INSTITUTE OF GEOLOGY, ESTONIAN ACADEMY OF SCIENCES
SUBCOMMISSION ON ORDOVICIAN STRATIGRAPHY, IUGS
SUBCOMMISSION ON SILURIAN STRATIGRAPHY, IUGS
PROJECT «GLOBAL BIOEVENTS» IGCP

FIELD MEETING ESTONIA 1990

An Excursion Guidebook

TALLINN 1990

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Edited by D. Kaljo and H. Nestor

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Cover by R. Mägar

PREFACE

Close co-operation of Ordovician and Silurian specialists or participation of them in the study of the both systems, have become a long tradition in many countries. This is surely due to common features in the structure, composition and evolution of these units, but also to their common historical background as the Silurian System established by R.I. Murchison.

The Ordovician and Silurian Subcommissions have organized regular field meetings and field excursions either belonging to several symposiums (particularly the Ordovician Subcommission) or specially for the investigation of certain areas and stratotypes (Silurian Subcommission). The present Estonian field meeting 1990, following the traditions of both subcommissions, is the first joint meeting, providing thanks to political changes in this country an opportunity for foreign colleagues to visit several outcrops which for a long time have been inaccessible for them.

The Ordovician and Silurian Subcommissions have chosen different ways for performing their tasks. Therefore also the present state of stratigraphic scales and the problems to be solved are differing in both systems. The global standard for the Silurian System has been accepted by the IUGS, although it should not mean that all is in ideal shape. In the Ordovician, however, formal decisions are still in preparation, but a good progress has been achieved in the field of regional correlation, etc.

In recent years event-stratigraphy has gained popularity, thus renewing a good old idea of catastrophes(resp. bioevents) in the stratigraphy. Here a leading role is played by the IGCP project "Global bioevents". Both subcommissions consider co-operation with this one important, therefore also the Tallinn meeting of the working group was planned as a joint gathering.

The organizers of the Estonian field meeting, 1990, hope that the excursions and discussions held give a possibility to all named international bodies to strive for progress in their work. In order to provide the participants with information on the stratigraphy, paleontology and lithology of the Estonian Ordovician and Silurian, we have prepared this guidebook. Shortage of time did not enable us to present all parts in the desirable scope, but we still hope that this material is of some help to make acquaintance of Estonian geology.

On behalf of the Organizing Committee I thank all the authors (see list of contributors) and others assisting in the preparation of this guidebook. We are greatly indebted to Mrs Anne Noor for linguistic aid. Mrs Ludmilla Lippert and Kaie Ronk for drawings, to typists Tiina Auli and Janne Oengo. It is also a pleasure to thank the publishing-house "Bit" for active co-operation.

D. Kaljo

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AN INTRODUCTION TO THE GEOLOGY OF ESTONIA

D. Kaljo

History of investigation. The first publications on Estonian geology date from the end of the 17th century (these were the descriptions of Narva waterfall and a mineral spring at Koorküla). A hundred years later Academician Georgi reported about the discovery of oil shale in North Estonia; however, geological investigations remained sporadic troughout the 18th and first half of the 19th centuries. Of consequence were the works by E. Eichwald (his first paper appeared in print in 1825) who presented a more or less complete stratigraphic subdivision of bedrock and described a great number of fossil species. He was the first to advance the idea that in the diluvial time a part of Estonian territory was covered by glaciers.

The middle of the 19th century brought about the "Golden Age" of investigations marked by the publications of fundamental works by A. Schrenk, F. Schmidt and C. Grewingk, which laid the foundation of modern stratigraphic scheme; in that period the palaeontological monographs by C. Pander (conodonts, agnathans, etc.), H. Asmuss (fishes), I. Nieszkowski (trilobites), W. Dybowski (corals), F. Rosen (stromatoporoids), F. Schmidt (trilobites, brachiopods) and several others were published. In Quaternary geology, beside the above-named A. Schrenk and F. Schmidt (his first works dealt with the drift theory, and later on he made a great contribution to the glacial theory) one should point out G. Helmersen who studied erratic boulders, the structure and development of coasts and several other problems.

As a result, by the beginning of the 20th century an excellent stratigraphic scheme of the Estonian Lower Palaeozoic had been elaborated (Schmidt, 1881) and the main types of Quaternary deposits established. This provided a basis for the compilation of the first geologic sketch maps.

The turn of the century was characterized by a certain slack in scientific activities. Another period of intensive studies began in the 1920s with the first generation of Estonian geologists settling down to work (H. Bekker, A. Luha, A. Öpik, K. Orviku et al.). The stratigraphy of Ordovician and Quaternary deposits underwent an improvement, a considerable number of palaeontological and the first lithological monographs appeared in print. Great attention was paid to the investigations of the mineral wealth of the republic. In the issue, in 1918 an open-cast mining of oil shale (kukersite) was started at Kohtla-Järve By 1940 a production level of 1.9 million tons of shale annually had been attained. The first phosphorite mine went into operation in 1923 at Ülgase in the vicinity of Tallinn. In 1939 a mine at Maardu was put into use, as a result of which the production level reached 20 thousand tons of phosphorite annually.

After World War II scientific investigations rose to an entirely new level. If before this the leading role was played by the staff of Tartu University and foreign scientists, after there were several specific organizations established - the Institute of Geology of the Estonian Academy of Sciences in 1947, the Board of Geology of the Estonian SSR (= Geological Survey) in 1957; in addition, groups of engineering geology were founded at several designing institutes, which in 1979 were partly joined into the State Engineering Research Institute.

The number of geologists, geophysicists, geochemists and other specialists amounts to more than 300 at such institutions. This enables us to deal with a wide circle of problems concerning different aspects of Estonian geology, providing the national economy of the republic with indispensable raw material. A set of different geological maps of the Soviet Baltic area (10 maps in all) and an explanatory monograph published eight years ago (Grigelis, ed., 1982) generalize a considerable amount of new data, especially the results of geological mapping, and may thus serve as a good guide for those wishing to learn about Estonian geology.

Geotectonic zonation. Estonia is located in the northwestern part of the East-European Platform. Its geology was determined by the development of several different scale tectonic structures distinguished by the position of the crystalline basement surface and geological composition of sedimentary rocks.

According to P. Suveizdis, A. Brangulis and V. Puura (1979) the major part of the Estonian territory lies within the boundaries of the southern slope of the Baltic shield, and only the area adjacent to the current Riga Gulf is referred to the Baltic syneclise (Fig. 1). The above named authors regard the first structure as a transitional zone bordering on the Baltic shield in the north and on the Baltic syneclise and Latvian saddle in the south. It falls into West- and East-Estonian monoclines, Võru saddle and Valmiera-Lokno swell (Fig. 1).

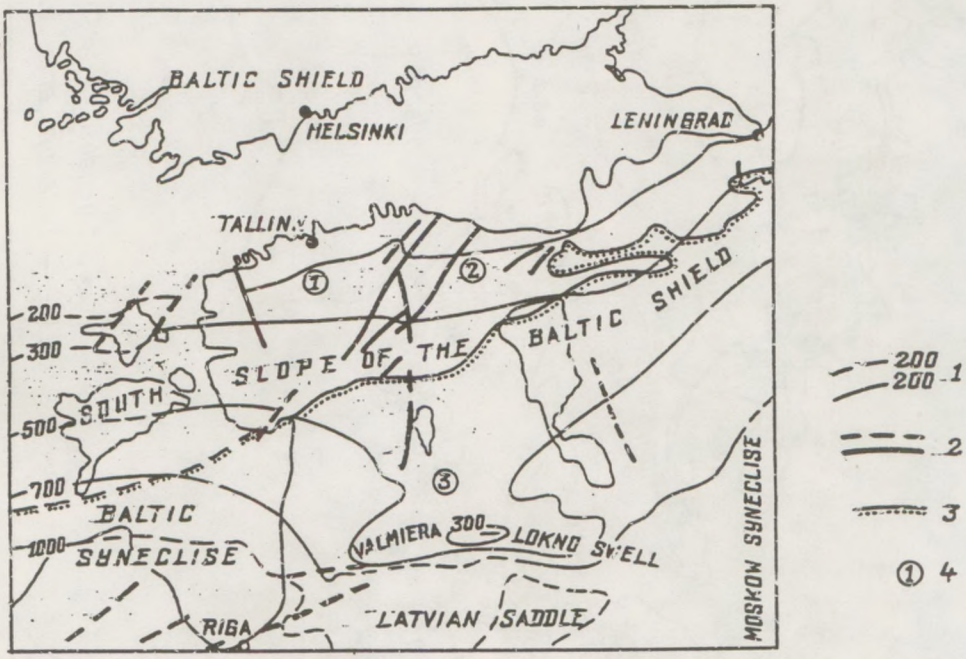


Fig. 1. Main geotectonic structures (according to V. Puura): 1 - isohypses of the surface of crystalline basement; 2 - rupture dislocations; 3 - southwestern border of discordance between the Devonian and the underlying Ordovician or Silurian rocks; 4 - geotectonic structures of second orders (1 - West- and 2 - East-Estonian monocline, 3 - Võru saddle).

The above boundaries of tectonic structures are rather distinct in the distribution of Early Palaeozoic facies as well (see below), which accounts for their long-term character. For example, the main facies boundary which in the Ordovician and Silurian divides the Baltic territory into the East- and West-Baltic structural-facies zones runs close to the boundaries of the Baltic syneclise or along their extensions on the southern slope. The main dislocation zones with a hiatus in continuity are related to these boundaries. For example, the Paide fault zone divides the Estonian monocline into two parts (see above), whereas the Liepaja-Riga-Pihkva zone of echelon-like dislocations and

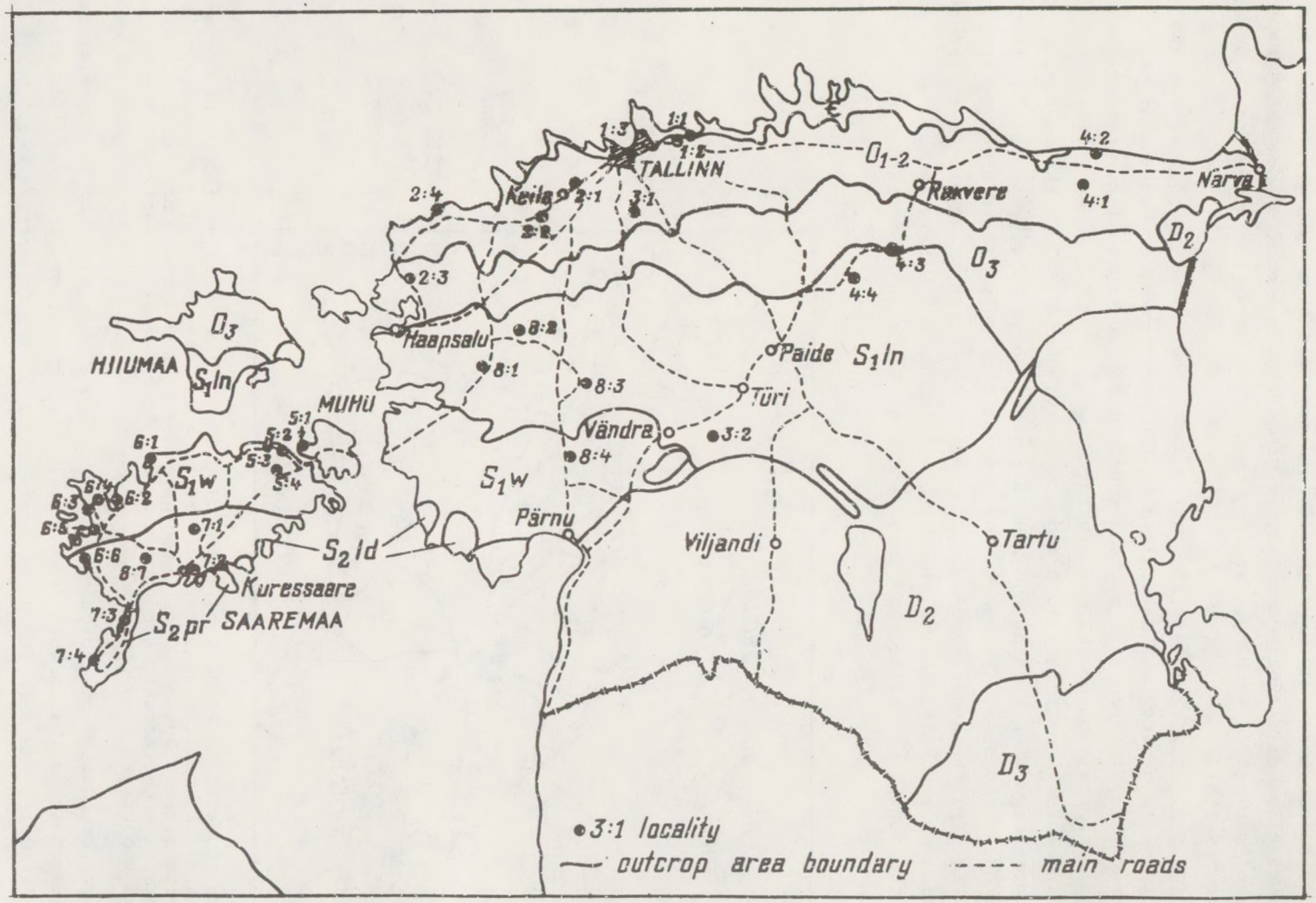


Fig. 2. Geological map of the pre-Quaternary rocks of Estonia with the routes of the excursions.

faults borders on the Baltic syneclise and Latvian saddle in the north.

It stands to reason that the geotectonic plan of the territory and the activity of tectonic movements in different parts of the paleobasin have undergone recurrent changes during the Early Palaeozoic. Fig. 2 shows the final situation in the form of a geological map.

Stratigraphy. The current stratigraphic scheme of the Estonian Lower Palaeozoic and Quaternary is based on a considerable number of recent investigations. The main results obtained through these studies are presented in the following generalizing publications (provided with extensive lists of references as well) on the crystalline basement - Puura, Vaher, Klein a.o., 1983; on the Vendian and Cambrian - Mens, Pirrus, 1977; on the Ordovician - Männil, 1966; Rõõmusoks,1970; on the Silurian - Kaljo, ed., 1970; Kaljo, Klaamann, edit., 1982; on the Devonian - Sorokin, edit., 1981, on the Quaternary Deposits - Raukas, 1978, etc.

On the grounds of the stratigraphic scheme compiled by preceding investigators, the present generation of stratigraphers has elaborated a new scheme which differs from the previous one by its basin treatment of the problem. The study of sections from subsurface areas has enabled us to establish the spatial relations of stratons and pay much more attention to facies analyses of the rocks.

The results obtained were summarized in stratigraphic schemes accepted in 1976 at the Baltic Stratigraphic Conference in Vilnius and improved in 1984 by Stratigraphic Conference on Ordovician and Silurian of the East-European platform (Resheniya, 1987).

According to the lithology of the rocks, the Estonian Lower Palaeozoic may be divided into two parts, the first of which will include Vendian, Cambrian and Tremadoc dominated by terrigenous, and the second one Ordovician since Arenig and Silurian with carbonate and fine-terrigenous rocks prevailing.

Devonian is represented mainly by Old Red facies; glacial, aqueoglacial, marine and lake deposits dominated in the Quaternary cover.

Ordovician and Silurian stratigraphy is presented in detail in the following chapters, outlines of stratigraphy of the under- and overlying rocks are given here as a concise list of main units (most important hiatuses are also marked).

Upper Devonian, Frasne

- Dubniki Formation - clays, dolomites, gypsum
- Plavinas Stage - dolomites, limestones, marls
- Amata Form. - sand- and siltstones
- Gauja Form. - sand- and siltstones, clays

Middle Devonian, Givet

- Burtnieki Form. - sand- and siltstones, clays, conglomerates
- Aruküla Form. - sand- and siltstones, marls

Eifel

- Narva Form. - dolomitic marls, siltstones, clays
- Pärnu Form. - sand- and siltstones, clays, dolomites

Lower Devonian

- Lemsi and Rezekne Form. - sandstones, marls, dolomites
- Hiatus
- Tilze Form. - sand- and siltstones

Silurian

Ordovician

Upper Cambrian

- Hiatus
- Ülgase Form. - silt- and sandstones
- Hiatus

Middle Cambrian

Ruhnu Beds - sandstone

Hiatus

Lower Cambrian

Irben Form. - clays

Soela Form. - sand- and siltstones

Tiskre Form. - sand- and siltstones

Lükati Form. - clays, silt- and sandstones

Sõru Form. - sand- and siltstones

Lontova Form. - clays

Hiatus (= Rovno Stage)

Upper Proterozoic Vendian, Valdai Series

Voronka Form. - sand- and siltstones, clays

Kotlin Form. - varved clays

Gdov Form. - silt- and sandstones

Hiatus (= Volynia Series Redkino stage)

Lower Proterozoic

Hogland series - porphyrites and quartzites

Jägala and Alutaguse Series - gneisses, quartzites

Main minerals (according to Mustjõgi, 1984). In the Cambrian terrigenous complex only the clays of the Lontova Formation are of economic significance. These so-called blue clays crop out and form several deposits in a narrow belt in North Estonia. They serve as raw material for manufacturing cement and rough ceramical products (bricks, roof-tiles, drainage pipes). The blue clay deposits are exploited in Tallinn, in the environs of Loksa, et Kunda and Aseri.

The lowermost terrigenous part of the Ordovician is composed of a fine-grained quartzose sandstone which contains phosphorus-bearing valves and valve fragments of brachiopods. The valves are rich in P_2O_5 (35-37 %). In Estonia the total phosphorite reserves are estimated at about 600-700 million tons of P_2O_5.

The Baltic oil shale (kukersite) is related to the carbonate rocks of the Middle Ordovician Kukruse regional Stage. There are two large oil shale deposits on Estonian territory - the Estonian and Tapa ones.

Ordovician and Silurian limestones and dolomites are used in the building materials industry for producing Portland cement, building lime, road metal, and facing panels. In Estonia limestones and dolomites are produced in numerous quarries located in the vicinity of towns and industrial centres. The most important deposits are those of Väo, Maardu and Harku in the vicinity of Tallinn (building limestones), Padise and Rummu in the Vasalemma settlement (building limestones and limestones for the production of lime), Aru near the town of Kunda (for cement production), Karinu, Rakke in the Rakvere district (limestones for the production of lime), Kadastik near the town of Narva (building limestones) and Anelema in Pärnu district (building dolomites of high resistance), Kaarma, and Tagavere on Island Saaremaa (building dolomites) etc.

THE ORDOVICIAN OF ESTONIA

R. Männil

A continuous outcrop belt of the Baltic Ordovician rocks extends from the Swedish Island of Öland in the southwest through northern Estonia to the Lake of Ladoga (Leningrad district) in the east. The Estonian territory has the central and most important position due to outcropping of the complete sequence of the Ordovician System with its both lower and upper boundaries accordingly conforming to the Cambrian and Silurian systems. In Estonia the Ordovician rocks crop out in a narrow (40-45 km) belt extending from the west to east for about 300 km. The practically undisturbed strata are almost flat-lying with a small dip (2.5-3.5 m pro km) to the south. The sequence consists of highly fossiliferous shallow water open shelf carbonates (mostly calcarenites) with the exception of its basal part which is represented by silty and clayey sandstones and graptolite argillites. The basal part of the succession (Tremadoc) contains productive phosphorite deposits, the main carbonate part productive oil shale (kukersite) deposits, building limestones and limestones for production of road metal, lime and Portland cement.

The thickness of the Ordovician sequence in Estonia ranges from 70 to 180 m having its maximum in the central, minimum in the northwestern part of the territory.

The circumstances considered above enabled the elaboration in Estonia of a stable detailed local classification for the Ordovician rocks which afterwards obtained the status of a regional standard for the most part of the East European platform area (see Alikhova, 1960; Männil, 1966; Resheniya ..., 1965, 1978, 1987).

The main pioneering work toward the classification has been done by Schmidt (1858, 1881, 1897, 1899) who established in sequence 14 formally named and lettered main units ($A_2 \ldots F_2$), most of which representing well-defined faunal assemblage zones. Some of these stages (B_2, B_3, C_1 and F_1) were subdivided lithologically and/or faunistically into lower and upper parts. In the current century Schmidt's scheme has been greatly revised, refined and improved by many subsequent authors (Lamansky, 1905; Raymond, 1916; Bekker, 1922-1925; Öpik, 1929-1930; Orviku, 1940, 1960, Jaanusson, 1944-1960; Rõõmusoks, 1956-1983; Männil, 1958-1984; and others) though the principal features of the classification remained. Of the most essential improvements the recognition of some additional stage rank divisions ($C_I a$, $C_I b$, $C_I c$, $F_I a$-$F_I c$) by Raymond (1916), Orviku (1940) and Jaanusson (1944) and the introduction of local Estonian (pro Schmidt's German) nomenclature by Bekker (1922) have to be mentioned. As a result the currently used classification consists of 18 stages, seven of which are subdivided into two or three substages (see table).

Attempts have also been made to establish in the Ordovician of Estonia and adjacent districts subdivisions of higher than stage rank resulting in the recognition of local resp. regional series and subseries. To this category belong the "Schichtengruppen" A, B, C, D, E and F by Schmidt (1881), the three-fold subsystemic division of the Ordovician by Raymond (1916), the four regional Baltic series by Öpik (1930), the subseries by Rõõmusoks (1956, 1960), and others. They remained, however, informal with the exception of the three divisions of subsystemic rank officially accepted in late 50s by the USSR Stratigraphic Committee.

In the 50s and 60s the first attempts were made (Sokolov, 1951; Alikhova, 1960, Männil, 1966) to use the same scheme in the large subsurface area extending to the south and east of the outcrop belt. In the following decades official correlation charts of the Ordovician System have been compiled and published (Resheniya..., 1965, 1978, 1987; see Männil, 1989) and in this connection Schmidt's scheme has been officially accepted as a regional standard. As for the Estonian territory, currently three types of local sequences and corresponding facies belts are distinguished (see Resheniya ..., 1987): the North Estonian Confacies Belt in the north, the Central Baltoscandian Confacies Belt in the far south and the transitional zone between them.

From the beginning of the 50s and in the following decades the correlation of the North-Estonian sequence with Scandinavian and Great Britain successions has been considerably improved (Jaanusson and Strachan, 1954; Jaanusson, 1957, 1960; Männil, 1966, 1976; Kaljo et al., 1986) mainly due to progress in research on ostracodes, graptolites, conodonts, and chitinozoans, as well as to results of internal correlations between sequences of different confacies belts of the East Baltic area (Männil, 1963, 1966; Ulst et al., 1982; Resheniya..., 1976, 1987).

The correlation of North Estonian Tremadocian rocks with Scandinavian sequences is sufficiently well-based on graptolitic and conodont evidence (Kaljo, Kivimägi, 1976; Kaljo et al., 1986). The Arenigian and lower Llanvirnian Latorp, Volkhov and Kunda regional stages are correlated with their Scandinavian counterparts directly by index conodonts and trilobites and on this base they may be considered as Baltoscandian stages (Jaanusson, 1960; and others). The same status has been attributed to the following upper Llanvirnian to the lowermost Caradocian Aseri, Lasnamägi, Uhaku and Kukruse stages (Jaanusson, 1960; Bergström, 1971; and others), their recognition in Sweden and in NE Poland (Modlinsky, 1973) being based mainly on trilobites, ostracodes, conodonts and graptolites. To the mentioned stages on the base of the record of chitinozoans the Idavere Stage may be added. There are still some problems with the precise correlation of the rocks of the Jõhvi and Keila stages but the level of the main bentonite, currently accepted as the boundary between them may be now well traced by ostracode distribution in central Estonia and by the presence of an index chitinozoan "*Illichitina*" *multiplex* near the top of the bentonite bed.

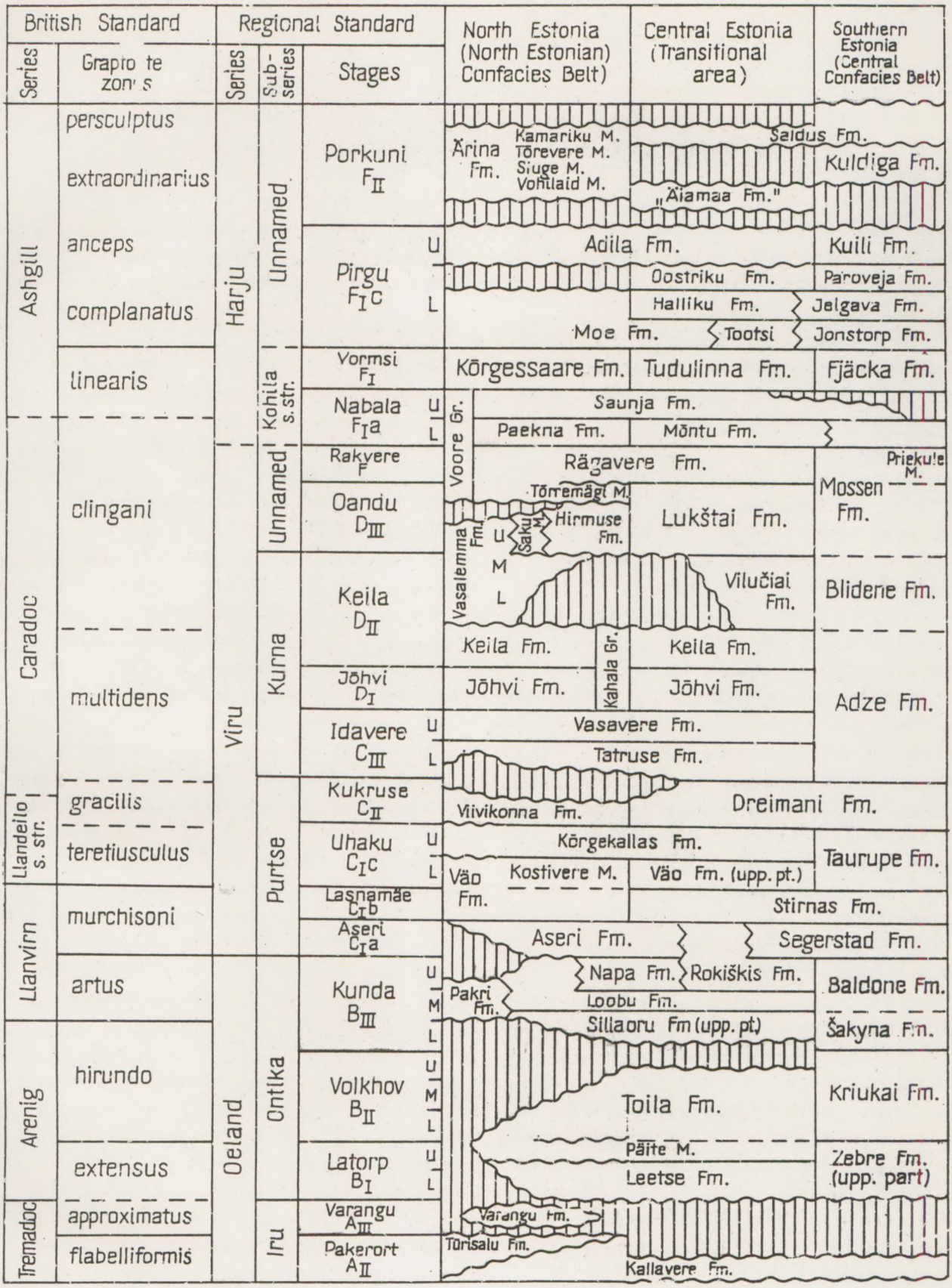
By some authors all the stages of the Viru Series (including or excluding the Rakvere Stage) are considered as Baltoscandian (Bergström 1971(a,b); Podhalanska, 1980). The Harjuan (Upper Ordovician) stages though differently named in the East Baltic and Sweden, correlate with each other quite well (Pirgu with Jerrestad, Porkuni with Tommarp), with the exception of the lower part of the succession roughly corresponding to the *linearis* Chronozone. The main problem seems to be here the still obscure position of the Rakvere Stage, which according to the presence of *Climacograptus diplacanthus* (= *C. spiniferus*) obviously correlates with some part of the clingani Chronozone and corresponds in Swedish sequence either to upper Mossen Formation or to a hiatus.

The external correlation of the North-Estonian sequence with the British standard is carried out mainly through the graptolite-bearing Scandinavian successions. There exist only few indices allowing direct correlation, e.g. *Nemagraptus gracilis*, *Amplexograptus fallax*, *Acanthochitina barbata*.

As far as long-distance correlations are concerned, one has to mention in addition to the North Atlantic zonal conodont ties with the Appalachian sequences (Bergström, 1971) the tie levels of zonal conodonts and some graptolites and chitinozoans with SE China, Portugal, etc.

In the following short comments on the series, stages and on some substages as well as some local units (formations and members) are given.

Table 1. Ordovician stratigraphy of Estonia



Oeland Series (Lower Ordovician)

The Oeland Series corresponds exactly to the term "Lower Ordovician" introduced in Baltoscandia by Raymond (1916). But the division is by no means a "natural" regional unit and may serve only as a convenient unit of the three-fold subdivision of the Ordovician System officially accepted by the USSR Stratigraphic Committee. The name has been proposed by Kaljo et al. (1958) in accordance with the type area (Swedish Island of Oeland in the Baltic Sea) possessing classical sections of the sequence from the base of the Ordovician System up to the top of the Kunda Regional Stage (= top of the *Didymograptus artus* Chronozone). The series consist of two lithologically sharply different parts, the lower of which is represented by terrigenous rocks of Tremadocian age (Iru Subseries) and the upper mainly by carbonates of the Arenigian and early Llanvirnian age (Ontika Subseries). These subdivisions may be informally regarded as units of the series category (see e.g. Öpik, 1930).

The series includes five regional stages, two lower ones of which belong to the "Schichtengruppe A" (= Iru Subseries) and the rest of them to "Schichtengruppe B" by Schmidt (1881) (= Ontika Subseries).

Pakerort Stage (A_{II}). The unit is defined as the lowermost regional stage of the Ordovician System in the East-European Platform area with its base coinciding with the base of the system. According to the current use (Kaljo et al., 1986; Resheniya ..., 1987) in the sections of the type area the boundary is tentatively drawn at the level of the first appearance of *Cordylodus* (= base of *C. andresi* Zone). The upper boundary coincides with the top of the *Dictyonema flabelliforme anglicum* and *D.f. multithecatum* Zone. Type and reference sections in NW Estonia, west and east of Tallinn. The stage boundaries in many districts do not coincide with the boundaries of the rock units: the base is lying inside the Kallavere Formation, the top inside the Türisalu Formation. Thickness in the outcrop area does not exceed 5-15 m. Corresponds to the lower Tremadoc.

Varangu Stage (A_{III}). The name has been introduced recently (Resheniya ..., 1987) to designate a division of stage level, previously referred to as "*Ceratopyge* Stage" (Männil, 1966; Resheniya ..., 1976). The base of the stage coincides with the top of the Pakerort Stage, and is drawn at the level of the boundary between the *Dictyonema flabelliforme anglicum - D.f. multithecatum* Zone and *Clonograptus sarmentosus* Zone. Type section 90 km east of Tallinn in which the stage is represented by the Toolse Member of the Türisalu Formation and the Varangu Formation with a total thickness of 3.5-4 m (Viira et al., 1970; Kleesment, Mägi, 1975; Mägi, Viira, 1976). The stage is well characterized faunistically in Norwegian and Swedish sections. In Estonia and adjacent regions of the USSR it is recognized mainly by graptolites and conodonts: *Clonograptus sarmentosus*, *"Didymograptus" primigenius*, *Bryograptus*, *Kiaerograptus*, *Drepanoistodus deltifer pristinus*, *Cordylodus rotundatus*, *C. angulatus*, *Oneotodus altus*, etc. (Kaljo, Kivimägi, 1970; 1976; Mägi, Viira, 1976).

The stage corresponds to the upper Tremadoc.

Latorp Stage (B_I). Corresponds to trilobite succession from the base of the *Megistaspis armata* Zone to the top of the *M. estonica* Zone. Type section in Nerike, central Sweden. (Tjernvik, 1956; Jaanusson, 1960). Lower boundary of the stage coincides with the base of the *Paroistodus proteus* Zone, which approximately corresponds to the lower limit of the *Tetragraptus approximatus* Zone. Two substages recognized: a lower, Hunneberg Substage, corresponding to the *Megistaspis armata* and *M. planilimbata* zones, and roughly to the *Paroistodus proteus* zone, and an upper, Billingen Substage, corresponding to the zones of *Megalaspides dalecarlicus* and *Megistaspis estonica*, and roughly to the *Oistodus lanceolatus* Zone. In Baltoscandian graptolite succession to the upper Hunneberg corresponds *Tetragraptus phyllograptoides* Zone, to Billingen the zones from *Didymograptus balticus* to the top of *Phyllograptus angustifolius elongatus* Zone (Tjernvik, 1956;

Jaanusson, 1982, etc.). In northern Estonia the stage is represented mostly by the Leetse Formation and the Päite Member of the Toila Formation with a total thickness rarely exceeding 5 m (for details see Mägi, 1970, 1984; Mägi et al., 1989).

Volkhov Stage (B_{II}) may be defined as the trilobite succession from the base of the *Megistaspis lata* Zone to the top of the *Megistaspis limbata* Zone. Type sections at the Volkhov River, Leningrad District. In the type area the stage is represented by the Volkhov Formation (6 m), subdivided into three succeeding informal subformations (Resheniya ..., 1987). According to them the stage is divided from base to top into three traditional substages: the Saka (B_{II}^{α}), Vääna (B_{II}^{β}), and Langevoja Substage (B_{II}^{γ}) (Lamansky, 1905; Orviku, 1960; Mägi, 1984). The substages seem to be sufficiently well recognizable on the bases of both trilobite and conodont evidence (see e.g. Tjernvik and Johansson, 1980; Löfgren, 1985; Stouge, 1989). The stage corresponds to the main part of the *Didymograptus hirundo* Chronozone. Thickness in northern Estonia 0.3-2.4 m, in southern Estonia up to 19.3 m.

Kunda Stage (B_{III}). Represents the top part of the Oeland Series and corresponds to the trilobite succession from the base of the *Asaphus expansus* Zone to the top of the *Megistaspis gigas* Zone. The stage has been named (Raymond, 1916) after a section in Kunda, 100 km east of Tallinn where it overlies the preceding Volkhov Stage with a considerable hiatus and consists of the Voka Member of the Sillaoru Formation and Loobu Formation with a total thickness of 7.3 m. A more complete sequence of the stage is developed in the Volkhov district where it is represented by the Obukhovo Formation with a thickness of 11.5-12.5 m (Resheniya..., 1987). The stage is subdivided into three substages which are from base to top the Hunderum (B_{III}^{α}), Valaste (B_{III}^{β}) and Aluoja Substage (B_{III}^{γ}). The lower division is regarded as corresponding to the *Asaphus expansus* Zone, the middle to the *Asaphus "raniceps"* Zone and the upper to the zones of *Megistaspis obtusicauda* and *M. gigas*. The stage contains a rich assemblage of index fossils, among them *Asaphus sulevi*, *Megistaspis heros*, *Pseudoasaphus globifrons*, *Orthambonites calligramma*, *Lycophoria nucella*, *Paracyclendoceras cancellatum*, *Pinnatulites procera*, *Eoplacognathus variabilis*, etc. The thickness of the stage varies in northern Estonia from 0.2 m in the west to 8 m in the east (Orviku, 1958, 1960; Mägi, 1970), in southern Estonia from 5 to 14 m.

The stage corresponds to the top part of the *Didymograptus hirundo* Chronozone and to the *Didymograptus artus* Chronozone.

Viru Series (Middle Ordovician)

The traditional base of the series (Raymond, 1916) coincides with the boundary between the informal subdivisions "B" and "C" by Schmidt (1881) and is marked by a well-defined macrofaunal change - the disappearance of *Megistaspis*, *Antigonambonites*, etc. and the first occurrence of *Asaphus (Neoasaphus)*, *Echinosphaerites*, etc. (see e.g. Alikhova, 1957, Rõõmusoks, 1956). Type area: the district of Virumaa, northeast Estonia.

The series may be subdivided into three regional subseries (resp. superstages), the lower one (Purtse Subseries by Rõõmusoks, 1956) including the stages C_{Ia}-C_{II}, the middle one (Kurna Subseries by Männil, 1958) the stages C_{III}-D_{II}, and the upper (unnamed) the stages D_{III} and E. The base of the upper subseries which seems to be well correlated with the base of the Woolston Stage ("Upper Longvillian") of South Shropshire (Männil, 1968) has long been recognized in northern Estonia as a well-marked level of appearance of a completely new fauna (Jaanusson, 1945; Rõõmusoks, 1970; Männil, 1960; and others). In accordance with this the upper subseries has been considered by many authors as basal Upper Ordovician (a.o. Hints et al., 1989).

The Viru Series includes in total 9 regional stages.

Aseri Stage ($C_I a$). Includes rocks, corresponding to the trilobite zones of *Asaphus (Neoasaphus) platyurus*, *A.(N.) cornutus*, and *A.(N.) kowalewskii*. Type section 115 km east of Tallinn (Orviku, 1940; Rõõmusoks, 1970). The lower boundary is drawn at the level of the first appearance of a new fauna including *Asaphus (Neoasaphus)*, *Echinosphaerites*, *Piretella tridactyla*, *Euprimites effusus* etc., and the disappearance of *Megistaspis*, *Paracyclendoceras*, *Pinnatulites*, etc. The stage is well recognizable on the base of index assemblages of trilobites, nautiloids, ostracodes. Thickness seems never exceed 6-7 m. Corresponds to the lower part of *Didymograptus murchisoni* Chronozone.

Lasnamägi Stage ($C_I b$). Corresponds in the revised form to the beds containing *Lituites*, *Orthoceras regulare*, *Illaenus schroeteri*, etc. (Jaanusson, 1960; Männil, 1966). Type section in abandoned quarry in Tallinn where the stage is represented by the lower part of the Väo Formation in a thickness of 3.8 m. Recognizable in most districts of East European platform by the presence of a distinct assemblage of macrofossils, ostracodes, graptolites and conodonts. In the North Atlantic conodont succession the stage exactly corresponds to the interval from the base of the *Eoplacognatus foliaceus* Subzone to the top of the *E. reclinatus* Subzone (Bergström, 1971; Dzik, 1978; Männil, 1986). Thickness varies from 2.5 to 8.5 m. The stage corresponds to the upper part of the *Didymograptus murchisoni* Chronozone.

Uhaku Stage ($C_I c$). Corresponds in the revised and amended form (Jaanusson, 1960; Männil, 1966, 1976) to beds containing *Ancistroceras*, *Xenasaphus*, *Illaenus intermedius*, *Gymnograptus*, etc. Type section 130 km east of Tallinn (Orviku, 1940; Rõõmusoks, 1970) in which the stage is represented by the upper part of the Väo Formation and Kõrgekallas Formation with a total thickness of 19 m. The lower limit of the stage coincides with the boundary between the conodont subzones of *Eoplacognatus reclinatus* and *E. robustus* of the *Pygodus serra* Zone. Among the graptolites the same level is marked by the first appearance of *Gymnograptus linnarssoni*, and its alliances. In the type area and some other districts the stage may be subdivided into lower and upper substages, corresponding to the upper Väo Formation and Kõrgekallas Formation, accordingly. The base of the upper substages seems to coincide with the boundary between the conodont zones of *Pygodus serra* and *P. anserinus* and is well marked by the first appearance of *Chasmops odini*, *Illaenus intermedius*, *Heliocrinites balticus*, etc. Previously this level has been used (Orviku, 1940; Rõõmusoks, 1960, 1970) as the base of the Uhaku Stage s.str. The thickness of the stage in most districts varies from 8 to 18 m.

The stage corresponds to the *Glyptograptus teretiusculus* Chronozone the bases both of them lying according to the reference section of the latter in Scania (see Bergström, 1973) exactly at the same level.

Kukruse Stage (C_{II}). In current use the stage is interpreted usually as beds containing in the type area index macrofossils *Paraceraurus aculeatus*, *Hoplolichas conicotuberculatus*, *Bilobia musca*, *Paucicrura navis*, *Cyrtonotella kuckersiana*, *Kullervo panderi*, etc. (Rõõmusoks, 1957, 1960, 1970; Alikhova, 1960), or beds with *Orthograptus uplandicus*, *Amplexograptus bekkeri*, *Climacograptus kuckersianus* and *Nemagraptus gracilis* (Männil, 1976, 1986; Resheniya ..., 1978). Type section at Kukruse (Kohtla-Järve), 140 km east of Tallinn (Rõõmusoks, 1970). In the type area the stage is represented by its lower 1/3 up to 2/3 part only, the upper part missing due to a hiatus between the Kukruse and Idavere stages in this district. The lower boundary is drawn in the type area at the base of the Kiviõli Member (oil shale seams of the Estonia deposit). This level is soundly correlated with the base of the Dreimani and Dalby formations of the Central Confacies Belt by ostracodes, graptolites and chitinozoans as well as by many macrofossils.

The upper boundary is suggested (Männil, 1984, 1986) to be defined in central Estonia in core sections in the vicinity of Laeva at the level of the kukersite seam X.

Approximately at this level *Orthograptus uplandicus, Amplexograptus bekkeri* and *Cyathochitina stentor* seem to disappear and a new fauna gradually appears. It results that the Kukruse Stage may be considered as one of the best marker horizons in the Viruan sequence of the East-European platform (Jaanusson, 1960; Männil, 1966; Podhalanska, 1980; Ulst et al., 1982; etc.). The thickness is usually 15-20 m.

The stage corresponds roughly to the *Nemagraptus gracilis* Chronozone. In terms of North Atlantic conodont succession the stage seems to correspond to the uppermost part of the *Pygodus anserinus* Zone, the *Prioniodus variabilis* (most part of the stage) and to the lowermost *P. gerdae* subzones of the *Amorphognathus tvaerensis* Zone (Männil, 1986).

Idavere Stage (C_{III}). This division has caused much confusion in the 20s and 30s (Bekker, 1924; Öpik, 1930; etc.) in connection with rare exposures and misinterpretation of core sections. In current practice (Resheniya ..., 1978, 1987), however, it is understood as a biostratigraphically well-defined division recognizable within the entire region at least on the base of micropaleontological data. In the type area the lowermost part of the stage is missing and its lower boundary may be defined only in core sections (see under the preceding stage). Type section near Rakvere, 100 km east of Tallinn (Rõõmusoks, 1970; Põlma et al., 1988) in which the stage is represented by the Tatruse and Vasavere formations with a total thickness of 4.5 m. The Tatruse Formation contains characteristic index fossils *Scopelochasmops wrangeli, Conolichas triconicus, Cyrtonotella concava*, etc. and many representatives of a new faunal assemblage including *Platystrophia chama, Oepikina anijana, Batostoma granulosum, Bichilina prima*, etc. The Vasavere Formation yields in addition to these *Estoniops bekkeri, Paucicrura plana, Tetrada memorabilis, Pyritonema subulare*, etc. The stage has been subdivided into the lower, Ojamaa (C_{III}^{α}), and the upper, Shundorovo Substage (C_{III}^{β}). The boundary between the substages coincides with the base of the Vasavere Formation, which seems to correspond to the base of the *Prioniodus alobatus* Subzone. In core sections the base of the Idavere Stage is usually well recognized by the presence of excellent index chitinozonas *Cyathochitina* aff. *reticulifera* and *"Eremochitina" dalbyensis* (Laufeld, 1967; Männil, 1971, 1972, 1986; Grahn, 1981). The thickness of the stage in the Estonian sections usually varies from 4 to 12 m. Corresponds to the lowermost part of the *Diplograptus multidens* Chronozone.

Jõhvi Stage (D_I). Separated in the type area as beds containing *Toxochasmops maximus, Rollmops wenjukowi, Clinambon anomalus, Porambonites schmidti, Amphorichnus mammulus*, etc. together with *Bilobia* aff. *musca, Clitambonites schmidti, Tetrada memorabilis*, etc. Type section near Jõhvi (Kohtla-Järve), 145 km east of Tallinn (Rõõmusoks, 1970; Põlma et al., 1988). The lower boundary of the stage is tentatively drawn at the level of bentonite bed *"b"* situated near the level of faunal change. At this level *Amplexograptus* cf. *fallax* seems to make its first appearance and it may be used to recognize the base of the stage in core sections (Männil, 1976). In spite of this the recognition of the stage in core sections of many districts is at present difficult. Thickness in the type area 9-12 m, in southern districts 3.5-15 m corresponds probably to the middle part of the *Diplograptus multidens* Chronozone.

Keila Stage (D_{II}). Biostratigraphically beds, containing in the type area *Toxochasmops maximus, conolichas deflexus, C. aequilobus, Clinambon anomalus, Horderleyella kegelensis, Strophomena asmusi, Bolbina major, Polyceratella spinosa*, etc. Type section 25 km southwest from Tallinn (Rõõmusoks, 1970; Põlma et al., 1988). In the type area the sequence is represented by the Keila Formation, and by the lower part of the Vasalemma Formation. The stratigraphy of the stage is complicated due to the presence of a hiatus at the top of the sequence and development of carbonate mounds ("bioherms") in the outcrop area, and further to the presence in southern subsurface area distinct argillaceous rocks (Vilučiai Formation) which may represent the upper part of the stage missing in

the northern district (Männil et al., 1968; Resheniya..., 1978, 1987). The lower boundary of the stage is drawn at the level of the base of the main bentonite bed "*d*" (in Scandinavia XXI), which in Central Estonia and East Lithuania is marked by the appearance of the ostracode fauna of the so-called Skagen type. The same level has yielded the index chitinozoan "*Illichitina*" *multiplex* in Estonian and Swedish sections. The upper boundary of the stage is tentatively drawn at the top of the Vilučiai Formation. Thickness of the stage varies in the East Baltic from 2 to 27 m. Corresponds presumably to the uppermost part of the *Diplograptus multidens* Chronozone and part of the *Dicranograptus clingani* Chronozone.

Oandu Stage (D_{III}). In the outcrop area the rocks of this division contain a distinct faunal assemblage, sharply different from those of the preceding stages: *Toxochasmops extensus, Otarozoum eichwaldi, Howellites wesenbergensis, Sowerbyella tenera, Ilmarinia dimorpha, Dactylogonia luhai, Zygospira gutta, Klimphores minimus, Eofletcheria, Lycopora, Stromatocerium,* etc. Type section 130 km east of Tallinn (Männil, 1960; Põlma et al., 1988). In northern Estonia the stage is represented mainly by marls and argillaceous calcarenites of the Hirmuse Formation, in the vicinity of Vasalemma by organodetritic (cystoid) and carbonate mound cryptocrystalline massive limestones of the uppermost Vasalemma Formation (details see Põlma et al., 1988). In south-central Estonia marls of the Lukštai Formation are developed, containing *Sampo, Skenidioides,* etc., in southernmost Estonia and western Latvia - graptolitic argillites of the Mossen Formation which have yielded *Climacograptus diplacanthus*. Thickness of the stage varies from 0.3 to 8 m. Corresponds approximately to the middle part of the *Dicranograptus clingani* Chronozone.

Rakvere Stage (E). Unlike all the older Ordovician stages, consists in northern and central Estonia mainly of calcilutites which at least in their lower part contain macrofauna closely related to the assemblage of the preceding division: *Conolichas eichwaldi, Toxochasmops wesenbergensis, Howellites wesenbergensis,* etc. Type section 100 km east of Tallinn. Represented according to the current use in the type area from base to top by the Piilse and Tudu formations (details see Põlma et al., 1988). Due to the lack of good exposures the macrofauna of the upper division is almost unknown but the ostracodes seem to have much in common with the overlying beds (Meidla, 1989). Thickness varies from 1.5 to 27 m. Corresponds according to the finds of *Climacograptus diplacanthus* and *Dicranograptus clingani* (Männil, 1976), and the stratigraphic position of the division, to the upper part of the *Dicranograptus clingani* Chronozone.

Harju Series (Upper Ordovician)

Corresponds to the division "F" by Schmidt (1881) and approximately to the term Upper Ordovician by Raymond (1916) and many subsequent authors as well as to the division Isotelus Series of Estonia by Öpik (1930). The accepted name has been introduced by Luha (1940). In modern terms the Harju Series has been defined by Jaanusson (1960) as a division corresponding to the interval from the base of the *Pleurograptus linearis* Chronozone to the top of the Ordovician System. Type area within Harju District, south of Tallinn.

According to current practice (Resheniya ..., 1987), the lower boundary of the series is drawn in Estonia at the base of the Nabala Stage.

The series includes 4 regional stages.

Nabala Stage (F_Ia). Has been first distinguished as a formal stage by Jaanusson (1944) under the name of Saunja; revised and renamed by Männil (1958). Type section in Harju district, 20 km south of Tallinn. In the type area the succession consists of a lower, Paekna and an upper, Saunja Formation with a total thickness of about 30 m. The

Paekna Formation has yielded *Wysogorskiella litviensis, Laticrura rostrata, Onniella? acuta, Ilmarinia sinuata, Bekkeromena, Trigrammaria, Oxoplecia, Eoplectodonta, Distobolbina nabalaensis, Tetradella pulchra, Kenophyllum canaliferum*, etc., the Saunja Formation - *Pionodema costata, Sampo hiiuensis, Boreadorthis recula, Thaerodonta, Dinorthis, Illaenus mascei, Leperditella globosa, Kenophyllum subcylindricum*, etc. The lower boundary of the stage has been defined as the base of the Paekna Formation, the upper boundary as the top of the Saunja Formation. At or near the base of the stage a distinct index chitinozoan *Cyathochitina reticulifera ("C. dispar")* occurs which is most useful for recognizing this stratigraphic horizon in core sections. Thickness of the stages varies from 2.5 to 35 m, being usually 15-20 m. The stage presumably corresponds to the uppermost *Dicranograptus clingani* Chronozone and to the lower part of the *Pleurograptus linearis* Chronozone. This assumption is based on the finds in the East Baltic area of *Climacograptus diplacanthus* and *Lasiograptus* cf. *harknessi* in the lower, and *Rectograptus gracilis* and *Archeoretiolites regimontanus* in the upper part of the stage.

Vormsi Stage ($F_I b$). Represented in the type area by calcarenites of the Kõrgessaare Formation, containing a rich fauna of tabulate and rugose corals, brachiopods, bryozoans, nautiloids, gastropods, etc. Most typical of them are *Catenipora wrighti, Protaraea schmidti, Brachyelasma hiumica, Plaesiomys solaris, "Orthis" lyckholmensis, Triplesia insularis, Eoplectodonta schmidti, Leurocycloceras foerstei, Schroederoceras hyatti*, etc. Type section on the Island of Vormsi, 100 km west of Tallinn. In southernmost Estonia and western Latvia as in other districts of the Central Confacies Belt the stage is represented by graptolitic shales (Fjäcka Formation) containing *Tretaspis seticornis* and graptoloids of the *Climacograptus styloideus* Zone (Skoglund, 1963; Ulst et al., 1982). In the top part of different formations of the Vormsi Stage an index chitinozoan *Acanthochitina barbata* occurs, the top of its range zone being in the entire region most useful for tracing the upper boundary of the stage. Thickness varies usually from 8 to 25 m, in the central East Baltic from 0.8 to 8 m. Corresponds to the upper part of the *Pleurograptus linearis* Chronozone.

Pirgu Stage (F_I). This unit corresponds to the top part of the previous Saaremõisa ("Lyckholm") Beds, as an independent stage first distinguished by Jaanusson (1944). Type section in Harju district is 40 km south of Tallinn. In the entire outcrop area in North Estonia the stage is represented by two succeeding formations (Moe and Adila formations) separated presumably by a considerable hiatus (Resheniya ..., 1978, 1987). The Moe Formation is characterized by the presence of *Plectatrypa (=Eospirigerina), Dicoelosia, Catenipora rubraeformis, Sarcinula venustum, Clathrodictyon microundulatum, Foramenella parkis*, etc., the Adila Formation by the presence of *Maclurites neritoides, Luhaia vardi, Palaeofavosites alveolaris, Proheliolites dubius, Trochiscolithus micraster, Cystostroma estoniense, Brevibolbina fissurata*, etc. The differences between these faunal assemblages have been taken as bases for subdivision of the stage into two informal substages, adopted in the official correlation charts of 1976 and 1984 as Lower and Upper substages. The boundary between them has been tentatively drawn at the level of the base of the Adila Formation, and, accordingly, the formations developed in the subsurface area and correlated with the hiatus, are thus considered as belonging to the lower substage. The thickness of the stage varies from 10 m in South Estonia to 40-60 m in most of other districts. The lower substage corresponds to the *Dicellograptus complanatus* Chronozone, the upper substage presumably to the *D. anceps* Chronozone or to a part of it.

Porkuni Stage (F_{II}). This division, according to current practice (Resheniya ..., 1978, 1987), includes all the uppermost Ordovician rocks lying between the top of the Adila Formation and the top of the Ordovician System. In the East Baltic area these rocks are represented by different local rock units with different faunas and their

stratigraphical relationship is in many cases still obscure (Männil, 1966; Männil et al., 1968; Oraspõld, 1975; Ulst et al., 1982). In the type area in northern Estonia the stage is represented by the Ärina Formation, containing a rich fauna with *"Proetus" ramisulcatus, Streptis undifera, Leptaena acuteplicata, Ilmarinia ponderosa, Rafinesquina luna, Sceptropora estonica, Clathrodictyon gregale, Paleofavosites, Palaeoporites, Rhabdotetradium, Palaeophyllum, Baltonotella kiesowii, Tetradella plicatula,* etc. In southernmost Estonia as in other districts of the central East Baltic *Dalmanitina* beds (Kuldiga and Saldus formations) are developed, which have yielded *Dalmanitina mucronata, Brongniartella platynota, Hirnantia sagittifera, Dalmanella testudinaria,* etc. In eastern Lithuania and eastern Latvia the stage is represented by the Taučionys Formation, containing *Holorhynchus giganteus*. In the subsurface of Saaremaa Island and central part of the mainland of Estonia up to 15-20 m unnamed marls and argillaceous limestones with occasional cherts are developed, resting on the Halliku Formation s.l. (Pirgu Stage). These unnamed beds have yielded *Conochitina taugourdeaui, Tetradella plicatula, Bulbosclerites unicornis, Sceptropora,* etc. Classification and correlation of these rocks is still obscure but they seem to represent at least in part an equivalent of the late Ordovician rocks known as Öjle Myr erratics in Gotland (Wiman, 1901; see e.g. Schallreuter, 1987). They may partly equate with the Taučionys Formation.

According to currently accepted correlations (Resheniya ..., 1987) the Taučionys Formation is considered as the lowermost and the Saldus Formation as the topmost Porkuni Stage. The Ärina and Kuldiga formations are regarded as approximate equivalents and placed on the correlation chart in the middle part of the succession. Thickness of the stage usually does not exceed 10-15 m, in some districts 30 m. The stage corresponds presumably to the *Climacograptus extraordinarius* and *Glyptograptus persculptus* chronozones, in its lowermost part possibly to the *Dicellograptus anceps* Chronozone.

THE SILURIAN OF ESTONIA

D. Kaljo

This summary is meant first of all as stratigraphic framework for the following chapters on Silurian lithology, facies and biostratigraphy, also for the description of outcrops to be visited during the excursion. Therefore there is no need to treat the aspects mentioned here in detail.

In the earlier period of studies on the Silurian stratigraphy of Estonia the most essential were the results by A. Schrenck, F. Schmidt, H. Bekker and A. Luha. From the more recent time we should mention A. Aaloe and E. Klaamann, all the other active Silurian researchers are among the authors of this guide. More concrete information can be obtained from a list of references.

The division into the earlier and later study periods was based not only on time aspect or the event of great war separating them, but also on considerable topical differences. Up to the middle of the 1940s the whole stratigraphy based on outcrops located (as we know now) in a rather restricted facies belt. Therefore only one scheme with one set of units - zone, (regional) stage, system, etc. was sufficient for the stratigraphy of this period. Although lateral varieties of rock bodies were established, A. Luha (1930) was one of the first Estonian geologists to apply the facies concept also in stratigraphy.

In the second half of the 1940s a deep boring programme was initiated in Estonia, particularly intensely performed in the 1960s and 1970s in the course of geological mapping carried out by the Estonian Geological Survey (has been renamed repeatedly). The examination of core sections called forth a new conception in the stratigraphy proceeding from facies zonality of the sedimentary basin, thus considering regional chronostratigraphic units (regional stages) as being composed of different local stratons (formations-comprising rocks of one facies belt, see H. Nestor in this guide; members - a ± homogeneous part of a formation, beds, etc.). First of all lithostratigraphical scheme was elaborated in connection with facies zonality of the basin (Kaljo, Jürgenson, 1977). Ecostratigraphical studies deepened the knowledge about the basin structure, expressed in the application of the concepts of palaeoecosystem and ecological model (see Kaljo, Klaamann, edits. 1982a,b; Kaljo et al., 1983). These studies needed detailed correlations for which community framework and biozonations of different faunal groups were elaborated (see the above books, particularly the corresponding chapters of this guide).

In the development of the concept of basinal stratigraphy (resp. ecostratigraphy) we proceeded from the well-known fact that any organism is not found everywhere but has its specific living conditions. Therefore, in order to get a complete picture of the basin, for the correlation of all facies, we need to know the relations between zonations of all characteristic fossils.

Table 2 presents some data obtained but detailed work in this field and publication of results is the task of the future.

One possible way for the correlation of biozonations is the so-called composite standard method by M. Rubel (this guide), which, according to the corresponding programme generalizes the data on the distribution of the organisms studied. The objective

picture revealed is quite instructive, although not sufficiently unambiguous in all aspects (although the demand for unambiguity could be doubtful in these cases). Complications appear due to scarcity of fossils (incompleteness of the record) and difficulties in the consideration of the ecological (resp. facies) situation.

Another possibility is the recording of levels of essential faunal changes, alterations at the boundaries of sedimentary cycles, the appearance-disappearance levels of guide-fossils (and their complexes), etc. which is (one) essence of the event stratigraphy. Table 2 presents some of such levels.

Speaking about event-stratigraphical planes or horizons, we should note very different ranks of events. Quite naturally, all event-levels which are important in the East Baltic Silurian basin, have no global significance. More probably it seems on the contrary, but still not with absolute certainty.

In the international stratigraphical practice much importance is attached to stratotypes, especially to boundary stratotypes. Their positive role in the improvement of the stratigraphical classification is well-known and therefore no additional comments are needed here. Considering the requirements made on the definition of the Silurian/Devonian, then Ordovician/Silurian and now Cambrian/Ordovician boundaries and stratotypes, we can note increasing demand for strictness and complexity. Undoubtedly more profound studies are of a greater value, but boundary working groups have to face inevitable complications in searching for suitable stratotypes, which is quite understandable as ideal sections are almost lacking in nature.

In the opinion of the author another way should be followed - using only one or a few exact criteria a boundary should be defined in a stratotype, thereupon shortcomings of the latter (answers to other demands) should be compensated (given) involving other sections of the same basin (also those from the other facies). Of great significance is here preciseness of transmission of the boundary level which actually accounts for current-strict requirements (ICS instructions) in the establishing of stratotypes. More probably such preciseness could be achieved easier by a thorough analysis of one basin than by interregional or intercontinental correlation. The system of parastratotypes enables to get additional criteria useful for those distant correlations.

The system of additional sections (para- or auxiliary) may appear more complicated than the previous one, but the aim of the aforesaid was to point out once more the need to pay attention to sedimentary basins beside separate sections.

The stratigraphical chart of the Estonian Silurian is presented in Table 2 in an officially accepted form (Resheniya, 1987) with some changes (in Table marked by an asterisk) made by the Estonian Stratigraphic Committee in December 1989. Two new names have been introduced (Tõstamaa and Anelema), the publication of which in the chart, according to the USSR Stratigraphic Code does not mean their formal definition. Description of stages mainly follows the conception presented in the monograph "The Silurian of Estonia" (Kaljo ed., 1970) and the above decisions (Resheniya, 1987).

In Table 2 the stratigraphical chart is presented in three parts - regional stages and local units of two different confacies belts (in Russian literature also structural-facies belts). The regional stages are established basing on the Estonian sections proceeding from the tradition created by F. Schmidt, a.o., but in their modern essence they have extended over the whole East Baltic area.

Local units reflect facies differences: Central Estonia and Saaremaa are dominated by shallow-water facies, in South Estonia and Sõrve Peninsula sedimentary rocks of the deep shelf and transition belt are prevailing. Such a division into two belts is somewhat tentative as in the course of basin evolution gradual shifts of facies took place.

The lithological and paleontological characterization of local units is presented in the part of the guide devoted to the description of outcrops. In the following some

comments on regional stages are given. As elsewhere in the text, we have sometimes omitted the term "regional". Only a few paleontological names most important for boundary definition or correlation appear in the stage descriptions below. The author has used different literature and, especially, biostratigraphical summaries in this guide, giving more complete account on main fauna and flora groups. We shall not repeat reference to these without any special need.

The Juuru Regional Stage comprises Rhuddanian rocks older than the *Coronograptus cyphus* Zone. It lies transgressively, mostly unconformably on the Porkuni Stage. The contact has displayed chanelling, infilling of which is tentatively considered of Silurian age. The lower boundary is defined mostly by the appearance of *Stricklandia lens prima* and *Ancyrochitina laevaensis*, also by different corals, conodonts, trilobites, etc. In the Central Estonian Confacies there occur *Borealis, Linoporella, Stricklandia-Zygospiraella* communities, characteristic of the shallow shelf belt. In the transition belt of the South Estonian Confacies (Óhne Formation) *Clorinda* Community occurs (Rubel, 1970; Kaljo, Rubel, 1982).

For the correlation of the lower boundary with the global stratigraphical standard there are no direct data in Estonia. The most important is above-mentioned *S. lens prima*, the position of which in the lower strata of the Varbola Formation and in the Rhuddanian A_2 Beds (=*acuminatus* Zone, Bassett, 1989) allows to place the base of the Juuru Stage to the O/S boundary or its immediate proximity. Thus, the occurrence of a hiatus at the beginning of the Silurian (the hiatus occurring at the end of the Ordovician is more wide-spread) is problematic, although being referred at by great regression at the end of the Ordovician, as well as by discontinuity surfaces and chanelling at the boundary. Probably the hiatus was restricted to shallow shelf area.

Correlation of the upper boundary is based on graptolite occurrences - *Dimorphograptus confertus* in the top of the Juuru Stage in the Ikla and *Atavograptus atavus* in the Pärnu core in the bottom of the Raikküla Stage. The records of several other graptolites (*Pribylograptus incommodus*, etc.) in the upper part of the Juuru Stage also show the possibility of correlation with the lower *cyphus* - *atavus* Standard Zone.

The Raikküla Regional Stage embraces the upper Rhuddanian and Aeronian rocks corresponding to graptolite zones from *Coronograptus cyphus* till *Demirastrites convolutus*. In the stratotype area there are wide-spread shallow-water rocks with corals and stromatoporoids, in South Estonia carbonate rocks alternate with frequent shale beds with graptolites. Relatively often graptolites have been recovered also at the level of the *Coronograptus gregarius* Zone in lime- and marlstones of Central Estonia, including a particular *Rhadinograptus jurgensonae* dendroid graptolite assemblage. The lower boundary is well marked by chitinozoans (*Conochitina electa*), conodonts and ostracodes occur more sparsely (see Table 2).

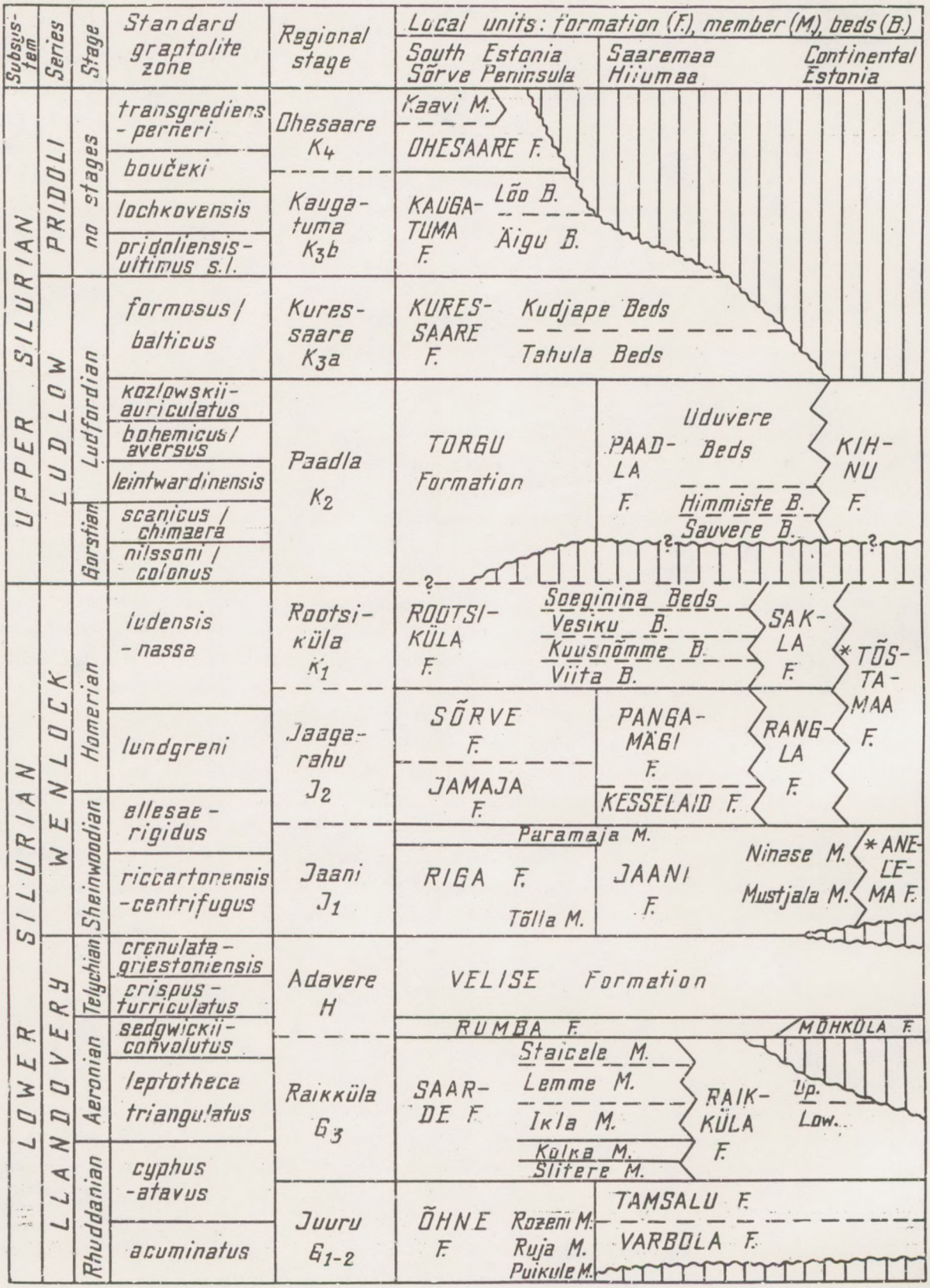
The end of the Raikküla time is characterized by rapid regression, bringing about a considerable hiatus in the peripheral part of the basin (the hiatus is distinctly traced by chitinozoan zones, V. Nestor, this guide).

The Adavere Regional Stage corresponds to the traditional upper Llandovery or Telychian + *M. sedgwickii* Zone. The stage is divided into two greatly different parts: the lower shallow-water Rumba Formation (various carbonate rocks with *Pentamerus oblongus*, abundant corals and other shelly fauna) and the upper deeper-water Velise Formation containing marls and argillaceous limestones with rich microfauna, particularly ostracodes and conodonts (*Beyrichia valguensis, Pterospathodus celloni, P. amorphognathoides*, etc).

The boundary of the Rumba and Velise formations has been treated as a boundary of a higher rank, especially in deep-water sediments from which onwards the character of sedimentation changes considerably (Einasto, 1986).

Table 2. Silurian Stratigraphy of Estonia

Regional and local units according to Resheniya, 1987, except new names marked by an asterisk. Standard graptolite zones according to Koren, 1984. Selected index-species



according to V. Nestor, P. Männik and V. Viira, T. Meidla and L. Sarv and T. Märss (this guide), correspondingly. Dots at boundaries denote that corresponding species occurs higher in the sequence.

Regional units		Represent. in Estonia	Selected index-species marking stage boundaries			
Stage	Graptolite zone		Chitinozoa	Conodonts	Ostracodes	Vertebrates
K_4			Urnochitina sp.	O. remscheidensis	Nod. protuberans	Por. punctatus
K_3b	? ultimus		Ancyrochitina fragilis	O. eosteinhornensis s. str.	Nod. tuberculata Frost. groenvaleiana	
K_3a	formosus		Con. granosa+ Pter. perivelata ⋮	O. aff. scanica	Plic. numerosa	T. sculptilis
K_2	balticus tauragensis Scanicus-progenitor nilssoni		Con. lauensis Con. latifrons Conochitina sp.1	O. crispa + D. dubius O. sp. S ⋮	H. hemsiensis N. ctenophora N. nutans	A. hedei P. elegans ⋮
K_1	ludensis			C. murchisoni O. boh. bohemicus	B. subornata	L. martinssoni
J_2	nassa testis radians perneri	*	Sphaerochitina indecora Lin. cingulata	O. sag. rhenana+ K. walliseri	L. quadricuspidata	L. taiti
J_1	flexilis antennularius riccartonensis murchisoni bohemicus	* * *	Mar. margaritana	P. amorphognathus		
H	spiralis griestoniensis crispus turriculatus sedgwickii	* * * *	Con. emmastensis	P. celloni ⋮	T. walensis B. valguensis B. ultima	
S_3	convolutus gregarius-triangulatus cyphus	* * * *	Con. electa	K. manitoulinensis	Bytho. sarvi ⋮	
G_{1-2}	confertus	*	Anc. laevaensis	D. kentuckyensis O. ex gr. oldhamensis	Steus. eris ⋮	

The Jaani Regional Stage corresponds to the Sheinwoodian from the base of the Wenlock to the level of the *M. flexilis* Zone. The stage is represented mainly by argillaceous limestones and marlstones formed during a maximum of the Wenlock transgression. In South-Estonian Confacies Belt the lower part of the stage is graptolite-bearing. The lower boundary is well marked by graptolites and chitinozoans (Table 2), but it is transitional judging by brachiopods and some other shelly fauna groups. The stage is rich in fossils, particularly trilobite ones.

The Jaagarahu Regional Stage comprises the rocks corresponding to the interval from the *M. flexilis* Zone to the lower part of the *G. nassa* Zone. Yet, in Estonia the stage is poorly characterized by graptolites (more abundant are retiolitids in the upper part), stratigraphically the most informative are ostracodes and chitinozoans (Table 2). Shallow-water rocks abound in coral-stromatoporoid bioherms with *Vikingia tenue* and *Ecclimadictyon astrolaxum* communities.

The Rootsiküla Regional Stage embraces the topmost Wenlock on the level of the upper *Gothograptus nassa* Zone and *M. ludensis* Zone. The stage corresponds to the Wenlock regression maximum and, like the previous stage, it has a very complicated lithostratigraphical structure reflecting changeable shallow-water conditions. Strong dolomitization has hampered paleontological studies, but for the first time in Estonian Silurian vertebrates, particularly thelodonts (Table 2) have gained significance in the fauna. Valuable are also eurypterids.

The Paadla Regional Stage corresponds to the whole Ludlow below the *formosus/balticus* Standard Graptolite Zone. On Estonian territory the stage is not represented in such an extent, as the corresponding deep-water rocks with graptolites are lacking and in the shallow shelf area, however, there is a hiatus in the lowermost Ludlow. This hiatus has been established according to chitinozoan data (see V. Nestor, this guide), but it is observable also in the ostracode zonation. Presumably in a region all analogs of the Gorstian are lacking.

The Kuressaare Regional Stage embraces the topmost Ludlow on the level of the *formosus/balticus* Standard Zone. Rich shelly fauna, especially ostracodes and thelodonts, favours exact definition of boundaries and correlations, although not all data is in harmony (e.g. among conodonts the first appearance of *O. crispa* and *O. eosteinhornensis* and their taxonomy).

The Kaugatuma Regional Stage covers the lower part of the Pridoli from the appearance level of *Frostiella groenvalliana* and *O. eosteinhornensis* s. str. up to the incoming of *O. remscheidensis*. In South East Baltic sparse graptolites have been recovered from the basal beds of the stage (*M. ultimus*, etc.), but not from higher levels. The stage is characterized by specific shallow-water rocks formed in the phase of basin filling (Late Silurian regression) containing rich shelly fauna.

The Ohesaare Regional Stage is the topmost part of the Silurian characterized by ostracodes (the so-called *Beyrichia* fauna) and vertebrates (see corresponding chapters). The lower boundary is defined by *Nodibeyrichia protuberans*, *Poracanthodes punctatus* and *Ozarkodina* referred to above. The stage contains many coral and brachiopod species common with the lower stages, but also several new, so-called Devonian elements among bryozoa (see Kaljo, ed., 1970), cephalopods (Kiselev, this guide), etc.

Beginning with the Kuressaare Stage a certain unity of the fauna can be observed in the Late Silurian joining these stages into a relatively homogeneous succession. The situation is reflected in the Silurian stratigraphical standard scheme by the lack of Pridoli subdivisions. Still, detailed studies (see biostratigraphy in this guide) have provided many criteria for determination its subdivision (stage) boundaries and the concurrent renovation and impoversihing of the fauna and flora in the Ohesaare Stage may serve as an adequate basis for the distinction of stages.

SOME ASPECTS OF LITHOLOGY OF THE ORDOVICIAN AND SILURIAN ROCKS

H. Nestor

Main regional peculiarities

The sequence of the Ordovician and Silurian rocks in Estonia is among the completest in the world. At the beginning of the Ordovician in the Tremadoc only terrigenous - sandy and clayey deposits accumulated here, while from the beginning of the Arenig carbonate type of sedimentation prevailed without any remarkable hiatus. In the marginal part of the sedimentary basin, corresponding to the present outcrop area various carbonate rocks dominate, rich in shelly fossils. Towards the deeper, axial part of the basin carbonate rocks are gradually replaced by clayey deposits and thus mixed calcareous-argillaceous rocks are widespread in the Baltic area. On the other hand, in many cases limestones are secondarily dolomitized to a different extent. Therefore the Ordovician and Silurian sections of Estonia contain the abundant so-called mixed rocks forming continuous series from pure limestones or dolomites to terrigenous mudstones.

Classification and nomenclature

Wide distribution of mixed rocks has raised a necessity for classification of carbonate rocks on the basis of the ratio of the main mineral components: terrigenous material, calcite and dolomite, together with textural features: grain size, type and packing of primary constituents of carbonate rocks. Basing mainly on the classifications by Vishnyakov (1933), Teodorovich (1958), and others, a "Unified classification and legend of carbonate[x] rocks" has been worked out for Estonia (Vingissaar, Oraspõld, Einasto, Jürgenson, 1964). With some modifications it has been used up to now.

Unfortunately, there have been certain difficulties in finding English equivalents to the lithological terms used in this classification. One of the major complications is due to the fact that in the British-American literature several textural classifications of carbonate rocks are used based on different principles and using different nomenclature (see Pettitjohn, 1957, Folk, 1959, 1962, Leighton and Pentexter, 1962, Dunham, 1962, etc.). These classifications base, to a certain extent, on microlithological characteristics. This complicates their usage in field geology or for other more general purposes and therefore in some cases it is useful to combine elements of different classifications.

Another main problem is that British-American classifications are, as a rule, restricted to pure rock types and do not consider the entire series of carbonate-terrigenous mixed rocks.

In the classification applied in Estonia, following the example of Russian, German and Scandinavian literature, marls (marlstones) are distinguished as a separate grouping in between lime- and mudstones (clays). In our usage they contain 25 to 75 per cent of argillaceous component. By analogy a new term "domerite" has been introduced in Estonia for the mixed dolomitic-argillaceous rocks with a similar clay content (i.e. 25-75 %).

[x] the classification comprises also terrigenous rocks with carbonate admixture

Table 3 shows the ratio of main mineral components - calcite, dolomite and clay in different mixed rocks.

Table 3. Ratio of the main mineral components in different carbonate-terrigenous mixed rocks

1. Limestone → mudstone (clay) mixtures

	$CaCO_3$, %	Clay, %
Pure limestone	100-90	0-10
Argillaceous limestone	90-75	10-25
Calcareous marlstone (or highly argillaceous lmst.)	75-50	25-50
Argillaceous marlstone (or highly calcitic mudstone)	50-25	50-75
Calcitic mudstone	25-10	75-90
Pure mudstone (clay, argillite, shale)	10-0	90-100

2. Dolomite → mudstone (clay) mixtures

	$CaMg(CO_3)_2$, %	Clay, %
Pure dolomite (dolostone)	100-90	0-10
Argillaceous dolomite	90-75	10-25
Dolomitic domerite (or highly argillaceous dolomite)	75-50	25-50
Argillaceous domerite (or highly dolomitic mudstone)	50-25	50-75
Dolomitic mudstone	25-10	75-90
Mudstone (clay, argillite, shale)	10-0	90-100

3. Limestone → dolomite (dolostone) mixtures

	$CaCO_3$, %	$CaMg(CO_3)_2$, %
Pure limestone	100-90	0-10
Dolomitic limestone	90-75	10-25
Highly dolomitic lmst.	75-50	25-50
Highly calcitic dolomite	50-25	50-75
Calcitic dolomite	25-10	75-90
Pure dolomite (dolostone)	10-0	90-100

The same principle as used for the classification of the rocks of limestone → dolomite series is applied also by the classification of members of limestone → sandstone, dolomite → siltstone and other series of mixed rocks which in our sections are of a relatively restricted distribution.

By adding attributive words names of three- and multicomponent mixed rocks can be formed (see Bissell and Chillingar, 1967, etc.), e.g. argillaceous-dolomitic limestone (calcium > 50 %; clay ≈ dolomite), dolomitic, argillaceous marl (clay = 50-75 %; dolomite < calcite) etc.

The most serious terminological problems concern textural classification of the carbonate rocks. Up to now Estonian geologists have designated textural varieties of limestones by adding corresponding adjectives to the basic word "limestone" while in the classifications by Pettitjohn (1957), Folk (1959, 1962), Dunham (1962) and others different textural types of limestones have received their own names. The greatest misunderstanding has been caused by different usage of the term "detritus". If in British-American lithological literature detritus means clastic particles in a wide sense, then in the Russian literature, and under its influence also in Estonian, the word "detritus" has been used in the sense of skeletal particles.

In more recent papers the prefixes "bio-" or "organo-" have been added (biodetrital or organodetrital limestones) but the latter terms associate with another meaning of the word "detritus", i.e. disintegrated particles of organic tissues - as used in marine biology and ecology. Therefore, these terms are inadvisable and in the present work we have used the terms "skeletal" or "bioclastic" for limestones consisting predominantly of the broken particles of skeletons and "coquinoid" for the rocks composed of more or less complete shelly fossils. Out of several textural classifications of limestones preference is given here to that by Dunham (1962) with supplements by Embry and Klovan (1971) (Table 4). It takes into account the grain size of the primary constituents of

Table 4. Textural classification of limestones by Dunham (1962), Embry and Klovan (1971)

Allochthonous limestones original components not organically bound during deposition						Autochthonous limestones original components organically bound during deposition		
Less than 10 % > 2 mm components				Greater than 10 % > 2 mm components		By organisms which act as baffles	By organisms which encrust and bind	By organisms which build a rigid framework
Contains lime mud (< 03 mm)			No lime mud	Matrix supported	>2 mm component supported			
Mud supported		Grain supported						
Less than 10 % grains (> 03 mm < 2 mm)	Greater than 10 % grains							
Mud-stone	Wacke-stone	Pack-stone	Grain-stone	Float-stone	Rud-stone	Baffle-stone	Bind-stone	Frame-stone

limestones(allochems) as well as their packing. The type of the allochems is given by adding attributive words: skeletal or bioclastic, lithoclastic, pelletal, oolitic, oncolitic, coquinoid etc. in different combinations. The main difficulty by the use of Dunham's classification is the distinction between the grain-supported packstone and mud-supported wackestone. This limit falls somewhere within 25-35 % of grain content depending on the degree of roundness and sorting of the grains. Determination of this theoretical limit is approximate even in thin sections. By field observations, however, the distinction of these two types is largely arbitrary. In such cases when the distinction between these two rock types is fairly impossible a joint term "biomicritic limestone" (or "biomicritic calcarenite") can be used. "Skeletal limestone" (or "skeletal calcarenite") is a still more general term joining all kinds of limestones (packstones, wackestones and grainstones) containing more than 10 % of skeletal particles.

Another shortcoming in Dunham's classification is the usage of the term "mudstone" for designation of the carbonate rock consisting of pure lime mud - micrite, whereas it has been generally accepted to apply "mudstone" as referring to terrigenous argillaceous rocks. Therefore, here we use the term "aphanitic limestone" for marking micritic calcareous rock (calcilutite), which, in turn can be subdivided into microcrystalline and cryptocrystalline varieties.

A more complete picture about the nomenclature of the rock types spread in the Ordovician and Silurian of Estonia, can be obtained from the lithological legend (Fig. 3). The legend contains more signs than used in the figures of the present guidebook as the aim of the legend is also to help an English reader to use lithological columns in our earlier publications. Combining the signs of the mineral composition, textural and structural characteristics it is possible to designate a number of additional variants of rock types.

Limestones:

- in general
- argillaceous
- dolomitic
- a, b silty (a), sandy (b)
- coarse skeletal grainstone
- unsorted skeletal packstone
- fine skeletal grainstone
- fine-grained skeletal wackestone
- bioclastic floatstone
- lithoclastic skeletal rudstone
- a, b oolitic grainstone (a) and packstone (b)
- a, b pelletal grainstone (a) and packstone (b)
- a, b coquinoid rudstone (a) and floatstone (b)
- boundstone (reef limestone)
- aphanitic lmst.

Bedding structures:

- horizontal bedding
- horizontal lamination
- limestone/marlstone interbedding (ratio ~1:1)
- wavy bedding
- cross-bedding
- nodular lmst. with thin clayey partings
- nodular lmst. with clayey intercalations
- seminodular lmst.
- marlstone with lmst. nodules
- hardground
- ripple marks
- mud cracks

Sandstones:

- in general
- calcitic
- dolomitic

Dolomites:

- in general
- argillaceous
- calcitic
- a, b silty (a), sandy (b)
- cavernous (porous) dolomite
- bioturbated argillaceous dolomite
- *Eurypterus*-dolomite
- cryptolaminated argillaceous dolomite
- reef dolomite
- breccia-dolomite

Marlstones:

- in general
- calcareous
- argillaceous
- dolomitic
- dolomitic, argillaceous

Domerites:

- in general
- calcareous
- argillaceous
- calcitic
- calcitic, argillaceous

Argillaceous rocks:

- clay
- mudstone
- a, b argillite (a), shale (b)
- calcitic mudstone
- dolomitic mudstone

Siltstones:

- in general
- calcitic
- dolomitic

Mineralogical and lithological characteristics:

- crystals of pyrite
- pyrite mottles
- pyritized skeletal detritus
- pyritized burrows
- pyritized pebbles
- phosphatic pebbles
- calcitic, phosphatic, goethitic } ooids
- glauconite
- silicification
- bitumen
- kerogen
- thin, thick } metabentonite layer
- intervals of red-colour rocks

Fossils:

- stromatolites
- oncolites
- calcareous algae
- sponges
- stromatoporoids
- tabulate corals
- rugose corals
- bryozoans
- brachiopods
- cephalopods
- tentaculitids
- gastropods
- bivalves (pelecypods)
- trilobites
- ostracodes
- eurypterids
- pelmatozoans
- graptolites
- vertebrates
- conodonts
- chitinozoans
- acritarchs
- horizontal, vertical } burrows

Fig. 3. Lithological legend to the logs of the outcrops and boring cores.

Distribution of rock types

A general review of the rock types and their distribution in the Ordovician and Silurian of Estonia has been given by Põlma (1982), Aaloe, Einasto, Jürgenson (1970) and Aaloe, Jürgenson (1977).

The lower part of the Ordovician - Pakerort and Varangu stages (= Tremadoc) considerably differs from the rest of the Ordovician and Silurian as it is represented by purely terrigenous sediments: arenaceous siltstones, fine-grained sandstones, dark kerogenous argillites and plastic clays being more closely related to underlying Cambrian strata. The sandstones contain lenticular interbeds of coquinite - obolus conglomerate, built of phosphatic shells of inarticulate brachiopods and used as raw material for the production of phosphate fertilizers.

The post-Tremadoc Ordovician is mainly represented by various limestones and marlstones. The marginal part of the sedimentary basin - the northern confacies belt, is dominated by micritic skeletal limestones (packstones and wackestones) associated with aphanitic, argillaceous and dolomitized limestones. In the Arenig and Llanvirn the limestones of the northern confacies belt (in places dolomitized) contain numerous impregnated hardgrounds, scattered pebbles, grains of glauconite, goethitic and francolithic ooids. The middle Ordovician (Llandeilo - lower Caradoc) is characterized by interlayers of volcanic ash (metabentonite) kerogenous limestone and oil shale (kukersite), the most important mineral resource in Estonia. In the upper Ordovician (upper Caradoc - Ashgill) some levels show also boundstones, skeletal, pelletal, oolitic and lithoclastic grainstones and rudstones; cyclic recurrence of aphanitic limestone formations in the section has been recorded.

In the deeper central or axial part of the basin during the post-Tremadoc Ordovician various marls are predominating, associated with argillaceous wackestones, argillaceous aphanitic limestones, and with dark kerogenous graptolitic argillites at some levels in the lower and upper Ordovician. In the lower Ordovician the rocks of the axial confacies belt are red-coloured due to the presence of dispersed hematite. Similar marine red-beds, however, occur in the upper Ordovician as well.

The Silurian rocks are commonly more variable than the Ordovician ones, mostly for the reason that several rock types absent or rarely occurring in the Ordovician (sedimentary or early diagenetic dolomites, various sparitic grain- and rudstones, graptolitic argillites and mudstones) are far more frequent in the Silurian. Thus, the shallow-water, marginal-marine sediments on the one hand and deeper-water rocks on the other hand, have gained more significance. This refers to a noticeably bigger lateral differentiation of sedimentation. The role of dolomite and clay components has increased considerably. Thicknesses of the Silurian sediments are much greater than in the Ordovician, this being indicative of more intense subsidence of the sea floor but also of the increased influx of terrigenous material and more rapid carbonate deposition. The first two phenomena were evidently caused by increased influence of tectonic movements in the Scandinavian Caledonides explained by gradual closure of the Iapetus Ocean. The growing rate of carbonate deposition was related to the drift of the Baltica continent from the moderate climate belt into tropics during the Ordovician (see Jaanusson, 1972; Scotese, 1986, etc.).

In the northern confacies belt of the basin a large variety of limestones, dolomites, marlstones and domerites was formed during the Silurian. At the regressive phases of the basin development (middle Llandovery, late Wenlock - early Ludlow) various rocks of marginal-marine genesis were widespread, including primary dolostones with mud cracks, microlaminated structures and stromatolites, skeletal and pelletal grainstones with ripple marks, cross bedding and graded bedding, lenses and banks of lithoclastic and coquinoid rudstone, organic build-ups.

During the Silurian transgression maximum (late Llandovery - early Wenlock) and at the periods of intense influx of terrigenous material (Pridoli) the northern confacies belt was dominated by marlstones and argillaceous limestones including skeletal marlstones. At the phases of relative stability the most common were nodular packstones and wackestones, in the early and middle Llandovery also aphanitic limestones. The cyclic alternation of the rock types in the sections is very common and especially well expressed in shallow-water sediments.

In the axial confacies belt of the basin graptolite-bearing grey, monotonous mudstones or dark brown kerogenous argillites predominate in the Silurian, only in the lowermost (lower Llandovery) and the uppermost (upper Ludlow-Pridoli) parts of the system there occurred almost barren calcareous mudstones, clays and marlstones, sometimes containing benthic shelly fauna. These types of rocks predominated during the whole Silurian also in the transition area from the northern to the axial confacies belt.

BASIN DEVELOPMENT AND FACIES MODELS

H. Nestor

The Early Paleozoic Baltic Basin has been considered as a typical cratonic sea, situated in the western part of the peneplained East-European Platform which represented an area of tectonical interaction of two neighbouring geosynclines: British-Scandinavian in the northwest and Middle European (Mediterranean) in the southwest; the latter's corresponding to the Iapetus and Rheic (Palaeo-Tethys) oceans, respectively.

In the early and middle Ordovician the southwestern part of the platform up to the area of the Moscow syneclise was slowly subsiding and was covered with shallow, epicontinental-type of sea with comparatively weak bathymetric differentiation. At the end of the Ordovician and mainly in the Silurian upheaval of the northwestern margin of the platform got dominance in connection with the closing of the Iapetus ocean. At the same time on the southwestern margin, belonging to the sphere of influence of Palaeo-Tethys, subsidence of the basin floor intensified. As a result of differential tectonic movements a comparatively deep, "starved" of sediments, intracratonic basin depression was formed within the limits of the axial confacies belt in West Latvia, West Lithuania, Kaliningrad district and North Poland, where hemipelagic argillaceous sediments accumulated. At the same time the sea gradually retreated from the northwestern and central parts of the platform and the basin evolved from epicontinental to a gulf-like pericontinental sea. As mentioned above, during the Silurian the influx of the clayey terrigenous material progressed from the direction of the Scandinavian Caledonides.

In a sedimentary basin the facies distribution may be generalized by means of facies models presenting lateral succession of the facies along the reconstructed bathymetric profile. For the Baltic Silurian basin a generalized facies model was worked out in the 1970s (Kaljo, ed., 1970; Einasto, Nestor, 1973; Nestor, Einasto, 1977, 1982). According to this basic model five main facies belts were distinguished: 1) tidal flat/lagoonal, 2) shoal, 3) open shelf, 4) transition (basin slope), 5) basin depression (Table 5). The first three facies belts formed a carbonate shelf or carbonate platform and two others a deeper basin with fine-terrigenous deposits.

Later R. Einasto (1986) worked out two modifications of the basic Silurian facies model: for the periods of weak and of intense supply with terrigenous material. It also became evident that the Silurian facies models are not applicable to the whole Ordovician, particularly to the interpretation of situations in the early and middle Ordovician which climatically and tectonically differed considerably from the late Ordovician and Silurian. As in the early and middle Ordovician carbonate accumulation took place in the conditions of the moderate climate, the main source of the carbonate was skeletal material and its production was extremely slow. Therefore, only a limited amount of loose skeleton particles lay on the sea floor. On the other hand, the wave action to the bottom was comparatively weak, because the waves subsided gradually in the shallow epeiric sea losing their energy before reaching near the shore. For these two circumstances presumably there did not form notable accumulations of winnowed skeletal sands (grainstones) characteristic of the shoal belt of the Silurian facies model. Typical lagoonal carbonate sediments were also lacking as evaporation was very weak. The position of the

Table 5. Facies belts and environments in the East Baltic Silurian basin (modified after Nestor and Einasto, 1977)

Main geomorphic units	Shelf (carbonate platform)			Deeper basin	
Type of sedimentation	Carbonate			Fine - terrigenous	
Facies belts	I Tidal flat/lagoonal	II Shoal	III Open shelf	IV Transition	V Depression
Lithogenetic types of sediments	Dolomicrites	Sparitic calcarenites	Micritic calcarenites	Calcareous mudstones	Mudstones
Hydrodynamic zones	Near-shore quiet-water	Agitated-water (high-energy, turbulent)	Quiet-water to storm-agitated (subturbulent)	Calm-water	Stagnant-water
Depositional environments	Tidal (mud)-flats, lagoons, restricted shelf	Shoals, reef belts, banks	Open shelf (platform)	Basin slope, shelf/basin transition	Basin depression
Characteristic rocks	Argillaceous dolomites and domerites (massive, laminated, bioturbated); dolomitic limestones, bioturbated marls	Skeletal, oolitic, oncolitic, pelletal grainstones, coguinoid bio- and lithoclastic rudstones; boundstones	Nodular skeletal packstones and wackestones; skeletal calcareous marls; aphanitic limestones	Argillaceous mares; calcareous mudstones, argillaceous aphanitic limestones	Mudstones, argillites, clays
Characteristic fossils	Burrows Stromatolites Eurypterids Agnathans Leperditids Scolecodonts Gastropods Lingulids	Stromatoporoids Corals Pelmatozoans Calcareous algae Oncolites Brachiopods Conodonts Vertebrates Bryozoans Bivalves	Brachiopods Pelmatozoans Ostracodes Burrows Corals Stromatoporoids Bryozoans Chitinozoans Conodonts Molluscs	Trilobites Pelmatozoans Burrows Chitinozoans Ostracodes Brachiopods Molluscs Conodonts Graptolites	Graptolites Chitinozoans Cephalopods Burrows Lingulids

lagoonal and shoal facies belts was probably occupied by the belt of nondeposition represented by a discontinuity surface (hardground). As mentioned above deeper, sediment-starved axial depression was not developed in the early and middle Ordovician. Taking into account the above-said, it is expedient to distinguish in the facies models of the early and middle Ordovician of the Baltic basin three facies belts: nondeposition belt, upper and lower ramp (Fig. 4).

Summing up, it is possible to distinguish five stages in the development of the Baltic post-Tremadoc Ordovician and Silurian basin which are characterized by different facies models (Figs 4, 5).

a) During the first - transgression stage (Arenig - Llanvirn) in the marginal part of the basin the deposition was very slow and with many gaps. Within the limits of the upper ramp micritic skeletal calcarenites accumulated, sometimes containing silt, scattered pebbles and abundantly glauconite grains, goethite and francolite ooids and impregnated hardgrounds. On the lower ramp, i.e. in the axial confacies belt, mainly red-coloured calcareous-argillaceous deposits (argillaceous limestones and marls) were formed. Thickness of the deposits of the lower ramp 2 to 10 times exceeded that of the contemporary upper ramp sediments.

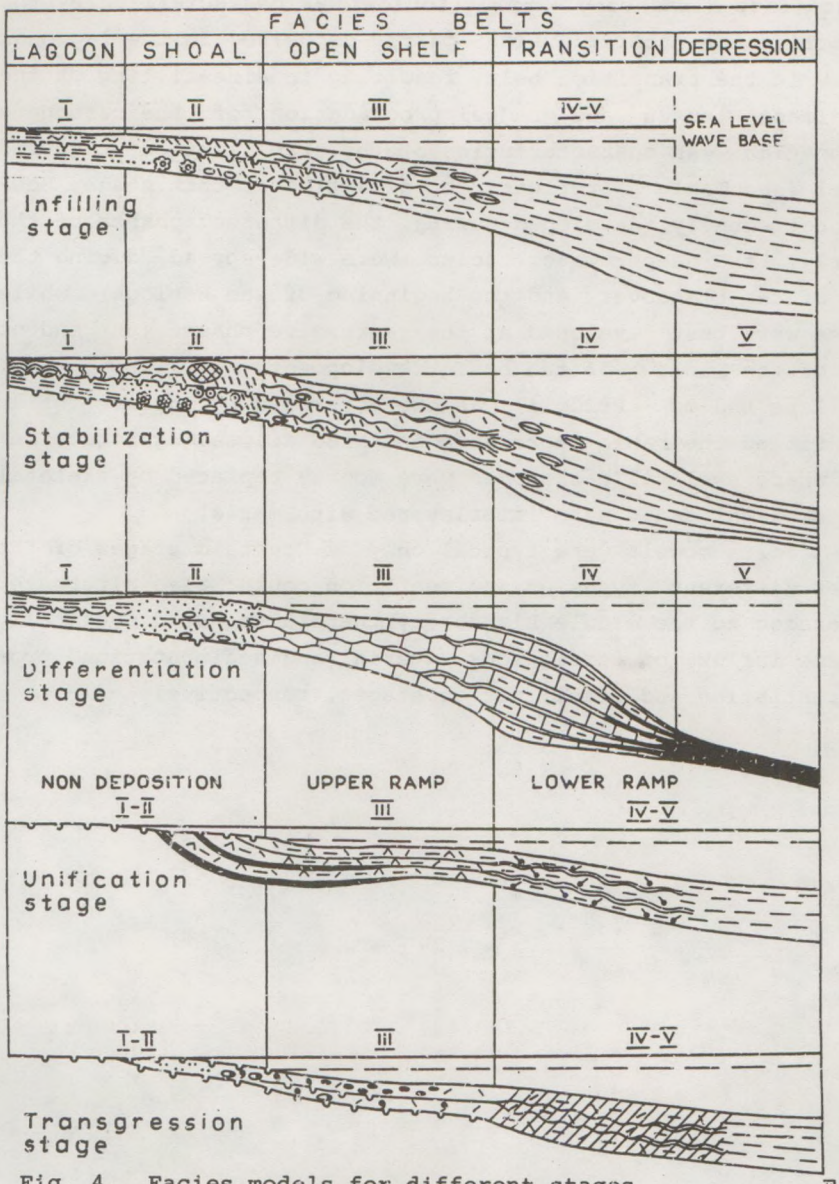


Fig. 4. Facies models for different stages of development of the post-Tremadoc Paleobaltic Basin.

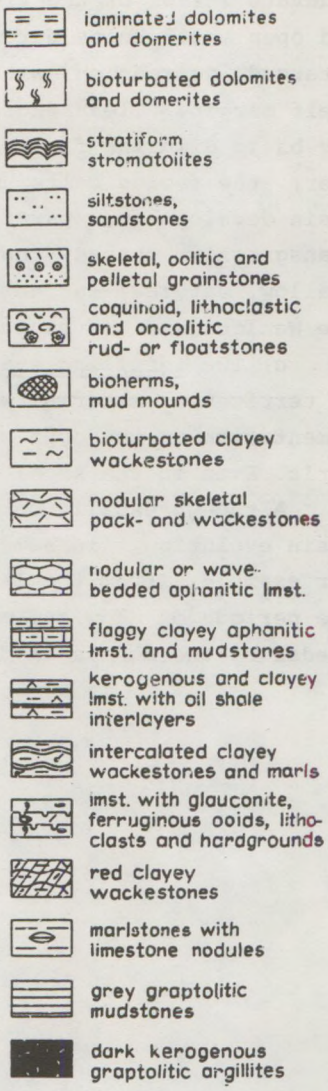


Fig. 5. Legend to the facies models (Fig. 4).

b) During the unification stage (Llandeilo - early Caradoc) along the whole extent of the bathymetric profile grey calcareous - argillaceous sediments (argillaceous limestones and marls) accumulated, although there remained the general trend for the increase of the clay component and decrease of the content of bioclasts in the offshore direction. Sediments of the upper ramp contained admixture of light brown kukersite kerogen and also pure kukersite interlayers. Interlayers of volcanic ash (metabentonite) were also characteristic of that stage of basin evolution.

c) During the differentiation stage (late Caradoc - middle Llandovery) a deeper axial depression was formed and typical of the Silurian facies zonation was developed. Influx of terrigenous material was periodically extremely low and comparatively pure calcareous muds were deposited at those periods on the open shelf and in the transition belt while in the basin depression condensed dark graptolitic argillites formed. Also an agitated-water shoal belt with pelletal and skeletal sands and lagoonal belt with dolomicritic sediments were developed.

d) The stabilization stage (late Llandovery - early Ludlow) was characterized by the moderate influx of the fine-terrigenous material which partly deposited in the lagoonal and open shelf belts but mostly in the transition belt, resulting in side-filling of the "starved" depression with sediment lenses and gradual progradation of the carbonate shelf margin. Clear facies zonation was characteristic of the stabilization stage and the basic Silurian facies model (see Table 5) reflects the situation of that stage. However, the facies belts were not equally developed during the different phases of the basin development, particularly, the deeper-water facies were wide-spread during the transgressive phases (the end of the Llandovery and the beginning of the Wenlock) while shallow, marginal-marine facies were best developed at the regressive phases (the end of the Wenlock and the beginning of the Ludlow) of the basin development.

c) The infilling stage (late Ludlow - Přídoli) was characterized by intense influx of terrigenous material which filled the basin depression and also diluted carbonate sedimentation on the open shelf where skeletal packstones were mostly replaced by skeletal marls. Even in the shoal belt skeletal sands were interlayered with marls.

Although usually certain facies models were typical only of certain stages of the basin evolution, in some cases different types of sedimentation could also alternate. For example, from the late Caradoc to the middle Llandovery there alternated cyclically the periods of low and moderate influx of terrigenous material and sedimentation proceeded by the models of differentiation and stabilization stages, respectively.

TREMADOC PHOSPHATE-BEARING ROCKS OF
NORTH ESTONIA AND SHELLY PHOSPHORITE

H. Heinsalu

Shelly phosphorite, also called Obolus phosphorite is one of the most important minerals of Estonia and interesting from the scientific viewpoint as well. This unique phosphorite is distributed in northern Estonia and Leningrad Region forming the early Tremadoc East Baltic phosphorite basin. The main resources occur in the western part of the basin, in the Rakvere area.

In North Estonia the phosphate-bearing rocks belong to the Kallavere Formation. Pakerort Regional Stage (see Table 1), mainly represented by monomineralic quartzose silty- and sandstones containing diverse fragments, more rarely complete phosphate shells of inarticulate brachiopods, mostly Schmidtites and Ungula. In some areas the concentration of brachiopod debris in the sandstone is very high and they form productive seams of phosphorite-bearing rocks. The brachiopod valves consist of fluor-carbonate-apatite with an admixture of clayey matter and fine scattered pyrite. The black colour of the valves is due to the latter. P_2O_5 concentration ranges from 35-37 per cent in the valves (Mustjõgi, 1984). In North Estonian sections Obolus sandstones are always associated with graptolitic argillites (Dictyonema shale), the latter may occur as thin interbeds in the sandstone, or as a thick overlying bed. Thickness of phosphate-bearing rocks in North Estonia ranges from about 20-30 cm to 20-23 m.

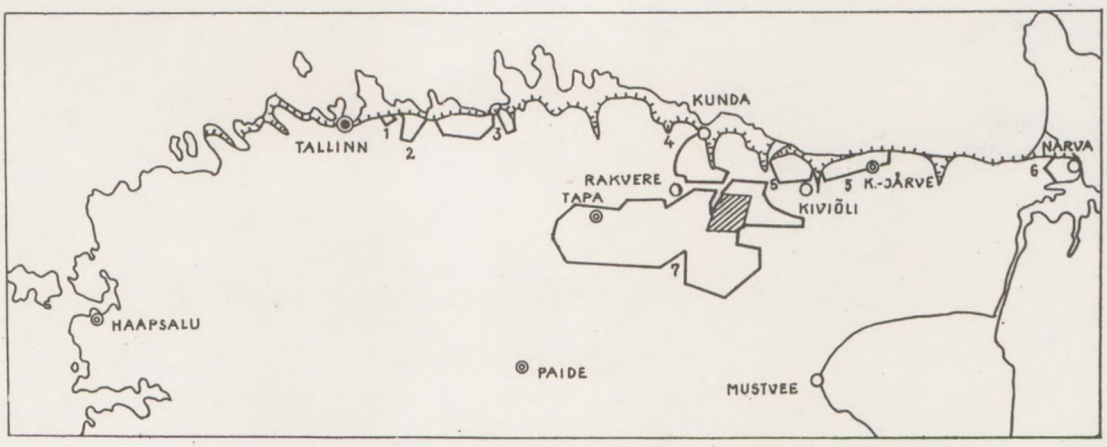


Fig. 6. Location of phosphorite deposits of Estonia. 1 - Maardu, 2 - Iru, 3 - Tsitre, 4 - Toolse, 5 - Aseri, 6 - Narva, 7 - Rakvere; striped area - Kabala district.

After 50 years of phosphorite studies the following deposits were established in North Estonia: Iru, Maardu, Tsitre, Toolse, Aseri, Narva and Rakvere (Fig. 6). All deposits, except Rakvere, are located in the North Estonia clint area where the phosphorite-bearing bed lies at a relatively small depth (max 25-45 m) and thus open-cast min-

ing is possible. Resources of most of these deposits are inconsiderable and for various reasons they have by now lost their commercial significance. Reserves of the Maardu deposit, the only deposit exploited in Estonia, are practically exhausted and the mine will be closed in the nearest future. More perspective deposits are only Toolse and Rakvere. However, before starting mining of phosphorites at these deposits new ecologically safe technologies must be elaborated. The most important limitations are danger of self-ignition of the overlying Dictyonema Shale and protection of groundwater in the mining course.

The phosphate-bearing rocks of the Kallavere Formation have a very complicated structure, being characterized by changeable lithologies, interrupted sedimentation and regional differences. This is reflected in the local stratigraphic chart where the Kallavere Formation is subdivided into 5 members (see Table 1 and Fig. 7). Biostratigraphic zonal boundaries, defined by conodonts and graptolites, almost always intersect with lithostratigraphic boundaries (Kaljo et al., 1986; Heinsalu et al., 1987).

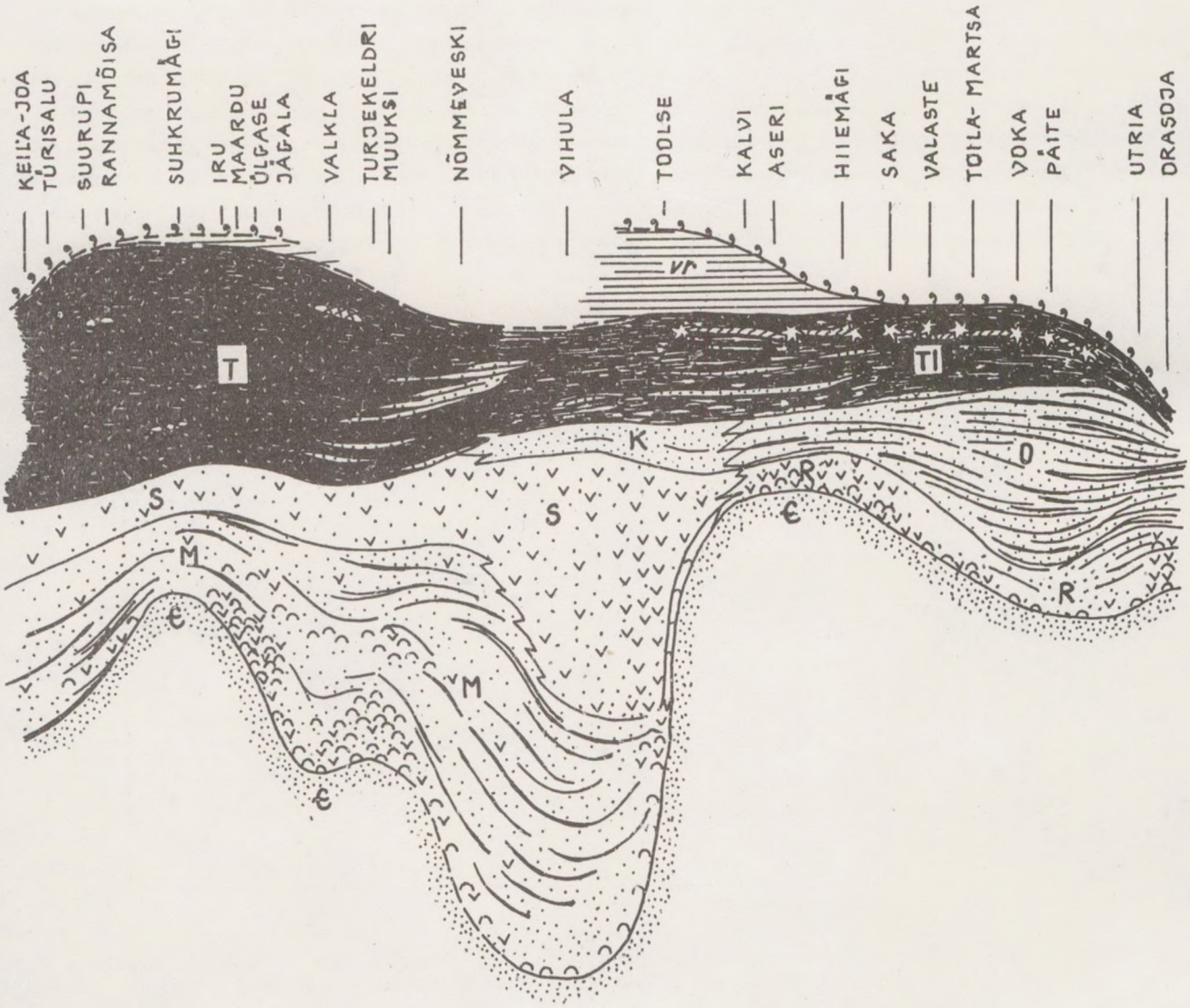


Fig. 7. Cross-section through the North Estonian Tremadoc outcrops.
Indices of the units: vr - Varangu Formation, T - Tabasalu Member, Tl - Toolse Member, K - Katela Member, S - Suurjõgi Member, M - Maardu Member, O - Orasoja Member, R - Rannu Member, Є - Cambrian.
For the lithological legend see Fig. 19.

Sections of the West-Estonian subregion are well observable at Ülgase (loc.1.1) and Maardu locality (1:2). Phosphorites occur here at two levels: mainly in the Maardu Member as "Obolus conglomerate" (thickness 0.3-2 m, P_2O_5 content - 6-23 %) and in the Suurjõgi Member as the bioclastic sandstone (thickness 0.4-1 m, P_2O_5 - content 3-10 %).

In the Toolse deposit phosphorite (average thickness 2.9 m, P_2O_5 content - 10 %) is mostly represented by bioclastic sandstones of the Suurjõgi Member.

The most variable is the structure of the Rakvere deposit, where the phosphorite lies at a depth of 50-200 m. The phosphorite-bearing rocks, belonging to the Rannu and Suurjõgi Members form a single commercial seam with the greatest thickness of about 12 m (average thickness about 4 m). In West-Kabala area the average thickness of the commercial seam exceeds 7 m, the mean P_2O_5 content is 14 %. In other areas of the Rakvere deposit these parameters are smaller. In the Rannu Member phosphorite is represented by brachiopod coquina ("Obolus conglomerate"), containing accumulations of fragments of brown thick-walled shells of inarticulate brachiopods occurring in varigrained quartzose, weakly cemented sandstone. Shell fragments differ in size, being often large (up to 2/3 and 3/4 of the whole shell), but complete shells are almost lacking. Phosphorite of the Suurjõgi Member is represented by skeletal varigrained (mostly medium-grained) quartzose sand. Skeletal debris is here always well-sorted, the grain size not exceeding 2-3 mm. Due to its light colour skeletal debris is often hardly distinguishable from quartz grains.

The sandy-silty phosphate-bearing sediments of Estonia were deposited during the early Ordovician transgression after a long continental period. Duration of this hiatus was different in certain areas of the basin.

Sedimentation took place in shallow sea with the differentiated bottom relief. Already small changes caused variability in facies. Thus, in relatively elevated, high-energy areas sediments were coarse-grained, containing abundantly phosphate-bearing skeletal debris of brachiopods, in the lowered bottom the siltstones with interbeds of kerogenous muds (Dictyonema shales) were formed.

GEOLOGY OF THE BALTIC OIL SHALE BASIN

H. Bauert and V. Puura

Introduction

The Baltic Oil Shale Basin is situated in the northern part of Estonia and in the western part of the Leningrad District of the Russian SFSR. It underlies an area of over 50,000 sq km. The Baltic basin is divided into the Estonian and Leningrad fields, comprising three large deposits, from which the Estonia and Leningrad deposits are exploited, and the Tapa one is considered as prospective (Fig. 8).

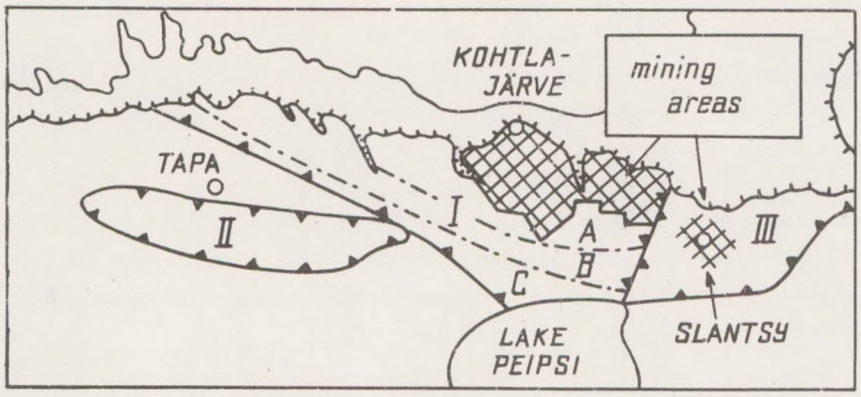


Fig. 8
Location of oil shale deposits (I - Estonia, II - Tapa and III - Leningrad) with commercial zonation of the Estonia deposit (A - commercial, B - subeconomic, C - distal). For legend see Fig. 5.

The northern border of the Estonia field is erosional, while the western and southern borders are delineated by the vanishing of organic matter (OM). The eastern border conventionally coincides with the Narva River.

The Estonian field is the largest explored and commercially exploited deposit of oil shale in the world. It contains over 60 % of explored reserves and is responsible for more than 80 % of the total USSR output (Kattai, Puura, 1988). The total explored reserves exceed 6.6 billion tons (Knutson et al., 1989). The Estonia deposit has been exploited since 1916, and the total output exceeds 770 million tons of shale. It is subdivided into three economic regions (Kattai, Puura, 1988): A - central commercial (exploited at present) with explored reserves for the next 40-50 years (at the production rate of 25-30 million tons/year); B - subeconomic part adjacent to the central region; C - distal marginal part (Fig. 8). At present, 6 underground mines and 3 open-pit mines are in operation, with total shale production of about 23 million tons/year (max was in 1985 - 31.6 tons/year). A little less than 50 % is produced by open-pit methods. All the operating mines are located in NE Estonia - i.e. in the central and eastern parts of the deposit (Fig. 8). In this area the overburden ranges 0-70 m due to the gentle southward dip of Ordovician strata.

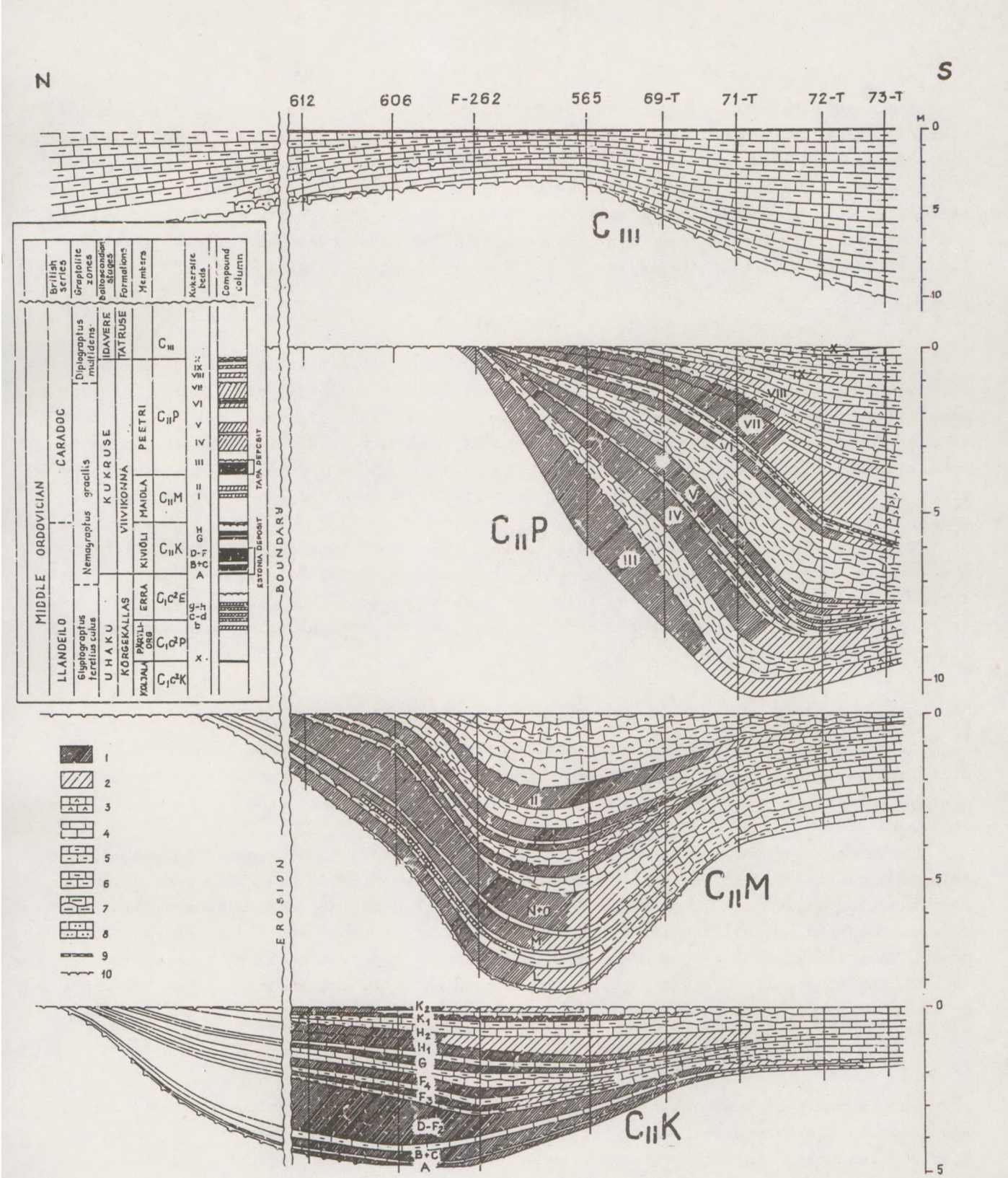


Fig. 9. Regressive succession of the Kiviõli, Maidla and Peetri Members (Viivikonna Formation, Kukruse Stage) overlain by the transgressive Idavere Stage in the meridional cross-section of the Baltic Oil Shale Basin (for location see Fig. 11) and Middle Ordovician stratigraphy for the kukersite-bearing succession (on the left). 1 - kukersite with nodules of kerogen-rich biomicritic limestone or kerogen-rich limestone with wavy kukersite layers; 2 - kerogen-lean biomicritic limestone with thin kukersite layers and lenses; 3 - grey biomicritic limestone with thin kukersite layers and lenses; 4-8 - biomicritic limestone: grey, pure (4); greenish-grey, slightly (5) and medium argillaceous (6); greyish-green, highly argillaceous, wavy-bedded to nodular (7); arenaceous (8); 9 - K - bentonite layer; 10 - discontinuity surface.

Stratigraphy

The main kukersite formation of the Baltic Oil Shale Basin is of early Middle Ordovician (Llandeilo - early Caradoc) age (Fig. 9), although it should be noticed that minor occurrences of kukersite-type OM are recorded throughout the Ordovician sequence (Põlma, 1982). The main kukersite accumulation took place during the late Uhaku - Kukruse ages and is lithostratigraphically restricted to the upper part of the Kõrgekallas and the entire Viivikonna Formations. According to the Baltoscandian graptolite zonation, it corresponds to the *Nemagraptus gracilis* Zone (Männil, 1989).

Lithology

The kukersite-bearing succession contains up to 50 intercalating kukersite and kerogenous limestone seams that are mostly alternating with variously argillaceous grey or greenish-grey limestone beds and in some cases with greenish marlstone beds. In the area of max development (NE Estonia) its thickness may reach up to 25-30 m. The thickness of kukersite-bearing seams ranges from 0.01 to 2.4 m. Of commercial value are only the group of seams A-F_2 (Estonia and Leningrad deposits) and seam III (unexploited Tapa deposit).

The texture of individual kukersite seams is rather complicated. Usually, in the area of max development they have a nodular texture, comprising various amounts of kerogenous limestone nodules and few interbeds, while towards the distal part (with decreasing OM content) they are represented by kerogenous limestone with thin wavy kukersite layers and/or lenses.

Organic matter

OM may occur dispersed in the mineral matrix or concentrated into individual kukersite layers, where its content reaches up to 60 wt % (~ 75 vol %) of the whole rock. Average values for productive seams of the Estonia deposit are ranging between 20-60 wt %.

The organic matter of kukersite is of yellowish-brown to dark-brown colour, containing alginite A, with the size of algal remains between 10-40 m. The morphologically recognizable individual colonies of these algae were described by Zalessky (1916) as *Gloeocapsamorpha prisca*, due to the morphological similarity to the living genus *Gloeocapsa*. These similarities have been also confirmed by quite recent SEM studies (Burns, 1982). The disorganized and/or aggregated, morphologically indistinct part of kukersite OM seems to be of cyanobacterial origin (Kõrts et al., in press).

Mineralogy

On the basis of semi-quantitative x-ray diffractometry, the following rock-forming minerals in the kukersite-bearing succession were determined: calcite, dolomite, quartz, feldspar, illite, chlorite and pyrite. The dominating carbonate mineral is low-Mg calcite (average content for kukersite seams - 45 %), forming fossils and micrite. Void filling spar is very rare. Dolomite occurs in subordinate amounts. Usually, the content of it does not exceed 10 %, but close to deep faults it has often replaced nearly all the calcite. The terrigenous component is mainly represented by silt-size quartz (5-10 %) and with rather negligible amounts of feldspar (2-3 %). The latter was identified mostly as orthoclase. Among clay the minerals well-ordered illite is dominant (5-10 %) with traces of chlorite. As for pyrite, the content in kukersites and kerogenous limestones is very low ($<$ 2 %).

Mineralogical variations in the Viivikonna Formation are depicted in Fig. 10, based on data from borehole K-7 (central part of the Estonia deposit).

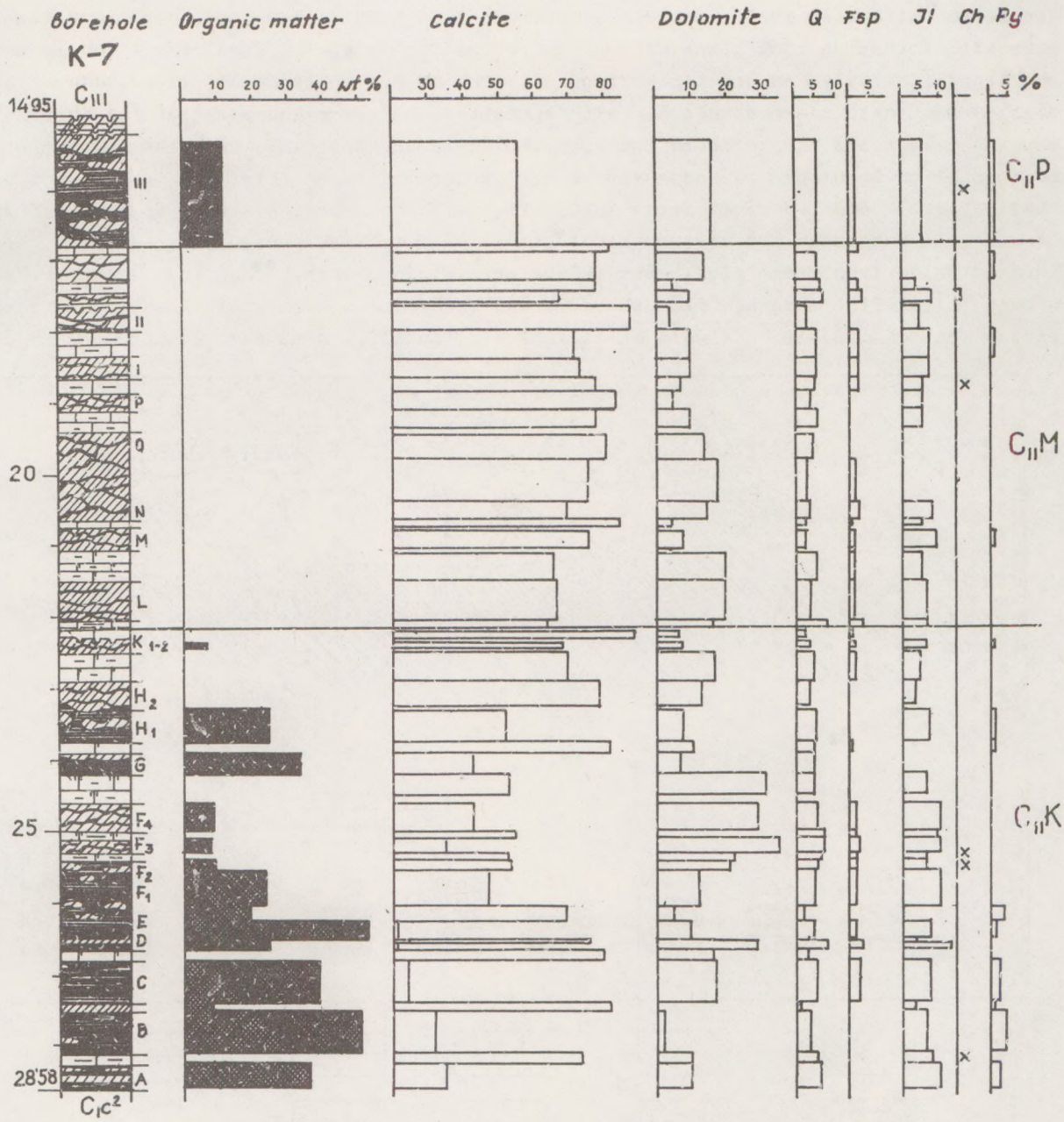


Fig. 10. The distribution of rock-forming minerals in the Viivikonna Formation (boring K-7; central part of the Estonia deposit) by semiquantitative X-ray diffractometry. For legend see Fig. 11.

Trace elements

There are no signs of metal enrichment in kukersites as observed in the Alum Shale and the Tremadoc Dictyonema Shales in the Baltoscandian region. In kukersites, the average content of V, Ni and U are even below the published estimates of these elemental abundances in shale (Vinogradov, 1962) and similar to that of carbonate rocks (Turekian and Wedepohl, 1961). Concentrations similar to average shale are reported for As, Mo, Pb, Ag and Au (Pets et al., 1985).

Conditions of kukersite formation

In the early Middle Ordovician the Baltoscandian epicontinental sea was the site of deposition of a relatively monotonous succession of bedded limestones. The main phase of kukersite formation took place during the regressive stage of development of the sea in the Llandeilo-early Caradoc time (Fig. 9). The OM of kukersite-type accumulated in a shallow subtidal regressive sea, with successive beds forming a pattern of rather narrow, east-westward extending belts. From the north and obviously from the west, the depositional environment was adjacent to the hardground area (Fig. 11; see also Bauert, 1989; Fig. 1 and Puura et al., 1988; Fig. 4). Considering the spatial distribution of kukersite and its chemical stability, it is supposed that most of the kukersite OM derived from algal mats (Kõrts et al., in press), covering extensive hardground (tidal flat) areas, from where it was transported to a shallow subtidal tranquil environment of deposition (Puura et al., 1988). Locally, some hard grounds bear evidence

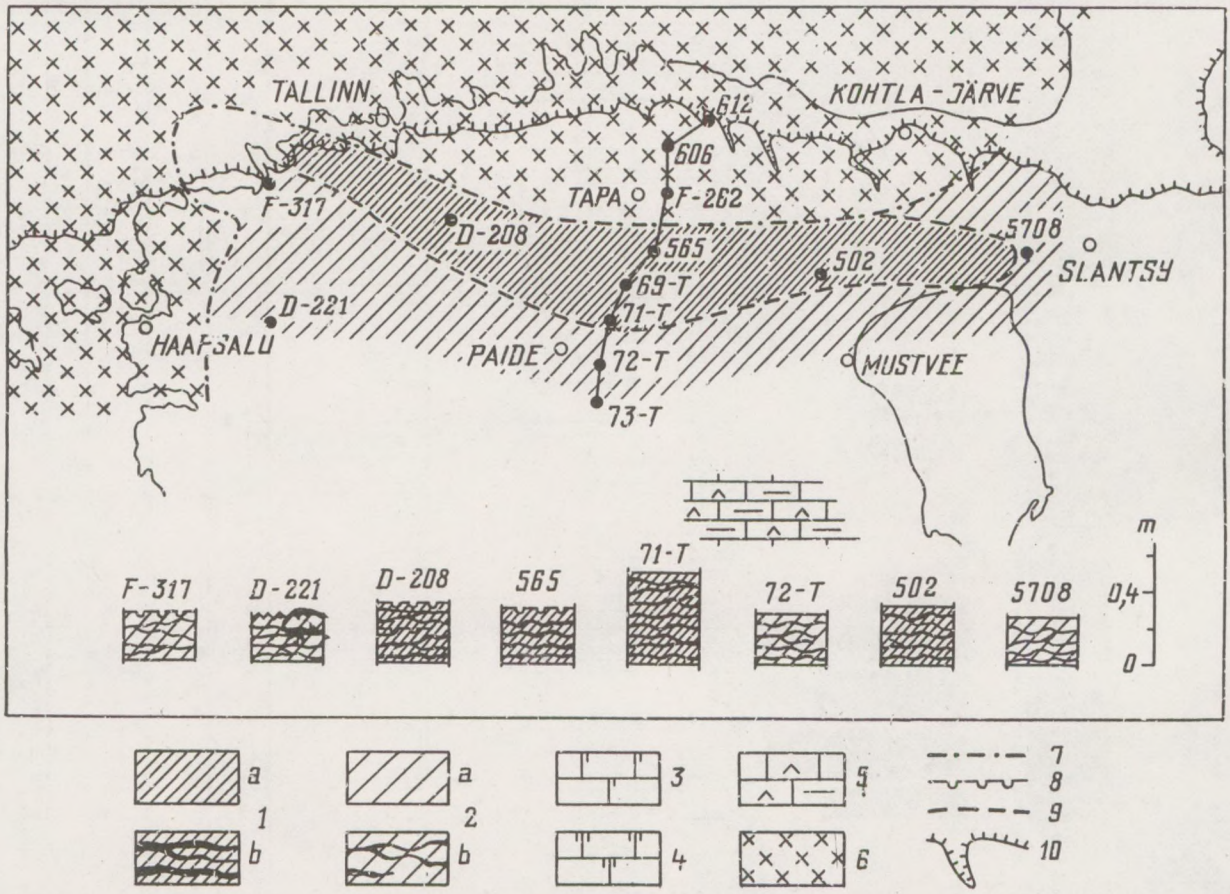


Fig. 11. Facies sketch-maps for kukersite seam VI. 1 - kerogen-rich limestone with wavy kukersite layers (a - in facies maps; b - in columns); 2 - kerogen-lean limestone with thin kukersite layers and lenses; 3-4 - limestone, slightly dolomitic (3) or dolomitic (4); 5 - grey, highly argillaceous limestone with thin kukersite layers and lenses; 6-7 - non-deposition area (= hardground) and its supposed boundary; 8 - discontinuity surface (= hardground); 9 - facies boundaries; 10 - recent erosional boundary of the Kukruse Stage.

of subaerial exposure (Bauert, 1989). As there are no signs of scouring in the kukersite formation, it may be concluded that the influence of bottom currents was negligible. The lack of tempestites in the sedimentary record indicates mild climatic conditions for this region in the early Middle Ordovician.

Judging from the isotopic data and from the nature of the host carbonate rock (lack of warm-water bahamitic carbonates and kaolinite) it seems plausible to suggest deposi-

tion in a cool-water environment (see discussion in Lindström, 1984). The relatively high latitude position (60° S) for Baltoscandia is indirectly supported also by palaeomagnetic data (Noltimier and Bergström, 1976), although this data is still somewhat contradictory (Webby, 1984).

The existence in the oil shale of a rich and diverse normal marine bottom fauna (more than 300 species recorded - Rõõmusoks, 1970; p. 172) with very low pyrite content suggests the absence of anoxic conditions in the bottom waters.

B I O S T R A T I G R A P H Y

STROMATOPOROIDS

H. Nestor

The Baltic area offers good opportunities for elaborating a regional standard for stromatoporoid stratigraphy due to relatively detailed researches on both sides of the Baltic Sea (Riabinin, 1951; Nestor, 1964, 1966, 1970, 1979, 1982; Mori, 1968, 1969, 1970).

Due to their relatively narrow ecological ranges stromatoporoids are distributed in Ordovician and Silurian rocks rather unevenly. The richest and the most diverse stromatoporoid association occurs in the sediments of the high-energy shoal facies belt represented by coral-stromatoporoid boundstones, skeletal and coquinoid grainstones and rudstones (Nestor, 1977). Stromatoporoids are rather numerous also in the deposits of moderate- to low-energy open shelf facies belt (in nodular skeletal packstones) although there they are less varied than in shoal facies.

Rare stromatoporoids may also occur at the periphery of lagoonal (restricted shelf) and transition facies belts adjacent to the shoal and open shelf correspondingly. They form there impoverished and rather long-ranging communities, such as *Araneosustroma stelliparratum*, *Forolinia brevis*, *"Pycnodictyon" densum* communities (Table 6).

Parallel successions of communities may also be distinguished for shoal and open shelf environments although these lateral communities of stromatoporoids are rather badly delimited. Usually there exsists a certain assemblage of species with a comparatively wide ecological range occurring both in shoal and open shelf facies. For example, such species are *Clathrodictyon boreale* and *Ecclimadictyon microvesiculosum* in the lower Llandovery, *Densastroma pexium* and *"Simplexodictyon" simplex* in the lower Wenlock, *Parallelostroma typicum* and *Lophiostroma schmidtii* in the Ludlow. As a rule, the same species have a comparatively wide stratigraphical range too. Such assemblages of species dominate on the open shelf environments although their representatives spread also into shoal facies. In the latter some more specialized forms are added which have relatively narrow spatial and stratigraphical ranges. These species make possible a more detailed biostratigraphic zonation of the rocks of the shoal facies belt in comparison with the open shelf facies.

Parallel successions of stromatoporoid communities in different facies of the Baltic Ordovician and Silurian are shown in Table 6 (see also Pl. 1). The full list of species in these communities is presented in Table 7. The latter table mostly includes data from the outcrops and borings in Middle Estonia and Saaremaa Island. *Labechia conferta* and *Parallelostroma tenellum* communities have not been established in Estonian sections and their species list is given by the Gotland sequence - by the Halla and Klinsteberg formations correspondingly. The *Plexodictyon? irregulare* Community is also unknown in the outcrop area of Estonia and it spreads in the Ventspils Formation in Latvia and in the Öved Ramsåsa Group of Scania. The deeper-water *"Pycnodictyon"* densum community is established in some Latvian and Lithuanian borings and in Mulde and Hemse marls of Gotland.

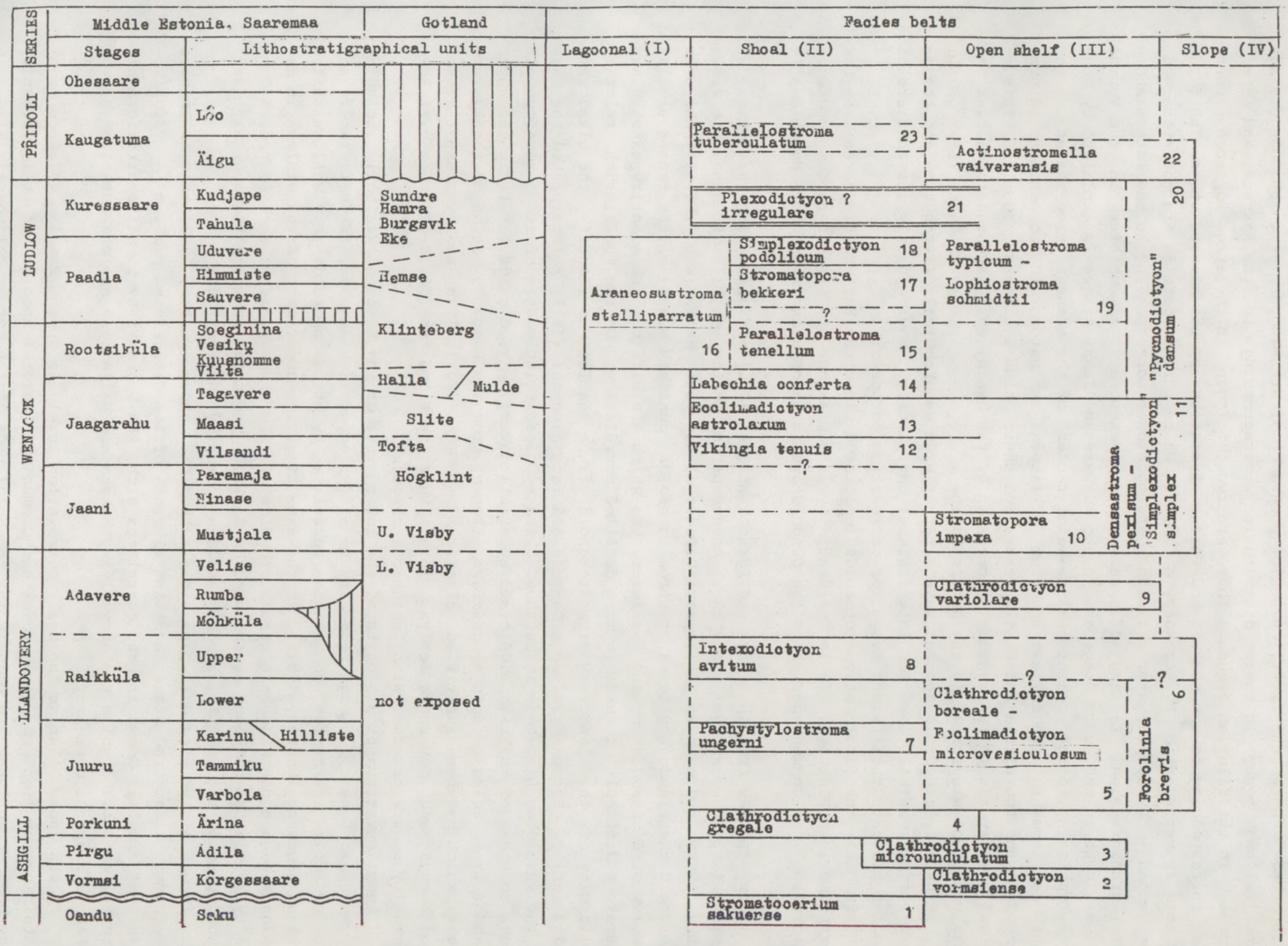


Table 6. Community successions of the Baltic Ordovician and Silurian stromatoporoids

Table 6 shows that not all stratigraphical levels are equally represented by stromatoporoids. After the first, episodic appearance of stromatoporoids in the Oandu Stage there follows a gap in their distribution corresponding to the Rakvere and Nabala stages. In the Silurian sequence there are two total gaps in the stromatoporoid succession corresponding to the Mõnküla and Velise formations of the Adavere Stage. The first of them is represented by secondary dolomites where stromatoporoids are not preserved, the second - by deeper-water marlstones and mudstones corresponding to the late Llandovery transgression. Lacking of shoalwater stromatoporoid communities in the Vormsi Stage, lower in the Juuru Stage and in the Adavere and Jaani stages is explained by non-preservation up to the present shallow-water facies of the transgressive phases of the basin development. The fullest spectrum of lateral stromatoporoid communities is preserved in the Rootsiküla and Paadla stages and their time analogues on Gotland. This interval corresponds to the maximum regression of the basin, when lagoonal/tidal flat facies were most widespread in the Baltic Basin.

Many stromatoporoid species have a rather wide geographical distribution and therefore offer possibilities for interregional correlation. Nowadays only uneven state of studies prevents their wider usage for correlation purposes.

Probably the first stromatoporoids immigrated into the East Baltic area from the North American Platform. It is evidenced by the presence of *Stromatocerium canadense* (Nicholson), a common species to the Oandu Stage in Estonia and Trenton in North America.

Some species from the Pirgu and Porkuni stages (*Clathrodictyon microundulatum, C. mammillatum, E. koigiense*) have their counterparts in the Ashgill of China (Lin Baoyu, Webby, 1988) and even in the topmost Caradoc of New South Wales (Webby, 1969). All over the world the Llandovery fauna of stromatoporoids consists mostly of the rather similar species of *Clathrodictyon* and *Ecclimadictyon* which are difficult to identify exactly and therefore difficult to use in more detailed correlation. On the whole, such relative uniformity of the Llandovery stromatoporoid fauna enables to identify the Llandovery quite easily. For example, Dong De-yuan and Yang Jing-zhi (1978) reinterpreted the age of the Shiniulan Limestone in Guizhou, China by close relationship of its stromatoporoid fauna to these of Estonian middle and upper Llandovery. A good guide fossil in the upper Llandovery is *Clathrodictyon variolare* (Rosen) from the Rumba Formation of the Adavere Stage, which has been identified also from Norway (Mori, 1978) and by present author from Novaya and Severnaya Zemlya. In all these sections the *Clathrodictyon variolare* Community occurs together with *Pentamerus oblongus*.

Local stratigraphical units of the lower part of the Estonian Wenlock, including *Stromatopora impexa, Densastroma pexisum - Simplexodictyon simplex, Vikingia tenuis* and *Ecclimadictyon astrolaxum* communities correlate by stromatoporoids very well with the Gotland sequence (Nestor, 1982). At the same time, the upper part of the Wenlock in Estonian sequence contains rare stromatoporoids of the *Araneosustroma stelliparratum* Community which has not been established on Gotland. There the same stratigraphical level is occupied by the *Parallelostroma tenellum* Community (Nestor, 1982).

In one of the previous papers the author has shown (Nestor, 1982) that in Podolia the former Kitaigorod Stage contains elements of the *Densastroma pexisum - "Simplexodictyon" simplex* Community and correlates with the Upper Visby to Slite stratigraphic interval on Gotland while the above-lying Muksha and Halla beds are characterized by the *Labechia conferta* Community.

In the upper Silurian the best correlation level is upper Paadla (Uduvere beds) containing the *Simplexodictyon podolicum* Community. Several species of this community have been established in Podolia in the Sokol beds of the former Malinovetsk Stage, in the Hemse Group of Gotland (Nestor, 1966) and in the Hatanzei Formation of Novaya Zemlya (Nestor, 1981).

Table 7. Taxonomical constitution of stromatoporoid communities in East Baltic

Species	Community numbers according to Table 6																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Labechiida																							
Stromatocerium canadense (Nich.)	+		+																				
S. sakuense Nestor	o																						
Cystostroma estoniense Nestor			+																				
Plumatalinia ferax Nestor			+																				
Pachystylostroma fragosum Nestor				+																			
P. rosensteinae Nestor					+																		
P. contractum Nestor					+																		
P. ungerni (Rosen)							o																
P. exile Nestor							+																
P. hillistense Nestor							+																
P. estoniense Nestor								+															
P. opiparum Nestor								+															
P. sp																		+					+
Forolinia brevis Nestor						o																	
F. lineata Nestor							?																
F. implana Nestor								+															
F. paka Nestor								+															
F. pachyphylla (Nicholson)									+														
Labechia venusta Yavorsky					+																		
L. conferta Lonsdale														o									
Rosenella dentata (Rosen)									+														
R. tuberculata Riabinin									+														
Lophiostromatida																							
Lophiostroma schmidtii (Nich.)																	+	+	o		+		
Clathrodictyida																							
Clathrodictyon vormsiense Riab.		o																					
C. microundulatum Nestor			o																				
C. mammillatum (Schmidt)				+																			
C. gregale Nestor				o																			
C. zonatum Nestor				+																			
C. boreale Riab.					o		+																
C. sulevi Nestor					+		+																
C. kudriavzevi Riab.					+		+				+	+											
C. demissum Nestor					?		+																
C. lennuki Nestor					+		+																
C. sarvense Nestor							?																
C. turritum Nestor					+			+															
C. clivosum Nestor									+														
C. variolare (Rosen)									o														
C. delicatulum Nestor									+														
C. conodigitatum Riab.									+														
C. regulare (Rosen)									+														
C. adaverense Riab.									+														
C. densatum Yav.									+														

Species	Community numbers according to Table 6																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
C. affabile Nestor										+													
C. linnarssoni Nich.										+													
C. vesiculosum Nich.														+									
C. mohicanum Nestor																	+						
Ecclimadictyon porkuni (Riab.)				+	+		+																
E. koigiense Nestor				+																			
E. microvesiculosum (Riab.)					o																		
E. macrotuberculatum (Riab.)					+		+				?	+	+										
E. nikitini (Riab.)					+		+																
E. laminaeungulatum (Riab.)					+		+																
Ecclimadictyon microfastigiatum (R.)					+		+		+														
E. pandum Nestor							+																
E. éx gr. cylindriforme (Riab.)								+															
E. fastigiatum (Nich.)									+														
E. arcuatum Nestor									+														
E. robustum Nestor													+										
E. astrolaxum Nestor													o										
E. aff. robustum Nestor																+					+		
Indexodictyon avitum Nestor								o	?														
I. olevi Nestor								+															
Oslodictyon suevicum (Nich.)									+														
O. aff. lepidum (Mori)																					+		
"Simplexodictyon" simplex Nestor										+	o		+										
S. validum (Nestor)													+										
S. podolicum (Yav.)																		o					
"S." convictum (Yav.)																		+	+				
"S." cf. pseudoconvictum Stock																				+			
Actinodictyon nestori Mori												+											
A. cf. quebecense Hubert et Stearn																		+					
Plexodictyon katriense Nestor																		+	+				
P.? irregulare (Mori)																					o		
P. densum (Yav.)																					+		
Clathrodictyella sp.																		+					
Actinostromatida																							
Plectostroma necopinatum Nestor							+																
P. intermedium (Yav.)																	+	+					
P. mirificum Nestor																		+					
P. schmidtii (Rosen)																							+
Densastroma pexisum (Yav.)										+	o												
D. podolicum (Yav.)																+	+	+	+		+		
Densastroma himmestum (Riab.)																	+	+	+		+		
D. astroites (Rosen)																							+
"Pseudolabechia" elegans (Rosen)									+														
"Pseudolabechia" hesslandi Mori										+	?												
Pseudolabechia granulata Yabe et Sug.																		+					
Vikingia vikingi (Nestor)												+											

Species	Community numbers according to Table 6																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
V. tenuis Nestor												+											
Araneosustroma stelliparratum Nestor																o		+					
"Pycnodictyon" densum Mori																				o			
Actinostromella vaiverensis Nestor																						o	
Stromatoporida																							
Stromatopora impexa Nestor										o													
S. antiqua (Nich.)														+									
S. bekkeri Nestor																	o						
S. lamellosa Riab.																	+						
S. clarkei Parks																					+		
Syringostromella tenerrima Mori													+										
S. borealis (Nich.)																		+					
Parallelostroma tenellum Mori															o								
P. typicum (Rosen)																			o				
P. cf. dnestriense (Riab.)																				+			
P. minosi Nestor																							+
P. tuberculatum (Yav.)																							o
"Parallelopora" ornata Mori																			+		?		

o - index species

CORALS

D. Kaljo

The Ordovician and Silurian of Estonia are rich in corals. The most considerable studies in this field have been performed by W. Dybowski (1873-1874) on rugose corals and by B.S. Sokolov (1951 et al.) and E. Klaamann (1959et al.) on tabulate corals. In the result of these and also several other studies more than 300 species have been identified, two-thirds of which make up tabulate corals.

Tabulate corals

The review is based on the publications by E. Klaamann (op.cit.).

The earliest tabulate corals in the Estonian Ordovician are known from the upper Caradoc Oandu Stage: *Lyopora tulaensis* Sokolov, *Saffordophyllum grande* (Sok.) and *Eofletscheria orvikui* (Sok.) occur rather frequently in Vasalemma reef facies. The last species is identified also from Mjösa and Encrinite Limestones in Norway.

In the Rakvere and Nabala Stages there occur only a few tabulate corals - *Sarcinulá rakverense* in the first one and *Catenipora obliqua* (Fischer-Benzon) in the latter.

The first rare members of the late Ordovician tabulate assemblage (*Palaeofavosites schmidti* Sok., *Catenipora wrighti* Klaamann e.a.) appeared in the Vormsi Stage.

In the Pirgu time tabulate corals gained abundance, some of them, e.g. *Eocatenipora parallela* (Schmidt), *Cryptolichenaria multiplex* Klaamann occurred only in reefs, outside them *Palaeofavosites* aff. *alveolaris* (Goldfuss), *Catenipora tapiensis* (Sok.) e.a. For Porkuni tabulate assemblage is characteristic occurrence of several s.c. Ordovician relicts, e.g. *Rhabdotetradium frutex* Klaamann and *Porkunites amalloides* (Dybowski), but beside numerous *Palaeofavosites* species also appearance of new evolutionary lineages, e.g. *Mesofavosites dualis* Sokolov and *Priscosolenia prisca* (Sok.). Well known is that in Porkuni where often very big colonies occur.

The distribution of Silurian tabulate corals has been repeatedly treated by E. Klaamann (1982, 1986, in Kaljo, ed., 1970, etc.), therefore in this review only two summarizing tables are given. The Table 8 provides all necessary information about the stratigraphic position of tabulate communities and their relations with facies belts. The supplementary data for this table showing the composition and abundance of species in communities, can be found in the paper of E. Klaamann, referred at in the explanation to the textfigure.

The possible correlations with the neighbouring areas on the basis of the distribution of tabulates are given in Table 9, taken from a publication by E. Klaamann (1982).

To sum up, we can say that tabulates constitute a very valuable group for the facies analysis and stratigraphy of sedimentary rocks of the shelf carbonate platform and even for interregional correlation.

Table 8. Succession of tabulate coral communities in the East Baltic Silurian (from Klaamann, 1986)

Series	Regio-stage	Lagoon	Shoal inner	Shoal outer	Open shelf	Transition	Dep-ression
Pridoli	K_4		Favosites ohesaarensis - F. effusus				No tabulate corals
	K_3b		Syringopora blanda Favosites muratsiensis		„F." eichwaldi		
Ludlow	K_3a		„Paleofavosites" moribundus Favosites forbesi				
	K_2		Laceripora cribrosa-Parastriatopora coreaniformis		Dnestrites	Halysites laticatenatus-Favosites gothlandicus	
			Thecia swindereniana-Favosites subgothlandicus		Halysites crassus		
Wenlock	K_1	Parastriatopora commutabilis	Paleofavosites tersus-Halysites klintebergensis Paleofavosites asper			Favosites gothlandicus	
	J_2	Riphaeolites lamelliformis	Halysites junior-Paleofavosites tersus Favosites mirandus				
	J_1		Halysites senior				
Llandovery	H				Angopora hisingeri		
			Mesofavosites obliquus - Favosites favosus				
	G_3		Parastriatopora celebrata				
	G_{I-II}		Paleofavosites karinuensis Mesofavosites fleximurinus - Paleofavosites paulus	Acidolites lateseptatus	Catenipora martinssoni		

Table 9. Succession of tabulate coral communities in the Wenlock-Ludlow boundary interval in the Gotland and East Baltic area (from Klaamann, 1982)

	GOTLAND					EAST BALTIC	
LUDLOW	HEMSE		crassus	lamelliformis coreaniformis-pseudoforbesi		K_2U	PAADLA
					No corals	K_2H	
				swindereniana		K_2S	
WENLOCK	MULDE	KLINTEBERG	laticatenatus gothlandicus	tersus-klintebergensis	commutabilis	K_1Sn	ROOTSIKÜLA
						K_1Vs	
		c		asper		K_1Kn	
						K_1Vt	
	HALLA	b		priva	lamelliformis	J_2T	JAAGARAHU
		a		junior		J_2M	
	SLITE	c				J_2V	

Rugose corals

These corals are considerably less studied, therefore biozonal and community analyses are premature. More or less complete lists and data on the distribution have been published some time ago (Kaljo, 1961, 1970) but are applicable also now, if to consider also more recent taxonomic revisions (especially Neuman, 1969; Weyer, 1973, 1982, etc.).

The first distinctly rugose corals appeared in the Middle Ordovician. In Estonia they are represented by *Primitophyllum primum* Kaljo and *Lambelasma dybowskii* (Kaljo), occurring in the Jõhvi Stage and undoubtedly belonging to the most primitive tetracorals. In the Keila Stage *Kenophyllum sociale* (Kaljo) and *Streptelasma oanduensis* (Kaljo) make their appearance, but they are rather rare.

Rugose corals are scarce also in the Oandu Stage, although their diversity is already comparatively high, especially for the middle Ordovician. Here occur *Kenophyllum reimani* (Kaljo), *Streptelasma concavum* (Kaljo), *S. fervida* (Kaljo), *Borelasma orientalis* (Kaljo) and *Estonielasma? praecox* (Kaljo).

The first *Grewingkia lutkevitchi* Reiman appeared at the end of the middle Ordovician (Rakvere Stage).

The purpose of the above fairly detailed account of the middle Ordovician rugose corals of Estonia was to demonstrate the high rate of formation of a considerably diverse fauna: the first primitive forms appeared in the *Diplograptus multidens* Zone, whereas the whole above-described assemblage was present already in the next zone. To a certain extent the result in Estonia was influenced by migration, but we have to keep in mind that this short period was the initial stage of evolution of the whole group of rugose corals.

The late Ordovician was mostly dominated by streptelasmatids (*Kenophyllum, Streptelasma, Grewingkia, Helicelasma, Dalmanophyllum*), but there occurred also rare lambelasmatids or calostylids s.l. (*Coelostylis (Vormsistylis), Neotryplasma, Calostylis, Estonielasma*) and the end of the period is marked by the incoming of the first paliphyllids and stauriids. As guide fossils we should mention *Kenophyllum canaliferum* (Reiman) in the Nabala Stage, *Grewingkia anthelion* Dybowski and *Strepteplasma hiumica* (Reiman) in the Vormsi Stage, *Grewingkia hosholmensis* Kaljo, *Kenophyllum subcylindricum* Dybowski and *Streptelasma duncani* (Dybowski) in the Pirgu Stage and *Paliphyllum sokolovi* (Reiman) and *Palaeophyllum fasciculus* (Kutorga) in the Porkuni Stage. Notable in Pirgu and Porkuni times many rugose corals were large-sized (*Kenophyllum subcylindricum, Grewingkia buceros*, particulary *Kaljolasma giganteum*, etc.). The Porkuni assemblage is characterized by the first appearance of numerous colonial rugose corals in Estonia (above-mentioned *Palaeophyllum*, *Strombodes middendorfi* (Dybowski), *Holacanthia? tubulus* (Dybowski).

The Silurian assemblage of rugose corals is taxonomically more diverse and their distribution shows distinct facies control. Reliable records of rugose corals from the lagoonal and depression facies are lacking, although their occurrence in the first one is quite probable (e.g. *Palaeophyllum* was recorded from the lagoonal rocks of the Porkuni Stage). Rugose corals are scarce also in the Pentamerus - or Borealis - banks of the shoaly belt and in the stromatoporoid- biostromes of the Jaagarahu and Paadla stages, being represented by rare, mostly small-sized corals of *Streptelasma* and *Crassilasma* types.

A rich assemblage of rugose corals is characteristic of the reefs and their surroundings. For instance, the Hilliste reef facies of the Juuru Stage contains very abundant *Cyathophylloides kassariensis* Dybowski, *Cyathactis balticus* Kaljo, *"Kodonophyllum" tubaeformis* Kaljo, etc. Practically similar assemblage was recorded from the analogous rocks of the Sepise outcrop of the Jaagarahu Stage, including *Microplasma schmidti* Dyb., *Kodonophyllum truncatum* (Linn.), *Spongophylloides cylindrica* (Wedekind), etc.

In the shoaly belt of the Kaugatuma Stage the most significant are *Cystiphyllidae* (*Cystiphyllum cylindrinum* Lonsdale) and *Arachnophyllidae*, particularly *Entelophyllum articulatum* (Wahlenberg).

In the shallow part of the open shelf also a diverse assemblage of rugose corals occurs. In the offshore direction on the increasingly muddy bottom sizes of solitary corals tend to become smaller (with some exceptions, e.g. *Neocystiphyllum keyserlingi* (Dyb.), in the marls of the Jaani Stage, Paramaja cliff) and the role of colonial rugose corals is seen to decrease.

A short list of guide-fossils from these rocks is as follows:

Juuru Stage - *Paliphyllum soshkinae* Kaljo

Raikküla Stage - *Rhegmaphyllum whittardi* (Smith)

Adavere Stage - *Calostylis luhai* Kaljo and *Cyathactis tenuiseptatus* Soshkina

Paadla Stage - *Phaulactis cyathophylloides* Ryder

Kuressaare Stage - *Entelophyllum articulatum* (Wahlenberg), *Tryplasma loveni* (M.Edw. et H.), etc. occurring also higher in the Paidoli.

From the transitional belt only a few species have been identified by now (e.g. *Porpites porpita* (Linn.) from the Velise Formation, *Rhegmaphyllum elitense* Wedekind from the Jaani Formation, etc.). Most of the fauna has not been described yet, but generally the corals in transitional facies are rather similar (e.g. densiphyllids in the Llandovery, etc.).

Although rugose corals are mostly considered as an environmentally controlled fauna, providing a good basis for facies analysis, there are several records from the Ordovician and Silurian referring to their possible, but by now limited application for interregional correlation.

ORDOVICIAN INARTICULATE BRACHIOPODS

I. Puura

Ordovician inarticulate brachiopods of Estonia and neighbouring Leningrad Region have attracted palaeontologists since early 19th century. E. Eichwald (1829, et al.) described the genus *Obolus* and several species obtaining later remarkable stratigraphic significance: *Obolus apollinis, Ungula ingrica, Thysanotos siluricus, Eosiphonotreta verrucosa, Siphonotreta unguiculata, Orthisocrania depressa, O. planissima*, etc. C. Pander (1830, et al.) established the genera *Ungula, Keyserlingia* and *Helmersenia* and E. de Verneuil the genus *Siphonotreta*. S. Kutorga (1848) studied the phylogeny of the family *Siphonotretidae* describing the new genus *Schizotreta*. A profound study of A. Mickwitz (1896) on obolids from Estonian "Obolus sandstones" was soon referred in the substantial monograph "Cambrian Brachiopoda" by C. Walcott (1912). The family *Craniidae* was studied by F. Huene (1899). In his thorough palaeontological study of Kukruse Stage, H. Bekker (1921) described a new genus *Pseudopholidops* and several new species. Major collection and almost finished manuscript of a monograph on Lower Ordovician inarticulates was left by A. Öpik who had to depart Estonia in 1944. Up to now, the work of V. Ya. Gorjansky presents the most complete review of Ordovician inarticulates in the North-East of the East-European Platform (Gorjansky, 1969). G. Biernat (1973) has described some new species from the Arenigian of Estonia. An updated taxonomy of the inarticulate brachiopods from the Cambrian-Ordovician boundary beds in Estonia and Leningrad Region is presented by L.E. Popov and K.K. Khazanovich (Popov, Khazanovich, 1989). L.E. Holmer (1989) has described a new acrotretid genus *Biernatia* including *B. holmi* and some species of *Torynelasma* from Estonia.

In Estonian Palaeozoic sequence, phosphatic inarticulate brachiopods represented by families *Obolidae, Acrotretidae, Siphonotretidae* and *Eoconulidae* are common from the Upper Cambrian to the Middle Ordovician and most abundant in the Cambrian-Ordovician boundary beds known as "Obolus sandstones", where obolid coquinas form the deposits of shelly phosphorites. Inarticulates with calcitic shell represented mostly by *Craniidae* range from the Uhaku to Porkuni Stage being most abundant in the Kukruse Stage. The latter are up to now rather poorly studied and therefore discussed below only in general terms.

In the lower part of the Pakerort Stage, phosphatic inarticulate brachiopods are the dominating fossil group. The sandstone beds at the Cambrian-Ordovician boundary (Loc. 1:1, 1:2) contain abundant inarticulates forming coquinas dominated by species *Ungula ingrica* (Eichw.) and *Schmidtites celatus* (Volborth), with *Keyserlingia buchii* (Verneuil) and *Oepikites obtusus* (Mickwitz) present. *Obolus apollinis* (Eichw.) and *Helmersenia ladogensis* (Yeremeev) appearing just above the lower boundary of the *Cordylodus proavus* Zone are widely distributed in Leningrad Region. In Estonia, these species have been found recently in the same level from the boreholes of Rakvere area and Hiiumaa Island, respectively. From the overlying beds of *Dictyonema* Shale, *Eurytreta* cf. *bisecta* (Matt.) and *Biernatia magna* (Gor.) have been reported (Popov, Khazanovich, 1989). The same authors report *Lingulella* aff. *tetragona* Gor., *Eosiphonotreta* aff. *acrotretomorpha* Gor. and *Eurytreta* sp. from the Varangu (= Ceratopyge) Stage.

The lower part of the Latorp Stage (Loc. 1:4), traditionally referred to as "*Thysanotos siluricus* Zone" yields besides the index species *Paldiskia obscuricostata* Gor., *P. orbiculata* Gor., *Foveola maarduensis* Gor., *Lingulella tetragona* Gor., *L.? nitida* Gor., *Leptembolon lingulaeformis* (Mickwitz), *L. recta* Gor., *Siphonotreta acrotretomorpha* Gor., *Schizambon esthonia* (Walcott), *Schizambon ovalis* Gor. From the upper part, *Spondylotreta faceta* Gor. and *Myotreta crassa* Gor. have been reported (Gorjansky, 1969; Mägi, 1984).

From the Volkhov Stage (Loc. 1:3), *Rowellella rugosa* Gor., *Spondylotreta faceta* Gor. and *Myotreta estoniana* (Biernat) have been reported. *Myotreta crassa* Gor., *Biernatia rossica* (Gor.) and *Eosiphonotreta verrucosa* (Eichw.) range from the Volkhov to Kunda Stage, while *Eoconulus cryptomyus* is ranging from the Volkhov to Aseri Stage and *Conotreta mica* Gor. from the uppermost Kunda to the lowermost Uhaku Stage. *Siphonotreta unguiculata* (Eichw.) ranges from the Aseri to Idavere Stage (Gorjansky, 1969; Biernat, 1973; Mägi, 1984; Holmer, 1989).

From the Kukruse Stage, *Biernatia holmi* Holmer and *Schizotreta elliptica* (Kutorga) have been described. Calcitic inarticulates are represented by *Philhedra baltica* Koken, *Orthisocrania planissima* (Eichw.) and about ten more species assigned to the genera *Philhedra*, *Orthisocrania*, *Craniops* and *Paracraniops* (Huene, 1899; Bekker, 1921; Gorjansky, 1969; Rõõmusoks, 1970).

In the Idavere and Jõhvi Stages, *Alichovia ramispinosa* Gor. and calcitic inarticulates *Philhedra metatypotheisa* Huene, *Orthisocrania curvicostae* Huene occur. *O. depressa* (Eichw.) ranges from the Jõhvi to Keila Stage and *Philhedra kegelensis* Huene from the Keila to lowermost Oandu Stage.

In the Upper Ordovician phosphatic inarticulates are very rare. From the Nabala Stage, V. Yu. Gorjansky has reported *Pseudolingula quadrata* (Eichw.) and established a new species *Lingulops mirus* Gor., represented by a single dorsal valve from Võhma borehole. L. Popov and J. Nõlvak (1987, in prep.) have described a fauna from the Vormsi and Pirgu stages of Viljandi borehole including *Acanthambonia portranensis* Wright, *Rowellella minuta* Wright, *Spondylotreta* cf. *parva* Wright, *Eoconulus semiregularis* Biernat, *Paterula* sp., *Schizotreta* sp. and three new species assigned to the genus *Opsiconidion* and two new genera. The latter rich assemblage originates from a lens of pure cryptocrystalline (aphanitic) limestones.

Calcitic inarticulate brachiopods are represented by *Pseudopholidops stolleyana* (Huene) in the Oandu Stage and about ten species assigned to the genera *Philhedrella?* (Rakvere and Nabala Stages), *Petrocrania?* (Vormsi Stage), *Pseudometoptoma*, *Elenthocrania* and *Pseudocrania* (Porkuni Stage) (Põlma et al., 1988; Huene, 1899; Rõõmusoks, unpublished).

Most of the species considered above are restricted to Estonia and neighbouring Leningrad region, but some have been recorded in other parts of Baltoscandia or Europe. *Ungula ingrica* and *Schmidtites celatus* occur in the Cambrian-Ordovician boundary beds of Sweden. The reported occurrences of *Obolus apollinis* and *Thysanotos siluricus* from Poland, questioned in the light of updated taxonomy need re-examination. *Siphonotreta acrotretomorpha*, *Biernatia rossica*, *Myotreta estoniana* and *Myotreta crassa* have been recorded from the Lower-Middle(?) Ordovician of Poland (Biernat, 1973). The Middle Ordovician species *Biernatia holmi* is ranging in Sweden from Seby to Dalby Limestone (Holmer, 1989). Upper Ordovician *Acanthambonia portranensis* and *Rowellella minuta* are originally described from Portrane Limestone (Cautleyan), Ireland (Wright, 1963).

ORDOVICIAN ARTICULATE BRACHIOPODS

L. Hints

Ordovician articulate brachiopods in Lower Paleozoic outcrop areas of North Estonia and adjacent territory of Leningrad district were first described by the well-known paleontologists of the last century C.H. Pander (1830), Ed. Eichwald (1860), Fr. Schmidt (1858) and A. Pahlen (1877). The most important studies of Estonian brachiopods from the first half of this century belong to A. Öpik (1930a, 1934a, a.o.), who revised and described altogether about 180 species, subspecies and forms, among them about 100 new ones. During the last 30 years Ordovician brachiopods were described by T. Alichova (1953), A. Rõõmusoks (1981, 1989), M. Rubel (1961), A. Oraspõld (1956) and the author of this survey (Hints, 1975; see also list of literature in Rõõmusoks, 1970; Männil, 1966).

In consequence of the 150-year study more than 300 species of Articulata have been described from the Ordovician in North-East Baltic, which belong to about 130 genera, mostly among *Orthacea, Clitambonitacea, Plectambonitacea* and *Strophmenacea* (Fig. 12). Beside them there is a great number of taxa identified in Central, or South-East Baltic (*Septorthis, Bimuria, Hirnantia* a. o.), many of them are common in the contemporaneous strata in Scandinavia.

The brachiopod fauna in the Baltic basin is known as a part of specific fauna containing numerous endemic elements. The increase of pandemic taxa in that fauna is more remarkable from the early Ashgill (see also Williams, 1973), later in Central East Baltic the Baltic-type fauna is replaced by Hirnantian fauna (s. l.; Männil, 1966).

Dynamics and comparison of contemporaneous Ordovician brachiopod faunas, including Balto-Scandian fauna (fauna of Baltic province; Williams, 1973) has been analyzed by V. Jaanusson (1973, 1976, 1979a, 1984), A. Williams (1969) and others, therefore these problems are not discussed here.

In East Baltic two distinct brachiopod faunas can be distinguished, the distribution of which generally coincides with the main confacies belts (Männil, 1966; Jaanusson, 1976). In the North-Estonian and Lithuanian confacies belts the brachiopod fauna comprises mostly orthaceans (many large forms) and clitambonitaceans together with the plectambonitaceans and strophomenaceans (Fig. 12). Two first groups have a restricted distribution in the Livonian Tongue of the Central-Baltoscandian confacies belt. Such species like *Dicoelosia transversa* Wright, *Leptestiina? indentata* (Spjeldnaes), *Rugosowerbyella rossettana* (Henningsmoen), and the Caradoc *Gunnarella, Skenidioides* and *Reushella* occur only in the Livonian Tongue or in the transitional belt (Põlma, 1967). The two latter genera appear in North Estonia only in the Ashgill.

In the North-Estonian confacies belt embracing the area of outcrops visited during the excursion, the first articulate brachiopods, orthids - *Prantlina, Panderina, Ranorthis,* dalmanellids - *Paurorthis,* plectambonitids - *Plectella* etc. (Fig. 12) appear in glauconitic sandstones of late Latorp Mäeküla Member (Rubel, 1961; see also Lamansky, 1905) (the corresponding sections in localities 1:1,1:2). This first brachiopod association is replaced in the carbonate rocks of the Volkhov and Kunda stages by the new one, which comprises beside orthids (*Productorthis, Orthambonites*) and plectanbonitids (*Ahtiella, Ingria*) several clitambonitids (*Antigonambonites, Gonambonites, Progonambonites* a. o.), mostly endemic in the Early Ordovician Baltic basin.

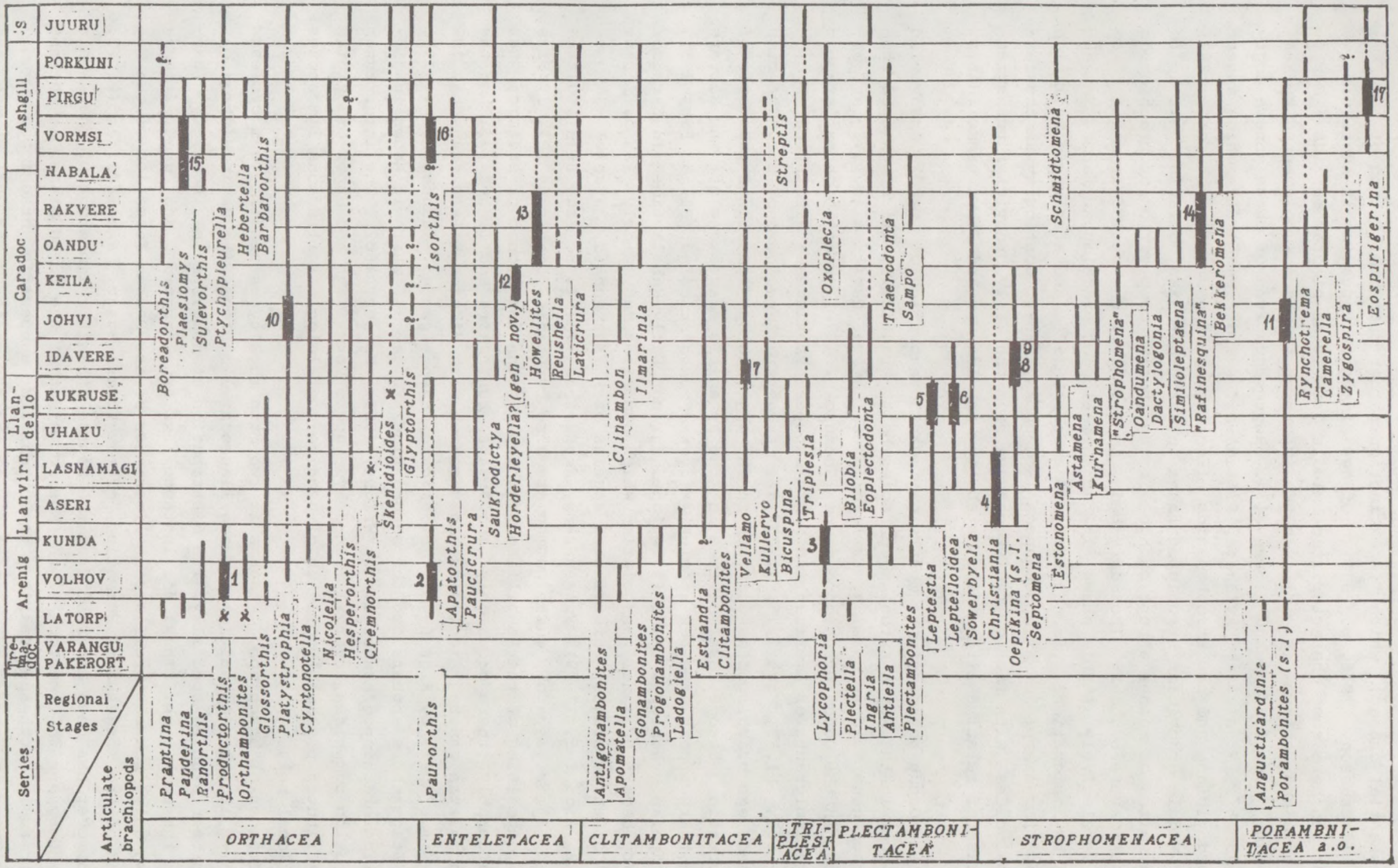


Fig. 12. Ranges of selected Ordovician articulate brachiopod genera in East Baltic.
Solid line - occurrences in the North-Estonian confacies belt; dashed line - in the transitional zone; x - the first appearance in the eastern part of Baltic basin; broad line - ranges of the index-species (1-17 of biozones distinguished by T. Alichova (1960).
1 - *Paurorthis parva*, 2 - *Productorthis obtusa*, 3 - *Lycophoria nucella*, 4 - *Christiania oblonga*, 5 - *Leptestia musculosa*, 6 - *Leptelloides leptelloides*, 7 - *Vellamo praeemarginata*, 8 - *Oepikina anijana anijana*, 9 - *Oepikina assatkini*, 10 - *Platystrophia trapezoidalis*, 11 - *Porambonites schmidti*, 12 - *Horderleyella? kegelensis*, 13 - *Howellites wesenbergensis*, 14 - *Rafinesquina (=Mjoesina?) inaequiclina*, 15 - *Plaesiomys solaris*, 16 - *Isorthis estona*, 17 - *Eospirigerina sulevi*.

At the Lower/Middle Ordovician boundary (Kunda/Aseri boundary) the brachiopod fauna undergoes an essential change, which "is extinction rather than immigration of new faunal elements" (Jaanusson, 1976, p. 311). Of new elements appearing in Aseri time we could still mention here some characteristic Middle Ordovician plectambonitids - *Christiania, Leptestia* and *Oepikina* (s. l.). In Lasnamäe time they are supplemented by *Hesperorthis, Vellamo, Leptelloidea* and *Sowerbyella*. Representatives of these genera together with *Glossorthis, Nicolella, Estlandia, Clitambonites* and *Porambonites* which appear in the Lower Ordovician and new strophomenids (*Kurnamena, Estonomena;* Rõõmusoks, 1989) form the basic Middle Ordovician brachiopod fauna in North-Estonian confacies belt up to Oandu time. In spite of rather abrupt change in the species composition of brachiopods at the Kukruse/Idavere boundary (boundary beds in Loc. 2:1) the period from Aseri to Oandu time is a relatively stable phase in the formation of brachiopode fauna, except changes caused by immigrations, faunal shift (Jaanusson, 1976) and also rapid evolution of some groups, for example of Strophomenacea (Rõõmusoks, 1989). Continuity in the faunal dynamics coincides with that of facies changes from the Early Ordovician transgression to the phase of relative lithofacial stability in Idavere and Jõhvi times (Hints, Põlma, 1986).

At the Keila/Oandu boundary the most significant renovation of Middle Ordovician fauna takes place in the North-Estonian confacies belt. Practically all brachiopod species and numerous genera (*Cyrtonotella, Estlandia, Clinambon, Oepikina* (s.l.), *Septomena*) disappear. In the Oandu brachiopod fauna (Rõõmusoks, 1970) great biostratigraphic importance have immigrants of American and North-European Provinces - *Howellites, Dactylogonia, Camerella* (Pl. 3, Figs 1, 6, 7, 13-19), *Zygospira, Rynchotrema*, etc. The rich and diverse Oandu age brachiopod association in the argillaceous limestones and marls of the Hirmuse Formation become less diverse in the aphanitic limestone of the Rakvere Stage, although there appear some new species (*Mjoesina? subaequiclina*, Pl. 3, Figs 2-5). This Late Caradocian brachiopod fauna is replaced during Early Nabala time (in Caradoc/Ashgill boundary beds) by a new association which comprises many widely (in different members of two or three stages) distributed species of *Platystrophia, Nicolella, Boreadorthis* (Pl. 2, Figs 1-5, 11-19), *Sulevorthis, Eoplectodonta* (Pl. 3, Fig. 8-12), *Bekkeromena, Vellamo, Ilmarinia* a.o., quite common are also *Triplesia, Oxoplecia* (Pl. 3, Figs 20-22). In the composition of the Ashgillian brachiopod fauna the amount of endemics has decreased considerably (there occur only *Apatorthis, Equirostra* and *Ilmarinia*), but the number of cosmopolitan genera, including those common with Hiberno-Salair fauna has increased (*Plaesiomys;* Pl. 2, Figs 6-10), *Dicoelosia, Eospirigerina;* Jaanusson, 1979). In the Vormsi Stage there appears for the second time *Kullervo*, which is known in different Ashgillian brachiopod associations (Wright, 1964; Harper, 1982). The interregnum in its distribution comprises interval from Jõhvi up to Vormsi age and Upper Ordovician species is distributed presumably only in glauconite-containing argillaceous limestones of the transitional belt.

The differences of brachiopod faunas in two main rock types of different cycles of sedimentation - in pure (aphanitic) and argillaceous limestones (Põlma in Hints a.o., 1989) have not been studied specially. The distribution of some species, however, clearly depends on the rock type. Thus, for instance *Laticrura rostrata* and *Paucicrura robusta* are known only from the argillaceous limestones of the Paekna Formation of the Nabala Stage and of the Kõrgessaare Formation of the Vormsi Stage. *Skenidioides* (Pl. 2, Figs 24-29), however, has been recorded from the Saunja aphanitic limestone of the Nabala Stage and pure *Dasyporella* limestone of the Moe Formation of the Pirgu Stage. At the end of the Ordovician in North-East Baltic, in Porkuni time a specific brachiopod association is distributed in reefs and connected with their deposits. The most common are *Streptis undifera, Schmidtomena acuteplicata* Öpik, *Laticrura* sp. n. a.o. (Loc. 4:3).

Articulate brachiopods are used widely in biostratigraphy of the Ordovician strata in East Baltic. All stratigraphic units (members, formations and stages) contain some index brachiopods (Resheniya, 1987). T. Alichova (1953, 1960) used some of them as zonal species (Fig. 12). Still it should be noted that although many brachiopod species serve as good index fossils for the age-dating of layers, their significance in the distinction of stratigraphic units is much smaller, first of all due to their low density in core samples.

The Ordovician brachiopod fauna of the East Baltic has not been analyzed from the aspects of associations or communities comparable with those established in the Caradoc of Wales and in the Upper Ordovician of America (Hurst, 1979; Lockley, 1985, Bretsky; 1969; Pickerill, Brenchley, 1979). Generally, the material from core sections is not realiable enough for such an analysis either. In spite of this in the East Baltic we could distinguish some similar communities. Such should be the *Howellites-Sowerbyella* communities in the Hirmuse Formation of the Oandu time in North Estonia, which, despite differences in species composition much resembles the *Howellites* community of Wales (Pickerill, Brenchley, 1979). Like the latter, the North-Estonian community could also be considered as related to the nearshore and quiet-water soft-bottomed environment with rather rapid sedimentation. Unlike the *Howellites* community of Wales which contains elements of the adjoining associations, we can suggest certain isolation of the corresponding community of North Estonia.

SILURIAN BRACHIOPODS

M. Rubel

Brachiopods constitute an abundant group of organisms in the Silurian open platform environments. Their significance in the stratigraphy of the corresponding rocks may be emphasized by wide geographical distribution as well as rapid evolution (lineages) of many, especially Early Silurian species (Bassett, 1989).

Brachiopods are numerous and diverse in carbonate facies of the platform margin sea located in Estonian area, too. Their most prominent occurrences are the Borealis-bank and *Pentamerus oblongus* interbeds in the Llandovery, the coquina of *Didymothyris didyma* and *Atrypoidea prunum* in the Ludlow and Pridoli, respectively. As most of Estonian Silurian brachiopods (see Pl. 4) are well preserved and can be easily washed out of clayey rocks, their biostratigraphical potential can be evaluated rather high even in subsurface study of the region.

Up to now nine genera of inarticulate and 110 genera of articulate brachiopods have been established from the Baltic Silurian comprising altogether about 200 species (Rubel et al., 1984). The latters have been at least once described on the Baltic collection although some papers have been made long ago and also by different authors (Rubel, 1963; 1970; 1977a; Rybnikova, 1966; 1967; Rubel and Rozman, 1977; Modzalevskaya, 1983). It is noteworthy that new collections got during the last decade from the Estonian Silurian do not include new taxa of brachiopods: they all are more or less known although not always formally described, especially, among representatives of the order *Strophomenida*. The known number of brachiopod genera decreases stepwise during the Silurian in Baltic area being always relatively high at the beginning of epochs.

The distribution of the brachiopods considered depends highly on the facies what complicates the use of Silurian brachiopods as guide-fossils, especially in regional stratigraphy. This was proved also by the brachiopod communities developed well in the Silurian of Estonia. Thus, the *Linoporella, Borealis-Pentamerus, Stricklandia-Zygospiraella* and *Meifodia-Clorindi* Communities can be clearly recognized in the Llandovery, the *Dicoelosia-Skenidioides, Whitfieldella* and *Stegerhynchus* Communities are the most widespread in the Wenlock, to which the *Dayia, Didymothyris-Salopina, Atrypoidea* and *Homoeospira-Delthyris* Communities can be added in the Ludlov and Pridoli of the East Baltic (Rubel, 1970; Kaljo and Rubel, 1982). Because of the inherent ecological control of the brachiopods distribution their lineages obtain a special significance (Fig. 13). In Estonian material two lineages have been studied in detail, those of the genera *Stricklandia* and *Dicoelosia* (Rubel, 1977b; Rubel, 1971; Musteikis and Puura, 1986). The first lineage represents a sequence of chronological subspecies or species while the zigzag evolution established within limits of the *Dicoelosia* species makes it impossible to apply the same concept for the classification as well as the use of the latter in stratigraphic purposes. The last review of the pentamerid lineages in the Estonian Llandovery as well as their use in time-rock correlation of distant sections has appeared only recently (see Johnson et al., in press).

Keeping in view the complicated usage of Silurian brachiopods in the last years they have served as a good touchstone for the elaboration and testing of various me-

thods, especially, in regional stratigraphy (Rubel and Pak, 1986). It became evident that the brachiopods cannot be used solely for the time-stratigrafic correlation of the East-Baltic Silurian but they constitute a significant part of the so-called joint paleontological time scale for the same aid (Musteikis, 1989). That explains well why so few brachiopod zones have been suggested for the East-Baltic Silurian.

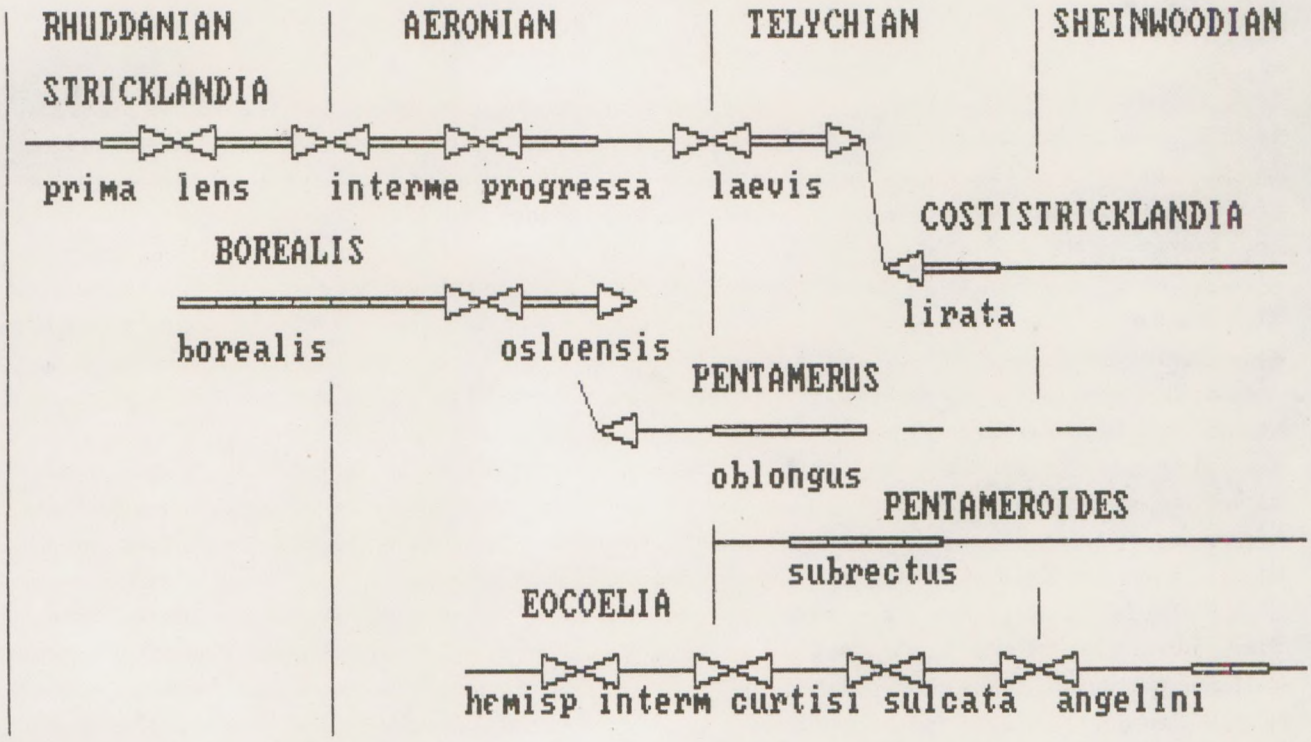


Fig. 13. Brachiopod lineages used for the correlation of the Llandovery in Baltoscandia (after Johnson et al., in press).

BIVALVIA AND GASTROPODA

M. Isakar

In the Silurian of Estonia the bivalves and gastropods occur sporadically. Most of them are badly preserved casts which often make the identification a guess-work and they never have been studied systematically. Very little has been published on the bivalves and a bit more on the gastropods (Schmidt, 1858; Teichert, 1928; Isakar, 1982; Sinicyna and Isakar, 1987).

A lot of the Silurian bivalves and the most of gastropods (see Pl. 5) are epifaunal in nature and show little correlation with rock type. But some of the bivalves occur in life position, e.g. a lot of infaunal *Ilionia prisca* in the Paadla Formation and semi-infaunal *Grammysia obliqua* in the Ohesaare Formation (the posterior part of the shell, which was above sediment, has usually not preserved).

From Llandovery bivalves have not been found. It might be due to unsuitable conditions to preservation of the shells or to the relatively cold water conditions in the beginning of the Silurian, which could be related to severe climatic conditions associated with the late Ordovician glacial advances in Gondvana.

Silurian gastropods are generally considered to be herbivores living in relatively firm substrata in the conditions of clear water. In shallow open-shelf deposits of the Varbola Formation single murchisoniids occur. In nearshore facies of the Tamsalu Formation *Loxoplocus (Lophospira)* occurs. Peel (1977) has presumed their deposit feeding, benthic existence on soft substrata. From reef associated facies (in the Hilliste Member) a lot of small platyceratids are known, e.g. *Platyceras (Platyostoma)*, *Cyclonema (Cyclonema) hiiumaa*, other cyclonematids. Also small *Megalomphala*, small *Liospira*, *Trochonema (Trochonema)*, *Murchisonia*, small *Loxoplocus (Lophospira)*, *Tryblidium* and from open-shelf deposits *Kjerulfonema ?* (the latter from a borehole).

In nearshore deposits of the Raikküla Formation *Sinuites*, *Loxoplocus (Lophospira)*, *Liospira*, *Murchisonia (Murchisonia)* and in open-shelf deposits *Cyclonema (Cyclonema)* cf.*C.(C.) distans* occur (the latter from a borehole).

In the Rumba Formation there are many big gastropods from open-shelf deposits: *Boiotremus* cf. *B.longitudinalis*, *Kiaeromphalus ?*, *Murchisonia*, *Stenoloron ? aequlatera*. From deep open-shelf of transitional facies of the Velise Formation only a small pleurotomariacea have been found.

From shallow part of open-shelf facies of the Jaani Formation (Ninase Member) *Euoumphalopterus (Euoumphalopterus) alatus*, *Poleumita discors*, *Crenilunula* are known. In the deeper part of the open-shelf facies many small *Platyceras (Platyostoma) cornutum*, *Cyclonema (Cyclonema)*, *Elasmonema*, *Subulites (Cyrtospira)* cf. *S.(C.) ventricosus curvus*, *Loxonema* cf. *L.intumescens*, *Poleumita discors*, *Oriostoma globosa*, *Crenilunula*, *Trochonema* and also small infaunal *Nuculoidea*, *Praectenodonta*, small epifaunal *Palaeopecten*, ? *Similodonta* and semi-infaunal *Grammysia* (the latter two are from the boreholes) occur.

In shoal deposits of the Jaagarahu Formation massive, thick-shelled *Megalomus gotlandicus* occurs (formed banks); also epifaunal *Mytilarca* and infaunal *Modiolopsis* (type *Janeia*) occur. From open-shelf deposits (from the boreholes) small, flat, epifaunal *Palaeopecten* and semi-infaunal small *Modiolopsis* are known. In reef associated facies *Po-*

leumita discors, Crenilunula limata, Siluriphorus gotlandicus, Euoumphalopterus ? angulatum, Murchisonia (Murchisonia) can be found. In open-shelf deposits *Oriostoma globosum, Loxonema* cf. *L. sinuosum* occur.

In the Rootsiküla Formation in very nearshore shallow water environment (with reduced salinity by Einasto, 1968) is formed about 0.8 m thick deposit from practically one type of epifaunal *Pterioids* (new genus?). In shoal part yet semi-infaunal Modiodonta and epifaunal *Pteronitella* occur. With reduced salinity probably accumulated in nearhore conditions a great number of the same species of small gastropod *Straparollus (Straparollus) helicites* and probably connected with *Pterioidea* occur *Murchisonia (Hormotoma) cingulata, M.(M.) obtusangula, M.(M.) compressa.*

In the Paadla Formation there are many bivalves in nearshore: infaunal *Ilionia prisca,* epifaunal *Kogulanychia bekkeri, Pteronitella retroflexa, Palaeopecten danbyi,* semi-infaunal *Modiolopsis* and *Ptychopteria;* from gastropods *Murchisonia (M.) compressa, M.(M.) obtusangula, M. (Hormotoma).* From open-shelf deposits *Cardiola interrupta, C.signata* and semi-infaunal *Modiolopsis, Cypricardinia* and also many molds of *Holopea ? undata, Loxonema strangulatum, Pycnomphalus acutus, P. obesus, Megalomphala taenia, Cyclonema (Cyclonema)* are known. The common occurrence of cardiolids is in deep shelf deposits in the Ludlow of Welsh Borderland (Watkins, 1978) and in the Poland (Korejwo and Teller, 1964). But Križ (1979) has described cardiolids from shallow water environments in the Silurian of Bohemia and the Carnic Alps.

In nearshore deposits of the Kuressaare Formation only a single valves of epifaunal *Pterioidea* occur. From open-shelf deposits small *Ilionia prisca,* semi-infaunal *Modiolopsis* and small epifaunal *Palaeopecten* and also *Loxonema* cf.*L.fasciatum, L.*cf. *L. minuta, Oriostoma roemeri* and *Murchisonia* occur.

In shoal deposits of the Kaugatuma Formation four big epifaunal *Pterioidea* (with various type of sculpture; only single valves may be found) and *Pteronitella retroflexa* occur. In open-shelf deposits infaunal small *Nuculoidea, Ilionia prisca* and semi-infaunal *Mulceodens* cf.*M.jaanussoni.* A small *Nuculoidea* prefer soft sediment to dig in and generally stay in situ after death. From gastropods *Oriostoma roemeri, Cyclonema (Cyclonema), Loxonema* and *Palaeoscurria calyptrata* occur.

In open-shelf deposits of the Ohesaare Formation many semi-infaunal *Grammysia obliqua, Hippocardia,* infaunal small *Ilionia prisca, Cypricardinia, Cardiola interrupta,* epifaunal *Palaeopecten danbyi, Pterioidea* (about four various types), *Actinopteria* are known. There are rare gastropods: *Oriostoma* cf. *roemeri, Murchisonia* and a trochiform holopeid. In nearshore deposits many infaunal *Modiolopsis* cf. *M.solenoides* and the greatest epifaunal pterioid (preservation very bad, only single valves) occur.

To sum up the previous, I may state that *Ilionia prisca* and *Palaeopecten danbyi* in nearshore are twice greater in size than in open-shelf deposits and in soft-bottom conditions there cannot be found very great epifaunal bivalves. Platyceratids and cyclonematids are quite useless for palaeoecolgical interpretations, because they are usually associated with crinoids. Accumulation of high-spired gastropods in nearshore deposits may be a result of secondary concentration.

SILURIAN CEPHALOPODS

G. Kiselev

Cephalopods were for the first time mentioned and described in the classic works of F. Schmidt and E. Eichwald in the 19th century. Later C. Teichert and Z.G. Balashov introduced a more detailed methodics considering also structure of phragmocone. They were followed by V.J. Saladzhius and author. In the Silurian of the Baltic area cephalopods are less abundant than corals and brachiopods, but more diversified than bivalves and gastropods.

Cephalopod fauna comprises 43 species of 29 genera, 17 families and 5 orders (some of them are illustrated in Pl. 6). They are known in wide range of lithofacies. Morphological, taphonomical and actuo-paleontological observations permit us to establish 6 "living forms" of cephalopods as follows:

1. Benthic forms. They crawled on their tentacles and could make the short jumps dashes above the bottom using their hyponomic. They lived in the shallow-water shelf zone and were very slow-moving. Their main characteristic features: big angle of orthoconic and cyrtoconic conchs, wide open aperture, wide, spreading outwards subventral siphuncle, the massive intrasiphuncle deposits, flattenal conch. Ornamentation is underdeveloped or absent. The type is represented by genera *Huroniella* and *Armenoceras* from shallow-water facies of the Adavere Stage as well as *Eushantungoceras* from the Kaugatuma Stage.

2. Bentho-pelagic forms. They could move above the bottom or suspend hydrostatically nearly the bottom feeding from it by their tentacles. They lived in the open shelf zone and had hypostomic or inclined aperture. Their characteristic features are the following: wide orthoconic or cyrtoconic conch with a contracted and inclined aperture. Orhamentation: transverse ring-shaped ribs occur or absent. Coiled nautiloid form of conch is also possible. The type is represented by genera *Podolicoceras*, *Armenocerina*, *Ormoceras* from the shallow shelf facies of the Ohesaare Formation and *Bickmorites* from the Jaagarahu and *Gomphoceras*, *Protophragmoceras* from the Paadla stages.

3. Necto-benthic forms. They inhabited the near-bottom layer of the open shelf as well as the slope and deeper basin. They had a mechanism of the precise orientation and balance of the mass centre and a natatory organ. Their characteristics are as follows: slightly widening orthoconic and cyrtoconic conch, narrow siphuncle with insignificant siphuncle deposit and some cameral deposit, with ornamentation or without it. This type is represented by genera *Temperoceras* and *Kionoceras* from the open shelf facies of the Jaagarahu and *Plagiostomoceras* from the Paadla stages.

4. Nectonic forms. They are found in the open-sea deposits. They moved actively using their hyponomic, had ortheconic or slightly cyrtoconic exogastric conch of good hydrodynamic form with the mechanism of the precise orientation. They used every possibility to cut down the weight and volume of the conch. This "living form" is represented by *Calorthoceras* from the open shelf zone of the Jaagarahu Stage.

5. Planctonic and hemiplanctonic forms are found in the open shelf and slope facies. They had the neutral flotation. The structure of the conch is adapted to the passive existence in the pelagic zone. They had the only possible hypostomical position and

could be suspended hydrostatically in the water. Their conchs has rich ornamentation of ridges, spikls, their aperture had collars and projectives, siphuncle was small without deposits. This type is represented by *Dawsonoceras, Pseudokionoceras* from the open-shelf facies of the Jaani Stage.

6. Necroplanctonic forms passively suspended near the surface, their conchs were partly filled by gas after the death as it is with the Recent *Nautilus* and *Spirula*. The examples of necroplanctonic type might be some species of *Temperoceras* and *Bohemites* which were transported into the shallow facies from deep-water parts of the basin in the Ohesaare time.

No one of these above mentioned "living forms" prevails in the Silurian of the Baltic area.

The results of the research of Silurian cephalopods show that they may be used for correlation. Cephalopods are rare in Llandovery. They are attributed to 4 species of 4 different genera. All the species are endemic but genera are widespread. Wenlock cephalopods are more abundant - there are 15 species from 12 genera found. In the lower part of the Jaani Stage important forms are the following: *Dawsonoceras annulatum* and *D. barrandei* which were identified by different authors from the lower part of Furmanovka Stage of Podolia, Motol and Kopanina formations of Barrandian, Wenlock of England, Clinton of North America. In the Jaagarahu Stage important are *Kionoceras studenitcense* and *Calorthoceras (Hornyoceras) illineatum*. The first one is common in the Restevo Subsuite of Podolia. Similar species are described from Clinton in North America. The second species is known from Kopanina of Barrandian as well as from the Wenlock of China and Kaliningrad area. Ring-shaped cyrtoconic *Cyrtocycloceras nitidum* is described from Kopanina of Barrandian, but not revised yet. Very specific case-shaped *Mandaloceras cinctum* is known from Wenlock-(?)Ludlow of Britain, Clinton of North America and similar species from Upper Wenlock-Lower Ludlow of the North Urals and China. Cephalopods of the Rootsiküla Stage are very scarce, but become more abundant in the Ludlow. In the latter there are established 13 species from 11 genera. The Paadla Stage is characterized by *Eushantungoceras pseudoimbricatum* and *Dawsonoceras obsoletum*. The former one is known from Hemse Beds of Gotland, the Konovka Stage of Podolia, the Gerdyuskij Stage of the North Urals and the Kopanina Formation (?) of Barrandian. The latter species is known from the middle Kopanina of Barrandian (*scanicus-tumescens Zone*). A reduction of the number of taxa is observed in the Kuresaare Stage. Endemic forms prevail, *Temperoceras kunkoyense* being among them. But some widespread species are known as well - *Temperoceras severum* and *Gomphoceras* cf. *pyriforme*. They were described from the Kopanina-Pridoli strata of Barrandian and the Ludlow of Britain. The Kaugatuma time was characterized by the new fauna. Some new local species appeared together with some widespread forms. The most characteristic species are the following: *Eushantungoceras uralicum* and *Podolicoceras balticum*. This complex is most similar to the cephalopod fauna of the Ludlow-Přidoli of Barrandian and the North Urals. The Ohesaare cephalopod assemblage changes likewise. The *Temperoceras volkovense* and *Armenocerina conica* are very important here, which are known from the Dzwinogorod Formation of Podolia. Some Pseudortocerida are similar to species from the transitional Silurian-Devonian deposits of the other regions. This fact proves the substantial diversity of cephalopod fauna of the Ohesaare time.

OSTRACODES

T. Meidla
L. Sarv

The first data about Ordovician and Silurian ostracodes from Estonia (North-East Baltic) were published in the second half of the last century by E. Eichwald, A. Schrenk and F. Schmidt, by the last author the monographs about Silurian leperditiids. In the first half of this century ostracodes from the kukersite-bearing beds were described by J. Bonnema and A. Öpik. The regular study of Estonian ostracodes was started in the 1950s by A. Neckaja and L. Sarv, nowadays these studies have been continued by T. Meidla. During the last forty years the coeval ostracodes from Latvia and Lithuania (Middle- and South-East Baltic) were studied by A. Neckaja, L. Gailite, A. Pranskevicius, and N. Sidaraviciene. In the knowledge about Estonian ostracodes, the results obtained from Poland, Sweden, Norway and from the Middle European erratic boulders have been greatly significant.

Ordovician Ostracodes

On the Estonian territory ostracodes (except Archaeocopida) appeared in Volkhov time with the incoming of early ctenonotellids, leperditellids and eurychilinids (Sarv, 1959; Sarv, 1972). The first metacopids (longiscuiids), tvaerenellids and bolbinids appeared at the end of the Early Ordovician. The Middle Ordovician was a prosperous period for beyrichicopids (especially ctenonotellids, also tvaerenellids, tetradellids). Species diversity increased considerably reaching the peak in Kukruse time (over 60 species). Noticeable renovation of the fauna in Idavere time was followed by the period of stable composition until Keila time. In Oandu time most of the species were replaced and the number of metacopid species started to increase reaching almost 1/3 by the end of the Ordovician. At this period among *Beyrichicopa* tetradellids, oepikellids, tvaerenellids, bolliids were dominating, while the importance of ctenonotellids decreased considerabely. In the Late Ordovician species diversity was the greatest in early Pirgu time (over 115 species), lowering abruptly (to 75 species) in Porkuni time. At the Ordovician-Silurian boundary a complete turnover in ostracode species took place.

Totally about 400 Ordovician ostracode species have been identified (see Pl. 7-8).

During the Early Ordovician the species association of ostracodes was rather similar on the whole studied area. Throughout the Middle and Late Ordovician the ostracode faunas were distinct in North and South Estonia; the first changes appeared at the end of the Early Ordovician. In North Estonia, usually considered the more shallow-water part of the palaeobasin, the species diversity was higher. Besides, in either regions geographically widely distributed species co-occurred with a group of specific local taxa.

The zonal chart based on the distribution of ostracodes (see Table 10) has not been much employed up to now. The ostracode zonation of the Lower and Middle Ordovician in the East Baltic has been performed by N. Sidaraviciene (Sidaraviciene, 1976). Generally this has been confirmed by Estonian sections, only in the lower half of the Middle Ordovician the distribution of zonal species is somewhat different. This has called for some

Table 10. Ostracode zonation in the Ordovician of Estonia
Lower and Middle Ordovician zones according to N. Sideraviciene (1976) and L. Sarv;
Upper Ordovician zones by T. Meidla

SUBSYSTEM	SERIES	GRAPTOLITE ZONE (Rešenija . . . , 1987)	REGIONAL STAGE	OSTRACODE ZONE, SUBZONE	
UPPER ORDOVICIAN	ASHGILL	Glyptograptus persculptus	PORKUNI	Medianella aequa - Circulina sp. n.	
		Climacograptus?extraordin.			
		Dicellograptus anceps	PIRGU	Tetradella plicatula	
		Dicellograptus complanatus			
		Pleurograptus linearis	VORMSI	Uhakiella curta	Eoaquapulex frequens
			NABALA		Disulcina explicata
MIDDLE ORDOVICIAN	CARADOC	Dicranograptus clingani	RAKVERE	Klimphores minimus	Daleiella sp. n.
					Tetradella egorowi - Olbia cf. braderupensis
			OANDU		Sigmoopsis granulata
		Diplograptus multidens	KEILA	Pedomphalella egregia - Bichilina prima	
			JOHVI		
			IDAVERE		
	LLANDEILO	Nemagraptus gracilis	KUKRUSE	Tallinnella reticulata - Tallinnopsis perplana	
		Glyptograptus teretiusculus	UHAKU	Sigmoopsis perpunctata	
	LLANVIRN	Didymograptus murchisoni	LASNAMAGI	Steusloffia linnarssoni	
			ASERI	Piretella tridactyla	
LOWER ORDOVICIAN	ARENIG	Didymograptus "bifidus"	KUNDA	Pinnatulites procera	
		Didymograptus hirundo	VOLHOV	Tallinnellina primaria	
		Didymograptus extensus	LATORP		

correction by the application of the chart for Estonian sequence in the interval from the *Steusloffia linnarssoni to Tallinnella reticulata - Tallinnopsis perplana* zones. Recent, yet unpublished data allow to distinguish three ostracode zones in the Upper Ordovician, evidently embracing the whole central confacies belt in the East Baltic and the adjoining transitional area. In North Estonia the *Klimphores minimus* and *Uhakiella curta* zones have been subdivided into subzones as presented in Table 10.

As a correlation tool, Estonian Ordovician ostracodes have so far been used on the distribution area of the so-called Baltoscandian type ostracode fauna. They are significant first of all in the correlation of northwestern and western sections of East Europe, also in the correlation of Norwegian and Swedish sections with East Baltic ones. For a long time ostracodes have been applied for dating of erratic boulders from North Germany.

Silurian Ostracodes

At present more than 300 ostracode species are known from the East Baltic Silurian (see Pl. 9-10).

By the beginning of the Silurian the rich and diverse paleocopid fauna characterizing the Ordovician period, has almost completely disappeared from the Baltic basin. Podocopids have been more surviving as their evolution continued also in the Early Llandovery when the first, strictly Silurian craspedobolbinids made their appearance. The first beyrichiids came in during the Middle Llandovery. The Wenlock epoch was marked by the appearance of early cavellinids and Silurian primitiopsids. The species diversity of Silurian ostracodes reached the maximum in the Ludlow, partly also at the beginning of the Pridoli, gradually dying out by the end of the Silurian period.

The lateral distribution of Silurian ostracodes in the Baltic basin has some characteristic features. Lagoonal sediments have yielded only representatives of large leperditiids which sometimes form accumulations of shells on bed surfaces or in interlayers. They have preserved mostly as moulds in the outcrops of the Raikküla, Adavere and Rootsiküla stages. Ostracodes of the shoal facies are less studied but some data allow to suggest a considerably different nature of this complex from that of the open shelf facies. Thus, for instance, a very specific shallow-water association has been recorded from the Late Wenlock Rootsiküla Stage (Sarv, 1980).

Most of the Silurian ostracodes were found from the sediments of the open shelf and transitional belts. The characteristic complexes comprise different species and genera whereas these differences are more distinct in the Ludlow and Pridoli. The existence of sufficiently many common species allows to use ostracodes for the correlation of rocks of different facies and belts. Sediments of the basinal belts have yielded no ostracodes.

By the vertical range the Silurian ostracodes of Estonia are divided into the Llandovery, Late Llandovery-Wenlock and Ludlow-Pridoli complexes (Sarv, 1979). Each complex is characterized beside the gradual renovation also by a number of long-ranging common species.

The Llandovery complex, occurring in the Juuru and Raikküla stages is not very numerous (about 40 species). Characteristic are mostly podocopids but already in the middle of Juuru time there appeared the first craspedobolbinids (*Aitilia, Bolbiprimitia, Kiltsiella*), at Raikküla time also beyrichiids made their appearence. In Adavere time this complex is replaced by the Late Llandovery-Wenlock complex comprising 70 species. Among them significant for detailed stratigraphy are craspedobolbinids and beyrichiids. This complex occurs in the Velise Formation of the Adavere Stage, in the Jaani, Jaagarahu and Rootsiküla stages. The most numerous is the Ludlow-Pridoli complex composed of about 100 species. Its appearance is accompanied by the renovation of faunal composition not only on the species but also on the generic level. At least 10 new beyrichiid-primitiopsid genera appear, the representatives of which are recorded abundantly also outside the Baltic basin.

Ostracodes are valuable by the subdivision and correlation of Estonian Silurian sections. All stages have their own characteristic species or species complexes widely used in geological studies (Sarv, 1968; Kaljo ed., 1970). On the basis of index-species also ostracode zones have been established, which in the extent completely or partly correspond to the stages (Table 11).

Table 11. Ostracode zones and the most characteristic species in the Silurian of Estonia

SERIES	REGIONAL STAGE	OSTRACODE ZONES	CHARACTERISTIC SPECIES: FOR REGIONAL STAGE OR ZONE	CHARACTERISTIC SPECIES: FOR SERIES	LONG RANGING SPECIES
Pridoli	Ohesaare	Nodibeyrichia protuberans	Berolinella steusloffi Juviella piltenensis Frostiella loodensis Orcofabella testata	Hemsiella maccoyiana Macrypsilon salterianum Neobeyrichia buchiana Frostiella pliculata Orcofabella araneosa Venzavella multicostata Venzavella costata	Retisacculus semicolonatus Juviella juvensis Ochesaarina variolaris Amygdalella subclusa Nemuniella solida Leiocyamus limpidus Orcofabella obscura Cytherellina magna Kuresaaria angulata Kuresaaria circulata
	Kaugatuma	Nodibeyrichia tuberculata	Frostiella cornuta Aechmina molengraaffii		
		Frostiella groenvalliana	Sleia equestris Nodibeyrichia bifida Signetopsis decorata		
Ludlow	Kuressaare	Plicibeyrichia numerosa	Retisacculus sulcatus Calcaribeyrichia altonodosa Primitiopsis minima Limbinariella maiornata	Hemsiella loensis Calcaribeyrichia simplicior Clavofabella contracta Limbinariella macroreticulata	
	Paadla	Neobeyrichia nutans	Hammariella pulchrivelata Berolinella praevia Hemsiella hemsiensis Neobeyrichia ctenophora Amygdalella paadlaensis Clavofabella diffusa		
Wenlock	Rootsiküla	Beyrichia subornata	Bolbiprimitia inaequalis Ochesaarina lunaris Leiocyamus apicatus Signetopsis maiornata Eukloedenella pilosa Lichvinia? silurica		
	Jaagarahu	Leptobolbina quadricuspidata	Beyrichia hellviensis Clavofabella extenta Clavofabella incurvata Clavofabella vicina Triemilomatella prisca	Craspedobolbina cuspiduiata Craspedobolbina percurrens Craspedobolbina insulicola Clavofabella reticristata Gotlandella cornuta Silenis subtriangulatus Daleiella ianica Daleiella acutafinis	Neoprimitiella versipella Bollia amabilis Paraparchites gregarius Neckajatia lata
	Jaani	Craspedobolbina mucronulata	Apatobolbina gutnica Beyrichia bicuspis Beyrichia suurikuensis Craspedobolbina ornulata Clavofabella juvenca Venzavella germana		
Llandovery	Adavere	Longiscella caudalis - Thlipsuroides walensis	Apatobolbina simplicidorsata Noviportia silurica		
		Beyrichia valguensis	Beyrichia ultima		
	Raikküla	Bythocyproidea sarvi	Craspedobolbina permira Bolbibollia estona Bingeria pristina Herrmannina hisingeri	Aitilia senecta Silenis estonus Microcheilinella mobile Paraprimitia bipunctata Polyzygia estonica Pseudorayella sp.	Neckajatia modesta Longiscula cf. L. smithi Paraparchites tenuicostatus Neoprimitiella litvaensis
	Juuru	Monoceratella edita - Steusloffina eris	Bolbiprimitia tamsaluensis Kiltsiella rosensteinae Bythocyproidea sp.		

ORDOVICIAN TRILOBITES

H. Aru

Ordovician trilobites from Estoria were first described by E. Eichwald and J. Nieszkowski in the middle of the 19th century. The most fundamental work is the monograph by Fr. Schmidt (1881-1907) comprising all the Ordovician and Silurian groups. In the 1930s they were studied by A. Öpik and P. Siegfried, in the fifties and later by E.A. Balashova, V. Jaanusson, Ralf Männil and A. Rõõmusoks. Almost all groups of Ordovician trilobites in the East Baltic need a new revision.

In the East Baltic Ordovician biostratigraphy trilobites have had particular significance since the establishment of the stage classification by Fr. Schmidt (1858; 1881). H. Bekker (1923) and A. Öpik (1930) made some attempts to distinguish trilobite-based series, e.g. *Asaphus*, *Chasmops* and *Isotelus* fauna resp. series. These units roughly correspond to the currently used Ontika Subseries and the Viru and Harju Series accordingly.

The earliest Ordovician trilobite is *Ceratopyge forficula* (Sars), which comes from the Varangu Stage of the Central Confacies Belt. In the North-Estonian Confacies Belt the earliest trilobites are found in the Mäeküla Member of the Latorp Stage, corresponding to the *Megalaspides dalecarlicus* Zone. From this member *M. (Megalaspides) dalecarlicus balticus* (Balashova), *M. (M.) paliformis* Tjernvik, *Megistaspis (Varvaspis) norvegica* (Tjernvik), *Proasaphus primus* Balashova, *Krattaspis viridatus* Öpik, *Evropeites lamanskii* (Schmidt) (jun. syn. *Pliomeroides (Evropeites) primigenus lamanskii*), *Cybele* ? sp. nov., *Encrinuroides* sp. nov., etc, are recorded. This rather diverse fauna contains the earliest representatives of several subfamilies and families.

The diversity of the trilobites of the basal part of the overlying carbonate sequence (Päite and Saka members of the uppermost Latorp Stage and lowermost Volkhov Stage, accordingly) seems to be much more restricted although *Megistaspis* is very common. In North-Estonian Confacies Belt the base of the Volkhov Stage is marked by the appearance of *Megistaspis (Megistaspis)*, but in the Central Confacies Belt and Oslo Belt the appearance of ptychopygids is to be mentioned.

In argillaceous limestones of the Middle Volkhov the megistaspid-ptychopygid fauna contains additionally abundant asaphids and the earliest pterygometopids, cybelids, cheirurids, pliomerids, raphiophorids, agnostids, etc. continue to occur. In the upper substage also illaenids and lichids come in. The Ontikan trilobite faunas of the East Baltic area and Scandinavia are related in general due to similar lithofacies the development of which favours the correlation of the corresponding beds (Männil, 1966).

In the East Baltic no notable faunal change takes place at the Arenig/Llanvirn boundary level. At the base of the Aseri Stage (= the base of the Viru Series), however, a remarkable faunal change can be observed, marked by the disappearance of *Megistaspis* and incoming of *Asaphus (Neoasaphus)* and new phylogenetic lineages of pterygometopids - *Estoniops* and *Chasmops*. The diversity of illaenids and asaphids increases remarkably, particularly in northern Estonia, whilst both families are represented by more than ten species in the Aseri Stage.

The Lasnamägi Stage is relatively poor in trilobites. The fauna becomes enriched in the overlying Uhaku Stage and most diverse in the Kukruse Stage, especially in the North-Estonian Confacies Belt. In the last-mentioned stages asaphids, pterygometopids, illaenids, cheirurids, cybelids, lichids, raphiophorids are very common, also the calymenid *Pharostona nieszkowskii* Schmidt.

The Kurtna Subseries is represented by a common fauna containing abundantly *Asaphus (Neoasaphus)* and different representatives of *Chasmopsinae*. Each stage is characterized by only some particular species.

At the boundary of the Keila and Oandu stages almost the whole fauna is renewed. Only *Stenopareia ava* (Holm) occurs in Vasalemma carbonate mounds ranging across this boundary. A new group of *Chasmopsinae* - the *Macrourus* group, *Hemiarges wesenbergensis* (Schmidt) and *Conolichas eichwaldi* (Nieszkowski) appear, passing up to the overlying Rakvere Stage. In the latter the trilobite fauna becomes impoverished but the new group of encrinurids and the first isotelids make their appearance.

In the stratotype area of the Nabala, Vormsi, Pirgu and Porkuni stages in the North-Estonian Confacies Belt trilobites are represented by a shallow-water illaenid-lichid-pterygometopid association, most often containing *Illaenus angustifrons* Holm s.l., "*Illaenus*" *roemeri* Volborth and *Chasmops eichwaldi* (Schmidt). In the Central Confacies Belt these stages are characterized by the deep-water trinucleid fauna, in Porkuni time comprising additionally also the *Dalmanitina* fauna - *Dalmanitina (Mucronaspis) mucronata* (Brongniart) and *Brongniartella platynota* (Dalman) (Ulst, Gailite, Jakovleva, 1982).

SILURIAN TRILOBITES

R. Männil

The Silurian trilobites of Estonia have been described already in the last century mainly by J. Nieszkowski (1857, 1859), G. Holm (1886) and especially by F. Schmidt in his comprehensive 8-volume monograph (1881-1907). In the current century particular families were described, such as encrinurids (Rosenstein, 1941; R.M. Männil, 1958; R.P. Männil, 1977, 1978), calymenids (R.P. Männil, 1977, 1983), phacopids, etc. Some relatively scarce groups are still in need of revision (*Illaenidae, Lichidae, Otarionidae,* etc.).

Trilobites have been little used in Silurian stratigraphy, particularly due to their general rarity, strong facies control and restricted geographical distribution. However, in similar lithofacies, some species and assemblages are of remarkable stratigraphical value, at least in stage-level correlation. Some of most common species are shown in Pl. 11, 12.

Llandovery faunas. During the late Ordovician the typical Ordovician families and genera gradually disappeared and only some rare genera are shared with the Silurian (*Stenopareia, Platylichas*). At the beginning of the Silurian *Phacopidae* and several new genera - *Calymene, Opsypharus, Encrinurus (Nucleurus), Acernaspis,* etc. first appeared. The latter two have particular significance being relatively numerous, diverse and restricted only to the Llandoverian strata.

No trilobites are known from the lowermost 10 meters of the Silurian sequence. The oldest finds are those of *Acernaspis* sp. indet. from South-Estonian boreholes. They belong to the Õhne Formation and in Ikla core occur below the finds of *D. confertus,* i.e. in the basal part of the Llandovery (Kaljo, Vingisaar, 1969).

The lower and middle Llandovery trilobite fauna is diverse but rather scarce and species described from here are not known abroad. From the shelf rocks of the Varbola Formation of the Juuru Stage only some specimens of *Leonaspis varbolensis* Bruton and undescribed *Calymene* have been recorded. A relatively diverse and numerous fauna is known from the Tamsalu Formation, containing in the western Estonia *Encrinurus (Nucleurus) kiltsiensis* Rosenstein, *Calymene ansensis* Männil, etc. in shoal sediments and locally abundant *Opsypharus* and *Stenopareia* in bioherms.

In marlstones of the Õhne Formation the most common are *Acernaspis estonica* Männil and *Encrinurus (Nucleurus) rotundus* Männil.

In the upper Llandovery the diversity and number of trilobites increase considerably. The Rumba Formation of the Adavere Stage contains the last species of *E. (Nucleurus),* most commonly *E.(N.) rumbaensis Rosenstein.* In the marlstones of the overlying Velise Formation these have been replaced by the first species of *Encrinurus* s.str. - *E. triangulus* Männil and *E. schisticola* Tõrnquist. The latter is originally described from the Retiolites Shale of the Kullatorp Stage in Sweden (Törnquist, 1884). In West Estonia und North Latvia it often co-occurs with *Acernaspis konoverensis* Männil and *Calymene frontosa* Lindström. The last one is a good index fossil in the upper Llandovery which due to its great facies tolerance occurs in the transition belt as well as in the open shelf sediments. Outside the East Baltic area it is common in the Teremtsy Formation of

Podolia (Gritsenko et al., 1987); has been found also in the Pentland Hill, Wether Law Linn Formation of Scotland (Clarkson, Howells, 1981) and in Gotland, where, however, the vertical range of the species is longer, extending from the lower Visby marls to Högklint limestones (Bruton et al., 1979).

Wenlock faunas. Across the Llandovery/Wenlock boundary the trilobite fauna changes remarkably. *Acernaspis* and *Stenopareia* disappear, *Proetus* (s.str.), *Bumastus* and *Dalmanites* come in, the latter being abundant in marlstones of the transition and basinal facies belts. Calymenids start to prevail, occurring in all trilobite facies. Typical is also *Encrinurus* (s.str.). The role of proetids increases, they are represented by *Proetus* (s.str.), *Cyphoproetus* and *Warburgella*, all appearing in the Wenlock for the first time.

From the outcrop area Lower Wenlock trilobites presumably have not been recorded. In South Estonia the oldest are the representatives of the deep-water *Calymene orthomarginata* species group (*C. orthomarginata* Schrank, *C. mimaspera* Schrank, *C. restevensis* Balashova). In the Ohesaare borehole the lowest finds of *C. mimaspera* belong to the *M. riccartonensis* zone (331-338 m; Kaljo, 1970), in Pärnu core the first specimens of relatively shallow-water *C. restevensis* occur just above the Llandovery/Wenlock boundary (ca 1 m higher of the range of *C. frontosa*). *C. restevensis* was first described from the Restevo Formation of the Lower Wenlock in Podolia (Balashova, 1975; Gritsenko et al., 1987).

The Wenlock trilobites are very common in the marlstones of the Jaani Stage, in South Estonia also in the lower half of the Jaagarahu Stage. Two extensive, more or less coeval associations are distinguished here. Relatively shallow-water calcareous marlstones contain dominantly *Encrinurus punctatus* (Wahl.), *Calymene blumenbachii* Brongniart and *Proetus concinnus osiliensis* Schmidt. This association is typical in the outcrops of the Jaani Stage on North Saaremaa and in Pärnu and Kaugatuma boreholes. Outside Estonia it is recorded from the South-Lithuanian subsurface (Ukmerge core) and from the Kitaigorod Stage of Podolia (Gritsenko et al., 1987). The dominant species of the association are known from the Wenlock of Great Britain and Gotland (Thomas et al., 1984; Bruton et al., 1979). The stratigraphic value of the association is reduced due to its relatively long vertical range. In Estonia it occurs in the Jaani and Jaagarahu stages, in other regions its members are found almost throughout the Wenlock.

The most deep-water Wenlock association is dominated by *Calymene orthomarginata*, *C. mimaspera* and *Dalmanites punctim* Schrank. In Estonia it is recorded only from the subsurface argillites in the southwestern part (Ohesaare and Ruhnu boreholes), but it is very numerous in the corresponding sediments of West Latvia and Lithuania. The named species are still known and originally described from the erratic boulders of North-German Plain (Schrank, 1970, 1972). The association ranges also from the Jaani into the Jaagarahu Stage (Männil, 1982).

Besides, the younger marlstones of the Jaagarahu Stage have yielded an association with a more restricted stratigraphic and areal distribution. It is represented by *Encrinurus balticus* Männil, *Cyphoproetus insterianus* Schrank, *C. latifrontalis* Schrank and *Calymene minimarginata* Schrank, and outside the East Baltic recorded only from the erratic boulders of North Germany.

Due to continuing regression the upper Wenlock is poor in trilobites. Only numerous finds of *Pseudotupolichas ornatus* (Angelin) have been made locally in bioherms of the Jaagarahu Stage and *Warburgella estonica* Männil in the Maasi Beds of the Stage. In the Rootsiküla Stage trilobites have not been found.

Ludlow and Pridoli faunas. The Upper Silurian trilobite faunas of Estonia are of shallow water origin and generically monotonous, differing notably from those of the transitional belt sediments of the Wenlock as well as of the Ludlow of Latvia. Greatly dominating are calymenids and proetids.

The Wenlock/Ludlow boundary is not defined by trilobites because they are unknown from the uppermost Wenlock and two lower beds of the Paadla Stage. Earliest to appear are rare specimens of *Balizoma obtusus* (Angelin), *Proetus* (s.l.) *pulcher* Nieszkowski, unnamed *Calymene*, etc. *B. obtusus* is known from the Hemse and Eke beds on Gotland (mostly from calcarenites, indicating ecological relationship to a high energy environment; Ramsköld, 1985). The species occurs abundantly also in the open shelf sediments of the Malinovets' Formation of Podolia (Gritsenko et al., 1987).

Trilobites of the Kuressaare Stage are of very low diversity. Only two species - *Calymene flabellata* Männil and *Proetus kuressaarensis* Männil have been described from the Kudjape Beds.

In the Pridoli the diversity and frequency of trilobites have increased considerably. The open shelf biomicrites of the Kaugatuma Stage have yielded numerous *Proetus* (s.l.) *nieszkowskii* Männil, *Calymene schmidti* Männil and C. kaugatumensis Männil, accompanied by rare *C. dnestroviana* Balashova, *Eophacops helmuti* Männil and *Acaste dayiana* R. et E. Richter. Outside Estonia a comparable association occurs in the Zvenigorod Formation of Podolia with the common species *C. dnestroviana* and *A. dayiana* (Gritsenko et al., 1987).

In calcareous mudstones and biomicrites of the Ohesaare Stage *Calymene conspicua* Schmidt is common, co-occurring with *C. soervensis* Männil, *Eophacops serotinus* Männil, etc. A generically similar fauna is characteristic also of the Zvenigorod Formation of Podolia.

ORDOVICIAN CHITINOZOANS

J. Nõlvak

Chitinozoans are geographically widespread and have proved to be a useful tool for the correlation of the Ordovician-Devonian rocks although their mode of life and systematic affinities (probably polyphyletic group) are controversial. They were discovered by A. Eisenack in 1929. His first studies were based on insoluble residues from the Ordovician and Silurian glacial erratics occurring along the southeast coast of the Baltic Sea (see Eisenack, 1937). For over forty years he continued to publish also numerous studies of Ordovician chitinozoans (Eisenack, 1955-1976; see Grahn, 1980, p. 39). Later important publications (R. Kozlowski, S. Laufeld, R. Männil, R. Wrona, N. Umnova, Y. Grahn: see Grahn, 1984, p. 30) have provided a substantial degree of maturity to Chitinozoa knowledge from the Baltic region.

Up to date, the chitinozoan succession in the East Baltic sequences through the entire Ordovician is not fully documented. More detailed work has been done mainly in the Middle and Upper Ordovician (Nõlvak, 1980; Männil, 1986), but mostly with very few adequate descriptive and/or illustrative support, except Grahn (1984) from the lower part of the Ordovician from Tallinn area.

The information about the level of the first appearance of chitinozoans in different Ordovician confacies belts on the East-European Platform is somewhat confused. In Moscow Basin it is pointed out by N. Umnova (1981) in the Leetse Stage and in the Tremadoc. (1) Now the term "Leetse" is used as a formation name. (2) If these beds with chitinozoans belong to the Leetse Formation they must be related to the Latorp Stage and to the lowermost Arenig (see also Männil, 1966; Achab, 1986, Fig. 3). In North Estonia chitinozoans appear in the rocks of the Leetse Formation (Latorp Regional Stage in East Baltic-Hunneberg Stage in Sweden, see Grahn, 1984).

The following account of chitinozoans from the North-Estonian Confacies Belt is based on the information from Rapla core through the entire Ordovician and data from more than 20 Estonian upper Ordovician sections. Rapla borehole is situated 60 km south of Tallinn. 215 rock samples (of 350-500 g weight) were obtained from the entire 160.3 m thick Post-Temadocian sequence. In this comparatively well documented section the lithological differentiation is relatively great (Põlma, 1972) and portions of the sequence are rich in fossils, except the Latorp and the lower part of the Volkhov stages and also the Porkuni Stage. The lack of chitinozoans was caused by locally developed strong dolomitization. As pointed out by L. Põlma (1972), the Ordovician carbonate sedimentation was interrupted by frequent breaks and more agitated environments (than in the Central Confacies Belt) were prevailing. In the Rapla sequence at many levels a change in lithology is associated with a change in the distribution of chitinozoans. Besides, the taxonomic diversity of chitinozoans is wider and the number of taxa with short vertical ranges is higher in the lower part of the Ordovician, as it is known for some other faunal groups.

So, the lower boundaries of the stages Volkhov-Idavere and also Oandu-Pirgu (Fig. 14) can be drawn relatively precisely, except for the boundary between the Lasnamägi and Uhaku stages. The chitinozoan association in the interval from the upper substage of the Idavere to Oandu is relatively stable.

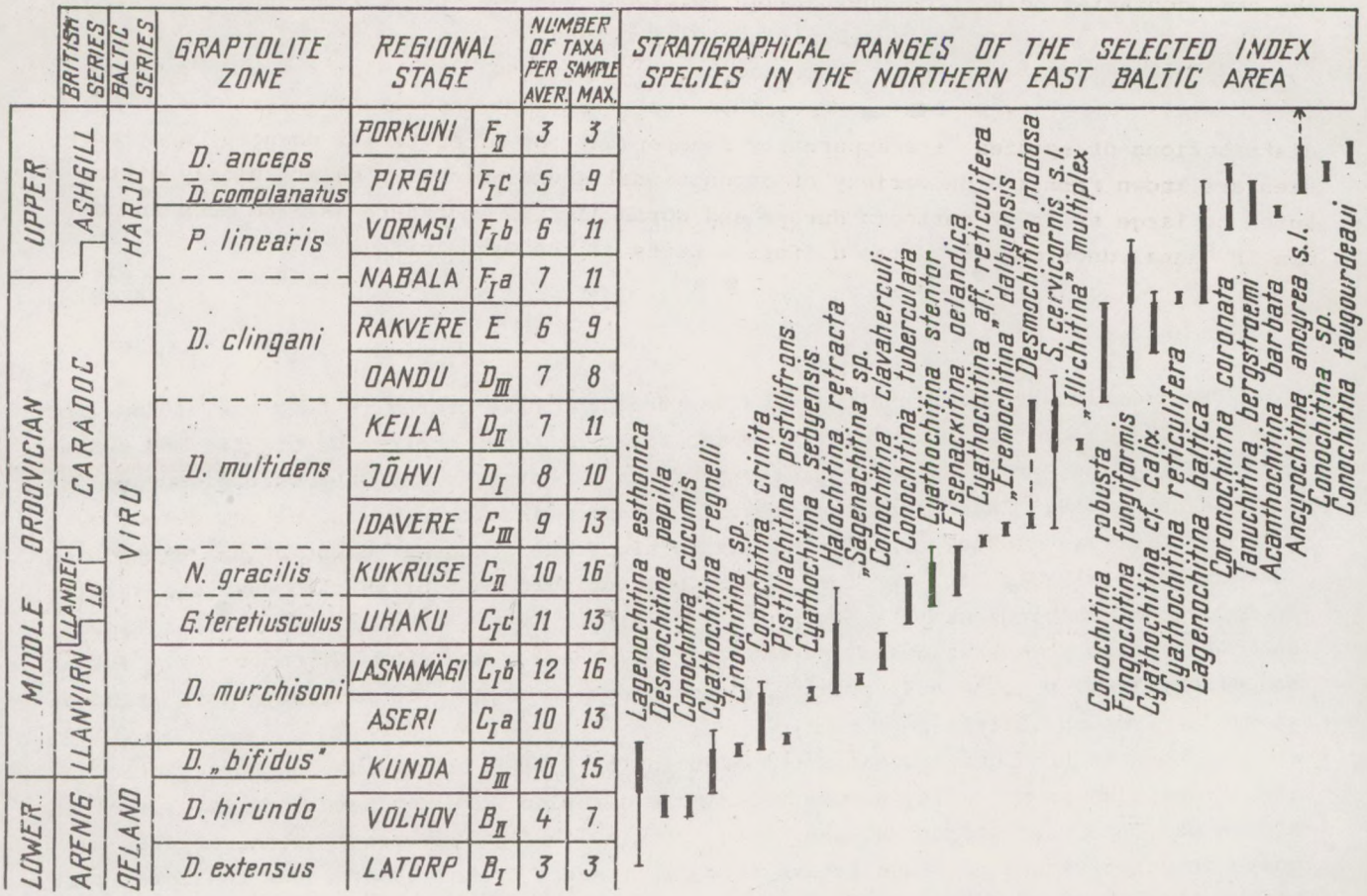


Fig. 14. Stratigraphical ranges of the selected chitinozoan species in the northern East Baltic Ordovician. Stratigraphy according to Resheniya (1987) and Bruton (1984).

The most pronounced change in chitinozoan fauna can be followed at the base of the Oandu Stage (see Hints et al., 1989, Fig. 2) and at the Ordovician-Silurian boundary. Only some species of *Cyathochitina*, *Ancyrochitina*, probably *Coronochitina* and *Conochitina* are found in the lowermost Silurian. Totally 110 species and subspecies have been recorded and at least five taxa can be added on account of the layers in the uppermost Ordovician, which are locally absent in the Rapla section. Among chitinozoans 12 taxa (from 76 recorded in the interval Volkhov-Keila and 34 in Oandu-Pirgu) have wide vertical ranges - almost through the entire Ordovician, which at the same time are somewhat fragmentary: they are not found in every bed. Most of the taxa range through 2-5 stages and may prove to be useful stratigraphical markers, at least locally. Selected short-ranging species are presented in Fig. 14 and Plate 13. The well-known fact is confirmed, that chitinozoan associations commonly consist of relatively few species: about 7 on average and rarely as many as 16 (Fig. 14). The abundance of specimens of different species fluctuates greatly, even in the samples from the units with the same lithology. The dominance of one species in the carbonate deposits of open sea facies belts is also greatly variable and has probably no stratigraphical value. However, these questions need more detailed analysis (layer by layer), but the size of samples is important and the widely used amount (50 grams) seems to be insufficient.

The associations and abundance of chitinozoans in the northern East-Baltic sections show a great similarity to those from equivalent beds in Sweden (Laufeld, 1967), but the stratigraphical ranges of some species are considered to be wider (Grahn, 1982). Except subjective views in taxonomy, these differences may be explained by future studies from

the same confacies belt (from the Latvian sections) and the direct comparison is appropriate. This is essential before defining zonal boundaries.

Conclusions based on data presented by many authors (Jenkins, 1967, 1969; Paris, 1979, 1981; Achab, 1986, 1987; Hart, 1986 etc.) support the opinion, that the lateral distributions of species are apparently independent of minor facies changes, many species are known from a wide variety of depositional environments. They are widely distributed on large areas of northern Europe and North America and there is also much in common in faunal development in the different parts of the Ordovician.

SILURIAN CHITINOZOANS

V. Nestor

Some Silurian rock-samples from Estonia have been studied already by A. Eisenack in his initial works on Chitinozoa (1931, etc.). Investigation of Silurian chitinozoans of Estonia were continued by R. Männil (1970) and by the author (Nestor 1976, 1982, 1987, etc.).

The present review is based on the material from more than 50 outcrops and core-sections. Lower Silurian chitinozoans are better known (Nestor 1976-1987), whereas the Upper Silurian ones have been examined in 6 core-sections and some outcrops only.

Distribution and facies control

Throughout the whole Silurian sequence of Estonia chitinozoans are of wide distribution, though their frequency and diversity are well controlled by rock types. The abundance and taxonomic variability of chitinozoans reach the maximum in the sections of South and South-West Estonia, where marls and mudstones are predominating. In more carbonate sections of Middle Estonia their diversity and number decrease, the occurrence becomes more sporadic. Chitinozoans were not found from the lagoonal dolomites, winnowed clastic, skeletal and pelletal grainstones, bioherms and marine redbeds.

Lateral chitinozoan communities have not been distinguished, except for one example at the level of the lowermost Raikküla Regional Stage (Nestor, in press).

Biozonation

In the Silurian sequence of the East Baltic area 31 chitinozoan zonal units have been distinguished, five of which are called interzones as they contain scarce chitinozoans without specific forms. The lower limit of the zone is usually defined by the first appearance of the zonal species or disappearance of a number of species occurring in the previous zone (interzone). Unfortunately, the restricted space of this paper does not enable to characterize Silurian chitinozoan zonation in detail.

Fig. 15 shows the stratigraphical range of 60 selected chitinozoan species, although the total number of species occurring in the East-Baltic Silurian sections is more than twice greater (see also Plates 14, 15).

Chitinozoan biozones are correlated with regional graptolite zonation (data by R. Ulst, 1987; D. Kaljo, 1970 and pers. comm.) on the basis of their co-occurrence in some sections (Ohesaare, Ikla, Ventspils borings, etc.) and are linked to the standard scale according to the correlation chart of the East-European Platform (Resheniya ..., 1987).

Fig. 15 shows also the correspondence between chitinozoan biozones and local stratigraphic units.

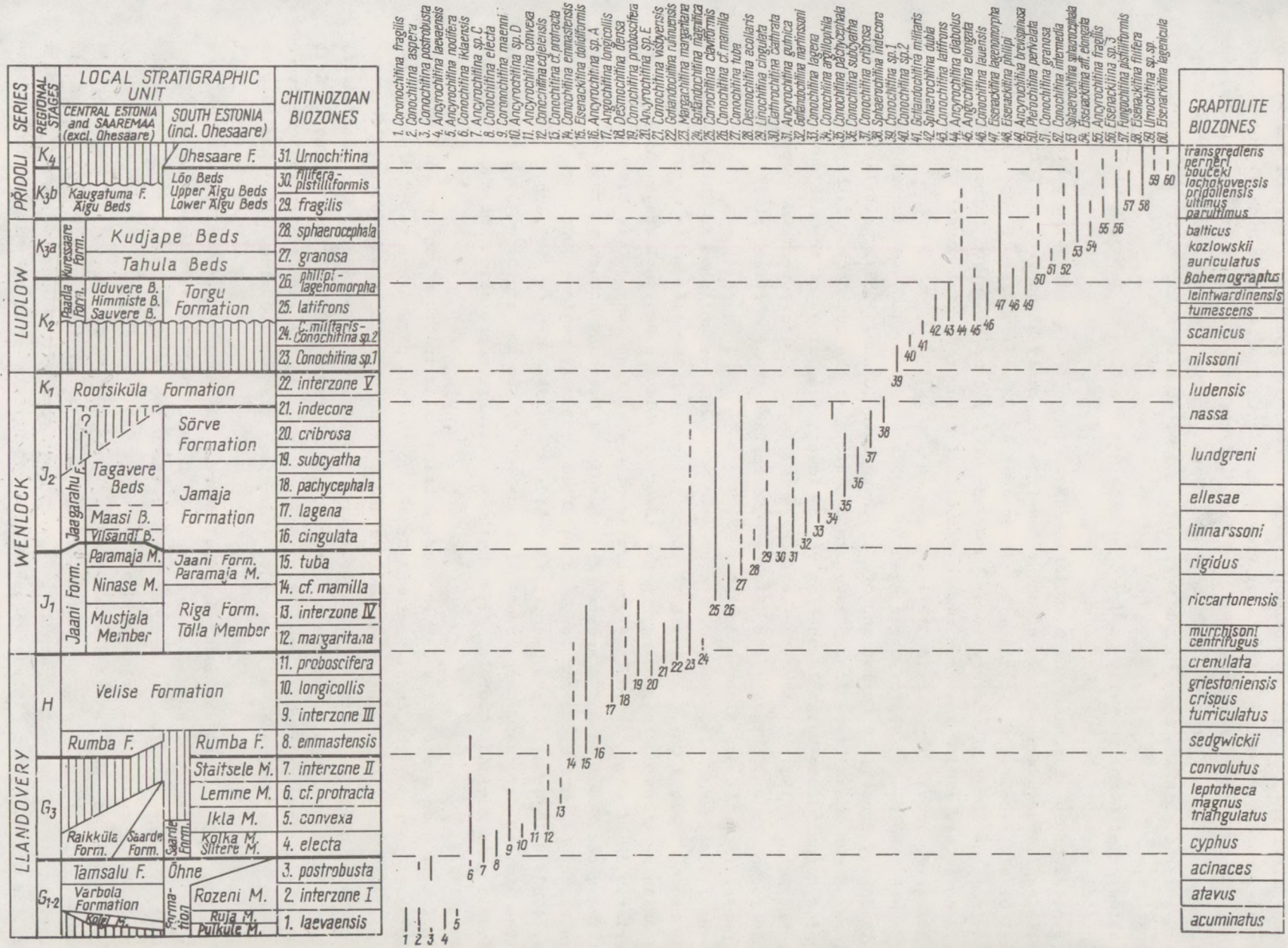


Fig. 15. Chitinozoan biozones in the Silurian of Estonia and ranges of 60 selected species, related to graptolite biozones and local stratigraphic units.
F - formation, B - Beds, M - Member.

Correlation

Wide distribution of many characteristic chitinozoan species, first of all within the North-European Paleobiogeographical Province, North America and China allows to use them as a good biostratigraphic tool. For example, recently F. Paris (1989) selected 50 Silurian taxa, mostly from Baltoscandia and North Gondvana and showed the total range of each species, linking them to the British standard stratigraphic scale and graptolite biozonation.

Below brief comments will be given on the distribution of some chitinozoan taxa, more useful for correlative purposes.

Typical of the Estonian Juuru Regional Stage *Conochitina postrobusta* Nestor and *Ancyrochitina laevaensis* Nestor were identified from the early Llandovery of Libya (Paris, in Hill et al., 1985). *C. postrobusta* (determined as *C. aspera* Nestor) was also established from the lower Llandovery (*acuminatus* and *vesiculosus* zones) of China, Yangzi region (Geng & Cai, 1988) and from the lowermost Silurian of Brabant Massif, Belgium (determined as *C. robusta* by Martin, 1973).

Conochitina electa Nestor, succeeded by *Coronochitina maennili* Nestor is known from the Llandovery Brassfield Formation of southern Ohio (Grahn, 1985), similarly to the sections of the Raikküla Regional Stage in Estonia, at the boundary of the *cyphus* and *gregarius* zones. Some Raikküla species can be identified also in the Anticosti succession. A. Achab (1981) listed *Conochitina sp. 1* (= *C. electa?*) from the upper part of Becscie Formation and *Conochitina iklaensis* Nestor and *Ancyrochitina sp. 1* (= A.sp.D in this paper) from the Gun River Formation.

The *Conochitina iklaensis* - *C. emmastensis* Zone was established in China, in the Yangzi region (Geng & Cai, 1989), where it coincides with the *sedgwickii* graptolite Zone in Estonian sections corresponding to the lowermost Adavere Regional Stage. A very characteristic chitinozoan assemblage consisting of *Angochitina longicollis* Eisenack, *Desmochitina densa* Eisenack and *Conochitina proboscifera* Eisenack occurs in the Velise Formation of the Adavere Stage and has been reported from many regions (Dorning, 1981; Verniers, 1982; Hill et al., 1985; Mabillard & Aldridge, 1985; Grahn, 1985,etc.).

The similar successive appearance of a number of species in the Wenlock and Ludlow of Estonia and Gotland (Laufeld, 1974) allowed reliable correlation of these sections (Nestor, 1982).

A lot of good correlative levels can be traced also in other regions. Analogically to the basal part of the Jaani Regional Stage, coincident disappearance of *Angochitina longicollis*, *Conochitina visbyensis* Laufeld and *C. acuminata* Eisenack in the lowermost Wenlock is recorded also from Great Britain (Aldridge et al., 1979), Brabant Massif, Belgium (Verniers, 1982), northern Kentucky, USA (Grahn, 1985), China (Geng & Cai, 1988). The disappearance of *Conochitina proboscifera* in the *riccartonensis* Zone is another good stratigraphic level, recorded from Great Britain (Dorning, 1981) and Belgium (Verniers, 1982).

At the base of the Jaagarahu Regional Stage, in the *flexilis* Zone *Clathrochitina clathrata* Eisenack, *Gotlandochitina martinssoni* Laufeld and *Linochitina cingulata* (Eisenack) appear successively in the lower part of the Slite Beds (Laufeld, 1974) and in the Coalbrookdale Formation of Great Britain (Dorning, 1981).

The basal part of the Paadla Formation of Estonia contains *Conochitina latifrons* Eisenack, *Angochitina elongata* Eisenack and *Ancyrochitina diabolus* Eisenack, which in the Latvian Ventspils section appear in the topmost part of the *scanicus* Zone (see Ulst in Gailite et al., 1987) in the sequence of Great Britain - in the Middle Elton Formation (Dorning, 1981) and in Gotland - in the lower part of the Hemse Beds.

At the base of the Kuressaare Regional Stage *Eisenackitina lagenomorpha* (Eisenack) and *E. philipi* Laufeld replace *Conochitina latifrons* Eisenack and *C. lauensis* Laufeld. A similar succession has been reported from the boundary of the Bringewood Formation and Leintwardine Beds (Dorning, 1981) in Great Britain and from the topmost part of the Hemse Beds of Gotland (Laufeld, 1974).

Pterochitina perivelata (Eisenack), one of the index species of the Pridoli Series (Paris, 1981; Kriz et al., 1986) in East-Baltic sections appears already in the lowermost part of the Kuressaare Regional Stage. Nevertheless, the successive appearance of *Conochitina granosa* Laufeld, *Sphaerochitina sphaerocephala* Eisenack, *Gotlandochitina villosa* Laufeld in the same stage allows to correlate it with the late Ludlow of Britain (Dorning, 1981) and Eke, Hamra and Sundre beds of Gotland (Laufeld, 1974).

In the Ohesaare core the section of the Kaugatuma Regional Stage contains *Ancyrochitina fragilis* Eisenack, *Eisenackitina filifera* (Eisenack) and *Fungochitina pistilliformis* (Eisenack), not recorded from Gotland, but constituting the assemblage of the so-called Beyrichia Limestone described by A. Eisenack (1955) from the erratic boulders of Pridoli age.

Unfortunately, *Urnochitina urna* Eisenack, the most characteristic species of the type area of the Pridoli Series (Paris in Kriz et al., 1986) has not yet been identified from the East Baltic sections.

In the Ohesaare Regional Stage at the lowermost part of the Ohesaare cliff species of *Urnochitina* appear for the first time. Representatives of this genus, earlier known only from the Lower Devonian of North Africa (Taugourdeau et Jekhowsky, 1960) and Poland (Wrona, 1980), have been found recently also from the early Ludlow strata (Y. Grahn, pers. comm.) of the Brasilian Silurian sequence.

In summary, stratigraphic ranges of selected chitinozoan species in Gotland (Laufeld, 1974), Great Britain (Aldridge et al., 1979; Dorning, 1981), Belgium (Verniers, 1982), China (Geng & Cai, 1988), Anticosti (Achab, 1981), USA (Grahn, 1985) show rather good similarity with the East Baltic chitinozoan succession. Their good relationship with the standard graptolite zones allows to use them for age determination in shelly sequences.

CONODONTS

P. Männik, V. Viira

Ordovician and Silurian conodonts of Estonia have been studied continuously during the last 25 years. The first decade was devoted to the Ordovician conoconts (Viira, 1966, 1974), later mostly to Silurian ones (Viira, 1982 a, b, 1983; Männik, Aldridge, 1989). In the course of the Cambrian-Ordovician boundary studies conodonts from the corresponding beds have gained much attention also in Estonia (Viira, Sergeeva, Popov, 1987).

In general, conodonts are well-preserved, CAI is as low as 1-2 (see Pl. 16-18). Distribution and abundance are clearly controlled by facies. According to preliminary data maximum abundances lay within shoal and open shelf belts, but minimum in the deeper part of a basin (Kaljo et al., 1986).

Lower and Middle Ordovician Biostratigraphic zonation is presented in Table 12. Weakly cemented quartz sandstones of the Kallavere Formation contain mostly species of the genus *Cordylodus*. The distribution of conodonts in the rock is uneven, in places they occur very abundantly, but there are some barren samples as well. All the *Cordylodus* zones from *andresi* until *rotundatus-angulatus* are represented in the Kallavere Formation, therefore Cambrian-Ordovician boundary will fall within this unit, no matter at which level it will be drawn. It is important that depending on the sedimentation process and later denudation there is no continuous *Cordylodus* zonation in a particular sections (Kaljo et al., 1986).

Recovery of conodonts from the argillites of the Türisalu Formation (= *Dictyonema* shale) is complicated. The study has shown that the base of the shale falls within *C. rotundatus-C. angulatus* Zone.

Conodonts of the Varangu Formation belong to the *Drepanoistodus deltifer* Zone and are represented by two complexes of different age (Viira, Kivimägi, Loog, 1970; Viira, 1970). The lower complex comprises *D. deltifer pristinus* Viira (= *Scandodus varanguensis* Viira, 1970) and *C. angulatus* Pander, *C. rotundatus* Pander, and others. The upper complex includes *D. deltifer deltifer* Lindström, *Paroistodus numarcuatus* Lindström, *Oneotodus variabilis* Lindström, etc. Our subdivision well corresponds to those established by H. Szaniawski (1980) in the Chalcedon Beds (Holy Cross Mountains, Poland).

Glauconite sands of the Leetse Formation contain a diverse conodont fauna referable to the *Paroistodus proteus* Lindström, *Prioniodus elegans* Lindström and *Oepikodus evae* Lindström zones. The first conodonts described by C. Pander in 1856 come from these sands in the Leningrad Region. There are some features in common between conodont assemblages of the Leetse Formation and of the North-Atlantic and Midcontinent Provinces.

Limestones of Toila Formation represent the beginning of the Ordovician carbonates containing a very diverse and rich conodont assemblages, unfortunately many of them are still poorly studied.

In the Sillaoru Formation stratigraphically the lowermost appearance of *Eoplacognathus* has been recorded by S. Mägi (1984).

In the Napa Formation *Polonodus clivosus* Viira has been identified.

Table 12. Conodont zonation for the Lower and Middle Ordovician in northern Estonia

Series	Graptolite & trilobite zones	Reg. stag.	Formations	Zones	Subzones
CARADOC	D. multidens	D_{II}		A. tvaerensis	
		D_{I}			B. alobatus
		C_{III}	Vasavere		
			Tatruse		B. gerdae
	N. gracilis	C_{II}	Viivikonna		B. variabilis
LLANDEILO			Korge kallas	P. anserinus	
	G. teretiusculus	$C_{I}c$	Väo	P. serra	E. lindstroemi
					E. robustus
					E. reclinatus
LLANVIRN	D. murchisoni	$C_{I}b$			E. foliaceus
		$C_{I}a$	Aseri	E. suecicus	2
	D. "bifidus"	B_{III}	Pakri / Loobu / Napa	E. pseudoplanus	
ARENIG	D. hirundo		Sillacru	E.? variabilis	1
		B_{II}	Toila	P. originalis	
				B. navis	
				B. triangularis	
	D. extensus	B_{I}	Leetse	P. flabellum	
				O. evae	
	T. approximatus			P. elegans	
				P. proteus	
TREMADOC	Angelina sedgwicki	A_{III}	Varangu	D. deltifer	D. deltifer deltifer
	Shumardia pusilla				D. deltifer pristinus
			Türisalu	C. angulatus - C. rotundatus	
	C. tenellus D. flabelliforme	A_{II}	Kallavere	C. lindstromi	
				C. intermedius	
				C. proavus	
				C. andresi	

1 - S. Mägi (1984) established in Ontika section *Microzarkodina flabellum parva* Zone. 2 - *Microzarkodina ozarkodella* from a corresponding subzone established by A. Löfgren (1978) is common in many sections of Estonia.

Skeletal limestones of the Väo Formation contain a very diverse conodont fauna corresponding to the *Pygodus serra* Zone and *Eoplacognathus foliaceus* (Fåhraeus), *E. reclinatus* Fåhraeus, *E. robustus* Bergström and *E. lindstroemi* (Hamar) subzones. According to R. Männil between the latter two subzones there is an interval with *E. miaopoensis* An, Du, Gao, Chen et Lee (= *E. bergstroemi* Männil, 1986).

From the Saku Member of the Vasalemma Formation a peculiar conodont assemblage has been identified, containing, i.a. *Ozarkodina* aff. *rhodesi* Lindström, *Icriodella* cf. *superba* Rhodes.

Table 13. Correlation of the Upper Ordovician and Lower Silurian conodont zonations

SERIES	STAGES	Graptolite zones	Regional stages	NORTH ESTONIA Formations	NORTH ESTONIA This paper	LITHUANIA & SCANDINAVIA Brazauskas 1987	GREAT BRITAIN Aldridge 1972	GREAT BRITAIN Aldridge & Schönlaub 1989	NORTH AMERICA EAST CANADA McCracken & Barnes 1981	NORTH AMERICA USA Nicoll & Rexroad 1969
WENLOCK	SHEINWOODIAN	M. riccartonensis			K. ranuliformis			O. sagitta rhenana	Uyeno & Barnes 1983	
		C. murchisoni	I_1	Jaani		K. ranuliformis				
		C. centrifugus			P. amorphognathoides		P. amorphognathoides Ass. Zone	P. amorphognathoides	P. amorphognathoides	P. amorphognathoides
LLANDOVERY	TELYCHIAN	M. crenulata				P. amorphognathoides / P. procerus; P. angulatus / P. celloni				
		M. griestonensis		Velise		L. pennatus	I. inconstans Ass. Zone		I. inconstans	
		M. crispus	H		P. celloni	A. latus		P. celloni	D. staurognathoides; D. staurognathoides; O. aldridgei	P. celloni
		M. turriculatus					H. staurognathoides Ass. Zone			
		R. maximus								
	AERONIAN	M. sedgwickii		Rumba						
		M. convolutus				D. kentuckyensis	I. discreta-I. deflecta Ass. Zone	D. staurognathoides	I. discreta-I. deflecta	D. kentuckyensis
		C. gregarius	G_3		P. tenuis			P. tenuis		
	RHUDDANIAN	C. cyphus		Raikküla	D. kentuckyensis					
		C. vesiculosus		Tamsalu				D. kentuckyensis		
		A. acuminatus	G_{1-2}	Varbola		O.? nathani			O.? nathani	
ASHGILL	HIRNANTIAN	G. persculptus				Bergström 1977	Orchard 1980	Savage & Barnes 1981	McCracen & Barnes 1981	Sweet 1984
		C.? extraordinarius	F_{II}	Ärina					Fauna 13	A. shatzeri
	2	D. anceps	U	Adila			A. ordovicicus			
	1				A. ordovicicus	A. ordovicicus				
	PUSGILLIAN	D. complanatus	F_I c L	Moe				A. ordovicicus	Fauna 12	A. divergens; A. grandis; O. robustus
		P. linearis	F_I b	Kõrgessaare			A. superbus		Fauna 11	O. velicuspis
			U	Saunja						
	ONNIAN		F_I a L	Paekna	A. superbus	A. superbus				
CARADOC		D. clingani	E	Rägavere				A. superbus	Fauna 10	B. confluens
			D_{III}	Hirmuse						
				Vasalemma						

Upper Ordovician

A correlation chart for Upper Ordovician and Lower Silurian is presented in Table 13. Conodonts in the Upper Caradocian-Ashgillian (E - F_{II}) are mostly represented by long-ranging species *Belodina compressa* (Brakson et Mehl), *Birksfeldia* cf. *circumplicata* (Orchard), *Decoriconus costulatus* (Rexroad), *Drepanoistodus suberectus* (Brakson et Mehl), *Eocarniodus gracilis* (Rhodes), *Walliserodus* cf. *amplissimus* (Serpogli), abundant *Panderodus* sp.sp. and the fragments of *Amorphognathodus* sp.

Rare diagnostic species appear at some levels. E.g. in the Paekna and Saunja formations *Hamarodus europaeus* (Serpagli) occurs, in the Kõrgessaare and Tudulinna formations (corresponding to the greatest Late Ordovician transgression), there appeared a rich conodont fauna with *Plectodina teamis* (?) (Branson et Mehl), *Icriodella* sp.n. Rhodes and *Icriodella* aff. *superba* Rhodes occurring only in these beds. The lowermost identifiable *Amorphognathus ordovicicus* Branson et Mehl in Estonia is also established from this interval.

The number of conodonts decreases rapidly in the overlying Moe, Oostriku, Adila and Halliku formations. Besides rare specimens of the long-ranging species, *Pseudooneotodus mitratus* (Moskalenko) and *Strachanognathus parvus* Rhodes occur. From South Estonia also *Icriodella* sp.n. has been established.

In the shallow-water Ärina Formation, corresponding to the final stage of the Late Ordovician regression, conodonts are extremely rare. Only a few specimens of *Ozarkodina* cf. *pseudofissilis* (Lindström), *Birksfeldia* cf. *circumplicata*, *Decoriconus costulatus*, *Belodina* ? sp. and *Walliserodus* sp. are established in a fauna dominated by *Panderodus* sp.

Silurian

In the Varbola, Tamsalu and Õhne formations conodonts occur rarely. Only a few specimens of *Distomodus kentuckyensis* Branson et Branson, *Oulodus* ? cf. *kentuckyensis* (Branson et Branson), and more abundant *Panderodus* cf. *unicortatus* (Branson et Mehl) are found. Rare *Ozarkodina* ex. gr. *oldhamensis* (Rexroad) appear in the lowermost part of the Õhne Formation (in the Ruja Member) in the sections of Central and South Estonia.

In the basal part of the Raikküla Formation there appears a quite rich conodont assemblage containing *Ozarkodina* ex. gr. *oldhamensis*, *Kockelella manitoulviensis* Pollock, Rexroad et Nicoll, *Ozarkodina excavata* ssp.n., *Oulodus* ? cf. *kentuckyensis*, *Pranognathus teruis* Aldridge et Männil, *Icriodella* sp., *Panderodus* cf. *unicostatus* and some new, undescribed species. In the upper part of the formation *Oulodus* ? sp. A Uyeno and Barnes comes in. In the cryptocrystalline limestones and marls of the Saarde Formation, southward replacing the Raikküla Formation very rare conodonts - only *Panderodus* sp. and probably *Distomodus* cf. *kentuckyensis* have been established.

The samples from the overlying Rumba Formation, as a rule, do not contain conodonts. Only a few small specimens of *Panderodus* sp. and *Ozarkodina* sp. are recorded from some sections.

An extremely rich *celloni*- and *amorphognathoides* fauna was brought to the Baltic Basin by the Late Llandovery transgression. Characteristic of the marls of the Velise Formation and the lower part of the overlying Mustjala Member (Jaani Formation) are *Pterospathodus celloni* Walliser, *P. amorphognathoides* Walliser, *Carniodus carnulus* Walliser, *Distomodus staurognathoides* (Walliser), *Ozarkodina polinclinata* (Nicoll et Rexroad) and Oulodus ? spp. As a rule, the fauna is dominated by *Panderodus* cf. *unicostatus*. In the deepwater carbonate clays the last one is replaced by *P. spasovi* Drygant and *Pterospathodus amorphognathoides* by *P. procerus* (Walliser). Only from the lowermost beds of the Velise Formation *Astropentagnathus irregularis* Mostler and *Aulacognathus kuehni* Mostler are established. *Apsidognathus tuberculatus* Walliser occurs in the *celloni* Zone

Table 14. Correlation of the Wenlock and Upper Silurian conodont zonations

Series	Stages	Graptolite zones	Regional Stages	Formations	Saaremaa offshore	Saaremaa nearshore	Lithuania Brazauskas 1987	Podolia Drygant 1984	Gotland Jeppsson 1983	Aldridge & Schönlaub 1989	Centr. Nevada Klapper & Murphy, 1975	Appalachian Mnts. Helfrich 1975
PŘÍDOLI		transgrediens	K_4	Ohesaare	O. eosteinhornensis	remscheidensis	O. aff. s. remscheidensis	S. s. eosteinhornensis	H. steinhornensis	O. r. eosteinhornensis	uppermost eosteinhorn.	S. steinhornensis
		perneri									eosteinhornensis	
		boucêki	K_3b	Kaugatuma		canadensis	O. s. eosteinhornensis					eosteinhornensis
		lochkovensis				eosteinhorn. s. str.					P. index fauna	
		ultimus										
LUDLOW	LUDFORDIAN	formosus	K_3a	Kuressaare		aff. scanica	O. crispa	S. crispus	H. s. crispa H. wimani	O. crispa	crispa	S. crispus
		Neocucullograptinae	K_2	Paadla	O. crispa	D. dubius	R. dubia	I. latialatus	P. dubius D. dubius	O. snajdri	latialata	S. tillmani
		leintwardinensis								P. silurious		
	GORSTIAN	tumescens			O. aff. snajdri	"Ozarkodina" sp. S	P. silucus	P. silurious	P. silurious		silurious	S. snajdri
		scanicus					K. variabilis	(A. ploeckensis) (O. crassa)	K. variabilis	A. ploeckensis	ploeckensis	S. bicornutus
		nilssoni					O. bohemica					
WENLOCK	HOMERIAN	ludensis	K_1	Rootsi kûla / Sakla	O. bohemica bohemica	C. murchisoni	O. silurious	S. sagitta	H. snajdri	O. bohemica bohemica	K. variabilis (lower)	S. sagitta bohemicus
	SHEINWOODIAN	lundgreni	J_2	Jaagarahu / Sârve	K. amsdeni		K. amsdeni	K. patula	K. walliseri	O. sagitta sagitta	K. stauros	
		ellesae		Jämaja							K. amsdeni	
		linnarsoni			K. walliseri	O. sagitta rhenana			H. s. rhenana	O. sagitta rhenana		
		rigidus	J_1	Jaani	K. ranuliformis		K. ranuliformis	K. walliseri	K? ranuliformis		K. ranuliformis	
		riccartonensis										
											Oklahoma Barrick & Klapper 1976	

only. It is replaced by *A. walmsleyi* Aldridge and *A. rugirosus* Mabillard et Aldridge in the *amorphognathoides* Zone interval. The first elements of *Kockelella ranuliformis* (Walliser) appear in the upper part of the *celloni* Zone and *Ozarkodina excavata* (Branson et Mehl) in the *amorphognathoides* Zone.

The boundary between the *celloni* and *amorphognathoides* zones lies in the upper part of the Velise Formation. The upper boundary of the *amorphognathoides* Zone is determined by almost total disappearance of the rich zonal assemblage of conodonts. Only *Ozarkodina excavata, Kockelella ranuliformis, Walliserodus* cf. *sancticlairi* Cooper, *Panderodus* sp. and a few other simple cones continue into the overlying sediments.

Correlation chart for upper Silurian (starting with Upper Wenlock) is presented in Table 14.

The Jaagarahu Formation is characterized by a relatively poor conodont assemblage. The Vilsandi Beds comprise *Ozarkodina sagitta rhenana* Walliser, occurring in shallow-water bioherm facies, therefore being not easily-used for standard zonation. J. Barrick and G. Klapper (1976) used for this purpose *Kockelella* which is more tolerant to facies. On Saaremaa *Kockelella* is found in deeper-water sediments. Thus, the Jämaja Formation has yielded *K. walliseri* Helfrich and the Sõrve Formation *K. amsdeni* Barrick et Klapper. The latter is recovered also from the Maasi Beds of the Jaagarahu Formation. Thus *K.* aff. *amsdeni* is known from Kurevere cliff section and *K. ranuliformis* (Walliser) from Sepise outcrop.

Dolomitic rocks of the Sakla Formation have yielded *Ozarkodina confluens bucerus* (Viira), in places occurring in great numbers.

The Viita Beds of the Rootsiküla Formation are characterized by the zonal species *O. bohemica bohemica* (Walliser) concurring with *O. confluens densidentatus* (Viira), *O. e. excavata* (Walliser), *Oulodus siluricus* (Walliser) and the earliest *Ctenognathodus murchisoni* (Pander). The Kuusnõmme Beds contain the same association except *O. e. excavata*, but several species have certain characteristic morphological features. From the Vesiku Beds a shallow-water "ecological specialist" *C. murchisoni* was described (Viira, 1982).

The rich and diverse conodont fauna of the Paadla Formation on Saaremaa Island stands out among the Ludlow conodonts. This is firstly due to identification of a very big (3-4 mm) *"Ozarkodina"* sp. S. from the Sauvere Beds at Roopa cliff, and now being described as a new genus. Secondly, the Paadla Formation is characterized by morphologic diversity of *O. confluens* (Branson et Mehl) referring to shallow shelf conditions. In the Ludlow of Saaremaa the deep water zonal species *Ancoradella ploeckensis* Walliser, *Polygnathoides siluricus* Walliser and *Pedavis latialata* Walliser have not been recorded, but the second species was identified from Latvia and by A. Brazauskas (1987) from Lithuania. Characteristic for shelf facies are *O. crispa* (Walliser) and long-ranging *O.* aff. *snajdri*. The first occurs only in the Upper Paadla Formation (outcrop Karala, borings Ohesaare, Kaugatuma).

Three succeeding formations - Kuressaare, Kaugatuma and Ohesaare - contain mostly few species. *Ozarkodina eosteinhornensis* (Walliser) as well as *Oulodus elegans* (Walliser) appear in the Tahula Beds ranging to the end of Silurian. *O. confluens*, a long-ranging species from the Wenlock and Ludlow, continues in the Pridoli. Abundance of all these species depends on the rock type. *O. confluens* is common in skeletal limestones and totally lacking in mudstones. *O. eosteinhornensis*, on the contrary, is more frequent in argillaceous rocks. Systematic study of *O. eosteinhornensis* enabled to distinguish four subzones in the eosteinhornensis Zone (Viira, 1982a).

GRAPTOLITES

D. Kaljo, R. Männil

In the Ordovician and Silurian of Estonia, mostly represented by carbonate rocks, graptolites occur abundantly in argillite and marlstone interlayers at certain levels only, sporadically also in carbonate rocks. Basing on the studies of graptolite facies of the neighbouring areas, particularly Latvia, Lithuania, Poland and Scandinavia, Estonian graptolites as well are of great significance for the chronostratigraphic and facies correlation.

Tremadoc

The oldest nematophorous dendroid graptolite *Gorgonia flabelliformis*, described by E. Eichwald in the middle of the 19th century, has played an important role in the Tremadoc stratigraphy, serving as a basis for the erection of the *Dictyonema* resp. *Rhabdinopora flabelliformis* graptolite Zone. Rather often this zone is considered as the beginning of the Ordovician.

Only a part of Tremadoc of Estonia is graptolite-bearing: the so-called Dictyonema Shale and its interlayers in sandstones of the Pakerort Stage (Türisalu and Kallavere formations) and in clays-argillites of the Varangu Stage.

For the last 50 years taxonomy of Estonian graptolites has been studied mainly by foreign geologists, the most prominent being O.M.B. Bulman (1966, etc.) and A.M. Obut (1953, etc.), recently also B.-D. Erdtmann (1982, etc.). Biostratigraphy of Tremadoc graptolites has found repeated treatment in connection with the Cambrian/Ordovician boundary problems (Kaljo, Kivimägi 1970; 1976; Kaljo et al., 1986).

The Türisalu Formation of the Pakerort Stage contains a very rich yet specific assemblage of *Rhabdinopora* - earlier forms (*parabola* group) and *Anisograptus* are practically lacking, frequent are *R. flabelliformis*, *R. norvegica* and *R. multithecata*, rarely occur *R. sociale*, *R. desmograptoides*, *R. anglica*, abundant are also transition forms between certain species.

Generally the species and subspecies appear in a typical order: *socialis* + *flabelliformis*, *norvegica*, *anglica* + *multithecata*. This succession can be treated as subdivisions of the *R. flabelliformis* Zone.

The upper part of the Türisalu Formation, chronostratigraphically belonging already to the upper Tremadoc Varangu Stage, and the Varangu Formation contain the so-called *Clonograptus-Didymograptus* fauna: *Kiaerograptus kiaeri* (= or partly not *"Didymograptus" primigenius*), *Clonograptus sarmentosus* group, *Bryograptus bröggeri*, etc. The relations between their distribution levels are not clear yet, as well as the transition to the overlying Arenig graptolite zones. The Estonian sections are of little help for solving the last problem, but correlation with Central Russian sections, where representatives of the *Tetragraptus approximatus* Zone appear above the *Adelograptus tenellus* Zone (Kaljo, 1974), seems to have more perspective.

At present we consider it correct to distinguish only one *Adelograptus-Kiaerograptus* Zone at the level of the Ceratopyge Beds in Estonia.

Post-Tremadoc Ordovician

In the East-Baltic area the upper Lower Ordovician (Ontikan) graptolites are well represented only in the subsurface of the Central Confacies Belt in western Latvia and North-West Lithuania. In this sequence the complete succession of the lower and middle Arenig graptolite zones from the *approximatus* Zone to the *angustifolius elongatus* Zone are well recognized by the presence of *Tetragraptus phyllograptoides*, *Didymograptus balticus*, etc. A higher extremely graptolitiferous interval in this sequence corresponds to the upper part of the *extensus* and the lower part of the *artus* (*"bifidus"*) zones and has yielded a typical assemblage (Gailite, Ulst, 1975; Ulst et al., 1982; Paškevičius, 1976).

In the Ontikan carbonate sequence of northern Estonia so far only rare finds of graptolites have been reported (Öpik, 1927; Jaanusson, 1960; Männil, unpublished). The Volkhov Stage has yielded *Didymograptus* sp. indet. and *Meandrograptus ? geniculatus*, the middle Kunda Stage - *Didymograptus pakrianus*, *D.* cf. *artus*, *Holmograptus* cf. *lentus*, etc. The rocks containing these graptoloids belong to the *hirundo* and *artus* zones, respectively, and are well correlatable with the Central Confacies Belt sequences of western Latvia and Öland.

In the Middle and Upper Ordovician carbonate sequence of Estonia graptoloids have been reported only by occasional rhabdosome finds. Graptoloid rhabdosomes have been found in outcrop sections of the Aseri to Jõhvi stages and they are currently identified as *Didymograptus acutus* (C_Ia), *Climacograptus distichus* (C_Ib), *Gymnograptus linnarssoni* (C_Ic), *Amplexograptus bekkeri* (C_{II}), *Climacograptus kuckersianus* (C_{II}-C_{III}), *Pseudoclimacograptus* cf. *scharenbergi* (D_I) and *Amplexograptus* cf. *fallax* (D_I-D_{II}). Most of these species are useful index fossils although generally they are represented in the collections by few specimens only and have a restricted correlative value. From the beginning of late 1960s new information about the diversity and distribution patterns of graptoloids of the carbonate sequence of Estonia became available due to processing of outcrop and drilling core samples for obtaining organic-walled microfossils. Most of the preliminary information about graptoloids obtained up to 1973 and some additional data have been published by Männil (1976, 1986, 1988). In the following the most essential results with some comments on correlations are briefly summarized.

In most samples of the Aseri Stage and in some of the Lower Lasnamägi (=*Climacograptus distichus* range zone) Stage didymograptid siculae are common indicating the *murchisoni* Zone. Higher up an interval follows which corresponds to the *Eoplacognatus reclinatus* Subzone and has so far yielded beside *Glyptograptus* sp. only rare specimens of *Dicaulograptus hystrix* and *Lasiograptus haplus* not found elsewhere. The base of this interval coincides with the top of the "Dolomite Bank" of the middle Lasnamägi and its thickness is 1.3 m in the Lasnamägi quarry and 0.5 m in the Osmussaare section. The top of this interval is marked by the appearance of *Gymnograptus linnarssoni* and its associates and coincides with the *reclinatus/robustus* subzonal boundary (= the base of the Uhaku Stage). This boundary level is well defined by graptoloids and/or zonal conodonts in all studied sections of both the North Estonian and Central Confacies belts as well as in Scania (Jaanusson, 1960; Bergström, 1971, 1973). The interval under consideration seems to correspond to the upper Folkeslunda limestone of Öland and the *murchisoni-teretiusculus* "interregnum" of the sequence of the Builth and Shelve inliers of Wales (see Hughes, 1989).

The basal Uhakuan *Gymnograptus linnarssoni* Range Zone contains in Estonia an assemblage of graptoloids completely different from that of the Folkeslunda Limestone, consisting of *Dicellograptus* sp. sp., *Nemagraptus*, *Dinemagraptus*, *Dicranograptus*, *Amygograptus* (?), etc. The base of the upper Uhaku which roughly corresponds to the *serra/an-*

serinus zonal boundary of the conodont succession is marked by the presence of a not yet identified species of *Pseudoclimacograptus*, the correlative value of which is unclear so far.

Near the base of the overlying Kukruse Stage a new assemblage of graptoloids appears including *Nemagraptus gracilis*, *Orthograptus uplandicus* and *Amplexograptus bekkeri*, in the upper part of the stage supplemented with *Leptograptus*, *Pseudoclimacograptus* and *Nanograptus*. This assemblage indicates directly the *gracilis* Zone, although its upper limit is currently in Estonia not yet possible to draw on graptolite evidence.

The Jõhvi and Keila stages are characterized in the type area by the presence of *Amplexograptus* cf. *fallax* which has been recorded in at least five different levels throughout the whole sequence, corresponding according to indirect correlations to the upper *multidens* and the lower *clingani* zones.

In the uppermost Viruan sequence *Climacograptus spiniferus* (= *C. diplacanthus*) has to be mentioned, which according to finds of its specific siculae seems to range from the lower Rakvere up to the very top of the lower Nabala Stage. At the last mentioned level, corresponding to the base of the Saunja Formation, a new assemblage of graptoloids including *Climacograptus* sp. n. aff. *C. kuckersianus* (with a sicula having a secondary nema developed from one prosicular thread), *Rectograptus gracilis* and *Archiretiolites regimontanus* appears. It seems reasonable to assume that this stratigraphic level of the Estonian sequence correlates with the *clingani/linearis* zonal boundary and according to the definition of the Upper Ordovician (Harjuan) series by Jaanusson (1960), it corresponds to the base of the latter.

Of the members of the last mentioned assemblage in the Estonian sequence at least *Rectograptus gracilis* seems to range upward to the top of the lower Pirgu Stage, which according to indirect correlations seems to represent an equivalent of the *complanatus* Zone. In the overlying beds in Estonia only *Climacograptus supernus* has been recorded which probably indicates an *anceps* or even a somewhat younger age.

Silurian

A detailed review about the East Baltic Silurian graptolite zones and their study history was recently published by D. Kaljo, I. Paškevičius and R. Ulst (1984). Among taxonomic studies basing on the Estonian material, the most outstanding is the paper by A.M. Obut and Y.V. Rytzk (1960) on dendroid graptolites.

In the Estonian Silurian graptolites are of a rather restricted occurrence as the corresponding deep-water facies only "touches" the study area (see the above paper, also Kaljo ed., 1970; Bassett, Kaljo, Teller, 1989, etc.) - particularly in the region of Sõrve Peninsula and in the south-western part of South Estonia, correspondingly in the upper Llandovery-lower Wenlock and in the middle Llandovery and somewhat higher.

Sporadic graptolite finds come from the Llandovery of Middle Estonia (Raikküla and Adavere stages) and very rarely from the upper Wenlock. These recordings, often made during the study of chitinozoans from carbonate rocks, refer to the possibility of using graptolites more widely in the correlation of the Silurian shelly facies like in the Ordovician. The corresponding materials are still being worked at or were presented above in the comments to the Silurian stratigraphic chart of Estonia (Table 2), therefore they are not repeated here.

As graptolites are highly significant in orthostratigraphy, the main task of the study of Estonian graptolites, mostly coming from the area with carbonate rocks and shelly fauna, is to correlate graptolite zonation with biozonal schemes of other groups. The relations between different biozonations help to settle several problems rising in practical as well as in theoretic stratigraphy.

VERTEBRATES

T. Märss

The study of Estonian Silurian (in the present sense) vertebrates started 136 years ago, the first paper was published by E. Eichwald in 1854. A short review of the most essential works is given below.

C. Pander (1856) was the first to describe the vertebrates from Saaremaa Island, showing the morphological and microstructural features of their skeletal remains. J.V. Rohon (1892, 1893) was interested in the position of Silurian fishes in the zoological system and their phylogenetic relationships.

Undoubtedly, of great significance in the study of Silurian fishes was the discovery of the Himmiste locality by A. Luha in 1929 containing abundant thelodont *Phlebolepis elegans* and several osteostracans. Fishes collected from the Himmiste (Loc. 6:6), and also the Viita quarry (Loc. 6:5) can be seen now in many geological museums of the world and these have been widely used in research.

G.M. Robertson (1938, 1950, plus about 20 papers) described the morphology of the head shields of Saaremaa osteostracans (to some extent also of anaspid fragments) and gave the criteria of the species. R. Denison (1951) also treated the exoskeleton morphology of our osteostracans but reviewed the habitat of fishes as well (Denison, 1956).

In 1931 K.-H. Hoppe, having visited Saaremaa, published data on stratigraphy, paleontology and paleogeography but also interpretation of living conditions of organisms.

Papers by W. Gross (1967, 1971, etc.) and V. Karatajute-Talimaa (1978), dealing with the morphology and microstructure of fish remains cover also the Estonian material.

By now the Silurian fishes of Estonia and of the whole East-Baltic area have been studied rather thoroughly. In the last decades a list of thelodont and fish species was established together with their stratigraphic and facies distribution, the zonal scheme was elaborated and the possible correlations were brought out (Mark-Kurik, 1969; Karatajute-Talimaa, 1978; Märss, 1982, 1986, 1989, etc.). A relatively high level of fish studies has allowed to propose the vertebrate-bearing sections of East-Baltic Silurian and Devonian for the standard of biostratigraphical zonation based on vertebrates (Blieck et al., 1988).

The oldest skeletal fragments of Silurian vertebrates have been recorded in Estonia from the Middle Llandovery. Only scarce finds come from the Llandovery, Lower and Middle Wenlock. In the Upper Wenlock and Lower Ludlow (up to the Himmiste Beds of the Paadla Regional Stage) less than 1/3 of the samples yielded vertebrates. In this interval species diversity is poor and the number of specimens is low. Higher in the Ludlow, the amount of samples with vertebrate scales and skeletal fragments reaches 3/4, in the Pridoli, however, almost 9/10 of the whole lot. Analogically grow the abundance and species diversity of vertebrates.

The increase in the significance of agnathans and fishes in time obviously had evolutionary reasons. Ecological factors seem to have played a secondary role, although at certain levels they are quite essential for the formation of faunal assemblages.

Among Silurian vertebrates articulated specimens occur rarely. Mostly we can find scattered elements of the exoskeleton: shield fragments, plates, tesserae, scales, fin

spines, jaw bones, teeth, etc. As the endoskeleton of Silurian vertebrates was not ossified, it has not preserved in the rocks. In the Silurian of Estonia all groups of agnathans are represented: Thelodonti, Heterostraci, Osteostraci and Anaspida. Of Gnathostomi occur Acanthodei and Osteichtnyes (subclass Actinopterygii). The oldest occurrences of both agnathans and gnathostomes come from the Llandovery.

Silurian agnathans and fishes constitute a rather heterogenous group of vertebrates. Differing from each other morphologically, they had also different modes and habitats of life. In the Silurian of Estonia and Latvia the transition and depression facies have been studied insufficiently and therefore we have no complete picture about the facies distribution of their animals.

Thelodonts and acanthodians were of the widest occurrence (Table 15), whereas the older beds were dominated by thelodonts, the younger ones by acanthodians. In younger beds the predominance of acanthodians shifted coastwards.

Table 15. Frequency of vertebrates in different facies of the East-Baltic Silurian. Below the bold line thelodonts preponderate over acanthodians, above the line - vice versa
T - *Thelodonti*, H - *Heterostraci*, O - *Osteostraci*, A - *Anaspida*, Ac - *Acanthodei*, Os - *Osteichthyes*. The groups have been arranged in order of frequency.

		Lagoon	Shoal	Open shelf	Slope	Depression
Přidoli	K_4	AcTHOsO	AcTHOsO	AcTHOs		
	K_3b	AcTH	AcTHOsO	AcTHOsO	AcT	
Ludlow	K_3a	TAcHOA	TAcHOA	AcTHOA	AcTHO	
	K_2	TOAAc	TOAAcOs	TAcHOsO	AcTHOs	
Wenlock	K_1	TOAAc	TOA	TAOAc	T	AcT
	J_2	TAc	TAc	TAOAc	TAc	
	J_1			TAc		
Llandovery	H			TAc		
	G_3		T			
	G_{1-2}					

In Estonia the first thelodonts were recorded from the grained skeletal grainstones of the shoal facies belt of the Llandovery Raikküla Regional Stage, the first acanthodians were found in the nodular limestone of the open shelf facies belt of the Adavere Regional Stage. In the Wenlock thelodonts and less numerous acanthodians occur in all facies. The Ludlow Kuressaare time was the most favourable period for thelodonts. Their maximum was in the near-shore facies belts. Acanthodians, however, occurred the most abundantly in the Pridoli shallow and open shelf sediments. In bioclastic, skeletal floatstones and skeletal grainstones of the shallow facies belt accumulations of skeletal fragments - Bone Beds - were formed.

Heterostracans are at present the oldest discovered vertebrates in the world, described from the iddle Ordovician of North and South America and Australia (Denison, 1967; Lehtola, 1973, 1983; Ritchie, Gilbert-Tomlinson, 1977; Gagnier et al., 1986). In the East-Baltic area they have been found in the Uduvere Beds of Paadla Regional Stage, in the rocks of transition and open shelf facies belts, in higher strata occurring also in the sediments of the lagoonal and shoal facies. The most abundant finds were recorded from the latter facies.

The oldest osteostracans and anaspids in Estonia were found in the Wenlock Jaagarahu Regional Stage from the rocks of the open shelf facies belt. In the Ludlow and higher they are more numerous in the deposits of the lagoonal and shoal facies belts, decreasing in number in offshore direction.

Osteichthyans, at present the dominating group of fishes, are represented by the oldest actinopterygians in the world (in Estonia beginning with the Ludlow Paadla time). From the Silurian only 2 genera with 3 species are known, mostly from the shelf and transition facies.

Due to their wide facies distribution thelodonts, acanthodians and osteichthyans have been used for the elaboration of the zonal scheme (Märss, 1982, 1989) presented here with some supplements. Below follow some comments on this scheme (Table 16).

The genus names *Logania* (Gross, 1967) and *Loganella* (Turner, Peel, 1986) were occupied, therefore these names have been replaced by *Loganellia* now (Turner, in press). The latter has been used by D. Fredholm (1989, 1990, in press) and in present review and scheme.

Obviously in the Middle and Upper Llandovery we can distinguish the *L. scotica* Biozone. It is given here provisionally without boundaries.

D. Fredholm (1990, in press) has described a new species of *Loganellia* from the upper part of the Slite Beds as it was different from *L. taiti*, originally described by H.C. Stetson (1931) from Scotland. As the whole genus Loganellia needs revision and *L. taiti* is to be redescribed, there seem to be no reason to change the name of this animal now. The thelodont, recorded from the middle Wenlock of the East Baltic, Gotland, Ringerike, Timan-Pechora region and Severnaya Zemlya, is one and the same species, serving as a good index-species.

On Saaremaa Island, in the upper part of the Sauvere Beds of the Paadla Regional Stage and on Gotland Island in the lower part of the Hemse Beds (b and c, Fredholm, 1988) in several sections *Phlebolepis ornata* precedes *P. elegans*. Obviously it would be expedient to distinguish it here as a separate zone. *P. ornata* seems to be related to the reef facies sediments.

A conodont sample of Ludlow age belonging to R.J. Aldridge (Nottingham) contains also scales of *Phlebolepis elegans*. This confirms the occurrence of that important species on the British Isles as well.

T. admirabilis occurs parallel to *T. sculptilis*, although appearing somewhat later. It is used as a local index-species. This and other vertebrates are depicted in Pl. 19.

Table 16. Correlation of the Silurian and lowermost Devonian vertebrate zonations.

Data by V. Karatajute-Talimaa (1983; Talimaa, Melnikov, 1987), S. Turner (1973; Aldridge, Turner, 1975; Siveter, Turner, 1982; Turner, Turner, 1974) and D. Fredholm (1988, 1989) were used. Characteristic species are illustrated in Plate 19

	SERIES	REGIONAL STAGE	BEDS	ESTONIA	LATVIA	GOTLAND	SOUTHERN BRITAIN	TIMAN-PECHORA REGION	C. URALS	SEV. ZEMLYA
				ZONAL AND/OR CHARACTERISTIC VERTEBRATES						
DEVONIAN	LOCHKOV	TILŽE			Tilže: Turinia pagei, Traquairaspis sp.		Turinia pagei; Traquairaspis sp.; Corvaspis sp.	Ovin-Parma: Traquairaspis cf. symondsi	Mikhailovsk: Turinia pagei, Traquairaspis sp.	Sev. Zemlya: Corvaspis sp., Tesseraspis sp.
SILURIAN	PŘIDOLI	OHESAARE K4		Por. punctatus	Targale Fm.: K. timanicus; Por. punctatus		Ledbury Fm.: Katoporus sp., G. alatus, L. kummerowi; Acanthodians	Greben Reg. Stage: K. timanicus, G. alatus, Por. punctatus; Lophosteus superbus	Demid Bds.: Turinia pagei, Traquairaspis sp.	Krasnaya Bukhta Fm.: ? L. cuneata
		KAUGATUMA K3b	L, Ä	N. gracilis; T. sculptilis (L. ludlowiensis); Tadmirabilis	Minija Fm.: N. gracilis; T. sculptilis; Tadmirabilis		Stages not yet defined; DICSF, TSF: L. ludlowiensis			
	LUDLOW	KURESSAARE K3a	K, T		Venta.:	FBHS: T. sculptilis (L. ludlowiensis)	Ludfordian	Gerd'ju Reg. St.: T. sculptilis; A. hedei	(Tabuska Bds.): T. sculptilis, A. hedei	Ust-Spokoinaya Fm.: A. hedei
		PAADLA K2	U, H, S	A. hedei; P. elegans; P. ornata; L. martinssoni	Mi.; E: A. hedei; P. elegans; L. martinssoni	Hemse: A. hedei; P. elegans; P. ornata; L. martinssoni	Gorstian: A. hedei ?; Loganellia sp.; Loganellia sp.B; L. martinssoni		Kuba Bds.: P. elegans	
	WENLOCK	ROOTSIKÜLA K1	Sn, Vs, Kn, Vt		Geluva:	M, H: Klinteb.	Homer.: RINGERIKE; 10: L. martinssoni, L. taiti; 9g: Loganellia sp.	Sed'jel Reg. St.: Loganellia sp.2	Voron'ya: L. martinssoni	Samolovich Fm.: ? L. martinssoni
		JAAGARAHU J2	T, M, V	L. taiti ?	Riga Fm.:	Slite: L. taiti				
		JAANI J1					Sheinwood			
	LLANDOVERY	ADAVERE H					Tel.: Loganellia sp.A	Filip.: L. taiti		
		RAIKKÜLA G3		L. scotica			Aer.: L. scotica	Dzhagal: Loganellia ex. gr. scotica		
		JUURU G1-2					Rhudd.			

CALCAREOUS ALGAE

A. Kõrts, R. Einasto, R. Männil, E. Radionova

Though the Ordovician calcareous algae of the Baltic Region first described came from the bedrock of Estonia (Eichwald, 1840) the main research on them (Stolley, 1893-1898, and others) has been carried out on the basis of erratic rocks which origin and age is not precisely known. In the 20th century some new information on the occurrences of the algae in Ordovician bedrock has been added (Bekker, 1924; Öpik and Thomson, 1933; Moskalenko, 1956; Männil, 1961), but the taxonomy and distribution patterns of most forms remain obscure due to the absence of systematic study and unsufficient preservation of algal remains.

Silurian calcareous algae of the Baltic Region were first described by A. Rothpletz (1908, 1913), but on the whole they remained poorly examined for a long time, while only V. Maslov (1956, 1962) recorded some red algae from the Silurian of Saaremaa. Thorough paleontological studies on calcareous algae of Wenlock and Ludlow were started by E. Radionova in the 1970s (Radionova, Einasto, 1986, 1988). As a result of these studies calcareous algae were distinguished in the rocks of all three main shallow-water facies belts - lagoonal, shoal and of open shelf.

Stratigraphic remarks

Calcareous algae are present in the Ordovician sequence starting with the Middle Ordovician Aseri Stage, where *Coelosphaeridium excavatum* appears (see Fig. 16). Up to now no answer has been found to the question, why calcareous algae have not been distinguished in the Lower Ordovician. It does not seem convincing to say that they did not exist there at all. Probably they didn't preserve or their occurrences are too rare.

Starting with the Idavere Stage the diversity of calcareous algae increases including the first appearance of red algae - *Solenopora filiformis*.

As already known from the studies by E. Stolley the dasyclad algae represent in the Viru and Harju Series of the Baltic area two different floras: the first being characterized by the presence of *Coelosphaeridium*, *Mastopora* and *Cyclocrinites* (C_Ia-E), the second - by the absence of cyclocrinitids and the dominance of *Vermiporella* and presence of *Dasyporella* and *Palaeoporella* (F_Ia-F_{II}).

Many species such as *Coelosphaeridium kohtlense* (C_{II}), *Cyclocrinites porsus* (D_I), *C. balticus* (E), *C. spasskii* (E) and some others have been so far recorded from certain stages only and they may be considered as index resp. zonal species. Still all such records need further confirmation.

As a rare exception *Mastopora concava* may be considered as a common and important indicator of the Idavere and Jõhvi stages and lower Keila beds. Among the other stratigraphically important cyclocrinitids the rich occurrence of *Cyclocrinites spasskii* in the lowermost Rakvere Stage of North-Western Estonia and that of *Coelosphaeridium wesenbergense* in the same stage of Eastern Estonia has to be mentioned. Rocks yielding these algae have been termed the *Cyclocrinites* - limestone (Eichwald, 1840) and *Coelosphaeridium* - limestone, accordingly. In the same stage *Vermiporella* is first recorded. *Vermiporella* is rock-building in the middle and upper Pirgu as well as in many small carbonate mounds of Porkuni age.

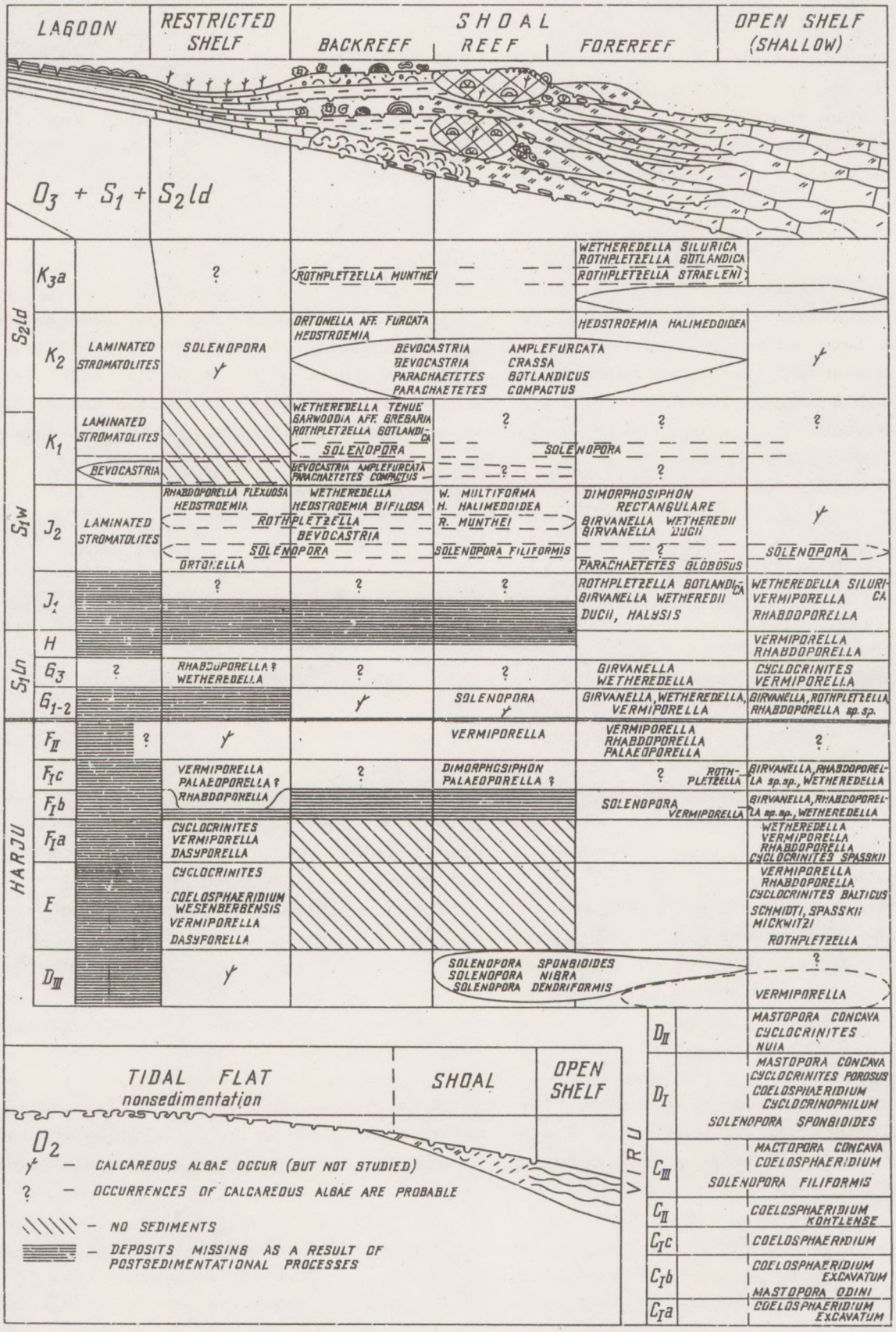


Fig. 16. Distribution of calcareous algae in the Ordovician and Silurian of Estonia.

Calcareous algae identified as *Dasyporella* and/or *Palaeoporella* make their first rare occurrences probably in the Rakvere Stage and become stratigraphically important starting with the lower Pirgu ("*Palaeoporella*"-*limestone*). In the North Estonia Confacies Belt they are known as characteristic fossils of the early Pirguan Moe Formation, as well as of the contemporaneous rocks in Scandinavia. Owing to almost complete recrystallization of these algal remains their identification even on the genus resp. family level has so far not been possible. Following the suggestion by E. Stolley (1898) and T. Moskalenko (1956) about the absence of *Palaeoporella* in rocks older than the Porkuni Stage the occurrences in the Pirgu have been usually considered as belonging to the genus *Dasyporella* (see Põlma, 1982).

In addition to the already mentioned genera in the Harjuan bedrock of Northern Estonia also *Rhabdoporella* (at least 3 species) and *Dimarphosiphon* are present. Finds of calcareous algae in Llandovery, although not very numerous, enable to presume that most of the Late Ordovician flora remained flourishing during the Llandovery as well. *Cyclocrinites* occurs in calcareous mudstones of the lower part of the Raikküla Stage (Seliste and Varbla cores). Juuru, Raikküla and Adavere stages (Kirikuküla, Seliste and Varbla cores) have yielded *Vermiporella, Rhabdoporella pachyderma, Rh. intermedia, Rh. flexuosa, Rothpletzella, Girvanella* and *Wetheredella*. *Rhabdoporella* seems to be abundant on some levels in Adavere and *Vermiporella* in the Juuru Stage.

The diversity of calcareous algae increased during the following Wenlockian regression and lasted till the end of Ludlow (see the next chapter).

Facial remarks

During the temperate Middle Ordovician time when argillaceous calcareous shallow open shelf facies were widespread the most common representatives of calcareous algae were *Coelosphaeridium, Cyclocrinites, Mastopora* and *Solenopora*. The content of algal skeletal debris in the Middle Ordovician rocks is 1-2 % but in the Upper Ordovician 45-90 % (Põlma, 1982).

Late Ordovician as well as Llandoverian tropical climate and widespread shallow open and restricted shelf lime mud areas and skeletal sand shoals with small reefs (D_{III}, $F_I c$, F_{II}, G_{1-2}, G_3) formed a suitable environment for dasyclads *Vermiporella, Rhabdoporella* and *Palaeoporella*. Encrusting algae *Wetheredella* and *Rothpletzella* being more characteristic to the following regressive Wenlock, started to appear already during Llandovery in shoaly and lagoonal parts of the basin.

Wenlock and Ludlow were characterized by the maximum diversity of shoal facies and respectively the calcareous algae as well. As a result of intense regression at the end of Wenlock, wide areas were covered with shallow-water lagoonal sediments. Rocks of lagoonal origin (Vesiku Beds of the Rootsiküla Stage) yield laminated stromatolites and oncolites containing *Bevocastria amplefurcata*. Microcrystalline skeletal wackestone of backreef (Maasi Beds of Jaagarahu, Vesiku and Soeginina Beds of Rootsiküla and Sauvere and Himmiste Beds of the Paadla Stage) contain *Rothpletzella* (Pl. 22), *Rhabdoporella*, skeletal stromatolites and oncolites with *Hedstroemia* (see Pl. 23). *Parachaetetes* (Pl. 20) and *Solenopora* are found forming the nucleus of bigger oncolites, while *Bevocastria* (Pl. 22), *Hedstroemia* and *Ortonella* (Pl. 22) are common in their outer layers. In biohermal rocks (Sauvere and Uduvere Beds of the Paadla Stage) algae occur in the form of debris - bushy fragments of *Ortonella, Hedstroemia, Parachaetetes gotlandicus*, as well as in oncolites *(Bevocastria, Ortonella)*. *Solenopora filiformis, Wetheredella multiforma* and *Rothpletzella munthei* form encrusting sheets on stromatoporoids and corals.

In coarse-grained skeletal grainstones of forereef origin (Sauvere and Uduvere Beds of the Paadla Stage) *Parachaetetes compactus, P. gotlandicus, Hedstroemia halimedoidea* (Pl. 23) and *Ortonella aff. furcata* are common.

Oncolites of Ninase Beds (the Jaani Stage) that formed surrounding brachiopod-shells contain *Girvanella ducii* (Pl. 21), *Girvanella wetheredii* (Pl. 22), *Rothpletzella gotlandica*, *Hedstroemia* and *Wetheredella*. Forereef has yielded a single and the only specimen of *Dimorphosiphon rectangulare*.

Calcareous algae have been noticed to disappear in the Silurian sequence of Estonia at the boundary of the Kuressaare and Kaugatuma stages. This event was probably the result of the increasing terrigeneous matter influx (Radionova, Einasto, 1986).

ACRITARCHS

I. Paalits

Acid-resistant microfossils, included to a formal group Acritarcha are known from Vendian to Silurian rocks of Estonia. Excellent preservation of acritarchs and their presence in the most types of rocks except coarse-grained sandstones, red-coloured deposits and dolomitized carbonate rocks make them a useful tool for correlation. After the pioneer works by A. Eisenack (1932, 1934), acritarchs from Estonian carbonate sequence are rather poorly studied. Last years some attention has been paid to Ordovician acritarchs.

In the Ordovician, two major stages of acritarch evolution can be distinguished. Diacroids (e.g. genera *Acanthodiacrodium, Dasydiacrodium, Arbusculidium)*, acritarchs with macropylom (genera *Stelliferidium, Cymatogalea)* and other acantomorphs (*Vulcanisphaera, Goniosphaeridium*) are appearing in the Upper Cambrian and are characteristic of the Tremadocian (Plate 24, Fig. 1-6, too). Most of these genera are disappearing on the Tremadoc/Arenig boundary. The genera *Baltisphaeridium* and *Peteinosphaeridium* appearing in the Arenig are also typical of Middle and Upper Ordovician. These changes occurring in the Tremadoc/Arenig boundary may reflect global phenomena, but more likely the switch from terrigenous to carbonate sedimentation in the local paleobasin. For providing more detailed acritarch zonality, further research is needed.

The dependence of acritarchs on depositional environments is illustrated by the following examples. The organic-rich argillites of the Türisalu Formation (approximately corresponding to *C.rotundatus - C.angulatus* conodont Zone) yield a specific assemblage of acritarchs where the dominating species *Leiosphaeridia tenuissima* Eisenack and *Lophosphaeridium zaleskyi* (Naumova) Umnova (Plate 24, Fig. 7, 8) are represented by thousands of specimens per 30 g sample. Morphologically simple, these species are of little stratigraphic value. In this assemblage, diacroids, acanthomorphs and acritarchs with macropylom (Plate 24, Figs 1-6, 9) widely distributed in underlying and overlying beds are very rare. The high dominance but low diversity of these two species in the assemblage refers to specific depositional environment for the argillites of the Türisalu Formation. Some geochemical features indicate the same.

In the Upper Ordovician, the Adila Formation (Pirgu Stage) yields abundant acritarchs from the genera *Micrhystridium, Baltisphaeridium, Orthosphaeridium, Veryhachium, Multiplicisphaeridium, Goniosphaeridium* and *Diexallophasis* (Pl. 24, Figs 14, 15) and leiosphaerids, unidentifiable on species level. This kind of assemblage is considered to be normal marine and especially characteristic of shelf facies (Staplin, 1961; Smith and Saunders, 1970). In the Ärina Formation (Porkuni Stage), possibly due to dolomitization, organic-walled microfossils are lacking, with the exception of the Vohilaid Member. The latter yields a low diversity acritarch assemblage containing abundant specimens of leiosphaerids referred to reef facies (Staplin, 1961). Consequently, the differences between the acritarch assemblages of the Pirgu and Porkuni stages can be explained first of all by different depositional environments.

COMPOSITE STANDARD

M. Rubel

Let define a local range of a taxon as an interval between its first and last occurrences in every section. Let its total range represent a projection of all local ranges of the same taxon onto the common time axes (Shaw, 1964). Then the mutual position of total ranges (the temporal sequence of taxa) comprises a paleontological time scale, by means of which the time-rock correlation can be realized.

There exist many algorithms on the basis of which such paleontological time scales can be constructed, including those designed as a composite standard (see Tipper, 1988). The Baltic Silurian data set (Table 17) has been used for the elaboration as well as testing of these algorithms, too (Rubel and Pak, 1984; Gradstein et al., 1985). The main goal here was formulated in the following ways: to subdivide the sections (mostly wells) by their fossil content into regional stages which in turn have to be defined by their lower boundary stratotype in the sections studied. Realization of that task means to draw isochrones through every boundary stratotype in all section. It can be made using some kind of time scales. The composite standard discussed above is one of such scales.

In the Baltic Silurian data set (Table 17) there is a number of taxa occurring only in one section. It is a good idea to exclude them from the further processing as they are useless in correlation of a finite number of sections. Let try now to arrange 196 taxa remained into the composite standard by the algorithm accepted here and by the corresponding programme DISTR written by Dr. D.N. Pak (Tadjikistan State University) for IBM PC/XT. Doing it the consumer must take into consideration that not all taxa can be included into one standard. Because of that the consumer must drive the selection of taxa to construct the standard so that the most informative (in his mind) data would be included into the standard. According to the programme the selection can be realized preferring the taxa with wide (in all sections) occurrence, or maximizing the number of taxa in the standard but usually excluding some taxa with wide distribution, or selecting first of all the eurytopic species before those of one community.

The standard considered here (see Table 19) has been formed starting from the taxa occurring in all sections studied. As a result 101 species from the 196 possible ones were included into the Late Silurian Standard for the five sections of the North-East Baltic. The standard that generalizes the temporal succession of species is subdivided into intervals got after the dating of each boundary stratotype accepted for this study. These intervals are designed as follows: K2 - the Paadla, K3a - the Kuressaare, K3b - the Kaugatuma and K4 - the Ohesaare times. The possible position of the lower boundaries in another than stratotype sections can be dated by means of the standard in the limits of the resolution determined by the number of samples and taxa in them (see Table 18 and Fig. 17). It is noteworthy that the boundaries of formations or members are not in all cases coinciding with the intervals for the stage boundaries.

The Late Silurian Paleontological Standard for the five sections studied is an example of the use of fossils in regional geochronology. In general such standards allow to summarize distributional data of all fossil groups into one succession which gives

the most detailed scale for the dating of any geological events including boundary stratotypes. Isochrones drawed through such stratotypes subdivide the sections into time-rock units, in the given case, into regional stages.

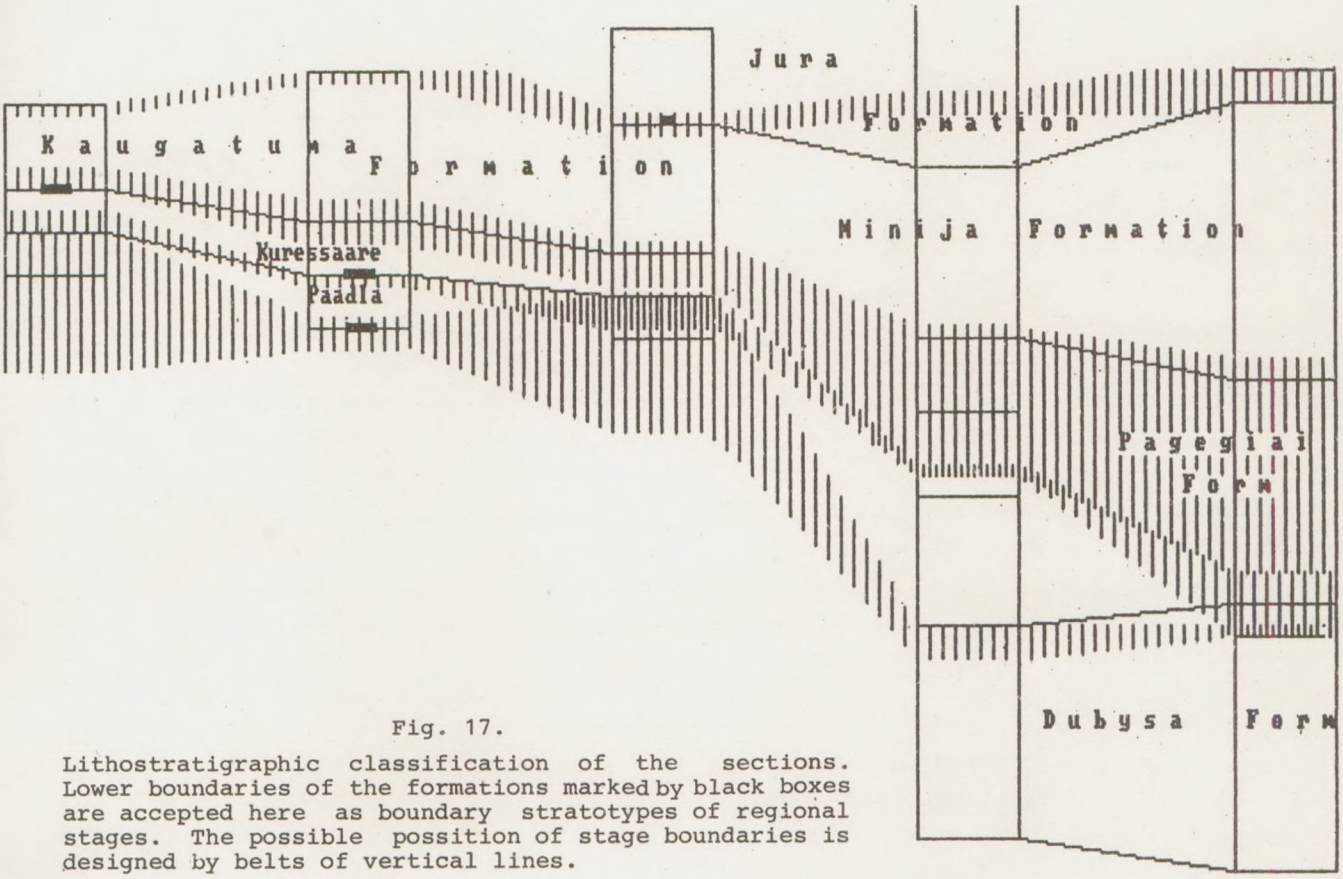


Fig. 17.

Lithostratigraphic classification of the sections. Lower boundaries of the formations marked by black boxes are accepted here as boundary stratotypes of regional stages. The possible possition of stage boundaries is designed by belts of vertical lines.

Table 17. The Baltic Silurian Data Set: distribution of species in sections

SECTIONS	OSTRA-CODA	BRACH-IOPODA	CHITI-NOZOA	THELO-DONTA	CONOD-ONTA	TRILO-BITA	GRAPT-OLITA	ALL
Kaugatuma	46	18	17	13	12	9	0	95
Ohessaare	51	35	30	24	11	13	0	164
Kolka-54	34	29	20	24	15	11	0	133
Ventspils	40	26	38	27	12	6	15	164
Pavilosta	37	28	29	7	10	7	20	101
All	84	48	47	37	22	30	22	290

Table 18. The intervals for the lower boundaries of stages. Fixed boundaries are marked by asterisk

STAGE	KAUGATUMA	OHESSAARE	KOLKA-54	VENTSPILS	PAVILOSTA
	-	3.10		309.60	-
K4			205.40^{x}		
	3.70	5.00		319.10	512.00
		58.50	260.50	417.50	623.00
K3b	37.20^{x}				
		80.00	281.00	488.80	726.50
	51.70		282.90	488.80	726.50
K3a		95.10^{x}			
	57.20		300.60	490.00	756.40
	57.30		284.50	560.00	750.60
K2		118.40^{x}			
	125.00		375.40	574.30	756.40

Table 19. Ranges of 101 species (*x*) in form of standard subdivided into time intervals K2...K4 by corresponding boundary stratotypes

	K2	K3a	K3b	K4
Monogratus uncinatus x				
Colonograptus colonus x				
Neodiversograptus wilsoni xx				
Sactograptus varians xxx				
Pristiograptus dublus xxxxx				
Bohemograptus bohemicus bohemicus xxxxxxx				
Leonaspis mutica xxxxxxxx				
Strophochonetes cingulatus xxxxxxxxxxx				
Eoplectodonta sp. sp. xxxxxxxxxxx				
Monograptus micropoma xxx				
Sactograptus chimaera chimaera xxx				
Lobograptus progenitor xxxxx				
Sactograptus chimaera salweyi xx				
Aegiria grayi xxxx				
Encrinurus ruhnuensis xxxxx				
Dalmanites cf. caudatus xxxxxx				
Calymene blumenbachi xxxxxxxxx				
Monoclimacia tauragensis xxx				
Pristiograptus dubius xx				
Pristiograptus tumescens minor x				
Proetus concinnus osiliensis xx				
Encrinurus punctatus xxx				
Dalejina hybrida xxxxxxxxxxxxxxxxxxxxxxx				
Ozarkodina confluens xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
Microsphaeridiorhynchus nucula xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
Ozarkodina sagitta bohemica xx				

Table 19 continued

	K2	K3a	K3b	K4
Thelodus laevis	xxx			
Logania martinssoni	xxx			
Ctenognathodus murchisoni	x			
Conochitina lauensis	xx			
Ozarkodina sp. 5	xxx			
Protochonetes cingulatus	xxxx			
Didymothyris didyma	xxxxx			
Distomodus dubius	xxxxxx			
Spathognathodus aff. snajdri	xxxxxxxxxxxxx			
Ancyrochitina diabolus	xxxxxxxxxxxxxxxxxx			
Orcofabella obscura	xxxxxxxxxxxxxxxxxxxxxx			
Cytherellina magna	xxxxxxxxxxxxxxxxxxxxxx			
Salopina conservatrix	xxxxxxxxxxxxxxxxxxxxxxxxxx			
Amygdalella subclusa	xxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Conochitina sp. A	xx			
Cyathaspidinae	xxxxxx			
"Ortonaria" perplexa	xxxxxxxxxxxxx			
Angochitina echinata	xxxxxxxxxxxxxxxxx			
Delthyris elevata	xxxxxxxxxxxxxxxxxxxxxx			
Cavellina circulata	xxxxxxxxxxxxxxxxxxxxxxx			
Conochitina intermedia	xxxxxxxxxxxxxxxxxxxxxxx			
Thelodus parvidens	xxxxxxxxxxxxxxxxxxxxxxxxx			
Eisenackitina lagenomorpha	xxxxxxxxxxxxxxxxxxxxxxxxx			
Ancyrochitina brevispinosa	xxxxxxx			
Homoeospira baylei	xxxxxxxxxxxxxxxxxxxxxxx			
Anaspidae sp. A	xx			
Thelodus sculptilis	xxxxxxxxx			
Gomphoncus hoppei-Paracanthodes porosus	xxxxxxxxxxxxxxxxx			
Plicibeyrichia numerosa	xxxxx			
Calcaribeyrichia altonodosa	xxxxxx			
Cavellina angulata	xxxxxxxxxxxxx			
Leiocyamus limpidus	xxxxxxxxxxxxxxxxx			
Ozarkodina steinhornensis eosteinhornensis	xxxxxxxxxxxxxxxxxxxxxx			
Oulodus elegans	xxxxxxxxxxxxxxxxxxxxxx			
Clavofabella maxima	xxx			
Clavofabella nodosa	xxxxx			
Hemsiella loensis	xxxxx			
Hebellum tetragona	xxxxxx			
Retisacculus semicolonatus	xxxxxxx			
Pterochitina perivelata	xxxxxxxxxxxxx			
Eisenackitina oviformis	xxxxxxxxxxxxxx			
Protochonetes piltenensis	xxxxxxxxxxxxxxxxxxxx			
Delthyris magna	xxxxxxxxxxxxxxxxxxxx			
Thelodus admirabilis	xxxxxxxx			
Hemsiella margaritae	xxxxxxxxx			
Eisenackitina cf. bursa	xxxxxxxxxxx			
Sleia inermis	xxxxxxxxxxxxxxx			
Beyrichia globifera		xx		

Table 19 continued

	K2	K3a	K3b	K4
Beyrichia venusta		xxx		
Neobeyrichia bulbata		xxxx		
Retisacculus sulcatus		xxxxxxxxxxxxx		
Shaleria dzwinogrodensis		xxxxxxxxxxxxx		
Clavofabella ? lativelata		xxxx		
Scipionis profundigenus		xxxxxxxx		
Sphaerochitina sphaerocephala		xxxxxxxxxxxxx		
Amygdalella solida		xxxxxxxxxx		
Amygdalella nasuta		xxxxxxxx		
Macrypsilon salteriana		xxxxxxxxxxx		
Hemsiella maccoyiana		xxxxxxxxxxxxx		
Frostiella pliculata		xxxx xxxxxx		
Fungochitina pistilliformis		xxxxxxxx		
Nostolepis gracilis		xxxxxxxxxxxx		
Conochitina aff. granosa		xxxxxx		
Ancyrochitina aff. fragilia		xxx		
Strosipherus indetatus			xxxxxxxxx	
Lophosteus superbus			xxxxxxxxx	
Goniporus alatus			xxxxxxxxx	
Dicygopleura opportuna				xxx
Nodibeyrichia jurassica				xxxxxxxx
Gomphonchus hoppei				xxxxxxx
Plectospathodus sp				xxxxx
Ozarkodina sp.				x
Tylodus deltoides				xxx
Nostolepis sp. n.				xx
Katoporus timanicus				x

E X C U R S I O N G U I D E

ITINERARY and PROGRAMME

Sunday August 19

Assembly in Tallinn, accommodation at Olympia Hotel. In the afternoon sightseeing tour in old town, short introduction to excursion.

Monday August 20

Excursion (Day 1): Cambrian/Ordovician boundary. Lower and middle Ordovician in the limits of Tallinn.

Localities: Ülgase ($Є_3$-O_1), Maardu and Suhkrumägi (O_1), Mäekalda (O_{1-2}).

Overnight at Olympia Hotel.

Tuesday August 21

Excursion (Day 2): middle and upper Ordovician west of Tallinn, lunch and short sightseeing in Haapsalu.

Localities: Peetri (Kukruse-Jõhvi stages), Vasalemma (Oandu Stage), Aulepa (Nabala and Vormsi stages), Ristna (Jõhvi and Keila stages).

Overnight at Olympia Hotel.

Wednesday August 22

Excursion (Day 3): upper Ordovician south of Tallinn and borehole sections at Särghaua field-station, Pärnu District.

Localities: Paekna (Rakvere and Nabala stages), Lohu (Pirgu Stage), boreholes at Särghaua.

Overnight at Olympia Hotel.

Thursday August 23

Excursion (Day 4): Ordovician and lower Silurian in East Estonia.

Localities: Kohtla (Kukruse Stage), Ontika (O_{1-2}), Porkuni (Porkuni Stage), Karinu (Juuru Stage).

Overnight at Olympia Hotel.

Friday August 24 and Saturday August 25

Indoor sessions at House of Tourism, Tallinn.

Sunday August 26

Excursion (Day 5): Wenlock on the islands of Saaremaa and Muhu.

Localities: Koguva, Pulli (Jaani and Jaagarahu stages), Paramaja (Jaani Stage), Tagavere (Jaagarahu Stage).

Sightseeing: Koguva village, Kaali meteorite craters.

Overnight at a camping near Võhma.

Monday August 27

Excursion (Day 6): Wenlock and Ludlow on Saaremaa Island.

Localities: Panga (Jaani and Jaagarahu stages), Abula, Jaagarahu, Sepise (Jaagarahu Stage), Viita (Rootsiküla Stage), Himmiste, Kogula (Paadla Stage).

Overnight at a camping near Kuressaare.

Tuesday August 28

Excursion (Day 7): Ludlow and Pridoli on Saaremaa Island.

Localities: Kaarma (Paadla Stage), Kudjape (Kuressaare Stage), Oheşaare (Ohesaare Stage), Kaugatuma (Kaugatuma Stage).

Sightseeing: Kuressaare castle.

Overnight at the camping.

Wednesday August 29

Excursion (Day 8): Llandovery and Wenlock in West Estonia.

Localities: Päri (Adavere Stage), Pakamägi (Raikküla Stage), Valgu (Adavere Stage), Anelema (Jaani Stage).

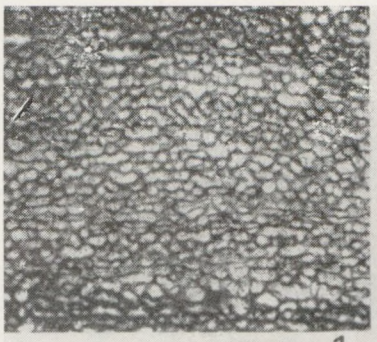
Overnight at Särghaua field-station.

Thursday August 30

Excursion (Day 9): borehole sections at Särghaua field-station.

Arrival at the Institute of Geology, Tallinn, before 15.00.

Dispersal of participants.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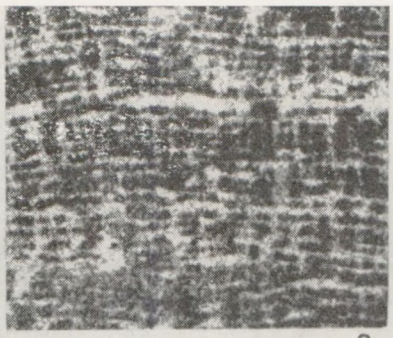
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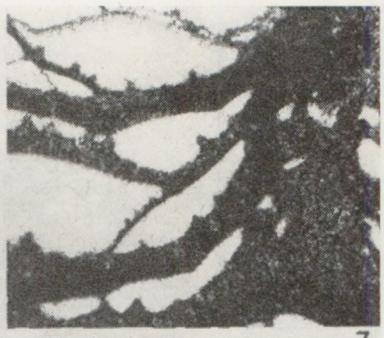
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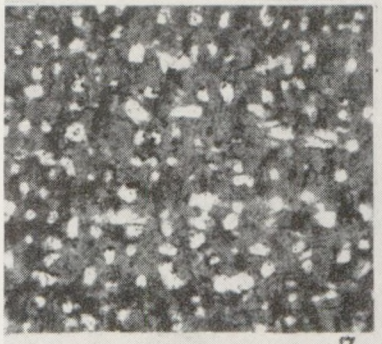
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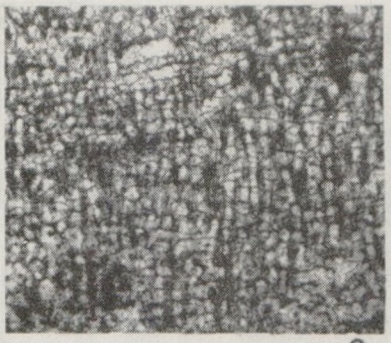
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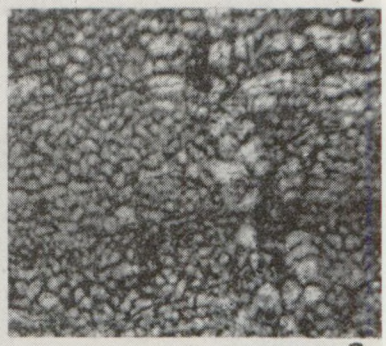
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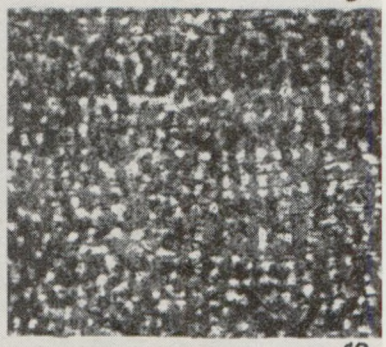
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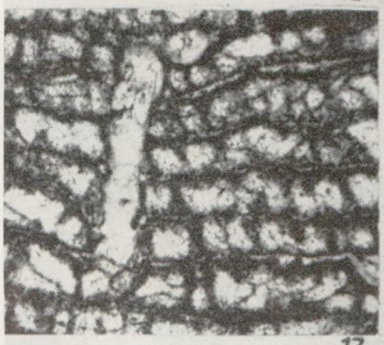
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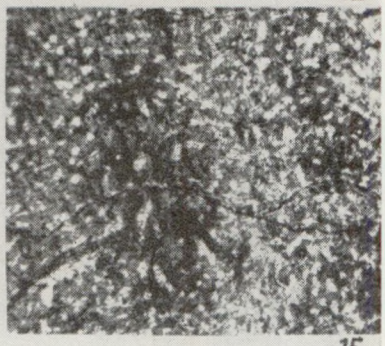
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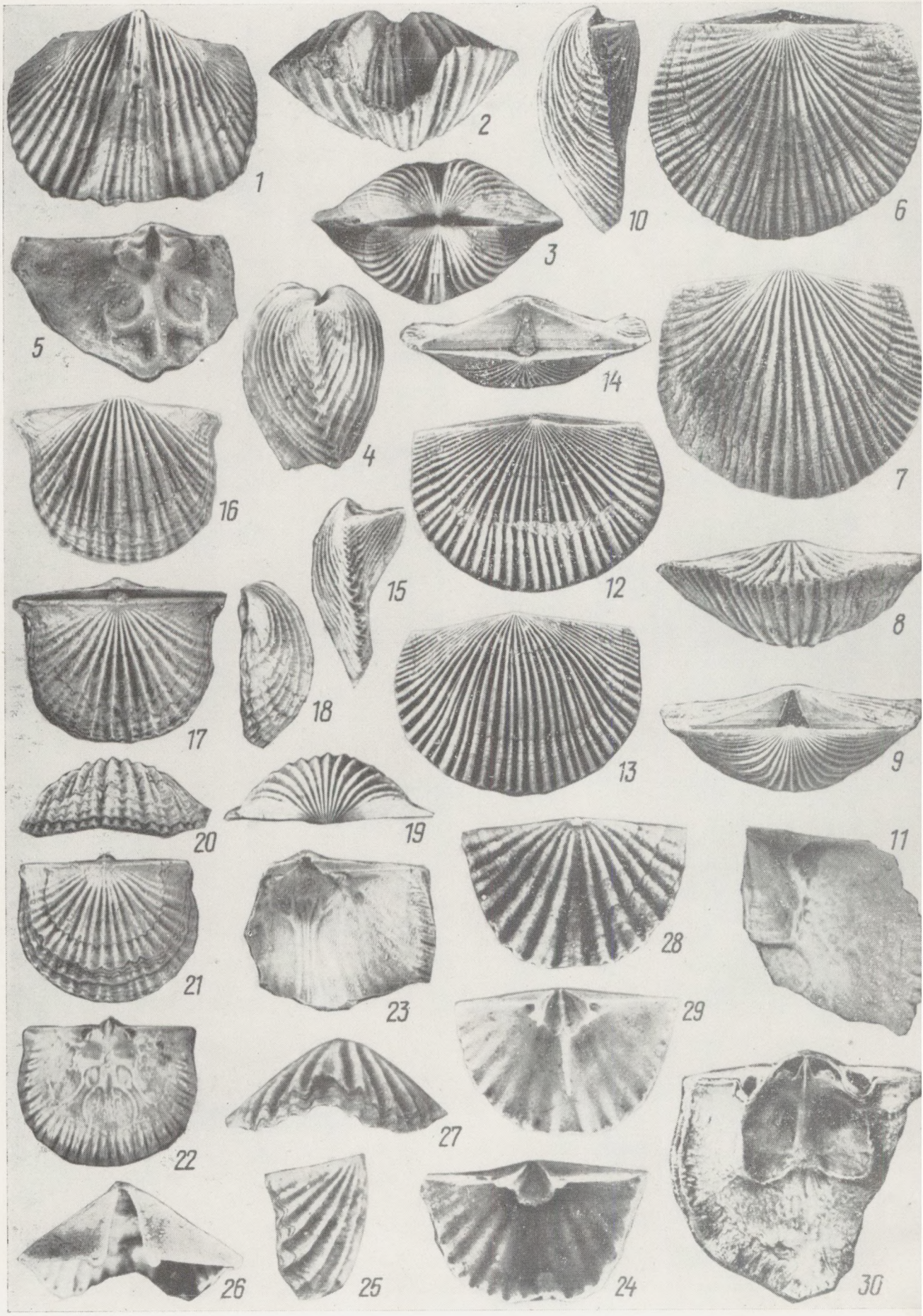
Plate 2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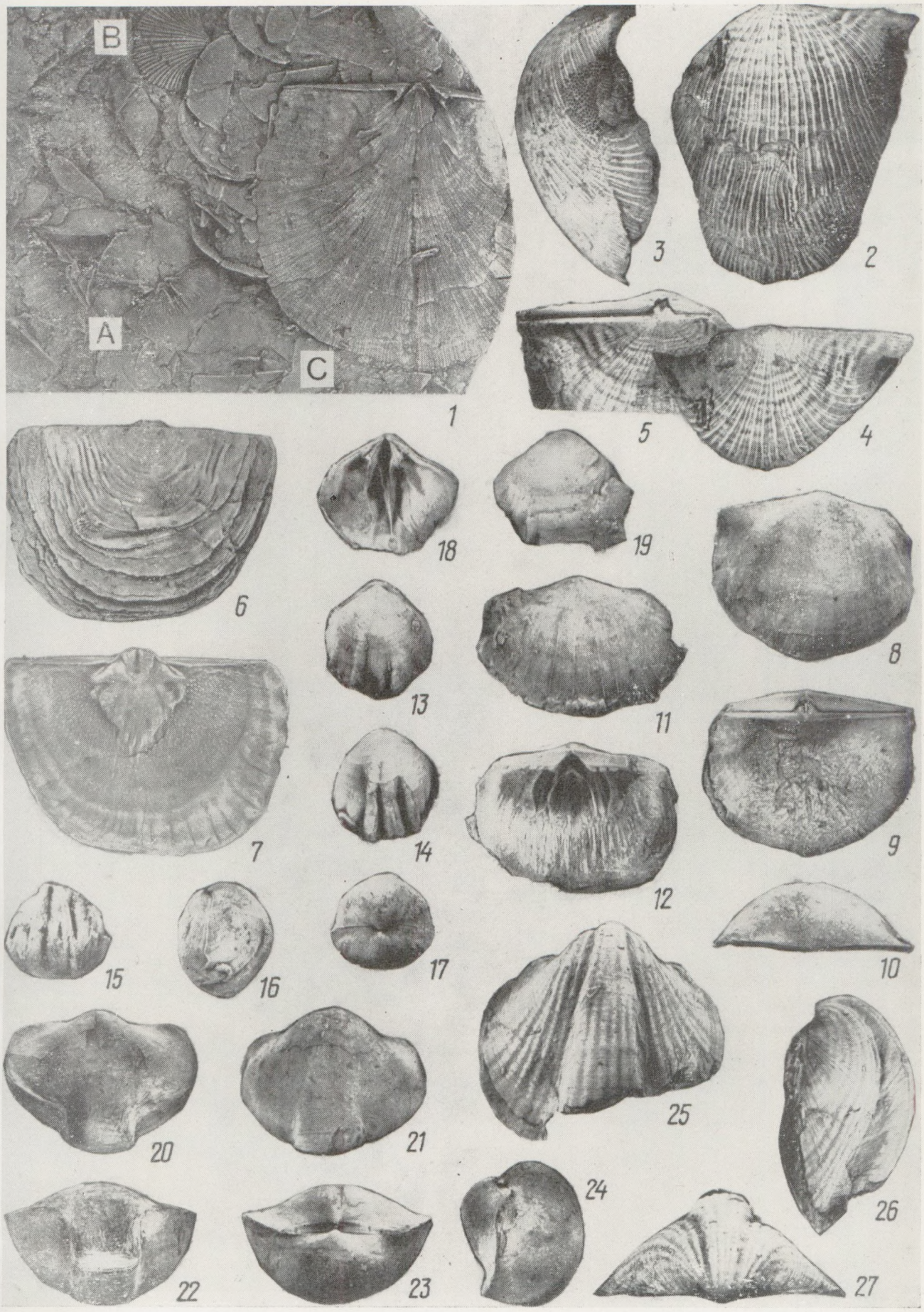
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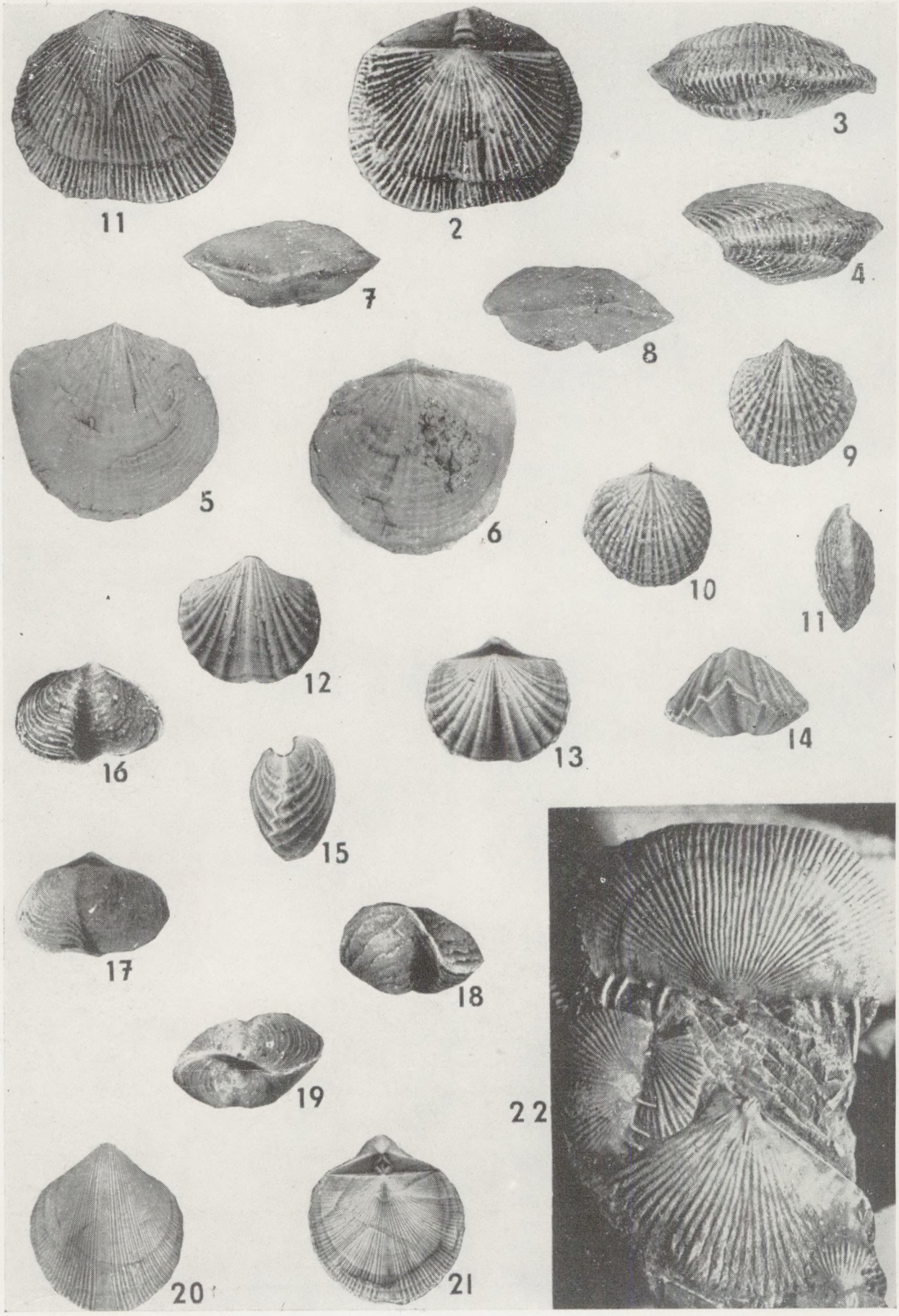
Plate 4

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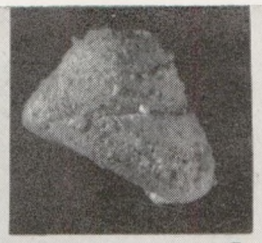
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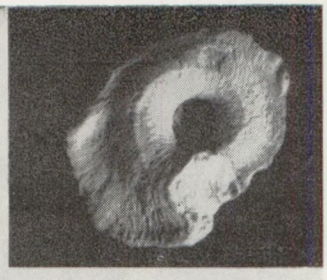
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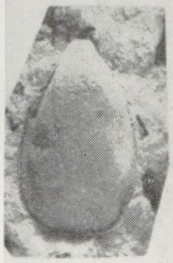
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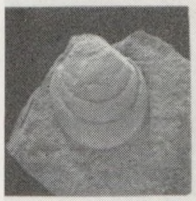
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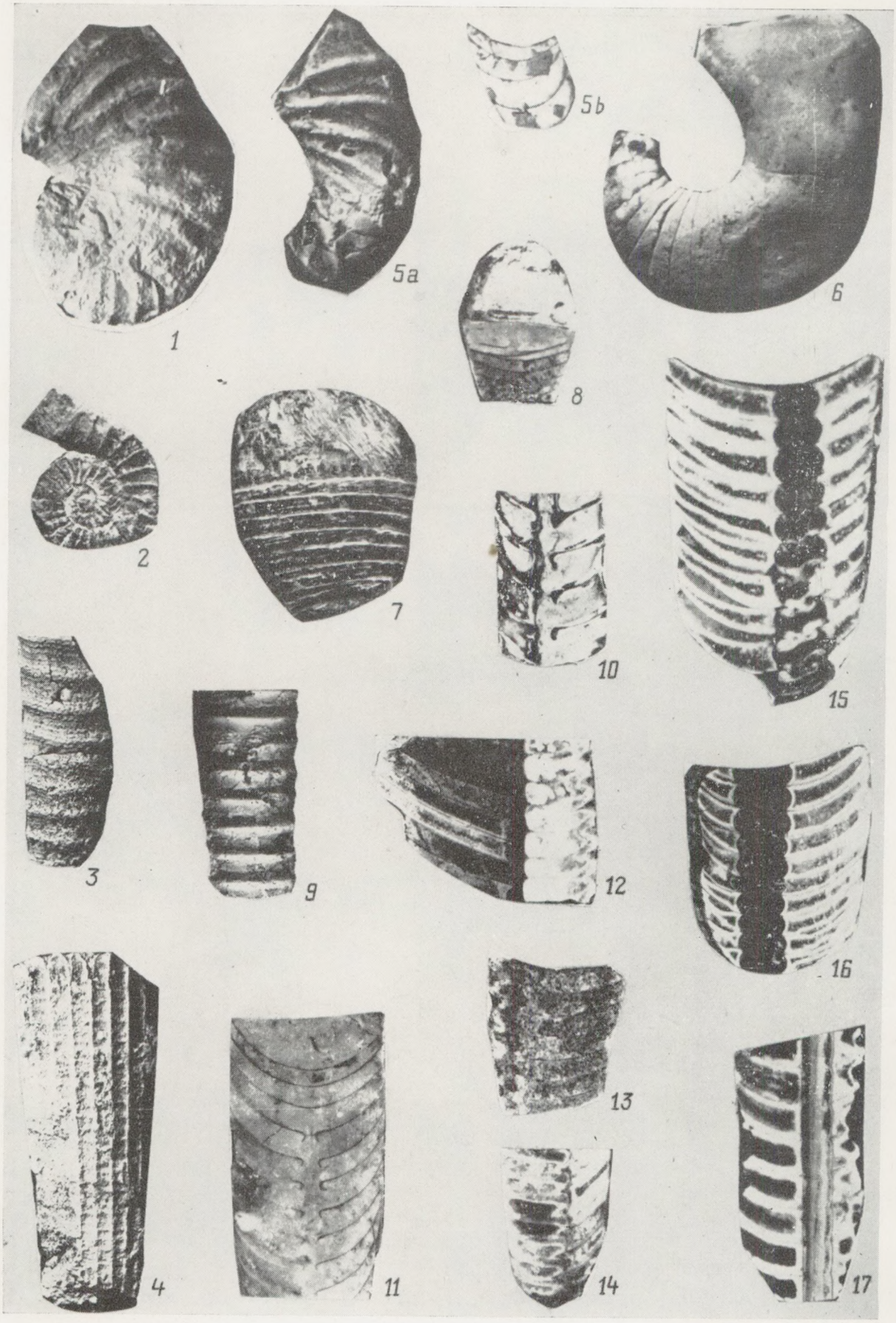
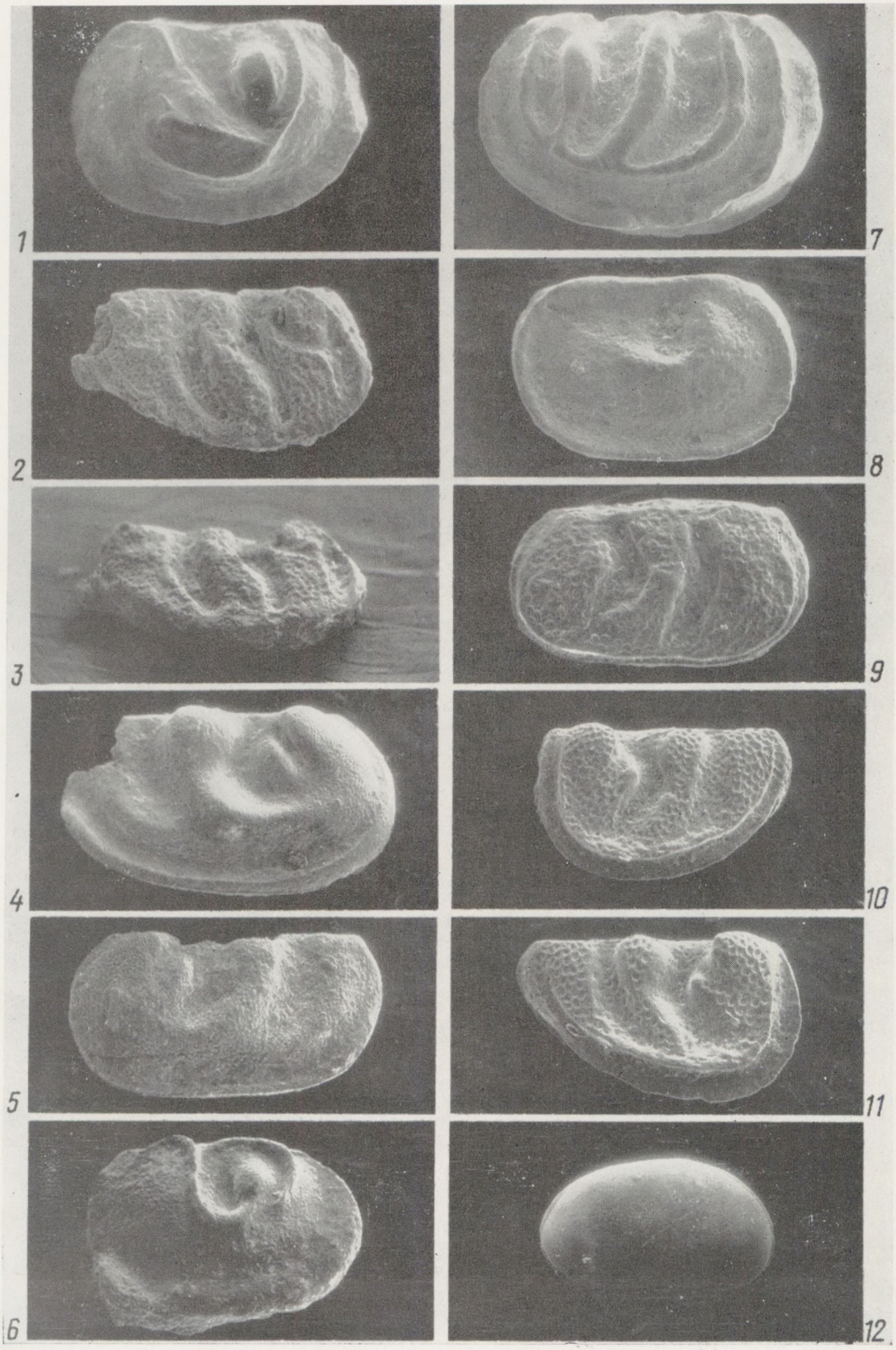
Plate 6

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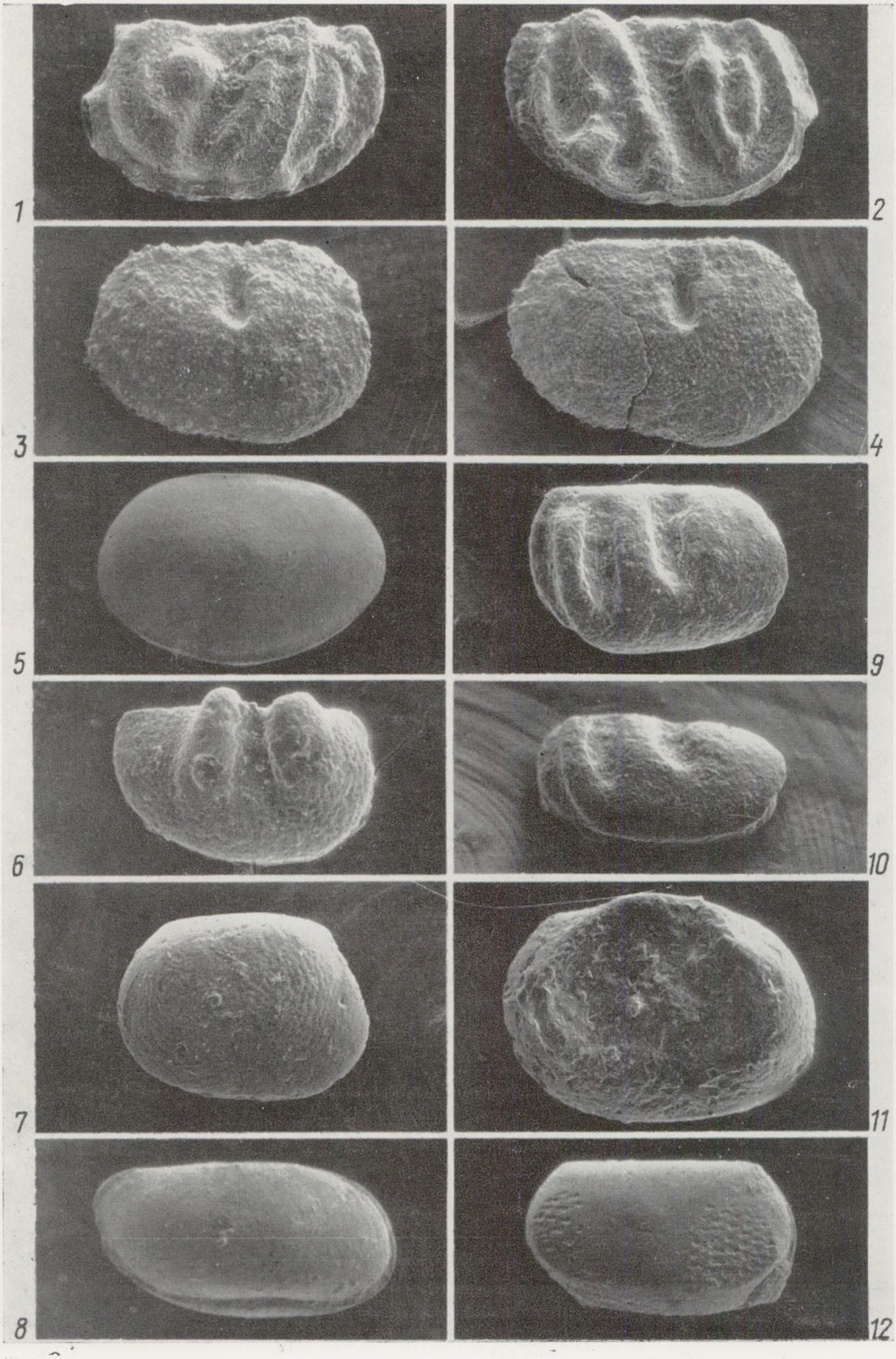
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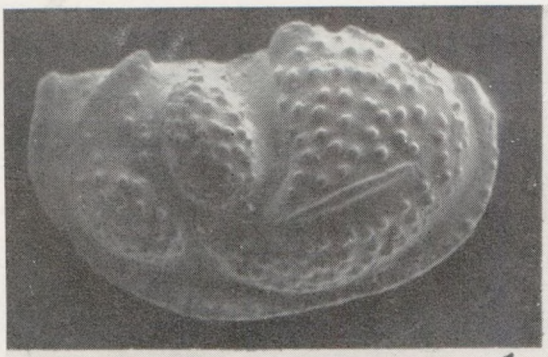
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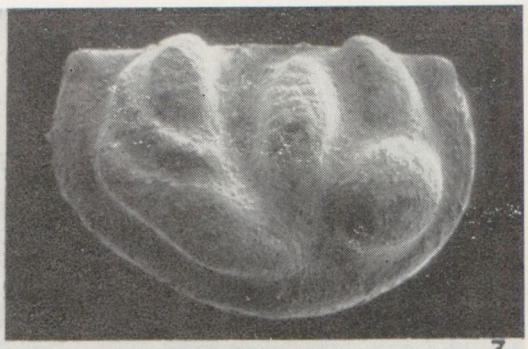
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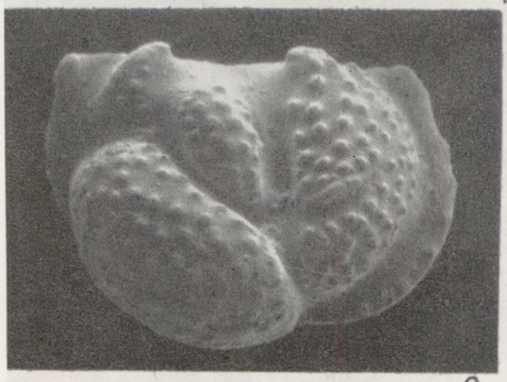
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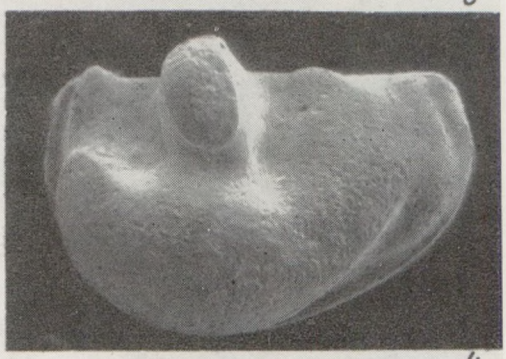
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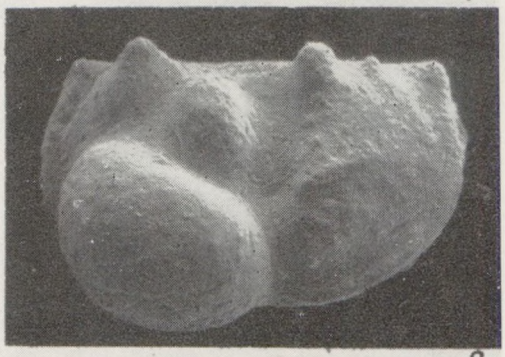
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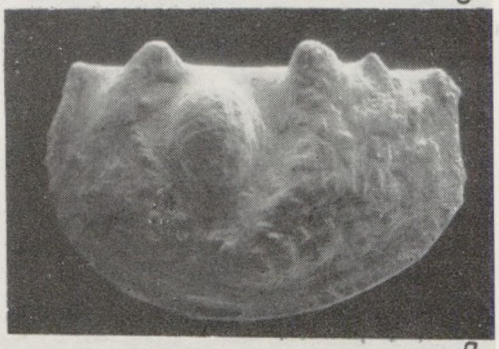
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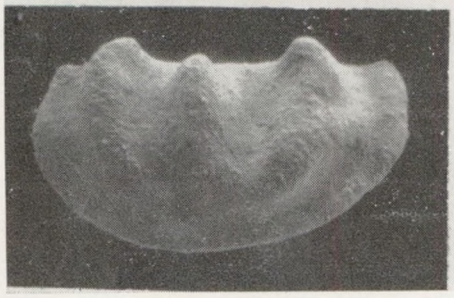
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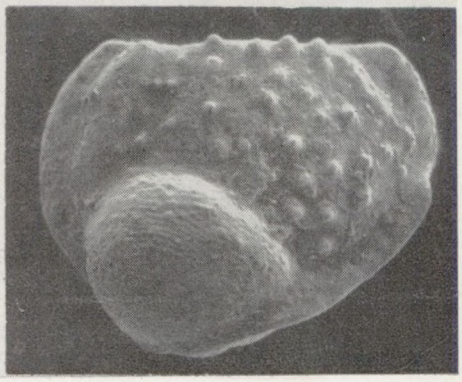
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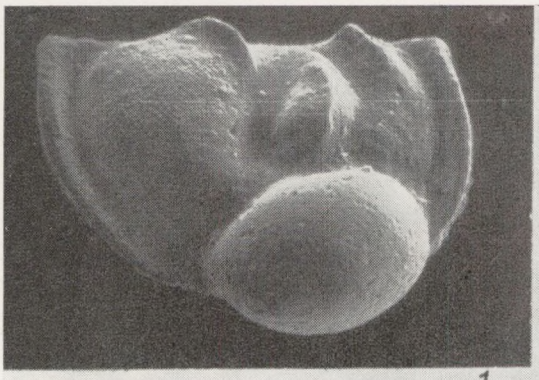
Plate 10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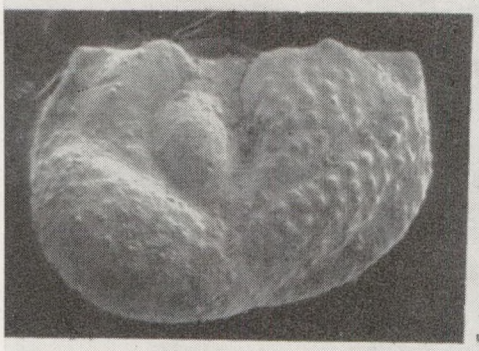
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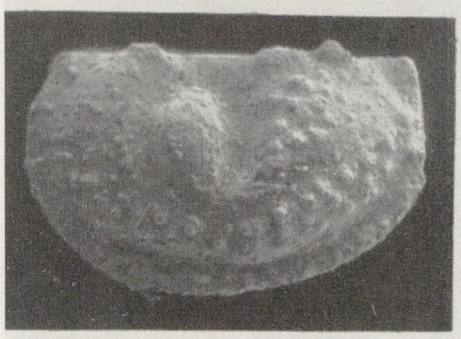
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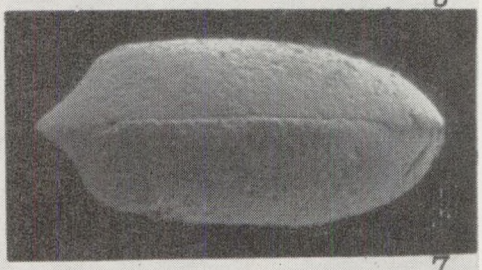
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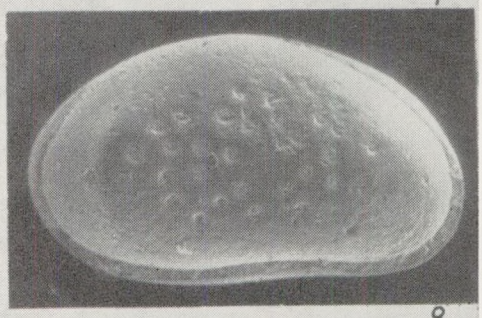
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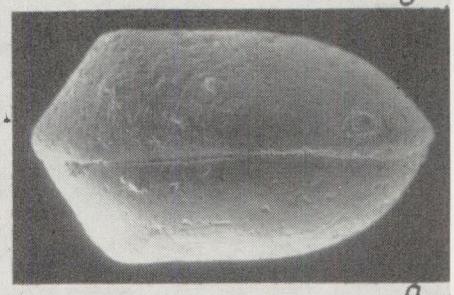
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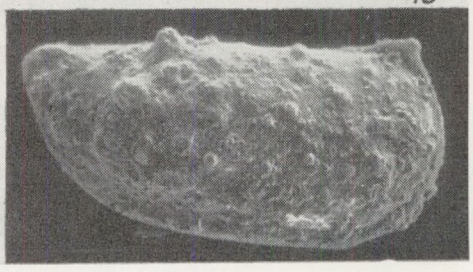
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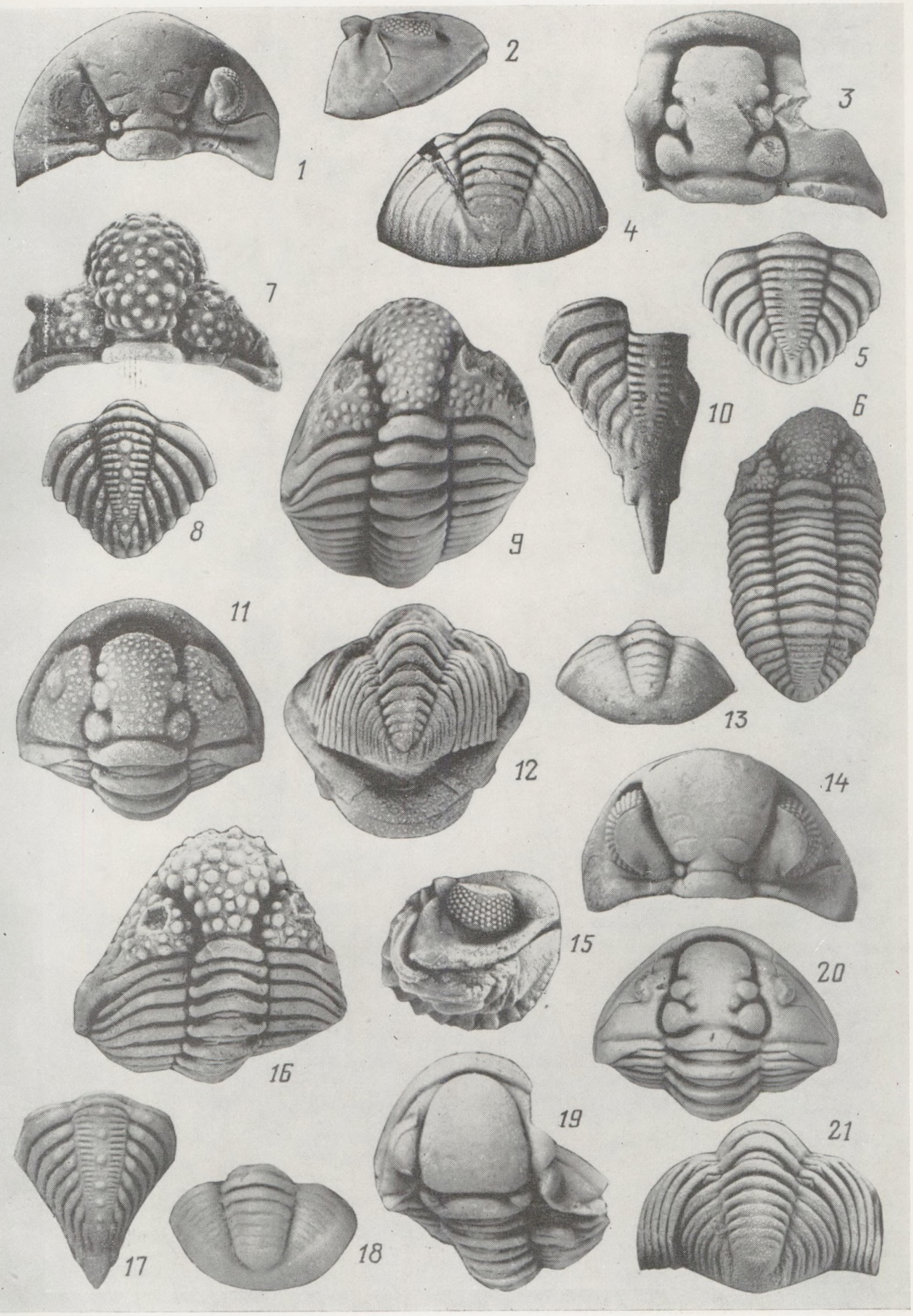
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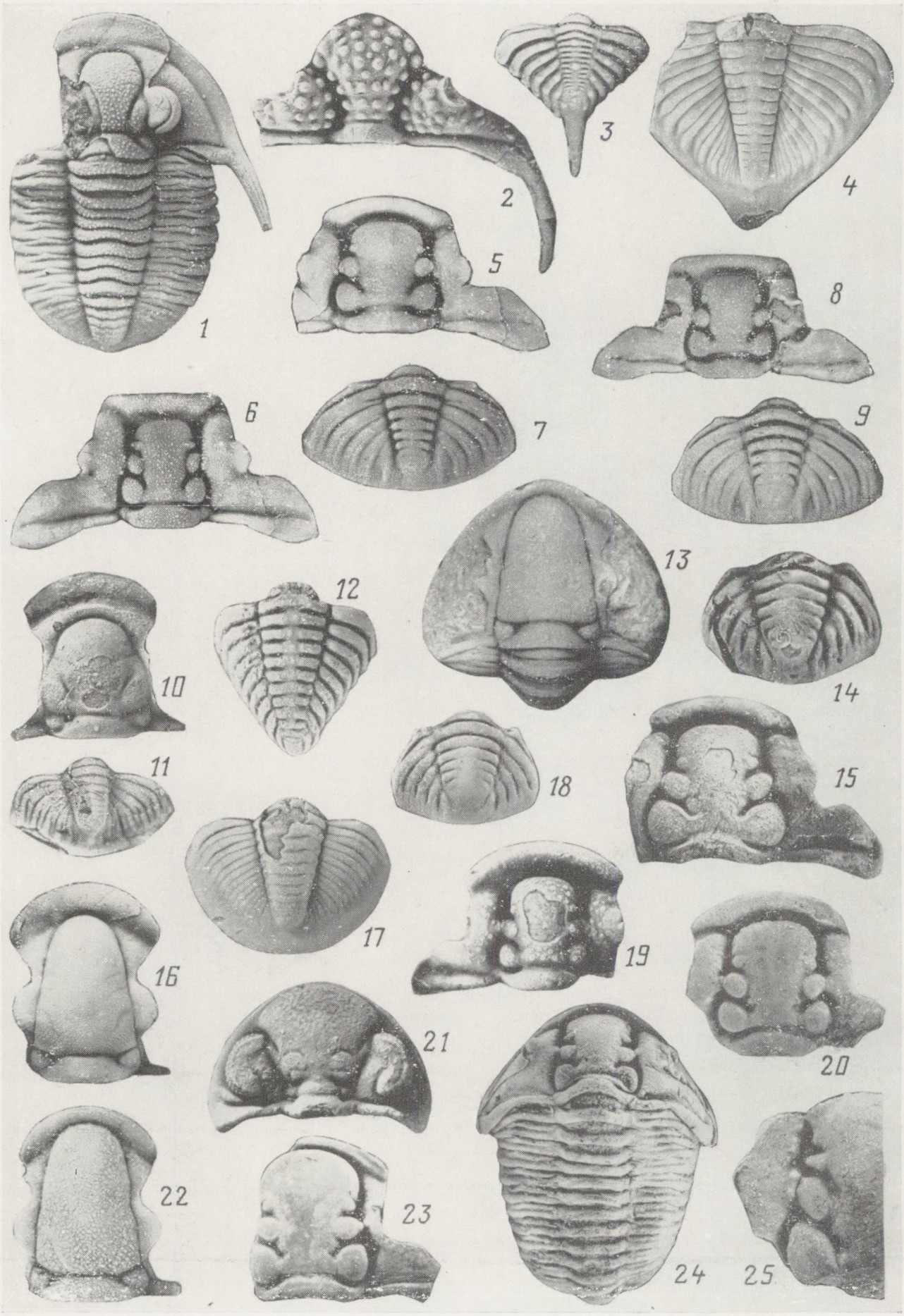
Plate 12



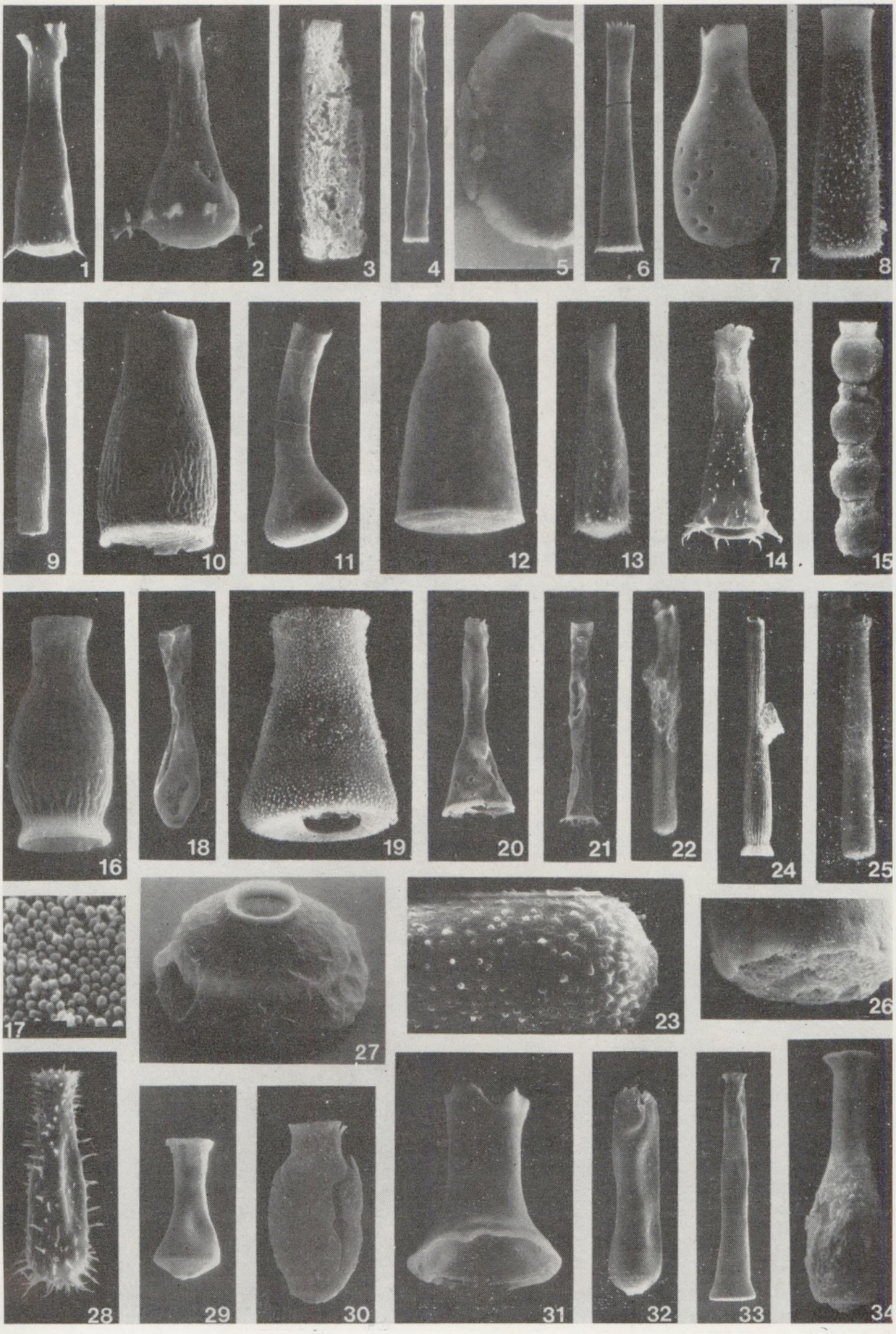

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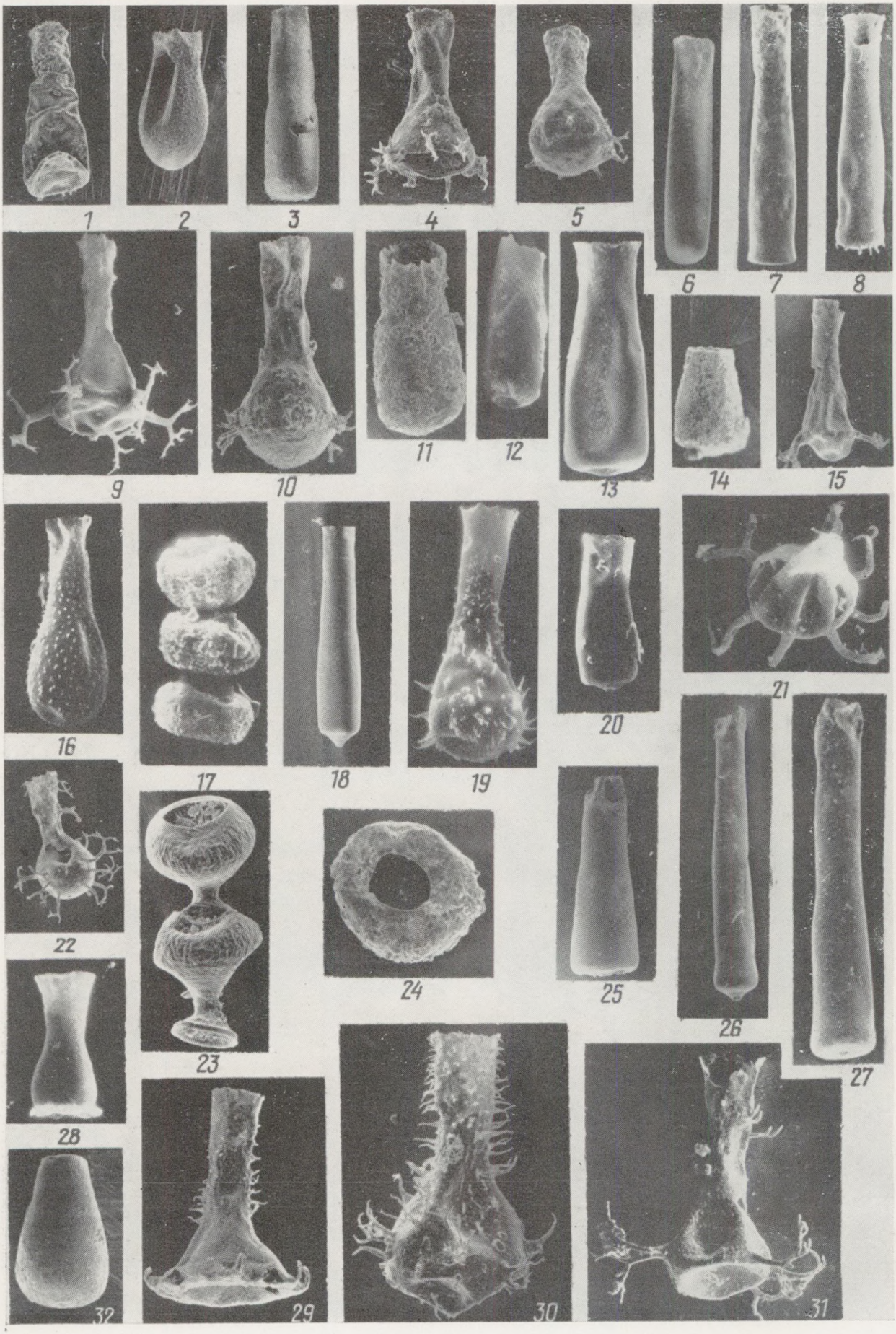
Plate 14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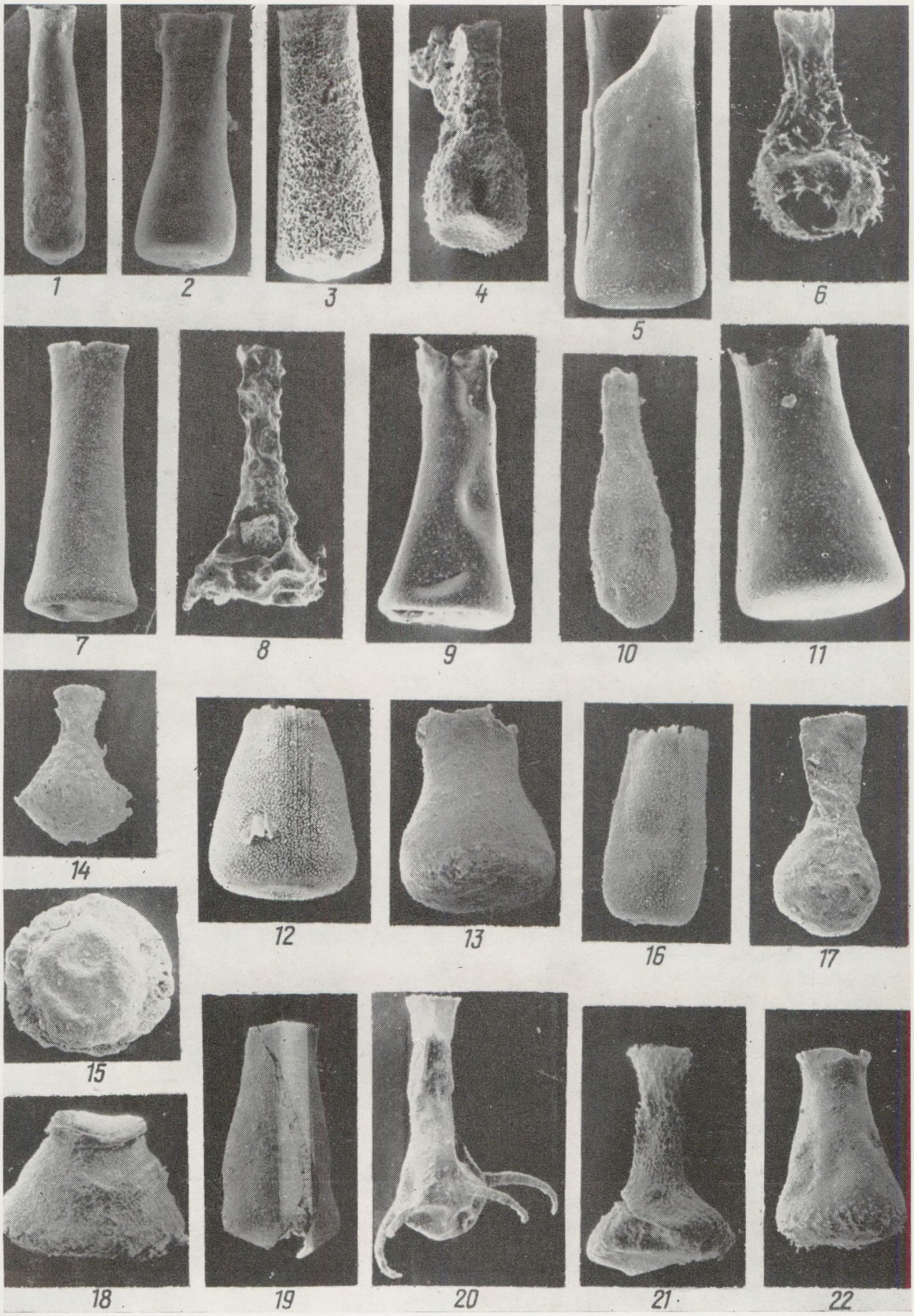
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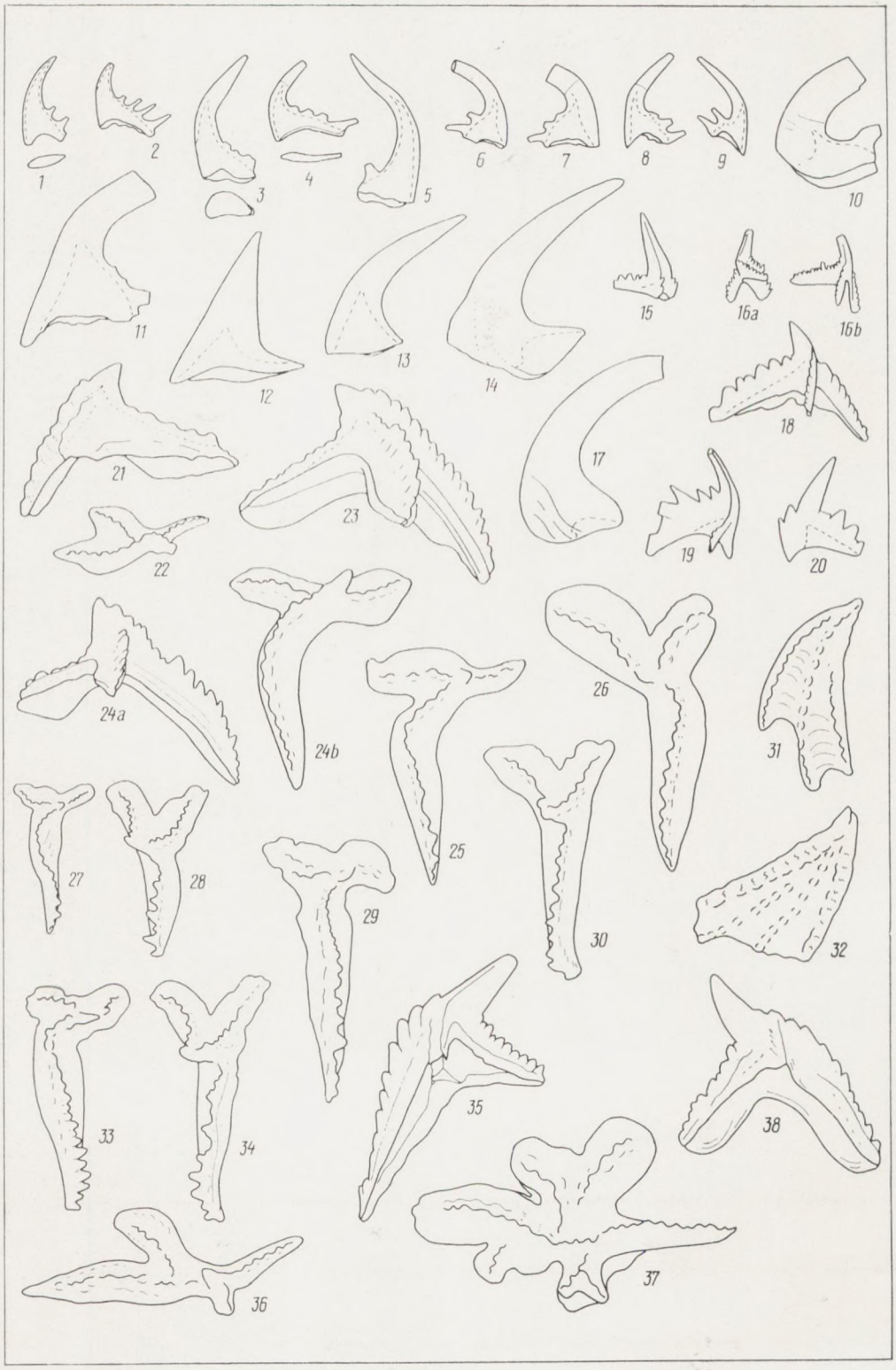
Plate 16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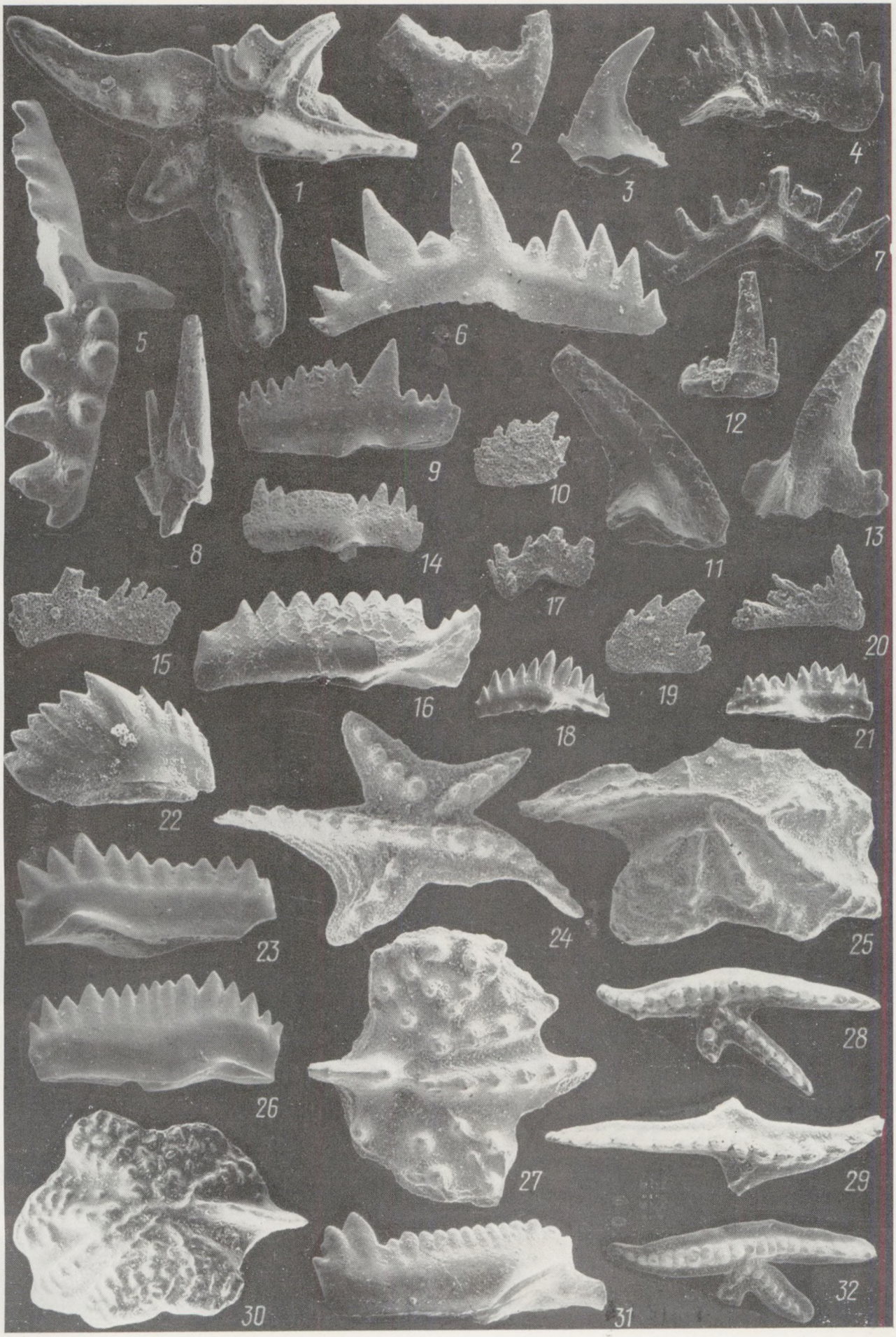
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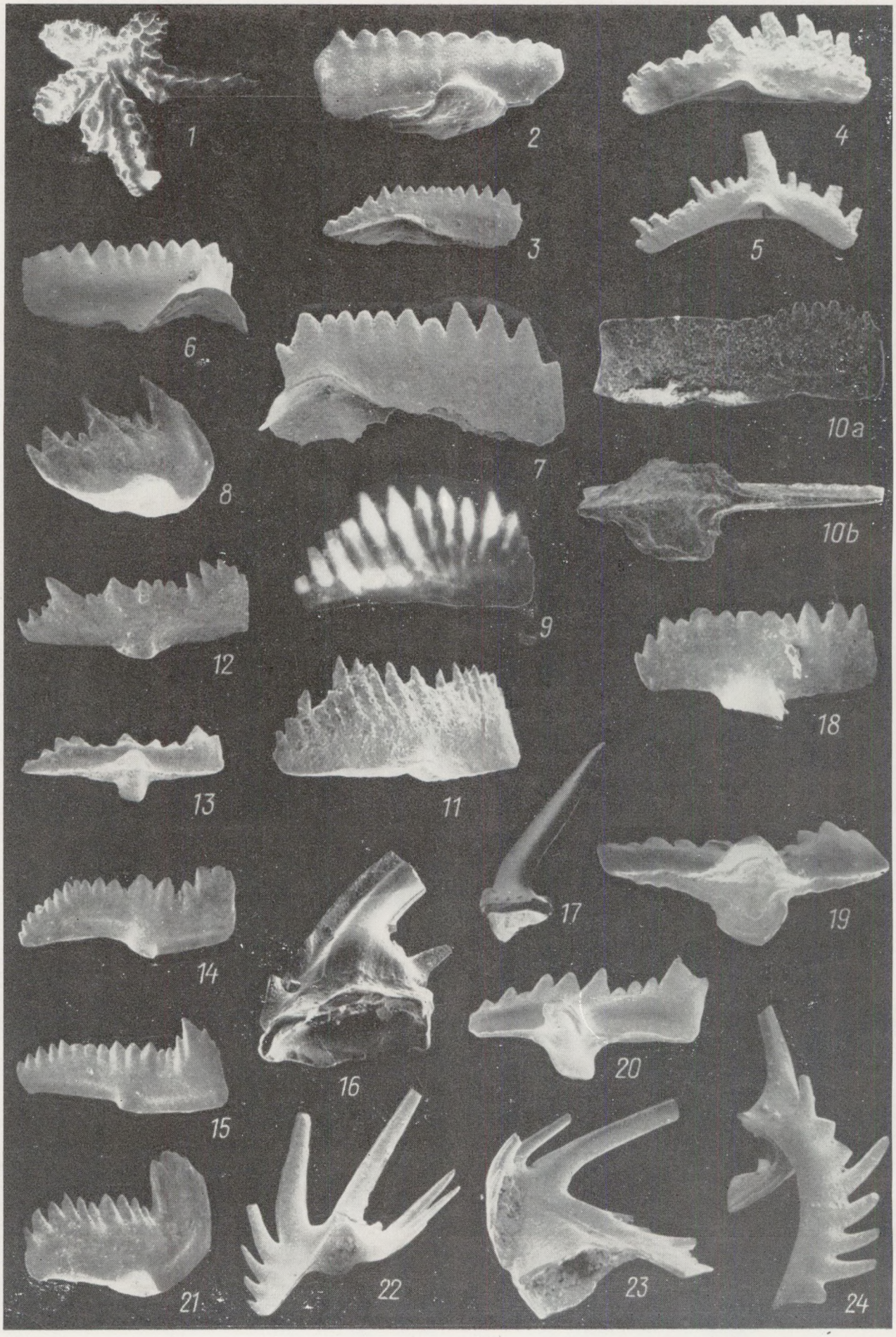
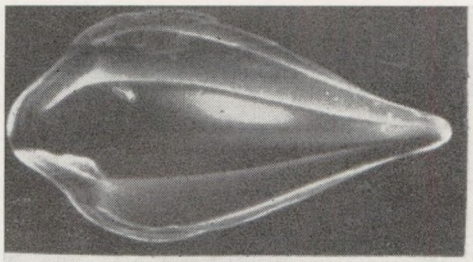
Plate 18

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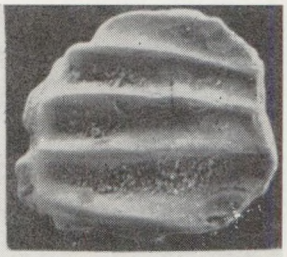
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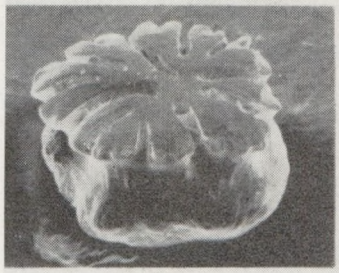
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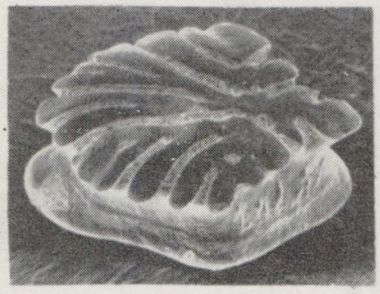
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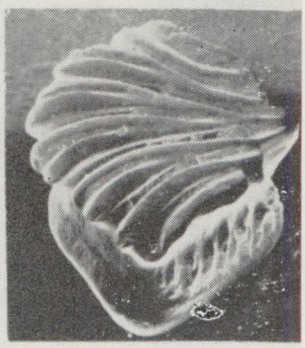
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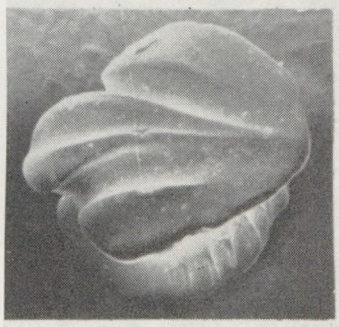
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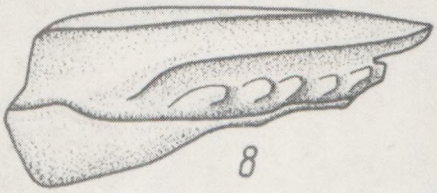
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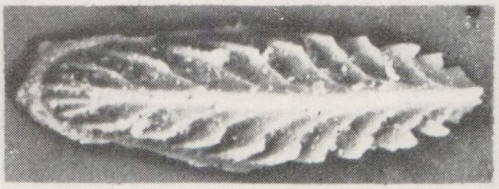
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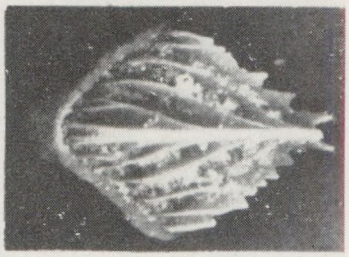
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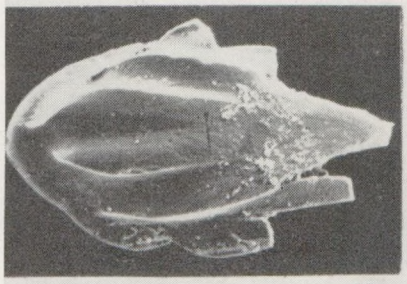
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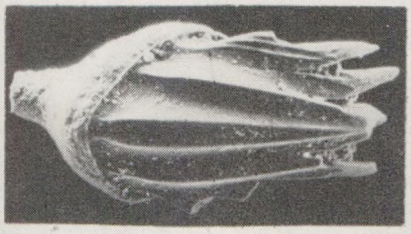
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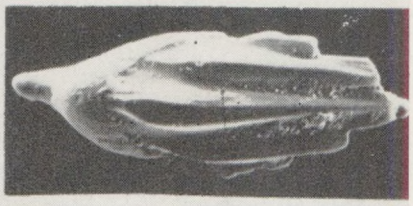
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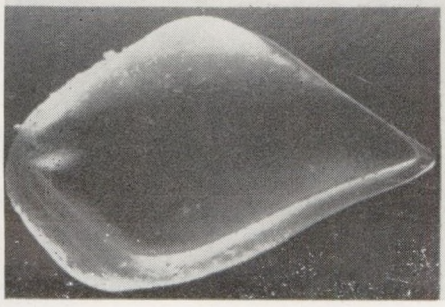
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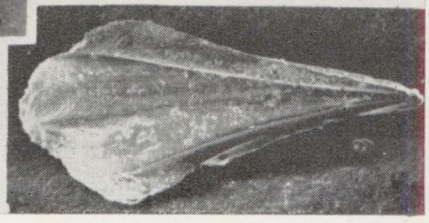
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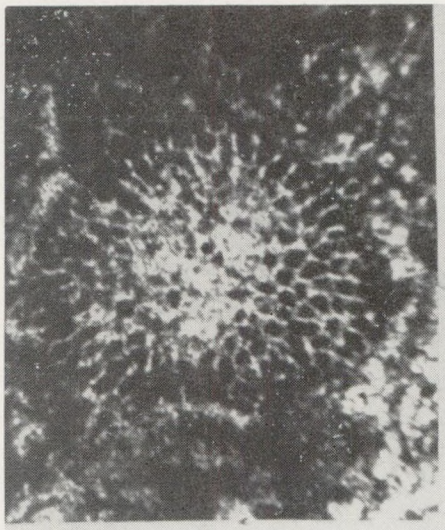
Plate 20



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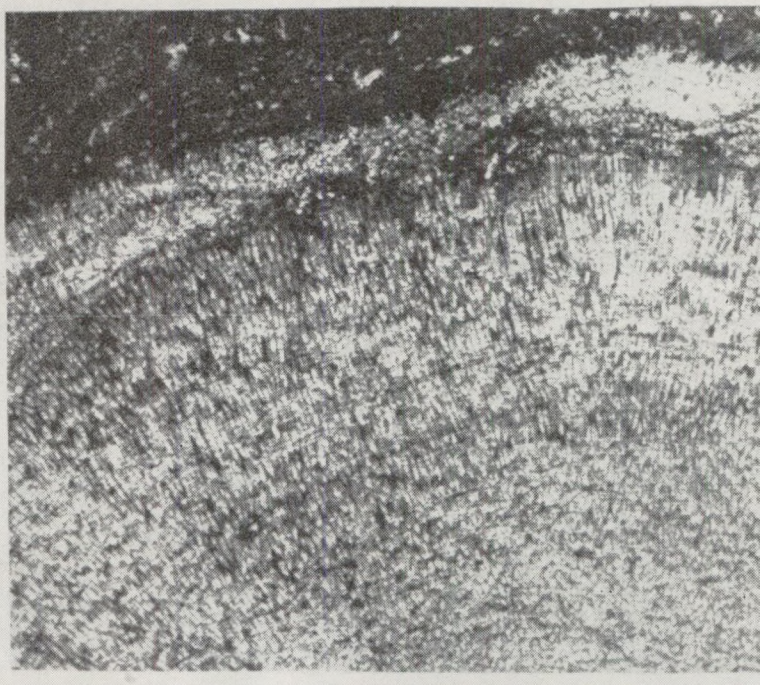

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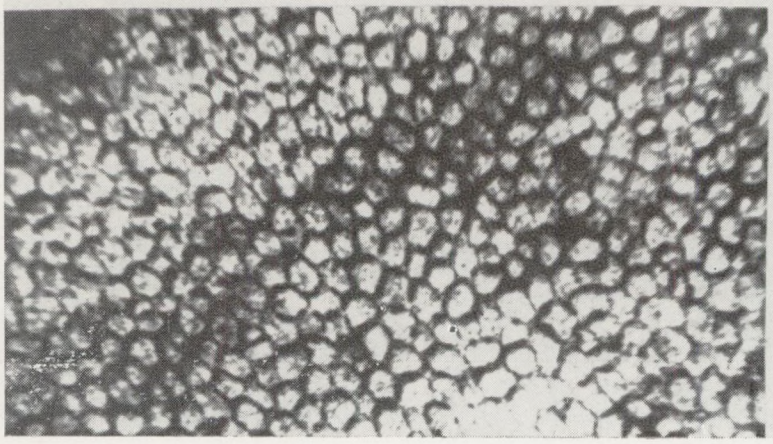

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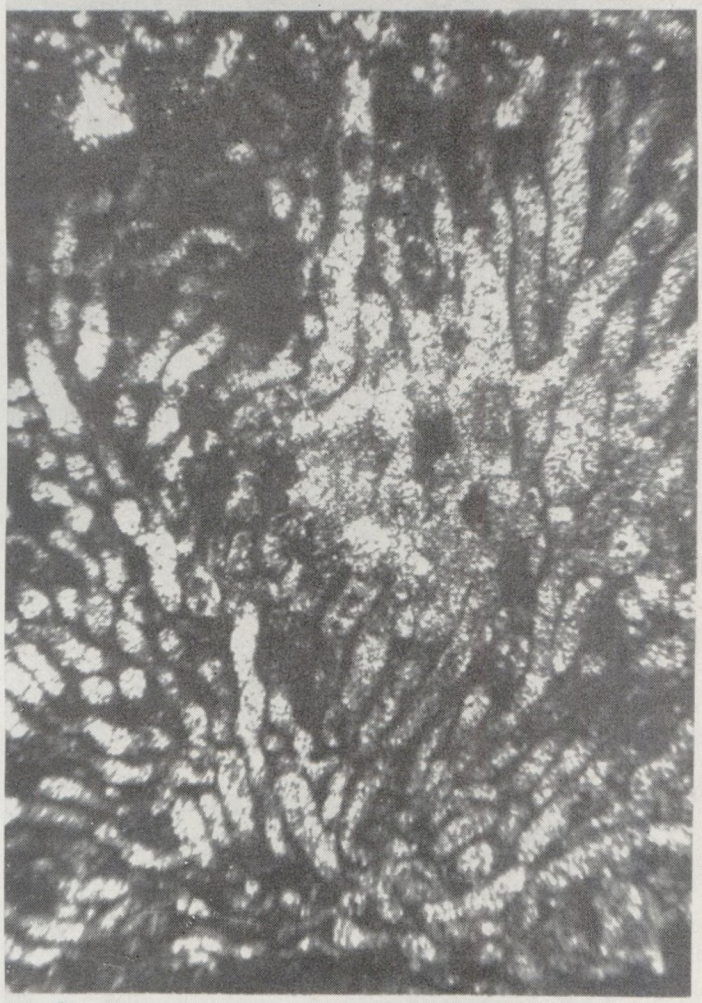

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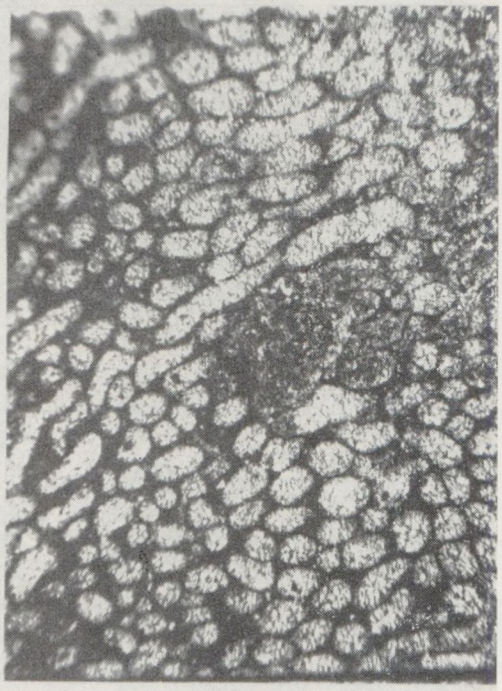

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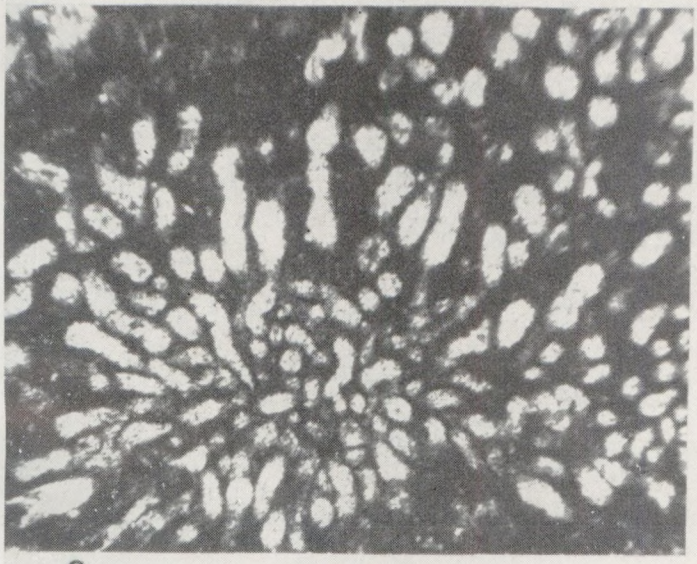

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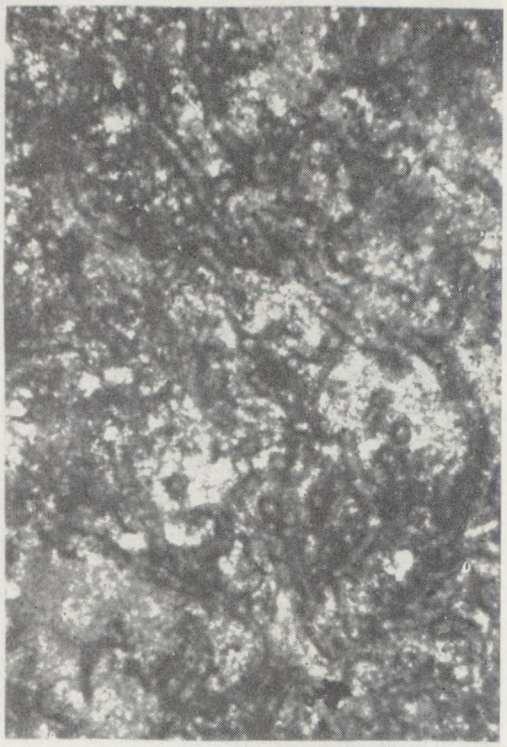

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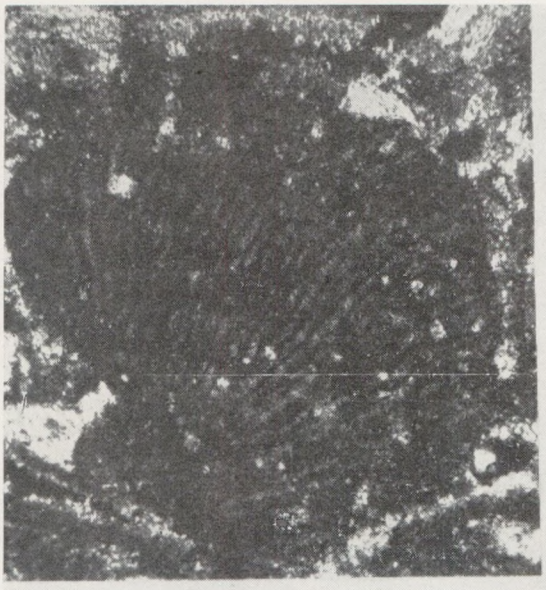
Plate 22



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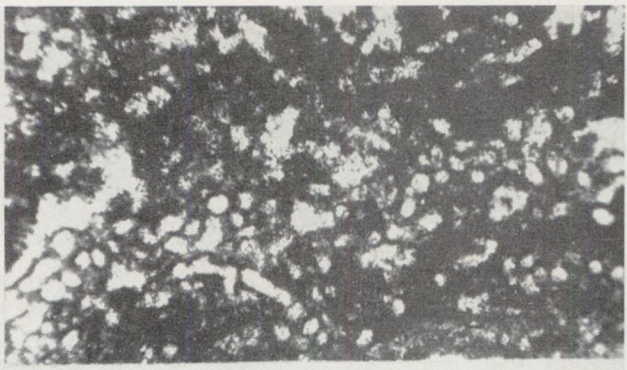

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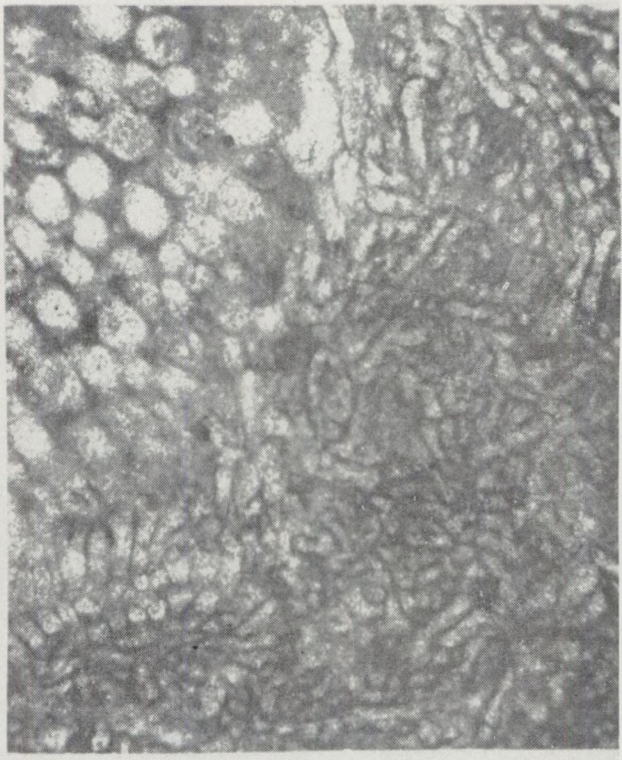

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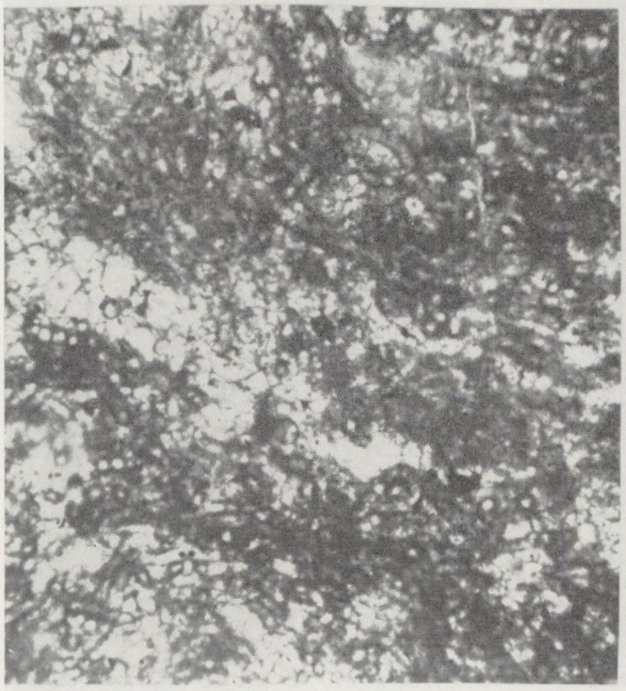

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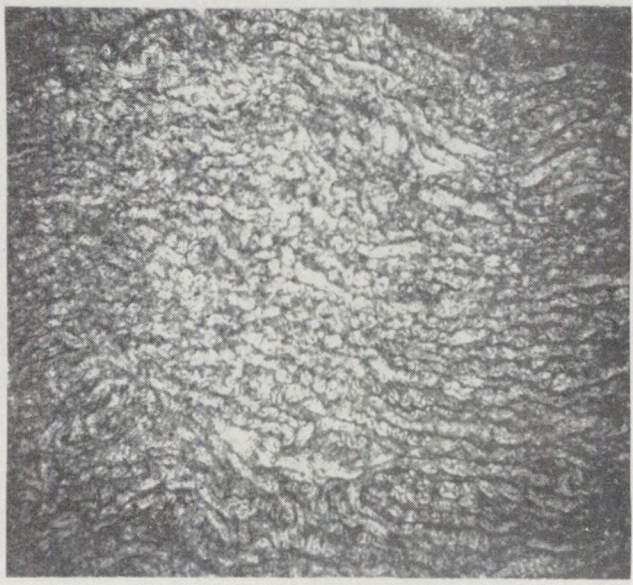

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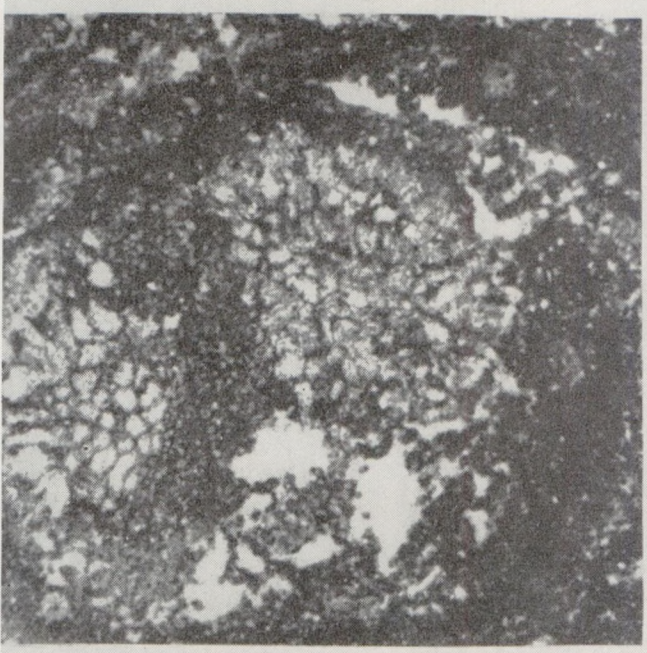

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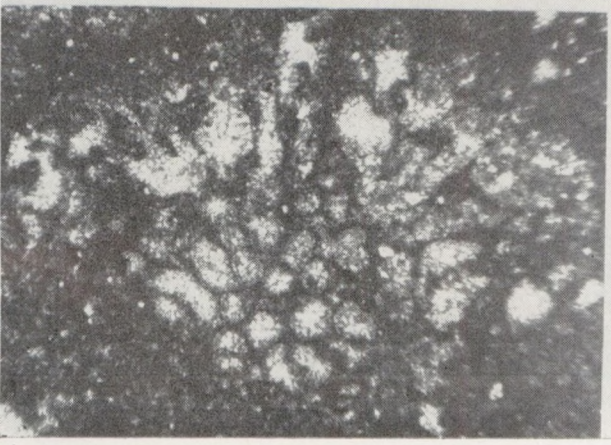

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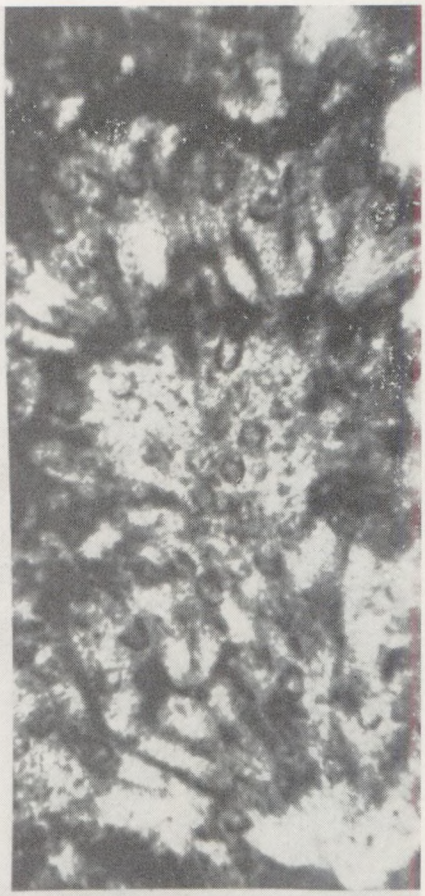

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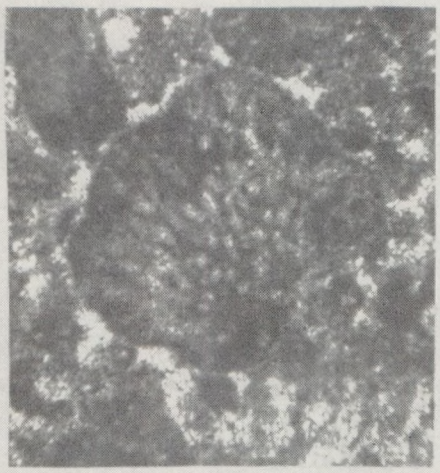

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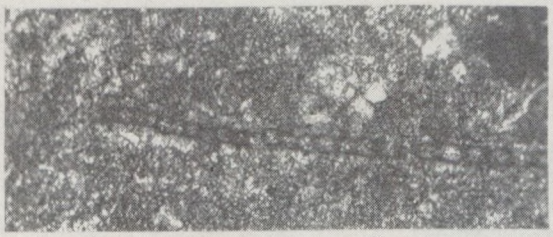

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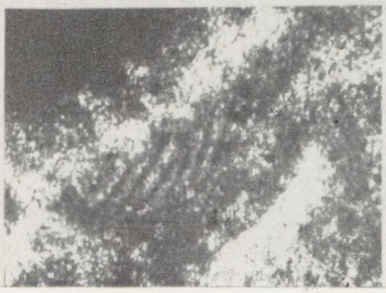

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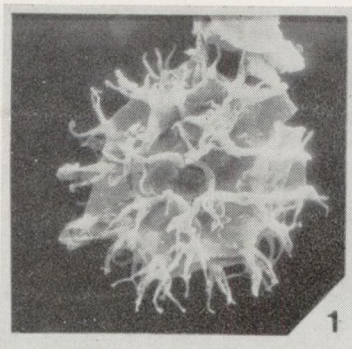
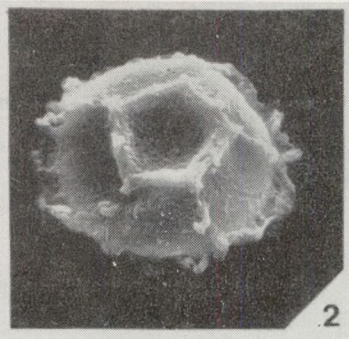
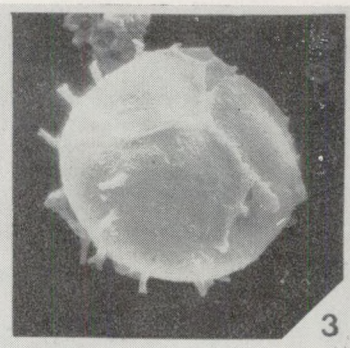
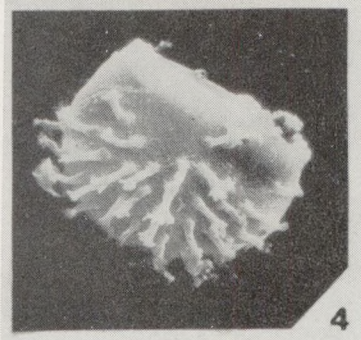
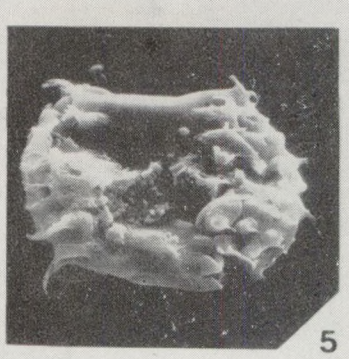
Plate 24

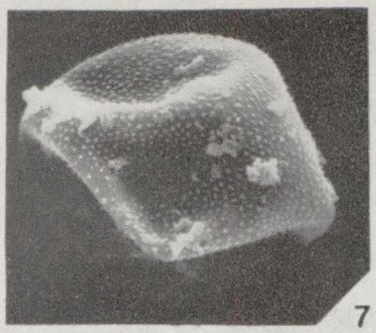


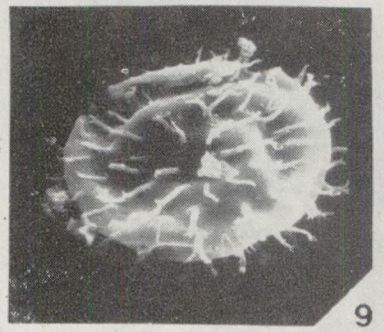


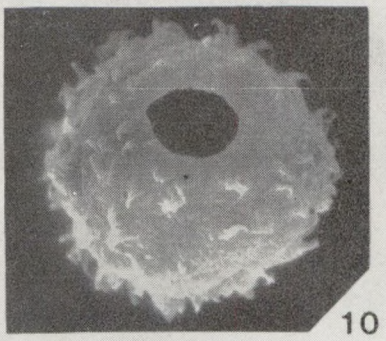


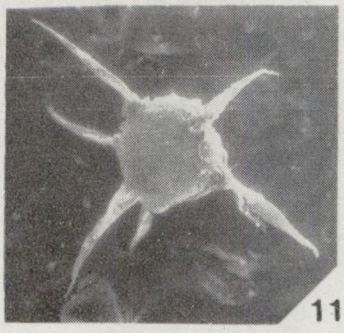


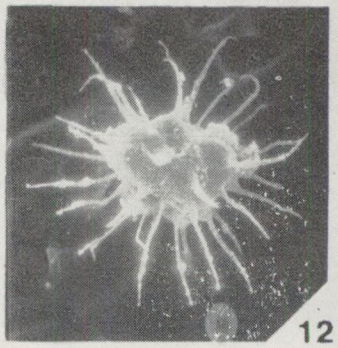


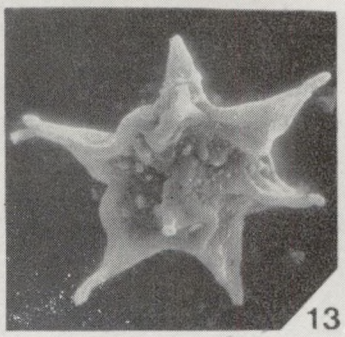


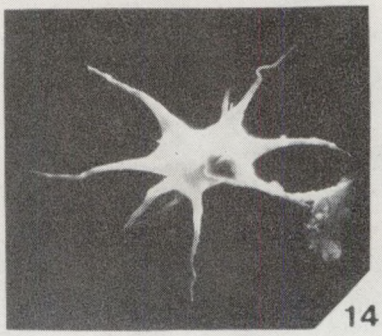












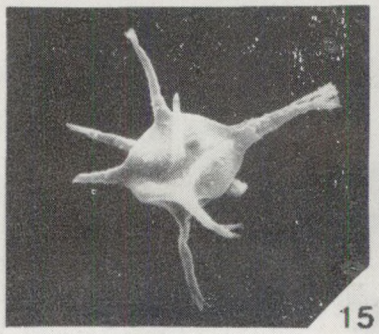


PLATE 1 - Stromatoporoids

Vertical sections, magnification x10

1. *Clathrodictyon gregale* Nestor. Holotype Co 3047. Koigi-Tõrevere; Porkuni Stage, Ärina Formation, Tõrevere Member.

2. *Forolinia brevis* Nestor. Vanaõue boring, depth 80.85; Juuru Stage, Varbola Formation.

3. *Pachystylostroma ungerni* (Rosen). Holotype Co 3011. Hiiumaa, Suuremõisa; Juuru Stage, Tamsalu Formation, Hilliste Member.

4. *Intexodictyon avitum* Nestor. Holotype Co 3090. Pakamägi (Laukna); Raikküla Stage, upper part.

5. *Clathtrodictyon variolare* (Rosen). Holotype Co 3006. Saaremaa, seashore at Jaani; drifted material from Adavere Stage, Rumba Formation.

6. *"Simplexodictyon" simplex* Nestor. Holotype Co 3134. Saaremaa, Liiva cliff; Jaani Formation, Mustjala Member.

7. *Stromatopora impexa* Nestor, 1966. Holotype Co 3168. Saaremaa, Liiva cliff; Jaani Formation, Mustjala Member.

8. *Vikingia tenuis* (Nestor). Holotype Co 3148. Saaremaa, Jaagarahu quarry; Jaagarahu Formation, Vilsandi Beds.

9. *Ecclimadictyon astrolaxum* Nestor. Holotype Co 3126. Saaremaa, Sepise, Jaagarahu Formation, Maasi Beds.

10. *Araneosustroma stelliparatum* (Nestor). Co 3121. Saaremaa, Kuusnõmme, Rootsiküla Formation, Kuusnõmme Beds.

11. *Lophiostroma schmidtii* (Nicholson). Co 3177. Saaremaa, Riiumägi; Paadla Formation, Sauvere Beds.

12. *Stromatopora bekkeri* Nestor. Holotype Co 3172. Saaremaa, Riiumägi; Paadla Formation, Sauvere Beds.

13. *Simplexodictyon podolicum* (Yavorsky). Co 3140. Saaremaa, Katri cliff; Paadla Formation, Uduvere Beds, Katri Member.

14. *Actinostromella vaiverensis* Nestor. Holotype Co 3159. Saaremaa, Vaivere; Kaugatuma Formation. Äigu Beds.

15. *Parallelostroma tuberculatum* (Yavorsky). Co 3166. Saaremaa, Lõo cliff; Kaugatuma Formation, Lõo Beds.

PLATE 2 - Ordovician brachiopods

1-5. *Platystrophia lutkevichi satura* Oraspõld. 1-4 - dorsal, anterior, posterior and lateral views of complete shell, Br 4195; 5 - interior of incomplete dorsal valve, Br 4196. Tõrma, Nabala Stage, Saunja Member. x2.

6-11. *Plaesiomys saxbyana* Oraspõld. 6-10 - dorsal, ventral, anterior, posterior and lateral views of complete shell, Br 4197. 11 - ventral interior of incomplete valve, Br 4198. Viru-Jaagupi, Vormsi Stage, Kõrgessaare Formation. x2.

12-15. *Boreadorthis recula* Öpik. Ventral, dorsal, posterior, lateral views of complete shell, Br 4133. Tõrma, Nabala Stage, Saunja Member. x2.

16-23. *Nicolella oswaldi mediofida* Alichova. 16-20 - ventral, dorsal, lateral, posterior and anterior views of complete shell, Br 4132. 21, 22 - exterior and interior of dorsal valve, Br 4131. 23 - interior of incomplete ventral valve, Br 4130. Tõrma, Nabala Stage, Saunja Member. x2.

24-29. *Skenidioides* aff. *oelandica* Wiman. 24-27 - interior, lateral, posterior and anterior views of ventral valve, Br 4127. 28, 29 - exterior and interior of dorsal valve, Br 4128. Moe, Pirgu Stage, Moe Formation. x9.

30. *Vellamo verneuili* (Eichwald). Dorsal interior, Br 4129. Viru-Jaagupi, Vormsi Stage, Kõrgessaare Formation. x2.

PLATE 3 - Ordovician brachiopods

1. Fossiliferous bedding surface with *Sowerbyella (Sowerbyella) tenera* Rõõmusoks (A), *Howellites wesenbergensis* (Alichova) (B) and *"Rafinesquina" poljensis* Alichova (Br 4199;(C). Kuusiku core, depth 14.5 m, Oandu Stage, Hirmuse Formation. x1.

2-5. *Mjoesina? inaequiclina* (Alichova). Pedicle exterior, lateral and posterior views, view on interarea of complete shell, Br 4135. Rakvere, Rakvere Stage, Rägavere Formation. x2.

6, 7. *Dactylogonia luhai* (Sokolskaya). Exterior and interior of dorsal valve, Br 4278. Voore (N. 1081) core, depth 7.05 m, Oandu Stage, Vasalemma Formation, Saku Member. x2.

8-12. *Eoplectodonta schmidti* (Lindström). 8-10 - ventral, dorsal and posterior views of complete shell, Br 4202. Viru-Jaagupi, Vormsi Stage, Kõrgessaare Formation. x2. 11, 12 - exterior and interior of ventral valve, Br 4203. Vormsi Island, Paope, Vormsi Stage, Kõrgessaare Formation. x2.

13-19. *Camerella dura* Oraspõld 13-17 - dorsal, ventral, anterior, lateral and posterior views of complete shell, Br 4200. Oandu. 18, 19 - interior and exterior views of ventral valve, Br 4201. Kuusiku core, depth 13.50-13.56 m. Oandu Stage, Hirmuse Formation. x2.

20-24. *Triplesia insularis* (Eichwald). Ventral, dorsal, anterior, posterior and lateral views of complete shell, Br 4349. Viru-Jaagupi, Vormsi Stage, Kõrgessaare Formation. x2.

25-27. *Oxoplecia* sp. Exterior, lateral and posterior views of dorsal valve, Br 4262. Viru-Jaagupi, Nabala Stage?. x2.

PLATE 4 - Silurian brachiopods

1-4. *Morinorhynchus orbignyi* (Davidson). Uduvere quarry, Paadla Stage. Ventral, dorsal, anterior and lateral views of complete shell Br 1534. x3

5-8. *Protatrypa malmoeyensis* Boucot, Johnson et Staton. Laeva-19 boring, 55.5 m, Raikküla Stage. Ventral, dorsal, anterior and lateral views of complete shell Br 1850. x2.

9-11. *Protatrypa malmoeyensis* Boucot, Johnson et Staton. Ruhnu boring, 493.6 m, Raikküla Stage. Ventral, dorsal and lateral views of complete shell Br 1807. x3.

12-15. *Resserella sawddensis* Hurst. Ruhnu boring, 402.6 m, Jaani Stage. Ventral, dorsal, anterior and lateral views of complete shell Br 1798. x5.

16-19. *Streptis grayii* (Davidson). Ruhnu boring, 402.6 m, Jaani Stage. Ventral, dorsal, posterior and anterior views of complete shell Br 1794. x5.

20, 21. *Visbyella visbyensis* (Lindström). Lätiküla, Adavere Stage. Ventral and dorsal views of complete shell Br 1840. x3.

22. *Protochonetes piltenensis* Rybnikova. Ohesaare boring, 25.65-25.68 m, Kaugatuma Stage. Exterior of ventral valves Br 3819 and Br 3817 (smaller) and interior of dorsal valve Br 3818. x3.

PLATE 5 - Bivalves and gastropos

All figures nat. size, except 11, 12.

1. *Poleumita discors* (Sowerby), apical view, TÜG 49/2, Jaagarahu, Vilsandi Beds of Jaagarahu Formation.

2. *Siluriphorus gotlandicus* (Lindström), side view, TÜG 2/163, Jaagarahu, Vilsandi Beds of Jaagarahu Formation.

3-4. *Euoumphalopterus (Euoumphalopterus) alatus* (Wahlenberg), apical and basal views, TÜG 49/1, Undva, Ninase Member of Jaani Formation.

5. *Holopea ? undata* (Sowerby), side view, TÜG 42/5, Kogula, Himmiste Beds of Paadla Formation.

6. *Murchisonia (Hormotoma) compressa* Lindström, side view, TÜG 2/24, Vana-Ado, Paadla Formation.

7. *Megalomphala taenia* (Lindström), side view, TÜG 2/27, Uduvere, Uduvere Beds of Paadla Formation.

8. *Crenilunula limata* (Lindström), side view, TÜG 2/162, Jaagarahu, Vilsandi Beds of Jaagarahu Formation.

9. *Loxonema strangulatum* Lindström, side view, TÜG 2/26, Sauvere, Sauvere Beds of Paadla Formation.

10. *Platyceras (Platyostoma) cornutum* (Hisinger), apical view, TÜG 40/60, Jaani, Paramaja Member of Jaani Formation.

11. *Cyclonema (Cyclonema) hiiumaa* Teichert, apical view. x2, TÜG 40/13, Hilliste, Varbola Formation of Juuru Stage.

12. *Mulceodens jaanussoni* Pojeta & Runnegar, left-lateral view. x2, TÜG 68/63, Kaugatuma Formation.

13. *Murchisonia (Murchisonia) obtusangula* Lindström, side view, TÜG 2/159, Kübassaare, Soeginina Beds of Rootsiküla Formation.

14. *Pycnomphalus acutus* Lindström, apical view, TÜG 2/22, Paadla, Himmiste Beds of Paadla Formation.

15. *Cardiola signata* Barrande, internal mold of right valve, Piltene core (No. 27, depth 742.6-746.9 m), Paadla Formation.

16. *Mytilarca* sp., internal mold of right valve, TÜG 2/161, Vilsandi Beds of Jaagarahu Formation.

17. *Kogulanychia bekkeri* Isakar, internal mold of right valve, La 1603, Kogula, Himmiste Beds of Paadla Formation.

18. *Grammysia obliqua* (McCoy), internal mold of left valve, TÜG 47/113, Ohesaare, Ohesaare Formation.

19. *Pteronitella retroflexa* (Wahlenberg), composite mold of left valve, TÜG 2/164, between Keskvere and Kübassaare, Soeginina Beds of Rootsiküla Formation.

20. *Ilionia prisca* (Hisinger), internal mold of right valve with shell material, TÜG 2/158, Paadla, Himmiste Beds of Paadla Formation.

21. Pelecypod limestone with *Pterioidea* n.gen. ?, TÜG 40/59, Anikaitse, Soeginina Beds of Rootsiküla Formation.

22. *Palaeopecten* sp., internal mold of left valve, Pavilosta core, depth 637.0 m, Kudjape Beds of Kuressaare Formation.

PLATE 6 - Cephalopods

1. *Gasconsoceras obesum* Foerste. Jaani Stage, Saaremaa, Jaani.

2. *Ophidioceras* cf. *simplex* (Barrande). Verkne Formation, Lithuania, Vishtites, depth 1,054 m.

3. *Dawsonoceras barrandei* Horny. Jaani Stage, Saaremaa, Jaani. Coll. E. Eichwald, N 1/2536 (Leningrad State University).

4. *Kionoceras studenitsense* Balashov. Jaani and Jaagarahu stages, South Baltic, Sovetsk, depth 1,081 m.

5. *Bickmorites falcigerum* (Eichwald). Jaani Stage, Saaremaa, Jaani. Coll. E. Eichwald N 1/1115 (Leningrad State University).

6. *Phragmoceras munthei* Hedström. Visby Beds, Gotland, Visby. Coll. E. Eichwald, N 1/1103 (Leningrad State University).

7. *Gomphoceras* sp. Neris Formation, Ludlow, Lithuania, Virbalis, depth 857 m.

8. *Mandaloceras cinctum* (Blake). Jaagarahu Stage, Saaremaa, Jaagarahu. N 40-1-77 (Leningrad State University).

9. *Palaeospyroceras* sp. Paadla Stage, Saaremaa, Kogula. N 8-4-77 (Leningrad State University).

10. *Temperoceras kybartense* (Saladzius). Jaagarahu Stage, Saaremaa, Jaagarahu. Coll. B.S. Sokolov, 1947, N 4-1-77 (Leningrad State University).

11. *Ephippiorthoceras* sp. Jaani Stage, Saaremaa, Jaagarahu. Coll. B.S. Sokolov, 1947, N 4-1-77 (Leningrad State University).

12. *Eushantungoceras pseudoimbricatum* (Barrande). Paadla Stage, Saaremaa, Kogula. Coll. Z.G. Balashov, 1948, N 8-4-77 (Leningrad State University).

13. *Armenocerina danica* (Teichert). Ohesaare Stage, Saaremaa, Ohesaare. N 11-5-77 (Leningrad State University).

14. *Eushantungoceras uralicum* Balashov. Kaugatuma Stage, Saaremaa, Kaugatuma. N 8500/354 (Leningrad State University).

15. *Armenocerina conica* Kiselev. Kaugatuma Stage, Saaremaa, Kaugatuma. N 14-3-77 (Leningrad State University).

16. *Podoliceoceras brevis* (Saladzius). Kaugatuma Stage, Saaremaa, Kaugatuma. N 10-1-77 (Leningrad State University).

17. *Orthodochmioceras saaremense* Kiselev. Kaugatuma Stage, Saaremaa, Kaugatuma. N 12-2-77 (Leningrad State University).

PLATE 7 - Ostracodes

1. *Steusloffia linnarssoni* (Krause, 1889), right valve Os 3228. x23. Karula boring, depth 433.3 m, Uhaku Stage.

2-3. *Sigmoopsis perpunctata* (Öpik, 1937), right valve Os 2175, lateral and lateroventral views. x40. Lasnamägi, Uhaku Stage.

4-5. *Tallinnella reticulata* Sarv, 1963. 4 - right heteromorphic valve Os 2796. x23; 5 - left tecnomorphic valve Os 2795. x23. Võru boring, depth 403.8 m, Kukruse Stage.

6. *Piretella tridactyla* Jaanusson, 1957, right heteromorphic valve Os 3227. x29. Otepää boring, depth 497.1 m, Aseri Stage.

7. *Tallinnellina primaria* (Öpik, 1935), left valve Os 2138. x49. Ubari, Volkhov Stage.

8. *Bichilina prima* Sarv, 1959, right valve Os 2559. x49. Alliku, Jõhvi Stage.

9. *Tallinnopsis perplana* (Neckaja, 1953), left valve Os 3229. x49. Russalu boring, depth 136.55 m, Kukruse Stage.

10-11. *Sigmoopsis granulata* (Sarv, 1956). 10 - left valve Os 2621. x49; 11 - right valve Os 2620. x49. Rakvere, Oandu Stage.

12. *Olbia cf. braderupensis* (Schallreuter, 1980), carapace Os 3130, right view. x31. Vinni boring, depth 40.0 m, Rakvere Stage.

PLATE 8 - Ostracodes

1. *Tetradella plicatula* (Krause, 1892), left heteromorphic valve Os 5048. x49. Porkuni, Porkuni Stage.

2. *Tetradella egorowi* Neckaja, 1952, right heteromorphic valve Os 2666. x60. Rägavere, Rakvere Stage.

3-4. *Uhakiella curta* Sidaraviciene, 1975. 3 - right heteromorphic valve Os 3230. x29. Vodja H-190 boring, depth 114.8 m, Vormsi Stage. 4 - right heteromorphic valve Os 3232. x29. Vodja H-190 boring, depth 110.3 m, Vormsi Stage.

5. *Eoaquapulex frequens* (Steusloff, 1894), tecnomorphic carapace Os 3230, left view. x29. Aulepa, depth 0.40-0.45 m, Vormsi Stage.

6. *Klimphores minimus* (Sarv, 1956), right valve Os 2014, x89. Oandu, Oandu Stage.

7. *Circulina* sp. n., carapace Os 3204, left view. x75. Taagepera boring, depth 419.0 m, Porkuni Stage.

8. *Medianella aequa* (Stumbur, 1956), carapace Os 5076, right view. x40. Porkuni, Porkuni Stage.

9-10. *Disulcina explicata* Sarv, 1959, right valve Os 2419, lateral and lateroventral views. x49. Nõmmeküla, Nabala Stage.

11. *Pedomphalella egregia* (Sarv, 1963), right valve Os 2729. x72. Rakvere, Keila Stage.

12. *Pinnatulites procera* (Kummerow, 1924), carapace Os 2058, right view. x29. Purtse, Volkhov Stage.

PLATE 9 - Ostracodes

1-2. *Nodibeyrichia protuberans* (Boll, 1862). 1 - tecnomorphic left valve Os 5379. x23; 2 - heteromorphic left valve Os 5378. x20. Cliff Ohesaare, Ohesaare Stage.

3. *Nodibeyrichia tuberculata* (Klöden, 1834). Tecnomorphic right valve Os 5792. x23. Ohesaare boring, depth 11.95 m, Kaugatuma Stage.

4. *Frostiella groenvalliana* Martinsson, 1963. Heteromorphic left valve Os 5763. x20. Äigu, Kaugatuma Stage.

5-6. *Plicibeyrichia numerosa* Sarv, 1968. 5 - heteromorphic left valve Os 5315. x30; 6 - tecnomorphic right valve Os 5318. x30. Kuressaare, Kuressaare Stage.

7. *Neobeyrichia nutans* (Kiesow, 1888). Tecnomorphic left valve Os 5768. x23. Ohesaare boring, depth 114.95 m, Paadla Stage.

8-9. *Beyrichia subornata* Martinsson, 1962. 8 - heteromorphic left valve Os 5901. x30; 9 - tecnomorphic left valve Os 5902. x30. Ohesaare boring, depth 149.03 m, Rootsiküla Stage.

10. *Leptobolbina quadricuspidata* Martinsson, 1962. Heteromorphic left valve Os 5812. Ohesaare boring, depth 169.22 m, Jaagarahu Stage.

PLATE 10 - Ostracodes

1-2. *Craspedobolbina mucronulata* Martinsson, 1962. 1 - heteromorphic right valve Os 5852. x42; 2 - tecnomorphic left valve Os 5853. x42. Haapsa, Jaani Stage (erratic).

3-4. *Beyrichia valguensis* Sarv, 1968. 3 - heteromorphic left valve Os 5864. x23; 4 - tecnomorphic right valve Os 5866. x23. Valgu, Adavere Stage.

5. *Thlipsuroides walensis* (Krandijevsky, 1963). Left valve. x70. Pärnu boring, depth 124.30 m, Adavere Stage.

6-7. *Longiscella caudalis* (Jones, 1889). 6 - carapace, left view, x42; 7 - carapace, dorsal view. x42. Pärnu boring, depth 124.30 m, Adavere Stage.

8-9. *Bythocyproidea sarvi* Neckaja, 1966. 8 - carapace, right view. x50; 9 - carapace, dorsal view. x50. Pärnu boring, depth 155,0 m, Raikküla Stage.

10. *Monoceratella edita* Sarv, 1962. Carapace Os 5031, right view. x56. Vahtrepa, Juuru Stage.

11. *Steusloffina eris* Neckaja, 1966. Carapace, right view. x50. Asuküla boring, depth 9.25 m, Juuru Stage.

PLATE 11 - Trilobites

1, 2. *Acernaspis estonica* Männil, 1970. Llandovery, Juuru Stage, Õhne Formation, Abja core, depth 310.2 m; Holotype cephalon, Tr 2472. x4.

3, 4. *Calymene ansensis* Männil, 1977. Llandovery, Juuru Stage, Kaugatuma core, depth 331.8 m; 3 - cranidium, Tr 2670 b. x3.5; 4 - pygidium, Tr 2670 c. x3.5.

5, 6. *Encrinurus (Nucleurus) rotundus* Männil, 1977. Llandovery, Juuru Stage, Õhne Formation; 5 - pygidium, Tr 1973. x4; Survaküla core, depth 190.5 m; 6 - holotype specimen, Tr 2504. x2; Laeva core, depth 121.2 m.

7, 8. *Encrinurus (Nucleurus) selistensis* Männil, 1977. Llandovery, Raikküla Stage; 7 - holotype cranidium, Tr 2750 a. x3; Seliste core, depth 283.4 m; 8 - pygidium, Tr 2751. x3.8; Seliste core, depth 284.1 m.

9, 10. *Encrinurus (E.) schisticola* Törnquist, 1884. Llandovery, Adavere Stage, Velise Formation; Konovere River, Lätiküla; 9 - partly enrolled specimen, Tr 2456. x3; 10 - incomplete pygidium, Tr 2446 b. x4.

11, 12. *Calymene frontosa* Lindström, 1885. Llandovery, Adavere Stage, Velise Formation; Konovere River, Lätiküla; complete enrolled specimen, Tr 1963. x3.

13-15. *Acernaspis konoverensis* Männil, 1970. Llandovery, Adavere Stage, Velise Formation; Konovere River, Lätiküla; 13 - pygidium, Tr 2460. x4; 14 - holotype cranidium, Tr 2458 a. x4; 15 - lateral view of enrolled specimen, Tr 2465. x4.

16, 17. *Encrinurus (E.) punctatus* (Wahlenberg, 1818). Wenlock, Jaani Stage, Paramaja Member; Paramaja Cliff; 16 - partly enrolled specimen, Tr 2775. x2.6; 17 - pygidium, Tr 2782. x2.5.

18, 19. *Proetus concinnus osiliensis* Schmidt, 1894. Wenlock, Jaani Stage, Paramaja Member; Paramaja Cliff; 18 - pygidium, Tr 2894. x4; 19 - incomplete specimen, Tr 2834. x4.

20, 21. *Calymene blumenbachii* Brongniart, 1822. Wenlock, Jaani Stage, Paramaja Member; Paramaja Cliff; 20 - complete enrolled specimen, Tr 2800. x1.5; 21 - posterior view of partly enrolled specimen, Tr 2673. x3.

PLATE 12 - Trilobites

1. *Cyphoproetus insterianus* Schrank, 1972. Wenlock, Jaagarahu Stage, Jämaja Formation; Ohesaare core, depth 268.8 m; almost complete specimen, Tr 2580. x6.

2, 3. *Encrinurus (E.) balticus* Männil, 1978. Wenlock, Jaagarahu Stage, Jämaja Formation; 2 - holotype cranidium, Tr 1998. x4; Kolka core, depth 428.8 m; 3 - pygidium, Tr 2872. x4. Kolka core, depth 440.9 m.

4. *Dalmanites* cf. *caudatus* (Brünnich, 1781). Wenlock, Jaagarahu Stage, Jämaja Formation; Ohesaare core, depth 292.7 m; incomplete pygidium, Tr 2574. x2.

5. *Calymene restevensis* Balashova, 1975. Wenlock, Jaani Stage, Mustjala Formation; Pärnu (Livonia) core, depth 116.6 m; cranidium, Tr 2602. x2.

6, 7. *Calymene orthomarginata* Schrank, 1970. Wenlock, Jaani Stage, Jaani Formation; 2 - cranidium, Tr 2587. x2.5; Kolka core, depth 521.7 m; 7 - pygidium, Tr 2692. x3; Kolka core, depth 500.2 m.

8, 9. *Calymene mimaspera* Schrank, 1970. Wenlock, Jaani Stage; Jaani Formation; 8 - cranidium, Tr 2667. x2.5, Ruhnu core, depth 433.3 m; 9 - pygidium, Tr 2666. x2.5; Ruhnu core, depth 434.8 m.

10, 11. *Warburgella estonica* Männil, 1979. Wenlock, Jaagarahu Stage, Maasi Beds; Tagamõisa ditch; 10 - cranidium, Tr 1890 a. x6; 11 - pygidium, Tr 1890 b. x6.

12. *Balizoma obtusus* (Abgelin, 1851). Ludlow, Paadla Stage, Uduvere Beds; Katri Cliff; pygidium, Tr 3341. x3.

13. *Proetus* (s.l.) *pulcher* Nieszkowski, 1857. Ludlow, Paadla Stage, Uduvere Beds; Uduvere locality; incomplete enrolled specimen, Tr 2880. x4.

14. *Calymene* sp. Ludlow, Kuressaare Stage, Kudjape Beds; Kudjape ditch; pygidium, Tr 2747. x3.

15. *Calymene flabellata* Männil, 1983. Ludlow, Kuressaare Stage, Kudjape Beds; Kudjape ditch; holotype cranidium, Tr 2728. x3.

16, 17. *Proetus* (s.l.) *kuressaarensis* Männil, 1981. Ludlow, Kuressaare Stage, Kudjape Beds; Ohesaare core, depth 68.8 m; 16 - holotype cranidium, Tr 2920 a. x5; 17 - pygidium, Tr 2920 b. x4.

18, 19. *Calymene kaugatumensis* Männil, 1983. Pridoli, Kaugatuma Stage, Äigu Beds; near Kaugatuma Cliff; 18 - pygidium, Tr 2705. x3; 19 - cranidium, Tr 2702. x3.

20. *Calymene schmidti* Männil, 1983. Pridoli, Kaugatuma Stage, Äigu Beds; same locality as Figs 18, 19; holotype cranidium, Tr 2723. x2.

21. *Eophacops helmuti* Männil, 1987. Pridoli, Kaugatuma Stage, Äigu Beds; same locality as Figs 18, 19; cephalon, Tr 3330. x4.

22. *Proetus* (s.l.) *nieszkowskii* Männil, 1981. Pridoli, Kaugatuma Stage, Äigu Beds; same locality as Figs 18, 19; cranidium, Tr 2826. x4.3.

23. *Calymene dnestroviana* Balashova, 1968. Pridoli, Kaugatuma Stage, Äigu Beds; same locality as Figs 18, 19. Incomplete cranidium, Tr 2706. x3.

24, 25. *Calymene conspicua* Schmidt, 1894. Pridoli, Ohesaare Stage, Ohesaare Cliff; 24 - complete specimen, Tr 1938. x2; 25 - incomplete cranidium, Tr 2719. x1.5.

PLATE 13 - Ordovician chitinozoans

1. *"Conochitina" taugourdeaui* Eisenack 1968. Rapla, 37.1 m; Pirgu Stage. Ch 1051/7802. x180.

2. *Ancyrochitina ancyrea* (Eisenack 1931). Rapla, 66.0 m; Pirgu Stage. Ch 1060/7766. x290.

3. *Acanthochitina barbata* Eisenack 1931. Rapla, 78.4 m; Vormsi Stage. Ch 1058/7753. x70.

4, 5. *Tanuchitina bergstroemi* Laufeld 1967. Rapla, 72.9 m; Pirgu Stage. Ch 1009/7760. x60; x500.

6. *Coronochitina coronata* (Eisenack 1931). Rapla, 49,0 m; Pirgu Stage. Ch 1040/7780. x115.

7. *Lagenochitina baltica* Eisenack 1931. Rapla, 95.5 m; Nabala Stage. Ch 1092/7735. x200.

8. *Conochitina robusta* Eisenack 1959. Rapla, 125.4 m; Rakvere Stage. Ch 1116/7703. x160.

9. *Conochitina* sp. Põltsamaa, 125.0 m; Pirgu Stage. Ch 1374/7914. x170.

10. *Cyathochitina reticulifera* Grahn 1981. Rapla, 106.6 m; Nabala Stage. Ch 1099/7722. x145.

11. *Fungochitina fungiformis* (Eisenack 1931). Rapla, 95.5 m; Nabala Stage. Ch 1082/7735. x210.

12. *Cyathochitina* cf. *calix* (Eisenack 1931). Rapla, 114.8 m; Rakvere Stage. Ch 1134/7713. x230.

13. *"Illichitina" multiplex* Schallreuter 1963. Viki, 329.6 m; Keila Stage. Ch 0980/7915. x80.

14. *Spinachitina cervicornis* (Eisenack 1931). Rapla, 137.5 m; Keila Stage. Ch 1150/7690. x200.

15. *Desmochitina nodosa* Eisenack 1931. Rapla, 128.0 m; Keila Stage. Ch 1131/7696. x110.

16, 17. *Cyathochitina* aff. *reticulifera* Grahn 1981. Imavere, 215.7 m; Idavere Stage. Ch 0774/7422. x170; x4000.

18. *"Eremochitina" dalbyensis* Laufeld 1967. Rapla, 153.9 m; Idavere Stage. Ch 1404/7670, x160.

19. *Eisenackitina oelandica* (Eisenack 1955). Rapla, 167.3 m; Kukruse Stage.Ch 1260/7652. x400.

20. *Cyathochitina sebyensis* Grahn 1981. Rapla, 180.2 m; Aseri Stage. Ch 1491/7909. x100.

21. *"Sagenachitina"* sp. Rapla, 179.2 m; Lasnamägi Stage. Ch 1416/7631. x80.

22, 23. *Conochitina tuberculata* Eisenack 1962. Rapla,172.8 m; Uhaku Stage. Ch 1222/7643. x75; x480.

24. *Cyathochitina stentor* (Eisenack 1937). Rapla, 167.3 m; Kukruse Stage. Ch 1250/7652. x35.

25, 26. *Conochitina clavaherculi* Eisenack 1959. Rapla, 175.3 m; Uhaku Stage. Ch 1279/7639. x50; x300.

27. *Halochitina retracta* (Eisenack 1955). Rapla, 167.3 m; Kukruse Stage. Ch 1240/7652. x300.

28. *Conochitina crinita* Grahn 1984. Rapla, 181.6 m; Aseri Stage. Ch 1364/7627. x180.

29. *Linochitina* sp. Rapla, 182.6 m; Kunda Stage. Ch 1386/7625. x200.

30. *Desmochitina papilla* Grahn 1984. Rapla, 189.1 m; Volkhov Stage. Ch 1471/7904. x320.

31. *Cyathochitina regnelli* Eisenack 1955. Rapla, 188.4 m; Kunda Stage. Ch 1318/7619. x300.

32. *Conochitina cucumis* Grahn 1984. Rapla, 189.5 m; Volkhov Stage Ch 1479/7903. x140.

33. *Pistillachitina pistillifrons* (Eisenack 1939). Rapla, 182.1 m; Aseri Stage. Ch 1493/7626. x100.

34. *Lagenochitina esthonica* Eisenack 1955. Rapla, 185.5 m; Kunda Stage. Ch 1297/7622. x65.

PLATE 14 - Silurian Chitinozoans

1. *Coronochitina fragilis* Nestor, 1980. Ch 9/1983 (HT). x140. Ohesaare boring, depth 446.5 m, Juuru Stage, Puikule Member.

2. *Conochitina aspera* Nestor, 1980. Ch 21/1431 (HT). x195. Ikla boring, depth 514.6 m, Juuru Stage, Ohne Formation.

3. *Conochitina postrobusta* Nestor, 1980. Ch 299/1430. x125. Ikla boring, depth 515.7 m, Juuru Stage, Ohne Formation.

4. *Ancyrochitina laevaensis* Nestor, 1980. Ch 11/8009. x230. Laeva boring, depth 122.5 m, Juuru Stage, Ohne Formation.

5. *Ancyrochitina* sp. C. Ch 253/1437. x250. Ikla boring, depth 505.7 m, Juuru Stage, Ohne Formation.

6. *Conochitina iklaensis* Nestor, 1980. Ch 39/1445. x125. Ikla boring, depth 492 m, Raikküla Stage, Slitere Member.

7. *Conochitina electa* Nestor, 1980. Ch 298/1355. x135. Varbla boring, depth 212.9 m, Raikküla Stage, Slitere Member.

8. *Coronochitina maennili* Nestor, 1980. Ch 297/1686. x135. Ruhnu boring, depth 573.3 m, Raikküla Stage, Slitere Member.

9. *Ancyrochitina* sp. D. Ch 474/1456. x245. Ikla boring, depth 472.6 m, Raikküla Stage, Kolka Member.

10. *Ancyrochitina convexa* Nestor, 1980. Ch 14/1810. x230. Ruhnu boring, depth 536 m, Raikküla Stage, Ikla Member.

11. *Conochitina edjelensis* Taugourdeau, 1963. Ch 32/1926. x230. Varbla boring, depth 176.05 m, Raikküla Stage, Ikla Member.

12. *Conochitina* cf. *protracta* (Zaslavskaya, 1980). Ch 306/9053. x165. Häädemeeste boring, depth 232.4 m, Raikküla Stage, Lemme Member.

13. *Conochitina emmastensis* Nestor, 1982. Ch 181/1385. x125. Varbla boring, depth 159.55 m, Adavere Stage, Rumba Formation.

14. *Eisenackitina dolioliformis* Umnova, 1976. Ch 296/1395. x135. Varbla boring, depth 141.35 m, Adavere Stage, Velise Formation.

15. *Ancyrochitina* sp. A. Ch 277/1385. x125. Varbla boring, depth 159.55 m, Adavere Stage, Rumba Formation.

16. *Angochitina longicollis* Eisenack, 1959. Ch 468/10661. x250. Jaagarahu boring, depth 49.5 m, Jaani Stage, Mustjala Member.

17. *Desmochitina opaca* Laufeld, 1974. Ch 471/10676. x250. Jaagarahu boring, depth 35.7 m, Jaani Stage, Mustjala Member.

18. *Conochitina proboscifera* Eisenack, 1937. Ch 101/1542. x100. Kipi boring, depth 136.85 m, Jaani Stage, Mustjala Member.

19. *Gotlandochitina ruhnuensis* Nestor, 1982. Ch 465/10662. x280. Jaagarahu boring, depth 48.5 m, Jaani Stage, Mustjala Member.

20. *Conochitina visbyensis* Laufeld, 1974. Ch 459/10665. x290. Jaagarahu boring, depth 46.4 m, Jaani Stage, Mustjala Member.

21. *Ancyrochitina* sp. E. Ch 274/1730. x230. Ruhnu boring, depth 465.4 m, Adavere Stage, Velise Formation.

22. *Gotlandochitina magnifica* Nestor, 1982. Ch 113/1736 (HT). x140, Ruhnu boring, depth 454 m, Jaani Stage, Tõlla Member.

23. *Margachitina margaritana* (Eisenack, 1937). Ch 108/9269. x230. Ohesaare boring, depth 300.7 m, Jaani Stage, Paramaja Member.

24. *Desmochitina acollaris* Eisenack, 1959. Ch 148/1826. x230. Ruhnu boring, depth 417.5 m, Jaani Stage, Paramaja Member.

25. *Conochitina tuba* Eisenack, 1932. Ch 315/1765. x130. Ruhnu boring, depth 356 m, Jaarahu Stage, Jamaja Formation.

26. *Conochitina* cf. *mamilla* Laufeld, 1974. Ch 358/1552. x70. Kipi boring, depth 115.15 m, Jaani Stage, Ninase Member.

27. *Conochitina claviformis* Eisenack, 1931. Ch 202/9086. x135. Häädemeeste boring, depth 141 m, Jaagarahu Stage, Jämaja Formation.

28. *Linochitina cingulata* (Eisenack, 1937). Ch 406/1764. x265. Ruhnu boring, depth 359.25 m, Jaagarahu Stage, Jämaja Formation.

29. *Clathrochitina clathrata* Eisenack, 1959. Ch 153/1572. x315. Ohesaare boring, depth 291.4 m, Jaagarahu Stage, Jämaja Formation.

30. *Gotlandochitina martinssoni* Laufeld, 1974. Ch 156/1572. x365. Ohesaare boring, depth 291,3 m, Jaagarahu Stage, Jämaja Formation.

31. *Ancyrochitina gutnica* Laufeld, 1974. Ch 251/1760. x285. Ruhnu boring, depth 371.5 m, Jaagarahu Stage, Jämaja Formation.

32. *Conochitina lagena* Eisenack, 1968. Ch 130/1763. x135. Ruhnu boring, depth 361.9 m, Jaagarahu Stage, Jämaja Formation.

PLATE 15 - Silurian Chitinozoans

1. *Conochitina pachycephala* Eisenack, 1964. Ch 203/1773. x250. Ruhnu boring, depth 333 m, Jaagarahu Stage, Jämaja Formation.

2. *Conochitina subcyatha* Nestor, 1982. Ch 168/773. x255. Ruhnu boring, depth 333 m, Jaagarahu Stage, Jämaja Formation.

3. *Conochitina cribrosa* Nestor, 1982. Ch 178/1598. x255. Ohesaare boring, depth 188.2 m. Jaagarahu Stage, Sõrve Formation.

4. *Sphaerochitina indecora* Nestor, 1982. Ch 164/650 (HT). x335. Ohesaare boring, depth 169.5 m, Jaagarahu Stage, Sõrve Formation.

5. *Conochitina* cf. *argillophila* Laufeld, 1974. Ch 201/10904. x500. Ohesaare boring, depth 159.6 m, Jaagarahu Stage, Jaagarahu Formation.

6. *Gotlandochitina militaris* Laufeld, 1974. Ch 500/9867. x370. Ventspils boring, depth 613 m, Paadla Stage, Dubysa Formation.

7. *Conochitina latifrons* Eisenack, 1964. Ch 501/1631. x230. Ohesaare boring, depth 110.4 m, Paadla Stage, Torgu Formation.

8. *Ancyrochitina diabolus* Eisenack, 1937. Ch 502/1640. x330. Ohesaare boring, depth 97.65 m, Paadla Stage, Torgu Formation.

9. *Conochitina lauensis* Laufeld, 1974. Ch 503/1640. x230. Ohesaare boring, depth 97.65 m, Paadla Stage, Torgu Formation.

10. *Angochitina elongata* Eisenack, 1931. Ch 504/10035. x330. Kaugatuma boring, depth 81.10 m, Paadla Stage, Sauvere Beds.

11. *Conochitina intermedia* Eisenack, 1955. Ch 505/1640. x330. Ohesaare boring, depth 97.65 m, Paadla Stage, Torgu Formation.

12. *Eisenackitina lagenomorpha* (Eisenack, 1931). Ch 506/9738. x330. Kolka boring, depth 282.9 m, Kuressaare Stage, Tahula Beds.

13. *Eisenackitina* cf. *philipi* Laufeld, 1974. Ch 507/9731. x330. Kolka boring, depth 261.3 m, Kuressaare Stage, Tahula Beds.

14. *Ancyrochitina brevispinosa* Eisenack, 1968. Ch 508/10055. x330. Kaugatuma boring, depth 51.4 m, Kuressaare Stage, Tahula Beds.

15. *Pterochitina perivelata* (Eisenack, 1937). Ch 509/9738. x330. Kolka boring, depth 282.2 m, Kuressaare Stage, Tahula Beds.

16. *Conochitina granosa* Laufeld, 1974. Ch 510/778. x330. Ohesaare boring, depth 79.2 m, Kuressaare Stage, Kudjape Beds.

17. *Sphaerochitina sphaerocephala* (Eisenack, 1932). Ch 511/918. x330. Kolka boring, depth 238 m, Kaugatuma Stage, Äigu Beds.

18. *Eisenackitina* sp. 3. Ch 512/9721. x330. Kolka boring, depth 217.5 m, Kaugatuma Stage, Lõo Beds.

19. *Eisenackitina* sp., aff. *elongata* Eisenack, 1972. Ch 513/9738. x230. Kolka boring, depth 253.6 m, Kaugatuma Stage, Äigu Beds.

20. *Ancyrochitina fragilis* Eisenack, 1955. Ch 514/1658. x330. Ohesaare boring, depth 65.7 m. Kaugatuma Stage, Äigu Beds.

21. *Fungochitina pistilliformis* (Eisenack, 1931), Ch 515/1670. x330. Ohesaare boring, depth 26.2 m, Kaugatuma Stage, Lõo Beds.

22. *Eisenackitina filifera* (Eisenack, 1931). Ch 516/1664. x230. Ohesaare boring, depth 40.1 m, Kaugatuma Stage, Äigu Beds.

PLATE 16 - Conodonts

1, 2. *Cordylodus andresi* Viira et Sergeyeva. x35. Kallavere Formation, outcrop Vihula.

3, 4. *Cordylodus proavus* Müller. x35. Kallavere Formation, outcrop Toolse.

5. *Cordylodus proavus* aff. *C. primitivus* Bagnoli, Barnes et Stevens. x40. Kallavere Formation, outcrop Saka.

6, 7. *Cordylodus intermedius* Furnish. x35. Kallavere Formation, outcrop Mäekalda.

8, 9. *Cordylodus lindstromi* Druce et Jones. x35. Kallavere Formation, 8 - outcrop Toolse, 9 - outcrop Mäekalda.

10. *Cordylodus rotundatus* Pander. x35. Kallavere Formation, outcrop Suhkrumägi.

11. *Cordylodus angulatus* Pander. x35. Kallavere Formation, outcrop Suhkrumägi.

12. *Drepanoistodus deltifer pristinus* Viira. x40. Varangu Formation, Toolse 420 boring, depth 18.6-18.85 m.

13. *Drepanoistodus deltifer deltifer* (Lindström). x40. Varangu Formation, Toolse 420 boring, depth 16.3-16.5 m.

14. *Paroistodus proteus* (Lindström). x40. Leetse Formation, Karula boring, depth 495.5 m.

15. *Prioniodus elegans* Pander. x35. Leetse Formation, Sturi boring, depth 1144.55 m.

16. *Oepikodus evae* (Lindström). x35. Leetse Formation, Kaagvere boring, depth 349.9 m.

17. *Paroistodus originalis* (Sergeyeva). x40. Toila Formation, Kaagvere boring, depth 347.7 m.

18. *Baltoniodus navis* (Lindström). x40. Toila Formation, Ohesaare boring, depth 517.25 m.

19. *Periodon flabellum* (Lindström). x45. Toila Formation, Ohesaare boring, depth 518.19 m.

20. *Microzarkodina ozarkodella* Lindström. x45. Loo Formation, Ohesaare boring, depth 510.44 m.

21. *Eoplacognathus variabilis* (Sergeeva). x40. Loobu Formation, Ohesaare boring, depth 511.14 m.

22. *Eoplacognathus* aff. *variabilis* (Sergeeva). x40. Aseri Formation, Ohesaare boring, depth 505.06 m.

23. *Eoplacognathus pseudoplanus* (Viira). x45. Loobu Formation, Ohesaare boring, depth 508.87 m.

24a,b. *Eoplacognathus suecicus* Bergström. x45. Aseri Formation, Ohesaare boring, depth 505.06 m.

25, 26. *Eoplacognathus filiaceus* (Fåhraeus). x45. Väo Formation, 25 - outcrop Suhkrumägi, 26 - Karula boring, depth 444.6 m.

27, 28. *Eoplacognathus reclinathus* (Fåhraeus). x40. Väo Formation, Ohesaare boring, depth 500.0 m.

29, 30. *Eoplacognathus robustus* Bergström. x40. Väo Formation, Ohesaare boring, depth 497.23 m.

31. *Pygodus serra* (Hadding). x45. Väo Formation, Ohesaare boring, depth 494.8 m.

32. *Pygodus anserinus* (Lamont et Lindström). x45. Kõrgekallas Formation, Karula boring, depth 426.5 m.

33, 34. *Eoplacognathus lindstroemi* (Hamar). x40. Väo Formation, 33 - Äiamaa boring, depth 224.0 m, 34 - Ohesaare boring, depth 495.95 m.

35. *Prioniodus variabilis* Bergström. x40. Kukruse Regional Stage, Kaagvere boring, depth 296.8 m.

36. *Prioniodus gerdae* Bergström. x40. Tatruse Formation, Kaagvere boring, depth 294.5 m.

37, 38. *Amorphognathus tvaerensis* Bergström. 37 - x40, 38 - x45. Kukruse Regional Stage, 37 - Äiamaa boring, depth 210.83 m, 38 - Kaagvere boring, depth 298.2 m.

PLATE 17 - Conodonts

1, 8. *Amorphognathus ordovicicus* Branson et Mehl. x100. Kõrgessaare Formation, outcrop Paope.

2. *Phragmodus* cf. *undatus* Branson et Mehl. x100. Adila Formation, Kirikuküla boring, depth 138.2 m.

3. *Hamarodus europaeus* (Serpagli). x100. Saunja Formation, Sturi boring, depth 1003.3 m.

4, 7. *Ozarkodina* cf. *pseudofissilis* (Lindström). x100. Ärina Formation, outcrop Porkuni.

5. *Icriodella* aff. *superba* Rhodes. x100. Kõrgessaare Formation, outcrop Paluküla.

6. *Plectodina ? tenuis* (Branson et Mehl). x100. Kõrgessaare Formation, outcrop Paluküla.

9. *Ozarkodina* aff. *hassi* (Pollock, Rexroad et Nicoll). x100. Raikküla Formation, outcrop Mündi.

10, 15, 17, 19, 20. *Ozarkodina* sp. x100. Rumba Formation, boring 43, 10, 15, 17, 20 - depth 9.5 m, 19 - depth 5.3 m.

11, 13. *Birksfeldia* cf. *circumplicata* Orchard. x100. Ärina Formation, outcrop Porkuni.

12. *Eocarniodus gracilis* (Rhodes). x100. Kõrgessaare Formation, outcrop Paope.

14. *Ozarkodina* ex gr. *oldhamensis* (Rexroad). x100. Varbola (?) Formation, outcrop Kallaste.

16. *Kockelella manitoulinensis* (Pollock, Rexroad et Nicoll). x100. Raikküla Formation, outcrop Pusku.

18, 21. *Pterospathodus celloni* (Walliser). x100. Velise Formation, Jõhve boring, depth 82.2 m.

22. *Carniodus carnulus* Walliser. x100. Velise (?) Formation, Viki boring, depth 153.35 m.

23, 26. *Ozarkodina polinclinata* (Nicoll et Rexroad). x100. 23 - Mustjala Beds, Viki boring, depth 123.25 m, 26 - Velise Formation, Viki boring, depth 168.6 m.

24. *Astropentagnathus irregularis* Mostler. x100. Velise Formation, Kaugatuma boring, depth 269.05 m.

25. *Apsidognathus ruginosus* Mabillard et Aldridge. x100. Mustjala Beds, Viki boring, depth 124.6 m.

27. *Apsidognathus walmsleyi* Aldridge. x100. Mustjala Beds, Viki boring, depth 125.6 m.

28, 32. *Pterospathodus amorphognathoides* Walliser. x100. Mustjala Beds, 28 - Jõhve boring, depth 50.15 m, 32 - Jaagarahu boring, depth 42.6 m.

29. *Pterospathodus procerus* (Walliser). x100. Velise Formation, Ohesaare boring, depth 352.0 m.

30. *Apsidognathus tuberculatus* Walliser. x50. Velise Formation, outcrop Velise-Kõrgekalda.

31. *Kockelella ranuliformis* (Walliser). x50. Mustjala Beds, outcrop Panga.

PLATE 18 - Conodonts

1. *Distomodus staurognathoides* (Walliser). x50. Mustjala Beds, Jaagarahu boring, depth 44.6 m.

2. *Ozarkodina* aff. *gulletensis* Aldridge. x50. Ninase Formation, outcrop Panga.

3. *Ozarkodina sagitta rhenana* Walliser. x50. Vilsandi Beds, Vesiku boring, depth 78.4 m.

4, 5. *Ozarkodina excavata excavata* (Walliser). x50. Paadla Formation, outcrop Karala.

6. *Kockelella walliseri* (Helfrich). x50. Ninase Formation, Jõhve boring, depth 25.5 m.

7. *Kockelella* aff. *ranuliformis* (Walliser). x50. Jaagarahu Formation, outcrop Sepise.

8. *Ozarkodina confluens bucerus* Viira. x70. Jaagarahu Formation, Sakla boring, depth 71.79 m.

9. *Ctenognathodus murchisoni* (Pander). x50. Rootsiküla Formation, outcrop Vesiku.

10a,b. *Ozarkodina* aff. *snajdri* (Walliser). x70. Paadla Formation, outcrop Karala.

11. *Ozarkodina confluens densidentatus* Viira. x50. Rootsiküla Formation, Ohesaare boring, depth 144.05 m.

12-14. *Ozarkodina confluens cornidentatus* Viira. 12,14 - x40, 13 - x50. Paadla Formation, 12,14 - Ohesaare boring, depth 106.23 m, 13 - outcrop Unimäe.

15. *Ozarkodina confluens ambiquus* Viira. x40. Kaugatuma Formation, Ohesaare boring, depth 67.4 m.

16, 17. *Distomodus dubius* (Rhodes). x50. Paadla Formation, Sakla boring, depth 14.47 m.

18. *Ozarkodina eosteinhornensis eosteinhornensis* (Walliser). x50. Kaugatuma Formation, Kaugatuma boring, depth 33.75 m.

19, 20. *Ozarkodina eosteinhornensis remscheidensis* (Ziegler). x50. Ohesaare Formation, 19 - outcrop Loode, 20 - outcrop Ohesaare.

21. *Ozarkodina confluens nasutus* Viira. x50. Ohesaare Formation, outcrop Ohesaare.

22-24. *Oulodus elegans* (Walliser). x50. 22,23 - Ohesaare Formation, outcrop Ohesaare, 24 - Kuressaare Formation, Ohesaare boring, depth 81.7 m.

PLATE 19 - Vertebrates

1. *Katoporus timanicus* (Kar.-Tal.), Pi 6893. x100. Ventspils boring, depth 273.6 m, Přidoli, Ohesaare Regional Stage, Targale Formation, Lūžni Beds.

2. *Poracanthodes punctatus* Brotzen, Pi 6234. x26. Kaavi-568 boring, depth 42.2-42.4 m, Přidoli, Kaugatuma Regional Stage, Lõo Beds.

3. *Nostolepis gracilis* Gross, Pi 7035. x80. Lõo cliff, Přidoli, Kaugatuma Regional Stage, Lõo Beds.

4-6. *Thelodus admirabilis* Märss, Pi 6500, Pi 6505, Pi 6506, appr. x60. Sakla boring, depth 6.2, Ludlow, Kuressaare Regional Stage, Tahula Beds.

7. *Thelodus sculptilis* Gross, Pi 6512. x80. Sõrve-514 boring, depth 138.8-139.0 m, Ludlow, Kuressaare Regional Stage, Tahula Beds.

8. *Loganellia ludlowiensis* (Gross), Pi 7149. x70. Ohesaare boring, depth 94.45-94.48 m, Ludlow, Kuressaare Regional Stage, Tahula Beds.

9. *Andreolepis hedei* Gross, Pi 7152, Mikhailovsk pond, southern section, sample 911-Б-18, Ludlow, Kuba Beds.

10. *Phlebolepis elegans* Pander, Pi 7150, Mikhailovsk pond, southern section, sample 3182, Ludlow, Kuba Beds.

11, 12. *Phlebolepis ornata* Märss, Pi 5826, Pi 5818. x44. Ohesaare boring, depth 111.8 m, Ludlow, Paadla Regional Stage, Sauvere Beds.

13-15. *Loganellia martinssoni* (Gross), Pi 7025. x110. Pi 7024, Pi 7027. x120. 13,14 - Kaarmise boring, depth 2.9-3.1 m; 15 - Varbla-502 boring, depth 32.3 m, Ludlow, Paadla Regional Stage, Himmiste Beds.

16-18. *Loganellia taiti* (Stetson), Pi 6545, Pi 6557, Pi 6554. x100. 16 - Sakla boring, depth 72.6 m; 18, 19 - Sakla boring, depth 62.55-62.70 m, Wenlock, Jaagarahu Regional Stage, Tagavere Beds.

PLATE 20 - Algae

1-2. *Parachaetetes gotlandicus* (Rothpletz). Kipi core, depth 4.6-4.9 m; Paadla Stage, Uduvere Beds. 1 - x32; 2 - x66.

3-5. *Parachaetetes compactus* (Rothpletz). Lümanda quarry; Paadla Stage, Uduvere Beds. 3 - fragment of the colony, x14; 4 - longitudinal section with sporangia, x33; 5 - transverse section, x40.

6. *Dimorphosiphon rectangulare* Hoeg. Saia core, depth 63.3-63.8 m; Jaagarahu Stage, Maasi Beds, x16.

PLATE 21 - Algae

1-4. *Garwoodia* aff. *gregaria* (Nicholson). Kingissepa core, depth 76.2-76.3 m; Rootsiküla Stage, Viita Beds. 1 - x12; 2-3 - x35; 4 - x40.

5. *Girvanella ducii* Wethered. Saia core, depth 63.3-63.8 m; Jaagarahu Stage, Maasi Beds, x180.

PLATE 22 - Algae

1. *Ortonella* aff. *furcata* Garwood. Saia core, depth 74.9-75.0 m; Jaagarahu Stage, Maasi Beds, x56.

2. *Bevocastria conglobata* Garwood. Kipi core, depth 40.6-40.7 m; Rootsiküla Stage, Kuusnõmme Beds.

3. *Wetheredella silurica* Wood. Suuriku cliff; Jaani Stage.

4. *Wetheredella silurica* Wood and *Rothpletzella gotlandica* Wood. Kingissepa core, depth 76.18-76.22 m; Rootsiküla Stage, Viita Beds, x56.

5. *Rothpletzella munthei* (Rothpletz). Kaugatuma core, depth 30.0-30.2 m; Kuressaare Stage, Kudjape Beds, x56.

6. *Girvanella wetheredii* Chapman. Kaugatuma core, depth 33.3-33.4 m; Kuressaare Stage, x180.

PLATE 23 - Algae

1-4. *Hedstroemia bifilosa* Rothpletz. 1 - forming outer layers of a nodule; Saia core, depth 79.0 m; Jaagarahu Stage, Vilsandi Beds, x15. 2 - forming nucleus of a nodule; Saia core, depth 74.5 m, x20. 3 - transverse section; Saia core, 74.8, x25; 4 - longitudinal section; Pahkla quarry; Paadla Stage, Uduvere Beds, x33.

5. *Hedstroemia halimedoidea* Rothpletz. Kipi core, depth 5.6 m; Paadla Stage, Uduvere Beds, x20.

6-7. *Halysis* sp. Suuriku cliff; Jaani Stage, Ninase Member, x80.

PLATE 24 - Acritarchs

1. *Vulcanisphaera turbata* Martin. Ülgase Formation (Upper Cambrian), Valkla outcrop.

2. *Gymathogalea* sp. Ülgase Formation (Upper Cambrian), Valkla outcrop.

3. *Cymathogalea virgulta* Martin. Ülgase Formation (Upper Cambrian), Valkla outcrop.

4. *Stelliferidium* sp. Lamoshka Formation (Upper Cambrian), Lamoshka outcrop.

5. *Acanthodiacrodium* sp. Lamoshka Formation (Upper Cambrian), Lamoshka outcrop.

6. *Acanthodiacrodium* aff. *timoveevii* Volkova & Golub. Lamoshka Formation (Upper Cambrian), Lamoshka outcrop.

7. *Lophosphaeridium zaleskyi* (Naumova) Umnova. Türisalu Formation (Tremadoc), Aseri outcrop.

8. *Leiosphaeridia tenuissima* Eisenack. Türisalu Formation (Tremadoc), Aseri outcrop.

9. *Stelliferidium bifurcatum*. Varangu Formation (Tremadoc), Aseri outcrop.

10. ? *Stelliferidium* sp. Aseri Stage, Leningrad District, boring 111.

11. *Baltisphaeridium* sp. Kunda Stage, Illuka boring.

12. *Goniosphaeridium* sp. Kunda Stage, Illuka boring.

13. *Goniosphaeridium* sp. Aseri Stage. Leningrad District, boring 111.

14. *Goniosphaeridium* sp. Pirgu Stage (Adila Formation), Nurme boring.

15. *Diexallophasis denticulata*. Pirgu Stage (Adila Formation), Nurme boring.

Bar denotes 20 microns.

L O C A L I T I E S

FIRST DAY

Lower and Middle Ordovician localities of the Tallinn area will be studied

LOCALITY 1:1 ÜLGASE OUTCROP

The outcrop is located 18-20 km east of Tallinn, near the ruins of a disused concentration plant of Ülgase phosphorite mine.

The outcrop section consists of two parts. In the upper part the Cambrian Ordovician boundary is exposed (tentatively placed at the base of the *Cordylodus proavus* conodont Zone). This part is the stratotype of the Kallavere Formation and the neostratotype of its Maardu Member.

The lower part of the section (exposed about 100 m eastwards) is the stratotype of the Ülgase Formation (C_3ül).

In 1925 A. Öpik visited the outcrop. He published the first bio- and lithostratigraphic subdivision of the Obolus-sandstone (Öpik, 1929).

The upper Cambrian Ülgase Formation, 6.5 m in thickness, is represented by quartzose siltstones with fragments or complete shells of inarticulate brachiopods (*Oepikites, Ungula, Angulotreta*). The basal and upper parts of the formation contain clay interbeds. The upper boundary of the Formation sharp and uneven. Higher the section is as follows (from bottom, Fig. 18):

Kallavere Formation ($Є_3$-O_1kl)

Maardu Member ($Є_3$-O_1klM)

1. Fine-grained quartzose sandstone with brachiopod coquina ("Obolus conglomerate") containing abundant shells and skeletal debris of *Ungula* and *Schmidtites*.
2. Fine-grained quartzose sandstone with graptolitic argillite interbeds in the lower part.
3. "Obolus conglomerate". The base coincides with that of the *Cordylodus proavus* Zone.
4. Fine-grained quartzose sandstone and siltstone in the upper part with graptolitic argillite interbeds.

Suurjõgi Member (O_1klS)

5. Medium-fine-grained cross-bedded quartzose sandstone with well-sorted skeletal debris of brachiopods ("Skeletal debris-bed). The top of the bed is strongly pyritized, thin argillite interbeds occur. The base of the bed coincides with that of the *Cordylodus rotundatus - C.angulatus* Zone.

Türisalu Formation (O_1tr)

Tabasalu Member (O_1trT)

6. Graptolitic argillite (Dictyonema shale).

Bed 1 and partly also bed 2 are observable in the adit, the others are exposed by stripping the clint of overburden.

H. Heinsalu

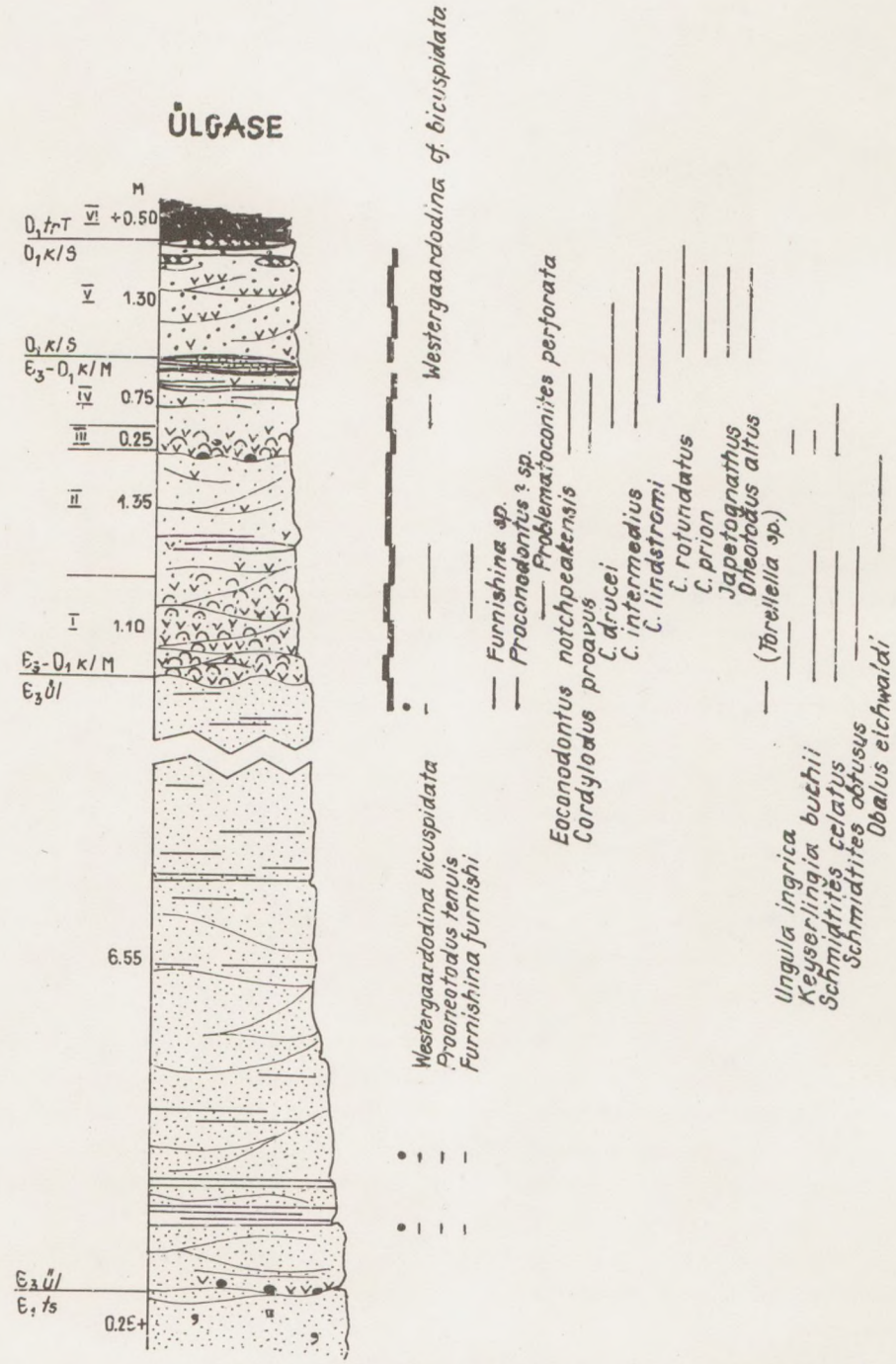


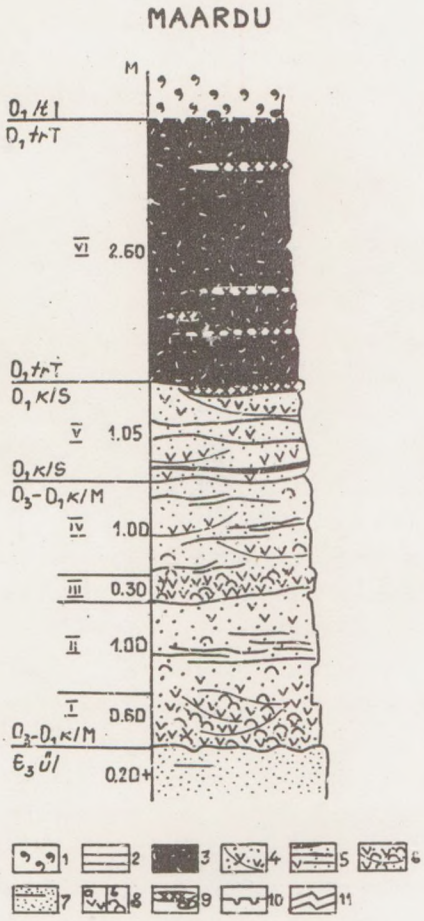
Fig. 18. Ülgase outcrop. For the lithological legend see Fig. 19. Conodonts identified by V. Viira (Tremadoc) and S. Sergeeva (Ülgase Fm.), brachiopods - by I. Puura.

LOCALITY 1:2 MAARDU QUARRY

The section is best exposed in the northeastern part of the northern quarry, about 1.5 km southwest of Ülgase outcrop.

In the Maardu quarry (Fig. 19) the same rocks of the Kallavere Formation ($Є_3$-O_1kl) are exposed as in Ülgase outcrop, but of a wider distribution. Characteristic is the appearance and thinning out of separate argillite interbeds, a coquina lense, etc. Graptolitic argillites of the Türisalu Formation are exposed here in the complete thickness (about 3 m). Graptolites, however, occur extremely rarely.

In the Kallavere Formation beds 1-5 are distinguished analogously with the Ülgase outcrop (Fig. 18). Occurrence of Graptolitic argillite interbeds in cross-bedded skele-



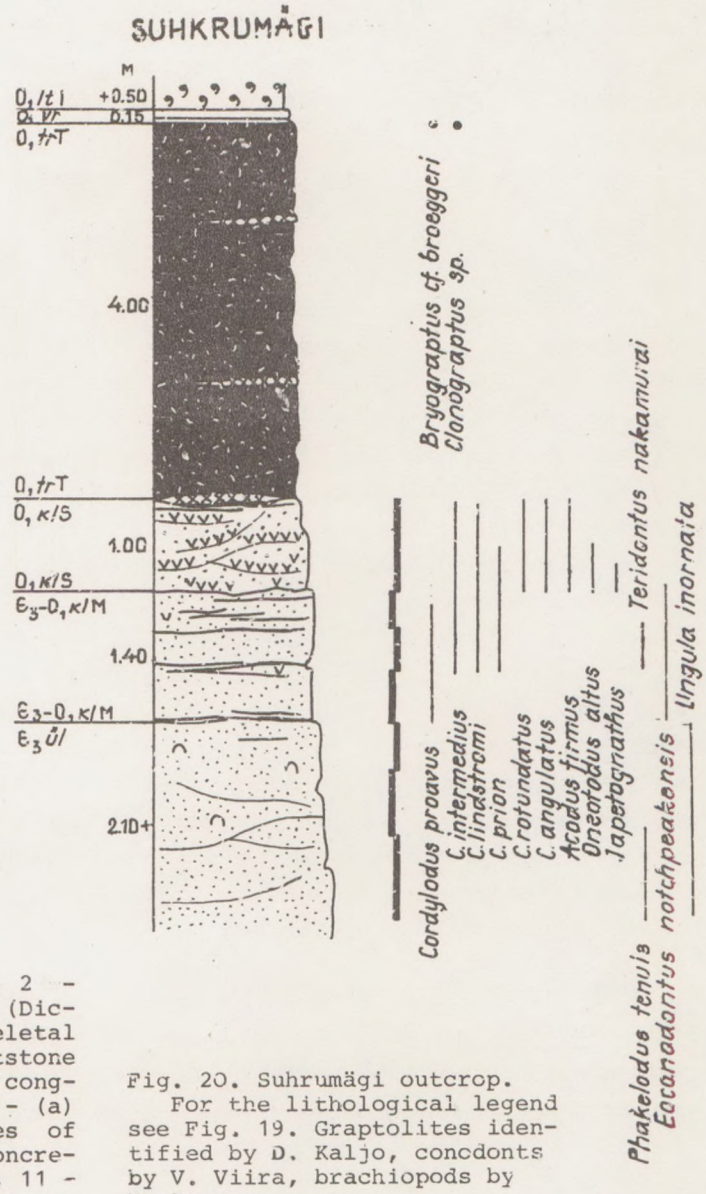


Fig. 19. Maardu quarry.
Legend: 1 - glauconitic sandstone, 2 - silty clay, 3 - graptolite argillite (Dictyonema Shale), 4 - cross-bedded skeletal debris sandstone, 5 - sandstone or siltstone with argillite interbeds, 6 - "Obolus conglomerate", 7 - clayey siltstone, 8 - (a) skeletal debris and (b) complete valves of brachiopods, 9 - pyrite lenses and concretions, 10 - discontinuity surfaces, 11 - transition from the upper outcrop to the lower one (Ülgase locality).

Fig. 20. Suhrumägi outcrop.
For the lithological legend see Fig. 19. Graptolites identified by D. Kaljo, conodonts by V. Viira, brachiopods by I. Puura.

tal sandstones of the Suurjõgi Member (bed 5) is generally uncommon in West Estonia.

In places the Türisalu argillites are overlain by 0.2 m greyish-green silty clays of the Varangu Stage (O_1vr).

H. Heinsalu

LOCALITY 1:3 SUHKRUMÄGI OUTCROP

The outcrop is located in the clint wall, in the eastern part of Tallinn near the song festival dais.

The section of the Kallavere Formation at Suhkrumägi differs from the Maardu and Ülgase section in the lack of the "Obolus conglomerate". Thus, a different type of the Cambrian/Ordovician boundary, without lithological changes, is seen here (Fig. 20).

The Maardu Member is represented here by quartzose five-grained sandstones or siltstones with scattered skeletal debris or complete shells of brachiopods, characteristic are dark graptolitic argillite interbeds.

The Suurjõgi Member is similar to that described at Ülgase and Maardu (bed 5).

Higher in the section there are graptolitic argillites of the Türisalu Formation and a thin bed (0.15 m) of silty glaucomitic compact clay of the Varangu Formation represented.

H. Heinsalu

LOCALITY 1:4 MÄEKALDA ROAD EXCAVATION

Mäekalda exposure is located in the eastern part of Tallinn alongside the ramp descending downtown from the new, Lasnamäe district of Tallinn. The total thickness of the exposed section is 15-20 m ranging from the base of the Ordovician to the lowermost part of the Kõrgekalda Formation (= Tremadoc, Arenig and Llanvirn). For over a century Lasnamäe limestone quarries and clint have been studied and visited by many world-famous geologists, the nearby Suhkrumäe outcrop has twice been the object of the International Geological Congress excursions (Schmidt, 1897; Kaljo, ed., 1984).

The abandoned Lasnamäe quarry, located near the Mäekalda outcrop, is the stratotype of the Lasnamäe Stage. Limestone of the Lasnamäe quarry has for centuries been used as the main building material of Tallinn. All the quarried limestone layers had individual popular names, mostly reflecting their specific features (thickness, colour, usage, etc.). Fig. 21 gives the subdivision of the quarry section into layers and the names of marker beds. The numbers correspond to the layers from top to base quarried by hand in the southern Lasnamäe quarry (Jürgenson, Möls, 1947). Most of the paleontological data, recorded below, comes from the adjacent sections of Suhkrumäe and Lasnamäe clint and Lasnamäe quarries. Conodonts are mostly identified by V. Viira (1966), chitinozoans by Y. Grahn (1982), ostracodes by L. Sarv (1959), articulate brachiopods by M. Rubel (1961).

Description of the Mäekalda section (Fig. 22) (from top to base):

Uhaku Stage. Kõrgekalda Formation

0.5+ m - Koljala Member: Greenish-grey variabily argillaceous, fine-grained skeletal packstone with irregularly-nodular or wave-bedded structure marked by argillaceous partings. Eight pyrite or phosphate impregnated discontinuity surfaces occur at the base.

Uhaku Stage (lower part), Lasnamäe Stage. Väo Formation

8.45 m - Various skeletal packstones with frequent wavy argillaceous partings and single up to 3 cm thick marlstone interlayers (Fig. 21). Characteristic are up to 7 cm thick interbeds pockets and lenses of skeletal grainstone (beds 16, 20, 21, 23), numerous (up to 89) phosphate impregnated and some (6) pyrite impregnated discontinuity surfaces. The rock is almost completely bioturbated containing numerous subvertical brownish burrows with clayey filling (particularly bed 34).

At the base (0.2 m) there occur rare white and brown goethite ooids.

The whole section is characterized by microcyclic structure, mostly revealed in the changes of clay content, amount, size and degree of sorting of skeletal debris. Boundaries of the cycles are often marked by discontinuity surfaces, covered with a thin argillaceous interlayer in the lower part along which the layers get detached by quarrying. The upper part of the formation is more pure, rich in skeletal debris.

The Väo Formation is subdivided into three members.

5.7 m - Kostivere Member: pure thick-bedded limestone.

0.6 m - Pae Member: secondarily dolomitized limestone, in weathered state brown, good marker bed.

2.1 m - Rebala Member: more argillaceous, medium-bedded limestone.

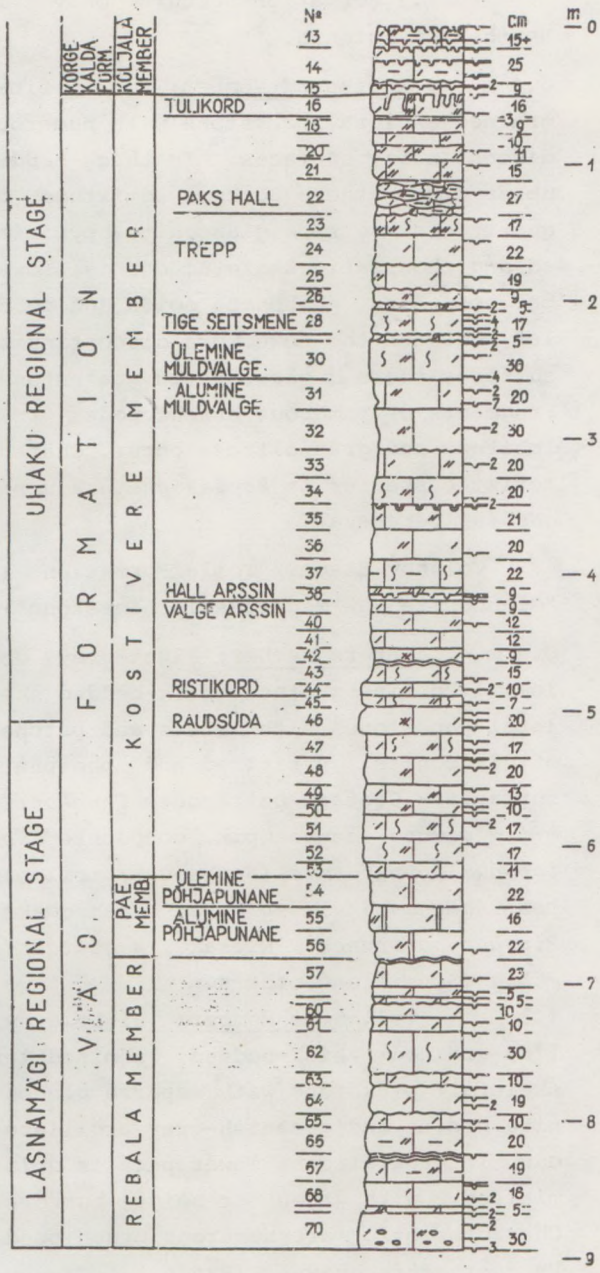


Fig. 21. Mäekalda section (upper part, after R. Einasto and T. Saadre). For legend see Fig. 3. Wavy-lined - interbeds of marl; double and threefold - thicker beds of marl. Discontinuity surfaces: thick line - pyritic; thin line - phosphatic. Traditional bed names are shown left from the column.

Aseri Stage. Aseri Formation

In North-West Estonia only uppermost part of the formation is represented.

0.46 m - Ojaküla Member: grey, fine-grained skeletal-oolitic packstone; middle part is rich in goethite ooids, lower part contains rare fine glauconite grains. Three levels with limonitized hardgrounds indicate sedimentation breaks. *Asaphus (Neoasaphus) kowalevskii* Lawrow, *A.* (cf.) *latus* Pander, *Chasmops rasutus* (Schmidt), *Illaenus sinuatus* Holm, *I. ariensis* Holm, *Orthoceras regulare* Schloth., *Cyrtoceras teres* (Eichw.), *Leptestia humboldti* (Verneuil), *Plectambonites planissimus* Pander, *Revalocrinus costatus* Jaeckel, *Bucania salpinx* Koken, *Proturritella reticulata* (Koken) have been recorded from the outcrops of Tallinn (Rõõmusoks, 1970).

Kunda Stage. Considerable parts of the lower and upper substages are lacking in the vicinity of Tallinn.

Loobu Formation (= Vaginatum or "Endoceras" Limestone).

0.35 m - Valgejõe Member: light-grey, fine-grained thick-bedded, in lower part bioturbated skeletal packstone with rare fine grains of glauconite, white phosphate ooids, phosphatized skeletal debris, rare pebbles and discontinuity surfaces (more distinct in the middle part of the member);

0.6 m - Ubari Member: dark-grey skeletal packstone, containing glauconite grains, rich in endoceratide cephalopods, chitinozoans, phosphatized skeletal debris and discontinuity surfaces. The abundance and coarseness of skeletal particles decrease downwards in the section. The lower part is bioturbated. Distinct discontinuity surfaces are found at the top and at the base of the member, the latter with deep (to 20 cm) irregular pockets.

Loobu Formation in Tallinn is characterized by *Pseudoasaphus globifrons* (Eichw.), *Pliomera fischeri* (Eichw.), *Illaenus wahlenbergi* (Holm), *Homalopyge stacyi* (Schm.), *Antigonambonites aequistriatus* (Gagel), *Pseudocrania antiquissima* (Eichw.), *Lycophoria nucella* (Dalm.), *Glyptograptus dentatus* (Brogniart), *Eoplacognathus variabilis* (Sergeeva), *Lobocyclendoceras buchi* (Lessnikowa), holotypes of *L. kundense* Balashov, *Paracyclendoceras cancellatum* (Eichw.), *Protocyclendoceras irvense* Bal., *Dideroceras amplum* Bal.

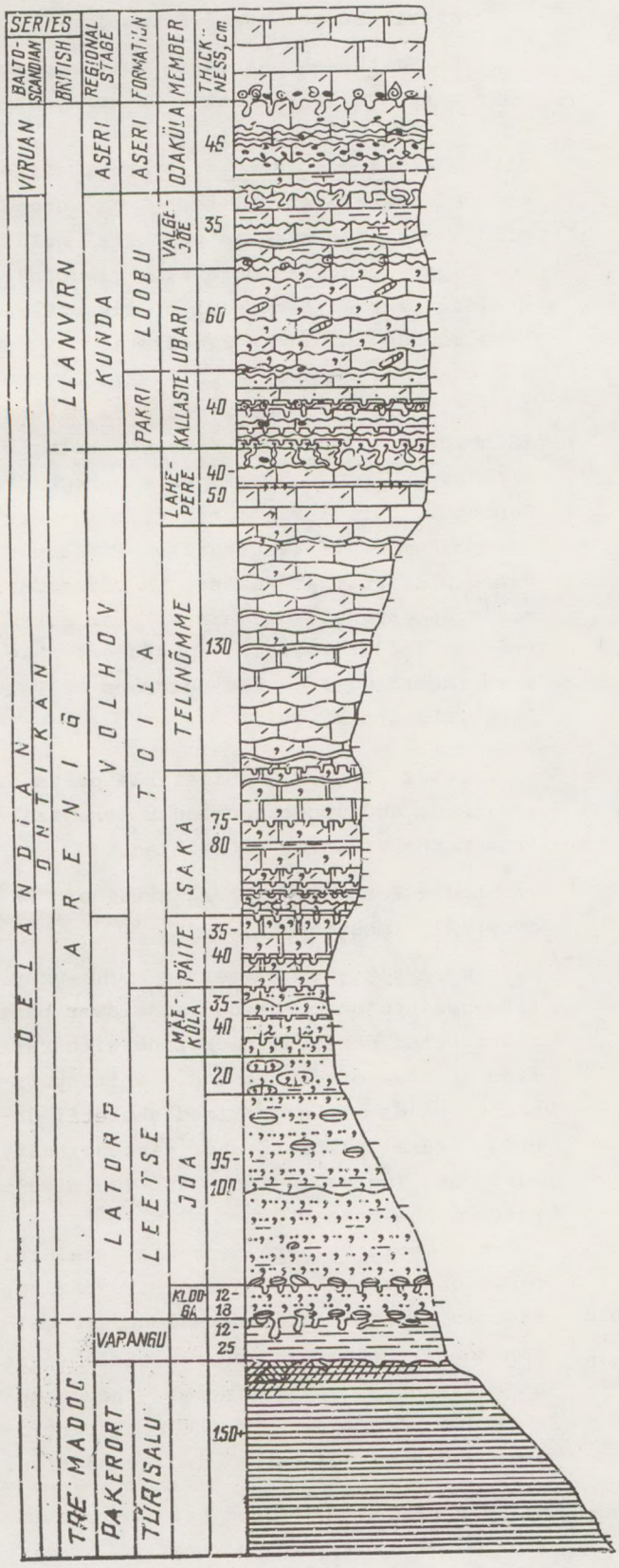


Fig. 22. Mäekalda section (lower part of the Ordovician, after S. Mägi). For the legend see Fig. 3.

Pakri Formation occurs only in North-West Estonia.

0.4 m - Kallaste Member: grey fine-grained skeletal packstone with numerous discontinuity surfaces. In thick-bedded upper part there occurs admixture of quartz grains, fine glauconite, pyritized and phosphatic skeletal debris; lower part contains phosphate ooids and pebbles; between the lowermost discontinuity surfaces there is glauconitic grainstone. Fragments of numerous brachiopods, trilobites and graptolites occur. Characteristic species is *Eoplacognathus variabilis* (Sergeeva).

Volkhov Stage. Toila Formation (= "Glauconite" or "Megistaspis Limestone").

0.4 m - Lahepere Member: light-grey, dolomitized fine-grained thick-bedded skeletal packstone with lenses and patches of glauconite, pyritized and phosphate surfaces. Contain ostracodes *Conchoprimitia gammae gammae* Öpik, conodonts *Scolopodus cornuformis* (Sergeeva); trilobites *Asaphus* (*A.*) *lepidurus* Nieszkowski, *Ptychopyge truncata* Nieszk., *Megistaspis gibba* (Schm.) and others.

1.3 m - Telinómme Member: light-grey, fine-grained thick-bedded seminodular skeletal packstone with sparse glauconite grains and greenish-grey argillaceous intercalations; lower part is dolomitized, with green or beige burrows. Characteristic are numerous brachiopods *Productorthis obtusa* (Pander), *Paurorthis parva* (Pander), *P. parallella* (Pander), *Ranorthis carinata* Rubel, *Paurorthis valida* Rubel, *Eosiphonotreta verrucosa* (Eichw.), trilobites *Asaphus bröggeri* Schm., *Megistaspis limbata* (Broeck), ostracodes *Protallinnella grewinkii* (Bock), *Tallinnellina palmata* (Krause), *T. primaria* (Öpik), *Rigidella mitis* (Öpik), conodonts of the *Paroistodus originalis* Zone and fragments of graptolites.

At the base (0.2 m) abundant coarse glauconite grains occur.

0.8 m - Saka Member: dark-grey, hard dolomite with glauconite and noticeable occurrence of fine brachiopods *Acrotretidae*. Lower part light-grey, at the base (0.15 m) pink, dolomitized, fine-grained skeletal packstone with abundant glauconite grains. Rough phosphoritized, partly limonitized discontinuity surfaces occur 4-6 cm below the top and above the base of the member. The lowermost smooth surface with numerous vertical burrows /so-called "püstakkiht" by Orviku (1929)/, is covered with rare pebbles of skeletal packstone forming "interformational conglomerate" (Orviku, 1960a). Characteristic fossils are: *Productorthis aculeata* (Pander), *Glossorthis schmidti* (Wys.), *Microzarkodina flabellum* (Lindström).

Laborp Regional Stage

0.35 m - Päite Member: grey, partly nodular, hard dolomitized fine-grained skeletal packstone, with fragments of brachiopods (often Acrotretidae), trilobites and crinoids; lower part contains quartz grains, abundant glauconite, many phosphate discontinuity surfaces and clayey intercalations (4-10 cm). *Panderina tetragona* (Pander), *Megistaspis estonica* (Tjernvik), *Periodon flabellum* (Lindström) occur.

Leetse Formation

0.35-0.4 m - Mäeküla Member: above (0.1 m) - dark green sandy glauconite clay with packstone nodules; in the middle (0.13-0.15 m) - thick-bedded varigrained glauconitic packstone containing numerous brachiopods *Ranorthis parvula* (Lamansky), *Paurorthina resima* Rubel, *Prantlina nasuta* Rubel, *Panderina bocki* (Lamansky), *P. abscissa* (Pander), *Angusticardinia recta* (Pander), *A. striata* (Pander); below (0.1-0.17 m) - silty and fine-grained nodular glauconite sandstone with clayey and argillaceous intercalations and white phosphatized smooth discontinuity surface with vertical *Amphora*-like burrows (1-2 cm) similar to "püstakkiht". Characteristic conodonts *Oepikodus evae* (Lindström), *Oistodus lanceolatus* Pander and brachiopods *Apheorthina ? daunus* (Walc.) are found from Mäeküla Member (Rubel, 1961) or from lower-lying transition beds.

0.3 m Transition beds (from Mäeküla to Joa members): dark green clayey glauconite silt with nodular intercalations of glauconitic sandstone and limonitized surface with pebbles at the base; fossils of the Prioniodus elegans Zone are characteristic of the bed.

1.0 m - Joa Member: clayey and silty glauconite sand; upper part greenish grey with sparse phosphatic nodules; lower part dark-green, more coarse-grained, rich in fragments of lingulid inarticulate brachiopods. In the middle of the member light-grey phosphatic, more clayey interbed occurs; at the base - conglomerate of phosphate and pyritized pebbles is present. *Thysanotos siluricus* (Eichw.), *Lingulella (L.) tetragona* Gorjansky, *Lingulella (Leptembolon) lingulaeformis* (Mickwitz), problematic forms (spongia ?) *Siphonia cylindrica* Eichw., conodonts of the *Paroistodus proteus* (Lindström) Zone have been recorded from the member.

0.12-0.18 m - Klooga Member: greenish dark-green quartz-glauconitic siltstone, in the upper part more abundant in glauconite. At the top and at the base limonitized smooth discontinuity surfaces occur with rounded phosphate pebbles.

Varangu Regional Stage. Varangu Formation

0.12-0.25 m - Beige argillite with Drepanoistodus deltifer (Lindström), at the base a smooth yellow-stained limonitized discontinuity surface is visible. *Bryograptus* cf. *broeggeri* Monsen, *Clonograptus* sp. have been recorded from the nearby Suhkrumägi outcrop (Kaljo, Kivimägi, 1976).

Pakerort Regional Stage. Türisalu Formation

1.5+ m - Tabasalu Member: dark-brown kerogenous argillite ("Dictyonema shale"). *Dictyonema* sp. is found 0.5 m below the top.

S. Mägi

SECOND DAY

Middle and Upper Ordovician westwards of Tallinn

LOCALITY 2:1 PEETRI HILL

In the northern slope of Peetri Hill, 0.3 km west of the Tallinn-Keila road (Fig. 23) a sequence of the Llandeilo-Caradoc boundary beds, the regional stages from Kukruse to Jõhvi is exposed to a total thickness of up to 13 m. The section was excavated due to construction of a Russian fortification system in 1912-1918.

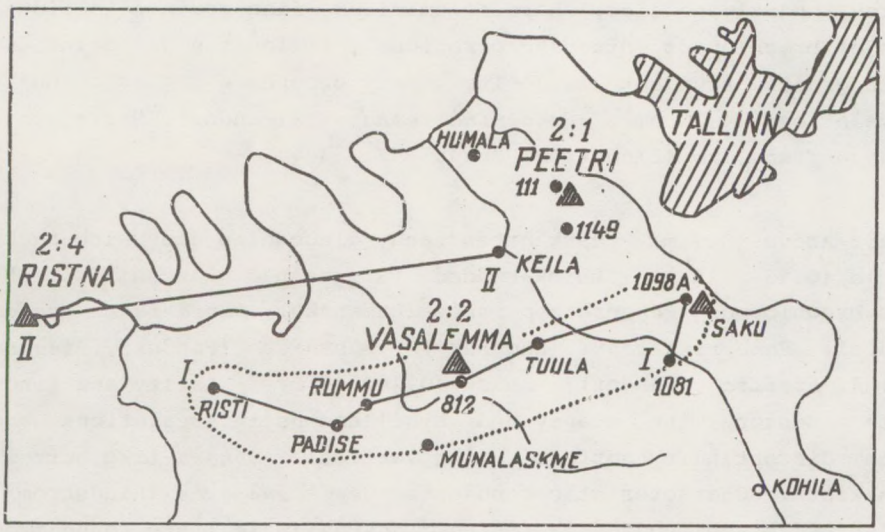


Fig. 23

Sketch map showing the location of the outcrops and boreholes in North-West Estonia. I-I and II-II - see Figs 27 and 31; dotted line - limits of shoal belt with mounds.

The Ordovician rocks at Peetri Hill were mentioned by N. Pogrebov (1920), later the section and fossils were studied by H. Bekker (1921), A. Öpik (1930) and others. The section characterizes quite well the corresponding stratigraphical interval in area located west of Tallinn. Here the Jõhvi Stage has the greatest thickness in North Estonia (max 15.1 m in the Niitvälja core; Sarv, Põlma, Hints, 1988, p. 43), the boundary of the Idavere and Kukruse stages is marked by a remarkable hiatus, mostly of Idavere age. The Kukruse Stage with total thickness of 11.3 m in the core of Peetri Hill boring (No 1100; Fig. 24) is in the outcrop 8.23 m thick and contains the upper and middle - Peetri and Meidla members of the stage. For the first member the Peetri section serves as a stratotype (Männil, Rõõmusoks, 1984).

There are two sections in the locality. One section (A; Fig. 24) comprising the Jõhvi and Idavere (?) stages and the upper beds of the Kukruse Stage, is exposed in the walls of the deep trench. The other section (B), located south of the trench can be observed in the walls of an inclinal pit. This section displays the Kukruse Stage and its upper boundary which in the current stratigraphical scheme (Resheniya.., 1987) corresponds to the Llandeilo-Caradoc boundary.

The description of the Peetri section is based on the data by A. Rõõmusoks (1970, p. 132-135) and unpublished data of L. Põlma (see also Põlma, Sarv, Hints, 1988, p. 18).

Section A

Jõhvi Stage. Jõhvi Formation. Aluvere Member

1. 0.00-2.95 m - Light-grey to greenish-grey, fine-grained, medium-bedded (2-10 cm), argillaceous biomicritic limestone with distinct intercalations of marl. Skeletal particles are sometimes pyritized.

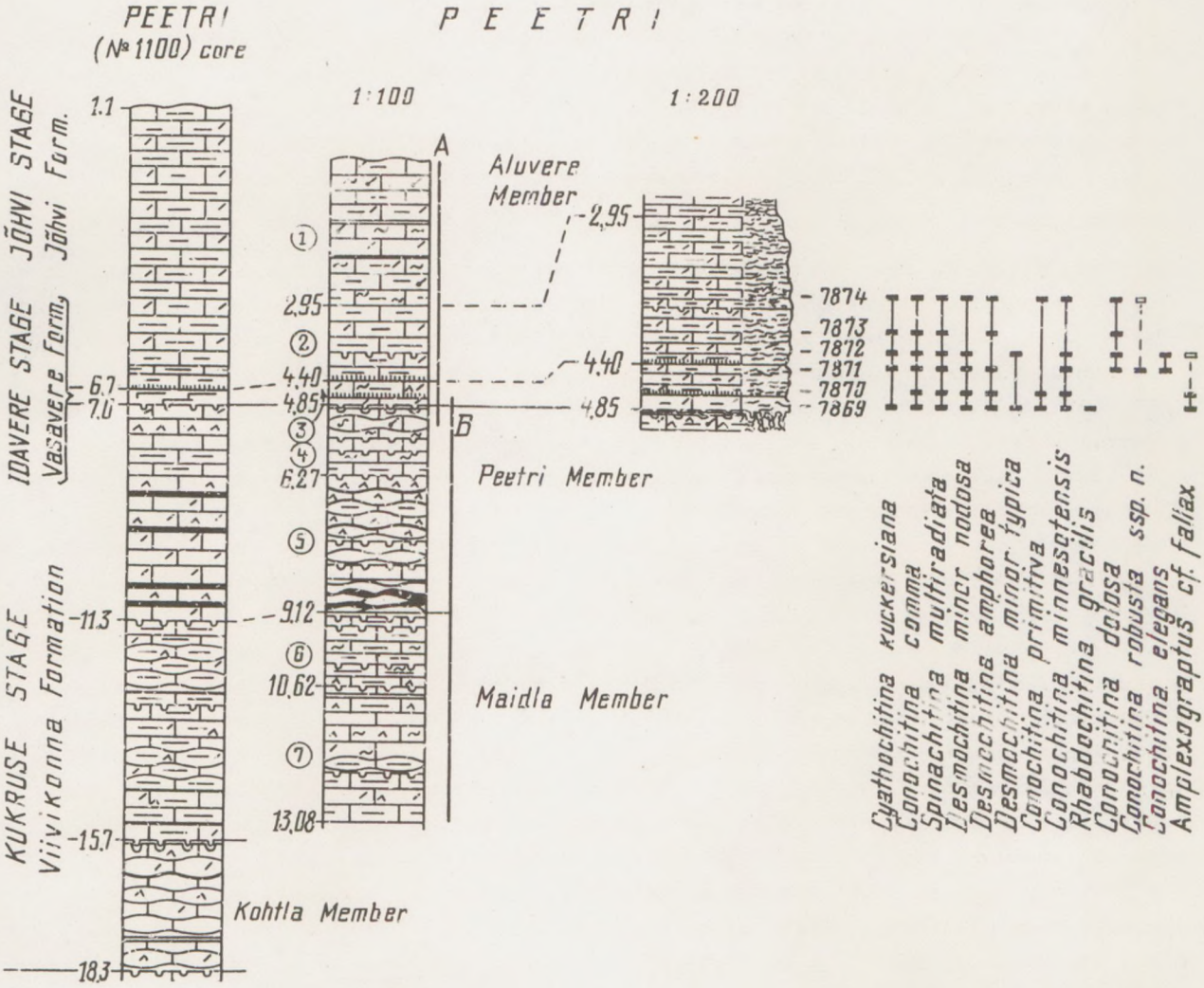


Fig. 24. Correlation of the sequences of the Viivikonna, Vasavere and Jõhvi formations in the Peetri Hill sections - core of borehole (No 1100; unpublished data of A. Haas), (A) trench and (B) inclinal pit sections. Numbers 1 - 7 (in circles) - distinguished lithounits. Right - faunal log (Chitinozoans, Graptoloids) of the Idavere and lower Jõhvi strata. For legend see Fig. 3.

2. 2.95-4.40 (1.45) m - Light-grey, fine-grained, medium to highly argillaceous biomicritic limestone with rare intercalations of marl. At a depth of 3.85 m, a discontinuity surface is observed. The lower boundary is marked by a metabentonite layer (3-5 cm).

Idavere Stage. Vasavere Formation

3. 4.40-4.85 (0.45) m - Light-grey, fine-grained, argillaceous biomicritic limestone. In the lower part the limestone is slightly kerogenous. At a depth of 4.75 m, a metabentonite layer (3-5 cm) is observed. The lower boundary is marked by a pyritized discontinuity surface.

Section B

Kukruse Stage. Viivikonna Formation. Peetri Member

4. 4.85-6.27 (1.42) m - Light-grey to buff-grey, thin to medium-bedded, pure to argil-

laceous bioturbated limestone with thin (2-3 cm) kukersite layers and lenses. The texture is wavy-bedded, rarely seminodular. The upper boundary is marked by a complex of at least 6 pyritized discontinuity surfaces.

5. 6.25-9.12 (2.87) m - Intercalation of light-grey, fine-grained, thin to medium-bedded biomicritic limestone and buff-grey, seminodular, pure to argillaceous kerogenous limestone with thin (2-3 cm) layers of kukersite. The lower boundary of the Peetri Member is placed below III kukersite seam (Männil, Bauert, 1986) which is the thickest (0.82 m) kukersite-bearing unit of the Viivikonna Formation in this area.

Maidla Member

6. 9.12-10.62 (1.50) m - Light-grey (seldom buff-grey), pure to argillaceous, bioturbated biomicritic limestone with rare, thin kukersite layers and lenses. Bioturbation is exhibited by burrows with kukersite fillings. Pyritized discontinuity surfaces are observed at the upper and lower boundaries.
7. 10.62-13.08 (2.46) m - Interbedding of pale buff-grey, thick-bedded, bioturbated, pure micritic limestone and light-grey, medium-bedded argillaceous limestone. The latter is partly of seminodular texture. Close to the lower and upper boundaries kerogenous limestone beds are observable.

The most complete list of fossils in Peetri Hill locality is given by A. Rõõmusoks (1970). In the Jõhvi Stage the species known from the underlying stage - *Clitambonites schmidti epigonus* Öpik, *Platystrophia chama* (Eichwald), *P. lynx lynx* (Eichwald), *Asaphus (Necasaphus) nieszkowskii* Schmidt, *Tetrada memorabilis* (Neck.), *Sigmoopsis rostrata* (Krause), *Disulcina auricularis* a.o. are distributed together with the new elements of the Middle Ordovician fauna - *Clinambon anomalus* (Schl.), *Nicolella alliku* Oraspõld, *Toxochasmops maximus* (Schm.), *Balticella binodis* (Krause), *Neotsitrella longota* (Rõõmusoks, 1970; Põlma, Sarv, Hints, 1988). The occurrence of numerous disarticulated pelmatozoan skeletal elements, especially the columnals of *Ristnacrinus* and *Babanicrinus* (=?*Virucrinus*: Rozhnov, 1990) is very characteristic of the Aluvere Member.

The only 0.45 m thick Idavere Stage lacks diagnostic species. All species of the rich ostracode association are also represented in the Jõhvi Stage (Jaanusson, 1976; Põlma, Sarv, Hints, 1988), e.g. *Platystrophia chama* mentioned by A. Rõõmusoks in both stages in Peetri locality.

The fossils of the Kukruse Stage have been studied unevenly. Most of the brachiopods - *Bilobia musca* (Öpik), *Clitambonites s. schmidti* (Pahlen), *C. squamatus* (Pahlen), *Estlandia marginata magna* (Öpik), *Kullervo lacunata* Öpik, *Oepikina d. dorsata* (Bekker), *Paucicrura navis* (Öpik) and trilobites *Achatella kuckersiana* (Schm.), *Atractopyge revaliensis* (Schm.), *Estoniops exilis* (Schm.) are known from the upper part of the Peetri Member (unit 4) (Rõõmusoks, 1970, Table 10). The other groups of macrofossils are less known.

The assemblage of chitinozoans in the unit 3 and the lowermost unit 2 (Fig. 24) is dominated by taxa ranging from the Kukruse to the Jõhvi and Keila stages, except *Spinachitina multiradiata* (Eisenack), *Desmochitina minor nodosa* Eisenack, *Conochitina comma* Eisenack. These appear in the Idavere Stage, but the former makes its debut earlier than suggested by R. Männil (1986). The relatively rich assemblage of chitinozoans (with "*Eremochitina*" *dalbyensis* Laufeld), known from the lower substage of the Idavere Stage, is absent in the Peetri section. Interesting is the occurrence of *Amplexograptus* cf. *fallax* below and between the metabentonite layers at Peetri, but it is also recorded in the same position from some other sections (Aluvere quarry and cores Mõigu, Keila, No 1149). Previously the appearance of this species was marked at the base of the Jõhvi Stage in the East Baltic (Männil, 1976), above the metabentonite layer "b" in North Estonia (Männil, 1986, p. 20). The new occurrences show the need to revise the biostrati-

graphical criteria of the lower Boundary of the Jõhvi Stage, especially in the area (in North-West Estonia) where the thickness of the Idavere Stage is reduced. However, the absence of the latter is not excluded either (see also Schmidt, 1881).

So, by acid-resistant microfossils the level and nature of the faunal change between the Idavere and Jõhvi stages is at present difficult to define.

L. Hints, J. Nõlvak

LOCALITY 2:2 VASALEMMA QUARRY

In the quarries of Vasalemma, 40 km southwest of Tallinn, the Middle Caradocian Vasalemma Formation of Late Keila and Oandu ages crops out to a thickness of 4-6 m. A total thickness of the formation is up to 15 m. Hard, bedded limestones of the formation have been well-known to builders and craftsmen for centuries as a good face-stone, perfect material for window and door frames, also for tombstones. As building material this limestone was used also outside Estonia (in Russia, Latvia, Finland, East Prussia).

In the 18th century in geological literature rocks of the Vasalemma Formation are known as "Hemicosmitenkalk" (Eichwald, 1854; Schmidt, 1881) and later as "Cystoid-limestone" or "marble of Vasalemma". The current understanding of the Formation is based mostly on the studies of A. Öpik (1934a, 1952), R. Männil (1960), A. Põõmusoks (1970) and also on the prospecting work of the Geological Survey (A. Haas, T. Lodjak).

The Vasalemma Formation (Lower, Middle and Upper Vasalemma and Saku members) is distributed in North-West Estonia as a 40 km long narrow belt spreading from Risti settlement in the west to Saku settlement in the east (Fig. 23). In this shallow water belt the carbonate mud mounds surrounded by skeletal sand are distributed. These irregular-form mounds of aphanitic limestone, reaching 10 m in heigth and 50-60 m (occasionally 300 m) in width are treated as reefs (Öpik, 1952), "bioherms" (Männil, 1960) or "mud mound" (Põlma, Hints, 1984). By L. Põlma skeletons of different organisms in these limestones seem to have never formed a real frame and therefore those bodies may be considered as carbonate mounds. The term is used here conventionally.

In the Vasalemma quarry the pure predominantly massive aphanitic limestone of "mounds" and the bedded skeletal grainstone ("marble of Vasalemma") represent two main rock types (Fig. 25). The greenish-grey (in places bluish) thin-bedded to massive aphanitic limestone contains up to 6 % of terrigenous material, fine, mostly unrounded skeletal debris is considerably rare (4-10 %; Fig. 26, thin section No 25), but in places coarse skeletal material forms 25 or more per cent of the whole bulk of rocks. Some of the "carbonate mounds" are rich in skeletons of *Cyathocystis rhizophora* Schmidt (Edriasteroidea), quite common are tabulate corals *Eofletcheria orvikui* (Sokolov) and *Lyopora tulaensis* Sokolov (in the Upper Vasalemma Member), trilobite *Stenopareia ava* (Holm) and also alga *Solenopora*. In the upper part of the formation in the marginal areas of the "mounds", greenish-grey argillaceous marls are distributed locally in the form of irregular inclusions, lenses and intercalations. Apart from brachiopods *Plectoglossa?* sp., *Vellamo* sp., *Saukrodictya* sp. these marls yielded *Rostricellula nobilis* (Oraspõld), the common species also in the Saku Member.

The second type of the rocks - light- or dark-grey, in weathered parts yellowish, medium- to thick-bedded skeletal grainstone contains terrigenous material usually below 2 %, the skeletal debris amounts to 50-60 %, sometimes up to 90 % and the content of medium-crystalline sparry calcite (in some sections dolomite) reaches 10-15 % (Põlma, 1977; Põlma, Hints, 1984; Fig. 26). In the lower part of the formation bryozoans debris is prevailing, upwards it is replaced by pelmatozoan debris. In these grainstones (mostly in the Lower Member) brachiopods are represented by *Sowerbyella*, rare *Vellamo*, *Porambonites* and some dalmanellids and strophomenids, which are less known.

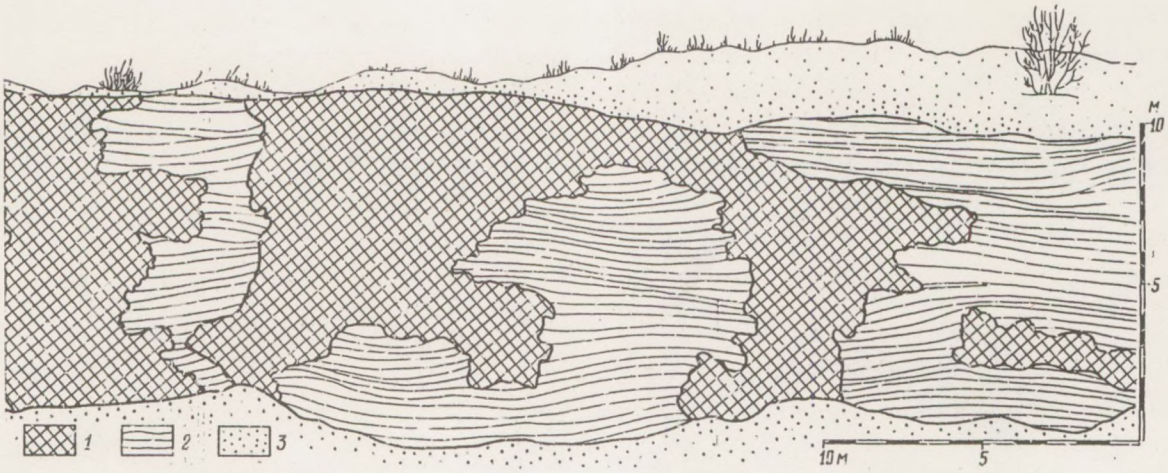


Fig. 25. Section of the Vasalemma Formation in the western part of the quarry. 1 - "carbonate mound", 2 - skeletal grainstone, 3 - dump.

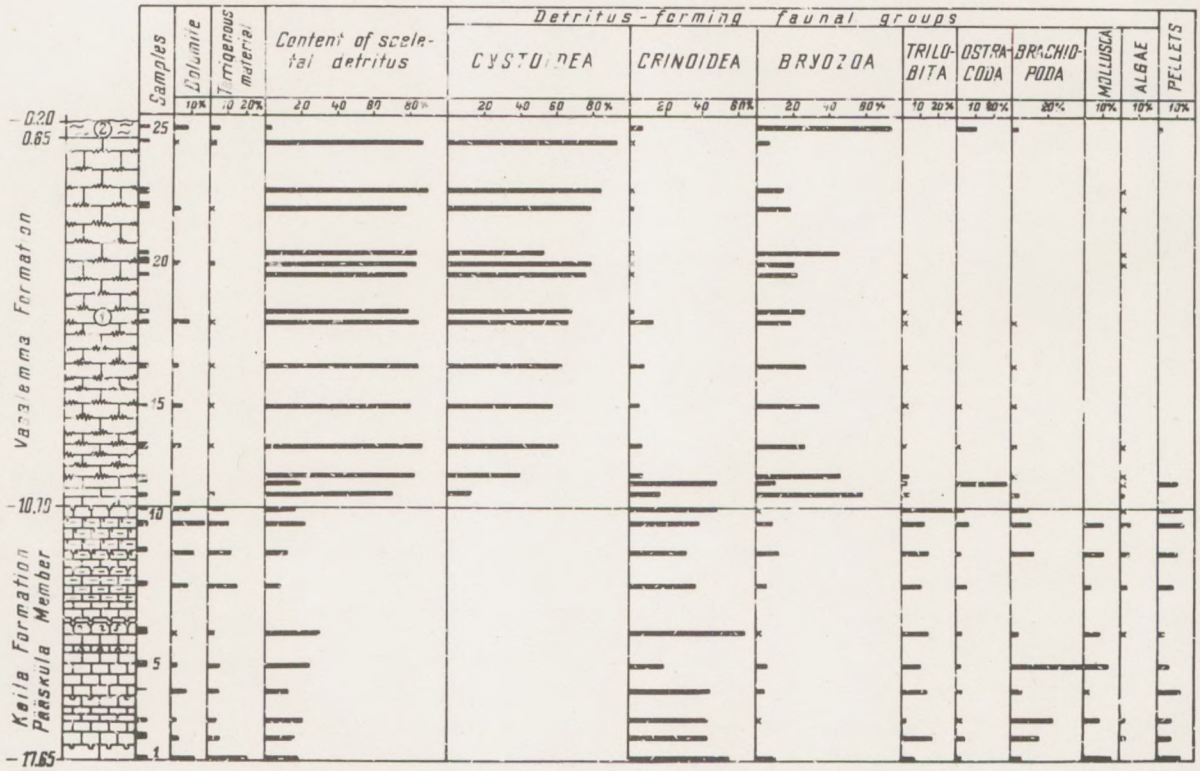


Fig. 26. Rock composition, the content of skeletal debris and distribution of different debris-forming faunal groups in the Pääsküla Member of the Keila Formation and Vasalemma Formation of the Vasalemma core (after Põlma, 1977, p. 19). 1 - skeletal grainstone, 2 - "mud mound". For legend see Fig. 3).

In cores of about 50 boreholes the thickness of grainstones varies from 0.10 to 6.0 m and they form about 2/3 of the extent of the Vasalemma Formation.

In two described rock types, in the lower and middle parts of the Vasalemma Formation, intercalations of the argillaceous greenish-grey biomicritic seminodular limestone occur in thickness of 0.10-1.00 m (Fig. 27). They contain a number of species common to the Keila Formation - *Estlandia pyron silicificata* Öpik, *Clinambon anomalus* (Schl.), *Horderleyella? kegelensis* (Alichova), *Sowerbyella (S.)* cf. *forumi* Rõõmusoks a.o. These

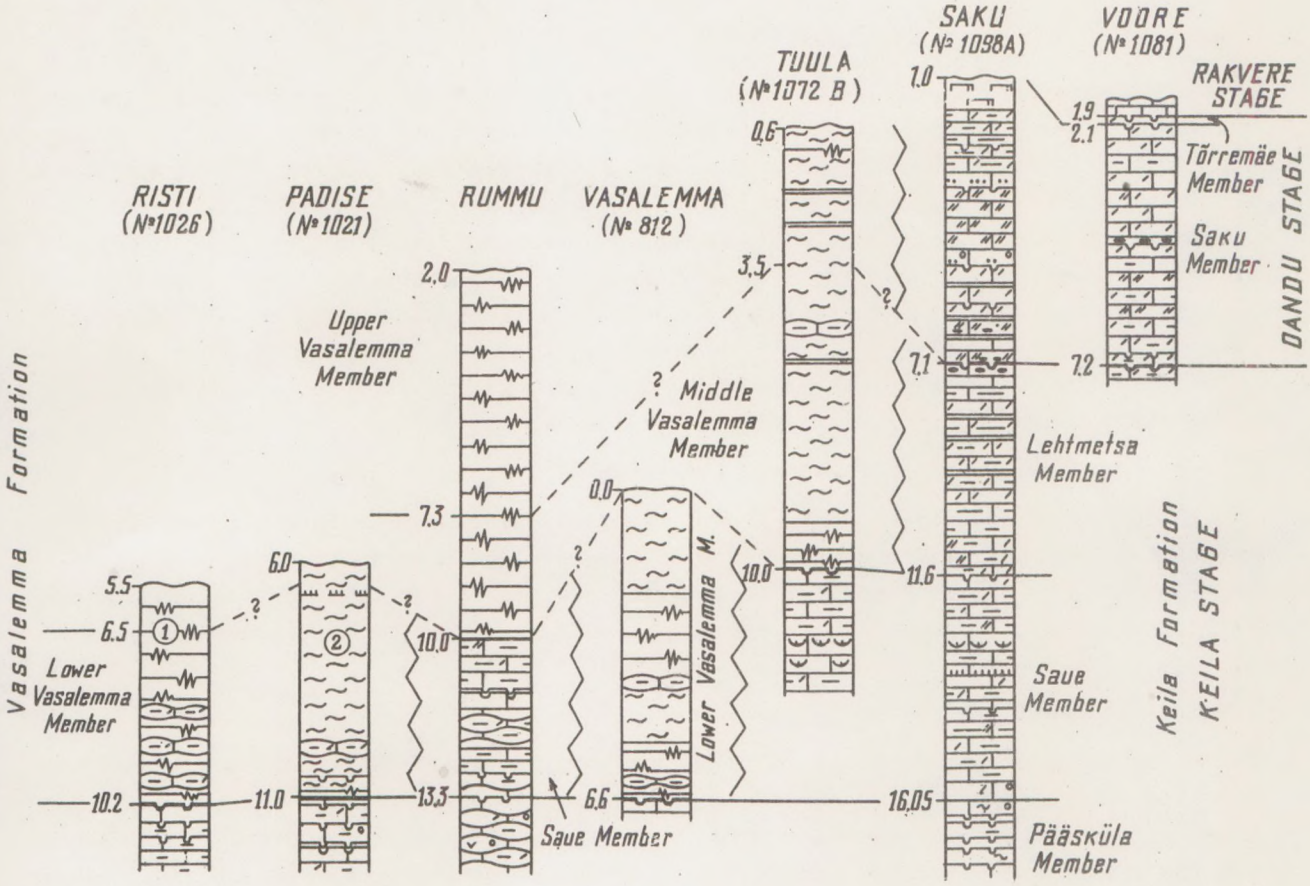


Fig. 27. Correlation of the sequences of the Vasalemma and Keila Formations in cores between Risti and Keila (line I-I, Fig. 23). 1 - skeletal grainstone, 2 - "mud mound". For legend see Fig. 3.

species are the most important arguments for including the lowermost and middle parts of the Vasalemma Formation to the Keila Stage. Possible coexistence of the Keila and Vasalemma faunas was first mentioned by V. Jaanusson (1945, textab. on p. 223).

The lower boundary of the Vasalemma Formation is diachronous. In the easternmost sections it coincides with the upper boundary of the Pääsküla Member, in the westernmost ones - with the upper boundary of the Saue or Lehtmetsa members of the Keila Formation (Fig. 27). The upper boundary is fixed only in a few sections where the Formation is overlain by the Tõrremägi Member of the Oandu Stage.

The subdivision of the Vasalemma Formation into the Lower, Middle and Upper members is based on gradual decrease in frequency of the interlayers of argillaceous limestones and decrease in grain size of the grainstones and replacement of the little Bryozoa-rich mounds of the Lower Member with large mounds containing the first tabulate corals and receptaculitids in the Upper Member (Männil, Rõõmusoks, 1984, p. 52). In spite of these differences we often have difficulties in determining the boundaries between the two lower members and also between the Middle and Upper members comprising the Keila-Oandu boundary. Usually in the northern Baltic the last boundary is marked by the most remarkable exchange of the Middle Ordovician fauna.

L. Hints

LOCALITY 2:3 AULEPA

The Aulepa quarry is situated 75 km south-west of Tallinn, 15 km north of Haapsalu. In a section between Aulepa and Nõmmküla villages the uppermost part of the Saunja Formation of the Nabala Stage and the lower part of the Kõrgessaare Formation of the Vormsi Stage crop out.

The Aulepa quarry was first mentioned by V. Jaanusson in 1956. Later A. Rõõmusoks described the section and gave the list of fossils in his manuscript (1966). By his description limestones of the Kõrgessaare Formation were exposed there in a thickness of 0.4 m.

Recently the quarry has been expanded and nowadays the following section can be recognized (in descending order):

Vormsi Regional Stage. Kõrgessaare Formation

0.45 m - Light-grey medium-bedded (2-10 cm) slightly argillaceous fine-grained skeletal limestone (wackestone). The lower boundary of the interval is transitional.
0.45 m - Light-grey medium-bedded (2-10 cm) fine-grained skeletal wackestone (pure limestone). The lower boundary of the interval is marked by a pyritized discontinuity surface.

Nabala Regional Stage. Saunja Formation

0.70+ m - Brownish-grey medium-bedded (2-10 cm) cryptocrystalline (aphanitic) limestone.

In the Aulepa section the Kõrgessaare Formation is quite rich in macrofossils. The noticeable increase in the role of corals in the East Baltic Upper Ordovician macrofauna during the Vormsi age is marked here after A. Rõõmusoks by the appearance of the species *Proheliolites dubius* (Schm.) *Kenophyllum siluricum* (Dybowski) and *Streptelasma (Streptelasma) distinctum* Wilson accompanied by the *Kenophyllum subcylindricum* Dybowski appearing in the Nabala Stage. New elements of the diverse brachiopod fauna are represented by *Eoplectodonta schmidti* (Lindström), *Triplesia* sp., *Eospirigerina* cf. *sulevi* Jaanusson in Alichova. The specimens of *Eospirigerina* in the Aulepa and also Kõrgessaare sections (Hiiumaa Island) are the lowermost finds of that genus in the East Baltic. The whole Estonian material on *"Plectatrypa"* (=*Eospirigerina*) needs revision and therefore it is difficult to estimate the stratigraphic value of the mentioned specimens. Brachiopods *Bekkeromena semipartita* (Roemer), *Plaesiomys solaris* (Buch) *Nicolella oswaldi oswaldi* (Buch), *Orthambonites* (=*Sulevorthis*) *lyckholmiensis* (Wysogorski), *Pseudolingula quadrata* (Eichw.), and also trilobites *Toxochasmops eichwaldi* (Schm.), *Illaenus angustifrons angustifrons* Holm. are common to the Nabala and Vormsi stages, but in the Aulepa section they are at present met only in the Kõrgessaare Formation of the last stage.

The aphanitic limestone of the Saunja Member seems to be poor in macrofossils. Only some poorly preserved gastropods and small echinoderm columnals have been noticed.

In the Aulepa section a rich ostracode fauna has been discovered (Fig. 28). The cryptocrystalline limestone of the Saunja Formation has yielded over 30 ostracode species of wide stratigraphical distribution, among them *Brevibolbina dimorpha dimorpha* Sarv, which in North-Estonian sections seems to disappear at this level. In the limestones of the Kõrgessaare Formation the number of ostracode species increases to more than 40. In addition to the species common in both above-mentioned stages, *Tvaerenella expedita* Sarv, *Eoaquapulex frequens* (Steusloff) and *Brevibolbina dimorpha altonodosa* Sarv were recorded, which in several sections of North Estonia mark the lower boundary of the Vormsi Stage.

Most taxa of chitinozoans recorded from the samples cross the boundary between the Nabala and Vormsi stages, except for the appearance of *Conochitina* sp. n., which is known from the Vormsi and lower Pirgu strata in North Estonia (Fig. 29). The absence of

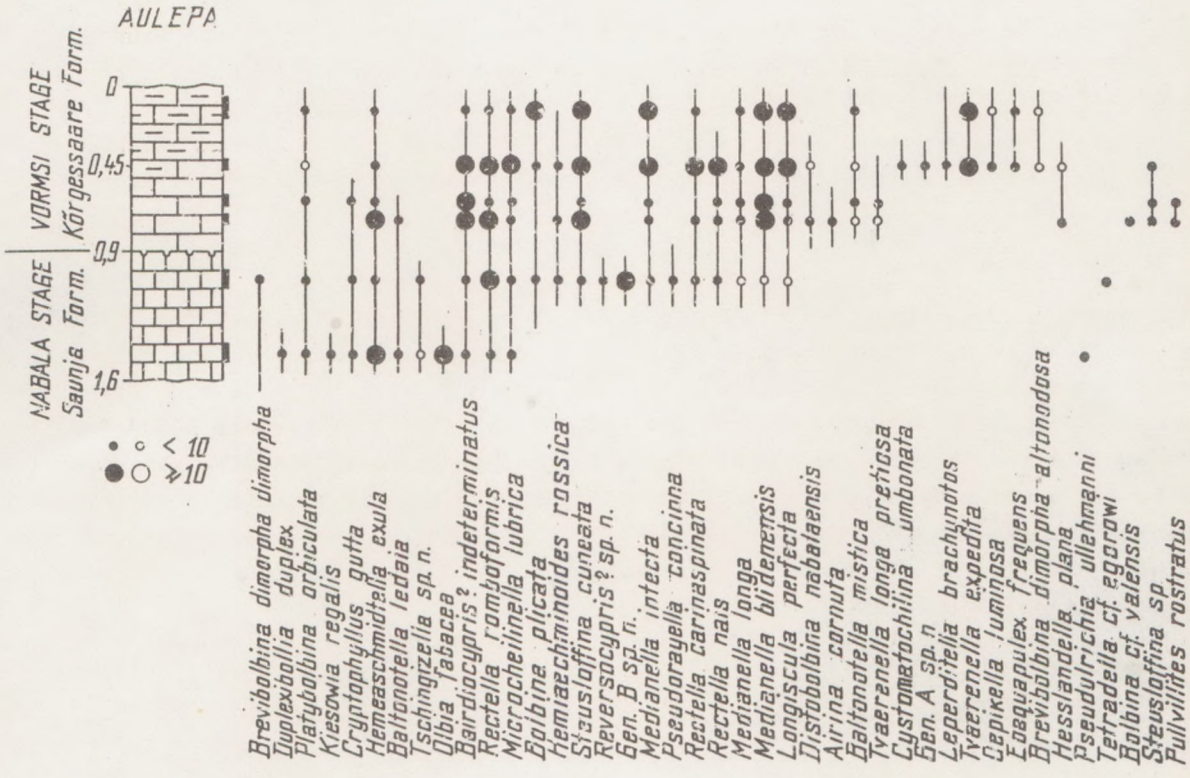


Fig. 28. Faunal log (Ostracodes) of the Aulepa quarry. For legend see Fig. 30.

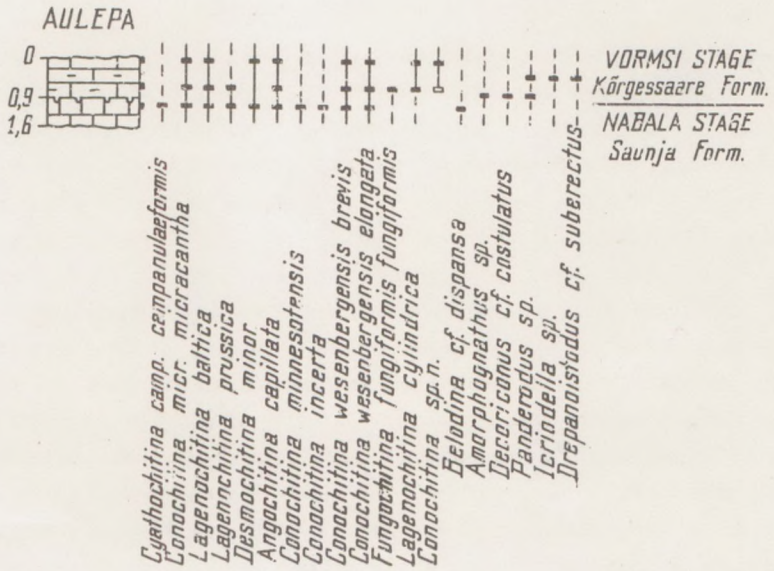


Fig. 29. Faunal log (Chitinozoans and Conodonts) of the Aulepa quarry.

the characteristic species (*Conochitina cactacea* Eis.) which in Estonian sections disappears at the top of the Nabala Stage (Saunja Formation) may be due to its low frequency. Both the association of chitinozoans and the assemblage of other acid-resistant microfossils (acritarchs, radiolarians, foraminifers, scolecodonts, etc.) are similar to those identified at the same stratigraphical level in other Estonian sections.

Conodonts in the Aulepa section are represented by long-ranging taxa (Fix. 29). The number of specimens increases in the Kõrgessaare Formation. Usually several new species appear at this level, but they are not discovered in the Aulepa section.

The whole available information confirms faunal difference between the Nabala and Vormsi stages, and the stratigraphical distribution of different fossil groups investigated exactly marks the lower boundary of the Vormsi Stage.

T. Meidla, L. Hints, P. Männik, J. Nõlvak

LOCALITY 2:4 RISTNA CLIFF

The westernmost outcrop of the Keila Stage is situated on the eastern coast of the Ristna headland in North-West Estonia (Fig. 23). During last decades the section has been somewhat neglected, but in earlier study it served as stratotype of the Ristna Member (beds) (Jaanusson, 1945; Männil, 1958; Rõõmusoks, 1970). The section deserves attention as the best section for collecting fossils and paleoecological observations of the early Keila fauna. The interlayers of the aphanitic limestone, uneven distribution of skeletal debris and occurrence of large number of shells and skeletons on some bedding-planes are essential features in the Ristna section characterizing the second half of the Ordovician (Põlma, 1982).

In the Ristna section the Kurtna Member of the Keila Formation is exposed in thickness over 3.5 m. The section continues in the sea floor as stepped plateaus. Due to uncommonly great inclination of the strata, considerably effected by block faulting in North-West Estonia, in the northern and southern parts of the headland the strata have different ages. In the northern part the older beds are exposed.

In the section four units were distinguished (Fig. 30). The uppermost (first) unit can be followed along the seacoast, northwards gradually decreasing in thickness.

Keila Regional Stage. Keila Formation. Kurtna Member

1. 1.40+ m - Light-grey with yellowish shade, thin-bedded argillaceous micritic limestone. Fine, partly pyritized skeletal debris is sporadically distributed.
2. 1.40-2.70 (1.30) m - Alternation of light-grey and yellowish slightly argillaceous and pure, by layers micritic limestones. Partly silicified, rarely pyritized skeletal debris is finer in pure limestones, than in argillaceous limestone. Accumulations of valves and shells of *Sowerbyella (Sowerbyella) trivia* Rõõmusoks occur in the upper part of the unit (Fig. 30). Some layers contain abundant columnals of *Ristnacrinus*.
3. 2.70-2.75 (0.05) m - Yellowish-grey metabentonite (layer "e"; Jürgenson, 1958) with rare biotite; lower part of the metabentonite is hard with a distinct lower contact. Upper half is partly dolomitized with silicified fragments of bryozoa and crinoid columnals, brachiopods *Sowerbyella (S.) trivia* and *Horderleyella? kegelensis* occur (Rõõmusoks, 1970). Metabentonite is well exposed in a deep abrasional niche in the northern part of the cliff.
4. 2.75-3.50 (0.75) m - Greenish-grey, by layers yellowish medium-bedded, slightly argillaceous, micritic limestone. Upper 0.15 m are represented by aphanitic limestone with fine rare skeletal debris. By layers skeletal debris is coarse, partly silicified, on some bedding planes occur numerous columnals and stems of *Ristnacrinus marinus* and fragments of alga *Mastopora*. 0.35-0.45 m from the top of the unit the burrows contain kerogen of kukersite.

During the Ordovician study in North Estonia the age of the rocks at Ristna cliff have been interpreted differently: as rocks of the Jõhvi Stage (Schmidt, 1881; Öpik, 1934a), or as boundary beds of the Jõhvi and Keila stages (Männil, 1958; Jaanusson,

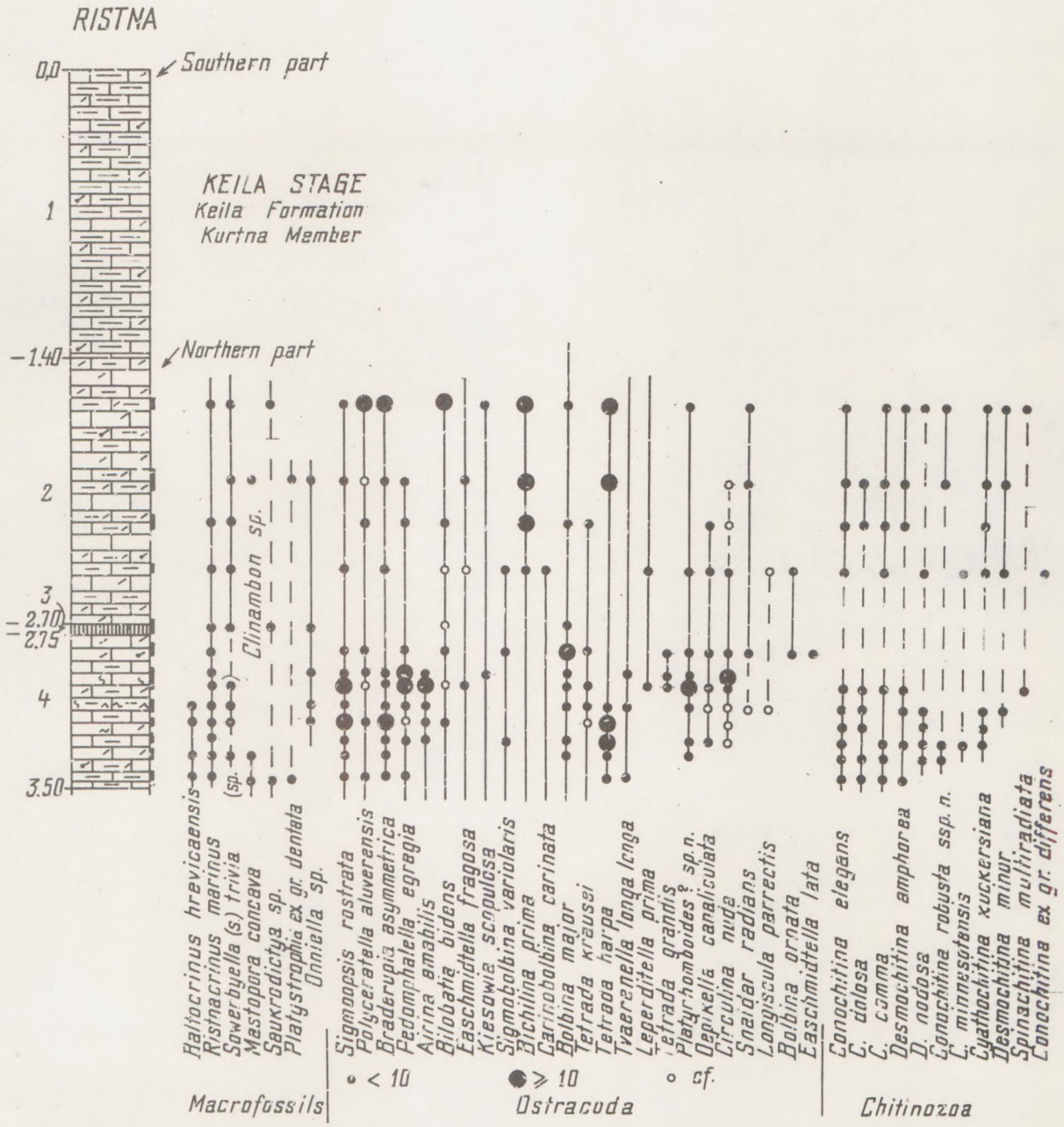


Fig. 30. The Ristna cliff section and distribution of fossils in the northern part of the Ristna foreland. 1 - 4 - distinguished lithounits. Number of ostracode specimens is shown by small (1-9) and large (10 or more specimens) circles; open circles - identified as cf. For legend see Fig. 3.

1945). Small thickness of the metabentonite layer, occurrence of typical Keila brachiopods in it *(Sowerbyella (S.) trivia, Horderleyella? kegelensis)* allow to correlate this section with the stratotype sections containing "e" bentonite at Keila and Pääsküla (Fig. 31). This viewpoint, expressed by A. Rõõmusoks (1970), was confirmed also by recent new data on ostracodes and chitinozoans (Fig. 30).

List of macrofossils in the Ristna section was given by A. Rõõmusoks (1970, p. 253). It contains brachiopods and trilobites in units 1 and 2 - *Estlandia pyron silicificata*

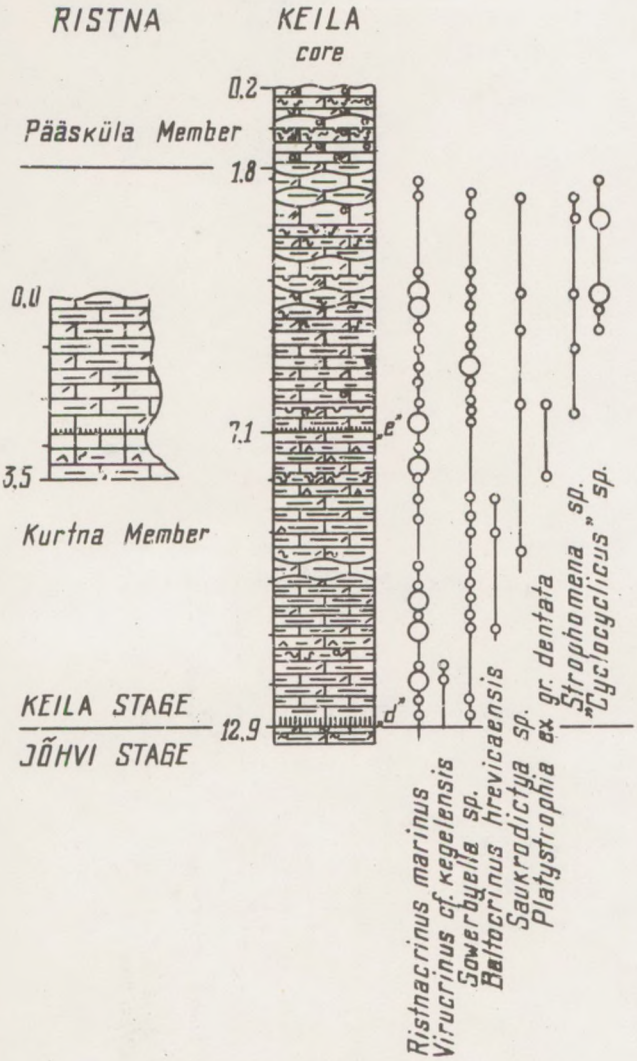


Fig. 31. Correlation of the sequences of the Kurtna Member in Ristna cliff and Keila boring sections and distribution of macrofossils in the latter (see Pólma, Sarv, Hints, 1988, Fig. 25). "d" and "e" - metabentonite layers (by Jürgenson, 1958). For legend see Fig. 3.

Öpik, *Porambonites ventricosus* Kutorga, *Clinambon anomalus* (Schloth.), *Asaphus (Neoasaphus) nieszkowskii* (Schm.), *Atractopyge dentata* (Esmark), *Chasmops emarginatus* (Schm.) a.o. Ristna is the topotypic section for *Ristnacrinus marinus* Öpik (Öpik, 1934b). In addition to the mentioned species brachiopods *Saukrodictya* sp. *Platystrophia* ex gr. *dentata*, small dalmanellids and columnals of *Baltocrinus brevicaensis* (Yelt.) and *Babanicrinus (=?Virucrinus)* cf. *kegelensis* (Yelt.) have been established in units 2-4 (Fig. 30).

The data on macrofossils in the Ristna section are very similar to that in the stratotype at the Keila Stage in the core of Keila borehole, in the strata above and below the metabentonite layer at a depth of 7.08 m (Fig. 31). The occurrence of *Baltocrinus brevicaensis* and lack or sparsity of *Virucrinus?* below, metabentonite in both sections are noticable and presumably have biostratigraphic importance in North-West Estonia. *Virucrinus*-like columnals are very common in the Jõhvi Stage and in the upper half of the Keila Stage (Pólma, Sarv, Hints, 1988).

Ostracodes established in the units 2-4 are represented first of all by species appearing already in the Idavere Stage (*Bichilina prima* Sarv, *Sigmoopsis rostrata* (Krause), *Polyceratella aluverensis* Sarv, *Braderupia asymmetrica* (Neckaja), *Pedomphalella egregia* (Sarv) or in the upper part of the Jõhvi Stage (*Tetrada krausei* (Steusloff), *Bolbina major* (Krause) (Fig. 30). New elements in ostracode fauna are *Tetrada grandis* (Sarv), *Leperditella prima* Sarv, *Tvaerenella longa longa* Sarv and *Tetrada harpa* (Krause), which, according to L. Sarv (in Pólma, Sarv, Hints, 1988, p. 60-61) confirm the Keila age of the strata. In the Ristna section beside the mentioned ostracode taxa several species like *Snaidar radians* (Krause), *Oepikella? canaliculata* (Krause), *Easchmidtella lata* (Neckaja) and *Bolbina ornata* (Krause) are established the distribution of which is as yet poorly known in East Baltic.

The early Keila age of the Ristna section is confirmed also by the chitinozoan association (Fig. 30). It consists of taxa established in the other sections in the lower part of the Keila Stage containing the metabentonite layer. The lack of microfossils in three samples can be possibly explained by weathering taking place right near the metabentonite interalyer.

L. Hints, T. Meidla, J. Nõlvak

THIRD DAY

Upper-Ordovician south from Tallinn and boring cores at Särghaua field-station

LOCALITY 3:1 PAEKNA QUARRY

The Paekna quarry lies on the north side of the road between Tõdva and Nabala villages, 3.5 km east of the Tallinn-Kohila highway. Nowadays this sequence, first mentioned by V. Jaanusson (1944, p. 95), exposes the boundary beds of the Rakvere and Nabala stages, representing uppermost Caradocian, *D. clingani* zone (see also Männil, 1976, p. 118).

Nabala Stage, Paekna Formation

Uppermost part of the quarry (Fig. 32) offers an exposure of about 0.6 m limestones of the Paekna Formation (type section) of the Nabala Stage (uppermost Middle Ordovician). This part of the section was described by V. Jaanusson (1944) under the name "Paekna Schichten" and was not mentioned by R. Männil (1958). These light yellowish-grey (in weathered state) medium-bedded (2-10 cm) microcrystalline limestones are medium argillaceous, with fine skeletal detritus (12-16 %), with thin (up to 1.5 cm) intercalations of marl.

The lower boundary is marked by the complex of highly irregular, undulating discontinuity surfaces (2-4), with yellowish-brown (weathered), thin, originally pyrite impregnation zone with *Trypanites* borings and pits, which extend up to 12 cm and are filled with coarse skeletal detritus, prevailingly consisting of brachiopods, bryozoans, echinoderms, ostracodes, algae, etc. The rock between the discontinuity surfaces (about 10 cm) is similar to the underlying rocks of the Rakvere Stage and macrofossils, recorded by V. Jaanusson (1944, p. 95) from this locality came probably from this part of the section (see also Männil, 1958, p. 6: layer 1).

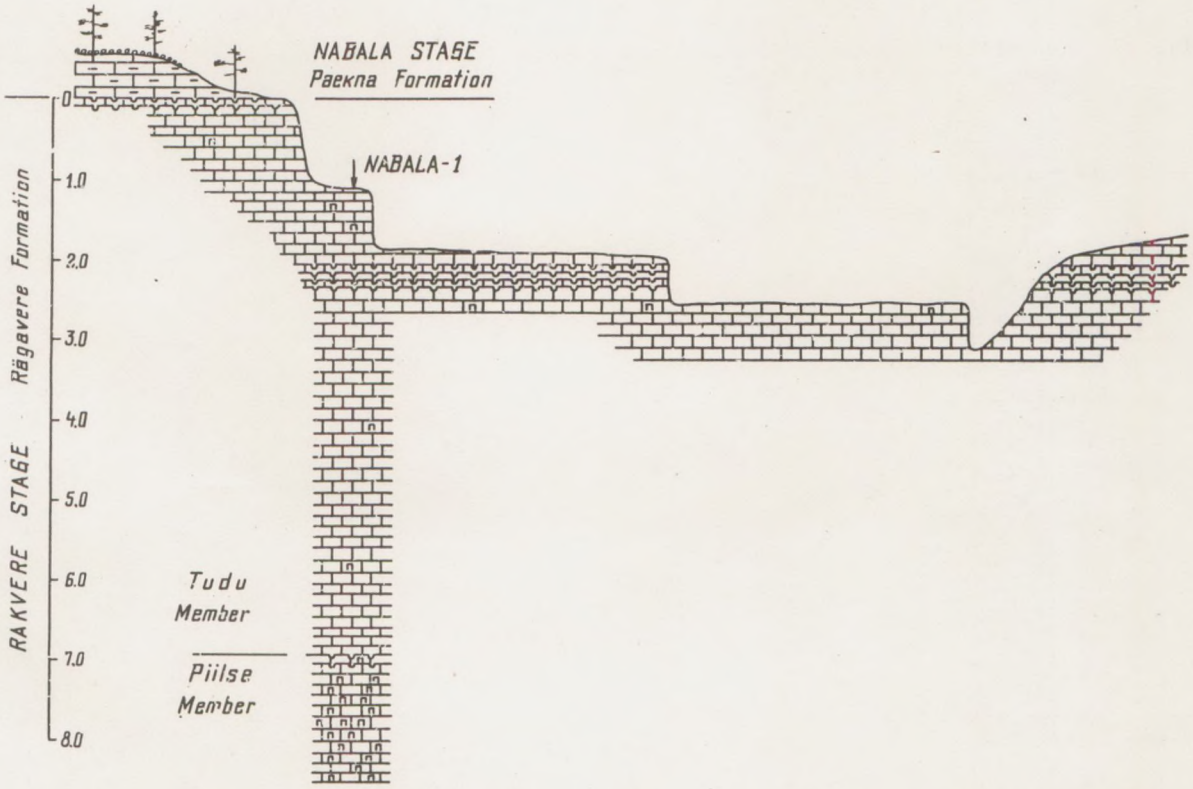


Fig. 32. Cross-section through the Paekna (Nõmmküla) quarry (data by L. Põlma was used).

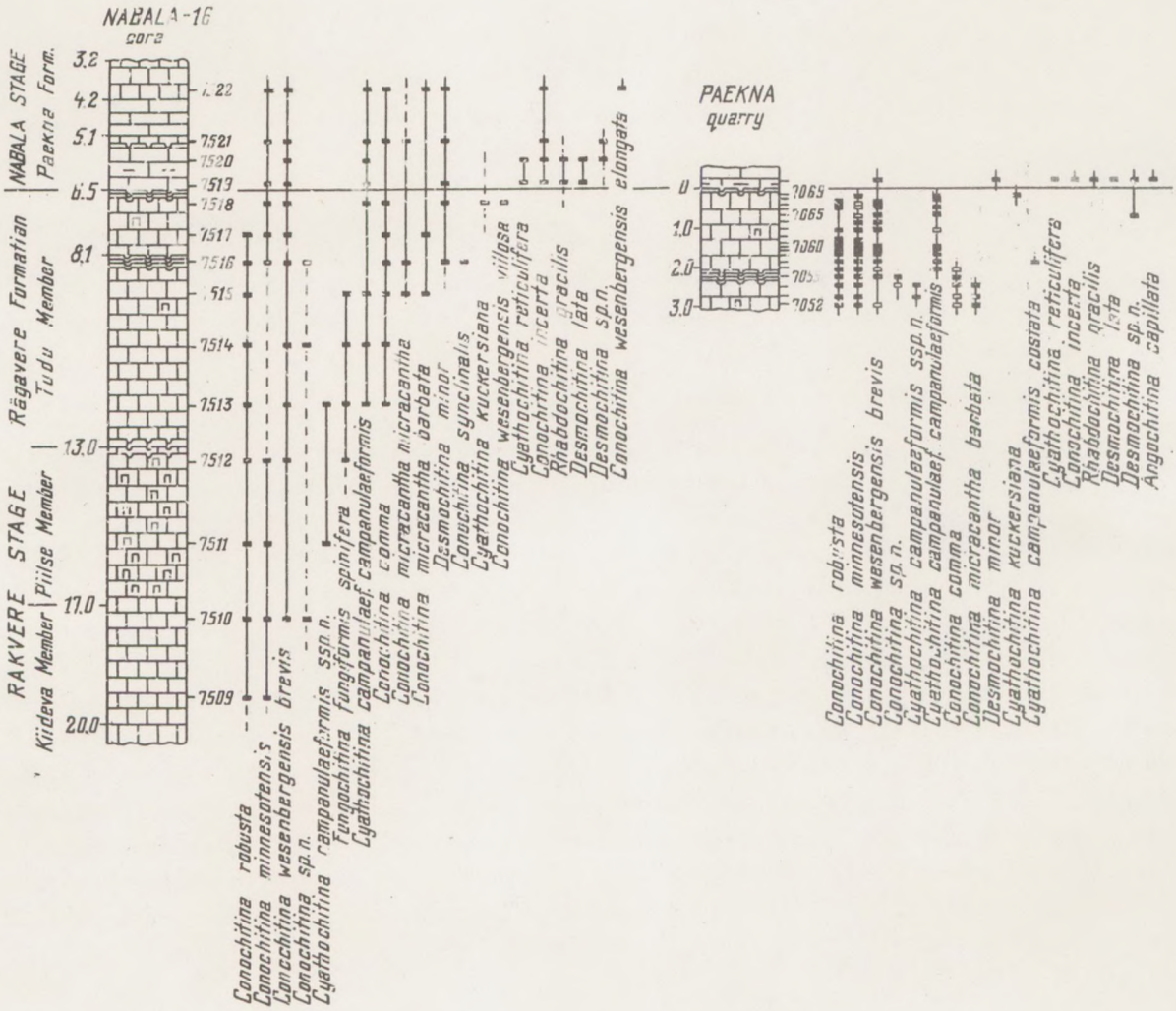


Fig. 33. Faunal log (Chitinozoans) of the Paekna quarry and Nabala-16 core. Open rectangle - conformis.

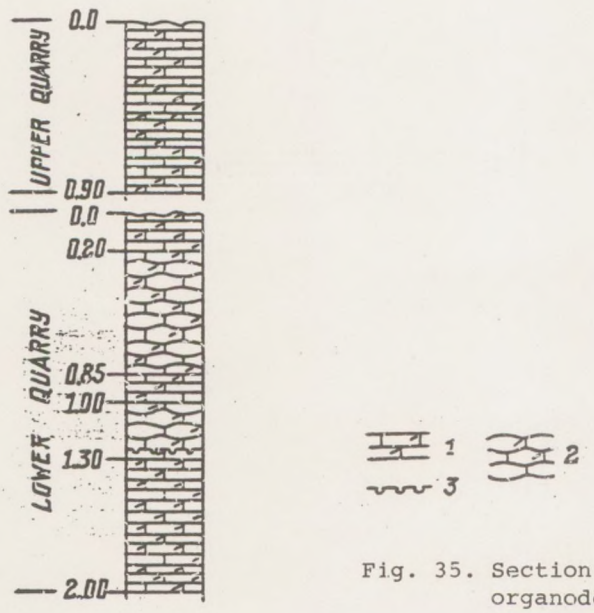


Fig. 35. Section of the Lohu outcrop: 1 - fine organodetritic limestone; 2 - nodular limestone; 3 - discontinuity surface.

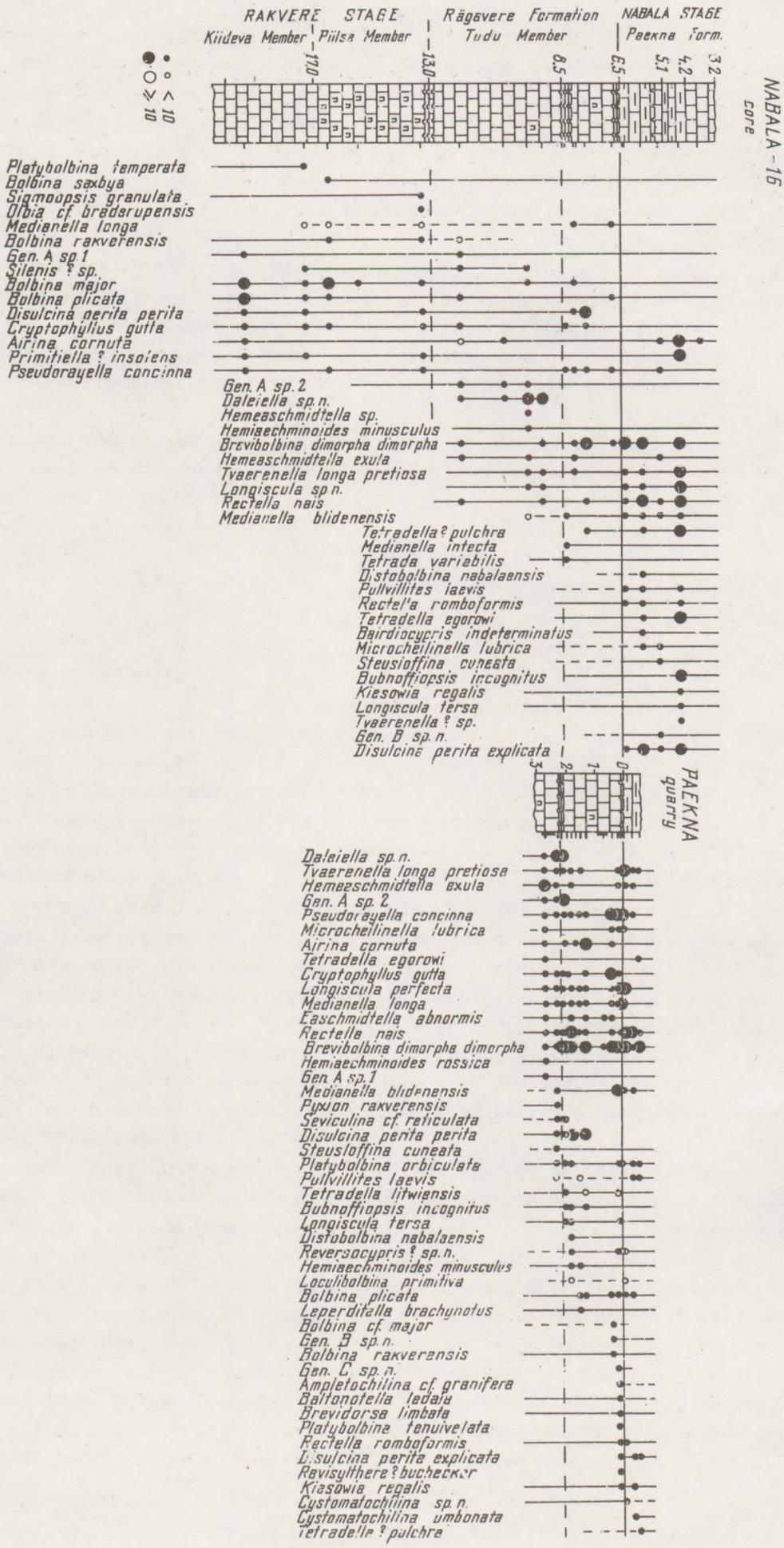


Fig. 34. Faunal log (Ostracodes) of the Paekna quarry and Nabala-16 core. Open circle - conformis.

Rakvere Stage. Rägavere Formation. Tudu Member

Main part of the section is represented by aphanitic limestones (calcilutites) which crop out in the thickness of up to 3.1 m. According to the new data these beds belong to the upper part of the Rägavere Formation, opposite to our earlier consideration (Põlma, Nõlvak, 1984, p. 57). The rock is light-grey (white), slightly yellowish, within the topmost 1 m weakly weathered, thin to medium-bedded (2-10 cm) pure ($CaCO_3$ more than 80 %), cryptocrystalline (aphanitic) limestone, with sparse (about 5 %) fine skeletal detritus (prevailingly *Vermiporella*). Less pronounced four pyritized discontinuity surfaces occur in the interval from 2.05 to 2.35 m from the top of the member.

The rocks of the Rägavere Formation are referred to shelf deposits of medium depth, where the influx of terrigenous material was more limited comparing with the overlying part of the section (Paekna Formation). The previous list of macrofossils needs a revision according to a new interpretation.

Most of the taxa recorded from the present locality presented have wider stratigraphical ranges (see Fig. 33, 34) as shows comparison with the faunal log of the Nabala-16 boring, which is situated 0.7 km southeast of the outcrop. (1) The beds of the Rägavere Formation in the core are characterized by the increasing taxonomic diversity of microfossils and this change seems to be in correlation with a decrease in the rate of sedimentation. (2) It should be mentioned that there are no principal differences in diversity in spite of the sample densities: 14 samples for chitinozoans and 8 for ostracodes from the quarry section are compared with 2 core samples from the upper 1.6-2 m part of the Tudu Member (between the complexes of the discontinuity surfaces, Fig. 33, 34). The size of the samples was roughly the same. (3) Among chitinozoans (Fig. 33) the boundary between the Rakvere and Nabala stages is best defined by disappearance of *Conochitina robusta* Eisenack (Plate 13, Fig. 8) and appearance of *Cyathochitina reticulifera* Grahn (Plate 13, Fig. 10; = *C. dispar* in Männil, 1976, p. 118) and among ostracodes the disappearance of *Disulcina perita* (Sarv) and the appearance of *Disulcina explicata* Sarv (Fig. 34). According to the data from the other sections at least in the northern East Baltic they seem to be good biostratigraphic tools.

J. Nõlvak, T. Meidla

LOCALITY 3:2 LOHU OUTCROP

On the left bank of the Keila River, 200 m south of the Lohu settlement, there is an old quarry, where in its lower section about 2 m of limestones are cropping out. These sediments are considered as the upper part of the Moe Formation of the Pirgu Stage.

The sequence is characterized (see Fig. 35) by prevailingly pure, micro- to cryptocrystalline, fine organodetritic (predominantly algal fragments), in the lower part fine organodetrital, light-grey, with slightly yellowish (in the upper part) or slightly brownish (in the lower part) shades of colour, medium-bedded to medium nodular limestone. A pyritized discontinuity surface is observed at about 0.7 m from the bottom of the quarry.

The section continues in a small overgrown quarry with an old lime-kiln. 50 m towards the road there is an outcrop of pure, prevailingly microcrystalline, fine organodetritic, thin to medium-bedded, light-grey limestone of a slightly brownish shade of colour, exposed in a thickness of 0.90 m. They belong probably to the lowermost part of the Adila Formation of the Pirgu Stage.

The rocks in Lohu quarries are assigned to the regressive deposits of a partly isolated, relatively shallow-water shelf.

The following fossils have been reported in the Lohu quarry: *Aulacopium aurantium* Oswald, *Stromatocerium canadense* Nichols et Murie, *Plectatrypa sulevi* Jaanusson, *Conochitina wesenbergensis brevis* Eisenack, *Tanuchitina bergstroemi* Laufeld, etc.

L. Põlma, J. Nõlvak

LOCALITY 3:3 SÄRGHAUA FIELD STATION

Geological setting and sightseeing

The Särghaua Field Station of the Institute of Geology is situated in central Estonia, approximately 100 km south of Tallinn, at the Pärnu River. The site lies about 15 km south-west of the drumlin field of Türi and belongs to the West-Estonian Lowland in the limits of the maximal range area of the Baltic Ice Lake (about 10,000 to 11,000 years ago). The bedrock in the surroundings of the field station is represented by the late Llandovery (Telychian) Adavere Stage, consisting of dolomitized limestones which yield a.o. *Costistricklandia*. The bedrock is exposed in many places at the Pärnu River and its tributaries (the localities lie at 5-10 km from the station).

At a distance of one km from the Särghaua Field Station the Museum of Kurgja, a farmstead of the prominent Estonia 19th century public figure C.R. Jakobson (1841-1882) is situated.

The Särghaua Field Station represents the site of a 18-19th centuries farm with its different buildings, some of which are reconstructed for the institute's needs. The oldest existing wooden buildings come from the middle of the 19th century, the oldest known planted trees in the farm park date from the beginning of the same century (1806...1837). The stone buildings have been constructed in 1881 (the meat barn) and 1923-1926 (the main stone building was used up to 1949 as a complex of creamery, cowhouse, and piggery). In 1972, when the Institute of Geology got possession of the site, the farm buildings were in tumbledown condition, the present state being a result of the reconstruction of stone buildings carried out by a local state building organization in the period of 1974-1979, 1984, and 1988, and the enthusiastic activity of the institute's staff interested in the functioning of the field station.

The field station serves for the maintenance and study of borehole cores and different lithological and paleontological collection, coming mainly from the Ordovician and Silurian subsurface of central and southern Estonia.

At the field station core sections representing different East Baltic Ordovician and Silurian confacies belt sequences will be demonstrated.

The Ordovician sequences (Loc. 3:3)

In the East Baltic area the presence of different confacies belts, earlier referred to as facies regions, or according to Soviet usage "the structural-facies zones" have been first recognized in the early 1960s (Männil, 1963, 1966). Two main confacies belts have been distinguished and currently used in the East Baltic, which are here referred to as eastern and western (central) confacies belts. The eastern (when concerning the Estonian territory - the northern) belt includes the surface bedrock of northern Estonia, and subsurface of eastern Latvia and south-eastern Lithuania and consists mainly of grey-coloured shallow-water calcarenites. The western belt includes subsurface of southern Estonia, western Latvia and western Lithuania and consists in its considerable part of clayey and argillaceous, often red-coloured deposits, calcilutites. The western belt represents an eastern (Livonian) tongue of the Central Baltoscandian Confacies Belt according to terminology introduced by Jaanusson (1976). It corresponds to the Swedish-Latvian facial zone of Männil (1966). The boundaries between the main confacies belts

are not linear and accordingly a comparatively narrow transitional zone between the belts may be distinguished (Põlma, 1967).

A comparative study of the lithology including characteristics of skeletal debris content of the confacies belts based mainly on Rapla and Engure core sections has been carried out by Põlma (1972 a,b, 1973, 1982). The subsurface lithology and faunas of the belts on the Latvian territory have been summarized by Ulst, Gailite, and Yakovleva (1982).

The significant lithological and faunal differences existing between the different confacies belts despite of the presence of core sections of transitional character (e.g. Laeva and Butkunai cores) cause serious problems in the correlation of different sequences. Some problems have been discussed by Jaanusson (1960, 1976), Männil (1977, 1972), Bergström (1971), Ulst et al. (1982), and others, many of them are still in urgent need of special studies.

In the field station two Ordovician drilling cores will be demonstrated: the Kullamaa core of western Estonia, and the Aizpute core of western Latvia representing the East Baltic eastern and western (central) confacies belts, accordingly. A schematic correlation of the core sections together with outlines of the local stratigraphic classification of the successions, characteristic biofacies indices (mainly trilobites, in part brachiopods or ostracodes), and selected correlational biostratigraphic tie points resp. faunal marker horizons is given in a figure provided separately (see Fig. 60 on pages 190...193).

R. Männil

FOURTH DAY

Middle and Upper Ordovician and Llandovery outcrops in North-East Estonia

LOCALITIES 4:1 A and B KOHTLA AND MAIDLA QUARRIES

Vicinity of Kohtla-Järve, nowadays a mining and chemical industry centre, is a historical area of oil shale geology studies (see Bekker, 1921; Öpik, 1925; Rõõmusoks, 1970 et al.). From a lot of quarries and outcrops two were chosen for this excursion.

Kohtla quarry (4:1A) is located 1 km south of Kohtla railway station and 7 km south-west of town Kohtla-Järve. Kukersite is excavated in this small quarry at present, but it is a suitable place for collecting fossils as well. The section presents the lowermost part (the Kivióli Member) of the Kukruse Stage. 34 alternating limestone and kukersite beds (from "A" to "K_2") can be distinguished here, 14 of what are brownish kukersite beds (Fig. 36). The Kivióli Member has its maximum thickness in this region. Towards east, south and west it decreases from 6 m to 1-1.5 m.

Maidla quarry (4:1B) is situated 10 km south-west of Kohtla quarry. Besides exposing the Maidla Member of the Kukruse Stage this big quarry is an example of wasteful excavation. The section presents the middle part of the Kukruse Stage - the Maidla Member (from "K/L" to "III") in its whole thickness of 6 m. Here kukersite beds are thinner and limestones (incl. kukersineous[x]) prevail (Fig. 37).

Kukersite is a unic mixed rock that consists of the following 3 main components:

1) organic matter of algal and/or microbial origin and of specific outlook (25-65 %)
2) terrigeneous matter, mainly pelitic (15-50 %)
3) calcareous component that consists mainly of calcitic matrix and skeletal remains (15-50 %).

Kukersite beds contain nodules of kukersineous limestone, lenses of densely packed skeletal debris or show horizontal lamination stressed by the accumulations of skeletal fragments. Kerogeneous matter of kukersite consists of yellow to brownish isolated globular and aggregate-like particles called "kuckers". Average diameter of kuckers varies from 40 to 200 microns. Inner structure of simple globules is homogeneous, aggregate-like ones show differentiated structure of algal and/or microbial origin. The latter are most common in calcareous kukersites, simple globules in kukersite beds "B", "G", "III".

The section (see Fig. 37) consists of following rock types:

1) kukersite (organic matter (OM) - 25-65 %)
   a) kukersinite (OM - 50-65 %)
      in beds "B", "E"
   b) argillaceous kukersite with sparse and few skeletal debris (OM - 25-50 %)
      in beds "A", "D", "G_1"
   c) calcareous kukersite rich in skeletal debris, its lenses and laminations (OM - 25-50 %)
      in beds "A", "C", "F_1", "G_2", "H_2"
2) kukersineous limestone (OM - 5-25 %)
   a) kukersineous fine-grained argillaceous skeletal wackestone in beds "A/B", "B/C", "C/D", "D/E"
   b) kukersineous unsorted skeletal wackestone
      in beds "B/C", "E/F", "F_3", "G_1/G_2"
3) limestone (with few kuckers or without them; OM - 5 %)

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[x] derived from the word "kukersine" that marks the kerogeneous component of kukersite comprised of specific globular and aggregate-like particles

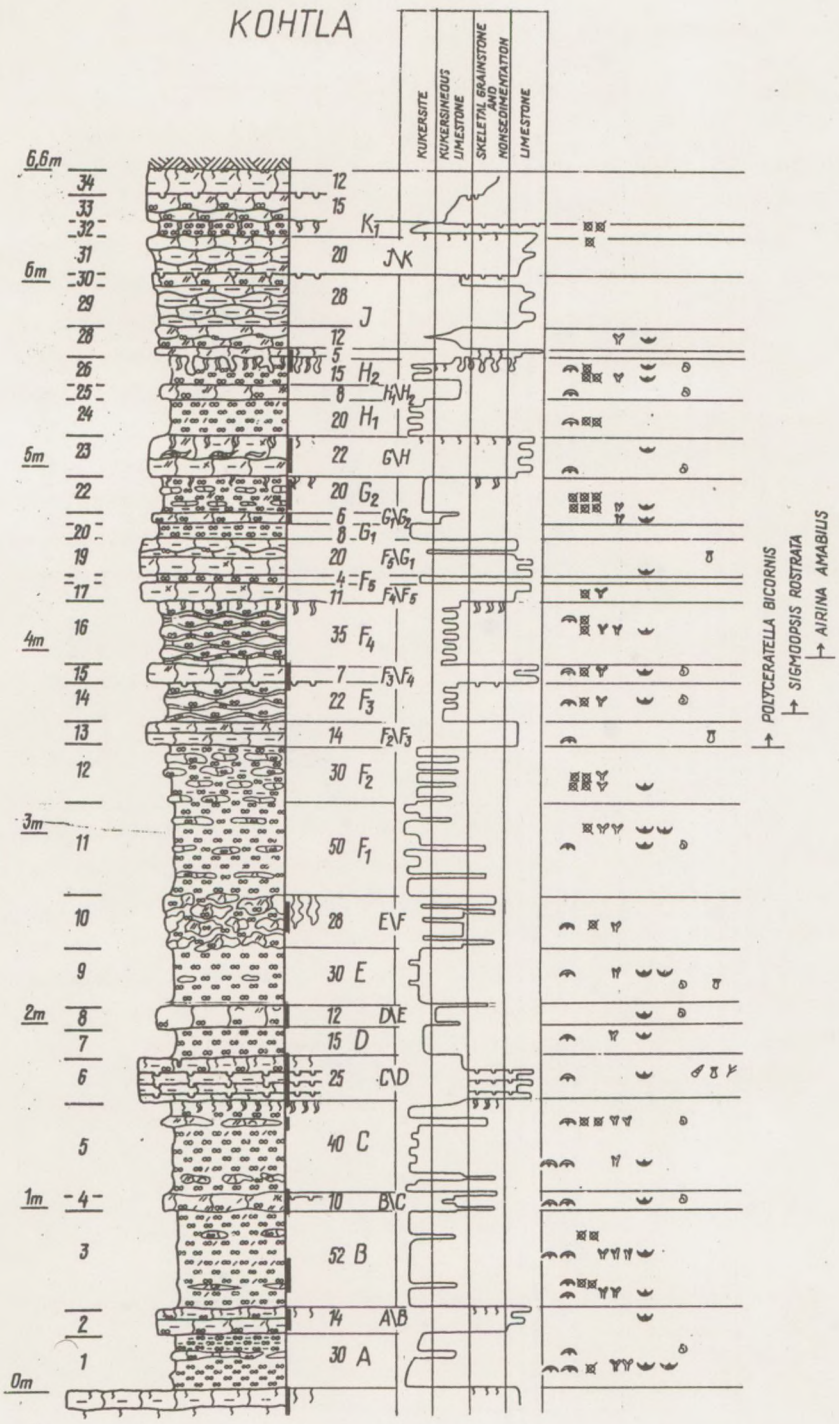


Fig. 36.

Kohtla quarry section. For legend see Fig. 3.

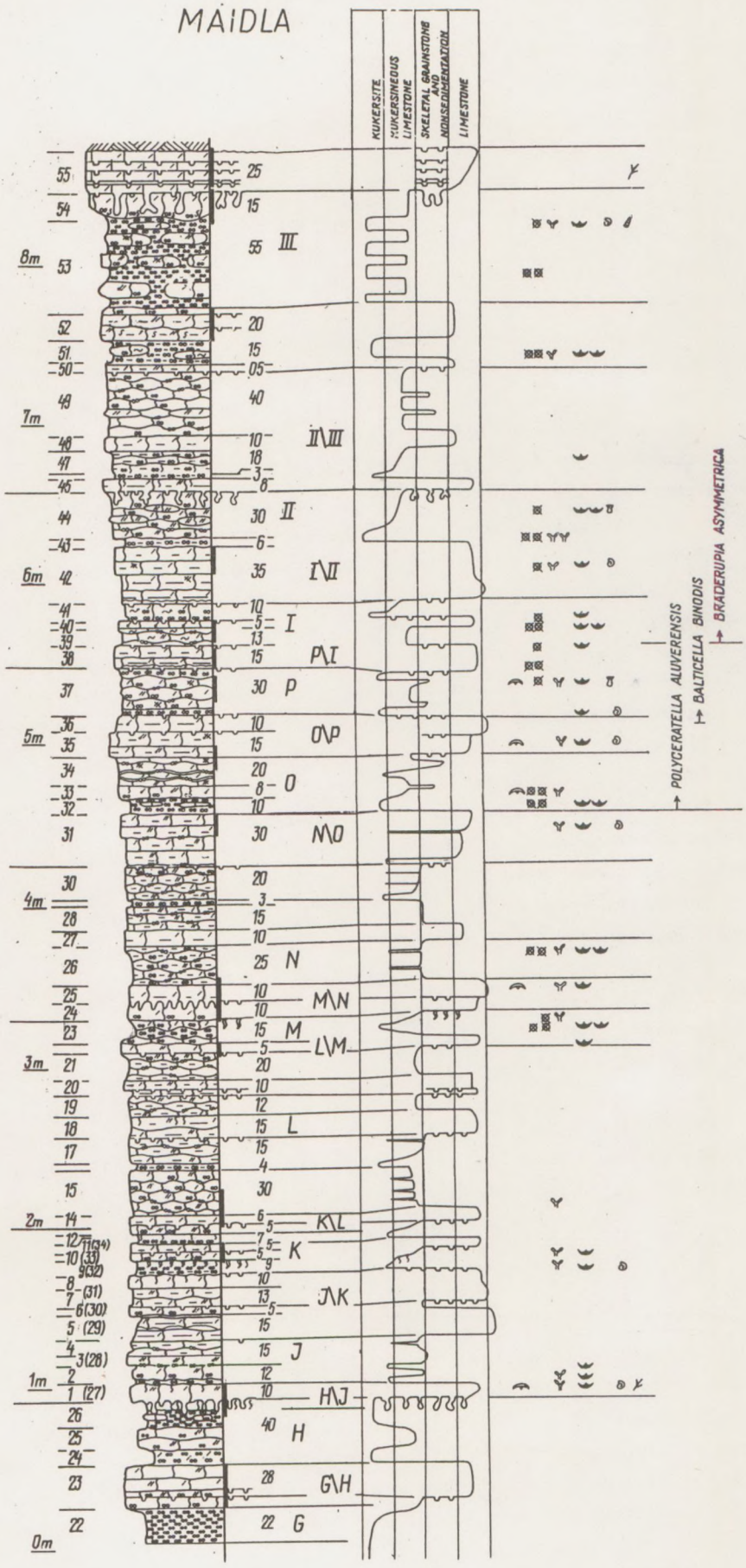


Fig. 37.

Maidla quarry section.
For legend see Fig. 36.

a) fine-grained argillaceous skeletal wackestone
in beds "C/D, the lower", "F_2/F_3", "F_4/F_5"

b) unsorted skeletal wackestone
in beds "F_3/F_4", "G/H", "H/I"

4) skeletal grainstone (might be kukersineous)
lenses in beds "B", "C", "E/F"

Nearly all beds of the sections are more or less bioturbated.

Kohtla and Maidla sections yield a diverse and abundant fossil assemblage. Over 200 species (trilobites, ostracodes, brachiopods, gastropods, pelecypods, cephalopods, bryozoans, pelmatozoans, sponges etc.) have been recorded from the Kohtla-Järve section (Rõõmusoks, 1970).

Detailed sampling has been carried out in these quarries (see Figs 36, 37). Using appearance of definite ostracode species two levels of changes in the taxonomic composition have been depicted. These levels can be well followed along the North-Estonian Confacies Belt (from Tallinn to Leningrad Region). The content and abundance of macrofossils, as well as the amount and composition of skeletal debris vary greatly through the sequence. To get an idea about it, preliminary and empirical estimates on macrofossil distribution (gained from ostracode samples and polished rock samples) have been added.

Kukersite of the lower part of the Kohtla section (beds "B", "C") is rich in cryptostome (*Graptodictya, Pachydictya, Phaenopora*) and some ramose bryozoans (*Homotrypa, Nematotrypa*), shown already by H. Bekker (1921), as well as pelmatozoan debris (*Ristnacrinus, Baltocrinus*). Especially the latter accumulations refer to the fluctuating energy levels that existed during the Kukruse Age. Kukersineous limestone beds contain mostly trepostome bryozoans, microgastropods, small trilobites, brachiopods.

The middle part of the Kohtla section (beds "D", "E", "F_1") is dominated by brachiopods (*Sowerbyella, Oepikina*). Here *Bilobia musca* and *Paucicrura navis* appear. Another good stratigraphical marker level follows, while ostracodes *Sigmoopsis rostrata, Polyceratella bicornis* and *Airina amabilis* make their first appearance in beds "F_2/F_3" - "F_3". Starting with the beds "F_4" - "G_1" *Kullervo panderi* can be distinguished.

Kukersite beds "F_4", "G_2" and "H_2" show a remarkably great content of echinoderm debris (eocrinoids, stylophorans, homoiostelean and asteroid species).

The commonest species of the Kiviõli Member *Chasmatopora furcata, Pseudohornera bifida, Diplotrypa petropolitana petropolitana, Mesotrypa excentrica, Bicuspina dorsata, Bilobia musca, Cyrtonotella kuckersiana kuckersiana, Asaphus (N.) nieszkowskii, Atractopyge rex, Chasmops aff. odini odini* etc. occur also in the Maidla Member (Rõõmusoks, 1970).

The Maidla Member is poorer in fossils, but it must be added that its macrofauna is less known, too. Beds "O", "P", "I" form an important stratigraphical level, where ostracodes *Polyceratella aluverensis, Balticella binodis* and *Braderupia asymmetrica* appear.

A. Kõrts, R. Einasto

LOCALITY 4:2 ONTIKA CLINT

The stratotype section of the Ontika Subseries is situated at the highest point of the North Estonian clint (56.4 m) near Ontika village, 15 km north of Kohtla-Järve town. In the section lower Ordovician Ontika beds (the Kunda, Volkhov, Latorp stages) are exposed. In the topmost part of the escarpment the above-lying middle Ordovician Aseri and Lasnamägi stages are overgrown with brushwood and can be observed only in pits excavated in the limestone plateau. The lower part of the clint is represented by terrigenous Tremadoc and Cambrian rocks.

A pioneer work on the Lower Ordovician stratigraphy of North-Estonian clint was done by F. Schmidt, later improved by W. Lamansky (1905), P. Raymond (1916) and K. Orviku (Jaanson-Orviku, 1927; Orviku, 1929, 1940; 1960a, b). Articulate brachiopods, found in nearby outcrops, are here given after M. Rubel (1961), trilobites, partly according to R. Männil (1963). Describing the present section and microfauna the author used identifications of ostracodes revised by L. Sarv (see Fig. 38). In descending order there are exposed:

Aseri Stage. Aseri Formation (forms together with the lower-lying Napa Formation the classical "Upper Oolitic Bed")

0.2+ m - Grey dolomitized skeletal packstone, with limonite ooids and pseudo-ooids contains *Panderina* cf. *sulcatus*, *Periodon aculeatus*, *Longiscula* sp., *Polyceratella* sp. At the base there is a sharp rough limonitized discontinuity surface.

Kunda Stage at Ontika is more complete than in West Estonia (Loc. 1:4 and Table 1)

Napa Formation

2.35 m - Grey argillaceous skeletal packstone with various amount of limonite pseudo-ooids, ooids and argillaceous intercalations. In the upper (1.1 m) and dolomitized lower (0.5 m) parts the rock is thick-bedded (5-8 cm), in the middle part (0.75 m) - seminodular, thin- and medium-bedded. The quantity of ooids increases from top to base, that of pseudo-ooids and coarse-grained skeletal material decreases. *Eoplacognathus suecicus*, *Microzarkodina ozarkodella* are the most typical conodonts, *Pliomera fischeri* (Eichw.), *Pseudasaphus globifrons* (Eichw.), *Productorthis eminens* (Pander), *Lycophoria globosa* (Eichw.) and from the upper part *Euprimites effusus*, *Pinnatulites procera*, *Aulacopsis simplex*, *Steusloffia levis*, *Desmochitina cocca* were identified.

Loobu Formation (= "Vaginatum" or "Endoceras" Limestone) forms together with the underlying Sillaoru Formation - the Kunda Formation according to P. Raymond, 1916.

Loobu Formation (= "Vaginatum" or "Endoceras" limestone)

2.0 m - Valgejõe Member: Grey, dolomitized coarse-grained skeletal packstone with soft argillaceous intercalations (especially frequent in the middle part) contains limonitic grains and burrows, rare fine glauconite and partly pyritized or glauconitized fragments of echinoderms, ostracodes, bryozoans, brachiopods, trilobites, numerous endoceratide cephalopods. Upper part is rich in ostracodes (*Euprimites effusus*, *Ogmoopsis variabilis*, *Steusloffia acuta*, *Pinnatulites procera*); lower part - in chitinozoans (*Lagenochitina esthonica longa*, *Rhabdochitina gracilis*, *Desmochitina minor*). *Bentoceras rubeli* Stumbur occurs.

2.5 m - Utria Member: Grey, generally varigrained, hard dolomitized skeletal packstone, more rich in cephalopods than the uppermost member. Upper 0.6-0.7 m is thick-bedded (5-10 cm), with limonitic burrows, molds of microgastropods, fine inarticulate brachiopods, ostracodes *Primitiella fastidiosa*, fragments of graptolites. Following bed (0.6 m) contains argillaceous intercalations, coarse grains of glauconite, single limonitic ooids, numerous cephalopods, fragments of graptolites *Glyptograptus* sp., ostracodes *Aulacopsis simplex*. The next 0.8 m is thick-bedded (18-20 cm), with numerous rough phosphatic discontinuity surfaces.

Lower part (0.4 m) is medium-bedded, with argillaceous intercalations (1 cm), rich in trilobites and cephalopods; a rough phosphatic discontinuity surface occurs.

Most abundant cephalopods of the Loobu Formation are *Paracyclendoceras cancellatum* (Eichw.), *Protocyclendoceras balticum* Balashov, *Dideroceras longispiculum* Balashov (Balashov, 1968), brachiopods *Lycophoria nucella* (Dalm.), *Cyrtonotella semicircularis* (Eichw.), trilobites *Megistaspis gibba* (Schmidt).

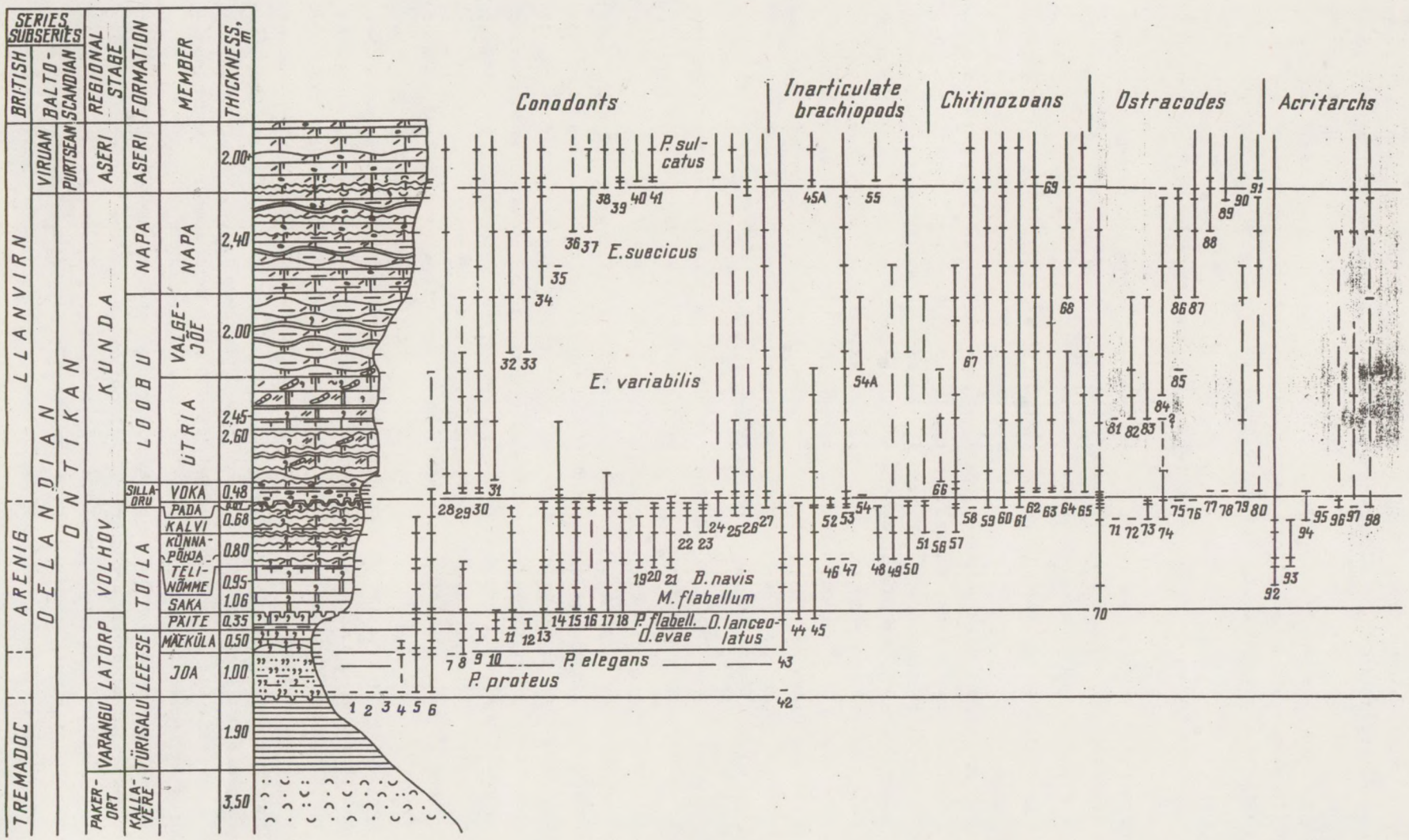

SERIES
SUBSERIES
BRITISH
BALTO-SCANDIAN
REGIONAL STAGE
FORMATION
MEMBER
THICKNESS, m
Conodonts
Inarticulate brachiopods
Chitinozoans
Ostracodes
Acritarchs
LLANVIRN
ARENIG
TREMADOC
VIRUAN
PURTSEAN
OELANDIAN
ONTIKAN
ASERI
KUNDA
LOOBU
VOLHOV
LATORP
VARANGU
PAKERORT
NAPA
VALGEJÕE
ÜTRIA
SILLAORU
VOKA
PADA
KALVI
KÜNNAPÕHJA
TELINÕMME
SAKA
PÄITE
MÄEKÜLA
JÕA
LEETSE
TÜRISALU
KALLAVERE
2.00+
2.40
2.00
2.45
2.60
0.48
0.68
0.80
0.95
1.06
0.35
0.50
1.00
1.90
3.50
P. sulcatus
E. suecicus
E. variabilis
B. navis
M. flabellum
P. flabell.
O. lanceolatus
O. evae
P. elegans
P. proteus

Fig. 38. Stratotypical section of Ontika Subseries

For lithological legend see Fig. 3. Ranges of fossils:

I Conodonts: 1 - *Drepanoistodus deltifer* (Pander), 2 - *Drepanoistodus acuminatus* (Pander), 3 - *Acodus deltatus* (Lindström), 4 - *Paroistodus* cf. *proteus* (Lindström), 5 - *Drepanoistodus forceps* (Lindström), 6 - *Drepanodus arcuatus* Pander, 7 - *Prioniodus elegans* Pander, 8 - *Scolopodus rex* Lindström, 9 - *Oepikodus evae* (Lindström), 10 - *Oistodus lanceolatus* Pander, 11 - *Periodon flabellum* (Lindström), 12 - *Stolodus stola* (Lindström), 13 - *Baltoniodus triangularis* (Lindström), 14 - *Protopanderodus longibasis* (Lindström), 15 - *Baltoniodus navis* (Lindström), 16 - *Milaculum scandicum* Müller, 17 - *Protopanderodus rectus* (Lindström), 18 - *Microzarkodina flabellum* (Lindström), 19 - *Triangulodus brevibasis*, 20 - *Paroistodus originalis* (Sergeeva), 21 - *Scalpellodus latus* (van Wamel), 22 - *Microzarkodina* cf. *parva* (Lindström), 23 - *Baltoniodus prevariabilis norrlandicus* Löfgren, 24 - *Protopanderodus* cf. *varicostatus* (Sweet et Bergström), 25 - *Drepanoistodus basiovalis* (Sergeeva), 26 - *Scolopodus cornuformis* (Sergeeva), 27 - *Scalpellodus gracilis* (Sergeeva), 28 - *Milaculum* sp. a v.d. Boogard, 29 - *Amorphognathus (Eoplacognathus?) variabilis* (Sergeeva), 30 - *Baltoniodus variabilis medius* Dzik, 31 - *Scolopodus* cf. *bulbosus* Löfgren, 32 - *Belodella* cf. *jemtlandica* Löfgren, 33 - *Microzarkodina ozarkodella* Lindström 34 - *Eoplacognathus* cf. *suecicus* Bergström, 35 - *Polonodus clivosus* (Viira), 36 - *Walliserodus* cf. *iniquus* (Viira), 37 - *Panderodus* cp. (cf. *compressus* Branson et Mehl), 38 - *Panderodus* cf. *sulcatus* (Fahraeus), 39 - *Baltoniodus prevariabilis prevariabilis* Fahraeus, 40 - *Periodon aculeatus* Hadding, 41 - *Acontiodus* sp.;

II Inarticulate brachiopods: 42 - *Siphonotreta unguiculata* (Eichwald), 43 - *Spondylotreta faceta* Gorjansky, 44 - *Scaphelasma septatum septatum* Gorjansky, 45 - *Myotreta crassa* Gorjansky, 46 - *Biernatia rossicum* (Gorjansky), 47 - *Leptembolon recta* (Gorjansky), 48 - *Eoconulus cryptomus* Gorjansky, 49 - *Eosiphonotreta* cf. *verrucosa* (Eichw.), 50 - *Paterula* sp.; 51 - *Biernatia minor* Cooper, 52 - *Scaphelasma septatum rugosum* Gorjansky, 53 - *Rowellella* sp. (cf. *rugosa* Gorjansky), 54 - *Conotreta mica* Gorjansky, 55 - *Orbiculoidea* cf. *schallochensis* Reed;

III Chitinozoans: 56 - *Conochitina primitiva* Eisenack, 57 - *Lagenochitina esthonica* Eisenack, 58 - *Desmochitina elongata* Eisenack, 59 - *Rhabdochitina magna* + *R. striata* Eisenack, 60 - Scolecodonts (*Anisocerasites* ? - B_{II}), 61 - *Cyathochitina calix* (Eisenack), 62 - *Desmochitina minor* Eisenack, 63 - *Rhabdochitina gracilis* Eisenack, 64 - *Cyathochitina* cf. *regnelli* Eisenack, 65 - *Cyathochitina campanulaeformis* (Eisenack), 66 - *Glyptograptus* sp., 67 - *Lagenochitina esthonica longa* Eisenack, 68 - *Desmochitina cocca* Eisenack, 69 - *Pistillifrons pistillifrons* (Eisenack);

IV Ostracodes: 70 - *Conchoprimitia gammae* Öpik, 71 - *Tallinnellina palmata* (Krause), 72 - *Rigidella mitis* Öpik, 73 - *Glossomorphites* ? cf. *grandispinosa* (Hessland), 74 - *Ogmoopsis bocki* (Öpik), 75 - *Regiopis* ? cf. *oepiki* Sarv, 76 - *Tallinnellina primaria* (Öpik), 77 - *Bolbina crassa* Sarv, 78 - *Glossomorphites* ? cf. *tenuilimbata* Hessland, 79 - *Ogmoopsis variabilis* Sarv, 80 - *Steusloffia levis* Sarv, 81 - *Tallinnellina divelata* Sarv, 82 - *Steusloffia acuta* (Krause), 83 - *Uhakiella* sp., 84 - *Aulacopsis simplex* (Krause), 85 - *Primitiella fastidiosa* Sarv, 86 - *Pinnatulites procera* (Kummerow), 87 - *Euprimites effusus* Jaanusson, 88 - *Longiscula* sp., 89 - *Baltonotella* sp., 90 - *Euprimites* sp., 91 - *Polyceratella* sp.;

V Acritarchs: 92 - *Leiosphaeridia* sp. (cf. *leptotheca* Eisenack), 93 - *Peteinosphaeridium* sp., 94 - *Tasmanites* cf. *trematus* Eisenack, 95 - *Leiosphaeridia* cf. *cylindrosum* Eisenack, 96 - *L.* cf. *voigti* Eisenack, 97 - *L. baltica* Eisenack, 98 - *Baltisphaeridium* sp.

Sillaoru Formation (= "Lower Oolitic Bed")

0.48 m - Voka Member: Dark brownish-grey dolomitized thin- and medium-bedded nodular argillaceous oolite bed with abundant (to 80 %) limonite (generally goethite) ooids and a limonitized discontinuity surface in the medium part. Above the surface there occur *Glyptograptus* sp., *Cyathochitina regnelli*, *C. campanulaeformis*; below the surface - *Desmochitina minor*, *Cysticamara acollis*. *Lycophoria nucella* (Dalm.), *Platystrophia costata* (Pander) occur.

0.07 m - Pada Member: Grey dolomitized, hard, thick-bedded fine-grained skeletal packstone abounding in fine glauconite grains, pseudo-ooids; contains fragments of echinoderms, brachiopods, algae and limonitized molds of ostracodes, algae, brachiopods *Orthis callactis* (?) Dalm., trilobites *Ptychopyge angustifrons* Dalm.

Volkhov Stage. Toila Formation forms together with the underlying Päite and Mäeküla members the "Glauconite Limestone" or "Megalaspis (= Megistaspis) Limestone", and these, according to R. Raymond (1916), together with glauconitic Joa Member - the Walchow Formation.

0.68 m - Kalvi Member: Grey, fine-grained hard, thick-bedded skeletal packstone, with thin argillaceous intercalations, rich in glauconite (often - glauconitized moulds of microgastropods) and rough phosphatic discontinuity surfaces. Characteristic fossils are: *Ptychopyge truncata* Nieszkowski, *Nileus armadillo* Dalm., *Productorthis parallela* (Pander), *Microzarkodina parva*, *Baltoniodus navis*, *Milaculum scandicum*, *Rowellella* cf. *rugosa*, *Tallinnellina primaria*, *Ogmoopsis bocki*; in the upper part there is an abundance of *Cyathochitina calix*, *Rhabdochitina* sp. (cf. *striata*), *Desmochitina minor elongata*. In the lower half of the member glauconitic spicules of sponges, *Tasmanites* sp., *Scolopodus cornuformis*, *Protopanderodus* cf. *varicostatus* have been recorded.

0.5 m - Künnapõhja Member: Grey dolomitized packstone. Upper part (0.3 m) is thin-bedded with argillaceous intercalations, lower part is medium- and thick-bedded with 7 rough limonitic discontinuity surfaces and limonitized skeletal debris (pseudo-ooids). Most characteristic conodonts are *Paroistodus originalis*, *Scandodus brevibasis*.

0.3 m - Telimõmme Member: Light-grey thin- and medium-bedded (5-6 cm) seminodular dolomitized skeletal packstone, with argillaceous intercalations (clayey marls), patches of glauconite; besides microfossils *Scandodus brevibasis*, *Paroistodus originalis*, *Microzarkodina flabellum*, *Baltoniodus navis*, *Ogmoopsis bocki*, *Tallinnellina palmata*, *Lagenochitina esthonica*, inarticulate brachiopods *Eosiphonotreta verrucosa*, *Eocoinulus cryptomyus*, *Biernatia minor* have been identified. Smooth and rough limonitized surfaces occur in the lower half.

0.95-1.06 m - Saka Member: Grey dolomite with numerous coarse glauconite grains (often moulds of microgastropods). In the upper part (0.6 m) the rock is thick-bedded (5-10 cm) with rose stripes; in the lower part (0.45 m) thin argillaceous intercalations and rough limonitic surfaces occur. Conodonts *Baltoniodus triangularis*, *B. navis*, *Microzarkodina flabellum* are common.

Latorp Stage

0.35 m - Päite Member: Grey, with rose patches and stripes thick-bedded dolomitized fine-grained skeletal packstone, containing glauconite. Characteristic conodonts are *Scolopodus rex*, *Drepanoistodus forceps*, *Oistodus lanceolatus*, rare *Periodon flabellum*; Inarticulate brachiopods *Spondylotreta faceta*, *Myotreta crassa* are also common. Lower part is rich in echinoderm fragments. At the top there occurs a smooth discontinuity surface with regular vertical Amphora-like glauconitic burrows (depth to 6 cm) ("püstakkiht" after K. Orviku, 1929).

Leetse Formation

0.5 m - Mäeküla Member: At the top (0.1 m) is a transition bed from glauconitic limestone to glauconitic sandstone. The main part of the member is represented by dark-green nodular glauconite sandstone with dolomitized carbonate cement. Many fragments of brachiopods *Ranorthis parvula* (Lamansky), *Spondylotreta faceta*, conodonts *Oistodus lanceolatus*, *Periodon flabellum*, *Oepikodus evae*, echinoderms have been established.
1.0 m - Joa Member: (= "Glauconite" or "Greensand") - dark-green glauconitic sandy and clayey silt, in the upper part with *Prioniodus elegans* and fragments of graptolites, below with yellow or grey clayey and sandy intercalations and lenses. Most of the fraction (0.1 mm = 65-80 %) contains glauconite to 90 %; quartz 10-20 %; coarser material contains dark-brown collophane fragments of inarticulate brachiopods and pebbles, pyrite, conodonts *Acodus deltatus*, *Drepanodus arcuatus*, *Paroistodus* cf. *proteus* et al.

Varangu and Pakerort stages. Türisalu Formation (= "Dictyonema Shales")
1.9-2.8 m - Dark-brown kerogenous argillite, in the upper part with concretions of dolomitized anthraconite. Not far to the east, in the upper part of the formation *Clonograptus* sp. and *C.* cf. *sarmentosus* were found (Kaljo, Kivimägi, 1976).

Kallavere Formation (= "Obolus Sandstone")
1.0+ m - Light-grained quartziferous silty sand and sandstone with phosphate skeletal debris of articulate brachiopods.

S. Mägi

LOCALITY 4:3 PORKUNI QUARRY

In an abandoned quarry located on the western slope of the river valley by the Tamsalu-Kullenga road 1 km west of Lake Porkuni various skeletal and reef limestones of the Ärina Formation of the Porkuni Stage are exposed.

The outcrop serves as a stratotype of the Porkuni Stage - the uppermost regional stage in the East Baltic Ordovician. It was well known to E. Eichwald (1854) and F. Schmidt (1858) already and the section was described in detail by A. Wahl (1923). In the course of years a very rich assemblage of fossils has been established here including more than 150 species, among them at least 45 holotypes.

In the Ärina Formation five members are distinguished, the four lower members - Röa, Vohilaid, Siuge, Tõrevere being exposed in the Porkuni quarry (see Fig. 39). The Röa Member is sometimes attributed to the underlying Pirgu Stage.

In the middle of the western quarry wall there are exposed (from top):

Tõrevere Member

1.0-1.0 (1.0+ m) - Light-grey indistinctly wave-bedded to massive coral - stromatoporoid limestone with microcrystalline matrix (skeletal wackestone). The rock is partly silicified, contains abundantly stromatoporoids, tabulate and rugose corals. Particularly typical are *Clathrodictyon gregale* Nestor, *Ecclimadictyon porkuni* Nestor, *Eocatenipora parallela* (Schmidt), *Mesofavosites nikitini* Sokolov, *Rhabdotetradium frutex* Klaam., *Holacanthia tubula* (Dybowski), *Lichenalia* cf. *concentrica* Hall, *Schmidtomena acuteplicata* (Öpik), *Rafinesquina luna* (Lindström). The lower boundary of the layer is represented by an indistinct hardground.

Siuge Member

2.1.0-2.6 (1.6 m) - Yellowish lenticular-nodular, in places slightly argillaceous fine-grained skeletal packstone with thin wavy intercalations of dolomitic marlstone. The rock contains small kerogen admixture. The layer has evidently yielded a great part of the ostracodes, gastropods and trilobites described from the outcrop. P. Männik has re-

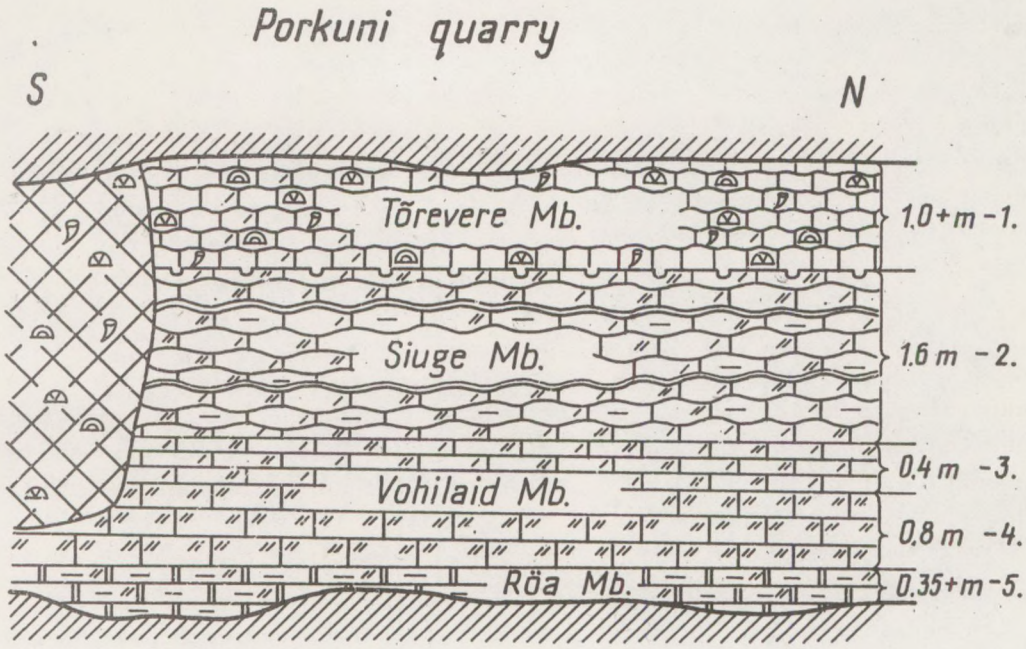


Fig. 39. Schematic cross-section of the Porkuni quarry exposing the Ärina Formation of the Porkuni Stage. For legend see Fig. 3.

cently identified the conodonts *Ozarkodina* cf. *pseudofissilis* (Lindström), *Birksfeldia* cf. *circumplicata* Orchard, *Decoriconus* cf. *costulatus* and L. Hints has recorded the brachiopods *Barbarorthis porkuniensis* Oraspõld, *Platystrophia* cf. *humilis* Oraspõld, *Schmidtomena acuteplicata* (Öpik), *Streptis undifera* (Schmidt). From this layer come also dendroid graptolites *Callograptus kaljoi* Obut et Rytzk, *Mastigograptus crinitus* O. et R., *Dictyonema delicatulum* Lapworth.

3. 2.6-3.0 (0.4 m) - Yellowish-grey horizontal-bedded fine-grained skeletal packstone with fragments of pelmatozoans, brachiopods, bryozoans and algae. It serves as a passage bed between the Siuge and Vohilaid members, in the rock texture resembling the first member, in the structure - the latter.

Vohilaid Member

4. 3.0-3.8 (0.8 m) - Light-grey thick-bedded to massive skeletal grainstone, mostly composed of the fragments of pelmatozoans, bryozoans and brachiopods: *Platystrophia* cf. *saxbyensis* (Oraspõld), *Ilmarinia ponderosa* Öpik, *Vellamo silurica* (Öpik), *Ptychopleurella* cf. *pirguensis* (Rõõmusoks), *Ptilodictya flabellata* Eichwald, *Lioclemella clava* Bassler. Rather often are also corals: *Mesofavosites dualis* Sokolov, *Priscosolenia prisca* (Sok.), *Palaeoporites estonicus* Kiaer, *Palaeophyllum fasciculum* (Kutorga).

Röa Member

5. 3.8-4.15 (0.35+ m) - Light-grey massive fine-porous argillaceous dolomite with partly preserved crinoid columnals. *Mjoesina pseudoalternata* (Schmidt), *Thaerodonte nubila* Rõõmusoks, *Elsaella bekkeri* (Rosenstein), *Chasmops eichwaldi* (Schmidt), *Pseudoonetodus* cf. *mirabilis*, have been identified connecting the Röa Member with the Pirgu Stage.

In the southern wall of the quarry a bioherm is exposed, beginning at the level of the Vohilaid Member (bed 4) and extending through the Siuge and Tõrevere members up to the top of the section. The thickness of the bioherm is over 3 m, the visible horizontal section exceeds 6 m. The frame is composed of corals, stromatoporoids, bryozoans. The basal part of the bioherm exposes the big overturned corallum of the holotype of tabulate *Mesofavosites dualis*.

In the quarry the uppermost Ordovician beds of the outcrop area are exposed. Judging by the nearby Vistla boring, the estimated distance from the outcrop top to the Ordovician/Silurian boundary, makes about 2 m.

Lithologically the Ärina Formation of the Porkuni Stage differs considerably from the underlying Ordovician stages, represented by open-shelf nodular packstones and wackestones of quiet-water genesis. The appearance of skeletal crinoidal grainstone of the Vohilaid Member marks abrupt lowering of the sea level, in the result of which the stratotype area fell into the agitated-water environment. In this shoal belt in places coral-stromatoporoid bioherms were formed. In quiet-water hollows remaining between the bioherms there accumulated kerogenous muds of the Siuge Member containing skeletal sand and coral-rich micritic sediments of the Tõrevere Member. According to present views the deposition of the Ärina Formation was followed by a short subaeral break in sedimentation corresponding to the deposition of the Salduse Formation, in the axial part of the basin. Thus the sequence of the Porkuni Stage gives evidence of an extensive two-stage regression well related to the global glacio-eustatic lowering of sea level at the end of the Ordovician in the Hirnantian time.

H. Nestor

LOCALITY 4:4 KARINU QUARRY

A large quarry (500x500 m) of the Rakke Lime Plant situated in Central Estonia, 4 km north-east of Järva-Jaani settlement exposes in the lower part coquinite rudstones of *Borealis borealis* (Tammiku Member), in the upper part stromatoporoid framestones and pelletal grainstones (Karinu Member) of the Tamsalu Formation constituting upper part of the Juuru Stage (lower Llandovery).

The quarry is considered as the stratotype of the Karinu Member and as the neostratotype of the Tammiku Member. The rock is quarried in two steps: the upper exposes about 3 m, the lower - 4.5 m of the section. The best studied exposure is in the middle part of the western quarry wall.

In the descending order the section is as follows (Fig. 40):

Tamsalu Formation, Karinu Member

1.3. 0-0.9 (0.9+ m) - Light, yellowish-grey, slightly dolomitic fine-grained pelletal grainstone comprises rounded pebbles of stromatoporoids, tabulates and heliolitids as well as scattered skeletal fragments of brachiopods, bryozoans and pelmatozoans. Fossils identified from the described interval are shown in Fig. 40.

In the northern part of the quarry wall a series of hardgrounds occurs in the middle of the interval (bed 2). They separate thin intercalating layers of yellow aphanitic limestone and multicoloured bio- and lithoclastic rudstone. The hardgrounds are coated with purple or yellowish goethite crust. Southwards the interlayer with hardgrounds (maximum thickness 30 cm) thins rapidly out and is replaced by a single hardground.

4. 0.9-1.2 (0.3-0.4 m) - Biostromal bank of stromatoporoids consisted of densely packed irregular nodular coenostea, for the most part buried in situ. Rounded and rolled coenostea occur as well. The matrix consists of greenish-grey dolomitic, argillaceous marl, in the upper part - of light pelletal rock. An uneven erosional hardground dissects the uppermost coenostea of stromatoporoids and acts as the upper surface of the stromatoporoid bank. *Clathrodictyon boreale* Riab., *C. kudriavzevi* Riab., *Ecclimadictyon microvesiculosum* (Riab.) and some heliolitoids are the most common frame-builders of the biostrome.

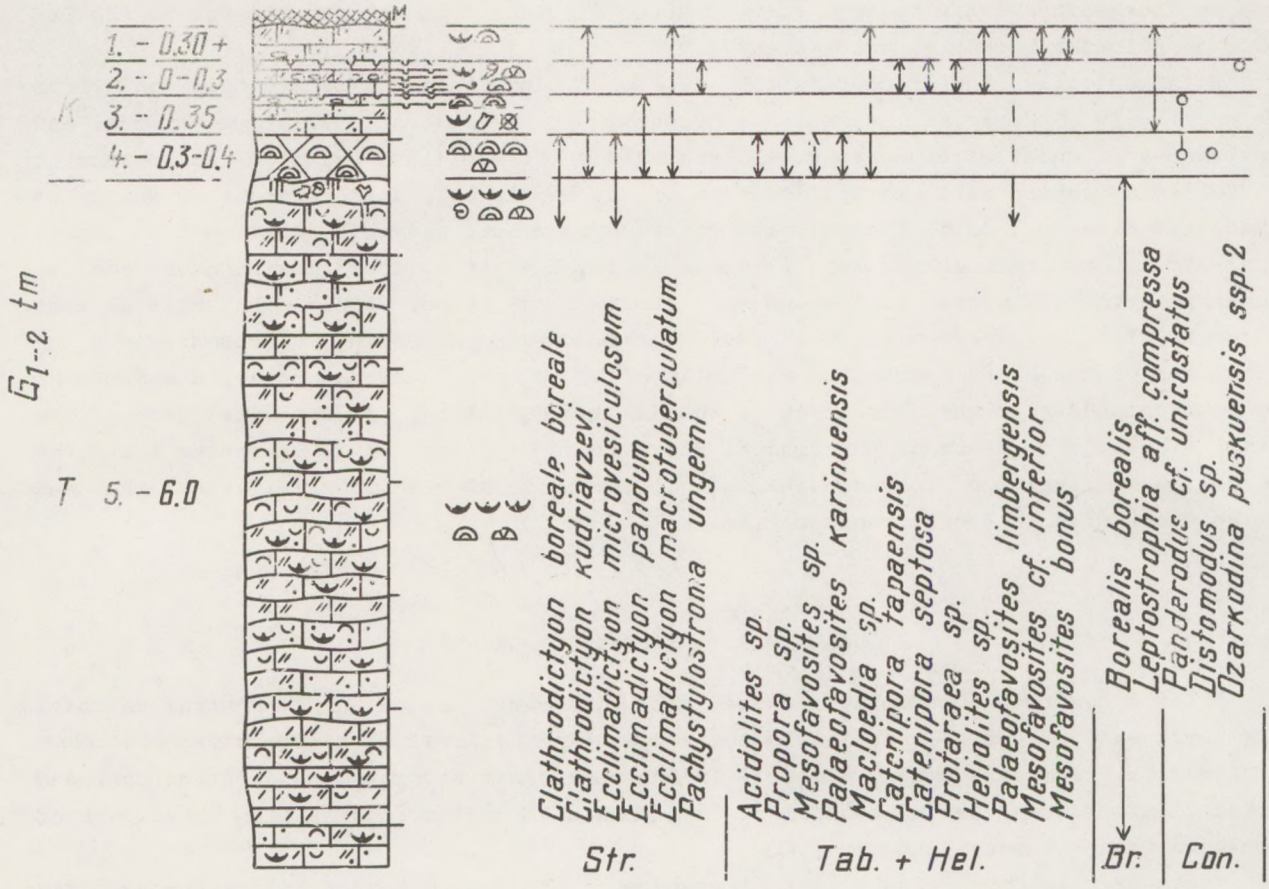


Fig. 40. Lithological log and distribution of fossils in the section of the Karinu quarry. T - Tammiku Member; K - Karinu Member. For legend see Fig. 3.

Tamsalu Formation, Tammiku Member

5. 1.2-7.2 (6.0+ m) - White, massive coquinoid rudstone, composed of the whole and fragmental valves of the brachiopod *Borealis borealis*, forming the famous Borealis-bank. The matrix contains pellets and rounded skeletal particles in sparry calcite. Scattered white skeletons of stromatoporoids and tabulates occur. Broad-wavy stylolitic surfaces covered with greenish marl partings, repeated after 10-20 cm, cause a wavy- lenticular internal structure of the bank. The upper surface of the Borealis-bank is very uneven erosional surface with purple-reddish goethite impregnation.

The deposits of the Tamsalu Formation, exposed in their most typical form in the present outcrop, have been accumulated during the first remarkable Silurian shallowing in the Baltic basin. They have been deposited in a shallow-water high-energy environment and thus represent typical facies of the shoal belt. The Borealis-bank is a unique fossil coquina bank reaching maximum thickness up to 13 m and spreading over the distance of more than 200 km. It has attracted attention of the geologists of many generations.

H. Nestor

FIFTH DAY

Localities of eastern Saaremaa and Muhu Island will be studied. Also the ancient Koguva village on Muhu Island and the famous Kaali meteorite craters in the central part of Saaremaa will be visited.

LOCALITY 5:1 KOGUVA QUARRY

A new quarry on the north-western coast of Muhu Island, 2 km northeast of the Koguva village exposes a contact of the Wenlock Jaani and Jaagarahu stages represented by domerites of the Paramaja Member and reef and flaggy dolomites of the Kesselaid Member correspondingly.

The lowermost strata crop out at the north-eastern end of the quarry (Fig. 41, point 1) showing the contact between the Paramaja argillaceous domerites and the Kesselaid mud-mounds and surrounding rocks. The south-eastern quarry wall exposes the upper contact of the mud-mounds and above-lying flaggy dolomites (Fig. 41, point 2).

At point 1 dark-grey massive argillaceous domerites (1) crop out at the bottom of the quarry (Fig. 41B). They contain *Encrinurus punctatus* (Wahlenberg), *Calymene* sp. indet., *Leptostrophia filosa* (Sowerby), *Atrypa reticularis* (L.), *Leptaena* sp. and chitinozoans *Conochitina claviformis* Eisenack, *Margachitina margaritana* (Eis.), *Ancyrochitina* sp.sp. The upper surface of the domerite is wavy, dipping down below the mud-mounds of the Kesselaid Member and rising in between (amplitude is up to 1.7 m). The uneven surface has an intense pyrite-limonite impregnation and is probably erosional marking the boundary between the Jaani and Jaagarahu stages.

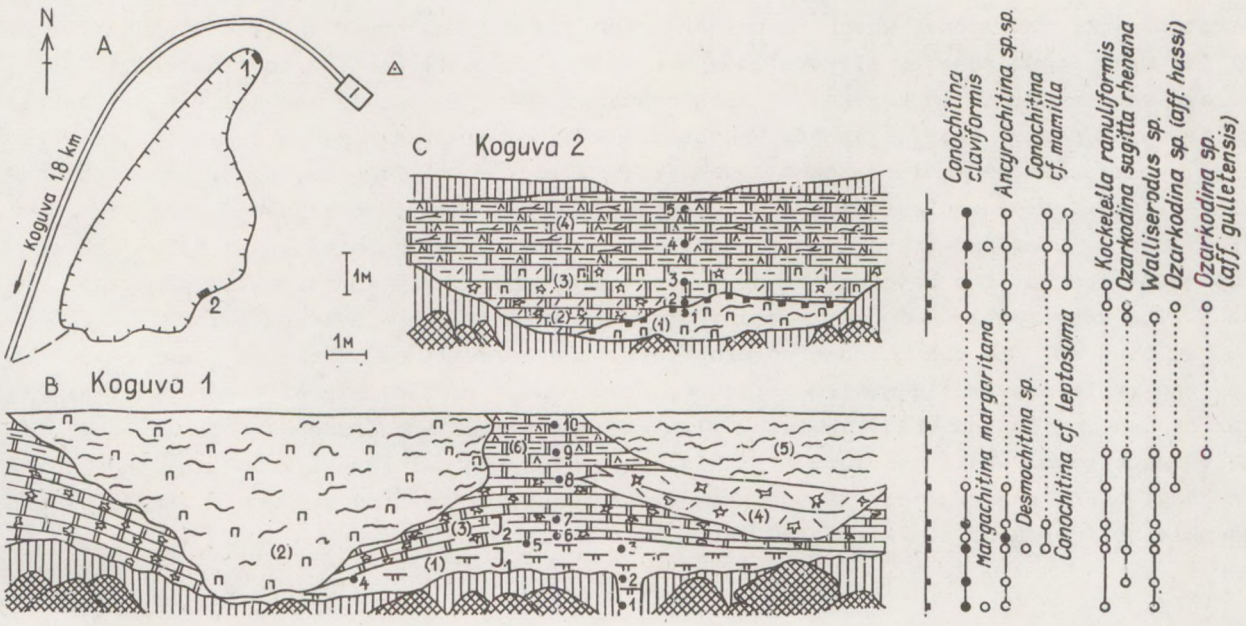


Fig. 41. Location of the Koguva quarry (A) at the points 1 (B) and 2 (C). Numbers in brackets indicate lithological units described in the text.

In the middle of the north-eastern wall of the quarry the best exposed mud-mound (2) makes its beginning straight from the upper surface of the Paramaja domerites and expands upwards (visible dimension are 4.7x11 m). It consists of dark-grey pyrite-mottled massive fine- to microcrystalline dolomite (epigenetically dolomitized aphanitic limestone). The mound lacks visible skeletal framework of fossils, only *Encrinurus* sp. indet. has been established. The mound rock contains thin discontinuous curved partings of domerite.

Surrounding rock for the lower part of the mud-mounds (3) is medium-porous coarse-crystalline dolomite - probably epigenetically dolomitized pelmatozoan grainstone. Upwards and farther from the mounds the rock becomes more fine-grained and seemingly grades from the dolomitized grainstone into packstone. *Leptaena* ? sp., *Conochitina claviformis* Eisenack, *C.* cf. *mamilla* Laufeld, *Ancyrochitina* sp., *Desmochitina* sp. have been identified from this bed.

At the same level with the stratifies surrounding rocks a lenticular body of comparatively massive porous dolomites (4) can be examined. Its relict texture confirms that originally it consisted of fine-dendroid fossils (? *Coenites*) in the lower part and of shells (? brachiopods) in the upper part, while the adjoining stratified rock (3) originally consisted mostly of the fragments of pelmatozoans. The contact between those rock types is rather sharp, therefore it is possible that the lenticular massive body represents filling sediments of an intermound erosional canal.

Above the described lenticule a peripheral section of a mud-mound (5) crops out with numerous curved partings of domerite marking irregular stratification of mound rock in its periphery. In the upper part of the section the intermound rock (6) is represented by flaggy, slightly kerogenous argillaceous dolomite.

At point 2 (south-eastern quarry wall) topmost part of a mud-mound and above-lying flaggy dolomites can be observed (Fig. 41). In the ascending order there are exposed: (1) 1.2 m - Dark-grey pyrite-mottled massive fine-grained dolomite of the upper part of a mud-mound. The upper surface of the mound has very intense pyrite impregnation and may be erosional. *Conochitina claviformis* Eisenack and *Ancyrochitina* sp. have been identified. (2) 0.2-0.7 m - Grey dolomite with relict fine-grained texture (dolomitized packstone or grainstone) which occurs only on the sloping upper surface of the mound. (3) 0.8 m - Brownish-grey flaggy fine-crystalline slightly argillaceous dolomite (dolomitized wackestone or packstone), which contains specific tubular stylolitic structures in the upper part. *Encrinurus* aff. *punctatus* (Wahlenberg), *Atrypa reticularis* (L.), rugosae, gastropods and chitinozoans *Conochitina claviformis* Eisenack, *C.* cf. *mamilla* Laufeld, *C.* cf. *leptosoma* Laufeld and *Ancyrochitina* sp. have been recorded from the bed. (4) 2.30 m - Brownish-grey flaggy argillaceous dolomite with partings of brown kerogenous domerite on the bedding planes, containing abundantly problematic plant (?) remains. The same species of chitinozoans occur as in the lower-laying strata.

Summing up, in the present outcrop there can be examined in the regressive succession the replacement of domerites of the transitional facies belt with the peculiar facies of mud-mounds and this, in turn, with the kerogenous argillaceous dolomites of probably restricted shelf genesis. In this succession typical deposits of the open shelf are lacking and their place is occupied by the deposits of the mud-mound facies, which resemble sediments of semi-isolated patch-reef environments.

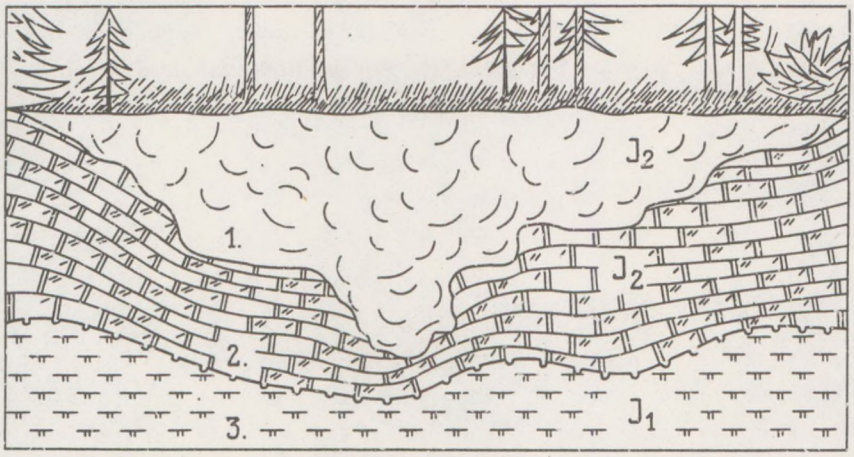
H. Nestor

LOCALITY 5:2 PULLI CLIFF

Pulli (=Oiu) cliff is located in the north-eastern corner of Saaremaa Island, about 10 km north-west of the Orissaare settlement. The boundary between the Jaani and Jaagarahu stages, i.e. the same stratigraphic level as in the Koguva quarry (5:1), is exposed here. The Jaani Stage is represented by domerites of the Paramaja Member, the Jaagarahu Stage - by stratified cavernous and massive reef dolomites of the Kesselaid Member of the Vilsandi Beds.

The outcrop was first described by Fr. Schmidt (1858) as Ojo cliff. A reference was made by A. Luha (1930). More detailed stratigraphic subdivision of the Jaani and Jaagarahu stages was proposed by A. Aaloe (1960), who distinguished the Paramaja and Kesselaid members, placing the latter in the lower - Oiu Substage of the Jaagarahu Stage. Later the name "Oiu Substage" was not used and the lowermost cycle of the Jaagarahu Stage was called the Vilsandi Beds (Aaloe et al., 1976).

The Pulli section reveals a distinct strongly wavy contact between the Kesselaid dolomites and Paramaja domerites, caused by bending of strata under the weight of mud-mounds (Fig. 42). Due to this, the thickness of beds is variable.



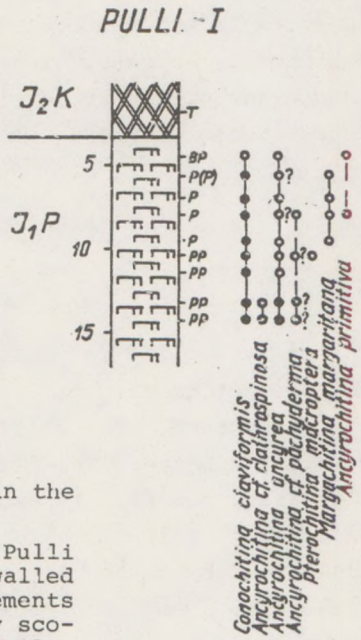


Fig. 42. Schematic cross-section through a mud-mound exposed in the Pulli cliff. For legend see Fig. 3.

Fig. 43. Distribution of chitinozoans in the core-section of Pulli I. J_1P - Paramaja Member; J_2K - Kesselaid Member. Organic-walled microfossil association in the samples: P, PP - planctic elements (mainly chitinozoans) prevailing; B - benthic elements (mainly scolecodonts); T - samples containing no organic-walled microfossils. Open circle - species occurrence, closed circle - species dominance.

Jaagarahu Stage, Kesselaid Member

1. In the upper part of the section (thickness up to 2 m) upwards expanding mud-mounds strike the eye, consisting of grey fine- to microcrystalline fine cavernous dolomite with irregular structure and uneven fracture surface. They contain small irregular pockets of greenish argillaceous domerite and brownish-grey dolomite.
2. Mud-mounds are underlain and laterally replaced by bluish- to greenish-grey medium-bedded fine crystalline cavernous dolomite (thickness about one metre) with relict texture of coarse-grained skeletal grainstone and thin discontinuous argillaceous partings. The caverns were formed by dissolution of calcitic skeletons of brachiopods, rugosae, pelamatozoans and bryozoans (Coenites?). Chitinozoans *Conochitina clavíformis* Eisenack, *Ancyrochitina primitiva* Eis. and *A.* cf. *pachyderma* Laufeld have been recorded from these dolomites. At the base of the Kesselaid dolomites there is an intensely impregnated limonitic discontinuity surface.

Jaani Stage. Paramaja Member

3. Lower part of the section (1.05+ m) is represented by bluish-grey, in weathered state yellowish argillaceous dolomite and dolomitic domerite with scarce pyritized fossil fragments (mostly brachiopods and trilobites), pyrite concretions and burrows. V. Viira has identified conodonts *Kockelella ranuliformis* Walliser, *Ozarkodina* cf. *excavata* (Branson et Mehl), *O. confluens* (Branson et Mehl), *Pseudoonetoides bicornis* Drygant and *Panderodus* sp. from the very top of the bed. Chitinozoans *Conochitina claviformis* Eis., *C.* cf. *mamilla* Laufeld, *Margachitina margaritana* (Eis.), *Desmochitina* cf. *acollaris* Eis., as well as trilobites *Encrinurus punctatus* (Wahl) and *Calymene blumenbachii* Brongn. have been recorded.

In order to link the outcrop with the general stratigraphic sequence two boreholes were drilled - one on the top of the cliff (Pulli I), the other at its base near the sea. Fig. 43 shows the lithological column and distribution of chitinozoans in the section of Pulli I.

The assemblage of chitinozoans in the upper part of the Paramaja Member indicates the *Conochitina tuba* Zone (see Nestor, 1984).

In general, the section of the Pulli cliff like several others located on the northern coast of Saaremaa and Muhu Islands, resembles those on the north-western coast of Gotland Island where very similar abrupt contact of Visby marls with Högklint reef limestones is exposed. The similarity is only seeming as the Paramaja-Kesselaid (= Jaani-Jaagarahu) boundary level is stratigraphically younger than the Visby-Högklint boundary (see Nestor, 1984).

E. Jürgenson
V. Nestor

LOCALITY 5:3 PARAMAJA CLIFF

Paramaja cliff is located at the eastern end of the northern coast of Saaremaa Island, about 1 km west of Jaani church. Marlstones of the upper part of the Jaani Stage are exposed here. The cliff serves as a stratotype of the Jaani Stage, Jaani Formation and Paramaja Member. The cliff and the pebbly coast lying immediately east of it (so-called Jaani coast), is known as a rich fossil locality already since the middle of the 19th century. Trilobites were described from here by J. Nieszkowski (1857) from the fauna collected by A. Schrenk. Fr. Schmidt (1858) gave the first lithological description of the cliff (Paramägi-Pank) and list of fossils collected from Jaani coast. He includes the section into the "Untere Oesel'sche Gruppe" formation comprising the present Jaani and Jaagarahu stages. The name "Jaani" was first used by W. Twenhofel (1916) referring to units of the same extent (St. Johannis Formation). The stage in its present range was first treated by A. Luha (1930; Jaani-Mergel). The Jaani Formation which in the stratotype area covers the whole stage was established in 1987 (Resheniya, 1987). Its upper part, the Paramaja Member, was distinguished by A. Aaloe in 1960.

The exposed section (by E. Jürgenson): 0.0-0.70 m (0.7) - covering; 0.7-2.00 m (1.3) - bluish-grey (in weathered state buff-grey) calcitic marlstone with argillaceous marlstone interlayers, with scarce argillaceous limestone nodules (10-20 cm in diameter). Common fossils in marlstone are brachiopods, trilobites and corals. Skeletal fragments are often pyritized, also pyritized burrows occur.

Lithologic composition of rocks and common articulated brachiopods and trilobite carapaces refer to a quiet-water environment at the boundary of the open shelf and transition belts.

Marlstone contains a diverse and scattered fauna dominated by the following species: brachiopods (data by M. Rubel) - *Megastrophia (Protomegastrophia) semiglobosa* (Da-

vidson). *Atrypa reticularis* (Linnaeus), *Dalejina hybrida* (J. de C. Sowerby), *Estonirhynchia estonica* H. Schmidt, *Strophonella euglypha* (Dalman), *Dolerorthis rustica* (J. de C. Sowerby); trilobites - *Encrinurus punctatus* (Wahlenberg), *Calymene blumenbachii* Brongniart, *Proetus concinnus osiliensis* Schmidt.(the cliff is the type locality of the *E. punctatus* trilobite Community, Männil, 1982); rugose corals (by D. Kaljo) - *Rhegmaphyllum elitense* Wedekind, *Neocystiphyllum keyserlingi* (Dybowski), *Phaulactis trochiformis* (M'Coy); tabulate corals and heliolitids - *Thecia podolica* Sokolov, *Favosites gothlandicus* Lamark, *F. desolatus* Klaamann, *Heliolites decipiens* M'Coy (type locality of the *F. gothlandicus* tabulate community, Klaamann, 1986); ostracodes (by L. Sarv) - *Craspedobolbina mucronulata* Martinson, *Beyrichia suurikuensis* Sarv and *Silenis subtriangulatus* Neckaja; gastropods (by M. Isakar) - *Platyceras (Platyostoma) cornutum* (Hisinger), *Poleumita discors* (Sowerby), *P. sculptum* (Sowerby) and *Praecordium striatum* (Sowerby); conodonts (by V. Viira) - *Kockelella* cf. *ranuliformis* (Walliser), *Ozarkodina excavata* (Branson & Mehl), *Pseudooneotodus bicornis* Drygant, *P. beckmanni* (Bischoff & Sannemann); chitinozoans - *Conochitina* cf. *claviformis* Eisenack, *Conochitina* cf. *tuba* Eisenack and *Desmochitina acollaris* Eisenack (Nestor, 1984).

V. Nestor has distinguished four chitinozoan zones in the Jaani Stage. The assemblage of microfossils of the Paramaja section shows that the corresponding beds belong to the upper, *Conochitina tuba* Zone and are correlated with the Högklint "C" Beds on Gotland (Nestor, 1984; herein).

Reet Männil

LOCALITY 5:4 TAGAVERE QUARRY

The Tagavere quarry is located in the eastern part of Saaremaa, about 10 km south of Jaani church. Here dolomite plates are produced, widely used as facing material e.g. for the building of National Library, Culture Centre "Sakala", etc. in Tallinn. The quarry serves as a stratotype of the Tagavere Beds forming the uppermost part of the Jaagarahu Stage.

The name "Tagavere" was originally suggested by A. Aaloe (1960) for the upper substage of the Jaagarahu Stage, containing Pangamäe and Maasi members. Later (Aaloe et al. 1976) the name "Tagavere Beds" was restricted to the uppermost (third) cycle of the Jaagarahu Formation, represented by nodular bioturbated and dolomitized skeletal limestones (bottom) and primary dolostones.

Description of the section (Fig. 44) is given in descending order, two upper beds are exposed only at the southern corner of the quarry.

1. 0.15 m Microcrystalline thick-bedded hard dolostone.
2. 0.15-0.35 m (0.2)- Argillaceous dolostone containing two 1-2 cm thin argillaceous

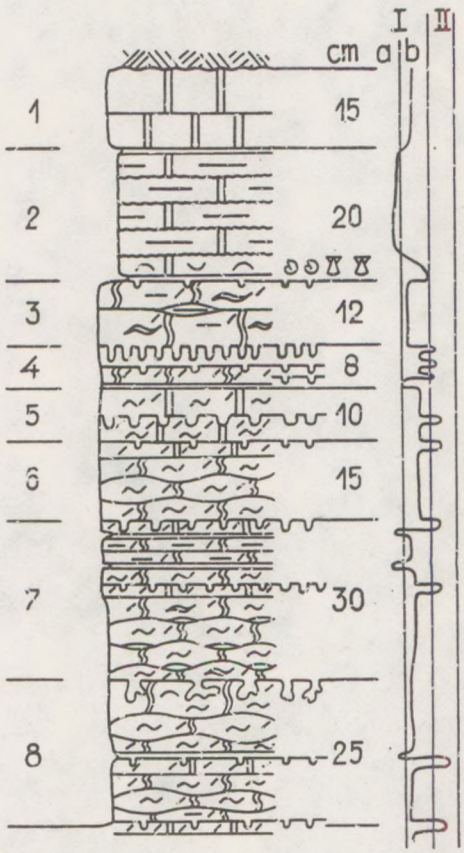


Fig. 44. Lithological log and facies curve of the Tagavere quarry. For legend see Fig. 3.

domerite interlayers at the top and at the bottom of the bed. Numerous gastropods (*Murchisonia*), pelecypodes and *Eurypterus* fragments occur on the hardground at the base.

3 0.35-0.47 m (0.12)-Bioturbated argillaceous dolostone with fine-grained skeletal debris, containing domerite lenses and vertical burrows. Distinct pyritized hardground at the base is a good marker level.

4. 0.47-0.55 m (0.08)-Bioturbated dolostone with skeletal debris, containing 3 distinct hardgrounds with underlying thin interlayers of dolomitized skeletal grainstones.

5. 8.0.55-1.35 m (0.80)-Bioturbated argillaceous dolostone with fine-grained skeletal debris, containing pyritized hardgrounds with underlying thin interlayers (1-3 cm) of dolomitized skeletal grainstones. Several flat or wavy interlayers and lenses of bioclastic domerite occur.

Thus in this quarry mostly secondary dolostones of the lower part of the Tagavere Beds are exposed, formed in the restricted shelf environment but also primary lagoonal dolostones of the upper part of these beds are represented (layers 1-2).

The outcrop is poor in micro- and macrofauna. The lower layers have yielded the gastropod *Murchisonia* cf. *M. cingulata* Hisinger, brachiopod *Howellella* sp. and nautiloids.

Acid-resistant microfossils are represented by acritarchs and scolecodonts. Chitinozoans were recorded from the lower, 80 cm thick interval of the section containing *Ancyrochitina primitiva* Eisenack and *A.* cf. *pachyderma* Laufeld. As the latter species disappear already in the *C. lagena* Zone which corresponds to the Jamaja Formation in the southernmost sections of Estonia (Ohesaare, Kihnu, Ruhnu), the Tagavere Beds of the Stratotype area seem to correspond stratigraphically (at least partly) also to the Jämaja Formation.

V. Nestor, R. Einasto

SIXTH DAY

Wenlock and Ludlow of north and west Saaremaa will be studied

LOCALITY 6: PANGA CLIFF

The Panga cliff is the highest (19.8 m) and the most prominent landform on the northern coast of Saaremaa Island near Mustjala village ranging arch-shapedly about 3 km from north to south along the seashore. As a wonderful sight and an important object for scientific studies, the Panga cliff (also called the Mustjala cliff) has been taken under state protection. In all cliffs of the northern coast rocks of nearly the same age are exposed - often dolomitized Wenlock carbonate rocks. The lower, more terrigenous part belong to the Jaani Stage and the upper reef carbonates belong to the Jaagarahu Stage.

The first escarpment on the seashore is composed of argillaceous dolomites of the Jaani Stage. Unfortunately the upper part of the cliff is very difficult to reach. On a smaller escarpment remaing inland of the main section, there are exposed cavernous dolomites of the Vilsandi Beds of the Jaagarahu Stage containing single bioherms. In the sea there is a subwater escarpment marked by a surf zone. Its height does not exceed 10 m and it is composed of highly terrigenous dolomitized limestones.

The section given in the figure represent the eastern part of the cliff: from the same place also 11 subwater samples were taken (Fig. 45).

The section from base to top:

1. 10 m - underwater part of the cliff; according to the samples taken after each metre it consists of grey domerite containing unsorted skeletal debris and skeletal argillaceous dolostone nodules, lenses and interbeds; rock is bioturbated.
2. 0.6 m - grey unsorted skeletal argillaceous dolostone.
3. 1.0 m - bioturbated skeletal argillaceous dolostone containing 1-3 cm thick domerite interbeds.
4. 1.8 m - skeletal domerite containing up to 5 cm thick fine-grained skeletal argillaceous dolostone interbeds and nodules: denudation-marks at the top surface; beds 2-4 form a parvacyclite.
5. 1.9 m - a separate parvacyclite, the basal part (0.4 m) of which consists of unsorted skeletal argillaceous or fine-grained dolostone (grainstone) - it is the basal part of the Ninase Beds.

   The upper part is similar to bed 3 but contains 35 cm high small "bioherms" formed of encrusting tabulate corals.
6. 1.2 m - parvacyclite similar to bed 5; its basal part contains mostly crinoidal debris and domerite of the upper part bryozoan bioherms (1.3x1.2 m).
7. 2.0 m - separate parvacyclite that consists of several microcyclites with their basal parts being less argillaceous and comprising coquinoid biomorphous(?) or skeletal dolostone; the upper part consists of skeletal argillaceous dolostone with domerite interbeds.
8. 1.3 m - parvacyclite similar to bed 7; the top surface marks the boundary of Ninase and Paramaja Beds(?).
9. 0.4 m - bioturbated skeletal argillaceous dolostone.
10. 1.2 m - domerite with scarce skeletal debris; interbeds of skeletal argillaceous dolostone.
11. 2.3 m - grey thinbedded highly argillaceous dolostone containing scarce and fine skeletal debris;

    the boundary of the Jaani and Jaagarahu stages.
12. 1.5 m - thickbedded skeletal dolostone.

13. 1.0 m - slightly argillaceous dolostone with unevenly distributed skeletal debris.
14. 1.3 m - skeletal cavernous dolostone containing small bioherms.

The whole section was subjected to secondary dolomitization which at least partly complicates the paleontological studies. The most fossiliferous seems to be the Mustjala Member. In several outcrops and core sections in the upper part of the member there is a distinct interlayer containing abundantly tabulate and stromatoporoid colonies. From this part the following tabulate corals were identified: *Thecia tenuicula*, *Syringolithes kunthianus*, *Catenipora quadrata*, *Halysites senior*, *Syringopora novella* (the holotype of the latter two species comes from this locality). The stromatoporoids *Densastroma paxisum*, *Simplexodictyon simplex* were also identified from this interlayer. Loose material has yielded *Clathrodictyon variolare*, *Clathrodictyon delicatulum* and *Oslodictyon suecicum*, which are supposed to be washed out from the Adavere Stage (H. Nestor, pers.comm., 1990). In the section M. Rubel has identified the following brachiopods: *Estonirhynchia estonica*, *Stegerhynchus borealis* *Atrypa reticularis*, *Dolerothis rustica*, *Microsphaeridiorhunchus nucula*, *Dalejina hybrida*, *Whitfieldella* sp., *Resserella* sp., *Leptaena* sp. These brachiopods are known from all members of the Jaani Stage. From the loose mate-

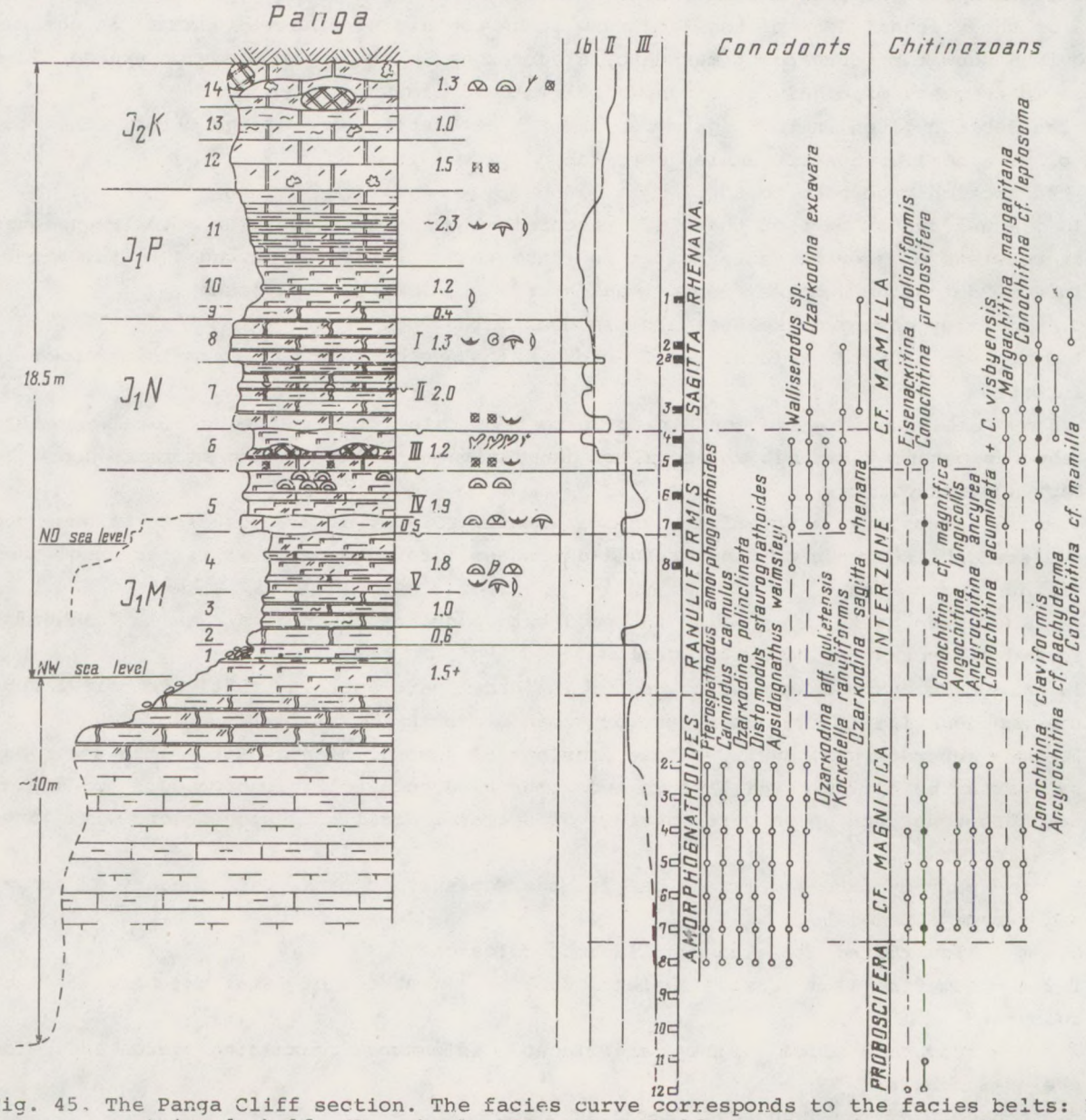


Fig. 45. The Panga Cliff section. The facies curve corresponds to the facies belts: Ia - restricted shelf, II - shoal, III - open shelf. For legend see Fig. 3. Microcyclites (marked I-V) are displayed right and conodont and chitinozoan distribution and biozones left of the column.

rial of the Ninase Member also trilobites *Calymene blumenbachii* and *Proetus concinnus osiliensis* have been recorded (Reet Männil, pers. comm. 1990).

Fig. 45 presents results of the conodont and chitinozoan studies provided by V. Viira and P. Männik and V. Nestor (pers. comm. 1990) correspondingly. The conodont zones established permit good correlation of the section with the Silurian standard. The chitinozoan zones, in turn, link the section to the regional stages. Thus the distinction of the *Conochitina proboscifera* zone in the lower part of the subwater escarpment confirms the assignment of the corresponding beds already to the Adavere Stage (V. Nestor, pers. comm., 1990).

In the Panga cliff, like in other cliffs at the northern coast of Saaremaa, we can see distinct lateral variability of beds, especially interesting is that of the Ninase Member.

M. Rubel, R. Einasto

LOCALITY 6:2 ABULA CLIFF

The Abula cliff is situated on the eastern coast of Tagalaht Bay, 3 km north of Mustjala-Veere road. The cliff exposes topmost lagoonal dolomitic marls of the Vilsandi Beds and the basal part of the Maasi Beds belonging to the Jaagarahu Stage. A. Luha (1934) referred to these rocks as to Kurevere Limestone.

The section from top to base (Fig. 46):

1. 0.4+ m - Skeletal wackestone, rich is stromatoporoids, with 0.1 m thick lenses of skeletal marl in the lower part; at the base - a district discontinuity surface, a boundary of a microcyclite.
2. 0.7 m - Light-grey wavy-bedded limestone with pelletal structure and several discontinuity surfaces in the upper 15-20 cm, stromatoporoids are common, in the middle of the bed brachiopod-shell accumulations occur.
3. 0.6 m - Light yellowish-grey fine-nodular pelletal limestone with stromatoporoids, tabulate corals (*Favosites mirandus* is the commonest, according to E. Klaamann), ostracodes and calcareous algae; the lower 0.1 m contains marl; the upper 0.2 m comprises irregularly nodular skeletal wackestone with 0.15 m thick and 1.5 m long skeletal grainstone lenses; large *Megalomus* - shells are found; the bad forms a separate microcyclite.
4. 0.10 - 0.15 - Grey fine-grained pelletal limestone - the upper part of a microcyclite.
5. 0.5 - Yellowish-grey fine-nodular pelletal and skeletal, slightly argillaceous limestone; brachiopods are common, while tabulate corals are rare; the basal 10-15 cm is more argillaceous; a discontinuity surface occurs at base - a boundary of a microcyclite.
6. 0.2 - Thin-bedded skeletal (ostracode-) packstone with 1-2 cm thick calcareous marl laminations.
7. 0.5 - Yellowish-grey wavy-bedded pelletal limestone containing large ostracodes and gastropods at the base a 3 cm thick ostracode grainstone layer with small oncolites.
8. 0.2 (exposed on the sea bottom) - Greenish-grey calcareous domerite with 1-2 cm lenses and laminations of fine-grained skeletal and pelletal packstone; large ostracodes and *Eurypterus* - fragments occur.

The last bed (= the top of the Vilsandi Beds) forming the first lagoonal complex in the Estonian Wenlock - is presumably of the same age as the *Pterygotus* - Marl in Gotland. Just below these lagoonal domerites a stromatoporoid limestone bed with *Vikingia tenue* occur, exposed north of Abula cliff.

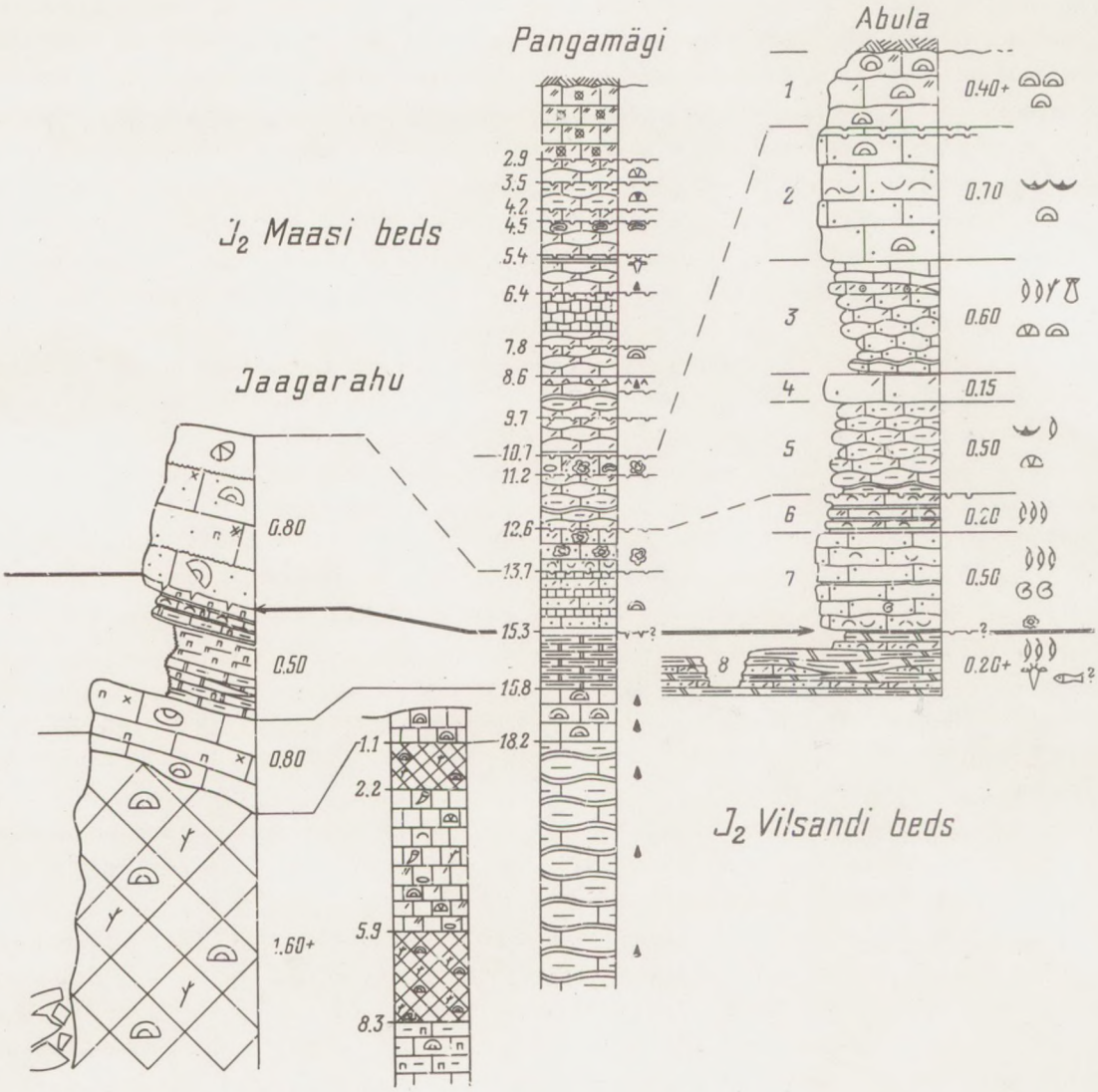


Fig. 46. The sections of Jaagarahu quarry, Abula cliff and Pangamägi core of boundary beds of the Vilsandi and Maasi Beds of the Jaagarahu Stage. For legend see Fig. 3.

The bottom part of the Maasi Beds exposed here containing oncolites forms a marker level distinguished everywhere in Saaremaa except Sõrve Peninsula.

The boundary of the Vilsandi and Maasi Beds is a very distinct event level in the Wenlock of Estonia; it is probably synchronous to the Högklint-Tofta boundary in Gotland. Therefore there have been suggestions to consider it as boundary of the Jaani and Jaagarahu stages.

R. Einasto

LOCALITY 6:3 JAAGARAHU QUARRIES

Jaagarahu old quarries are situated on the western coast of Saaremaa, 6 km northwest from the Kihelkonna settlement. In the 1930s limestone was quarried (about 300 tons per day) and exported mainly to Sweden, Finland, Poland and Germany. Now these over 3 m

deep quarries are filled with water but they still expose the lower part of the middle Wenlock Jaagarahu Stage - Vilsandi Beds, its reefs and the surrounding limestone rich in well-preserved algae, corals and stromatoporoids. In the southern corner of the quarry lagoonal domerites of the topmost Vilsandi Beds are exposed, as well as the basal part of the overlying Maasi Beds (Fig. 46). In this point the following section is described (from base):

1. 1.6+ m (mostly under the water only in the eastern part of the quarry partly above it) - Light-grey massive boundstone of shoal reef facies. The commonest fossils of the reef are *Vikingia tenue, Favosites mirandus, Solenepora filiformis, Wetheredella multiformis, Rothpletzella munthei.*
2. 0.8 m (0.4 m above the water) - Bluish-grey dolomitic skeletal argillaceous packstone of backreef origin. The rocks have fine pyritic pattern and contains calcite druses. Stromatoporoid and tabulate coral colonies are not in the living position bearing erosion marks.
3. 0.5 m - Greenish- or bluish-grey thinbedded argillaceous dolostone or domerite with little skeletal debris. Numerous big ostracodes *Leperditia* occur on some bedding planes. The upper surface of the bed shows mud cracks with abraded edges. It marks the boundary of the Vilsandi and Maasi beds.
4. 0.8+ m - Bluish-grey thickbedded or massive microcrystalline pelletal limestone with slight pyritic patterns. The rock contains abundant abraded stromatoporoids and dolomite pebbles from the underlying strata. The lower part of the bed is more argillaceous, contains ostracode debris and abundantly *Cladopora perrara* (identified by E. Klaamann). This kind of a basal bed of a cyclite is only locally spreaded, bordering a bioherm.

Elsewhere in Saaremaa (except Sõrve Peninsula) this basal part of the Maasi Beds consists of floatstones and skeletal limestones with discontinuity surfaces and oncolites. It corresponds to the Tofta Limestone of Gotland.

Accordingly, the Vilsandi Beds (bed 3 here) are of the same age as the Pterygotus-Marl of Gotland.

These boundary beds are exposed also at Abula cliff (6:2).

R. Einasto

LOCALITY 6:4 SEPISE

In a thin pine forest at the Kihelkonna-Tagamõisa road, 8 km north of Kihelkonna settlement a surface exposure of argillaceous coral limestones of the middle part of the Maasi Beds (Jaagarahu Stage) can be observed.

Well-preserved fossils of corals, stromatoporoids and brachiopods can be collected directly from the ground and in small ditches. Skeletons of corals and stromatoporoids are relatively small and very often overgrown with each other. A number of holotypes of tabulate and stromatoporoid species come from this outcrop (Klaamann, 1961, Nestor, 1966). Below they are marked by the abbreviation (H.T.) after the species name. The following more frequent and typical species have been recorded: stromatoporoids - *Ecclimadictyon astrolaxum* Nestor (H.T.), *Simplexodictyon validum* Nestor (H.T.), *Densastroma pexisum* (Yavorsky); tabulates - *Thecia confluens* (Eichwald), *Palaeofavosites collatatus* Klaamann (H.T.), *Aulopora enodis* Klaam. (H.T.), *Halysites junior* Klaam. (H.T.), *Coenites juniperinus* Eichwald (neotype); brachiopods. - *Stegerhynchus diodonta* (Dalm.), *Salopina conservatrix* (Mc Learn), *Atrypa reticularis* (L.), *Strophonella euglypha* (Dalm.) *Howellella cuneata Rubel;* conodonts - *Ozarkodina excavata excavata* (Brans. et Mehl), *O. confluens* (Brans. et Mehl), *Kockelella ranuliformis* Walliser.

The outcrop is considered as one type locality of the Halysites junior - *Palaeofavosites tersus* tabulate community (Klaamann, 1986). Tabulates and stromatoporoids enable to correlate the section with the Slite Beds of Gotland. E. Klaamann (1986) stressed the similarity with the Slite Unit at Stora Myre locality.

H. Nestor

LOCALITY 6:5 VIITA TRENCH

Wartime trenches are located 1.5 km south-west of Kihelkonna church near Lülle Bay.

The Viita quarry, a previously widely known locality of well-preserved eurypterids and osteostracans, and the stratotype of the Rootsiküla Stage and the Viita Beds was levelled during amelioration in the 1970s. At present the Viita trench is demonstrated, instead. Here the part of the section lying a little below the quarry section is exposed.

Section (Fig. 47) from base to top:

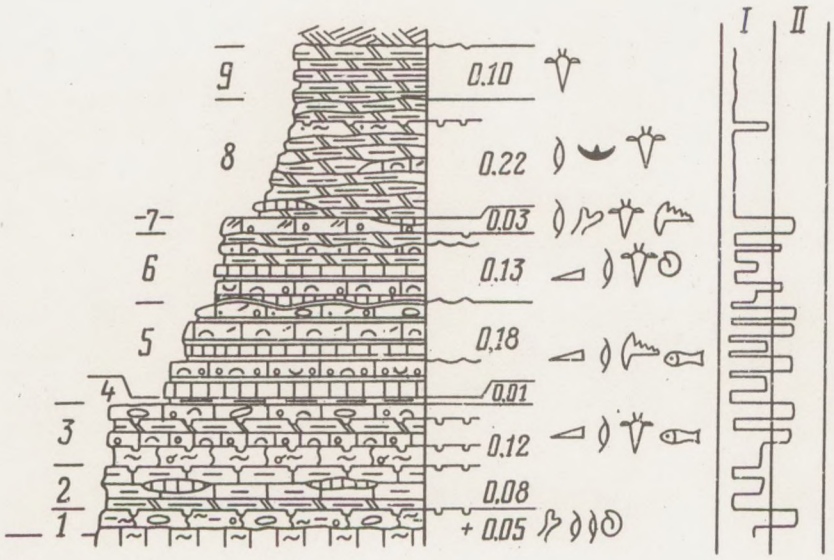


Fig. 47.
Viita section: the upper part of the Viita Member of the Rootsiküla Stage. The facies curve corresponds to the facies belts: I - lagoonal, II - shoal. For legend see Fig. 3.

1. 0.05+ m - Light-grey, cryptocrystalline thin-bedded partly bioturbated limestone, in the upper part with small flat pebbles of the underlying rock, psammite, pelletal material. Discontinuity surface at the upper boundary.
2. 0.08 m - Dark-grey, horizontal-bedded argillaceous limestone with lenses of pure aphanitic limestone. A distinct discontinuity surface occurs at the upper boundary.
3. 0.12 m - Thin interbedding of bioclastic pelletal tentaculite-limestone, containing flat limestone pebbles, with aphanitic limestone and *Eurypterus*-dolomite.

   Three distinct discontinuity surfaces mark the boundaries of cyclites, underlain by argillaceous wackestone and overlain by sparitic grainstone. The lower part of the layer is highly bioturbated.
4. 0.01 m - Argillaceous domerite interbed.
5. 0.18 m - Horizontal-thin-bedded aphanitic limestone, intercalated with argillaceous domerite and skeletal-bioclastic packstone containing small pebbles of aphanitic limestone. The upper surface of bioclastic limestone interbeds often bears ripple marks.
6. 0.13 m - Thin wavy interbedding of microcrystalline micritic limestone and *Eurypterus*-dolomite with lenticular ostracode- and tentaculite-limestone layers, the upper surface of which bears N-S oriented ripple marks.

7. 0.03 m - Dark-grey bioclastic, skeletal packstone with lenses of aphanitic limestone. Both boundaries are sharp, wavy.
8. 0.22 m - Wavy-laminated *Eurypterus*-dolomite with lenses of aphanitic limestone. Towards the base bed becomes more calcareous.
9. 0.10 m - Horizontal-laminated *Eurypterus*-dolomite.

The Viita Beds constitute shallow-water carbonate sediments, deposited in near-shore environment. Pebbles, oolites, mud cracks, discontinuity surfaces give evidence of shallow-water conditions.

The Viita trench section is rich in fossils: ostracodes, gastropods, brachiopods, bryozoans, tentaculites, conodonts, eurypterids and fishes. The strata contain the brachiopods *Howelella cuniculi*, *Janius barrandi* (Verneuil); ostracodes *Hermannina phaseola*, eurypterid *Baltoeurypterus remipes tetragonophthalmus*, tentaculitid *Styliolina*. Conodont fauna includes *Ozarkodina bohemica bohemica* (Walliser), *Ctenognathodus murchisoni* (Pander). The Viita quarry was the type locality of a number of osteostracan species. Dissolved limestone samples of the lower part of the trench section have yielded *Thelodus laevis* (Pander), *Loganellia martinssoni* (Gross), *Trematapsis schmidti* Rohon, *Tr. milleri* Patten, *Oeselaspis pustulata* Patten and some birkeniids.

T. Märss

LOCALITY 6:6 HIMMISTE QUARRY

Himmiste quarry is situated in western Saaremaa 3 km east of Karala village.

In a small peasant quarry the upper part of the Himmiste and the basal part of the Uduvere Beds of the Paadla Stage are exposed. The lower part of the section is the stratotype of the Himmiste Beds.

Section (Fig. 48) from base to top:

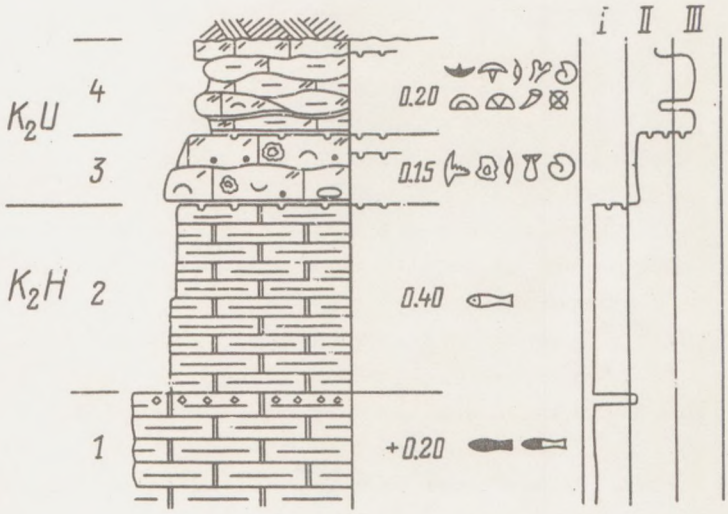


Fig. 48.
The Himmiste quarry section: the boundary beds of the Himmiste and Uduvere Beds of the Paadla Stage. The facies curve corresponds to the facies belts: I - lagoonal, II - shoal, III - open shelf. For legend see Fig. 3.

1. 0.2 m - Grey thick-bedded microlaminated argillaceous dolostone containing articulated fishes.
2. 0.4 m - Yellow-grey homogeneous microlaminated argillaceous dolostone, the top is marked by a discontinuity surface constituting the boundary of the Himmiste and Uduvere Beds.
3. 0.15 m - Buff-grey skeletal packstone or grainstone with pellets, skeletal psammite, pebbles and oncolites; a thin (1 cm) domerite intercalation occurs at the base and a sharp discontinuity surface at the top. This bed forms a transgressive basal part of mesocyclite.

4. 0.20+ m - Grey argillaceous nodular limestone with unsorted skeletal debris and some lenses of grainstone; a thin (0.5 cm) argillaceous intercalation occurs in the lower part.

Rocks of the Himmiste Beds belong to the shallow quiet-water lagoonal facies belt, those of the Uduvere Beds to the agitated water shoal and subturbulent open shelf belts.

The lowermost bed (1) in the Himmiste quarry is the famous vertebrate horizon discovered by A. Luha in 1929. This dolomite was quarried by W. Patten, USA, during four seasons. The result of this work was an enormous collection which contained several thousands of specimens including the articulated skeletons of the thelodont *Phlebolepis*. This bed has yielded *Thelodus laevis* (Pander), *T.carinatus* (Pander), *Loganellia martinssoni* Gross, *Phlebolepis elegans* Pander, *Trematapsis mammillata* Patten, *Tr. milleri* Patten, *Dartmuthia gemmifera* Patten, *Oeselaspis pustulata* Patten, *Witaaspis schrenkii* (Pander), *Procephalaspis oeselensis* (Robertson), Birkeniida sp.C and Birkeniida sp.D?, i.e. a rich assemblage consisting mainly of thelodonts and osteostracans. Bed 2 contains only scales of thelodonts.

The Uduvere Beds (3 and 4) exposed at this locality, contain the stromatoporoids *Lophiostroma schmidtii* (Nich.), *Simplexodictyon podolicum* (Yav.), *Densastroma himmestum* (Riab.), *Plectostroma intermedium* (Yav.), *Parallelostroma typicum*, together with the tabulate corals *Favosites forbesi* M.-Edw. et Haime, *Favosites similis* Sokolov, *Syringopora affabilis* Klaam., and molluscs *Modiolopsis* sp. The conodonts *Oulodus siluricus* (Branson et Mehl), *Ozarkodina confluens* (Branson et Mehl) and *Ozarkodina* sp. are recorded from a bed rich in ostracodes.

T. Märss, R. Einasto

LOCALITY 6:7 KOGULA QUARRY

The new Kogula quarry is situated 1 km south-west of the main Kogula crossroad. The middle part of the Sauvere Beds of the Paadla Stage is exposed.

The sequence is as follows (from base, m, Fig. 49):

1. 0.2+ - Brownish-grey kerogeneous and bioturbated argillaceous dolostone with lenses of domerite, discontinuity surface at the top.
2. 0.2 - Bioturbated slightly argillaceous (calcareous ?) dolostone. The upper part of the bed is more calcareous; *Hermannina*, *Didymothyris*, branching and massive tabulate corals occur.
3. 0.2-1.0 - Light-grey massive rudstone with small bioherms (height 1 m, width from some meters to 20 cm); the base of the bioherm consists of rounded tabulate corals and stromatoporoids.
4. 0.25 - Greenish-grey bioturbated packstone alternating with wavy dark-grey interbeds of fine-grained skeletal grainstone; from the base towards the top packstone beds become thinner and those of grainstone thicker.
5. 0.7 m - Greenish-grey bioturbated dolomitic argillaceous wackestone forming wavy beds; in the lower part two 1-2 cm interbeds of argillaceous domerite can be distinguished.
6. 0.5 m - Grey bioturbated unsorted packstone at the base and skeletal grainstone at the upper part of the beds a pyritic discontinuity surface occurs at the top.
7. 0.15 - Dark limestone, occurring between discontinuity surfaces, at the base - fine-grained skeletal grainstone, in the upper part - unsorted skeletal packstone.
8. 0.3 - Strongly bioturbated argillaceous wackestone resembling bed 5, marlstone interlayers on both surfaces.
9. 0.2 - Limestone like bed 7, with some pebbles, discontinuity surfaces occur.
10. 0.3 - Homogeneous fine-grained skeletal argillaceous packstone with abundant *Ilionia*, in the middle occur discontinuity surface and marl interbed.

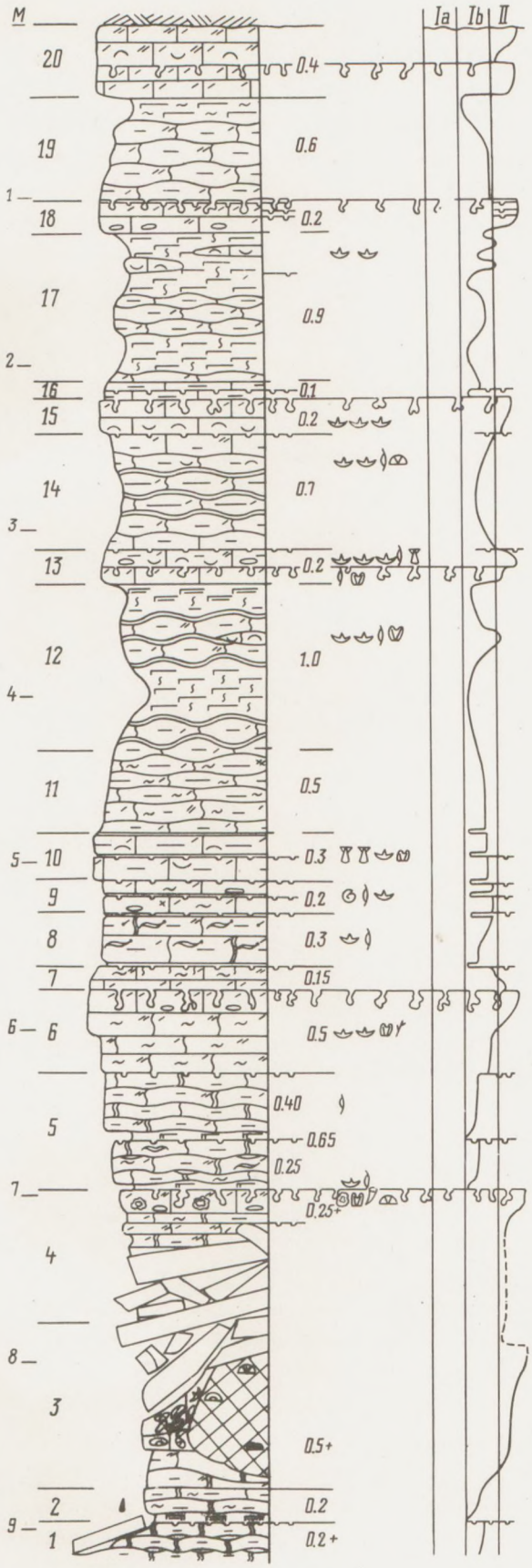


Fig. 49. The Kogula quarry section: middle part of the Sauvere Beds of the Paadla Stage. The facies curve corresponds to the facies belts: Ia - lagoonal, Ib - restricted shelf, II - shoal. For legend see Fig. 3.

11. 0.5 - Wavy-bedded to lenticular nodular bioturbated unsorted skeletal wackestone, higher becoming more argillaceous.
12. 1.0 - Lenticular nodular bioturbated argillaceous wackestone alternating with burrowed marlstone; the most argillaceous part in the section, in the upper part containing lenses of *Didymothyris*-Limestone.
13. 0.2 - Fine-grained skeletal grainstone at the base argillaceous *Didymothyris*-Limestone with pebbles in the upper part, strongly pyritized discontinuity surface occurs in the middle.
14. 0.7 - Resembles bed 12, the middle part is the most argillaceous, on the upper surface a discontinuity surface.
15. 0.2 - Grey limestone, at the base *Didymothyris*-Limestone, in the upper part purer limestone; a sharp discontinuity surface occurs on the upper boundary.
16. 0.1 - Argillaceous packstone with a discontinuity surface in the middle.
17. 1.9 - Like bed 12 with the maximum clay content.
18. 0.2 - At the base packstone with pebbles containing two discontinuity surfaces, in the upper part fine-grained skeletal grainstone. On the upper boundary a strongly pyritized double discontinuity surface.
19. 0.6 - Wavy-bedded bioturbated argillaceous wackestone and marl on the top.
20. 0.4 - Fine-grained skeletal grainstone of the base, unsorted skeletal packstone in the upper part and distinct discontinuity surface between them.

A cyclic succession of wacke- and grainstones (packstones) can be seen here. Distinct discontinuity surfaces with deep borrows mark boundaries of cyclites.

Palaeontologically this quarry is not well enough studied. Among most common fossils found in the old quarry situated 1 km northward (beds 5 to 11 are exposed) are: stromatoporoids *Araneosustroma stelliparratum, Stromatopora bekkeri, Parallelostroma typicum*; tabulate corals *Thècia swinderniana, Favosites kogulaensis, F. forbesi, F. subgothlandicus, Syringopora schmidti, Parastriatopora coreaniformis*; brachiopods *Didymothyris didyma, D. biohermica, Protochonetes striatellus, Salopina conservatrix, Morinorhynchus orbignyi*; molluscs *Ilionia prisca, Holopea ? undata, Murchisonia compressa*; fishes *Phlebolepis ornata, Thelodus* sp.; conodonts *Ozarkodina confluens, O. excavata excavata, Oulodus siluricus*, etc.

R. Einasto

Ludlow and Pridoli of Saarema will be studied

LOCALITY 7:1 KAARMA QUARRY

The Kaarma quarry is located 12 km north of Kuressaare town, by Uduvere-Saia road. In this quarry a bed of microbedded lagoonal argillaceous dolostones is exposed in the complete thickness (3.8 m). Kaarma dolostone may be well processed and is weather-resistant, therefore being widely used as building and sculpture stone.

Earlier the stratigraphical positi n of the bed has been interpreted differently - being attributed to the upper part of the Rootsiküla Stage (Bekker, 1925; Luha 1930) or to the Uduvere Beds of the Paadla Stage (Klaamann, 1970). According to the present views, Kaarma dolostone represents the upper part of a mesocyclite, tentatively attributed to the junction of the Sauvere and Himmiste Beds.

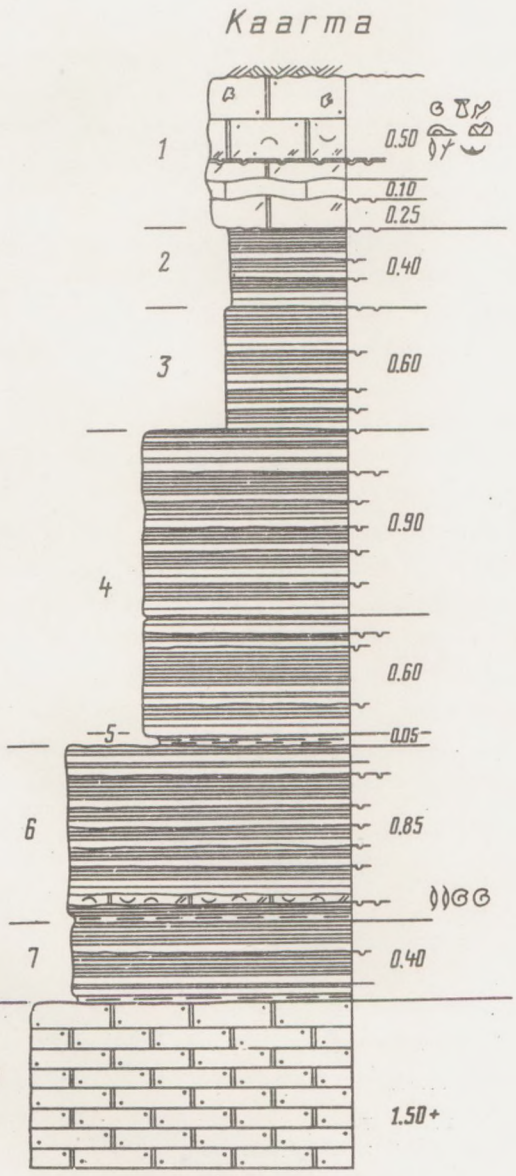


Fig. 50. The Kaarma quarry section: the boundary beds of Sauvere and Himmiste Beds of Paadla Stage. For legend see Fig. 3

The section from top (Fig. 50):

1. 0.85-1.0 m - Yellowish-grey cavernous massive secondary dolostone of variable texture, the basal layer of the mesocyclite mostly unsorted - skeletal to skeletal micktitic rock containing imprints of gastropods, pelecypods, large ostracodes (*Herrmannina*), bryozoans, calcareous algae (*Solenopora*), brachiopods, small tabulates and encrusted stromatoporoids.

In the south-eastern part of the quarry this bed is partly not dolomitized containing up to 0.15 m thick lenses and interrupted interbeds of skeletal grainstone, and several wavy discontinuity surfaces occur.

2,3,4,6,7 - Typical wavy microbedded argillaceous Kaarma dolostones with distinct irregular lamination and microcycles (Fig. 50) greatly resembling algal dolomite from Shark Bay (Davies, 1972).

5 - Argillaceous domerite interbed.

8 - Brownish-grey mediumbedded dolostone, originally pelletal limestone.

Generally the section is poor in fossils, only at some levels the lower parts of microcycles show moulds of gastropods, pelecypods, ostracodes.

R. Einasto

LOCALITY 7:2 KUDJAPE DITCH

The outcrop is located north-east of Kuressaare town, by the road leading to Kudjape cemetery.

The section of Kudjape ditch is the parastratotype of the Kuressaare Stage (its stratotype is the interval 1.5-13.4 m in Kingissepa boring). The upper part of the stage, i.e. lower half of the Kudjape Beds is exposed here.

The section (Fig. 51) from base to top:

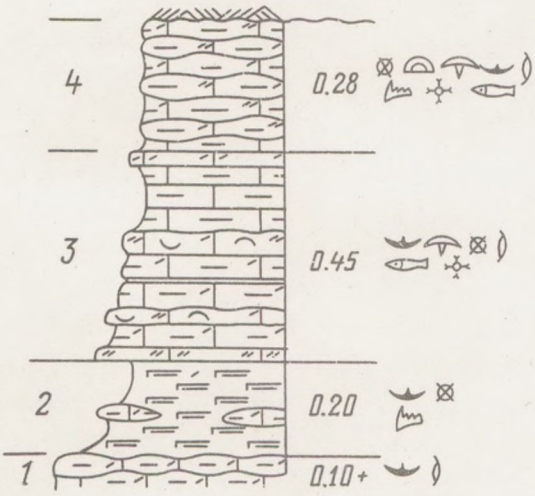


Fig. 51. The Kudjape trench section: the middle part of the Kudjape Beds of the Kuressaare Stage. For legend see Fig. 3.

1. 0.1+ m - Greenish-grey nodular skeletal argillaceous packstone with abundant coarse skeletal debris of crinoids and brachiopods.
2. 0.2 m - Greenish argillaceous marlstone with bioturbated argillaceous limestone nodules, contains scattered unsorted skeletal debris. Both boundaries are transitional.
3. 0.45 m - Wavy-bedded fine-grained skeletal argillaceous wackestone with frequent interbeds of fine-grained skeletal grainstone and coquinoid-skeletal packstone. Characteristic are burrows.
4. 0.28+ m - Greenish-grey fine-grained skeletal nodular argillaceous limestone with abundant fossils.

The skeletal limestones and marlstones exposed in Kudjape ditch belong mostly to the open shelf facies belt.

The fauna is dominated by brachiopods of which *Delthyris elevata* Dalm. is the commonest. Trilobites from this locality include *Calymene flabellata* Männil and *Proetus kuressaarensis* Männil, stromatoporoids - *Densastroma astroites* (Rosen). In the middle part of the section trace fossils (of *Diplocraterion* type?) are frequent. Crinoids, acritarchs and gastropods (*Loconema* sp.) also occur. Conodonts are dissolved from the argillaceous nodular limestone, and include *Ozarkodina eosteinhornensis* (Walliser), *Oulodus elegans* (Walliser), *Ozarkodina* aff. *snajdri* (Walliser) and *Ozarkodina confluens* (the latter dominate). In the marlstone there occur three first of them.

Most common vertebrate remains are scales of *Thelodus parvidens* Agassiz, *T. sculptilis* Gross, *T. admirabilis* Märss, *Nostolepis striata* Pander and *Comphonchus sandelensis* (Pander) identified from limestones.

T. Märss, R. Einasto

LOCALITY 7:3 KAUGATUMA CLIFF

The 2.5 m high Kaugatuma cliff is situated on the western coast of Sõrve Peninsula, some kilometers southward from its neck and about 100 metres from the sea. Rocks of two different facies types in the regressive succession can be seen representing the middle part of the Äigu Beds of the Kaugatuma Stage. Section (Fig. 52) from the base 1 upwards:

1. 05+ m - Greenish-grey unsorted skeletal medium-nodular argillaceous wackestone of open shelf origin. Skeletal debris consists mostly of echinoderm and brachiopod fragments. Ostracodes, trilobites, gastropods, bryozoans and fishes are not so common. Upper boundary of the bed is a quick transition within a mesocyclite.

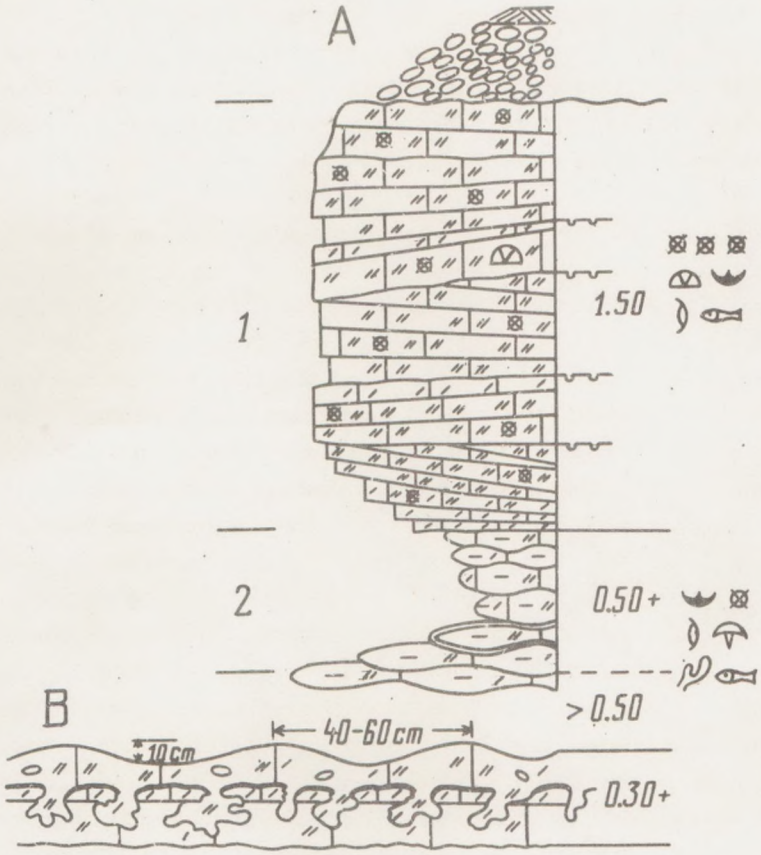


Fig. 52. (A) The Kaugatuma Cliff section: Upper Äigu Beds of the Kaugatuma Stage. For legend see Fig. 3. (B) Ripple marks exposed at the present sea level.

2. 1.5+ m - Yellow-grey coarse-grained wavy-bedded crinoidal grainstone of fore-reef origin. Grain size and sorting degree of skeletal debris vary from bed to bed. Some bedding planes show erosion marks. In this part of the section big colonies of *Syringopora blanda* (0.30 m in diameter), massive tabulate corals and stromatoporoids occur. Because of the presence of *Crotalocrinites rugosus* columnals in this rock local people call it "ring-rock".

At Kaugatuma drift beds one inclined in the northern direction and the lower argillaceous wackestones are exposed for 0.5 km southward on the beach. From this point many fossils have been collected, including trilobites by Reet Männil: *Proetus nieszkowskii, Calymene schmidti, C. kaugatumensis, C. dnestroviana, Acaste dayiana* and *Eophacops helmuti*.

From the cliff the following vertebrate remains have been found (T. Märss): *Nostolepis striata, Gomphonchus sandelensis, Poracanthodus porsus*; from the lower part only - *Thelodus parvidens* and from the top *Nostolepis gracilis*.

According to V. Nestor (pers. comm.) most of chitinozoans identified from the section belong to the wideranging species (*Angochitina ancyrea, Eisenackitina lagenomorpha* etc.), only *Eisenackitina filifera* from the bed 2 is characteristic of the upper Äigu Beds.

About 1 km south of the cliff large east-west directed well-preserved Silurian ripple marks are exposed on a 200 m long seashore, observable only during the low stand of the sea level. Ripple marks are best preserved in a 30 cm thick interval of the section, immediately underlying the basal part of the cliff. Distance between the rounded crests is 40-60 cm (max up to 80 cm), height up to 10 cm. Under the uneven discontinuity surface that forms the base of this ripple mark bed, up to 10 cm of dark-grey unsorted skeletal packstone is exposed.

R. Einasto

LOCALITY 7:4 OHESAARE CLIFF

The Ohesaare cliff is located on the western coast of Sõrve Peninsula near Ohesaare village, 2.5 km southwest of Jämaja church. The cliff is an object of the nature conservation.

The lower beds of the Ohesaare Stage, the youngest stage in the Silurian of Estonia are exposed here. The outcrop serves as a stratotype of the Ohesaare Stage, being one of

the best-known Silurian localities in Estonia. As a famous fish locality it is known already since the pioneer work by C. Pander (1856). More recently the Ohesaare section has attracted attention in connection with the definition of the Silurian/Devonian boundary as the youngest Silurian surface exposure in the whole Baltic area containing a rich association of different fossils - fishes, ostracodes, conodonts (see Kaljo, Sarv, 1966; Mark-Kurik, 1970; Kaljo, Klaamann, Sarv, Viira, 1971, etc.). The description of the section can be found in the papers by Hoppe (1931), Orviku (1934), Kaljo ed. (1970), Mark-Kurik, Märss (1976).

The Ohesaare cliff is over 600 m long and up to 4 m high, it is located immediately by the sea in the zone of storm abrasion.

The total thickness of the exposed bedrock is 3.5 m, whereas the thicknesses of separate layers are rather variable throughout the outcrop. The lithological log (Fig. 53) presents the thicknesses of layers in observation points 1 and 2 (the first ones in brackets). The section is almost completely observable in the northern part of the cliff in a small inlet (point 1). Yet, the middle part of the cliff is a better place for the studies (point 2). Here, moving southwards of the steep cliff corner ever younger beds become accessible. Between these points there remains a zone with small bedding disturbances.

The section is characterized by the intercalation of thin-bedded lime- and marlstones. The intervals, containing relatively few or thin marlstone interlayers form three cornices in the cliff section: I - beds 2 and 3, II - beds 5-7, III - beds 10-13. In the niches the marlstone/limestone ratio changes from equal to predominance of marlstones. In the middle part of the section limestones are mostly with a biomicritic texture (skeletal packstones), but in its upper (bed 2) and especially in the lower parts (beds 10 and 13) they are biosparitic (skeletal grainstones). A few lens-shaped interca-

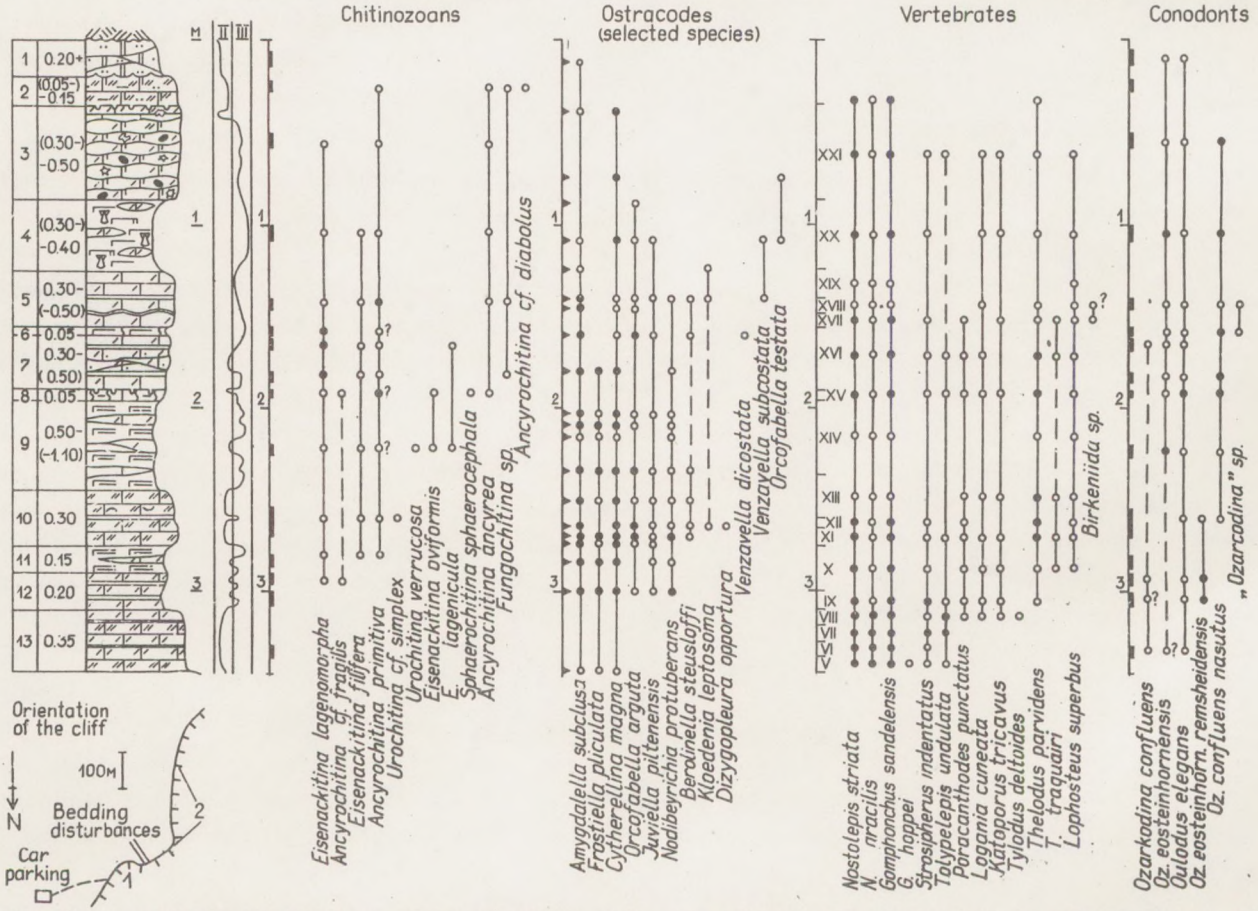


Fig. 53. Lithological log, facies curve and ranges of microfossils in the section of Ohesaare cliff. For legend see Fig. 3.

lations of cross-bedded fine-grained pelletal-skeletal grainstones are found also in the middle part of the section, in beds 7 and 9.

Marlstone interlayers are highly argillaceous, in places reaching the condition of the plastic carbonate clays.

In the upper beds of the outcrop (1-4) the rocks are somewhat dolomitized.

In this rather monotonous section there are some clearly traceable interlayers. The lower part of the section reveals a layer of coarse-grained skeletal grainstone to coquinoid rudstone (10) with a 3-5 cm thick interbed of argillaceous marlstone in the middle. 0.5-1.0 m higher of it there is a 2-5 cm thick interlayer of fine-grained limestone (8) pierced by thin vertical burrows filled with light-green marl. Still higher (0.3-0.5 m) there is a thin (5 cm) interlayer (6) of light-green calcareous marlstone containing vertical cracks with brownish granular infilling.

In the upper half of the cliff a layer (4) of greenish-grey marlstone forms a distinct niche containing abundantly shells of *Grammysia obliqua* (Mc Coy) buried in living position.

The section ends up with an up to 20 cm thick layer (1) of fissile wavy- to cross-microbedded-laminated calcareous siltstone which has preserved only in the southern end of the observation point 2. It is underlain by a 5-15 cm thick interbed (2) of light-grey silty skeletal grainstone, the upper surface of which bears large ripple marks and the lower boundary displays a hardground.

The Ohesaare cliff is rich in diverse shelly fauna which has given the main part of the fauna recorded from the youngest Silurian Stage in the East Baltic. Of macrofossils the most frequent are brachiopods, represented by *Delthyris magna* Kozlowsky, *D. elevata* Dalman, *Homoeospira baylei* (Davidson), *Morinorhynchus orbignyi* (Dav.), *Isorthis ovalis* (Paškevicius), *Dalejina hybrida* (Sowerby), *Shaleria dzwinogrodensis* (Kozl.), *Collarothyris collaris* (Rubel). As compared to other Silurian sections, relatively numerous are here bryozonas *Fistulipora tenuilamellata* (Bassler), *F. aculeata* Astrova, *Eridotrypa parvulipora* Ulrich et Bassler, *Trematopora porosa* (Dybowski) and others and also bivalves *Grammysia obliqua* (McCoy), *Cardiola interrupta* Sowerby, *Palaeopecten danbyi* (McCoy), *Modiolopsis complanata* Sowerby and others. Trilobites are most often represented by *Calymene conspicua* Schmidt, *C. soervensis* Männil, *Acaste dayiana* [illegible] et E. Richter.

Stromatoporoids have not been recorded from the cliff section, corals occur at certain levels in the middle part and are represented by species having an extensive stratigraphical distribution: *Favosites forbesi* M: Edw. et Haime, *F. pseudoforbesi* Sokolov, *Entelophyllum articulatum* (Wahlenberg), *E. pseudodianthus* (Weissermel). The middle part of the section (beds 5-10) has yielded also tentaculites: *Tentaculites scalaris* (Schlotheim) and *Lowchidium inaequale* Eichwald (H.T.).

Very diverse and rich is the characteristic association of microfossils (particularly ostracodes) (see Fig. 53). The figure shows no remarkable changes in the vertical range of species if not to consider abrupt decrease in the content of fossils in the lower and upper beds of the section. This seems to be in direct correlation with the occurrence of sparitic grainstones at these levels.

From the above-said it can be concluded that the Ohesaare cliff section is characterized by sediments of two facies belts. The upper (beds 1 and 2) and lower (beds 10-13) parts of the section are dominated by sparitic rocks of the high-energy shoal belt, whereas in the middle part mostly biomicritic limestones and marls of the open shelf belt are represented. Characteristic is the high marls content in the section, possibly caused by intense inflow of clay material into the basin at the final stage of its development. The alternation of purer and more argillaceous layers constitutes a lower-degree cyclicity of the sequence.

Notable is the historical significance of the Ohesaare section in stratigraphic correlation, as it has permitted the rich fauna described in the 19th century from the drift boulders (Beyrichienkalk) in the countries south of the Baltic, to be linked to the bedrock stratigraphic sequence (Martinsson, 1963, 1977). Such a correlation, however, was suggested already by Fr. Schmidt (1859).

H. Nestor

EIGHTH DAY

Silurian outcrops in the western part of Estonia

LOCALITY 8:1 PÄRI OUTCROP

The outcrop is located 5 km south-west of Kullamaa village on a flat limestone hillock. Nearby a disused quarry, there is a recently made ditch on the alvar. In earlier German literature the outcrop was known by the name Kattentack and serves as a type locality of several species, e.g. coral *Darvinia speciosa*, described by W. Dybovski and revised recently by C. Scrutton (1988).

Argillaceous nodular limestones containing *Pentamerus oblongus* are exposed. They belong to the upper part of the Rumba Formation of the Adavere Stage (Fig. 54).

The following section can be observed in the ditch (from the top, Fig. 54B):

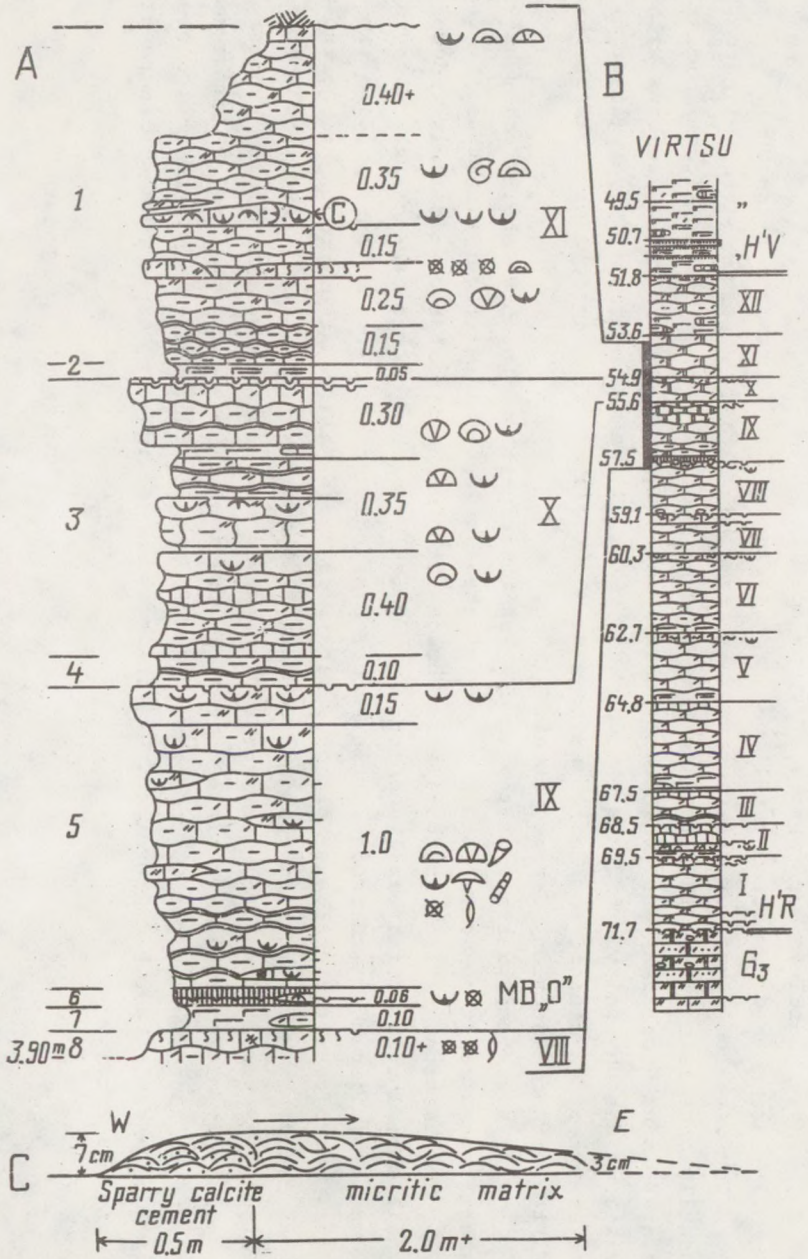
1. 1.30 m - Irregularly nodular argillaceous limestone (skeletal packstone) with lenses of Pentamerus-rudstone and skeletal grainstone. The basal 15 cm is highly argillaceous, in the uppermost 40 cm grainstone lenses are rare. Fig. 54C shows a detail through a ripple mark filled by a Pentamerus-rudstone.
2. 0.05 - argillaceous marl lying on a twofold discontinuity surface.
3. 1.05 - Different grey argillaceous, mostly irregularly nodular limestones (packstones) containing pentamerid and stromatoporoid rudstone lenses, some beds of microcrystalline limestones and thin marl intercalations.
4. 0.10 - Grey argillaceous limestone with marl intercalations.
5. 1.15 - Greenish-grey irregularly nodular argillaceous skeletal limestone (packstone) with lenses of skeletal grainstone (*Pentamerus*-coquinas). Upper 15 cm contains purer limestone with a pyritic discontinuity surface at the top.
6. 0.06 - Bioturbated metabonite bed with fragments of pentamerids.
7. 0.1 - Grey calcitic marl with grainstone nodules.
8. 0.1 - Brownish-grey microcrystalline irregularly nodular limestone (packstone).

The detailed study of the section has revealed rather distinct microcyclicity - usually a cycle begins with a thin marlstone layer (No. 2, 4 and 7 in the Figure) higher clay content decreases and grainstone lenses and coquinas appear, the cycle ends with distinct discontinuity surfaces (hardgrounds). Using the metabentonite layer (layer 6) as a marker, cycles of the Päri section can be correlated with microcycles IX-XI in the Virtsu borehole section (Einasto et al., 1972).

Päri packstones were deposited in the shallower part of the open shelf facies belt where some grainstone lenses and coquinas of the shoal belt interfinger with them.

The section is rich in fossils (although intense sampling has considerably reduced their abundance), particularly common are typical members of the *Pentamerus oblongus* community, including numerous corals. Characteristic are *Clathrodictyon variolare* (Rosen), *Mesofavosites obliquus* Sokolov, *Calostylis luhai* Kaljo. Rather common are gastropods *Boiotremus* cf. *longitudinalis* (Lindström), *Hormotoma* sp., etc., also trilobites *Calymene frontosa* Lindström, *Encrinurus (Nucleurus) rumbaensis* Rosenstein, etc. occur. Suprisingly microfossils are rare at Päri - practically no ostracodes and chitinozoans have been found, only scanty conodonts (*Panderodus* sp., *Ozarkodina* sp.) and thelodonts (*Thelodus* sp.) have been recorded. Was the reason "washing out" or something else needs a special study.

D. Kaljo, R. Einasto



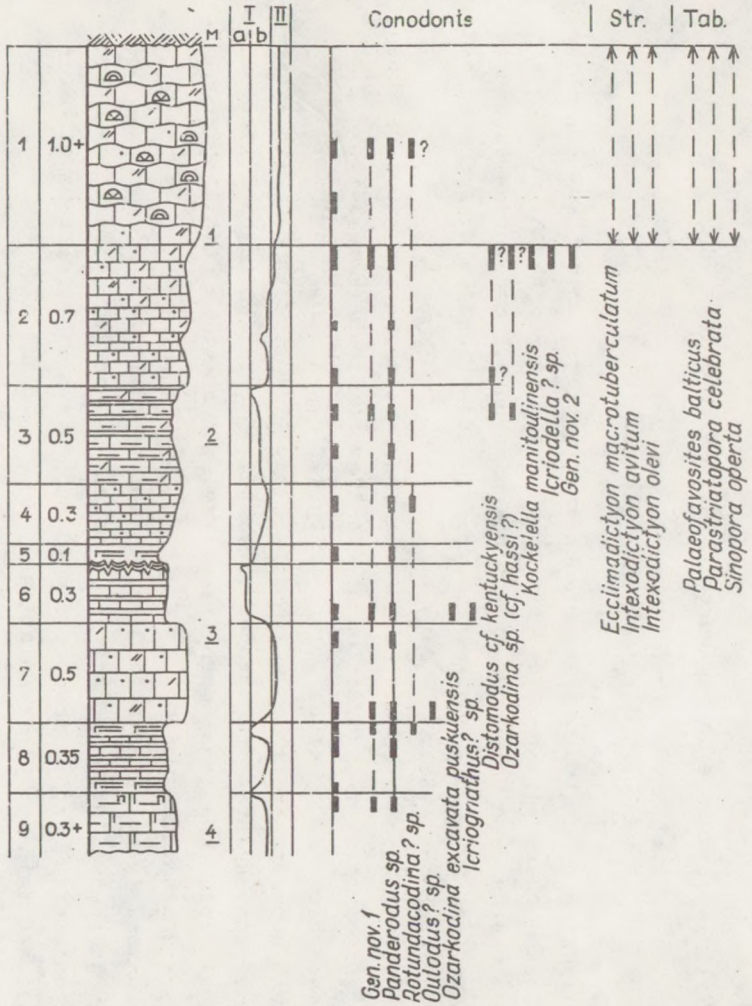


Fig. 55. Lithological log, facies curve and distribution of fossils in the section of Pakamägi cliff. For legend see Fig. 3.

Fig. 54. Lithological log of the Päri quarry and correlation with Virtsu borehole section (according to R. Einasto).

LOCALITY 8:2 LAUKNA (PAKAMÄGI CLIFF)

An ancient inland cliff of the Yoldia Stage of the Baltic Sea, 5 km north-east of the Koluvere castle at Tallinn-Virtsu road exposes flaggy aphanitic and coral-stromatoporoid limestones from the middle part of the Raikküla Formation (middle Llandovery).

In descending order there crop out (Fig. 55):

1. 0-1.0 (1.0 m) - Coral-stromatoporoid biostromal bank of a micritic matrix and nodular structure, consists of tabulates *Parastriatopora celebrata* Klaamann (H.T.), *Sinopora operta* Klaam. (H.T.), *Palaeofavosites balticus* Rukhin and stromatoporoids *Ecclimadictyon macrotuberculatum* (Riab.), *Intexodictyon avitum* Nestor (H.T.), *J. olevi* Nestor (H.T.), buried only partly in life position.
2. 1.0-1.7 (0.7 m) - Light-grey medium-bedded flaggy aphanitic (pelletal?) limestone containing scattered skeletal particles. Thickness of the layers is decreasing downwards.
3. 1.7-2.2 (0.5 m) - Grey argillaceous limestone with marl partings in the upper part.
4. 2.2-2.5 (0.3 m) - Flaggy aphanitic limestone, similar to bed 2, but more thin-bedded.
5. 2.5-2.6 (0.1 m) - Interlayer of greenish-grey soft argillaceous marlstone.
6. 2.6-2.9 (0.3 m) - Interlaminated aphanitic limestone and marlstone with polygonal mud cracks on the upper surface of the bed.
7. 2.9-3.4 (0.5 m) - Light-grey massive aphanitic (pelletal?) limestone with scattered skeletal particles.
8. 3.4-3.75 (0.35 m) - Interlaminated aphanitic limestone and marlstone, the same as layer 6.
9. 3.75-4.05 (0.3+ m) - Massive argillaceous dolomitic limestone.

Excluding the uppermost bed (1) rich in corals and stromatoporoids, the rest of the section contains a very poor assemblage of fossils. Only conodonts (see Fig. 55) and in some beds fragments of leperditian ostracodes have been recorded.

The exposed rocks have been formed during a regressive phase of the development of the Baltic Silurian Basin and are related to the first tongue of lagoonal/restricted shelf deposits which is preserved in the Estonian sequence. The section shows a transition from lagoonal, and restricted shelf deposits (most of the section) to more or less normal-marine sediments at the top.

H. Nestor

LOCALITY 8:3 VALGU OUTCROP

Three sections at the drainage canal and in the bank of the Valgu River (see Fig. 56) reflect the development of the Upper Llandovery transgression represented by an alternation of open-shelf deposits (the Rumba Formation) with transition belt deposits (the Velise Formation).

At point 1 light-grey argillaceous bioclastic *Pentamerus* Limestone of the upper part of the Rumba Formation crops out. In the topmost part of the limestone there are abundant discontinuity surfaces (hardgrounds). They are smooth, with abundant variegated holes (up to 2 cm in depth), surrounded by intensive bluisn pyrite impregnation. Frequently the abrupt discontinuity surface cuts the shells of *Pentamerus oblongus* buried in life position. The exposure also offers occasional tabulates *(Paleofavosites septosus)*, stromatoporoids *(Actinodic-*

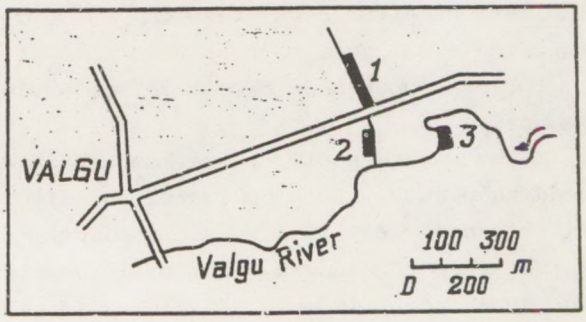


Fig. 56. Localities in Valgu village.

tyon suevicum) and trilobites (*Fragiscutum rumbaense*). The microorganisms are represented by occasional elements of *Distomodus staurognathoides* etc.

At point 2 *Pentamerus* Limestone is overlain by argillaceous fine-nodular limestones and marls (the Velise Formation). The fauna of the latter is sharply different. A deep-water association occurring here is composed of a variety of brachiopods (*Stegerhynchus borealis, Pentlandella tenuistriata, Dalmenella rosensteinae*, etc.), abundant ostracodes *Beyrichia (Asperibeyrichia) valguensis*, characteristic of the Lower Visby marls of Gotland. *Apatobolbina simplicidorsata* and an extremely abundant complex of conodonts: *Pterospathodus* cf. *celloni, Aulacognathus kuehni, Neospathognathodus ceratoides*, etc.

The stratigraphically higher-lying beds of the Velise Formation are exposed in the bank of the Valgu River (point 3). 1.6 m of the section are built up of bluish-grey thin-bedded marls with occasional, skeletal detritus and abundant marks of bioturbation. The imprints of large straight or coiled cephalopod shells are to be met in the shelly fauna. A thin (5 mm) cream-coloured metabentonite layer crops out approximately in the middle of the section.

E. Klaamann

LOCALITY 8:4 ANELEMA QUARRY

The Anelema quarry is situated about 6 km east of the small town of Pärnu-Jaagupi. The quarry affords road metal for local needs. Earlier the quarry was known as an exposure of the Jaagarahu Stage until E. Klaamann in a guidebook for IGC 27 session (Kaljo et al., 1984) motivated the Jaani age.

The section exposes dolomitized rocks containing rare specimens of poorly preserved shelly fauna. According to their structure, the rocks of the upper part of the section are referred to the bahamitic type, consisting of fine pellets. The lower part of the section is more argillaceous.

The sequence from base to top is as follows (Fig. 57):

1. 1.5 m+ - Grey bioturbated argillaceous dolostone alternating with medium-bedded greenish-grey bioturbated domerite.
2. 3.0 m - Dark-grey medium-bedded (8-20 cm) bioturbated argillaceous dolostone with horizontal 2 cm interbeds of domerite.
3. 0.06 m - Highly argillaceous laminated kerogen-bearing dark dolostone and domerite of sublagoonal origins. The bed is considered at the top of a mesocyclite and the Mustjala Member.
4. 2.2 m - Yellow-grey micro- to finecrystalline medium-bedded (5-12 cm) dolostone alternating with dark-grey 1-3 cm domerite laminations.
5. 0.5 m - Microcrystalline thick-bedded dolostone at the top subjected to denudation.
6. 0.8 m - Light yellow-grey microcrystalline thick-bedded dolostone with wavy domerite laminations after each 10-20 cm. Dolostone is a little cavernous and contains stylolites. The basal 5 cm contain domerite lithoclasts.

Three upper-beds belong to the Anelema Formation, three lower beds to the Mustjala Member.

The scarce shelly fauna, mostly in the lower part of the section, is related to the bedding planes. It is dominated by atrypids, dalmanellids, gastropods and cephalopods. Microfossils, especially scolecodonts, are abundant (Klaamann in Kaljo et al., 1984). V. Viira and P. Männik identified *Kockelella ranuliformis, Ozarkodina gulletensis* and in the upper part (sample 1) *O. sagitta rhenana*, V. Nestor - *Conochitina claviformis, C.* cf. *mamilla* etc. This data permits us to refer to the Anelema section, stratotype of the Anelema Formation, to the level of the corresponding conodont and chitinozoan biozones

which are correlated with *M. riccartonensis* graptolite Zone of early Wenlock.

The sediments of the Anelema Formation were deposited in the eastern part of a shallow bay in the restricted shelf environment.

R. Einasto

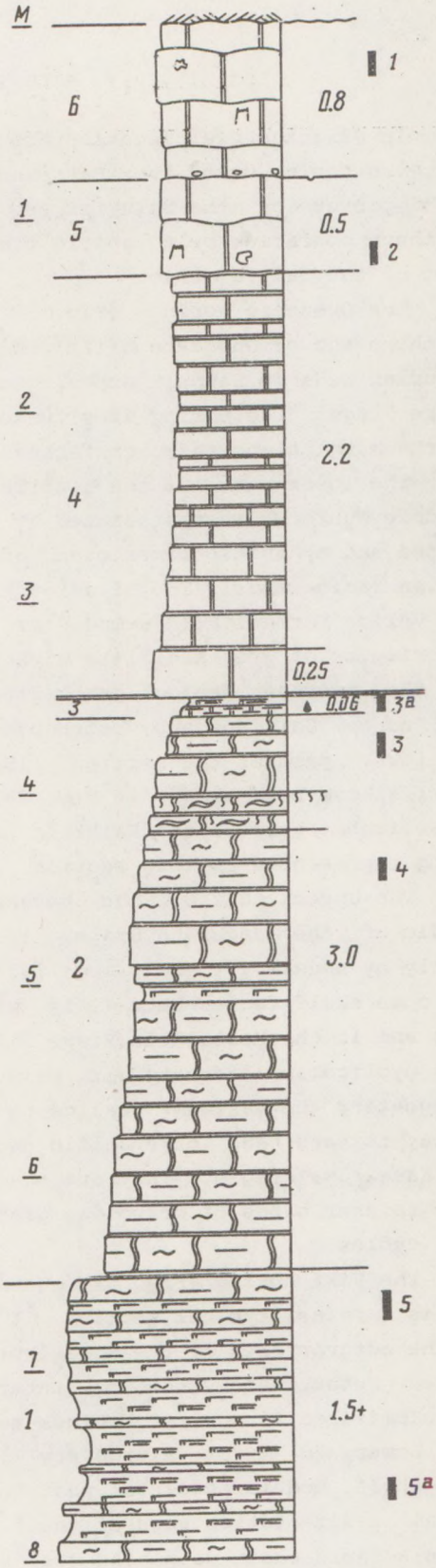


Fig. 57.
The Anelema quarry section: the Mustjala Member (Beds 1-3) and the Anelema Formation (Beds 4-6) of the Jaani Stage. For legend see Fig. 3.

NINTH DAY

LOCALITY 9:1 SILURIAN SEQUENCES AT SÄRGHAUA FIELD STATION

In Särghaua field station of the Institute of Geology, Estonian Academy of Sciences, two boring cores from Saaremaa Island will be demonstrated in order to give the general picture of the Silurian sequences in different facies settings: in shallow-water northern confacies belt and in transitional area to the deeper-water axial confacies belt of the Baltic basin.

The Ohesaare boring (Fig. 58) was drilled on Sõrve Peninsula of Saaremaa at the southern end of Ohesaare cliff and up to now its core is the completest section of the Silurian beds in Estonia exposing all Silurian regional stages except the topmost - Ohesaare Stage. The boring is situated in transitional area from the axial confacies belt to the marginal-northern confacies belt.

The lower part of the section (205-448 m) up to the middle of the Jaagarahu Stage (middle Wenlock) is represented by the basin-type sediments: marlstones, domerites, mudstones and aphanitic limestones of the transition facies belt (IV) according to the Silurian facies model. The Silurian transgression maximum coincided with the deposition of the Velise Formation (Adavere Stage) and Tõlla Member (Jaani Stage) which contain thin interlayers of grey argillite with graptolites allowing to date the uppermost Llandovery and the lowermost Wenlock graptolite zones from *turriculatus* to *riccartonensis* (*flexilis*) zones. Chitinozoans, ostracodes, conodonts and other fossils are well represented in the lower part of the section. (Stratigraphical ranges of a selected number of guide fossils have been shown in Fig. 58). A remarkable local stratigraphic hiatus has been established between the Raikküla and Adavere stages: only a lower half of the former being represented in this section.

The upper half of the Ohesaare boring section (1.8-205 m), beginning from the middle of the Jaagarahu Stage, is represented by the shelf-type carbonate sediments, mostly by nodular, partly argillaceous packstones and wackestones or skeletal marls of the open shelf facies belt (III) with diverse shelly fauna. In the uppermost Jaagarahu Beds and in the Rootsiküla Stage different dolomitized grainstones of shoal facies belt (II) cyclically alternate with primary argillaceous dolostones of the lagoonal belt (I) designating the maximum shallowing of the basin at the end of the Wenlock. Smaller interlayers and beds of sparitic grainstones and rudstones occur also in the Kuressaare and Kaugatuma stages. They are mostly of tempestite origin but in the Kaugatuma Stage some thicker bands of crinoidal grainstones occur at the top of the regressive sedimentary cycles.

The Viki boring (Fig. 59) was drilled in West Saaremaa near Kihelkonna settlement and is a rather typical section of the northern confacies belt. The boring is situated on the outcrop area of the Rootsiküla Stage and therefore it exposes only lower Silurian stages. Unfortunately the most interesting, upper part of the section (~ 100 m) is highly dolomitized as most of Wenlock sections in the outcrop area of Estonia.

Lower and middle Llandovery (the Juuru and Raikküla stages) are represented by open-shelf nodular skeletal packstones and aphanitic limestones respectively with erosional sedimentation gaps at their upper boundaries. The section of the Adavere Stage shows a rapid basin deepening over the open-shelf skeletal wackestones of the Rumba Formation (183.5-191.2 m) up to the basin-type red-coloured mudstones of the Velise Formation (153.8-183.5 m). The next, Jaani Stage demonstrates shallowing upwards in the sequence and grading from marlstones of transition facies belt (the Mustjala Formation: 99.6-153.8 m) up to the dolomitized grainstones of shoal facies belt (Ninase Formation: 90.0-99.5 m). The uppermost, Jaagarahu and Rootsiküla stages have been characterized by

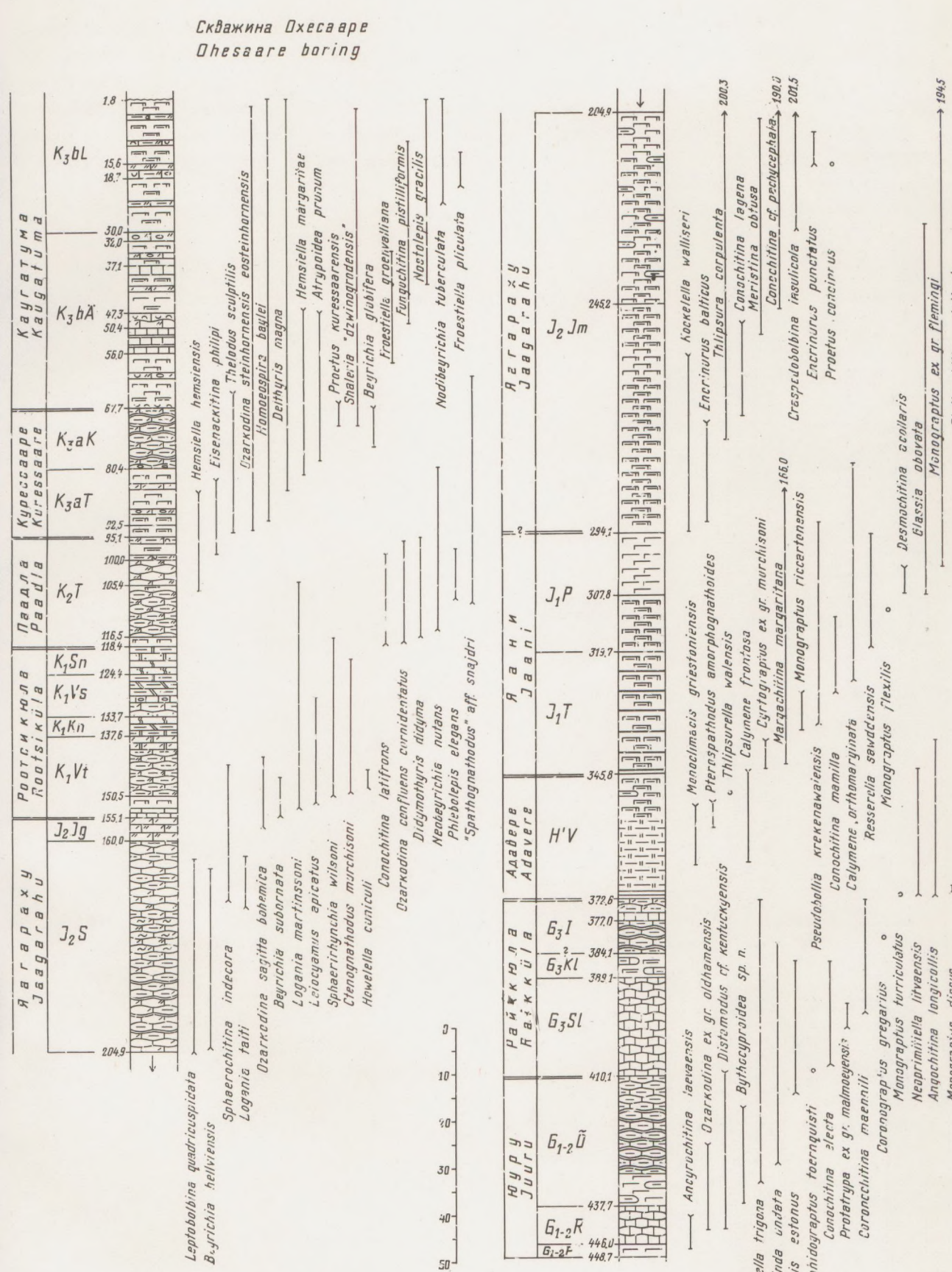
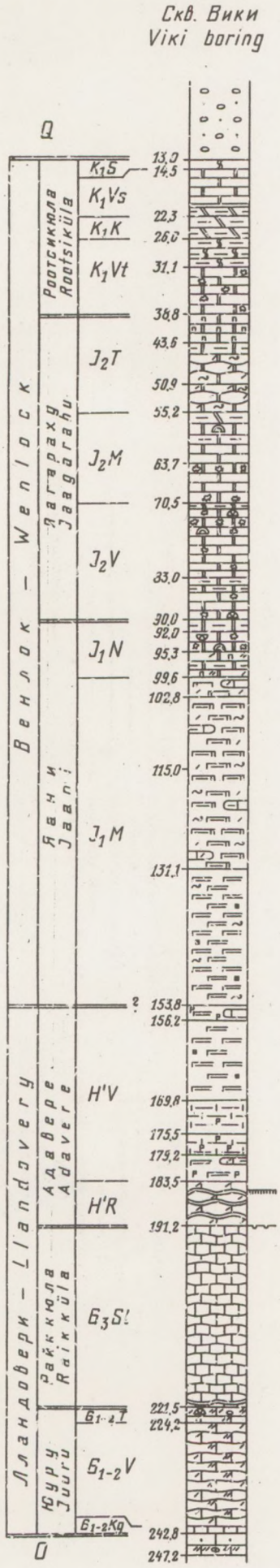


Fig. 58. The Ohesaare boring section. For legend see Fig. 3.



cyclic alternation of secondary and primary dolomites of shoal and lagoonal facies belts. By these, shallowing-up mesocycles the Jaagarahu Stage has been subdivided into the Vilsandi, Maasi and Tagavere Beds and the Rootsiküla Stage respectively into the Viita, Kuusnõmme, Vesiku and Soeginina Beds.

H. Nestor

Fig. 59.
The Viki boring section. For legend see Fig. 3.

S O M E T H I N G F O R S I G H T S E E I N G

SAAREMAA

The excursion to Silurian outcrops will last five days, the last two days being reserved for examining outcrops in West Estonia and to visit Särghaua, the field station of the Institute of Geology in order to study some boring cores. Yet, the main destination of our field excursion is Saaremaa Island (previously Oesel) which has become a rather exotic place for geologists from abroad. After a long period of about 50 years the West Estonian islands are now open to foreign visitors again. Mostly the whole excursion is bus-based, only a short boat trip (about 25 minutes) over the 8-km-wide strain takes us from the mainland to the port of Kuivastu on MUHU ISLAND, that serves as a gate to Saaremaa. Although a relatively small island (territory 200 sq km) - Muhu Island, has much interesting to offer for tourists. The favourite place for the visitors is Koguva village, considered as the oldest monument of peasant architecture of the islands. The whole village constitutes a kind of open-air museum with the only difference that all houses are still lived in. Koguva is a very old village, first mentioned in the records of 1532 when local peasants were freed from serfdom. They had still several tasks to fulfil for the landlord including carrying post from Muhu to Saaremaa Island as well as to the mainland. Koguva is a typical island village, the so-called cluster village. Its most characteristic feature is numerous stone fences, built of stones collected from the fields. The ancient islanders had a belief that stone fences around the farms protected them from evil spirits. The buildings are thatched-roof houses, mainly dating from the years 1880-1930. The museum was opened at Koguva in 1973.

From Muhu Island we shall travel on to Saaremaa, crossing the strain between the two islands by road built already in 1894-96.

SAAREMAA is one of the biggest Baltic islands, 2,668 sq km in area and with the population of 38,000 inhabitants. The island has a deeply indented coastline of about 1,300 km, the longest peninsula being Sõrve, 32 km. The typical coasts are stony, but there are some stretches of nice sandy beaches as well. Numerous steep and picturesque cliffs are situated on the northern coast of Muhu and Saaremaa. Several of them have been taken under state protection, e.g. Üügu, Rannaniidi, Tupenurme cliffs on Muhu Island; Panga, Ohesaare, Soeginina, Kaugatuma cliffs on Saaremaa Island. Saaremaa is surrounded by numerous smaller islands, about 500 in number. Due to land uplift new islets appear, bays, however, turn gradually into brackish-water coastal lakes.

The formation of the West-Estonian islands began 10,000 years ago when small pieces of land in West-Saaremaa rose from the sea. The bedrock is composed of Silurian limestones and dolomite. On the islands, as well as elsewhere on the Estonian territory, the bedrock layers are inclined southwards, cropping out on the surface as East-West directed belts. The older layers are exposed in the north, the younger ones in the south. Thus, moving from the north to the south, we can get a picture about the geology of the island's bedrock from the older strata to the younger ones.

Because of its maritime climate and variety of soils Saaremaa is rich in plant species - four fifths of the species found in Estonia grow here. 44 per cent of the island's area is woodland; fertile agricultural land, however, makes up only a small proportion. Natural features of world-wide significance include the alvars covered with sparse juniper groves, as well as the nature reserves of VIIDUMÄE and VILSANDI. The for-

mer is the habitat of several rare plant species comprising the greatest rarities of Estonian flora. One third of all plant species that have been taken under state protection, are represented here, including the unique endemic Saaremaa yellow rattle. Viidumägi is also the highest point of the island rising up to 54 m above sea level. The small Vilsandi Island constitutes a bird sanctuary founded in 1910 where numerous species of nestling and migratory birds are protected. The most famous natural attraction, however, is the KAALI METEORITE CRATERS (see below).

Saaremaa is rich in archeological monuments. The oldest are the stone age settlement sites lying at an altitude of 15-16 m above sea level. 4,000-5,000 years ago, however, they were coastal settlements of hunters and fishermen. The beginning of the 2nd millennium A.D. has left us some monumental fort sites, several of them being linked with the Estonians' struggle for freedom. Numerous architectural monuments date from the 13th-16th centuries. The most outstanding among them is KURESSAARE CASTLE, the only completely preserved medieval stone castle in the Baltic. The castle was built as the episcopal residence in the late 14th century when Kuressaare became the centre of the Saare-Lääne (Oesel-Wiek) bishopric. The surrounding fortifications were added in the 15th-18th centuries. The castle is a quadrangular three-storey building with only one entrance to the courtyard from the northern side. The first floor of the castle holds the living- and reception-rooms, including a big refrectory, dormitories and a church-chapel. On the ground floor there were the kitchen, well and other management rooms. The topmost floor served as living-rooms for servants and guards. The castle has two towers - the main tower at its north-west corner and a smaller one at the south-west corner.

The settlement, present KURESSAARE TOWN, that grew up around the castle, was first mentioned in 1424, town status was conferred upon it in 1563. Since 1564 Kuressaare has been the administrative centre of the whole Saaremaa county. A new stage in the history of the town started in the 19th century with the discovery of curative muds in Kuressaare Bay. The first mud-bath sanatorium was established here in 1840. Since then Kuressaare has developed as a health and summer resort. Formerly known as the pearl of Livonian small towns, Kuressaare has largely retained its particular historical charm, mainly thanks to extensive restoration work.

Among the sphere of life of the whole of Saaremaa tourism and the resort industry are gradually gaining importance. Having in mind specific natural conditions the island in the beginning of 1990 was transformed into an international biosphere protection area.

A. Noor

KAALI METEORITE CRATERS

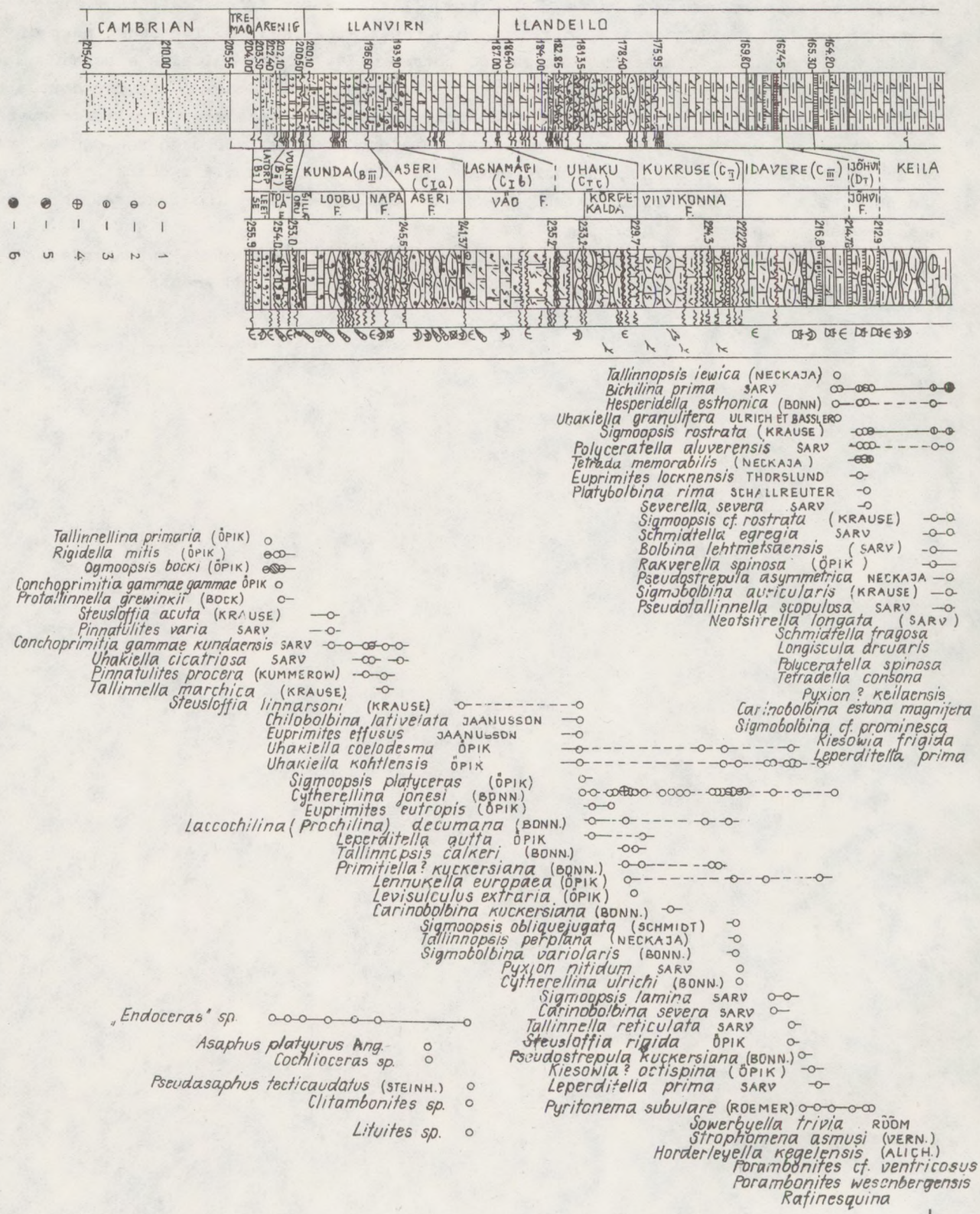
The Kaali meteorite fell about 3,500 years ago from the east-northeast under the approximate angle of 35°. The initial weight of the meteorite may have been about 1,000 tons. In passing through the atmosphere it was hotted up by the air pressure to such an extent that at 5-10 km from the earth it broke into pieces and a part of its masses melted and evaporated. The pieces came down as a meteorite fall. The greatest one (ca 80 tons) fell to the ground with the approximate velocity of 20 km/sec. At this moment due to immense kinetic energy there occurred a powerful explosion. In the result of it the main crater, now Lake Kaali was formed. The smaller parts evaporated only partly and mostly broke into fine pieces that were scattered about on the ground. In this way eight smaller craters were formed with the diameter of 12-40 m and depth of 1-4 m.

Kaali meteorite craters were formed in thickbedded Silurian dolomite of the Paadla Formation covered with clayey till. The wall of the main crater rises 4-7 m above ground

level. The exterior slope of the crater is comparatively slanting, the interior is steep, gradually slanting towards the bottom. The diameter of the wall from rim to rim amounts from 105 to 110 metres, the depth of the crater is 22 m. The upper part of the crater wall consists of nine huge, about 50 metres wide, tilted dolomite blocks displaced by the explosion. They are underlain by a zone of dolomitic meal. Near the bottom the crater filling contains more abundant dolomite splinters with clayey till and coarser rock fragments. On the bottom solid rock has remained in situ, although the central part of it is shattered and burnt. The hard bottom is covered with a 6.4 m thick layer of mud and peat. 2.5 kg of meteoritic material has been collected from the craters. The mass of the greatest sample after cleaning it of rust was almost 30 g.

In 1959 a protection area was established at Kaali. A memorial stone near Kaali schoolhouse perpetuates the study of craters by Ivan Reinwald and Ago Aaloe.

R. Tiirmaa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CAMBRIAN
TREMADOC
ARENIG
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KUNDA (B III)
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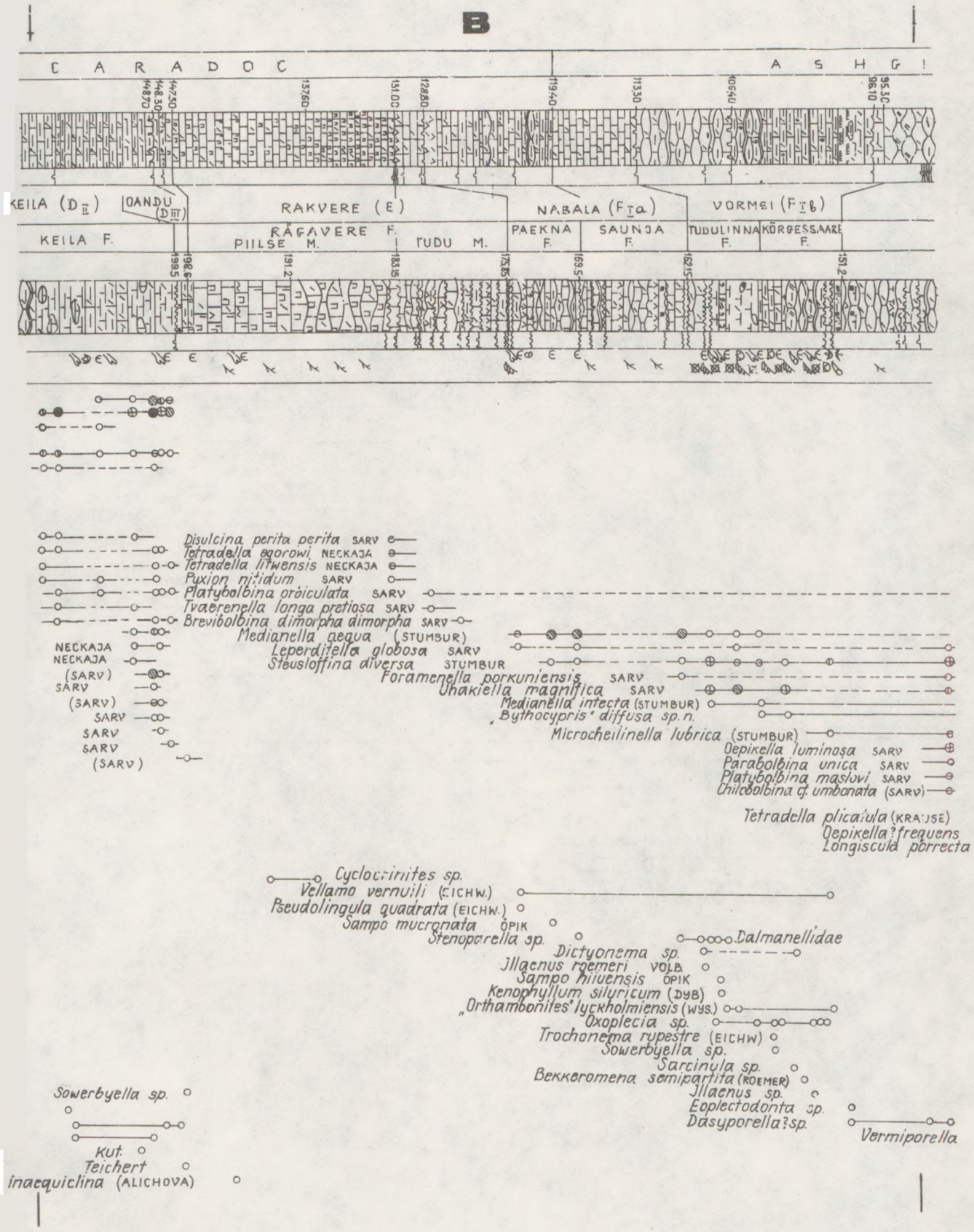
UHAKU (C Ic)
KUKRUSE (C II)
IDAVERE (C III)
JÕHVI (D I)
KEILA
LOOBU F.
NAPA F.
ASERI F.
VÄO F.
KÖRGE-KALDA
VIIVIKONNA F.
JÕHVI F.
Tallinnopsis iewica (NECKAJA)
Bichilina prima SARV
Hesperidella esthonica (BONN)
Uhakiella granulifera ULRICH ET BASSLER
Sigmoopsis rostrata (KRAUSE)
Polyceratella aluverensis SARV
Tetrada memorabilis (NECKAJA)
Euprimites locknensis THORSLUND
Platybolbina rima SCHALLREUTER
Severella severa SARV
Sigmoopsis cf. rostrata (KRAUSE)
Schmidtella egregia SARV
Bolbina lehtmetsaensis (SARV)
Rakverella spinosa (ÖPIK)
Pseudostrepula asymmetrica NECKAJA
Sigmobolbina auricularis (KRAUSE)
Pseudotallinnella scopulosa SARV
Neotsirella longata (SARV)
Schmidtella fragosa
Longiscula arcuaris
Polyceratella spinosa
Tetradella consona
Pyxion ? keilaensis
Carinobolbina estona magnifera
Sigmobolbina cf. prominesca
Kiesowia frigida
Leperditella prima
Tallinnellina primaria (ÖPIK)
Rigidella mitis (ÖPIK)
Ogmoopsis bocki (ÖPIK)
Conchoprimitia gammae gammae ÖPIK
Protallinnella grewinkii (BOCK)
Steusloffia acuta (KRAUSE)
Pinnatulites varia SARV
Conchoprimitia gammae kundaensis SARV
Uhakiella cicatriosa SARV
Pinnatulites procera (KUMMEROW)
Tallinnella marchica (KRAUSE)
Steusloffia linnarsoni (KRAUSE)
Chilobolbina lativelata JAANUSSON
Euprimites effusus JAANUSSON
Uhakiella coelodesma ÖPIK
Uhakiella kohtlensis ÖPIK
Sigmoopsis platyceras (ÖPIK)
Cytherellina jonesi (BONN)
Euprimites eutropis (ÖPIK)
Laccochilina (Prochilina) decumana (BONN.)
Leperditella qutta ÖPIK
Tallinnopsis calkeri (BONN.)
Primitiella? kuckersiana (BONN.)
Lennukella europaea (ÖPIK)
Levisulculus extraria (ÖPIK)
Carinobolbina kuckersiana (BONN.)
Sigmoopsis obliquejugata (SCHMIDT)
Tallinnopsis perplana (NECKAJA)
Sigmobolbina variolaris (BONN.)
Pyxion nitidum SARV
Cytherellina ulrichi (BONN.)
Sigmoopsis lamina SARV
Carinobolbina severa SARV
Tallinnella reticulata SARV
Steusloffia rigida ÖPIK
Pseudostrepula kuckersiana (BONN.)
Kiesowia? octispina (ÖPIK)
Leperditella prima SARV
Pyritonema subulare (ROEMER)
Sowerbyella trivia RÜÜM
Strophomena asmusi (VERN.)
Horderleyella kegelensis (ALICH.)
Porambonites cf. ventricosus
Porambonites wesenbergensis
Rafinesquina
„Endoceras" sp.
Asaphus platyurus Ang.
Cochlioceras sp.
Pseudasaphus tecticaudatus (STEINH.)
Clitambonites sp.
Lituites sp.


B
C A R A D O C
A S H G I
KEILA (D II)
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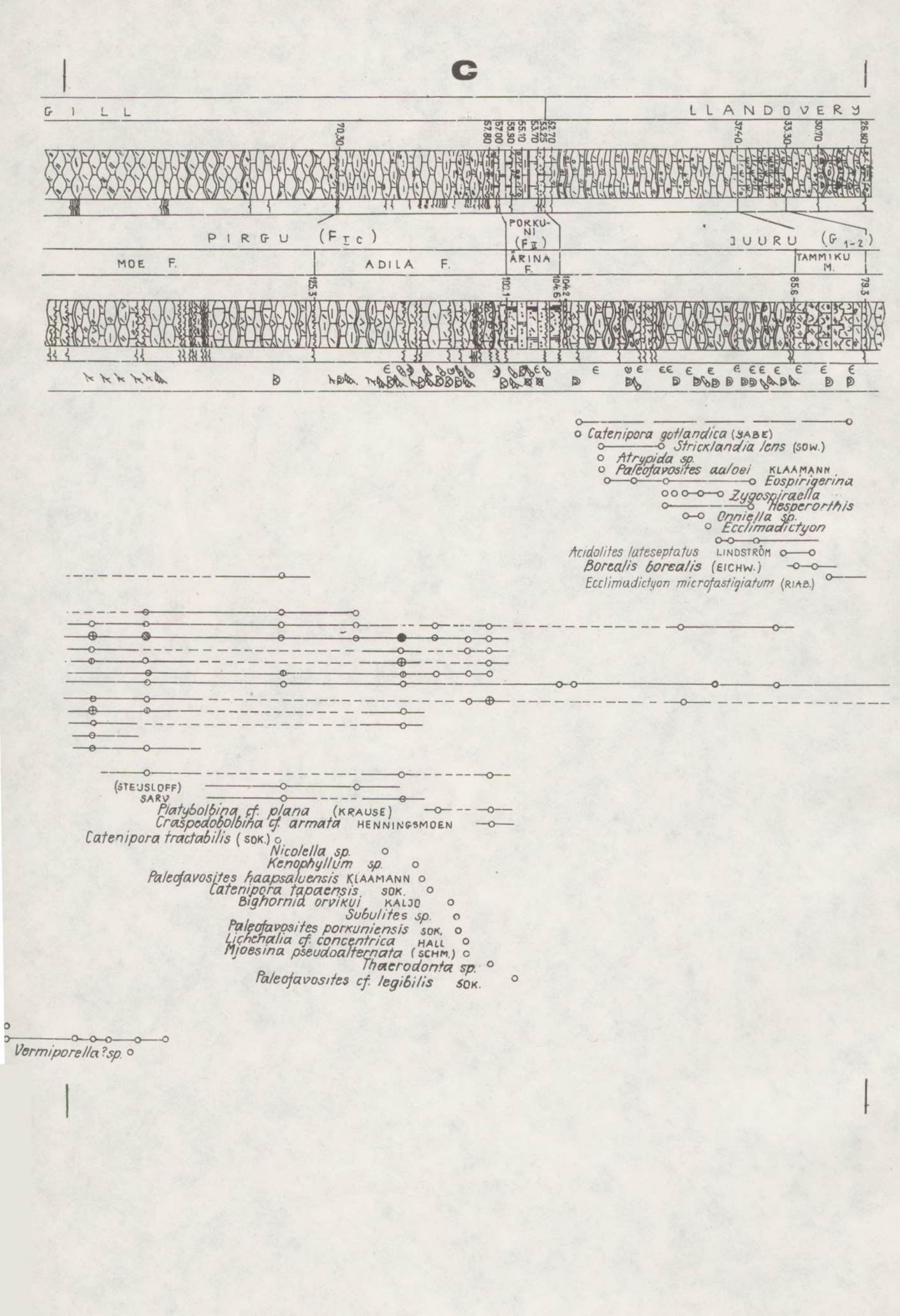
RAKVERE (E)
NABALA (F Ia)
VORMSI (F Ib)
KEILA F.
RÄGAVERE F.
PIILSE M.
TUDU M.
PAEKNA F.
SAUNJA F.
TUDULINNA F.
KÖRGESSAARE F.
Disulcina perita perita SARV
Tetradella egorowi NECKAJA
Tetradella litwensis NECKAJA
Pyxion nitidum SARV
Platybolbina oriculata SARV
Tvaerenella longa pretiosa SARV
Brevibolbina dimorpha dimorpha SARV
Medianella aequa (STUMBUR)
Leperditella globosa SARV
Steusloffina diversa STUMBUR
Foramenella porkuniensis SARV
Uhakiella magnifica SARV
Medianella intecta (STUMBUR)
„Bythocypris" diffusa sp.n.
Microcheilinella lubrica (STUMBUR)
Oepikella luminosa SARV
Parabolbina unica SARV
Platybolbina masloví SARV
Chilobolbina cf. umbonata (SARV)
Tetradella plicatula (KRAUSE)
Oepikella? frequens
Longiscula porrecta
Cyclocrinites sp.
Vellamo vernuili (EICHW.)
Pseudolingula quadrata (EICHW.)
Sampo mucronata OPIK
Stenoporella sp.
Dalmanellidae
Dictyonema sp.
Illaenus roemeri VOLB.
Sampo hiiuensis OPIK
Kenophyllum siluricum (DYB)
„Orthambonites" lyckholmiensis (WYS.)
Oxoplecia sp.
Trochonema rupestre (EICHW)
Sowerbyella sp.
Sarcinula sp.
Bekkeromena semipartita (ROEMER)
Illaenus sp.
Eoplectodonta sp.
Dasyporella? sp.
Vermiporella
Sowerbyella sp.
Kut.
Teichert
inaequiclina (ALICHOVA)


C
GILL
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57.80
57.00
55.90
55.10
53.70
53.25
52.70
37.40
33.30
30.70
26.80
PIRGU (F I c)
PORKUNI (F II)
JUURU (G 1-2)
MOE F.
ADILA F.
ÄRINA F.
TAMMIKU M.
125.3
100.1
104.6
104.2
85.6
79.3
Catenipora gotlandica (YABE)
Stricklandia lens (SOW.)
Atrypida sp.
Paleofavosites aaloei KLAAMANN
Eospirigerina
Zygospiraella
Hesperorthis
Onniella sp.
Ecclimadictyon
Acidolites lateseptatus LINDSTRÖM
Borealis borealis (EICHW.)
Ecclimadictyon microfastigiatum (RIAB.)
(STEUSLOFF)
SARV
Platybolbina cf. plana (KRAUSE)
Craspedobolbina cf. armata HENNINGSMOEN
Catenipora tractabilis (SOK.)
Nicolella sp.
Kenophyllum sp.
Paleofavosites haapsaluensis KLAAMANN
Catenipora tapaensis SOK.
Bighornia orvikui KALJO
Subulites sp.
Paleofavosites porkuniensis SOK.
Lichchalia cf. concentrica HALL
Mjoesina pseudoalternata (SCHM.)
Thaerodonta sp.
Paleofavosites cf. legibilis SOK.
Vermiporella ? sp.

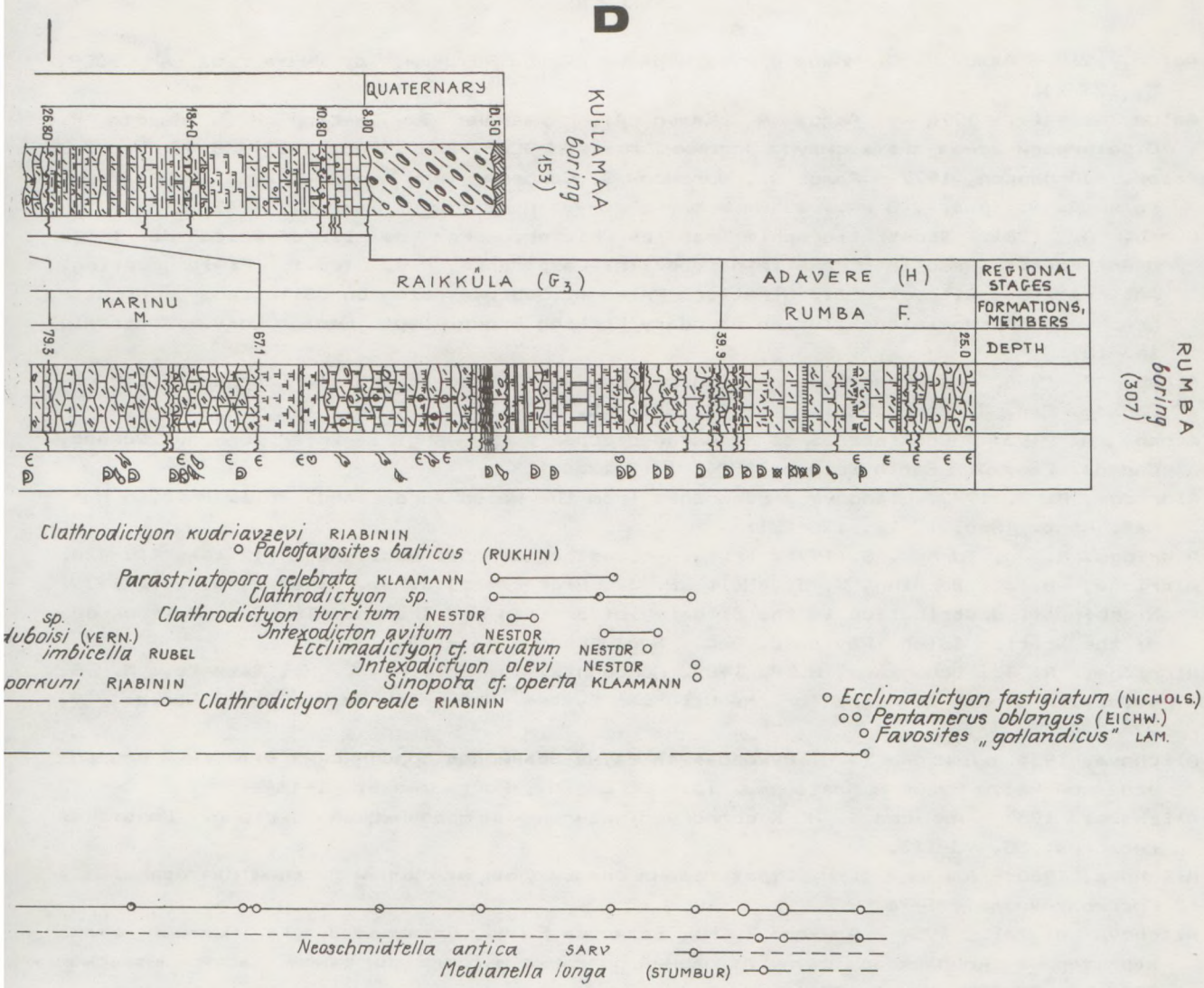

Fig. 60. The Kullamaa and Rumba boring sections of West Estonia. Kullamaa section after L. Põlma. Rumba section after S. Mägi (lithology, stratigraphy), ostracodes after K. Stumbur; macrofossils after: H. Nestor (stromatoporoids), E. Klaamann (tabulates), D. Kaljo (rugosae), A. Rõõmusoks, M. Rubel, S. Mägi (others).
Number of specimens in the samples:

1 - up to 8	4 - up to 40
2 - up to 15	5 - up to 60
3 - up to 25	6 - over 100

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