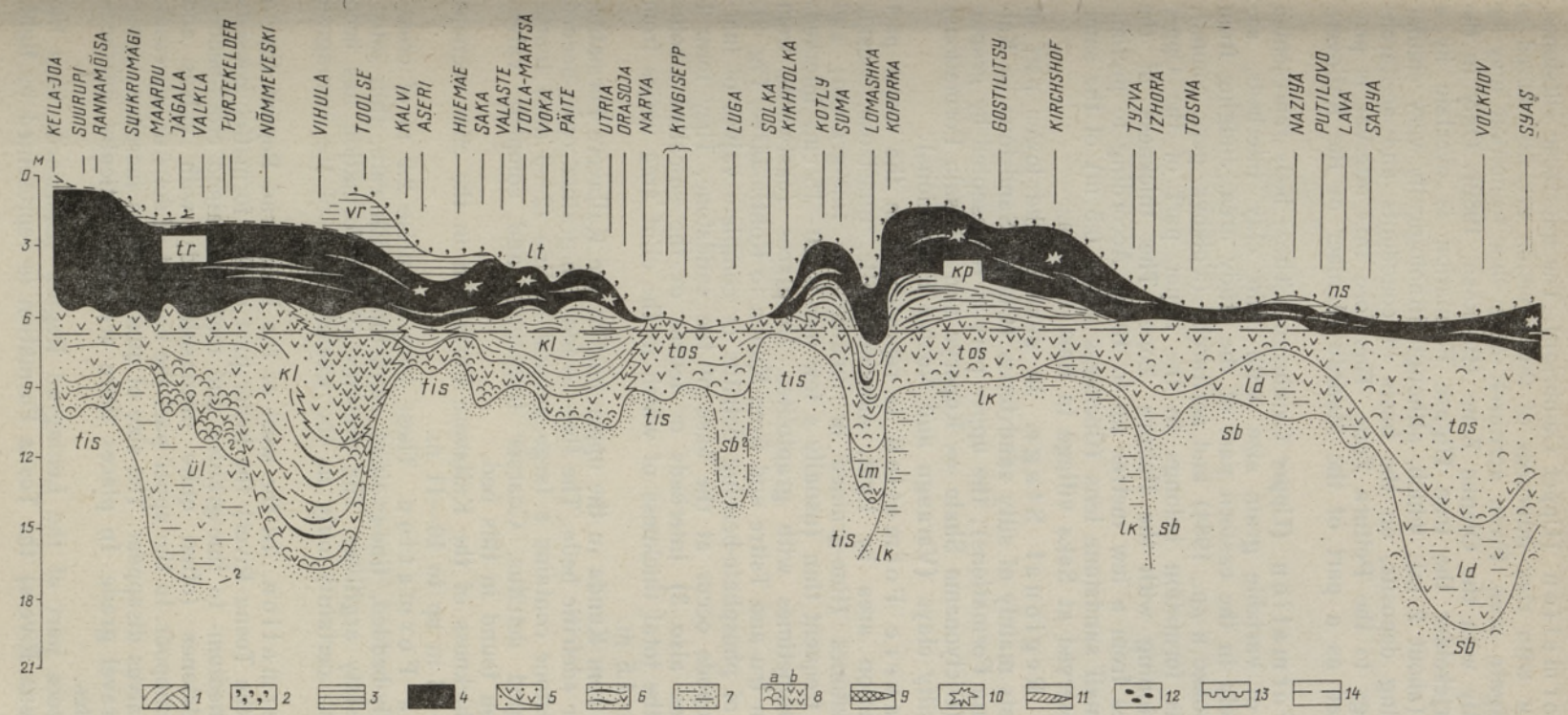


Fig. 2. Sequence of the Cambrian-Ordovician Boundary deposits in the outcrops of the Baltic-Ladoga clint area.

Legend: *1* — Quaternary deposits, *2* — glauconitic sandstone, *3* — aleuritic clay, *4* — argillite (Dictyonema Shale), *5* — cross-bedded detritic sandstone, *6* — sandstone or siltstone with argillite interbeds, *7* — clay interbeds, *8* — complete valves (*a*) and detritus (*b*) of brachiopods, *9* — pyrite concretions and lenses, *10* — anthraconite concretions, *11* — lenses of amorphous silica, *12* — phosphatic pebble, *13* — discontinuity surfaces, *14* — base of the Cordylodus angulatus — C. rotundatus Zone .

Indexes of the units: tis — Tiskre Formation; lk — Lükati Form.; sb — Sablino Form.; ül — Ülgase Form.; ld — Ladoga Form.; kl — Kallavere Form.; tos — Tosna Form.; lm — Lomashka Form.; tr — Türisalu Form.; kp — Koporye Form.; vr — Varangu Form.; ns — Naziya Form.; lt — Leetse Form.

Ülgase Formation (Upper Cambrian). The quartzose siltstones, locally sandy or with clay interbeds of this division are distributed in the Tallinn—Jägala area. From acritarch data this formation may be correlated mostly with the Olenus Zone (Волкова, 1982). Only in the vicinity of Turjekelder the true Ülgase Formation is overlain by a short interval (about 2 m), which, although lithologically very similar to the underlying deposits, on the basis of conodonts and acritarchs evidently belongs to the Peltura Zone. Therefore this interval is provisionally treated as a part of the Maardu Member of the Kallavere Formation.

Ladoga Formation (Upper Cambrian). These beds represented by sandstones of variable grain size with thin clay interbeds, are distributed widely in the eastern part of the study area. Judging from conodonts (Боровко и др., 1984) and acritarchs (Volkova, pers. comm.), the top of this formation belongs to the upper part of the Upper Cambrian, beginning with the Peltura Zone. The thickness of the formation varies from a few metres up to 10 m. According to preliminary data, a small sandstone lens (thickness about 0.5 m) of the same age is also preserved at Saka village in East Estonia.

Pakerort Regional Stage. In general, the lower part of the stage consists mainly of silty sandstones (Obolus Sandstone = Kallavere and Tosna Formations); the upper part is represented by graptolitic argillites (Dictyonema Shale = Koporye and Türisalu Formations) and compact, silty clays (Varangu and Naziya Formations).

The Kallavere Formation is represented in the major part of the distribution area by light, monomineralic, quartzose, weakly cemented sandstones (fine-grained or medium- to fine-grained) and siltstones with frequent thin (usually a few mm to 10—15 cm) interbeds of argillites, sometimes with graptolites. In places (eastwards from Tallinn between Iru and Tsitre and from Kunda to Kohtla-Järve, Fig. 2), accumulations of phosphate-bearing detritus or complete valves of inarticulate brachiopods occur at the base of the sandstone. They form 1 or 2 (in places also 3) interbeds or lenses of the so-called Obolus conglomerate, the total thickness of which in the clint area varies from about 10 cm to 1.5 m.

Westwards from Kunda in the upper part of the Kallavere Formation there is another «detritic bed». The fine- to medium-grained cross-bedded quartzose sandstone contains a large amount of fine (2—3 mm) inarticulate brachiopod detritus. Coarser fragments and complete valves have never been found in this bed.

The total thickness of the Kallavere Formation in the clint sections ranges from 2—3 m up to 10—11 m.

Lomashka Formation. These beds comprise 2.2 m of cross- and horizontally-bedded, fine-grained sandstones with rare, thin interbeds of dark slaty argillites. The presence of the formation has been established with certainty only in the western part of the Leningrad Region.

Tosna Formation. In the west of the Leningrad Region (up to and including the Tosna River) the lower part of this formation consists of quartzose, medium- to fine-grained and medium-grained cross-bedded brownish sandstones (often quite unconsolidated) with valves and detritus of brachiopods. In the upper part the content of detritus increases, but complete valves disappear. The size of quartz grains increases, sometimes up to gravel grade. In places there are rare lenticular interbeds of dark argillites.

In the eastern part of the Leningrad Region (eastwards from the Izhora and Tosna Rivers) the Tosna Formation is represented by light,

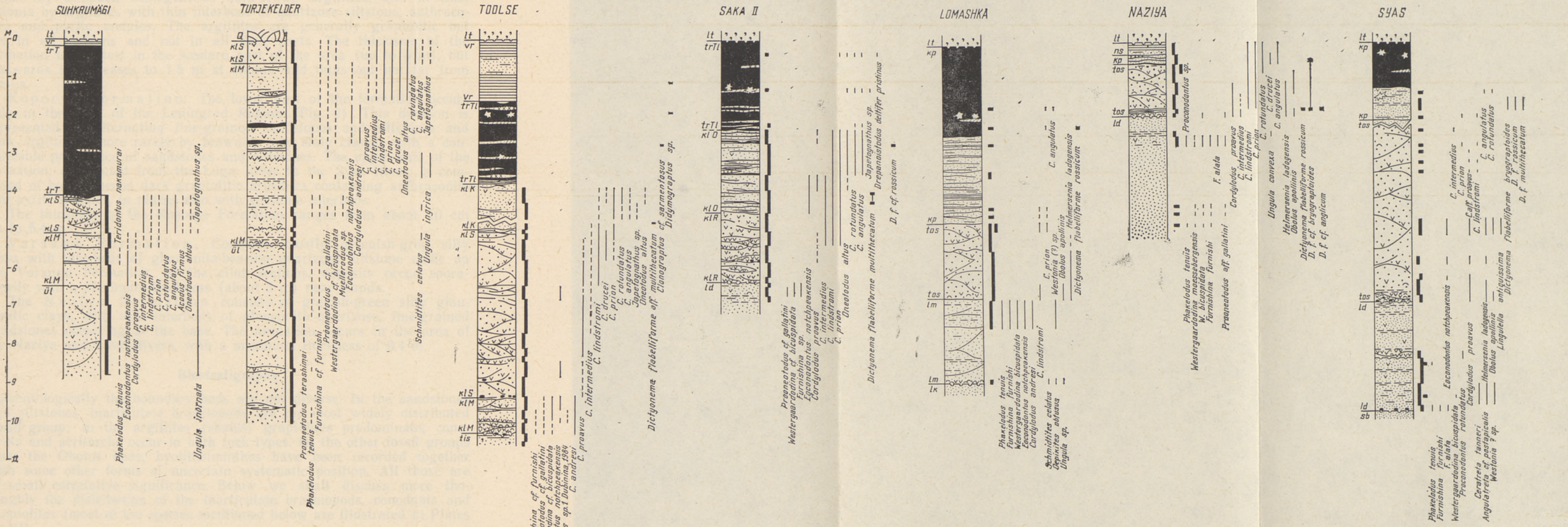


Fig. 3. Investigated sections of the boundary deposits. On the right of the column are shown the sampled intervals. The stratigraphical boundaries marked by the indexes of the units remain to the left of the column. The last (capital) letter of the index shows the subdivision of the formation (member), the names of which are not given here for purposes of shortness. For lithological and paleontological logs of studied sections see Fig. 2.

fine-grained, weakly cemented sandstones with a lesser amount of detritus or complete brachiopod valves.

The total thickness of the Tosna Formation ranges from 0.5 to 7.5 m, increasing eastwards.

Türisalu Formation. In West Estonia this formation is represented by compact, homogeneous dark-brown argillites, and in East Estonia by argillites with thin interbeds of quartzose siltstone, anthraconite and pyrite nodules. The argillites are generally graptolitic but not in all sections and not in all their parts. The thickness of the formation is greatest in the western part of the area (up to 5 m), but eastwards it decreases to 1.5 m at Kunda and thins out not far from Narva.

Koporye Formation. The lower part of the formation occurs only in the west of the Leningrad Region (Fig. 2). This division is represented by alternating fine-grained sandstones and siltstones and dark argillites (more rarely by brownish-grey slaty clays), with a considerable prevalence of sandstones and siltstones. The upper part of the formation, distributed from the Luga River to the Syas River, is composed of homogeneous dark graptolitic argillites containing anthraconite and pyrite nodules, in places also with siltstone interbeds.

The thickness of the Koporye Formation ranges from about 10 cm up to 5.4 m.

Varangu Formation. Compact, mostly greenish-grey silty clays with interbeds of glauconite-bearing quartzose siltstone make up the Varangu Formation. In the clint sections, deposits occur sporadically with a maximum thickness (about 3 m) near Kunda.

The Naziya Formation consists of greyish-green silty glauconitic clays, with thin interbeds of glauconitic-quartzose, fine-grained sandstones occurring at the base. The formation occurs in the area of the Naziya and Lava Rivers, with a maximum thickness of 0.4 m.

Biostratigraphy

Paleontologically the boundary beds are not diverse. In the sandstones and siltstones inarticulate brachiopods are the most widely distributed fossil group; in the argillites (shales) graptolites predominate; conodonts and acritarchs occur in both rock types. Of the other fossil groups from the Obolus beds, hyolithelminthes have been recorded together with some other forms of uncertain systematic position. All those are of small correlative significance. Below we shall discuss more thoroughly the distribution of the inarticulate brachiopods, conodonts and graptolites (most of the species mentioned below are illustrated in Plates I—VI).

Inarticulate brachiopods. Recent investigations have shown that obolids may well be used for the subdivision and intraregional correlation of the East Baltic Cambro-Ordovician. However, the endemic character of this fauna and the inadequate state of study in many areas make it impossible to use them for wider correlation. The distribution of inarticulate brachiopods shows a clear lateral zonality which changes only a little throughout a rather long period: in the Middle and Late Cambrian the areas nearest to shore (mostly the areas of accumulation of fine- to medium-grained cross-bedded sands) were inhabited by the monotypic *Obolus* Community or in places the *Ungula* Community.* Seawards (mostly in the area of fine-grained sands) there

* The authors have made use of the nomenclature of inarticulate brachiopods in accordance with revision carried out by L. Popov. Reinvestigation of the types of E. Eichwald and topotypes of Ch. Pander has revealed the independence of the genera *Obolus* and *Ungula*. Results of this work will be published separately.

occurred communities of different species of the genus *Oepikites*, and later (beginning with the Proconodontus Zone) those of *Schmidtites*.

The offshore facies (mainly areas with silty deposits) were characterized by more varied communities consisting of acrotretids, siphonotretids (*Schizambon*) and obolids (*Oepikites* and *Westonia?*). At a level of the C. proavus Zone the brachiopod zonality becomes simpler and only two communities remain — a nearshore one with *Obolus apollinis* and a more offshore one with a siphonotretid (*Helmersenia ladogensis*) predominating.

At present at least four biostratigraphical levels are distinguished for the Late Cambrian and Early Ordovician of the clint area. Beds with *Ungula inornata* (= *Obolus triangularis Mickwitz* ≠ *Ungula triangularis* Pander) and *Angulotreta postapicalis* are distinguished at the base of the Upper Cambrian (Ülgase Formation, lowermost beds of the Ladoga Formation). Beside the index species, the assemblage of inarticulate brachiopods of these beds also includes *Oepikites* sp. nov., *Westonia* ? sp. nov., *Schizambon* sp. nov. and *Ceratreta tanneri* (Metzger).

Beds with *Ungula convexa* are distinguished within the upper part of the Ladoga Formation. In addition to the index species they have yielded «*Ungula*» ovata Pander, *Oepikites* sp. nov., *Westonia* ? sp. nov. and *Keyserlingia reversa* (Vern.); a little higher *Keyserlingia buchii* (Vern.) and *Schmidtites celatus* (Volborth) make their appearance. These beds may be correlated with the Westergaardodina moessebergensis-Problematoconites perforata Conodont Zone.

Beds with *Ungula ingrica* are distinguished in the lower part of the Kallavere Formation and its equivalents occurring in some places up to the Koporka River in the east. The assemblage of inarticulate brachiopods includes *Ungula ingrica* (Eichwald), *Oepikites obtusus* (Mickw.), *Schmidtites celatus* (Volborth), *Keyserlingia buchii* (Vern.) and *Westonia* ? sp. nov. These beds correspond with the Cordylodus andresi Zone and possibly partly with the C. proavus Zone.

Beds with *Obolus apollinis* and *Helmersenia ladogensis* are distinguished in the Tosna Formation and in the upper part of the Kallavere Formation. The assemblage of inarticulate brachiopods includes only *Lingulella antiquissima* (Jerem.) apart from the index species. The beds are correlated with the conodont zonation from the C. proavus Zone to the C. angulatus — C. rotundatus Zone (inclusive).

Conodonts occur in the East Baltic from the Upper Cambrian onwards. In the Upper Cambrian the Westergaardodina Zone has been defined conditionally and subdivided into three subzones (Table 1). The W. bicuspidata Subzone is the oldest and has been distinguished in the Ülgase Formation and in the lower part of the Ladoga Formation, where in addition to the index species *Phakelodus tenuis*, *Furnishina furnishi*, *F. alata* and *Prooneotodus terashimai* have been identified. Conodonts of the two subsequent subzones were studied in the sections eastwards from Leningrad (Боровко и др., 1984; Боровко, Сергеева, 1981, 1985). The W. moessebergensis Subzone includes the index species plus *W.* cf. *fossa*, *W. wimani*, *Hertzina americana*, *Problematoconites perforata*, *F. furnishi*, *Prooneotodus rotundatus* and *P. terashimai*. The uppermost Proconodontus Subzone is characterized by the following assemblage: *Proconodontus primitivus*, *Prooneotodus rotundatus*, *P.* aff. *gallatini*, *W. bicuspidata*, *W. fossa*, *F. furnishi* and *F. alata*. An interval of the Turjekelder section has been assigned to the same subzone where below the first occurrence of *C. andresi* a similar assemblage has been recorded, but containing also *Eoconodontus notchpeakensis* (one specimen) and phosphatic sclerites of *Hadimopanella* Gedik, 1977.

In higher beds, the Obolus Sandstone is characterized by various and in places numerous specimens of *Cordylodus*. The following succession of conodont zones has been established here (Table 1), in many aspects resembling the Australian sequence (Druce, Jones, 1971). The identified species of *Cordylodus* have been named according to multielement taxonomy, except *C. prion*, which was distinguished *sensu formo*, as it is useful for correlation in this sense.

The Cordylodus andresi Zone was established in four outcrops by the appearance of the zonal species. This taxon was first described by D. Andres (1981) on the basis of material from lenses of the «stink limestone» of the Westergaardia Subzone of the Acerocare Zone on the Island of Öland, Sweden. The description of the East Baltic material is in print (Viira, Sergeyeva). *C. andresi* is characterized by a deep basal cavity, a lack of white matter and a variable number of denticles. Some specimens with a single small denticle are reminiscent of *Cordylodus* sp. 1 (Apollonov et al., 1984). However, it is difficult to say whether such specimens are marginal members of variations of this species or whether they represent a new species recorded by S. Dubinina below the beds with *C. proavus* in Kazakhstan. In this context it should be noted that *C. andresi* has not been found in Kazakhstan, but in the East Baltic it occurs at a level below the typical *C. proavus*. Apart from numerous specimens of the index species, the assemblage of the C. andresi Zone includes *Phakelodus tenuis, Eoconodontus notchpeakensis* and different paraconodonts (*Westergaardodina, Furnishina,* etc.), first appearing in the underlying beds. The full thickness of the interval (about 1.5 m) is seen at Vihula.

The C. proavus Zone is of wider distribution, being recorded from six outcrops. Specimens of this species are morphologically rather variable and do not form large accumulations like *C. andresi*. In this assemblage, among others the most common species *is E. notchpeakensis*. The maximum thickness of the C. proavus Zone (over 8 m) has been recorded in sandstones at Vihula.

Correlation of the C. proavus Zone has been discussed widely in recent literature (Miller, 1984; Chen et al., 1983; and others), and there is no reason to expand here these discussions further.

The C. intermedius Zone assemblage has been recorded from the Ülgase, Toolse and Naziya sections. In the other studied sections this species appears together with *C. lindstromi*, i. e. the index species of the following zone. At the three outcrops, the C. intermedius Zone occupies a short interval in the Obolus Sandstone, with a maximum thickness of up to 1 m at Toolse; the assemblage includes *C. proavus* and *E. notchpeakensis*. Despite unsatisfactory characteristics of this zone, we distinguish it here for purposes of correlation. The C. intermedius Zone has also been established in North China between the C. proavus and C. angulatus Zones (Chen et al., 1983). In Australia, *C. intermedius* defines the lower boundary of the C. oklahomensis — C. lindstromi Zone (Druce, Jones, 1971); in North America it appears in the Hirsutodontus simplex Subzone of the C. proavus Zone (Miller et al., 1982).

The C. lindstromi Zone has been established in all the studied sections, with a maximum thickness (1.60 m) at Toolse. Besides the index species, the zonal assemblage contains *C proavus*, *C.* aff. *proavus* (Syas), *C. drucei*, *C. prion*. In this zone *E. notchpeakensis* is replaced by *Oneotodus altus*, the species which J. Miller (1980) includes within the multispecies *E. notchpeakensis*. Until the description of East Baltic conodonts is completed, we consider it expedient to retain the taxon *O. altus* separately. The C. lindstromi Zone has been established in Australia (Druce,

Jones, 1971), and in Kazakhstan (Дубинина, 1982), but the species is also known in North America from Fauna B (Miller et al., 1982).

The C. rotundatus — C. angulatus Zone has been recorded from all the studied sections and is defined by the first appearance of *C. rotundatus*. It is characterized by the presence of a considerable number of different species: rare *C. proavus* co-occur with *C. lindstromi, C. intermedius, C. drucei, C. prion, Iapetognathus* sp. and *Oneotodus altus*. Simple conical *Acodus firmus* and *Drepanodus* ? sp., considered to characterize the Ceratopyge Stage (Upper Tremadoc), make their first appearance at this level.

Graptolites. Since the papers of E. Eichwald in the 19th century, North East Baltic *Dictyonema* has been of considerable interest for researchers. In this paper we do not deal with taxonomic problems, and therefore we make use of the most commonly accepted nomenclature of O. M. B. Bulman (1954), leaving aside the views of A. M. Obut (Обут, 1953) regarding the species groups *flabelliforme* and *graptolithinum*, as well as those of B.-D. Erdtmann (1982) concerning *Rhabdinopora*, although some of us support the various ideas presented by these authors.

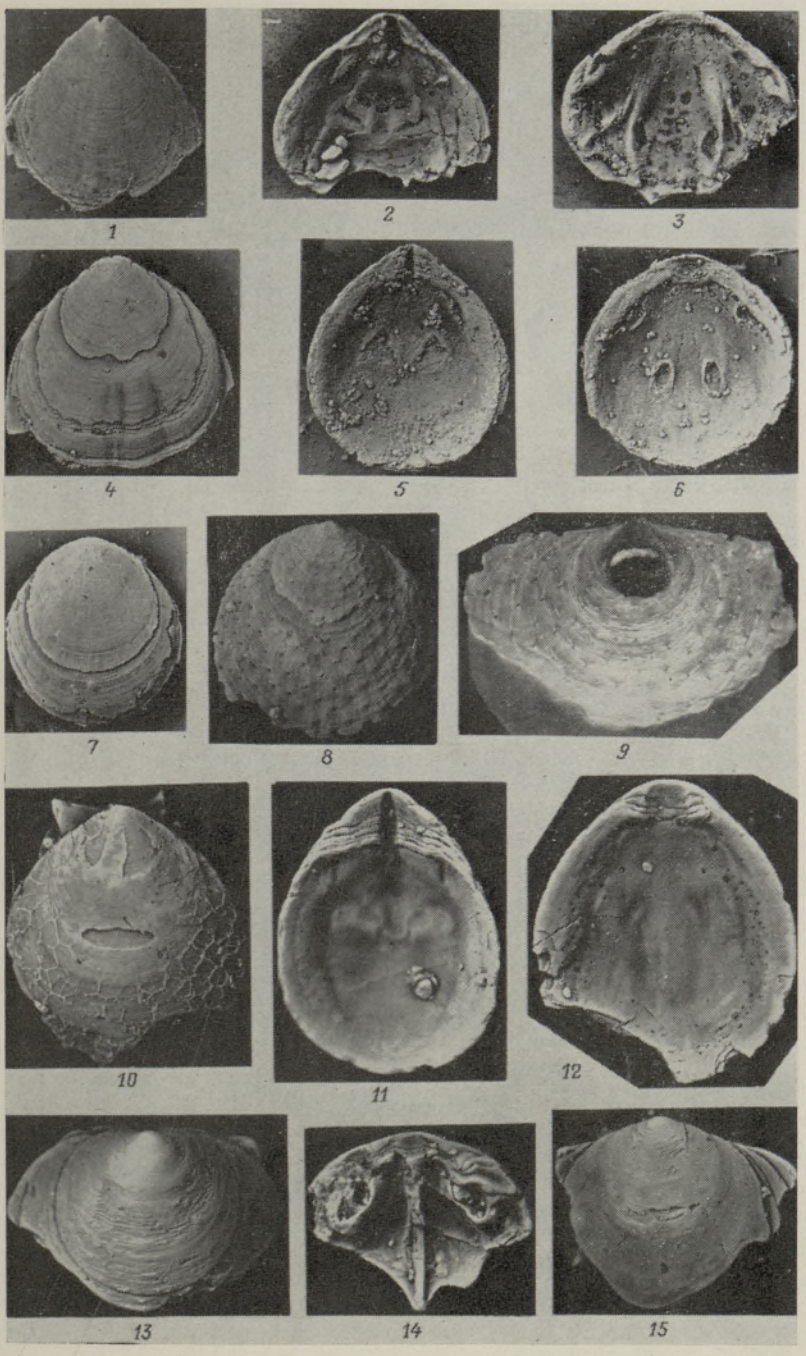
Graptolites occur throughout the whole section of the Pakerort and Ceratopyge Regional Stages of the East Baltic Tremadoc. The most common are those in Dictyonema Shale, but they are also fairly abundant in clay interbeds within sandstones, but only rare finds come from the sandstones themselves. The oldest specimens of Dictyonema sp. (fragments only) have been recorded from the Upper Cambrian Ülgase Formation (collected by K. Khazanovich from Maardu).

The distribution of Tremadoc graptolites has been discussed by D. Kaljo and E. Kivimägi (Кальо, Кивимяги, 1970, 1976) and the corresponding zonation is given in Table 1. The sections treated in this paper have yielded scarce graptolites (Fig. 3), but they enable correlations to be made between the graptolite and conodont zones. A generalized distribution of the identified graptolite species given in Table 2 was composed on the basis of their relations with conodont zones. As graptolites and conodonts have been studied together only in a small number of sections, the mutual position of zonal boundaries drawn from these groups (Table 1) must be considered tentative.

Especially insufficiently founded is the position of the D. f. sociale Zone, whose presence has been established in a number of sections in the lowermost beds of the Pakerort Regional Stage (vicinity of Tallinn, Orasoja, and elsewhere). Of these sections, conodonts have been studied only in the outcrop of Suhkrumägi. *D. f. sociale* was identified from a shale intercalation below the Detritus Bed in the Hundikuristik Section. The latter is situated less than one kilometre south of the Suhkrumägi outcrop. Together with the other subspecies, *D. flabelliforme flabelliforme* occurs throughout the whole section of the Pakerort Regional Stage. Therefore it has not been indicated specially in Fig. 3.

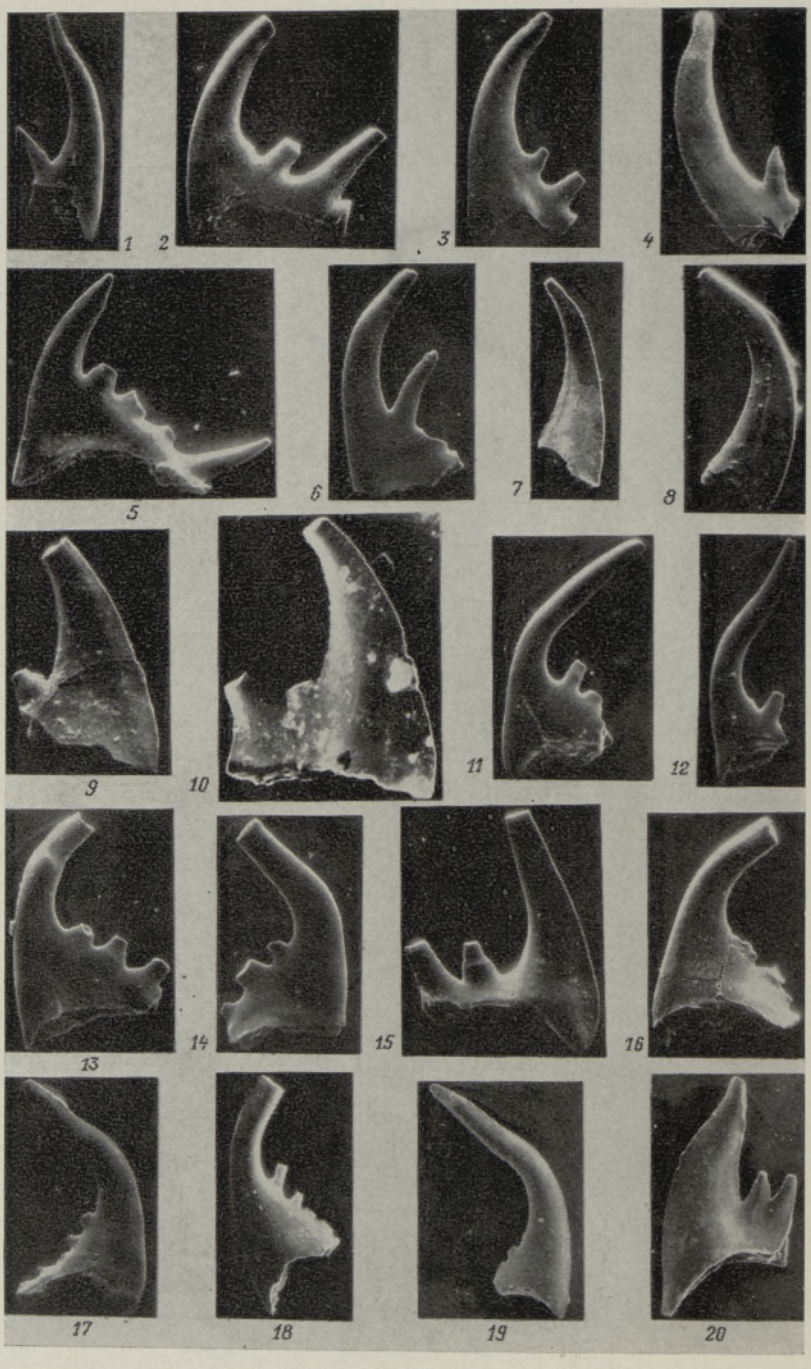
PLATE I

1—3. Ungula ingrica (Eichwald); *1* — outer view of the ventral valve, B 1701, X3.2; *2* — inner view of the ventral valve, B 1700, X3.2; *3* — inner view of the dorsal valve, B 1702, X3.2; Turjekelder section, C. andresi Zone; *4—7. Obolus apollinis* Eichwald; *4* — outer view of the ventral valve, B 1705, X3.2; *5* — inner view of the ventral valve, B 1703, X3.2; *6* — inner view of the dorsal valve, B 1706, X3.2; *7* — outer view of the dorsal valve, B 1704, X3.2; section along the Lava River, Tosna Formation. *8, 9. Helmersenia ladogensis* (Yeremeyev); *8* — outer view of the dorsal valve, B 1707, X8; *9* — outer view of the ventral valve, B 1708, X20; Volkhov River,



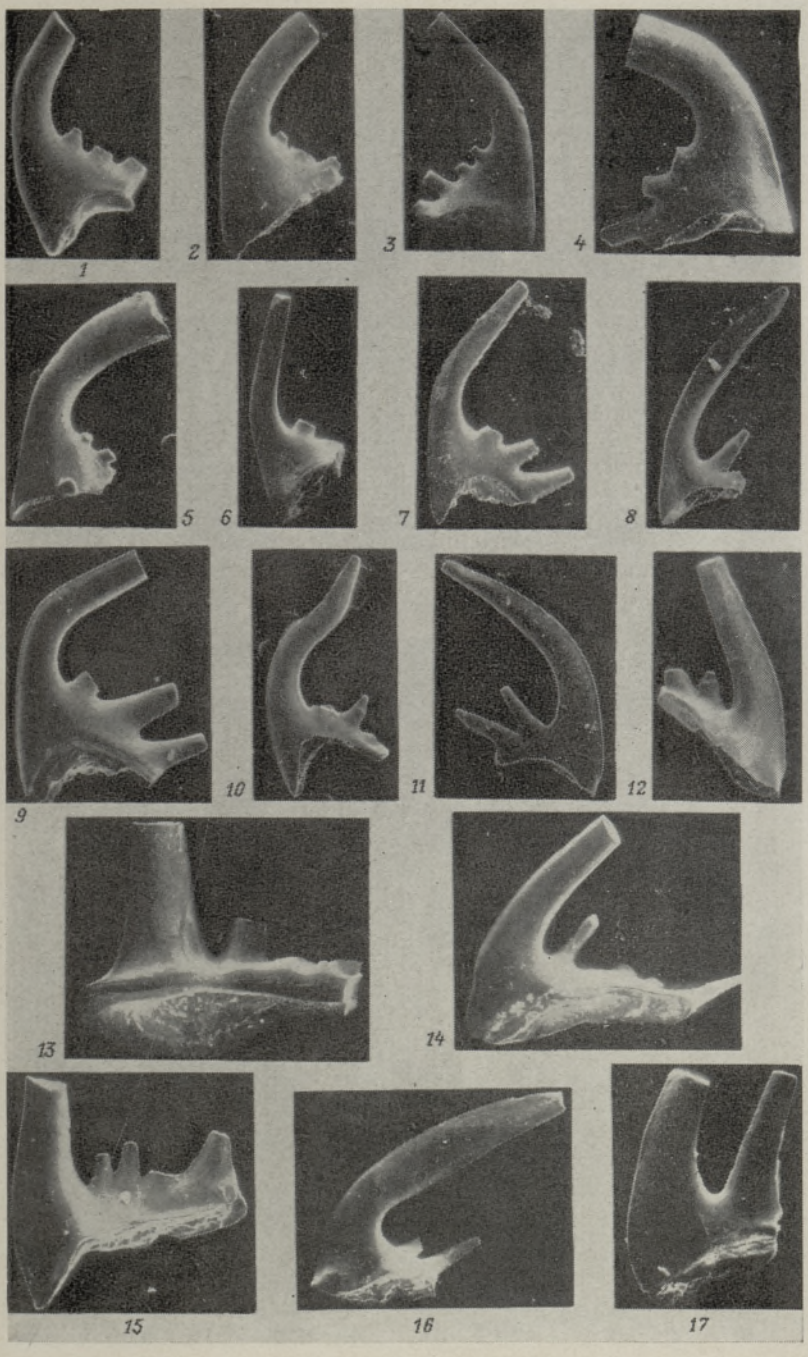
Tosna Formation, C. proavus Subzone. *10. Marcusodictyon priscum* Bassler on the ventral valve of *Schmidtites celatus* (Volborth), B 1711, X6.4; Turjekelder section, C. andresi Zone. *11, 12. Schmidtites celatus* (Volborth); *11* — inner view of the ventral valve, B 1709, X6.4; *12* — inner view of the dorsal valve, B 1710, X6.4; Turjekelder section, C. andresi Zone. *13—15. Keyserlingia buchii* (de Verneuil): *13* — outer view of the ventral valve, B 1712; *14* — inner view of the dorsal valve, B 1714, X6.4; *15* — outer view of the dorsal valve, B 1713, X6.4; Turjekelder section, C. andresi Zone.

PLATE II



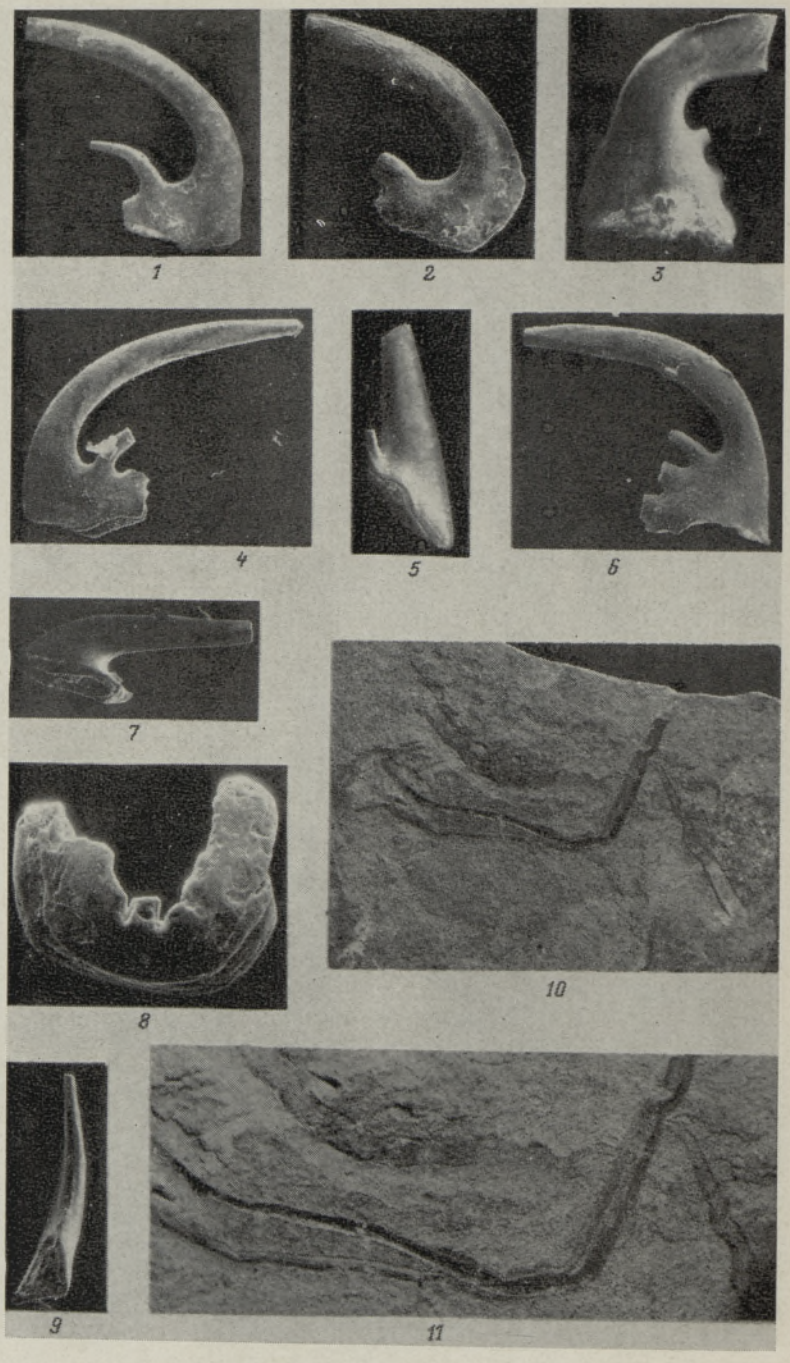
All conodont magnifications are ×55.

1—6, 9, 10. Cordylodus andresi sp. nov. (Viira, Sergeyeva, in print): *1—3, 5, 9* — Cn 1032—1036, Vihula; *4, 6* — Cn 1037, 1038, Toolse, Kallavere Formation; *10* — Cn 1039, Lomashka, Lomashka Formation. *7, 8. Eoconodontus notchpeakensis* (Miller): Cn 1040, 1041, Vihula, Kallavere Formation. *11—20. Cordylodus proavus* Müller: *11—15* — Cn 1042—1046, Vihula; *16, 17,* — Cn 1047, 1048, Toolse, Kallavere Formation; *18, 20* — Cn 1049, 1051, Syas; *19* — Cn 1050. Naziya, Tosna Formation.

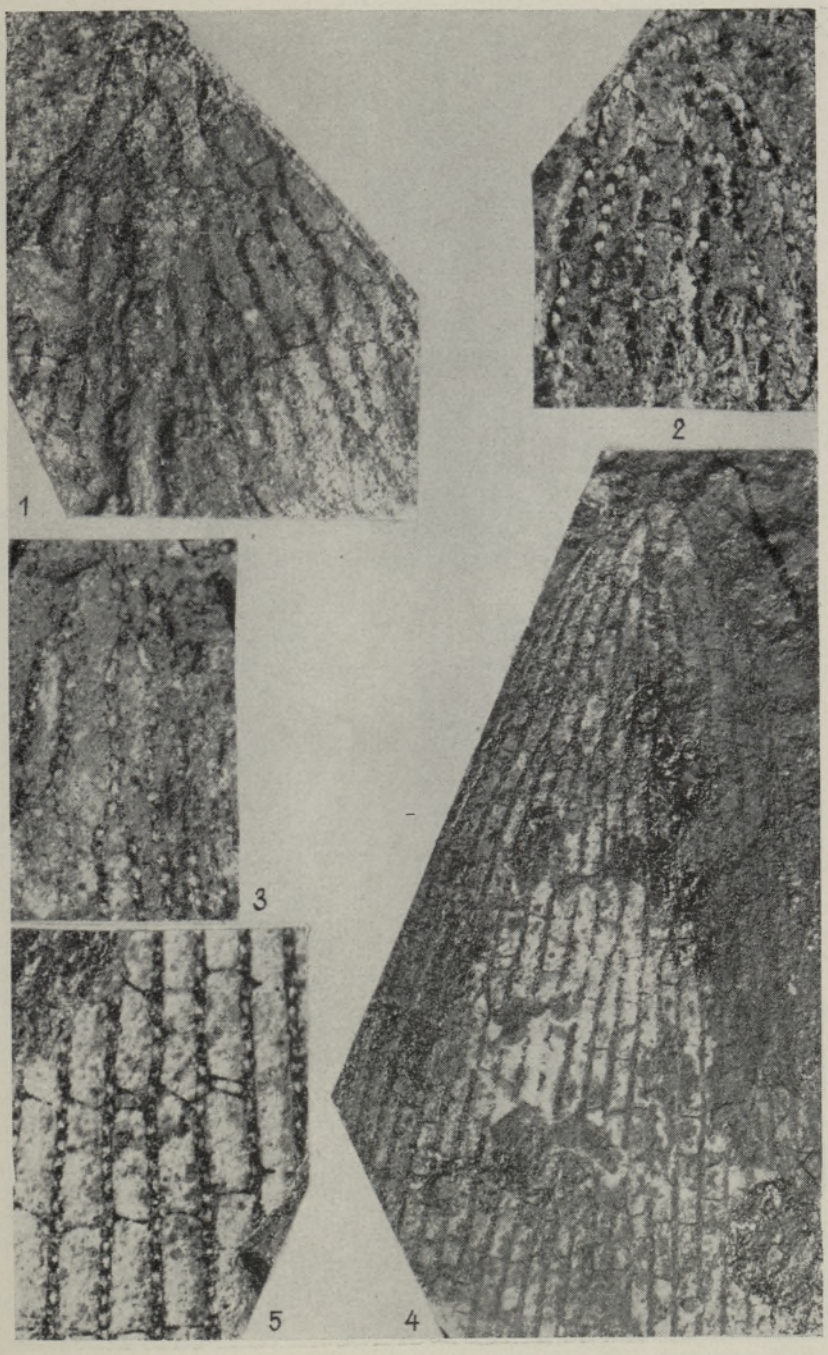


1. Cordylodus proavus Müller: Cn 1052, Toolse, Kallavere Formation. *2—6. Cordylodus intermedius* Furnish: Cn 1053—1057, Toolse, Kallavere Formation. *7—11. Cordylodus lindstromi* Druce et Jones: Cn 1058—1060, Toolse, Kallavere Formation, *10, 11* — Cn 1061—Cn 1062, Naziya, Tosna Formation. *12, 14, 16. Cordylodus drucei* Miller: *12* — Cn 1063, Toolse, *14, 16* — Cn 1065, 1066, Turjekelder, Kallavere Formation. *13* — *Iapetognathus* sp.: Cn 1064, Turjekelder, Kallavere Formation. *15. Cordylodus prion* Lindström: Cn 1067, Syas, Tosna Formation. *17. Cordylodus* sp.: Cn 1068, Vihula, Kallavere Formation.

PLATE IV

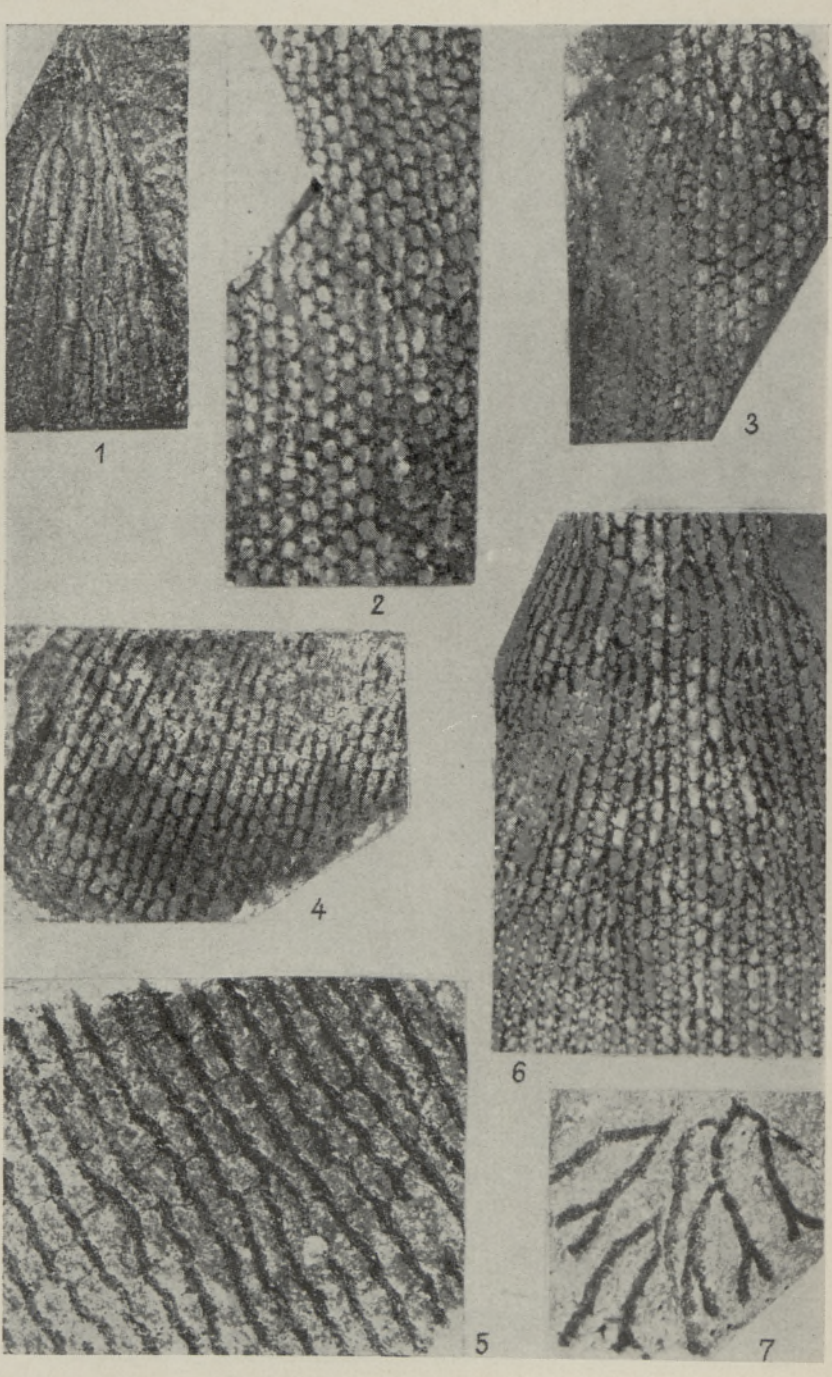


1, 4, 6. Cordylodus angulatus Pander: Cn 1069—1071, Suhkrumägi, Kallavere Formation. *2. Cordylodus rotundatus* Pander: Cn 1072, Ülgase, Kallavere Formation. *3. Cordylodus angulatus* cf. *C. intermedius* Furnish: Cn 1073, Turjekelder, Kallavere Formation. *5. Cordylodus prion* Lindström: Cn 1074, Toolse, Kallavere Formation. *7. Cordylodus drucei* Miller: Cn 1075, Toolse, Kallavere Formation. *8. Westergaardodina* cf. *moessebergensis* Müller: Cn 1076, Toolse, Kallavere Formation. *9. Cordylodus* sp.: Cn 1077, Toolse, Kallavere Formation. *10, 11. Torellella* sp.: *10* — three specimens in situ, Cn 1031, X2; *11* — proximal parts of the tubes and the places of attachment. X4; section along the Toolse River, base of the C. andresi Subzone.



1. Dictyonema flabelliforme cf. *anglicum Bulman*, Va 1024, Naziya, Tosna Formation. *2, 3. Dictyonema flabelliforme* aff. *bryograptoides* Bulman: 2 — Va 1025; 3 — Va 1026, Naziya, Tosna Formation. *4, 5. Dictyonema flabelliforme flabelliforme* (Eichw.): Va 1027, 1028, Syas, Koporye Formation. *2* — X4.3; *4* — X2, others — X4.

PLATE VI



1. Dictyonema flabelliforme aft. *multithecatum* Bulman, Va 1029, Viruküla boring, Türisalu Formation. *2, 3. Dictyonema flabelliforme norvegicum* (Kjerulf): *2* — Va 1030, X2,5; *3,* — Va 1031, X2,7, Risti boring, depth 183 m, Türisalu Formation. *4, 5, Dictyonema flabelliforme rossicum* Obut; *4* — Va 1032, X2,6; *5* — Va 1033, X5, Syas, Koporye Formation. *6. Dictyonema flabelliforme sociale* (Salter): Va 1034, X2,5, Põõsaspea boring, depth 38.8 m, Türisalu Formation. *7. Anisograptus* sp.: Va 1035, X5, Syas River, Koporye Formation.

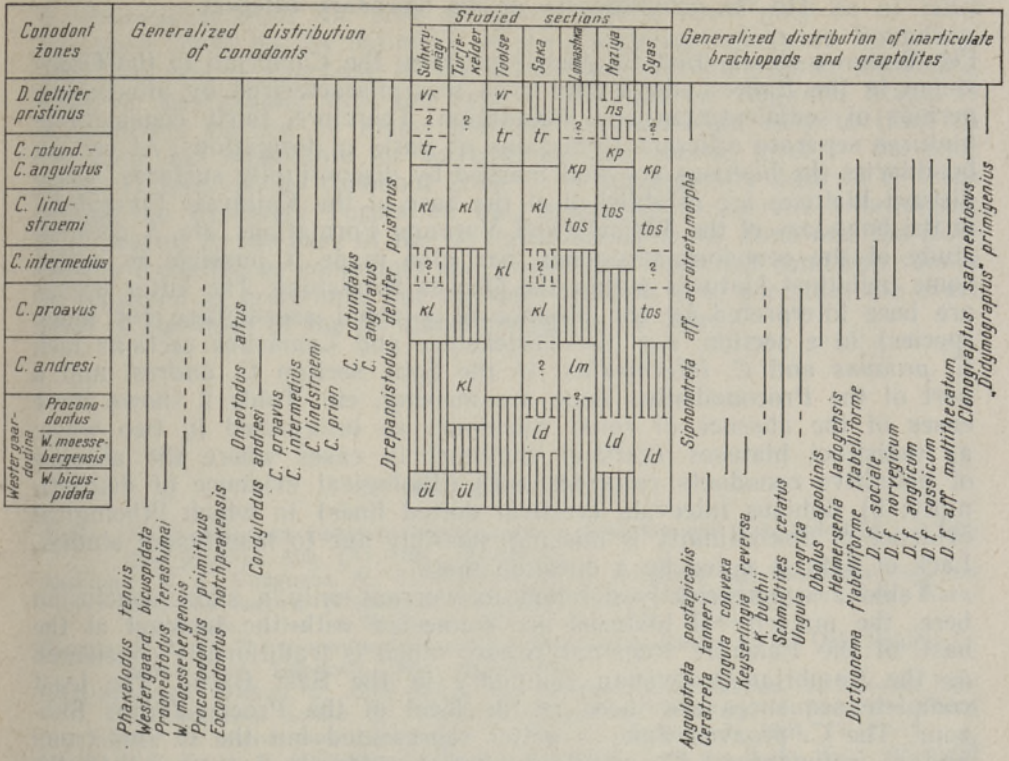


Table 2.

The available material allows us to conclude, though somewhat tentatively, that the group of *D. flabelliforme* appeared in the East Baltic not later than the C. intermedius Zone, but at present we cannot prove it for the upper part of the Cordylodus proavus Zone.

Graptolites are most common at the level of the C. lindstromi and C. rotundatus — C. angulatus Conodont Zones. In the Pakerort Regional Stage the most abundant subspecies beside *D. f. flabelliforme* are *D. f.* aff. *multithecatum* and *D. f. rossicum*; in the west *D. f. norvegicum* also occurs.

It should be noted that a number of transitional forms occur between the typical *D. f. flabelliforme* on one side and *D. f. anglicum* and *D f. multithecatum* on the other side within the upper part of the Pakerort Regional Stage. A revision of the type material of *D. rossicum* described by A. M. Obut (Обут, 1953) (housed at Leningrad State University) enables us to consider it a distinct subspecies of the *D. flabelliforme* group, and to reveal its wide distribution at the level shown (Fig. 3). In its undulating branches, oval meshes and more or less regularly placed dissepiments *D. f. rossicum* is undoubtedly similar to *D. f. norvegicum*, but differs clearly from the latter in its fine dissepiments.

In the Ceratopyge Regional Stage (Clonograptus — Didymograptus Zone) the composition of the assemblage changes completely. *Dictyonema* is replaced by *Clonograptus* and *Didymograptus* together with *Adelograptus*, *Bryograptus* and *Kiaerograptus*. The latter was found recently in the Türisalu Formation in the sections south of Tallinn.

Fig. 2 shows clearly that the transition from the Cambrian to the Ordovician in the Baltic-Ladoga clint area was characterized by alternating periods of sedimentation and denudation. Therefore, fairly considerable hiatuses separate different formations or parts of formations. At certain boundaries the hiatuses are well marked by discontinuity surfaces. These distinct hiatuses are established at the base of the Kallavere Formation, at the boundary of the Türisalu and Varangu Formations, etc. A detailed study of the conodont succession has also made it possible to detect some indistinct hiatuses within the Obolus Sandstone. The latter breaks are here interpreted by the absence of a zonal assemblage (or index species) in a section, e. g. the Turjekelder and Lomashka sections lack *C. proavus* and *C. intermedius*; in the Syas section *C. andresi* and a part of the Proconodontus Zone are missing, etc. Table 2 shows these cases of the absence of zonal conodonts as interpreted in two ways: a) indistinct hiatuses (vertical shading) in cases where the absence of definitive conodonts coincides with lithological evidence of discontinuity; b) dubious intervals (vertical dotted lines) in which lithological evidence of discontinuity is missing, possibly due to insufficient studies. Lack of data is noted by a question mark.

Table 2 is sufficiently detailed to warrant only a short conclusion here: the majority of hiatuses are connected with the interval at the base of the Pakerort Regional Stage, which is traditionally considered as the Cambrian-Ordovician Boundary in the East Baltic. The least complete sequences are those at the level of the Proconodontus Subzone. The C. proavus Zone is better represented but the C. lindstromi and C. rotundatus — C. angulatus Zones evidently correspond to the transgression maximum of the earliest Ordovician sea in the East Baltic. The transgression started somewhat earlier, but in general its level coincides with the Black Mountain eustatic event as described by J. Miller (1984).

Conclusions

1. Despite the shallow-water character of the sandstones at the Cambrian-Ordovician Boundary interval, and the several local and regional hiatuses in the sections (most importantly those at the level of the Proconodontus Subzone), we are able to establish a relatively complete sequence of conodont, graptolite and also brachiopod zones.

2. Co-occurrence of the named fossil groups have made it possible to correlate conodont and graptolite zonations.

The relations of the lowest graptolite and conodont zones are not very well documented, so that with certainty we can only conclude that the *Dictyonema* (= *Rhabdinopora*) *flabelliforme* group appears not later than the Cordylodus intermedius Zone. At the level of the C. andresi Zone we have found no graptolites, but we cannot exclude the possibility that the D. f. sociale Subzone may be correlated, at least partly, with the C. proavus Zone.

A correlation of the D. norvegicum and D. anglicum—multithecatum —rossicum Subzones with the Cordylodus lindstromi and partly C. intermedius Zones is well documented.

The lower boundary of the C. rotundatus-angulatus Zone falls within the D. anglicum-multithecatum-rossicum Subzone.

3. East Baltic sections provide interesting data for discussion of the Cambrian-Ordovician Boundary, but none of them can be recommended for use as a stratotype section.

4. Proceeding from the data presented above, there may be at least two good levels for the definition of the Cambrian-Ordovician Boundary. The first one — the base of the C. andresi conodont Zone, coinciding more or less exactly with the base of the Pakerort Regional Stage, is a boundary marked by major hiatuses and therefore easy to trace in the field, but unsuitable for correlations. The second level — the base of the C. intermedius conodont Zone — is lithologically difficult to trace within the Kallavere Formation but, according to current information, it is nearest to the base of the D. flabelliforme (s. l.) Zone and therefore readily traceable by conodonts and graptolites. This last condition should be regarded as preferable, but the only problem is to ascertain the exact level of the base of the D. flabelliforme (s. l.) Zone.

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Received
Feb. 6, 1986

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KAMBRIUMI JA ORDOVIITSIUMI PIIR BALTI—LAADOGA KLINDI PIIRKONNAS (PÕHJA-EESTI JA LENINGRADI OBLAST, NSV LIIT)

Seitsme läbilõike detailse uurimise (vt. litoloogia ja fossiilide levik joonisel 3) ja muu materjali alusel väidetakse, et *Dictyonema flabelliforme* tsoon (s. l.) algab mitte hiljem kui *Cordylodus intermedius*'e tase. Selle tsooni algus on üks sobivaid kambriumi ja ordoviitsiumi piiri tasemeid. Teine võimalus on traditsiooniline Pakerordi lademe (Kallavere kihistu) algus (*Cordylodus andres*'i tsooni algus), mis litoloogiliselt on selgem (alla jääb ka ulatuslikum settelünk), kuid kaugem graptoliitidega määratletud piirist.

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ГРАНИЦА КЕМБРИЯ И ОРДОВИКА В РАЙОНЕ БАЛТИЙСКО-ЛАДОЖСКОГО ГЛИНТА (СЕВЕРНАЯ ЭСТОНИЯ И ЛЕНИНГРАДСКАЯ ОБЛАСТЬ, СССР)

На основе детального изучения семи разрезов (литологию и распространение фоссилий см. рис. 3) и других материалов утверждается, что зона *Dictyonema flabelliforme* (s. l.) начинается не позже уровня зоны *Cordylodus intermedius*. Начало этой зоны — один из возможных уровней проведения границы кембрия и ордовика. Вторая возможность — традиционная подошва пакерортского горизонта (каллавереской свиты) на уровне подошвы зоны *Cordylodus andresi*. Литологически она более четко выражена (ниже установлен наиболее существенный перерыв осадконакопления), но находится дальше от определенной по граптолитам границы.