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GRAIN SIZE ANALYSIS AND MINERALOGY OF THE TREMADOCIAN DICTYONEMA SHALE IN ESTONIA

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The Tremadocian black shale or so-called Dictyonema shale of Estonia consists of 65–70 % mostly silicate minerals, 10–15 % organic and 10–20 % X-ray amorphous matter. Grain size and the quantitative analysis of silicate minerals in black shale was carried out. After disintegration of shale it was found out that siliceous crystalline part contains 70 % silt-sized and 30 % clay-sized particles. Sand-sized particles are in negligible amounts. The composition of the silicate minerals is rather uniform: up to 40 % clay minerals (mainly illite and illitic illite-smectite) and micas, over 30 % K-feldspar and almost 30 % quartz. However, gradual changes in grain size and mineral composition occur laterally as well as vertically.

Grain size distribution of K-feldspar and quartz in the shale is unimodal and closely similar; both minerals are most frequent in the 5–10-μm fraction. Most of the K-feldspar, especially in the <10-μm fraction, is authigenic as recognised by its euhedral non-altered crystal form. XRD-analysis revealed that this K-feldspar is a monoclinic low sanidine.

Thus, we cannot draw far-reaching conclusions about the sedimentation process based on grain size analysis of the Dictyonema shale, but conclude that silicate grains in Dictyonema shale are reflecting most of all the kinetics of diagenetic processes.

Propose of Study

Shales are fine-textured terrigenous rocks, which are poorly known and incompletely understood because their particles are so small [1]. Especially the mineralogical composition and the size of minerals are poorly investi-

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gated. Usually the mineralogical composition has been effected by recalculation of chemical analysis. The first attempt to investigate the mineralogy of the Dictyonema shale in different fractions was made by K. Utsal and others [2] by XRD. The mineralogy of authigenic components in the Dictyonema shale – carbonates and siliceous minerals – was done by A. Loog and others [3, 4]. T. Kallaste and E. Pukkonen [5] have presented some data about of sulfides and the mineralogy of the very fine sand and coarse silt fraction was analysed by T. Kurvits and A. Kleesment [6].

This study tries to enlarge data on grain size and mineralogy of the Dictyonema shale [7]: determine the grain size distribution of the Dictyonema shale in vertical and in horizontal dimensions. XRD quantitative analysis of the main constituents – silicate minerals in the whole rock as well as in different grain size fractions – and the changes in the area were made by J. Aruväli and T. Kurvits. The grain size distribution of these minerals is given by T. Kurvits.

Geologic Setting

The Tremadocian black shale or so-called Dictyonema shale occurs in northern Estonia (Fig. 1). It is a part of the extensive Cambrian-Ordovician black shale in Baltoscandia and constitutes the eastward, younger facial continuation of the Alum shale of southern and central Sweden.

The Dictyonema shale is fine-grained, finely laminated to massive, dark-brown sedimentary rock commingled with light-gray quartzitic silt layers from tens of millimetres up to several centimetres in thickness. It contains 65–70 % mineral particles, 10–20 % X-ray amorphous mineral matter and 10–15 % organic matter [2].

In western Estonia the Dictyonema shale belongs to the Pakerort Stage and in eastern Estonia to the Varangu Stage, Lower Ordovician [8]. The most complete stratigraphic sections of the Dictyonema shale occur in the central part of its distribution area, between Tallinn and Tapa, where the lower part of the Dictyonema shale belongs to the Pakerort Stage and the upper to the Varangu Stage [9, 10]. Based on sedimentary structures, the Dictyonema shale is divided into two facies [8]. In general, the Dictyonema shale is finely laminated, but the western facies contains mainly up to 10-cm thick massive shale beds, whereas the eastern facies is less homogeneous, with frequent silty interlayers. The boundary between these facies coincides roughly with the line marking the Varangu age of the entire Dictyonema shale section.

The thickness of the Dictyonema shale reaches 7 m in northwest Estonia, decreasing in eastern and southern directions. With decreasing thickness, the number of quartzitic silt laminae and layers increases. These layers are associated with several authigenic carbonate, phosphatic, siliceous and sulphide mineralizations. In the vertical section the interval of shale is clearly distin-

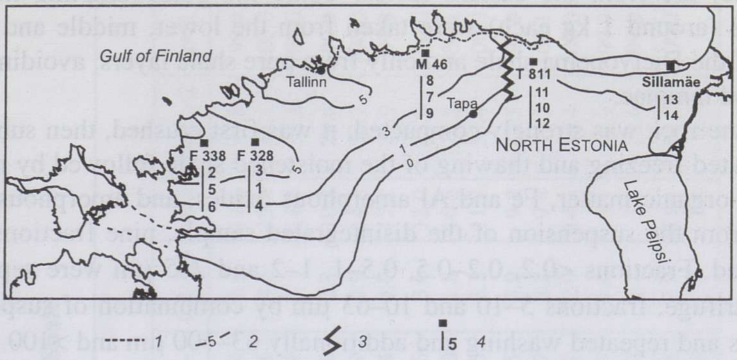

Fig. 1. Locations of core and outcrop sample sites in the Dictyonema shale, northern Estonia: *1* – North Estonian klint, northern border of the Dictyonema shale; *2* – isopachs of the Dictyonema shale, m; *3* – separating line of the Dictyonema shale facies; *4* – sample number.

Borehole (outcrop)	Longitude	Latitude
F 338	23°40′	59°08′
F 328	24°11′	59°08′
M 46	25°38′	59°28′
T 811	26°29′	59°27′
Sillamäe	27°43′	59°25′

guished from the over- and underlying beds. The boundary with the underlying bed is sedimentational or erosional, lithologically distinct, but the contact with the overlying Varangu or Leetse Formation is always erosional.

'Dictyonema' used for the name of Tremadocian shales in Estonia was given after *Dictyonema flabelliforme* found in Dictyonema shale. Today the taxonomy of these graptolites is revised [11] and they are assigned to the genus *Rhabtinopora*. And more, not the whole section of shale belongs to *D. flabelliforme / R. flabelliformis* Zone, but also to the *Kiaerograptus* Zone [10]. Thus, the rock name 'Dictyonema shale' carries only a traditional not a true scientific meaning. Previously used terms 'graptolite/graptolithic argillite', 'kerogenous argillite', 'Dictyonema argillite' [2, 3, 6, 9] for the Dictyonema shale stress one or another quality of the rock. The term 'argillite' is in many shale classifications used for metamorphosed rock [12] and therefore not proper here, and also does not stress the fact that Dictyonema shale belongs to black shales.

Sample Preparation

Analyses were made on samples collected from four drill cores and from exposures near Sillamäe (Fig. 1). Two drill cores (F 338, F 328) represent the western facies, one (M 46) is from the central part and two (T 811 and

Sillamäe) are from the eastern facies. Using the point-sampling method, samples (around 1 kg each) were taken from the lower, middle and upper parts of the Dictyonema shale and only from pure shale layers, avoiding silty beds and laminae.

As the rock was strongly compacted, it was first crushed, then subjected to repeated freezing and thawing of the moistened shale followed by removing the organic matter, Fe and Al amorphous oxides, and amorphous silica [13]. From the suspension of the disintegrated sample, nine fractions were separated. Fractions <0.2, 0.2–0.5, 0.5–1, 1–2 and 2–5 μm were separated by centrifuge, fractions 5–10 and 10–63 μm by combination of suspension analysis and repeated washing and additionally 63–100 μm and >100 μm by wet sieving. Accumulation of salts in the smallest fraction during the processing of samples was eliminated. XRD analysis of the fractions to determine mineral composition was carried out using the method described previously [13].

Grain Size Analysis of the Silicates

Results

After the chemical treatment of the Dictyonema shale samples only the silicate minerals remained in considerable amounts. A few other minerals occurred in negligible quantities. These were distributed randomly between different fractions (apatite) or formed sand-sized concretions (pyrite), which were eliminated from the grain size analysis.

The Estonian Dictyonema shale consists of 70 % silt (2–63 μm) and 30 % clay (<2 μm). The sand fraction (>63 μm) is almost missing (grain size fractions after Friedman and others [1], Table 1, Fig. 2). According to the classification of shales and mudrocks [12, 14], the laminated (thickness of layers <10 mm) rock containing over two thirds silt should be termed 'siltshale' or 'laminated siltstone', and the rock containing one third to two thirds silt should be referred to as 'mudshale'. In these classifications the upper size limit of clay particles is defined at 4 μm. Estimating from the grain size data (see Table 1), the Estonian Dictyonema shale is mudshale according to the different classifications [15]. Due to high organic content, which makes the rock black-coloured, Dictyonema shale belongs to black shales, which are usually defined as dark-coloured mudrock consisting of silt- and clay-size mineral grains and containing organic matter >5 % by weight [16].

Surely, grain size analysis reflects not only sedimentary conditions but also postsedimentary processes. In ancient mudrocks, authigenic clay minerals may have formed as a result of diagenesis, further modifying the original grain size distribution [14]. Postsedimentary processes have no doubt altered the grain size distribution of the Dictyonema shale.

Table 1. **Grain Size Analysis Data of Silicate Minerals in the Dictyonema Shale**

Sample	Content of fractions (μm), wt.%												
	>100	63–100	**Sand**, >63	10–63	5–10	2–5	**Silt**, 2–63	1–2	0.5–1	0.2–0.5	<0.2	**Clay**, <2	Total
F 338-2	0.0	0.0	0.1	12.2	45.0	12.9	70.1	10.2	4.4	2.4	12.8	29.8	99.9
F 338-5	0.0	0.0	0.0	7.7	35.3	19.9	62.9	12.1	5.1	4.5	15.4	37.1	100.0
F 338-6	0.0	0.0	0.0	8.3	35.1	20.3	63.7	12.3	5.9	4.1	14.0	36.3	100.0
F 328-3	0.0	0.1	0.1	10.6	44.6	15.0	70.2	12.2	4.6	2.3	10.5	29.6	99.9
F 328-3	0.0	0.0	0.0	10.6	53.4	7.3	71.3	7.4	3.9	2.9	14.5	28.7	100.0
F 328-4	0.1	0.0	0.1	14.0	45.7	10.6	70.3	10.0	4.4	3.0	12.1	29.5	99.9
M 46-8	0.0	0.0	0.0	8.3	35.6	21.1	65.0	13.8	5.6	3.6	12.0	35.0	100.0
M 46-7	0.0	0.0	0.0	13.4	42.6	14.6	70.6	11.1	6.0	1.8	10.6	29.5	100.1
M 46-9	0.0	0.0	0.0	10.2	38.4	18.0	66.6	12.9	5.5	3.3	11.7	33.4	100.0
T 811-11	0.0	0.0	0.0	9.9	38.4	19.1	67.4	12.9	6.5	3.9	9.2	32.5	99.9
T 811-10	0.0	0.1	0.1	15.7	35.8	19.0	70.5	11.2	5.7	3.2	9.4	29.5	100.1
T 811-12	0.3	0.0	0.3	10.3	34.0	21.0	65.3	12.2	5.2	2.9	14.1	34.4	100.0
Sillamäe-13	0.1	0.7	0.8	28.9	28.2	23.1	80.2	9.5	2.7	1.6	5.1	18.9	99.9
Sillamäe-14	0.1	0.1	0.2	27.9	41.2	15.0	84.1	8.7	2.0	1.1	3.8	15.6	99.9
Mean	0.1	0.1	0.1	13.4	39.5	16.9	69.9	11.2	4.8	2.9	11.1	30.0	100.0
SD	0.1	0.2	0.2	6.8	6.4	4.5	6.00	1.8	1.3	1	3.4	6.1	

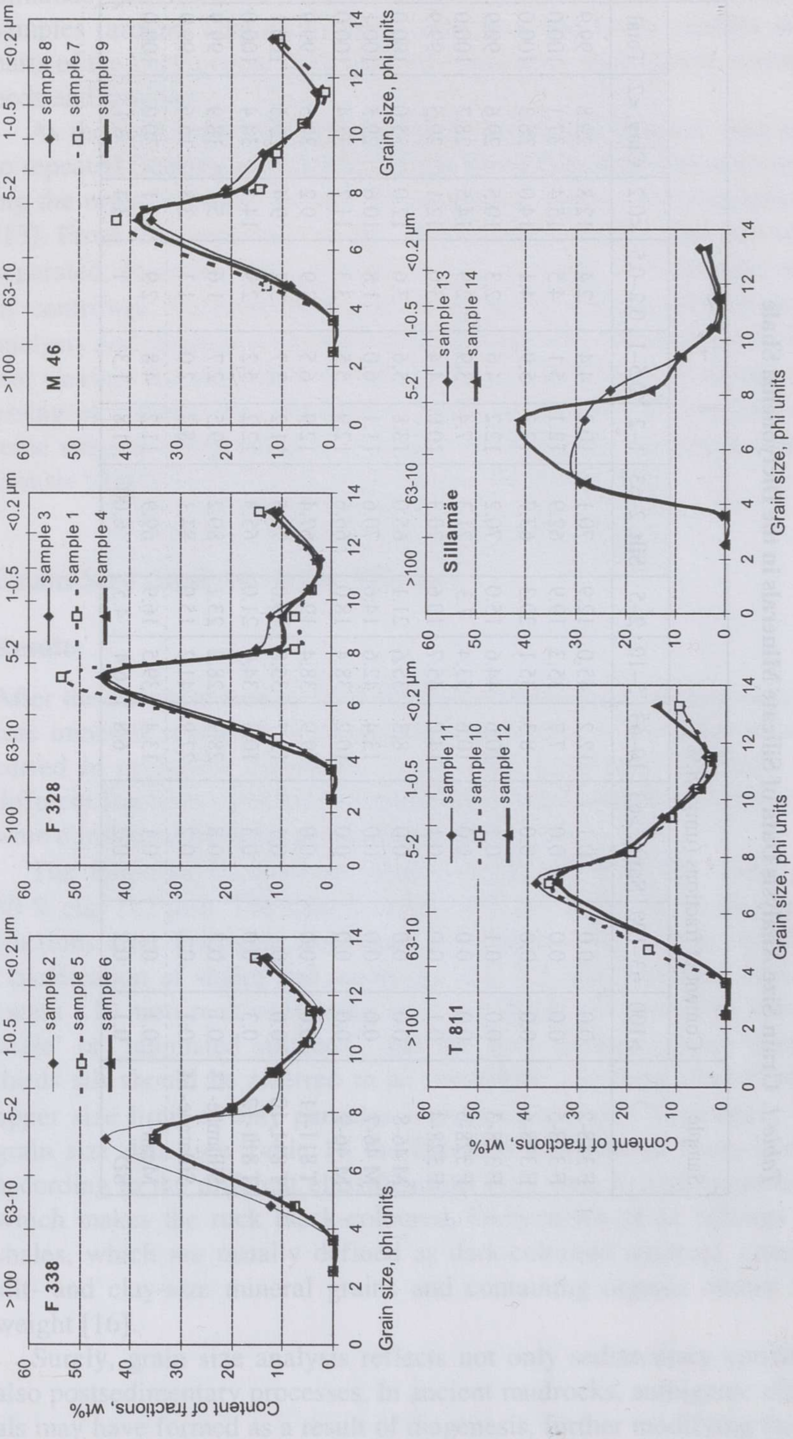

Fig. 2. Grain size distributions: F 338 and F 328 represent the western facies, M 46 the middle zone, and T 811 and Sillamäe the eastern facies of the Dictyonema shale

Separation of fine-grained fractions allowed detailed study of the vertical and lateral changes in grain size in the Dictyonema shale. From western Estonia (F 338) to Toolse (T 811) the Dictyonema shale grain size is rather uniform (Fig. 2): the distribution curves are of a similar shape. However, against a background of relative uniformity, we can note that lateral changes in the contents of fractions (standard deviation) exceed the vertical ones by two times. The most important vertical change is the variation in the content of the predominating fraction (5–10 μm), which shows no clear directional regularity in the section. The youngest, easternmost part of the eastern facies at Sillamäe differs from the rest of the Dictyonema shale by having a higher content of coarser but still fine-grained fractions.

The main feature characterizing the Dictyonema shale grain size over the entire distribution area is the predominance of one fraction, 5–10 μm, its content averaging about 40 %. In spite of this the distribution curve is not always unimodal. In the western Dictyonema shale facies and at Toolse the grain size distribution curve is skewed positively and is bimodal, due to the relatively large proportion of the smallest fraction (<0.2 μm) or even multimodal (Fig. 2). The curves show that the amount of the smallest fraction is higher in the western facies than in the eastern facies.

An earlier grain size study of the Dictyonema shale [2] revealed the predominance of the 2–5-μm fraction. This was probably due to incomplete disintegration of clay aggregates in <5-μm fractions, which is proved also by comparison of data on the mineral composition with the results of the present study. In the 2–5-μm fraction analysed by K. Utsal and others [2] clay minerals are dominating, while our study shows the prevalence of K-feldspar and quartz. At the same time, the cumulative content of <5-μm fractions is equal in both studies, but the content of 0.2–2-μm fraction is smaller in the former case. The scarcity of particles over 10 μm in size in the present work as compared to the previous work is probably caused by the circumstance that we considered only "pure" Dictyonema shale, without silty laminae.

K. Utsal and others noted that in general the content of the 5–100-μm fraction (treating it as silt) increases in the upper part of the Dictyonema shale. This result was not confirmed by the present study.

Comparison with Other Shales and Claystones

The grain size of the silicates of Estonian Dictyonema shale is close to that of relatively little altered Upper Cambrian autochthonous shale of Sweden (Häggenås) [17]; (Fig. 3). The sand fraction is almost missing in both rocks, and the number of particles rises abruptly towards smaller fractions, beginning with the 5–10-μm fraction. The clay content is higher in the autochthonous shales of Sweden than in the Estonian Dictyonema shale, 45 and 30 %, respectively.

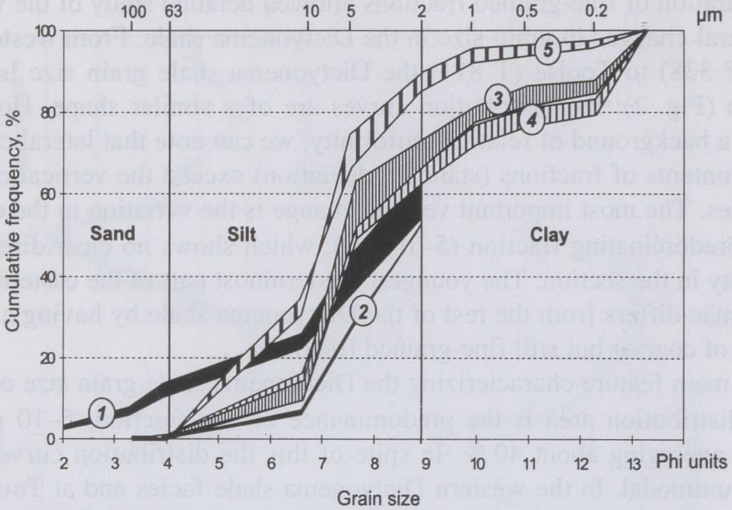

Fig. 3. Grain size cumulative frequency curves of silicates in Swedish Alum shale: allochthonous (*1*) and autochthonous (*2*) Upper Cambrian Alum shales (after Snäll [17]); and in Estonian Dictyonema shale: western facies (*3*), middle zone (*4*) and eastern facies (*5*)

The grain size fractions are more evenly distributed in all allochthonous and some autochthonous Upper and Middle Cambrian Alum shales. They contain more sand and clay. The cumulative frequency curve of grain size does not show as clear a breakpoint at 10 µm as observed in the Dictyonema shale (see Fig. 3). Similar grain size frequency curves are characteristic also of the Cambrian clays of Estonia [18] and modern muds [14], which contain up to 15 % sand and 40–50 % clay. The grain size frequency curve of the Dictyonema shale is sharp. The peak of a predominating fraction is formed (see Fig. 2), as in the rocks compared the curve is platykurtic or often multimodal.

For the Swedish Alum shales considered [17], grain size is affected by alteration and recrystallisation of shale, what causes growth of minerals (quartz), especially in allochthonous shales. Up to half of the silt in the Dictyonema shale consists of K-feldspar, mostly of authigenic origin.

Also, at least one third (see Table 2, content of K-feldspar in the whole rock) or apparently more of the grains of quartz and illite in the Dictyonema shale are new-formed and/or transformed reflecting kinetics of diagenetic processes. Comparison with other clayey rocks suggests that a decrease in the clay fraction and an increase in the silt fraction of the Dictyonema shale occur during diagenesis. Thus grain size analysis does not enable to draw far-reaching conclusions about sedimentation processes.

Table 2. **Content of Silicates in the Dictyonema Shale, Average to Whole Rock, Calculated from XRD Data and Quantity of Separated Fractions (Aggregates Are Excluded)**

Sample	Quartz	K-feldspar	Mica	Phyllosilicates			Total, %
				Illite	Illitic illite-smectite	Chlorite	
F 338-2	32	30	15	9	12	2	100
F 338-5	29	33	14	11	10	3	100
F 338-6	27	35	15	11	12	1	100
Average	29	33			38		100
SD	3.3	1.1			2.3		
F 328-3	29	34	15	10	10	2	100
F 328-1	26	31	18	9	14	2	100
F 328-4	24	34	19	10	12	1	100
Average	26	33			41		100
SD	2.2	1.6			3.3		
M 46-8	27	38	14	11	10	2	100
M 46-7	27	37	17	9	7	3	100
M 46-9	25	36	15	12	10	2	100
Average	26	37			37		100
SD	1.2	1			2.1		
T 811-11	29	37	16	10	7	1	100
T 811-10	29	34	18	9	8	2	100
T 811-12	25	33	18	10	12	2	100
Average	28	35			37		100
SD	2.8	1.9			4.1		
Sillamäe-13	38	31	17	8	4	1	100
Sillamäe-14	30	37	19	9	2	3	100
Average	34	34			32		100
SD	3	5.4			1.9		
Total average	29	34			37		100
Vertical SD	2.5	2.2			2.7		
Lateral SD	3.3	1.7			3.2		

Mineral Composition of the Silicates

Using XRD, the mineral composition of the Dictyonema shale was determined in seven fractions (63-µm and smaller) [13]. The amount of coarser particles was insufficient for analysis and these were studied by the immersion method (see below).

As calculated from the XRD data – the average mineral composition of the Dictyonema shale is: 37 % phyllosilicates, 34 % K-feldspar and 29 % quartz (see Table 2). Carbonates and pyrite, here excluded, amount to only few percent.

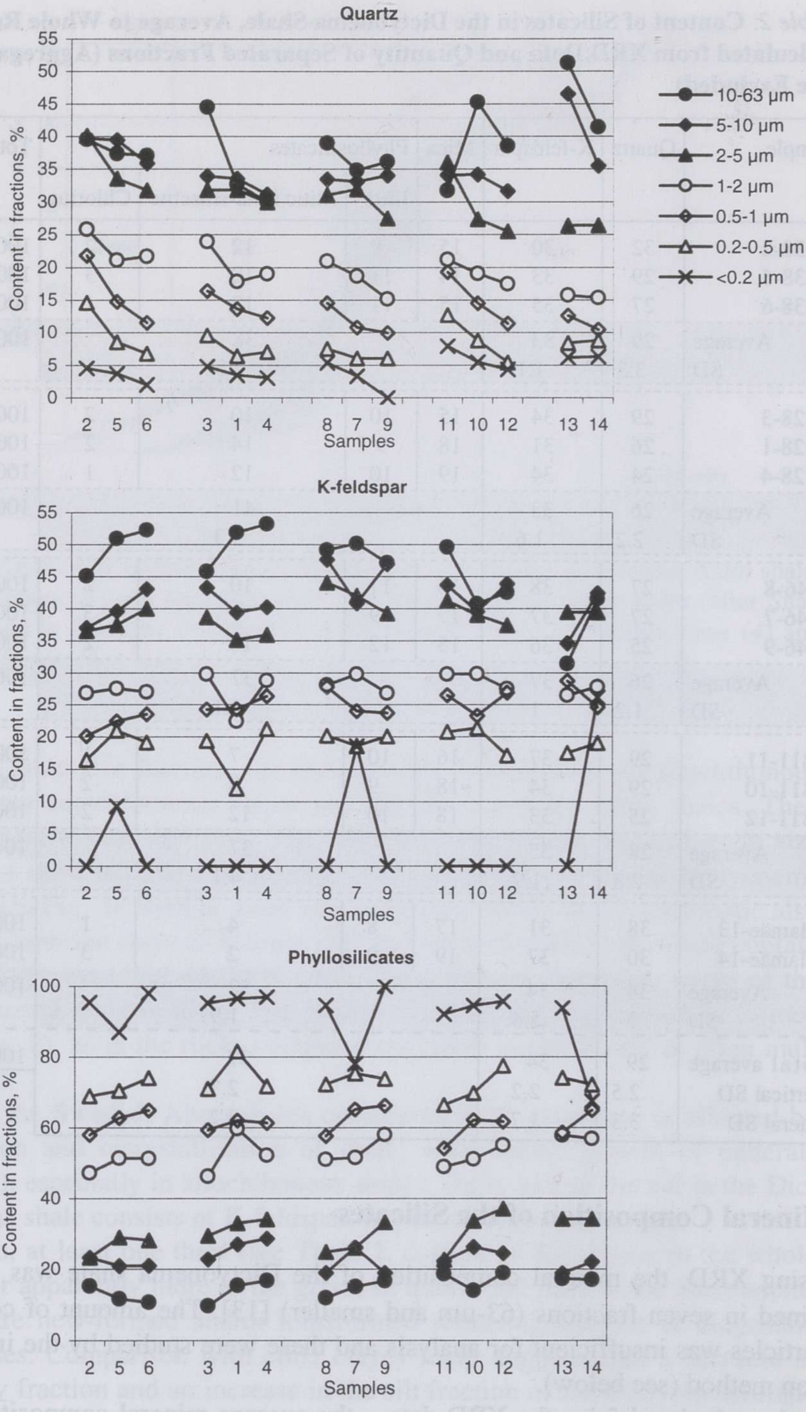

Fig. 4. Distribution of the main silicates in different fractions (for numbers of samples see Fig. 1), see changes in sections and laterally

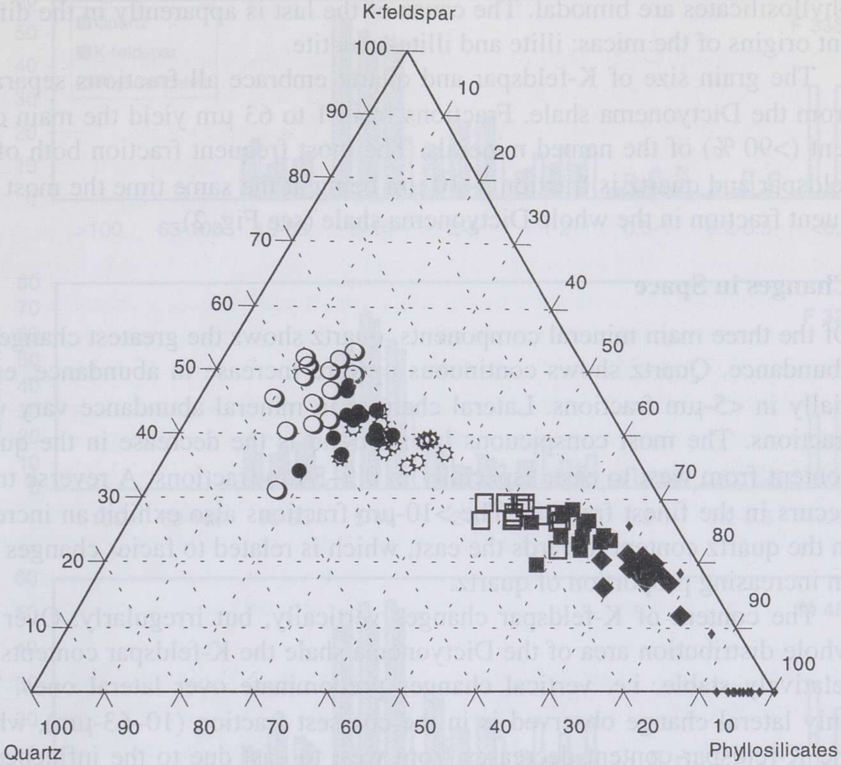

Fig. 5. Ternary diagram of the main silicates in different fractions, %. Fractions, µm: ○ – 10–63; ● – 5–10; ☼ – 2–5; □ – 1–2; ■ – 0.5–1; ◆ – 0.2–0.5; ♦ – <0.2

Changes in Fractions

The main silicates in the Dictyonema shale are phyllosilicates, K-feldspar and quartz. In clay fractions the phyllosilicates consist mainly of illite and illitic illite-smectite with minor chlorite (up to 3 %), making up 50–100 % (Fig. 4). K-feldspar occurs in amounts from 0 to maximum 10–30 and quartz from 0 to 5–25 %. In the silt fractions K-feldspar ranges in abundance from 35 to 50 % and quartz from 25 to 45 %. In the silt fraction the content of the phyllosilicates is a little overestimated by XRD because of the presence of clay aggregates. The phyllosilicates in the true silt fraction are considered to be represented by micas.

Among all fractions the following trends in three-mineral-system were noted: the phyllosilicates increase towards smaller fractions, while quartz and K-feldspar decrease, K-feldspar nearly always predominating a little over quartz (Figures 4 and 5).

The three main mineral components of the Dictyonema shale have normal positively skewed distribution curves (Fig. 6). The difference is only in modality: the distribution of K-feldspar and quartz are unimodal, but the phyllosilicates are bimodal. The cause of the last is apparently in the different origins of the micas: illite and illite-smectite.

The grain size of K-feldspar and quartz embrace all fractions separated from the Dictyonema shale. Fractions from 1 to 63 µm yield the main content (>90 %) of the named minerals. The most frequent fraction both of K-feldspar and quartz is fraction 5–10 µm being at the same time the most frequent fraction in the whole Dictyonema shale (see Fig. 2).

Changes in Space

Of the three main mineral components, quartz shows the greatest changes in abundance. Quartz shows continuous upward increase in abundance, especially in <5-µm fractions. Lateral changes in mineral abundance vary with fractions. The most conspicuous lateral trend is the decrease in the quartz content from west to east, especially in 0.5–5-µm fractions. A reverse trend occurs in the finest fraction. The >10-µm fractions also exhibit an increase in the quartz content towards the east, which is related to facies changes and an increasing proportion of quartz.

The content of K-feldspar changes vertically, but irregularly. Over the whole distribution area of the Dictyonema shale the K-feldspar contents are relatively stable, i.e. vertical changes predominate over lateral ones. The only lateral change observed is in the coarsest fraction (10–63-µm), where the K-feldspar content decreases from west to east due to the influence of the allochthonous quartz-rich component.

The content of phyllosilicates in different fractions changes vertically as well as laterally, increasing from the top to the base in the section and from the west to the east. In general, the amplitude of changes (standard deviation) is equal in both directions. Lateral changes are the most distinct in the 1–5-µm fraction, in other fractions vertical ones dominate.

The grain size distribution of quartz and K-feldspar in the Dictyonema shale (see Fig. 6) shows no difference in space although changes in lithology of the Dictyonema shale resulted from shallowing the facies eastwards can by observed. Thus, the abundances of quartz and K-feldspar are not related to facies changes and are not detrital.

The equal grain size distribution of quartz and K-feldspar in the Dictyonema shale suggests that they are products of one or of some simultaneous processes. K-feldspar is defined as authigenic, therefore the origin of the main part of quartz in silt and clay fractions seems to be also authigenic. This is supported with the fact, that in <10-µm fractions the abundances of quartz and K-feldspar are in positive correlation but inverse with the content of phyllosilicates.

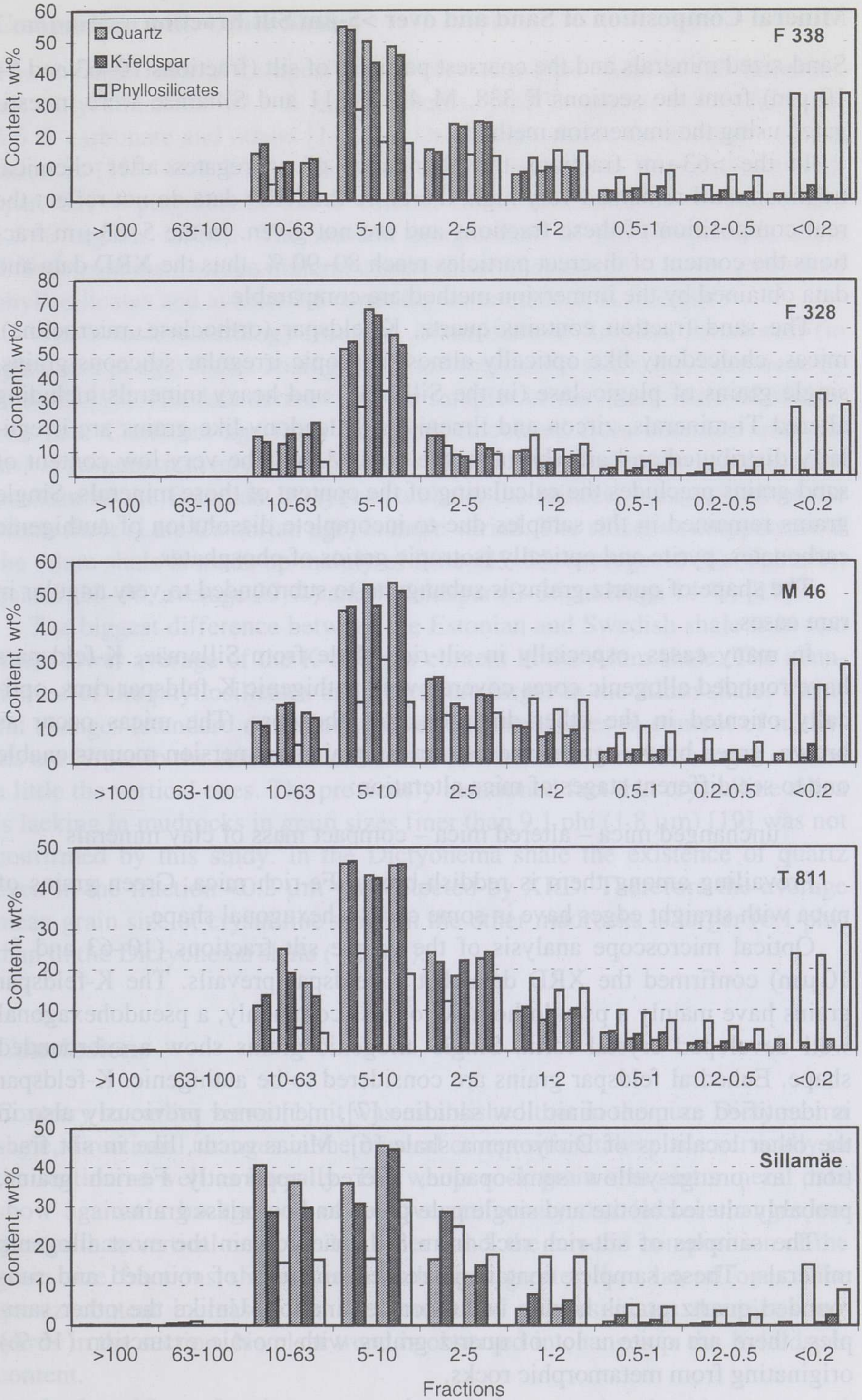

Fig. 6. Grain size frequency distribution of the silicates in the Dictyonema shale

Mineral Composition of Sand and over >5-µm Silt Fraction

Sand-sized minerals and the coarsest particles of silt (fractions 10–63 and 5–10 µm) from the sections F 338, M 46, T 811 and Sillamäe were investigated using the immersion method.

In the >63-µm fractions the abundance of aggregates after chemical treatment still remained very high, therefore the XRD data do not reflect the real composition of these fractions and are not given. In the 5–63-µm fractions the content of discreet particles reach 80–90 %, thus the XRD data and data obtained by the immersion method are comparable.

The sand fraction contains quartz, K-feldspar (orthoclase, microcline), micas, chalcedony-like optically almost isotropic irregular siliceous grains, single grains of plagioclase (in the Sillamäe) and heavy minerals including altered Ti-minerals, zircon and ilmenite. Chalcedony-like grains are irregularly distributed and are absent in the core M 46. The very low content of sand grains precludes the calculating of the content of those minerals. Single grains remained in the samples due to incomplete dissolution of authigenic carbonates, pyrite and optically isotropic grains of phosphates.

The shape of quartz grains is subangular to subrounded to very angular in rare cases.

In many cases, especially in silt-rich shale from Sillamäe, K-feldspars have rounded allogenic cores covered with authigenic K-feldspar rims, optically oriented in the other direction than the core. The micas occur as brown, green-brown, green and colourless grains. Immersion mounts enable one to see different stages of mica alteration:

unchanged mica – altered mica – compact mass of clay minerals

Prevailing among them is reddish-brown Fe-rich mica. Green grains of mica with straight edges have in some cases a hexagonal shape.

Optical microscope analysis of the coarse silt fractions (10–63 and 5–10 µm) confirmed the XRD data that K-feldspar prevails. The K-feldspar grains have mainly a pseudorhombic, or less commonly, a pseudohexagonal well developed crystal form. Single allogenic grains show a subrounded shape. Euhedral feldspar grains are considered to be authigenic. K-feldspar is identified as monoclinic low sanidine [7], mentioned previously also in the other localities of Dictyonema shale [6]. Micas occur, like in silt fraction, as orange-yellow semi-opaque, altered, apparently Fe-rich grains, probably altered biotite and single pale-green and colorless grains.

The samples of silt-rich rock from Sillamäe contain the most allogenic minerals. These samples contain increased amounts of rounded and subrounded quartz grains having undulatory extinction. Unlike the other samples, there are quite a lot of quartz grains with mosaic extinction (16 %) originating from metamorphic rocks.

Comparison with Other Shales

The average mineral composition of claystone-type shale is (all minerals, not only silicates): 60.9 % clay minerals, 30.8 % quartz, 4.5 % feldspar, 3.6 % carbonate and others [14]. For Ordovician shales the average composition is [16]: 44.9 % clay minerals, 32.2 % quartz, <1 % potassium feldspar, 6.3 % plagioclase, 9.8 % calcite, 0.5 % dolomite, 3.4 % pyrite and 1.5 % organic carbon. The mineral composition of the Dictyonema shale differs from the average mineral composition of shales by a lower content of phyllosilicates and at least 7-8 times higher content of K-feldspar.

Whole rock mineralogy from the Alum shale of Sweden, the closest (in space and in age) facies analogue to the Dictyonema shale, has been done by S. Snäll [17]. His data derive from the samples of the Alum shale of Middle and Late Cambrian age from Jämtland, calculated from chemical analysis and semi-quantitatively determined by XRD. Compared to the mineral composition of the Estonian Dictyonema shale, the mineral composition of the Alum shale (Late Cambrian age) is more varied. The siliceous component of the Alum shale is made up mainly of illite (25–55, average 46 %) (Table 1); quartz (30–40, average 39 %) and K-feldspar (0–36, average 14 %) [17].

The biggest difference between the Estonian and Swedish shale is in two times lower average of the K-feldspar content in the Alum shale. The abundances of the phyllosilicates and quartz are larger in the Alum shale. Vertical changes (standard deviation) as well as lateral ones in content of minerals are larger in the Alum shale, but in both rocks the lateral changes exceed a little the vertical ones. The previously mentioned fact that crystalline silica is lacking in mudrocks in grain sizes finer than 9.1 phi (1.8 μm) [19] was not confirmed by this study. In the Dictyonema shale the existence of quartz even in the fraction <0.2 μm was detected by XRD. Therefore the average mean grain size of crystalline silica in the other mudrocks is larger (6.1 phi) than in the Dictyonema shale (7.3 phi).

Conclusions

Contrary to earlier views [1], it was established that in the pure Dictyonema shale, directional changes in the mineral composition take place vertically in the section as well as laterally. The whole rock grain size and mineral data show against a background of relative uniformity that lateral changes are greater than vertical ones. On the other hand, the mineral composition of the grain size fractions shows vertical changes greater than lateral ones. The quartz content increases and the content of phyllosilicates decreases upwards in the section. No clear trend is observed in changes in the K-feldspar content.

In the >10-μm fractions reverse lateral changes take place in quartz and K-feldspar contents. These agree well with facies changes in the Dictyonema shale and are therefore obviously primary, caused by influx of allochthonous material from east. Also, an inverse correlation between them is typical for detrital material. Smaller fractions show positive correlation between quartz and K-feldspar, while changes in the contents of phyllosilicates are opposite. Based on the euhedral crystal form most of the K-feldspar is specified as authigenic one. The equal grain size frequency distribution of quartz and K-feldspar in the Dictyonema shale suggests that they are products of one or of some simultaneous processes reflecting most of all the kinetics of diagenetic processes.

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