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# Comments to the Modernized Silurian Correlation Chart of Estonia and Latvia

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**Heldur Nestor**

*Institute of Geology, Estonian Academy of Sciences, Estonia pst. 7, EE 0100 Tallinn / Estonia*

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## INTRODUCTION

The Baltic Stratigraphic Commission and its successor the Baltic Stratigraphic Association have greatly contributed to the elaboration and unification of regional stratigraphic charts. Important stages of this activity have been the preparation of the so-called unified correlation charts and their improvement on regional stratigraphic conferences. The Silurian System has been dealt with at such conferences as the First Baltic Regional Interdepartmental Stratigraphic Conference in Vilnius in 1976 and the Interdepartmental Stratigraphic Conference on the Ordovician and Silurian of the East-European Platform, held in Tallinn in 1984. The corresponding materials were published in 1978 and 1987 [32, 33], accordingly. Unified charts and their modifications have been reproduced in various publications. Unfortunately, in most cases the charts lack the commentaries explaining different amendments.

For the Second Baltic Conference, held in 1993, catalogues of stratotypes of all systems were prepared also with stratigraphic charts. The present author compiled the catalogue of the Silurian stratigraphic units and stratotypes of Estonia and Latvia together with a somewhat modified stratigraphic chart [30]. Below the chart will be presented in its complete form together with the global standard, biostratigraphic divisions and explanatory comments (Fig. 1). Concrete amendments and additions concerning the Estonian part of the chart have been approved by the Estonian Stratigraphic Commission and Silurian working group. During the discussions a lot of valuable suggestions were made by D. Kaljo and H. Perens. Biostratigraphic zonal scales were compiled by P. Männik and V. Viira (conodonts), V. Nestor (citinozoans), L. Sarv (ostracodes), T. Märss (vertebrates), basing on their earlier published data, particularly in the excursion guidebook in 1990 [16]. The author is grateful to them for the suggestions and materials provided.

## GLOBAL STANDARD

In the previous unified Silurian correlation charts of the East Baltic [32, 33] the so-called "general stratigraphic scale", approved by the Interdepartmental Stratigraphic Committee of the USSR in 1975, was used as a chronostratigraphic scale. In the present chart a draft of the global chronostratigraphic standard was used, distributed by the I.U.G.S. Subcommittee on Silurian Stratigraphy. Provided with some supplements, it was published in the newsletter "Silurian Times" [10]. Its main difference from the previous one lies in the addition of the column of standard (global) stages. In the zonal scale of graptolites besides well-defined individual zones also their groupings have been shown in cases they were harder to distinguish globally. A provisional zonal scale of conodonts, prepared by G.S. Nowlan [10], has been added. By compiling the global standard an attempt was made to express the extent of stratigraphic units in the absolute time, but it is rather arbitrary due to small number of absolute age determinations.

## REGIONAL CHRONO- AND BIOSTRATIGRAPHIC DIVISIONS

In the East Baltic area the system of stages, established in the outcrop area of Estonia, has been used as a regional chronostratigraphic standard. In general outline it was established already before World War II [8, 9, 25, 26, 27, 34, 35] and has been used in an unmodified form since 1970 [19]. It has been widely applied also in international practice including the most recent global survey on Silurian stratigraphy [17]. Nevertheless, several times a problem has arisen about the shallow-water sections of the Estonian outcrop area not being representative enough as a regional standard due to the occurrence of lagoonal rocks and local hiatuses, and they should be replaced (particularly in the upper-Silurian part) by the sections of the South Baltic subsurface area (Lapinskas

in Reshenia ..., 1987 [33]). In the author's opinion in the recent years considerable success has been achieved by the correlation of different facies using chitinozoans and conodonts. This has permitted to correlate successfully the sections of the outcrop area with deeper-water sections of the axial part of the basin. In this connection we should also consider the fact that most of the Silurian classical platform sections (Oslo region, Gotland, Siberian Platform, Anticosti, the Great Lakes region in the U.S.A., western slope of the Urals) are represented by similar shallow-water shelly-fauna sequences, which could be correlated using the same biostratigraphic criteria as in the case of the Estonian outcrop area.

In previous regional stratigraphic charts of the East Baltic Silurian only the zonal succession of graptolites was given according to D. Kaljo et al. [22]. Now it has turned possible to add also conodont (Männik, Viira), ostracode (Sarv), chitinozoan (V. Nestor) and vertebrate (Märss) zonations, which have been published already in a geological excursion guidebook [21] and in some other papers [22].

## CORRELATION OF LOCAL LITHOSTRATIGRAPHIC UNITS

In Estonia and Latvia the local lithostratigraphic classification has been relatively stable already since the 1970s, when some monographs [19, 36] and materials on the first unified stratigraphic chart [5, 32, 37] were published. Certain amendments were made by the preparation of the correlation chart of the Silurian of the East-European Platform, which were included in the explanatory text to the chart [33] and publications on the Silurian of Latvia [15, 38]. In more recent years the studies on Silurian stratigraphy in Latvia have come to a standstill. In Estonia large-scale geological mapping continued up to the recent time. The data obtained served as a main basis for making certain changes and additions in the lithostratigraphic divisions. These amendments concern mostly the stratigraphic intervals represented by lithologically very variable rocks of shallow-water genesis, particularly corresponding to the Juuru/Raikküla Regional stages in the Llandovery and Jaani/Jaagarahu Regional stages in the Wenlock.

## LLANDOVERY

The first supplement concerns the boundary beds of the Juuru and Raikküla stages in western Estonia, Haapsalu district and on Hiiumaa Island, which are represented by a variable complex of shallow-water rocks of the **Hilliste Formation**. They are mostly characterized by crinoidal grainstones and associated coral-stromatoporoid bioherms. A. Aaloe [1] treated these biohermal and crinoidal limestones initially as the Hilliste Member as-

cribing them to the Juuru Stage. P. Männik [28] has recently proved that, in Hiiumaa, crinoidal grainstones contain the same conodont species as the beds traditionally attributed to the Raikküla Stage. Owing to this the Stratigraphic Commission of Estonia decided to treat Hilliste as a formation, in vertical extent covering the topmost part of the Juuru Stage and the lower part of the Raikküla Stage. Apart from crinoidal grainstones and bioherms it contains also pelletal limestones, as well as marlstone, argillaceous limestone and conglomerate interbeds. The Hilliste Formation lies on the Borealis limestone of the Tamsalu Formation (= Tammiku Member) and is disconformably overlain by the Pentamerus limestone of the Rumba Formation of the Adavere Stage. The stratotype of the formation is the Hilliste quarry in southeastern Hiiumaa.

**Raikküla Formation.** In its stratotype area in middle and western Estonia the Raikküla Stage is represented by micritic, pelletal and coral-stromatoporoid limestones, cyclically alternating with argillaceous lagoonal dolomites, which are here treated as the Raikküla Formation in a more restricted geographical extent. In the alternation of the above-mentioned rocks two cycles are distinguished, starting with micritic nodular limestones and ending with lagoonal dolomites. On this basis the Raikküla Formation can be subdivided into two subformations with distinctly different coral and stromatoporoid faunas [21, 24, 29]. The stratotype of the Raikküla Formation is the ancient Raikküla-Paka coastal scarp and the Raikküla core in the interval of 0.5 - 35.0 m [30].

South and east of the stratotype area of the Raikküla Stage the lithologic composition of the cycles changes notably and these sections could be considered a separate formation which is here called the **Nurmekund Formation** (after an ancient county in central Estonia). Shallowing-up sedimentary cycles start with a relatively thin layer of marlstone or argillaceous limestone, the main middle part of the cycle is represented by aphanitic limestones, the upper part by skeletal wackestones to grainstones and contains numerous discontinuity surfaces. The Nurmekund Formation consists of five cycles, the first, third and fifth ones from below being thicker and completely developed, the second and fourth cycles are thinner and more untypical. These beds have been used in middle Estonia for large-scale geological mapping. In the ascending order they are called the Järva-Jaani, Vändra, Jõgeva, Imavere and Mõhküla beds [14]. From the Järva-Jaani Beds graptolites of the **cyphus Zone**, from the Jõgeva Beds *Pristiograptus* aff. *gregarius* have been identified by Kaljo [19, Fig. 61]. The rocks of the Nurmekund Formation are mostly very strongly dolomitized, particularly in its upper half. In western Estonia and on islands a hiatus corresponds to the upper part of the Nurmekund Formation, increasing northwestwards. The type section of the Nurmekund Formation is the Põltsamaa-163 borehole in the interval of 1.5-70.2 m.

		GLOBAL STANDARD					
SYSTEM	SUB-SYSTEM	SERIES	STANDARD STAGES	CRAPTOLITE BIOZONES	CONODONT BIOZONES	REGIONAL STAGES	
SILURIAN	UPPER	PŘÍDOLI	—	lochkovensis/transgrediens	O. eosteinhornensis	OHESAARE	
				parultimus/ultimus		KAUGATUMA	
		LUDLOW	LUDFORDIAN	formosus	O. crispa	KURESSAARE	
				bohemicus / kozlowskii	O. snajdri	PAADLA	
				leintwardinensis	P. siluricus		
			GORSTIAN	scanicus	A. ploeckensis		
		LOWER	WENLOCK	HOMERIAN	ludensis	O. bohémica bohémica	ROOTSİKÜLA
					nassa / deubeli		JAAGARAHU
					lundgreni		
				SHENWOODIAN	rigidus / ellesae	O. sagitta	JAANI
	riccartonensis						
	centrifugus/murchisoni				P. amorphognathoides		
	LLANDOVERY		TELYCHIAN	crenulata	P. celloni	ADAVERE	
				griestoniensis			
				turriculatus / crispus			
			AERONIAN	convolutus / sedgwickii	D. staurognathoides	RAIKKÜLA	
	gregarius						
	RHUDDANIAN	cyphus	D. kentuckyensis	JUURU			
		vesiculosus					
		acuminatus					

Fig. 1. Global standard and regional stages of the Baltic Silurian

The uppermost, Mõhküla Beds of the Nurmekund Formation cropping out in the vicinity of Adavere were earlier assigned to the Adavere Stage as a member [18, 19]. Bed-by-bed correlation of the sections, carried out recently [14], have shown that in middle Estonia the Mõhküla Beds lie stratigraphically lower than the

**Pentamerus oblongus beds** (= Rumba Formation) in western Estonia, which have always been considered typical of Fr. Schmidt's "Esthonus Schicht" or Adavere Stage by the current nomenclature. Now it has been established (M. Rubel, pers. comm.) that the pentamerid occurring in the Mõhküla Beds is a representative of the genus

BIOZONES

GRAPTOLITE (Kaljo et al., 1984)	CONODONT offshore   nearshore (Männik, Viira)		CHITINOZOAN (V. Nestor)	OSTRACODE (Sarv)	VERTEBRATE (Märss)	
— ultimus	O. eostein- hornensis	O. e. rem- scheidensis	Urnochitina	N. protuberans	K. timanicus Por. punctatus	
		O. e. cana- densis	E. filifera - F. pistilliformis	N. tuberculata	N. gracilis	
		O. eosteinhor- nensis s. str.	A. fragilis	F. groenvalliana	T. sculptilis (L. ludlowiensis)	
	formosus balticus tauragensis	O. crispa	O. e. aff. scani- ca	S. sphaerocephala C. grandosa	P. numerosa - U. balticum	A. hedei
			R. dubia	E. philipi - E. lagenomorpha	N. ctenophora - N. lauensis	Phl. elegans Phl. ornata
	scanicus - progenitor	O. aff. snajdri	"Ozarkodina" sp. S	E. latifrons	C. ezerensis	L. martinssoni
nilssoni			G. militaris - C. sp. 2 Conochitina sp. 1			
ludensis	O. bohémica bohémica	C. murchisoni	Interzone	B. subornata		
nassa	K. absidata		S. indecora	L. quadricuspidata	L. taiti	
testis			C. cribrosa			
radians perneri			C. subcyatha			
flexilis	C. pachycephala					
antennularius	K. amsdeni		E. lagena			
riccartonensis	K. walliseri	O. sagitta rhenana	C. cingulata	C. mucronulata	?	
murchisoni bohemicus	K. ranulii- formis		C. tuba			
spiralis			C. cf. mamilla			
griestoniensis		P. amorphognathoides	M. margaritana			
crispus		P. celloni	C. proboscifera	L. caudalis - T. watensis		
turriculatus			A. longicollis	Interzone	B. valguensis	L. scotica
sedgwickii	?	O. aff. pirata	C. emmastensis	?		
convolutus		O. excavata	Interzone	?		
gregarius - triangulatus		puskuensis	C. cf. protracta			
cyphus	D. kentuc- kyensis	K. manitou- linensis	A. convexa	B. sarvi	?	
			C. electa			
confertus			C. postrobusta A. laevaensis	M. edita - S. eris		

Fig. 2. Correlation of the biostratigraphic zones

*Borealis* and that there exists a disconformity between the Mõhküla Beds and Rumba Formation. Therefore the Estonian Stratigraphic Commission has decided to assign the Mõhküla Beds to the Raikküla Stage and to choose the Pärei outcrop in western Estonia as the neostratotype of the Adavere Stage.

WENLOCK

In the stratotype area the stratigraphic division of the Jaani and Jaagarahu stages has been changed for several times. This has been due to uncertainty by the correlation of the sections of eastern and western Saaremaa. A. Luha [25] and A. Aaloe [2, 3, 6, 7] treated the limestone

sections of western Saaremaa and dolomitic sections of eastern Saaremaa as different lithostratigraphic subdivisions replacing each other laterally. Since 1970 [4] they were defined as "beds" vertically lying on each other. This resulted in the uniting of rock bodies of laterally very different composition and genesis [4, 5, 11]. During detailed geological mapping of Saaremaa there appeared a practical need for returning to previous division as much as possible. In the present scheme the original subdivision of the Jaani Stage (Formation) into members by A. Aaloe [2, 3] has been restored.

According to this, in the lower half of the, **Jaani Formation**, marlstones and dolomitic marlstones of the Mustjala Member were distinguished. In the upper half of the Jaani Formation the Ninase and Paramaja members were distinguished, replacing each other laterally. At that the Ninase Member is represented by biohermal and skeletal limestones, which in middle Saaremaa formed a northwest - southeast directed shoal barrier, northeast and east of which there occur marlstones and domerites of the Paramaja Member of restricted shelf.

**Anelema Formation.** On Estonian mainland, in the easternmost part of the outcrop area of the Jaani Stage in the vicinity of Pärnu-Jaagupi its upper half is represented by medium- to thick-bedded platy micritic dolomites, which have initially probably been pelletal limestones, formed in the restricted shelf environment. The formation contains the conodonts *Kockelella ranuliformis*, *Ozarkodina gulletensis*, *O. sagitta rhenana*. The need of establishing this rock body as an independent formation was pointed out by E. Klaamann [16] and R. Einasto [21], but so far it has not been defined formally. The type section is the Anelema dolomite quarry near Pärnu-Jaagupi, where the Anelema Formation comprises the uppermost 3.5 m of the section [21, Fig. 57]. The lower boundary is defined by the abrupt increase in the carbonate content. The formation lies on domerites and argillaceous dolomites of the Mustjala or Paramaja members and from above it is limited by Prequaternary denudation.

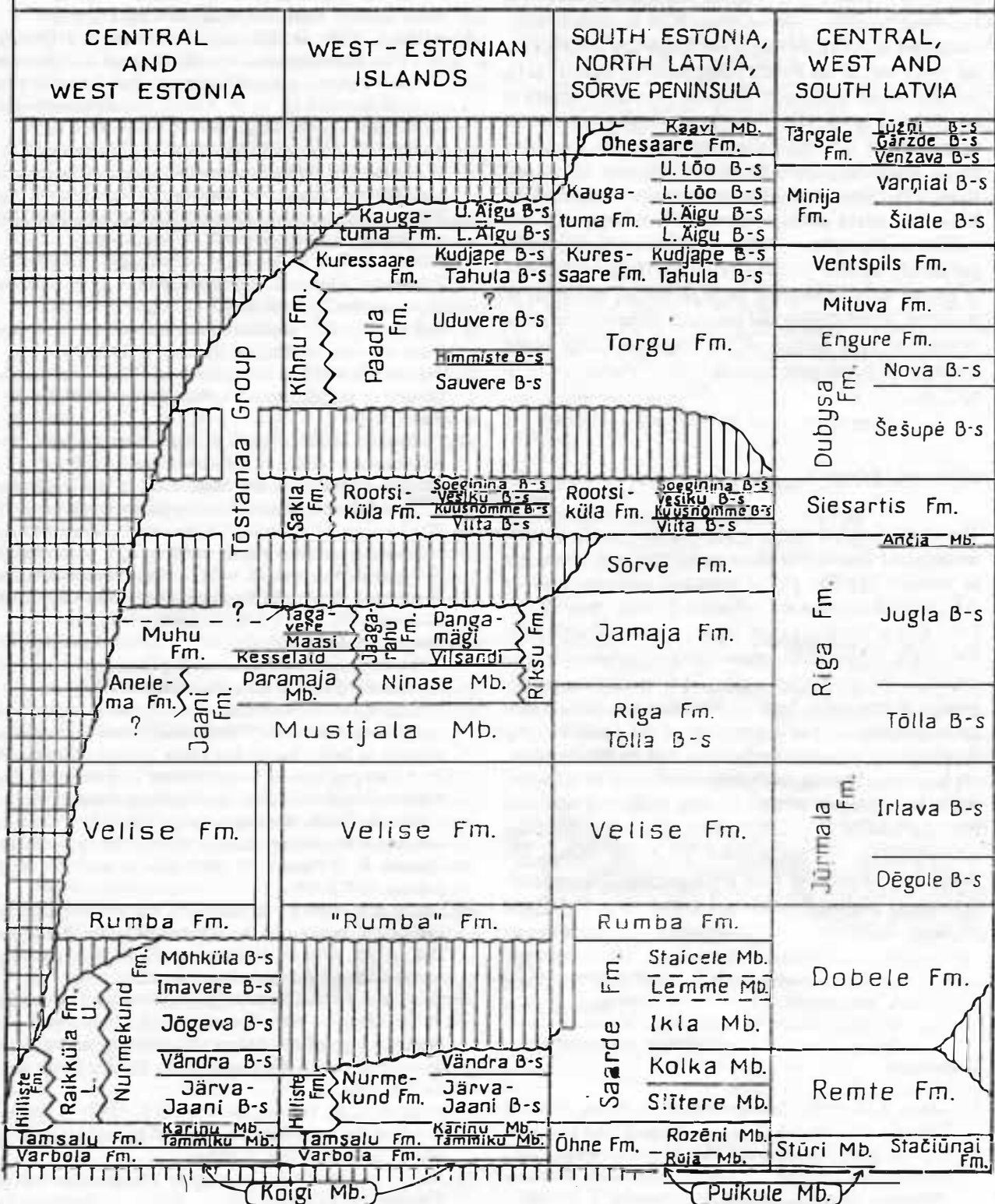
**Riksu Formation.** Southwest of the Ninase reef- and shoalbarrier rocks there occur nodular biomicritic lime- and marlstones of open shelf genesis, which are here treated as a new - Riksu Formation. The formation is represented by cyclically alternating marlstones, argillaceous limestones and nodular biomicritic limestones, which lithologically resemble the Sõrve Formation of the Jaagarahu Stage, stratigraphically, however, occur lower. Among the marlstone - limestone cycles the lowermost and the most distinct one correlates probably with the Ninase Member of the Jaani Formation, the rest part with the Jaagarahu Formation. Generally the carbonate content in rocks increases upwards. The Riksu core section in southwestern Saaremaa in the interval of 80.4-144.7 m has been chosen as the stratotype of the formation. The lower boundary coincides with a distinct discontinuity surface at the base of the first marlstone - limestone cycle. The formation occurs in southwestern Saaremaa and is southwards (on Sõrve Peninsula) replaced by a relatively

homogenous marlstone complex of the Jamaja Formation, northeastwards, however, by skeletal and reef limestones of the Ninase Member of the Jaani Formation and the Jaagarahu Formation.

Since 1976 [5] the **Jaagarahu Formation** was defined as the whole complex of limestones and dolomites of shallow-water genesis, occurring throughout the outcrop area of the Jaagarahu Stage. Basing on its cyclic structure it was subdivided into the Vilsandi, Maasi and Tagavere beds. For practical reasons it has appeared more expedient to distinguish dolomitic rocks in eastern Saaremaa, Muhu and Estonian Mainland as a separate formation, in this way returning to the original division of A. Luha [25], who established on this stratigraphic level the Pangamägi - Jaagarahu limestone complex in the west and the Muhu dolomite complex in the east. The Jaagarahu Formation in the restricted geographic extent, as used here, consists (in the lower part) of the Vilsandi Beds represented mostly by reef limestones and (in the upper part) by coral-stromatoporoid, skeletal and argillaceous limestones which A. Aaloe [2] treated as the Pangamägi Member. The stratotype of the Jaagarahu Formation is the abandoned Jaagarahu quarry and core section in the interval of 0.3-13.1 m [11, 21]. The stratotypes of the Vilsandi and Pangamägi beds are correspondingly the outcrops on Vilsandi Island and at Kurevere-Pangamägi [30]. The formation lies on the Ninase Member of the Jaani Formation and is disconformably overlain by the Rootsiküla Formation. It occurs in northwestern Saaremaa, being replaced by the Muhu Formation to the east and by the Riksu Formation to the south.

The **Muhu Formation** is represented by dolomites of different genesis. More dominating are epigenetic porous dolomites with massive dolomitized reef mounds (in the lower part) and flaggy micritic, often argillaceous primary dolomites (in the upper part). The former ones constitute the rocks of the shoal belt, the latter those of the lagoonal belt. The formation occurs in eastern Saaremaa, on Muhu and Kesselaid islands and in western Estonia in Virtsu - Lihula area. It lies on domerites and dolomitic marlstones of the Jaani Formation, whereas the lower boundary is mostly represented by a distinct wavy erosional surface, above which the carbonate content in rocks increases abruptly. It is not excluded that the lower boundary of the formation is diachronous and that reef-formation started at somewhat different times in different places [12]. The upper boundary of the formation is erosional and related to the pre-Rootsiküla gap in sedimentation [31] combined with Prequaternary denudation. The stratotype of the formation is the Üügu cliff on the north coast of Muhu Island [30]. The Muhu Formation is divided in ascending order into the Kesselaid, Maasi and Tagavere beds. The two first names were introduced by A. Aaloe [2, 6], basing on A. Luha [25], the third was added by Aaloe et al. in 1976 [5]. The Kesselaid Beds (Member) are represented by massive reef dolomite mounds, surrounded by porous platy dolomites

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difficult to establish the boundaries of stages in totally dolomitic sections of Tõstamaa Peninsula on Estonian mainland, as well as the occurrence of hiatuses in sedimentation in the upper part of the Jaagarahu Stage and in the lower part of the Paadla Stage proved recently [31]. For that reason this hardly divisible dolomite complex is here treated as the Tõstamaa Group. Stratigraphically it extends from the Jaagarahu Stage up to the Kuressare Stage, proceeding from the data of Einasto, Märss and Kala [13]. (The name of Tõstamaa was introduced by Kaljo [21] in the stratigraphic chart in a lower rank and smaller stratigraphic volume). The corresponding rocks are mostly micritic to fine-crystalline flaggy dolomites, in places with interlayers of argillaceous dolomite or domerite. Stromatolites and oncolites occur also on some levels. The type section of the Tõstamaa Group is the Varbola -502 borehole section in the interval of 19.0-62.3 m.

## CONCLUSIONS

The most essential changes, introduced into the present modernized correlation chart of Estonia and Latvia are as follows: (1) The global standard, recommended by the Subcommission on Silurian Stratigraphy of the I.U.S.S. was used. (2) Four regional biozonal scales (by conodonts, chitinozoans, ostracodes and vertebrates) were added to the graptolite scale. (3) Considerable stratigraphic hiatuses have been established in the outcrop area, corresponding to the upper part of the Raikküla and Jaagarahu stages and to the lower part of the Paadla Stage. (4) In central Estonia, including the vicinity of Adavere, the lower boundary of the Adavere Stage was removed from the base of the Mõhküla Beds to their top, therefore a neostratotype for the Adavere Stage was chosen. (5) Some new formations were distinguished (Nurmekund, Anelema, Muhu, Riksu) and some were redefined (Hilliste, Raikküla, Jaani, Jaagarahu).

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#### Хелдур Нестор

### КОММЕНТАРИИ К ОБНОВЛЕННОЙ СТРАТИГРАФИЧЕСКОЙ СХЕМЕ СИЛУРА ЭСТОНИИ И ЛАТВИИ

#### Резюме

Публикуются дополнения к стратиграфической схеме силура Эстонии и Латвии с необходимыми объяснениями. В качестве глобального стандарта использован проект, рекомендованный подкомиссией стратиграфии силура МСГН. Четыре региональные биоэональные шкалы (по конодонтам, хитинозоям, остракодам, позвоночным) прибавлены к граптолитовой шкале. В районе выходов заметные стратиграфические перерывы установлены в верхней части райккюлаского и ягарахуского горизонтов и в низах паадлаского горизонта. В Центральной Эстонии, включая окрестность Адавере, нижняя граница адавереского горизонта перемещена с основания мыхкюласких слоев к их кровле, поэтому для адавереского горизонта выбран неостратотип - каменоломня Пяри. Дефинированы некоторые новые свиты (нурмекундская, анелемаская, мухуская, риксуская и переопределены объемы других (хиллистеской, райккюлаской, ягарахуской).