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New correlations of Telychian (Silurian) bentonites in Estonia

Toivo Kallaste and Tarmo Kiipli

Institute of Geology at Tallinn University of Technology, Estonia pst. 7, 10143 Tallinn, Estonia; tarmo.kiipli@lx.egk.ee

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Abstract. Seventy-seven Telychian bentonite samples from six drill-core sections were correlated on the basis of their sanidine composition. In total, bentonites from 43 volcanic eruptions, of which six are new discoveries, were established in the Telychian of Estonia. Names and identification (ID) codes were assigned to the bentonites. The different distribution patterns of volcanic ash thicknesses indicate different source volcanoes. Lack of several bentonites near the transition between the Rumba and Velise formations and at the Llandovery–Wenlock boundary indicates sedimentary hiatuses in the eastern part of the studied area.

Key words: bentonite, K-bentonite, Telychian, sanidine, correlation.

INTRODUCTION

The use of bentonites in the correlation of geological sections offers a unique possibility for recognition of exactly the same time levels in several outcrop and drill-core sections (e.g. Einasto et al. 1972). Limestones (Rumba Formation) and marlstones (Velise Formation) of the Adavere Stage contain a large number of thin altered volcanic ash beds – bentonites (Jürgenson 1964). These regional stratigraphic units belong to the Telychian Stage of the international stratigraphic scheme (Bergström et al. 1998; Nestor & Nestor 2002; Kiipli et al. 2006). The sanidine composition has been studied in twelve drill-cores with an aim to identify the ash beds in the Telychian of Estonia. The results show that the volcanogenic interbeds originate from at least 37 different eruptions (Kiipli et al. 2001; Kiipli & Kallaste 2002), although the greatest number of bentonite interbeds found in one section is only 22.

The aims of bentonite study are precise correlation of sections, mapping of the distribution of bentonites, and restoration of wind directions at the eruption time and locations of source volcanoes. Herein, we are going to report the results obtained through the study of bentonites in six new sections using the same method as in Kiipli & Kallaste (2002). To bring some clarity to this rather difficult and confused subject, identification (ID) codes were assigned to all the identified bentonites. Names were given to more widespread bentonites.

MATERIAL AND METHODS

Seventy-seven bentonite samples from six drill-cores (see Fig. 1) were collected from 0.2–20 cm thick interbeds, which differed from their host marlstones and limestones in their soft clayish consistency and/or in colour. The abundance of biotite flakes was a good criterion for recognizing volcanogenic bentonites in situ. For correlation purposes, the data on bentonites studied earlier in the

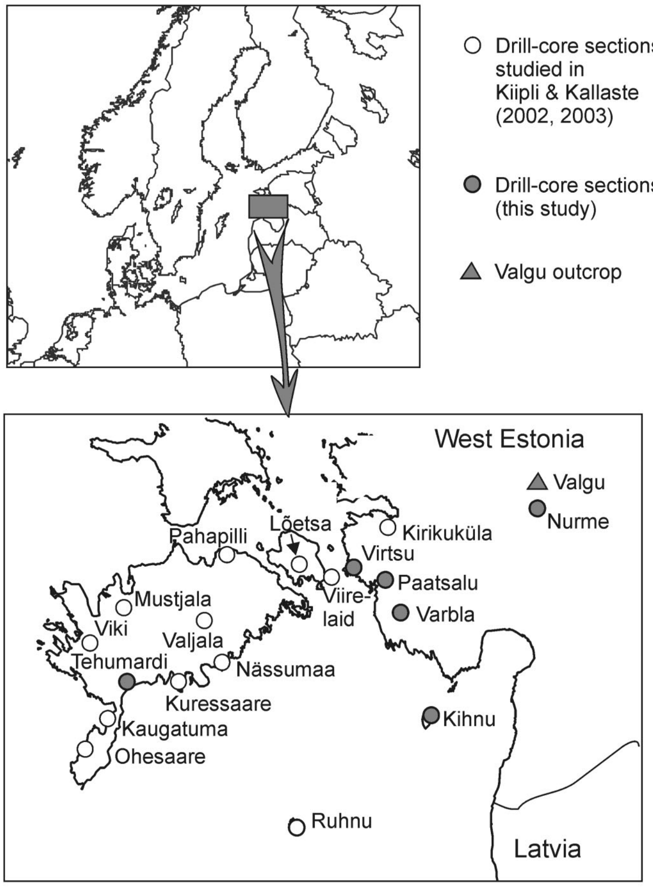

Fig. 1. Location of the studied sections.

Ohesaare, Viki, and Ruhnu sections were used (Kiipli & Kallaste 2002, 2003). The lithology and distribution of microfossils of many studied sections are discussed in Einasto et al. (1972), Jeppsson & Männik (1993), Nestor (1994), and Hints et al. (2006).

All bulk samples were scanned by X-ray diffractometry (XRD) from 5 to 45 degrees using Co Kα radiation. The occurrence of illite-smectite and/or kaolinite reflections was considered as an indication of volcanogenic material. Some volcanogenic interbeds had a high content of authigenic potassium feldspar. A low content or absence of quartz was typical of bulk volcanogenic bentonite material.

The Na content of K–Na sanidine was studied by XRD (Kiipli & Kallaste 2002). From the separated 0.04–0.1 mm fraction the range from 23.5 to 26.0 °2θ was scanned using Co Kα radiation with the step size of 0.01 °2θ; the measuring time was 15 s per point. The content of $NaAlSi_3O_8$ in K–Na sanidine (in mol %) was calculated according to Orville (1967), who established that the position of the $20\overline{1}$ reflection almost linearly depends on the composition of sanidine solid solution. The precision of the analysis of the K–Na sanidine composition was ±1% in favourable cases (low intensity of authigenic feldspar reflection, no kaolinite, high intensity of the reflection of interest) and ±2% in less favourable cases. Separate beds were correlated on the basis of the magmatic K–Na sanidine composition (Table 1). As several bentonites may have the same sanidine composition, graphic correlation between sections was applied to improve the probability of correlations.

RESULTS

The $NaAlSi_3O_8$ content of sanidine varied from 21 mol % in the Osmundsberg Bentonite to 45–48 mol % in the Valgu, Ruhnu, and Viki bentonites. The width of the sanidine reflection varied from sharp (0.05–0.15 °2θ; indicating homogeneous sanidine composition) to very wide (exceeding 0.35 °2θ). Such wide reflections were difficult to characterize in numerical values and were described as wide or very wide (Table 1). A wide sanidine reflection clearly discriminates a particular bentonite from those with sharp reflections, but is useless for discrimination between other bentonites with wide sanidine reflections. Wide reflections probably indicate heterogeneous (maybe zoned) sanidine crystals.

By combining sanidine properties and graphic correlation most of the studied bentonites can be correlated with volcanogenic interbeds established earlier in other drill-cores (Table 2). Many volcanic eruptions have been detected in more than five sections, thus their stratigraphic position among other bentonites is well proven. Compared with the earlier study (Kiipli & Kallaste 2002), six new volcanic eruptions have been established: ID 504, 720, 750, 773, 793, and 794, five of those only in one section. ID 504 was additionally found in the earlier studied Kaugatuma section at a depth of 262.2 m and possibly in the new Kihnu section in the lower part of the 10 cm thick bentonite at a depth of 211.95 m. The total number of Telychian volcanic eruptions recorded in Estonia is 43.

Table 1. Sanidine properties of Telychian bentonites

Identification numbers and names			Number of sections	Stage and formation	Pyroclastic K–Na sanidine, main component parameters	
Viki depth ID	Interpolated depth in the Viki core, m	Bentonite name			Width of the reflection (degrees) and other notes	Content of $NaAlSi_3O_8$ in sanidine, mol %
127	112.70	Ireviken	6	Jaani Stage	Much of biotite and quartz, little sanidine	
150	115.00	Lusklint	7	Mustjala	0.19–0.34	35.2–35.8
210	121.00	Ohesaare	6	Formation	0.25–0.35	38–40
311	131.10	Aizpute	6		0.08–0.12	36.2–37.8
457	145.75	Kirikuküla	10		Very wide reflection	
475	147.50	Viki	12		0.12–0.20	45.2–46.3
480	148.00	Kaugatuma	6		0.18–0.27	42.0–42.8
488	148.80	Kuressaare	8		Very wide reflection	
494	149.40	Ruhnu	14		0.05–0.09	45.7–46.4
504	150.40		2		0.08–0.20	45.6–46.6
518	151.80	Viirelaid	10		Very wide reflection	
520	152.00	Lõetsa	10		Very wide reflection	
521	152.10		8?		Very wide reflection	
564	156.40		3		0.12–0.17	45.0–45.8
568	156.80		10?		Very wide reflection	
569	156.90		1		0.07	29.0
658	165.80		2		0.09	45.5
682	168.20		2		Very wide reflection	
693	169.30		2		0.05	22.6
696	169.60	Nässumaa	13	Adavere Stage	0.04–0.06	22.9–23.3
719	171.95	Virtsu	12	Velise	Much of biotite and quartz, little sanidine	
720	172.00		1	Formation	0.085–0.122	26.5–28.0
722	172.20		2		26.5 + wide reflection	
731	173.10	Nurme	13		0.10–0.16	38.7–40.3
744	174.40	Tehumardi	11		0.07–0.10	25.8–26.7
750	175.00		1		Wide reflection	
755	175.55	Paatsalu	8		0.25–0.30	25.5–26.2
772	177.20	Pahapilli	8		0.30–0.34	20.5–24.1
773	177.30		1		Feldspathic	
774	177.40		1		0.09–0.12	46.2–48.2
776	177.60		5		0.07–0.08	28.1–28.8
777	177.70		2		0.25–0.30	22.3–26.2
788	178.80		2		0.17–0.19	40.1–40.6
793	179.30		1		Biotite flakes on bedding plane	
794	179.40		1		0.12	43.7
795	179.50	Mustjala	6		0.05–0.11	24.5–25.3
800	180.00		2		Feldspathic	
805	180.50		2	Adavere Stage	Feldspathic	
818	181.80		3	Rumba–Velise	Very wide reflection	
823	182.30	Valgu	5	transition	0.12–0.17	45.2–47.6
841	184.15		2		0.19–0.22	35.5–35.8
843	184.35		3	Adavere Stage	Very wide reflection	
851	185.10	Osmundsberg	15	Rumba	0.05–0.09	20.7–21.5
880	188.00		4	Formation	Very wide reflection	

Table 2. Correlated Telychian bentonites in the studied core sections (depth in metres). Small font indicates that sanidine was not studied – graphic correlation was used. Provisional correlation is embraced by a frame

Viki depth ID	Viki	Kures-saare	Ohe-saare	Ruhnu	Kihnu	Varbla	Paat-salu	Virtsu	Nurme
127		158.30	340.76						
150	115.00	160.00	342.08						
210	121.00		345.83			134.90			
311	131.10		351.72	459.00		137.20			
457	145.75		359.31	467.60	211.20	139.40		68.55	
475	147.50		361.30	470.80	211.70	139.85	72.50	69.20	
480	148.00		361.70	471.80					
488	148.80	184.80	362.23	473.10					
494	149.40	185.40	362.46	473.70	211.85	140.28		69.50	
504					211.95				
518	151.80	187.40	364.76	478.90	212.20		73.70		
520		188.50					74.00	71.30	
521	152.10	189.50	365.08	478.90	214.50	141.50			
564			367.39						
568	156.80	193.75	367.60		215.70	143.25			
569					215.72				
658			369.12						
682		205.20							
693			369.72						
696	169.60		369.75	488.24	220.70	146.90		79.25	
719	171.95	205.40		488.30	221.70	148.00	80.80	80.20	
720				488.30					
722				488.40					
731	173.10		369.98	489.05	222.30	148.20	81.05	80.68	17.90
744	174.40			489.05	222.70	148.60	81.09		20.10
750		209.20							
755	175.55		370.09		223.10		81.50		21.10
772		210.20	370.44				82.00	81.40	23.45
773							82.10		
774		210.30							
776			370.63				82.40		
777							82.40		
788	178.80								
793							83.75		
794		212.70							
795		212.80				150.40	83.90		
800						150.75			
805									24.50
818	181.80	214.00	370.77						24.60
823	182.30		370.77						
841			370.99						
843	184.35								
851	185.10	215.70			228.40	155.60	88.20		
880		223.80				158.30			

BENTONITE IDENTIFICATION NUMBERS AND NAMES

The former bentonite ID numbers (Kiipli et al. 2001) started from 0 (Osmundsberg Bentonite) and were assigned in stratigraphic order up- and downward from it. However, difficulties arose when new bentonites were found, because no vacant numbers were available between the earlier known and numbered bentonites. Therefore, new bentonite finds were left without an ID number in Kiipli & Kallaste (2002).

In the present study, new stratigraphic ID numbers were assigned to all established bentonites. The ID numbers were derived from the projection of the bentonite stratigraphic position to the Viki drill-core depth scale. The number marks the depth in decimetres in the Viki section. For the sake of shortness, centimetres were discarded from the end of the depth number. Besides, 1000 decimetres were subtracted from the depth, as all bentonites occur between 1000 and 2000 decimetre depth. This combination resulted in a list of three-digit ID codes for bentonites (Tables 1–3). Any new bentonite find can be easily accommodated into this list. The Viki section was selected as a basis for deriving ID numbers

Table 3. Type localities of bentonites

Viki depth ID	ID (Kiipli et al. 2001)	Bentonite name	Type locality	Thick-ness, cm	Reference
127	29	Ireviken	Ireviken section, Gotland, Sweden	10	Batchelor & Jeppsson (1994)
150	28	Lusklint	Lusklint section, Gotland, Sweden	5	Batchelor & Jeppsson (1994)
210	27	Ohesaare	Ohesaare drill-core, depth 345.8 m	2	Kiipli & Kallaste (2006)
311		Aizpute	Aizpute drill-core, depth 931.8 m	1	Kiipli & Kallaste (2006)
457	26	Kirikuküla	Kirikuküla drill-core, depth 12.59 m		
475	23	Viki	Viki drill-core, depth 147.5 m	5	
480	21	Kaugatuma	Kaugatuma drill-core, depth 261.1 m	0.5	
488	22	Kuressaare	Kuressaare drill-core, depth 184.8 m	0.5	
494	19	Ruhnu	Ruhnu drill-core, depth 473.7 m	5	
518	18	Viirelaid	Viirelaid drill-core, depth 67.75 m	1	
520	17	Lõetsa	Lõetsa drill-core, depth 47.2 m	3	
696	13	Nässumaa	Nässumaa drill-core, depth 219.4 m		
719	12	Virtsu	Virtsu drill-core, depth 80.2 m	1	
731	11	Nurme	Nurme drill-core, depth 17.9 m	6	
744	10	Tehumardi	Tehumardi drill-core, depth 185.1 m	1.2	
755	9	Paatsalu	Paatsalu drill-core, depth 81.5 m	4	
772	7	Pahapilli	Pahapilli drill-core, depth 68.5 m	5	
795		Mustjala	Mustjala drill-core, depth 117.8 m		
823	3	Valgu	Valgu trench, Rapla district	3	
851	0	Osmundsberg	Osmundsberget, Central Sweden	115	Bergström et al. (1998)

because of the great thickness of the Telychian, large number of bentonites, and a well-established conodont biostratigraphy (Jeppsson & Männik 1993; Kiipli et al. 2001).

Names were assigned to 20 widespread bentonites recognized in more than five sections in Estonia (Table 3). Most of those were named after Estonian drill-cores where they were found. The Valgu Bentonite was named after the Valgu outcrop (Klaamann 1990) in southern Rapla District. The names of Osmundsberg, Lusklint, and Ireviken were applied on the basis of correlation with the described bentonites in the literature (Batchelor & Jeppsson 1994; Bergström et al. 1998). The most frequent (found in 10–15 sections) bentonites in Estonia are as follows: Osmundsberg (851), Tehumardi (744), Nurme (731), Virtsu (719), Nässumaa (696), Lõetsa (520), Viirelaid (518), Ruhnu (494), Viki (475), and Kirikuküla (457). Correlation of these and other named bentonites forms a well-proved framework, where the stratigraphic position of rarely occurring bentonites can be established.

DISCUSSIONS ON SEDIMENTOLOGY IN THE TELYCHIAN

Bentonites were formed from very fine-grained volcanic dust and are therefore rarely preserved in shallow-water sediments from where wave activity transports fine ash material to the deeper and quieter sedimentary environments. The Telychian sediments in Estonia are represented by relatively deep-water marlstones and limestones, containing therefore a large number of bentonites. Despite a presumed quiet sedimentary environment, the record of bentonites in these sediments is still uneven. As a maximum, only 22 out of the total of 43 bentonites were found in one core (Ohesaare). Although the completeness of an established bentonite record depends partly on the quality of drilling and the experience of the sample-collecting researcher, the studied material revealed some regularities in the natural distribution of bentonites (Kiipli & Kallaste 2002 and the present study):

1. The Ireviken and Lusklint bentonites occur only in the sections of south-western Saaremaa. They are lacking in eastern Saaremaa and mainland Estonia. Often even the Ohesaare and Aizpute bentonites are absent there. This gap in the bentonite record was probably caused by a break in sedimentation near the Llandovery–Wenlock boundary, which was also proposed on the basis of biostratigraphical evidence (Nestor & Nestor 2002, 2003). Now this is also confirmed by the distribution of bentonites.
2. In many drill-cores in the eastern part of the study area several bentonites are absent in the lower part of the Velise Formation and the Velise–Rumba transition interval. The most extensive gap in the bentonite records was established in the Ruhnu section, where even the bentonites of the Rumba Formation are entirely absent. In mainland Estonia, the Paatsalu section is the

only exception with its almost full record of bentonites in the lower part of the Velise Formation. The best records of bentonites in this interval were established in the southwestern part of Saaremaa Island (Tehumardi, Viki, and Ohesaare sections). This gap in the record of bentonites was possibly caused by a major hiatus in sedimentation near the Rumba–Velise boundary.

3. Correlation of bentonites from the Nurme section is provisional as all bentonites there are very rich in authigenic feldspar, which complicates seriously the analysis of sanidine. The Nurme and Tehumardi bentonites were identified on the basis of sanidine composition, but other bentonites were correlated only graphically.
4. Correlation of bentonites 518, 520, and 521 (embraced by the frame in Table 2) is provisional as these bentonites reveal similar wide sanidine reflections and occur closely in a section. The occurrence of at least three bentonites with similar properties at this level is proved by the Kuressaare section, where all three bentonites were found.
5. In some cases an extremely low rate of sedimentation caused the deposits of two succeeding eruptions to merge. As a result, the sanidine originating from those different eruptions occurs within a single volcanic ash bed. The examples are 731 + 744 (Nurme and Tehumardi bentonites) in the Ruhnu section and 823 (Valgu) + 818 bentonites in the Ohesaare section.
6. The occurrence of a mixed (823 + 818) bentonite in the Ohesaare section at 370.77 m, which in other sections is found in the Rumba–Velise transition interval, indicates the presence of a condensed marlstone section in Ohesaare (370.9–372.6 m) corresponding to the Rumba Formation in shallow-water sections.
7. The mapped thickness of the volcanic ash layer can provide useful information on the direction of wind at the time of eruption and location of the source volcano. Up to now only the Kinnekulle eruption layer (Caradoc) is well mapped over a large area in Baltoscandia (Vingisaar 1972; Bergström et al. 1995). A number of the Osmundsberg Bentonite outcrop sites were described by Bergström et al. (1998). The thickness map of the Osmundsberg Bentonite in Estonia, presented by Kiipli et al. (2006), indicates ash transport from the northwest. The thickness of three other Telychian bentonites in Estonia shows different distribution patterns (Fig. 2). The Ruhnu Bentonite is characterized by even distribution of thickness (3–5 cm). Possibly the source volcano was located so far that no changes could be observed within the small studied area measuring 150 km × 200 km. The thickness of the Nässumaa and Nurme bentonites decreases rapidly to the southeast, probably perpendicular to the ash cloud axis. If this interpretation is correct, the Nässumaa ash was transported from the southwest and the Nurme ash from the west.
8. Restricted distribution of several bentonites, including all new discoveries, can be explained by patchy sedimentation accompanied by areas of 0-sedimentation, small thickness of many bentonites complicating their identification, and loss of soft bentonite interbeds during drilling.

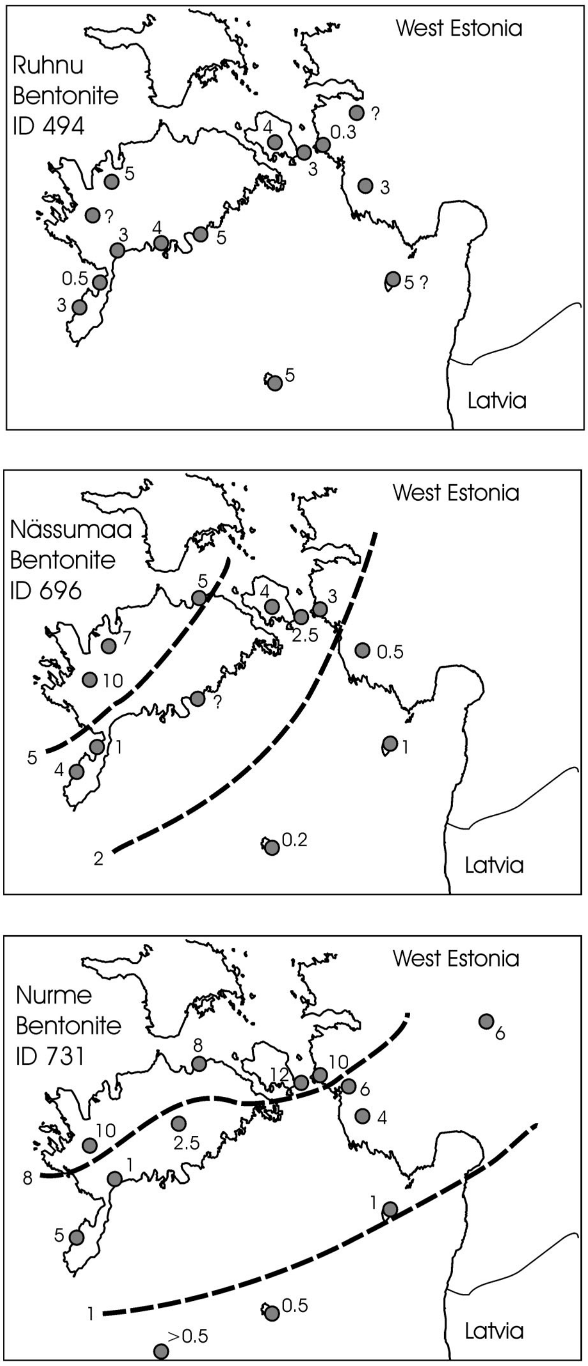

Fig. 2. Thickness (cm) distribution patterns of the Ruhnu, Nässumaa, and Nurme bentonites in Estonia.

CONCLUSIONS

The study of bentonites in new Telychian sections revealed a more complete volcanogenic record in Estonia including bentonites from 43 different volcanic eruptions. The assigned ID numbers and stratigraphic names make it easier to handle the information available on bentonites. New correlations enable us to trace gaps in the sedimentary record. Large hiatuses were confirmed at the transition of the Rumba and Velise formations and the Llandovery–Wenlock boundary. On the basis of the identification of bentonites, we assume that the deep-sea marlstone in the Ohesaare section correlates with the shallow-water Rumba Formation. Thickness distribution patterns of bentonites indicate volcanic ash transport from different directions and, correspondingly, from different sources.

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Telychi (Silur) bentoniitide uued korrelatsioonid Eestis

Toivo Kallaste ja Tarmo Kiipli

Sanidiini koostise alusel on korreleeritud seitsekümmend seitse bentoniiti kuuest puursüdamikust. Kokku on kindlaks tehtud bentoniite neljakümne kolmest vulkaanipurskest. Avastatud on kuus uut bentoniiti. Bentoniitidele on omistatud stratigraafilised nimed ja ID-koodid. On diskuteeritud vulkaanilise tuha leviku-suundade ja ümbriskivimi sedimentoloogia üle.