УДК 552.54:549/1/:551.733.3/474.2+486.92/

DISTRIBUTION AND MINERALOGY OF SILT-SIZED TERRIGENOUS MATERIAL IN THE NORTH BALTIC UPPER SILURIAN DEPOSITS

E. Jürgenson

The Upper Silurian section in the North Baltic area consists primarily of biogenic calcarenites and calcilutites interbedded with thin lithocalcirudites and interlayers of marl. Reef-limestones are not uncommon. The content of terrigenous material varies between 3-5 % in reef-limestones and 70-90 % in marls and clays. Most of the terrigenous material is represented by clay fraction with clay minerals, such as illite and chlorite. Grains in silt- and sand-size are commonly minor increasing upwards in the section.

In the course of a general study of the Baltic Silurian carbonate rocks a special study of its terrigenous material (insoluble residue) was carried out (Юргенсон, 1970, 1977). The present study is based on the granulometric and mineralogical investigation of Upper Silurian silt fraction. Samples were collected from 9 boreholes of Western Estonia (Saaremaa, Ruhnu) and South-Western Latvia (Fig.). In order to compare the material with neighbouring areas a series of determinations was made in samples from Lithuania and Gotland. At the author's disposal were some samples from the Silurian sequence of Gotland, kindly given her by Dr. Einar Klaamann and Dr. Sven Laufeld.

250 samples were acidized in the standard manner with 3.5 % HCl. Granulometric analyses were performed by pipetting and sieving. For the mineralogical analyses the clay fraction was washed out and the rest of residues separated into two classes: sand (grains with diameter over 0.1 mm) and silt (0.01-0.1 mm). The presence of sand grains is commonly rare, their content does not exceed 10 %, even in the deposits known as Ohesaare Sandstones from Saaremaa and the Burgsvik Sandstone from Ronehamn, samples analysed by the author of the present paper.

The silt fraction of the insoluble residue varies between 5 % and 90 %. We can calculate the real content of silt fraction of terrigenous material after the identification and exclusion of authigenic minerals (pyrite, chalcedony). The maximum silt fraction in the North Baltic occurs in the Ohesaare Stage as 88-93 % (Fig.). Taking into account the carbonate component the silt content in the whole rock does not exceed 60 %. Calcareous siltstones are known in the Ohesaare Stage from boreholes Ohesaare-2 (4.6-5.2 m) and Kaavi (7.8-8.9 and 17.5-18.0 m) in the thickness of about 0.5-1 m. The carbonate component consists mainly of sparry calcite with skeletal detritus in Ohesaare-2 and dolomite crystals in Kaavi. The calcareous siltstones of Gotland are older and occur mainly in Burgsvik Beds (the stratigraphic nomenclature and correlation used in this paper is that proposed in Решения..., 1978). A. Hadding gives the thickness of Burgsvik Sandstones about 40 m (Hadding, 1941). The content of sand-silt fraction in the total rocks reaches 80 % (after Stel, 1978). In the sample from Ronehamn analysed by author the content of sandsilt fraction in the sandstone was 46.2 %. The silt content in the deposits of the same age in the East Baltic area does not exceed 10-15 % of the total rock.

Local maxima of the silt content occurred in the Kaugatuma Stage in the boreholes of Ohesaare, Kolka and Ventspils (26-37 % of total rock) (Fig.). In Lithuania the maximum of silt content in terrigenous material of Upper Silurian deposits was established, in most cases, in the beds analogous to the Kaugatuma Stage. Further to the south (bore-

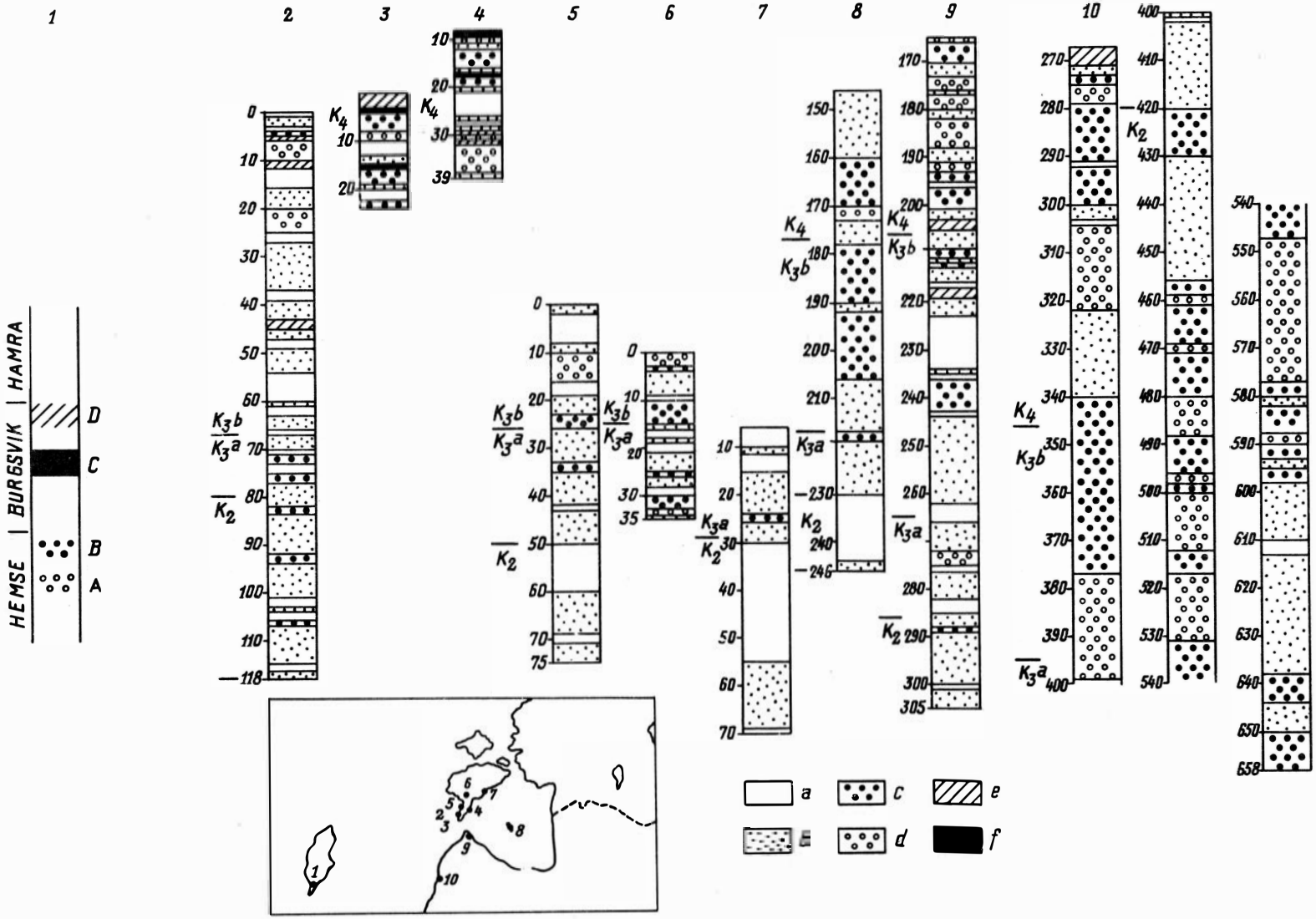

Fig. Location of the sections studied and distribution of the sand-silt-sized fraction in the Upper Silurian carbonate rocks of North Baltic and Gotland.
1 - succession of the samples studied in outcrops of Gotland. A - Ocksarve, B - Hallsarve, C - Ronehamn, D - Lunde. Borings: 2 - Ohesaare, 3 - Ohesaare-2, 4 - Kaavi, 5 - Kaugatuma, 6 - Vaivere, 7 - Tulpe, 8 - Ruhnu, 9 - Kolka, 10 - Ventspils.
The content of sand-silt-sized fraction in terrigenous material: a - less than 10 %; b - 10-20 %; c - 20-30 %; d - 30-50 %; e - over 50 %; f - calcareous siltstone beds.

hole Virbalis 875.5 m) the maximum occurs in calcareous marls corresponding to the Paadla Stage.

There is no definite relationship between grain size and amount of terrigenous material. We can preliminarily distinguish two main types of the accumulation of sand-silt-sized material. The first type is connected with an intensive accumulation of terrigenous material (20-80 %). These are the argillaceous limestones and marls of transgressive character distributed mainly in the lower part of the Paadla Stage, in the Kuressaare Stage and in the lower part of the Ohesaare Stage. The second type of accumulation exists in limestones containing terrigenous material moderately (15-30 %); these are the coarse crystalline limestones, particularly some lithocalcarenites of regressive character occurring in the upper part of the Paadla Stage, in the Kaugatuma Stage and some uppermost beds in the Ohesaare Stage (Ventspils 271.0 m).

According to the granulometric analysis carried out by pipetting and direct measurements made under the microscope, the most frequent diameter of the silt grains is 0.03-0.08 mm. The material is coarser in the calcareous siltstones, with median grain size of Ohesaare siltstone 0.05-1.0 mm and Burgsvik Sandstone 0.08-0.115 mm (after Stel, 1978). The silty ooidal limestones from the upper part of the Burgsvik Beds contain quartz grains with diameter about 0.05 mm (Hadding, 1941). Biocalcarenitic limestone with ooids at the boundary of Burgsvik and Hamra Beds, analysed by the author, in a sample from Lunde contained quartz grains with diameter about 0.8-1.2 mm.

The mineralogical identification of the sand-silt-sized fraction was carried out under a microscope; the grains were mounted in immersion-liquids. The light and heavy minerals were not separated with bromoform (Юргенсон, 1976). More than 500 light and 100 heavy mineral grains were counted in each sample. The relative frequencies (percent) of different minerals were computed separately for the light and heavy fractions. It must be noted that heavy minerals are concentrated mostly in the smaller size fractions (< 0.05 mm).

The light mineral fraction of the terrigenous material accounts for about 98-99 % of the total number of silt grains in most of the samples studied. Of this total, the light fraction less than 1-2 percent is composed of mica (muscovite, chlorite). The content of quartz and feldspar varies between 30-40 % and 60-70 %. In most cases the quartz prevails. In the sandclass the content of quartz is higher, reaching 99 %. The index of maturity (quartz: feldspar) varies in the Upper Silurian terrigenous material from 1.5 to 4.7, increasing in younger deposits. More remarkable concentrations of silt are often characterized by a high index of maturity (over 3), only in samples with a notable content of mica (biotite, muscovite) the values of indexes are moderate (1-3).

Quartz grains are mostly subangular or angular. Rounded grains occur as a rule in the sand class. Inclusions of gas and rutile, and traces of solution and overgrowths of chlorite are typical of quartz grains. The wavy extinction is not rare. Grains with microcrystalline texture were found in the Kuressaare and Kaugatuma Stages.

Feldspars are represented mainly by orthoclase. Grains of plagioclase occur sporadically. In general the grains of feldspar are subangular and moderately or strongly weathered. Grains with traces of solution and secondary overgrowths are known from the terrigenous material of the Paadla Stage.

Muscovite is common in many of the samples as well rounded colourless flakes. Chlorite is represented by greenish flakes, partly allothigenous, partly occurring as a weathering product of biotite. Fragments of extremely fine-granular siltstone are present in many samples of the Upper Silurian terrigenous material (boreholes of Kaugatuma, Tulpe, Ventspils). The diameter of the siltgrains does not exceed 0.02 mm and they are cemented mostly by silicious material, which is sometimes weakly phosphatic. The diameter of the siltstone particles varies between 0.03-0.06 mm. In the Burgsvik Sand-

Table

Average content of heavy non-opaque minerals in the silt-sized terrigenous material of Upper Silurian rocks of borehole sections from Saaremaa, Ruhnu, North-West Latvia, and outcrops of Gotland

	Ohe-saare	Ohe-saare-2	Kaavi	Kauga-tuma	Vai-vere	Tulpe	Ruhnu	Kolka	Vents-pils	Ock-sarve	Hall-sarve	Rone-hamn	Lunde
					Paadla Stage					Hemse Beds			
1. Number of samples	14	-	-	7	13	-	7	9	10	3	3	-	-
2. Heavy mineral fraction	2.6	-	-	0.8	1.0	-	0.5	1.1	2.1	0.6	7.8	-	-
3. Zircon	11.3	-	-	41.2	23.4	-	30.7	32.5	38.8	39.0	60.0	-	-
4. Garnet	8.1	-	-	23.0	26.1	-	25.4	29.2	14.3	32.7	8.5	-	-
5. Tourmaline	2.4	-	-	13.4	8.4	-	19.1	14.0	7.0	5.3	1.7	-	-
6. Titaniferous minerals	12.0	-	-	8.8	9.8	-	15.9	10.4	6.4	9.2	12.8	-	-
7. Amphiboles-pyroxenes	1.8	-	-	1.9	0.8	-	0.9	0.3	0.5	1.1	0.6	-	-
8. Corundum	19.1	-	-	0.6	0.6	-	3.0	0	0.7	0	0	-	-
9. Biotite	35.6	-	-	9.5	26.5	-	2.9	10.6	31.0	11.6	15.4	-	-
0. Et al.	9.7	-	-	1.6	4.4	-	2.2	3.0	1.3	1.1	1.0	-	-
	100.0	-	-	100.0	100.0	-	100.0	100.0	100.0	100.0	100.0	-	-
					Kuressaare Stage							Burgsvik Beds	
1. Number of samples	20	-	-	7	6	8	3	13	7	-	-	3	3
2. Heavy mineral fraction	1.3	-	-	1.3	1.2	1.6	1.9	1.1	0.9	-	-	1.0	0.4
3. Zircon	14.8	-	-	42.2	16.0	14.1	20.0	27.3	43.5	-	-	12.6	34.0
4. Garnet	11.0	-	-	16.1	7.6	7.3	19.2	11.3	16.6	-	-	0	10.0
5. Tourmaline	3.0	-	-	7.9	3.7	8.6	15.2	3.7	7.7	-	-	1.9	2.0
6. Titaniferous minerals	21.8	-	-	10.8	5.4	4.2	22.4	12.0	10.3	-	-	3.0	12.2
7. Amphiboles-pyroxenes	0.2	-	-	1.6	0.5	0.3	0.8	2.1	1.9	-	-	0	1.7
8. Corundum	15.5	-	-	0.5	0.2	0.1	0	1.0	0.7	-	-	0	0
9. Biotite	29.1	-	-	20.5	66.5	65.3	21.6	33.4	15.9	-	-	72.5	40.0
0. Et al.	4.6	-	-	0.4	0.1	0.1	0.8	9.2	3.4	-	-	0	0.1
	100.0	-	-	100.0	100.0	100.0	100.0	100.0	100.0	-	-	100.0	100.0

Table (continued)

	Ohe-saare	Ohe-saare-2	Kaavi	Kauga-tuma	Vai-vere	Tulpe	Ruhnu	Kolka	Vents-pils	Ock-sarve	Hall-sarve	Rone-hamn	Lunde
						Kaugatuma Stage							
1. Number of samples	32	10	-	13	-	3	5	19	14	-	-	-	-
2. Heavy mineral fraction	1.7	1.8	-	1.5	-	1.9	1.0	2.4	2.2	-	-	-	-
3. Zircon	6.8	14.0	-	20.0	-	27.8	33.2	17.6	19.8	-	-	-	-
4. Garnet	7.2	7.5	-	14.7	-	21.2	20.8	9.4	11.5	-	-	-	-
5. Tourmaline	2.5	4.4	-	6.9	-	9.9	11.4	6.3	7.2	-	-	-	-
6. Titaniferous minerals	6.6	5.4	-	6.3	-	10.6	19.3	6.0	7.7	-	-	-	-
7. Amphiboles-pyroxenes	0.4	0.6	-	1.2	-	1.7	1.5	0.1	0.3	-	-	-	-
8. Corundum	0.2	0.3	-	0.1	-	0	0.3	3.9	0	-	-	-	-
9. Biotite	71.5	66.2	-	50.0	-	28.8	10.8	55.5	52.9	-	-	-	-
0. Et al.	4.8	1,6	-	0.8	-	0	2.7	1.2	0.6	-	-	-	-
						Ohesaare Stage							
1. Number of samples	-	13	23	-	-	-	4	24	8	-	-	-	-
2. Heavy mineral fraction	-	1.1	3.2	-	-	-	1.3	2.5	1.9	-	-	-	-
3. Zircon	-	29.3	15.6	-	-	-	22.4	27.3	18.0	-	-	-	-
4. Garnet	-	19.5	12.1	-	-	-	11.7	11.6	7.8	-	-	-	-
5. Tourmaline	-	5.0	6.0	-	-	-	9.8	6.9	5.5	-	-	-	-
6. Titaniferous minerals	-	17.8	5.0	-	-	-	15.3	7.3	5.7	-	-	-	-
7. Amphiboles-pyroxenes	-	1.6	0.2	-	-	-	0.3	0.3	0.4	-	-	-	-
8. Corundum	-	0.4	0.2	-	-	-	0	3.3	0.2	-	-	-	-
9. Biotite	-	21.1	58.8	-	-	-	35.8	36.4	61.4	-	-	-	-
0. Et al.	-	5.3	2.1	-	-	-	4.7	6.9	1.0	-	-	-	-
	-	100.0	100.0	-	-	-	100.0	100.0	100.0	-	-	-	-

stone of Ronehamn siltstone fragments were noticed in the sand class (diam. 1.0-1.? mm) composed of quartzouse grains with diameter 0.05-0.08 mm (~15 % of the light fraction). The first-mentioned siltstone fragments are well rounded and most likely of allochthonous origin. The siltstone fragments in Burgsvik Sandstone seem to be more compactly cemented particles of autochthonous origin.

The non-opaque heavy mineral suite observed in samples taken from the Upper Silurian silt-sized terrigenous material is characterized by a biotite-zircon-garnet-tourmaline association (Table). The content of biotite prevails in most samples taken from the central part of the Paadla Stage (excluding boreholes of Kaugatuma, Kolka, Ruhnu). In the Kuressaare Stage it prevails only in samples taken from boreholes more closely situated to the probable shore line (Vaivere, Tulpe). The amount of biotite is higher in the Kaugatuma Stage and in the Ohesaare Stage (Kaavi and Ventspils) not including the uppermost beds of the sequence. There is much biotite in samples taken from the Burgsvik Beds. Brown-coloured biotite is more common in the deposits of the Paadla Stage, the greencoloured variety is more frequent in younger deposits. Many of the flakes of biotite are attacked by weathering. Abundant bleached biotite has been noticed in the deposits of the Kuressaare Stage which has entirely lost colour.

The highest precentages of zircon in the Upper Silurian are found in the Paadla Stage (Table) where the maximum values reach 60-70 %. 60 % of zircon was also noticed in the samples from the upper part of the Hemse Beds of Gotland. The zircons studied were of two types: slightly rounded colourless fragments and idiomorphic crystals. Fragmental rounded zircons are more common and distributed throughout all the size classes whereas the idiomorphic crystals are rare and confined to the upper limits of the silt size grains.

As a rule the garnet is less abundantly distributed in the Upper Silurian than zircon. Most frequently it varies between 10-20 %. Only in the boreholes of Vaivere and Ruhnu does garnet prevail over zircon in some samples from the Paadla and Kuressaare Stages. The highest content of garnet in the analysed samples of Gotland occurred in the Hemse Beds from Ocksarve. The grains of garnet are very often subangular with traces of solution; the colourless or yellowish grossular is most widely distributed. Rare grains of brown andradite have been also found.

Tourmaline is a minor component of the heavy mineral association, the average content usually does not exceed 10 %. The amount of tourmaline is higher in the Paadla Stage in boreholes of Ruhnu, Kolka and Kaugatuma. Most tourmalines occur as subangular prismatic grains with a pleochroism from green to brown. Blue-coloured varieties are rare and they are known only from the Ohesaare Stage.

Titaniferous minerals are represented by rutile, brukite, anatas, titanite and leucoxene. Most common of them are rutile, titanite and leucoxene, the latter as a weathering product of ilmenite and rutile. The average amount of titaniferous minerals varies from 4.2 to 22.4 %, it seems to have local concentrations in the boreholes of Ruhnu and Ohesaare. The rutile and brukite are represented mainly by reddish brown little prismatic grains (0.01-0.05 mm).

The occurrence of amphiboles and pyroxenes is in most cases sporadic. Average content does not exceed 2 %. Of the amphibole group the green hornblende is most common. The pyroxenes are represented mainly by augite and hypersthene; diopside was identified in the deposits of the Ohesaare Stage.

The average content of corundum may reach 19.0 % among the non-opaque heavy minerals of Upper Silurian deposits. In the former investigations it was noted (Юргенсон, 1977) that corundum is concentrated in the Upper Wenlock deposits in the north-western part of the Silurian sedimentation basin (Ohesaare, Kipi) where the maximum content reaches up to 80 % of the heavy mineral fraction. The average abundance of corundum is

considerably high in the section of Ohesaare, even in the Paadla and Kuressaare Stages, and decreases at the lower boundary of the Kaugatuma Stage. The analyses from samples of Gotland do not indicate corundum in Ludlow. However, it is present in the terrigenous material of the Slite and Högklint limestones. Corundum occurs as colourless angular grains with relatively high diameters compared with zircon, garnet and other heavies.

The rest of the non-opaque heavy fraction is represented by staurolite, disthene, epidote, sillimanite, apatite and monacite. Staurolite and disthene are commonly present in transgressive deposits at the lower boundary of the Kuressaare Stage and the Ohesaare Stage. The appearance of these minerals is mainly connected with the beginning of megacycles of sedimentation. Disthene occurs in slablike little grains, colourless or pale bluish. Staurolite was found as prismatic grains, slightly rounded, pleochroic from dark brown to yellowish-grey.

The presence of epidote and sillimanite is of occasional character. Grains of epidote are well rounded pale green, and weakly pleochroic. Sillimanite was mainly identified in the Ohesaare Stage as little prismatic grains.

The presence of apatite and monacite in the insoluble residue of carbonate rocks depends on the activity of the solution process. Dissolvable in dilute hydrochloric acid the preservation of phosphatic minerals depends mostly on the duration of solution and lithologic character of the rocks analysed. It is certain that we cannot account for the absolute amounts of these minerals in such cases.

Based on the accumulated evidence reported in this paper some general conclusions may be derived. The Upper Silurian rocks in the North Baltic and Gotland are considerably rich in silt-sized terrigenous material, which concentrations occur on several levels as lenses and layers of calcareous siltstones. The distribution of the latter is limited and strictly depends on local hydrodynamic conditions. Owing to that fact they cannot be taken as a very reliable correlation criteria.

The mineralogical composition of silt concentrations may be of two kinds: 1. high value of maturity index accompanied with much micas (muscovite, biotite, chlorite) and a moderate suite of non-opaque heavy minerals and 2. lower value of maturity indexes, moderate content of micas and a more numerous suite of heavies. The total content of terrigenous material is higher in the first case.

Comparison of heavy mineral suites might afford a basis for correlation when there has been a major change in conditions of sedimentation (transgression, regression).

The non-opaque heavy minerals have long been used as valuable indices to provenance or source areas. Their usefulness is greatly reduced in our case, because many of them are most likely to be derived from older sedimentary rocks. The heavy mineral suites observed in samples taken from the deposits in the North Baltic and Gotland contained nearly the same minerals but in varying frequencies. It seems very likely that a great part of the silt fraction was derived almost entirely from one and the same source area, though the quantity and coarseness of the silt fraction is greater in the deposits of Gotland.

References

Hadding, A. The Pre-Quaternary sedimentary rocks of Sweden, VI. Reef limestones. Meddelanden från Lund Geologisk-Mineralogisk Institution n:o 90, 1941.

Stel, J. H. van Studies on the palaeobiology of Favositids. Rijksuniversiteit te Groningen. 1978, p. 46-49; p. 195-213.

Решения Межведомственного регионального стратиграфического совещания по разработке унифицированных стратиграфических схем Прибалтики, 1976 г. Ленинград, 1978.

Юргенсон Э. А. Распределение и состав терригенного материала. - В кн.: Силур Эстонии, Таллин, 1970, с. 69-101.

Юргенсон Э. А. Опыт исследования нерастворимого остатка карбонатных пород. - В кн.: Методика и интерпретация результатов минералогических и геохимических исследований, Вильнюс, 1976, с. 31-36.

Юргенсон Э. А. Расчленение разрезов силурийских отложений Прибалтики по терригенному материалу. - В кн.: Фации и фауна силура Прибалтики, Таллин, 1977, 56-70.

РАСПРЕДЕЛЕНИЕ И МИНЕРАЛЬНЫЙ СОСТОВ АЛЕВРИТОВОЙ ФРАКЦИИ ТЕРРИГЕННОГО МАТЕРИАЛА В ВЕРХНЕСИЛУРИЙСКИХ ОТЛОЖЕНИЯХ СЕВЕРНОЙ ПРИБАЛТИКИ

Э. А. ЮРГЕНСОН

Исследован гранулометрический и минеральный составы алевритовой фракции верхнесилурийских карбонатных отложений Западной Эстонии и Северо-Западной Латвии. Для сравнения приведен ряд данных из соответствующих отложений Литвы и острова Готланд. Максимальная концентрация алевритовой фракции установлена в Северной Прибалтике в даунтоне, в охесаареском горизонте /рис./, на острове Готланд - в известковом алевролите слоев Бургсвик /лудловский ярус/.

Минеральный состав терригенного материала Северной Прибалтики и Готланда мало отличается между собой. В основном варьируются количество и частота встречаемости отдельных минералов. Прозрачные аллотигенные минералы тяжелой фракции представлены биотит-циркон-гранат-турмалиновой ассоциацией /табл. 1/. Можно предполагать, что большинство терригенного материала происходит из одного и того же источника, располагавшегося, видимо, ближе к Готланду, чем Прибалтике, так как его количество и размер зерен в первом районе больше.