

Glendonite occurrences in the Tremadocian of Baltica: first Early Palaeozoic evidence of massive ikaite precipitation in temperate latitudes

Leonid E. Popov¹, J. Javier Álvaro², Lars E. Holmer^{3,4}, Heikki Bauert⁵, Mansoureh Ghobadi Pour^{1,3,6}, Andrei V. Dronov^{7,8}, Oliver Lehnert⁹⁻¹¹, Olle Hints⁵, Peep Männik⁵, Zhifei Zhang⁴, Zhiliang Zhang⁴

¹ Department of Earth Sciences, National Museum of Wales, Cathays Park, Cardiff CF10 3NP, UK

² Instituto de Geociencias (CSIC-UCM), Dr. Severo Ochoa 7, 28040 Madrid, Spain, jj.alvaro@csic.es

³ Department of Earth Sciences, Palaeobiology, SE-752 36 Uppsala, Sweden, lars.holmer@pal.uu.se

⁴ Shaanxi Key laboratory of Early Life and Environments, State Key Laboratory of Continental Dynamics and Department of Geology, Northwest University, 710069, Xi'an, China

⁵ Institute of Geology at Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia, heikki.bauert@ttu.ee, olle.hints@ttu.ee, peep.mannik@ttu.ee

⁶ Department of Geology, Faculty of Sciences, Golestan University, Gorgan 49138-15739, Iran

⁷ Geological Institute of Russian Academy of Sciences, 7 Pyzhevskii Lane, Moscow 119017, Russia, dronov@ginras.ru

⁸ Kazan (Volga Region) Federal University, 18 Kremlevskaya Street, Kazan 420008, Russia

⁹ GeoZentrum Nordbayern, Lithosphere Dynamics, FAU Erlangen-Nürnberg, Schloßgarten 5, D-91054 Erlangen, Germany, oliverlehnert@yahoo.de

¹⁰ Key Laboratory of Economic Stratigraphy and Palaeogeography, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, China

¹¹ Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Praha 6 – Suchbát, Czech Republic

*Correspondence to lars.holmer@pal.uu.se

SUPPLEMENTARY DATA

Supplement. Fig. 1. Revised lithostratigraphical correlation chart for the Cambrian (Miaolingian) - Ordovician (Tremadocian) of North Estonia and European Russia; modified from ⁵. New (prepared by MGP in Corel Draw 15, <https://www.corel.com/en/products/coreldraw/>).

Supplement. Fig. 2. Lower Tremadocian stratigraphical logs sampled for glendonites and conodont biogenic phosphates; (a) drill core of T-555 borehole in vicinity of Kunda (Fig. 1b)³⁸, A, B, C show stratigraphical intervals of conodont samples used in the oxygen isotope analysis; **(b)** Koporiye Formation in vicinity of Kolchanovo and Yurtzevo, showing glendonite occurrences; **(c)** Orasoja Member of Kallavere Formation and Toolse Member of Türisalu Formation showing setting of glendonite samples; modified from ⁵. New (prepared by MGP in Corel Draw 15, <https://www.corel.com/en/products/coreldraw/>).

Supplement. Fig. 3. Geological cross section through Furongian-Tremadocian deposits in North Estonia. Legend: 1, glauconitic sands of Leetse Formation (Floian); 2, glauconitic clays of Varangu Formation (Tremadocian); 3, black shales of Türisalu Formation (Tremadocian); 4-12, Kallavere Formation (upper Furongian-Tremadocian); 4, Orasoja Member of black shale interbeds ($P_2O_5 < 3\%$); 5, Vikhula Member of fine grained sands with reworked obolid shells and subsidiary black shales ($P_2O_5 = 1-3\%$); 6, 7, Rannu Member of quartzose sands ($P_2O_5 = 3-9\%$) and detrital phosphoritic sands ($P_2O_5 > 9\%$); 8, Suurjõgi Member of quartzose sands often with bidirectional cross-lamination ($P_2O_5 = 3-9\%$); 9, 10, Maardu Member of silty sands with subsidiary black shales ($P_2O_5 = 1-3\%$) and coquina accumulations ($P_2O_5 > 18\%$); 11, Ülgase Formation (lower Furongian) of silts and silty clay; 12, Tiskre Formation (Cambrian Series 2). Zero datum level coincides with the inferred position of the Cambrian–Ordovician boundary⁵ (modified). New (prepared by MGP in Corel Draw 15, <https://www.corel.com/en/products/coreldraw/>).

Supplement. Fig. 4. BSE-SEM images of the calcite (ca) to low-Mg calcite (LMC) zoned growths in the pseudomorph glendonite; py - pyrite.

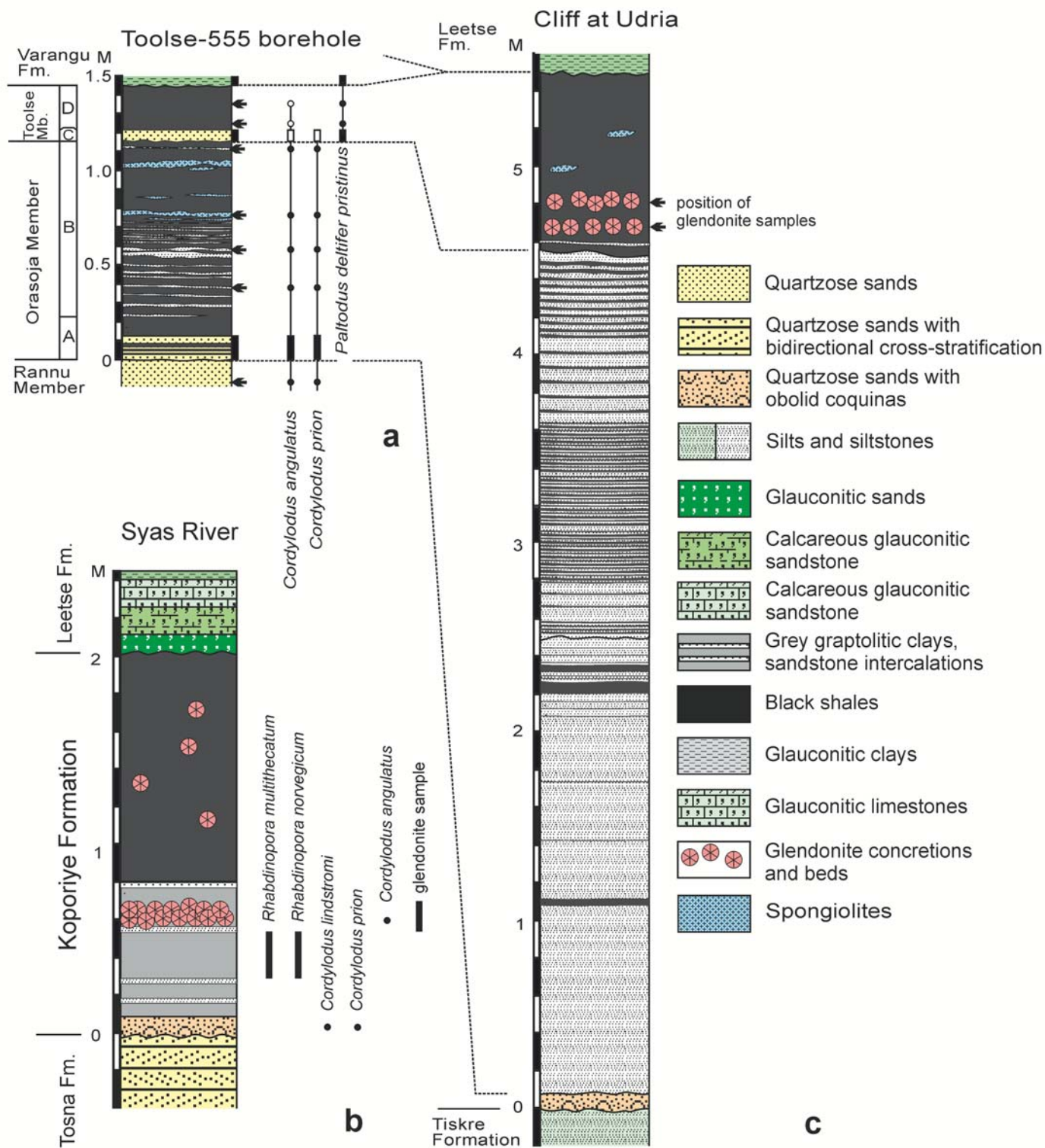
Supplement. Fig. 5. View of upper-bedding surfaces resembling *Kinneya* wrinkle structures showing meandering and partly interfering, flat-topped to rounded crests and intervening grooves and pits; **(a)** with higher and **(b)** lower density patterns; base of Türisalu Formation at Pakri cape, Estonia; scale arrowed.

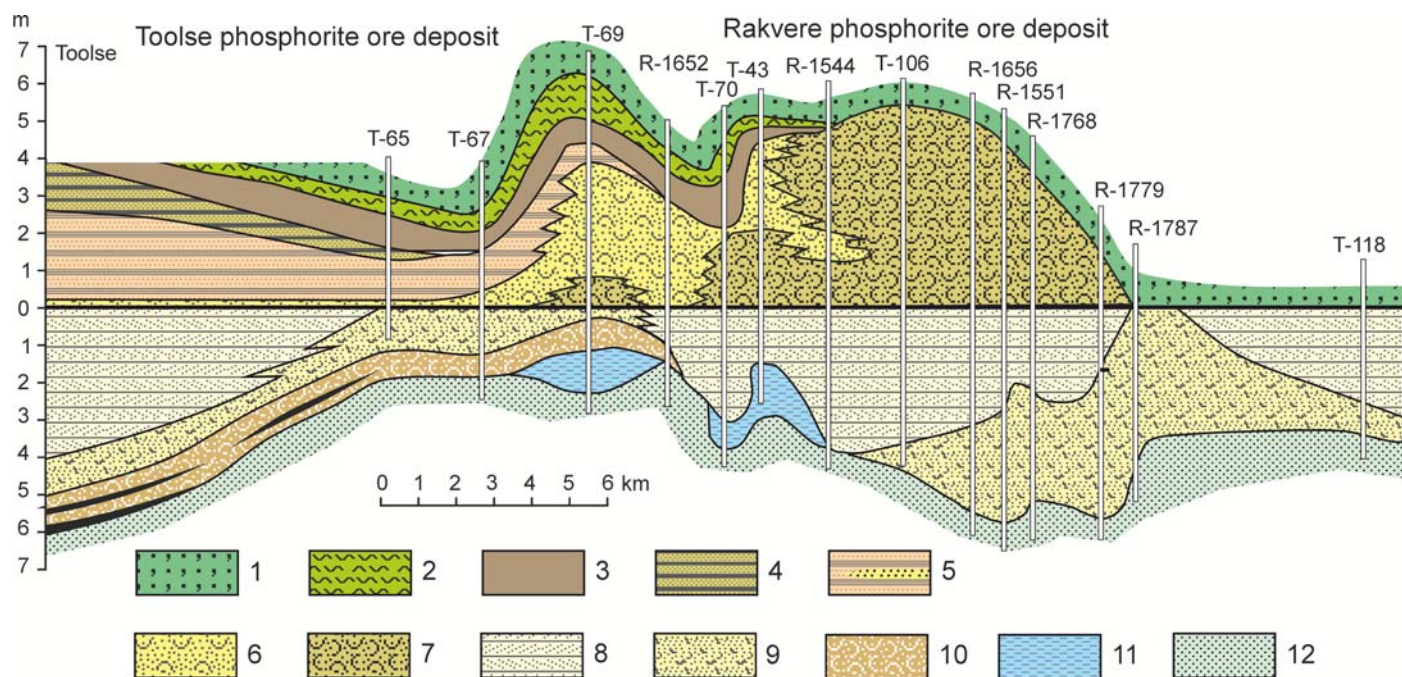
Supplement. Table 1. Major element composition of glendonite calcite.

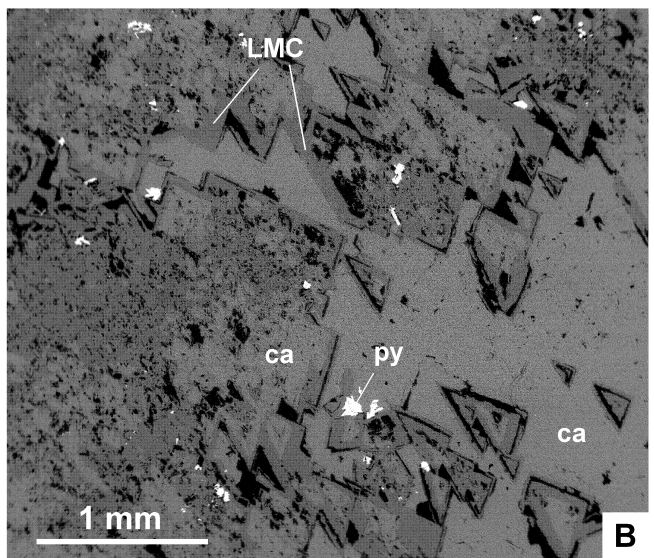
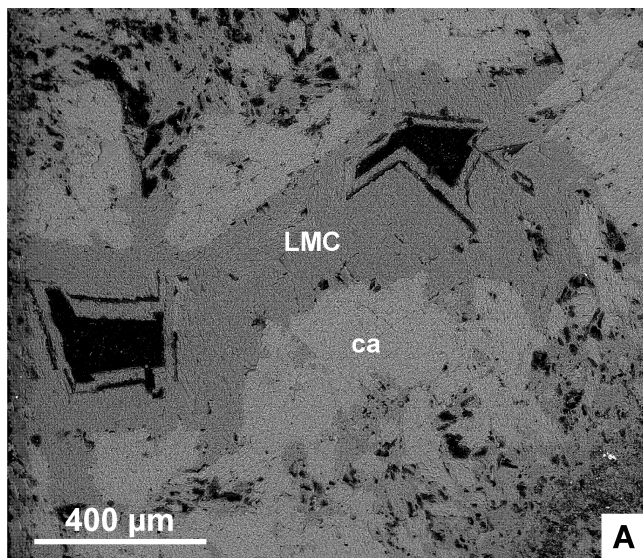
Supplement. Table 2. Carbon and Oxygen isotope data from the glendonites from the Türisalu Formation (Udria, DMA) and the surroundings of St Petersburg (SP).

Supplement. Table 3. $\delta^{18}\text{O}$ data from conodont apatite (NSB 120c = 21.7 ‰) sampled in the Toolse 555 drill core".

[illegible]







	MgO	CaO	Fe2O3	Na2O	K2O	
SP1a	23,4	42,9	11,6	0,04	1,3	
SP1b	23,6	42,8	11,4	0,06	1,3	
SP1c	23,5	43	12,1	0,05	1,2	
SP1d	24,2	42,8	11,9	0,05	1,2	
SP2a	0,9	92,6	1,1	0,01	0,3	
SP2b	0,7	83,5	0,8	0,01	0,3	
SP2c	0,8	88,6	1,2	0,01	0,4	
DMA	0,8	95,3	1,3	0,01	0,4	

MnO	Sr (ppm)	
0,6	52	low-Mg calcite
0,7	52	low-Mg calcite
0,7	50	low-Mg calcite
0,7	56	low-Mg calcite
0,4	120	calcite
0,5	116	calcite
0,4	132	calcite
0,2	124	calcite

sample	$\delta^{13}\text{Ccarb V-PDB}$	$\delta^{18}\text{Ocarb V-PDB}$
DMA-1	-1,23	-6,68
DMA-2	-1,18	-6,82
DMA-3	-1,34	-6,77
DMA-4	-3,82	-8,21
DMA-5	-1,45	-7,11
SP-1	0,33	-6,53
SP-2	-2,59	-5,71
SP-3	-4,9	-8,06
SP-4	0,6	-6,21
SP-5	0,35	-6,81

sample	East Baltic Stage	Conodont Zone	$\delta^{18}\text{O}$ (‰VSMOW)	1 std. Dev.
OL-A2	Pakerort Stage	<i>Cordylodus angulatus</i>	14,42	0,14
OL-B 3-4	Pakerort Stage	<i>Cordylodus angulatus</i>	14,44	0,26
OL-C	Pakerort Stage	<i>Paltodus deltifer</i> (<i>P. d. pristinus</i> Subzone)	14,66	0,29