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Ordovician turbidites and black shales of Bennett Island (De Long Islands, Russian Arctic), and their significance for Arctic correlations and paleogeography

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Supplementary Material 1
(Additional Figures)

Figure S1. Silty sandstones in the lowermost part of the Middle Unit. Lower Floian, T. approximatus Zone. South coast of Bennett Is. near site 279 (see Figure 3 in the paper).

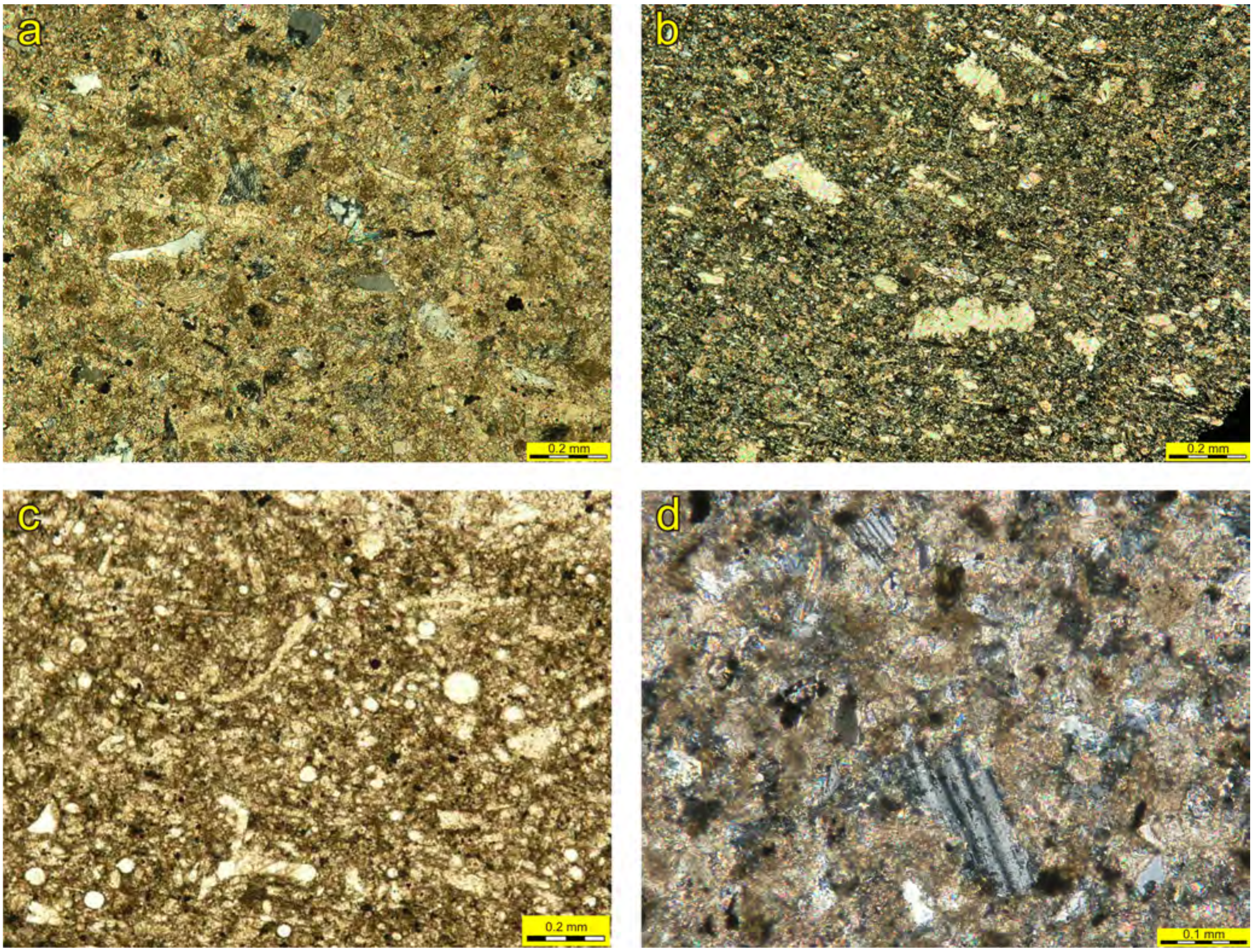

Figure S2. Microphotographs of rocks from Carbonate turbidite Unit. (a) Carbonate siltstone with silicate grains (cross-polarized light). Boundaries of carbonate grains are fuzzy due to carbonate cement. (b) Sandy siltstone with large carbonate grains and small silicate ones (dominantly quartz; cross-polarized light). (c) Carbonate siltstone with bioclasts (plane-polarized light). (d) Plagioclase grains in carbonate siltstone (cross-polarized light).

Figure S3. General view of the Ordovician section in the Subglacial Canyon (Four Crates River basin). Upper part of the Carbonate turbidite Unit, Upper Floian.

Figure S4. Undulating lamination in carbonate siltstone, resembling hummocky cross-stratification (HCS), and rudimentary climbing ripples in the lower part. These structures were likely formed under combined-flow (compare with Figure 3b in Dumas & Arnott, 2006).

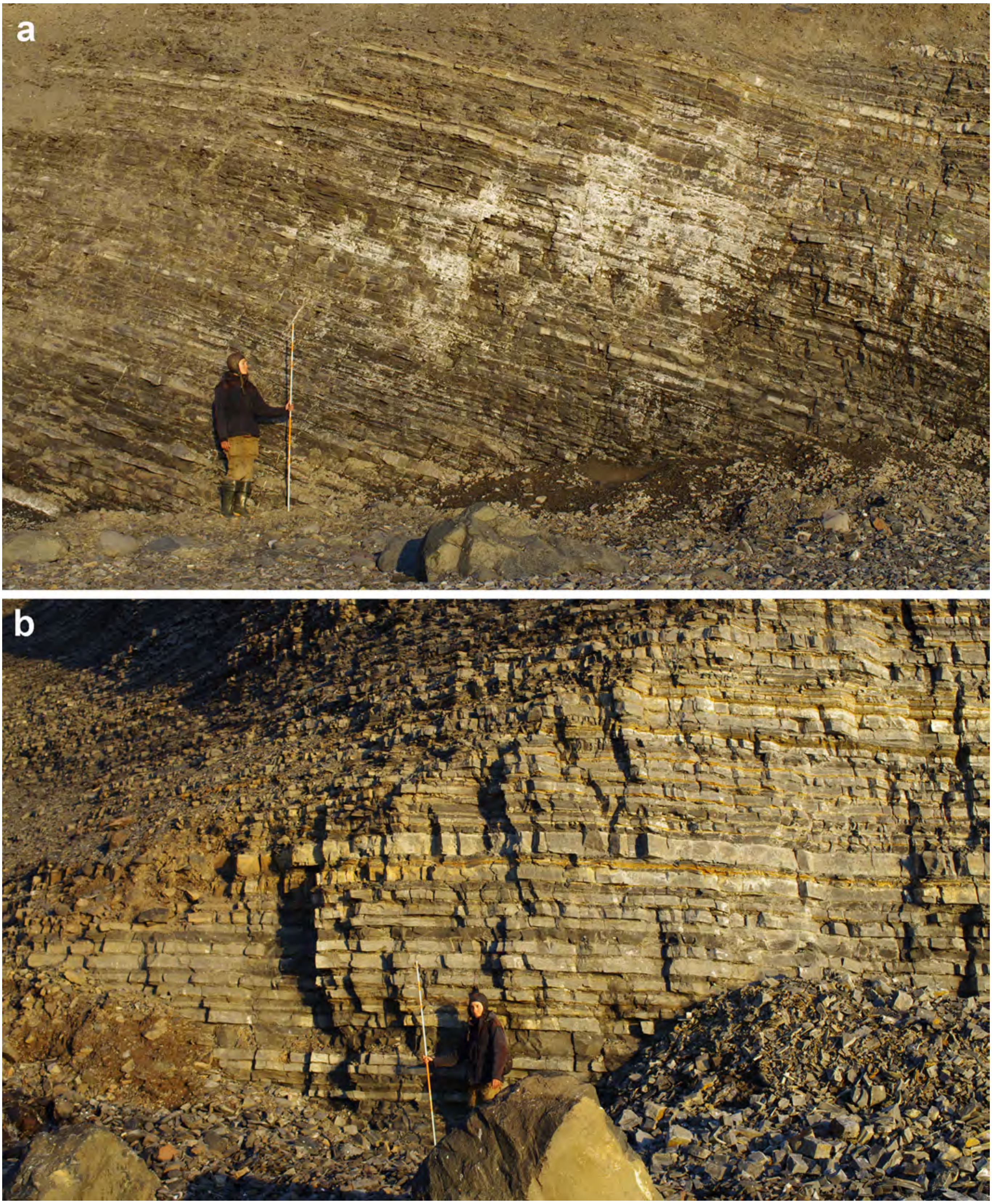

Figure S5. Two types of rhythmicity in flysch of the Three Streams locality: thin alternation in lower visible part of the section (a) and more thick alternation with predominance of clastic carbonate rocks – in upper half of the section (b). These photographs show extreme cases. In general, lower and upper parts of the section are less contrast. Note lenticular shape of some carbonate beds in lower-left part of picture (a). Range pole is 2 m high.

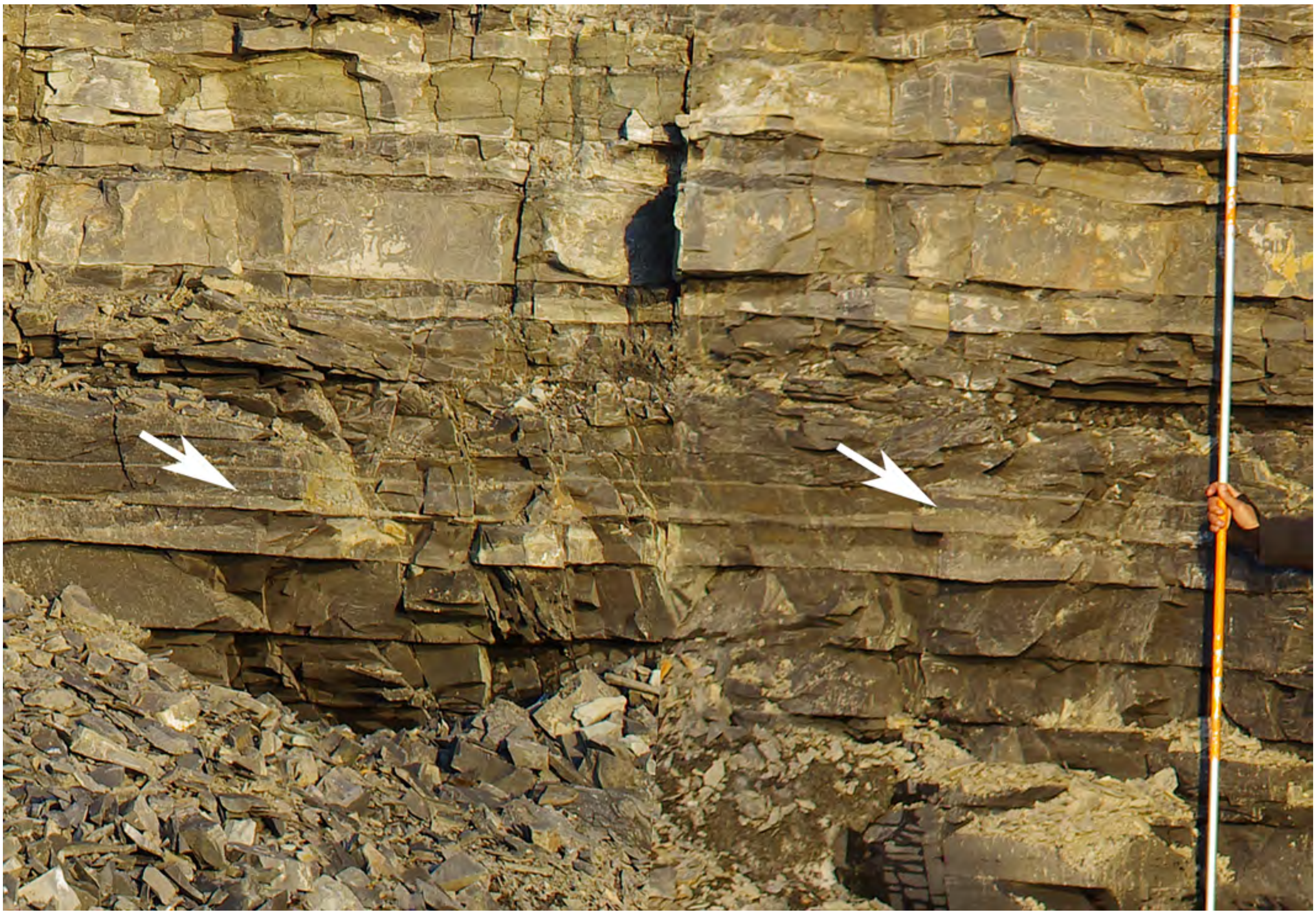

Figure S6. HCS-like carbonate siltstone bed with sharp base and thin hummocks (arrows) due to undulating top.

Figure S7. Fragment of the Carbonate turbidite Unit in the Three Streams locality. Note thin lenticular bed in 1 m above the beach (the lowermost one in the series of light-coloured carbonate beds). In contrast with previous picture, this layer has both bottom and top curved. Range pole is 2 m high.

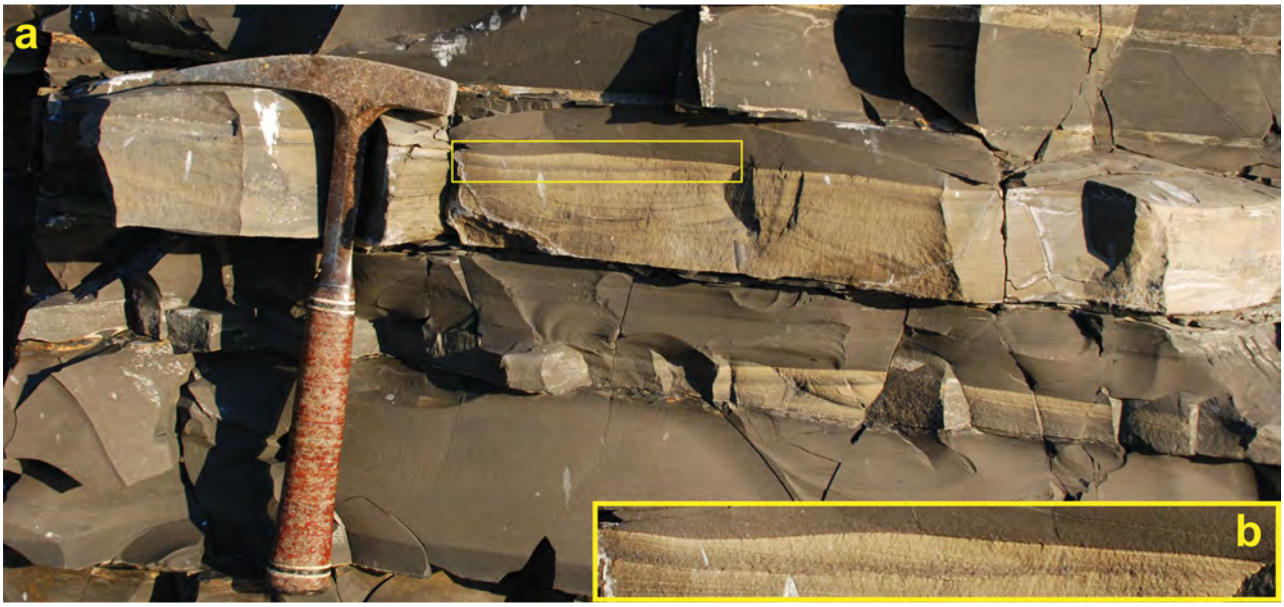

Figure S8. (a) Gently undulating HCS-like cross-lamination in carbonate siltstone. Note thin pinching-out layer with current ripples at the top of siltstone bed. Yellow rectangle shows contour of Figure S8b. (b) Enlarged fragment of previous photograph. Slightly asymmetrical rounded shape of ripple and gently dipping laminas are usually distinctive for combined-flow deposits (He et al., 2011; Basilici et al., 2012). Sedimentary structures shown in Figures S8a and S8b were formed under prevailing unidirectional flow but probably were slightly affected by waves (oscillatory flow; see text).

Figure S9. Soft-sediment deformations in cross-bedded carbonate sandstone. Upper surface of the bed demonstrates large-scale ripple marks. This sandstone is about 20 cm thick.

Figure S10. Thin-bedded carbonate flysch in Northern Central Valley.

Figure S11. Deformed ripples (?) sunk in underlying sediment. Photograph is 0.5 m high.

Figure S12. Slump folds in sandstone-dominated package. Rocks are coloured in weathering crust. Photograph is 2.1 m high.

Figure S13. Sole marks, typical for turbidites. Upper Unit.

Figure S14. Middle and upper parts of the picture represent muddy sandstone-dominated interval (member 5 of the southern segment of the Key exposure, see Figure 22 in the paper). Black mudstone package in the lower part of the cliff bears graptolites of I. maximo-divergens Subzone of the I. gibberulus Zone (Early Dapingian, sample # 137/1). Range pole is 2 m high.

Figure S15. Sandstone package (member 6 in Figure 22) made of a series of thick sandstone beds with faint horizontal lamination divided by thin mudstone layers from each other. Uppermost sandstone demonstrates amalgamation surface.

Figure S16. The uppermost part of southern segment of the Key exposure. This interval consists of rather thin-bedded light-coloured sandstones that intercalate with mudstones, dark muddy sandstones and ‘black packages’. Lithologic column is slightly deformed to fit the photograph. Range pole (encircled) is 2 m high.

Figure S17. Two thick sandstone beds (lower half of ‘pole 8’ in Figure 23 in the paper) with very thin mudstone between them. Note leached carbonate concretions and parallel lamination in the lower one. Dark grey diamictitic sandstone and its transition to overlying mudstone is in the base of cliff. In the upper part of the photograph there is a series of lenticular sandstone beds, partly amalgamated (on the right). Range pole is 2 m high.

Figure S18. Flute casts on the bottom of thick sandstone bed. Flow direction was from right to left.

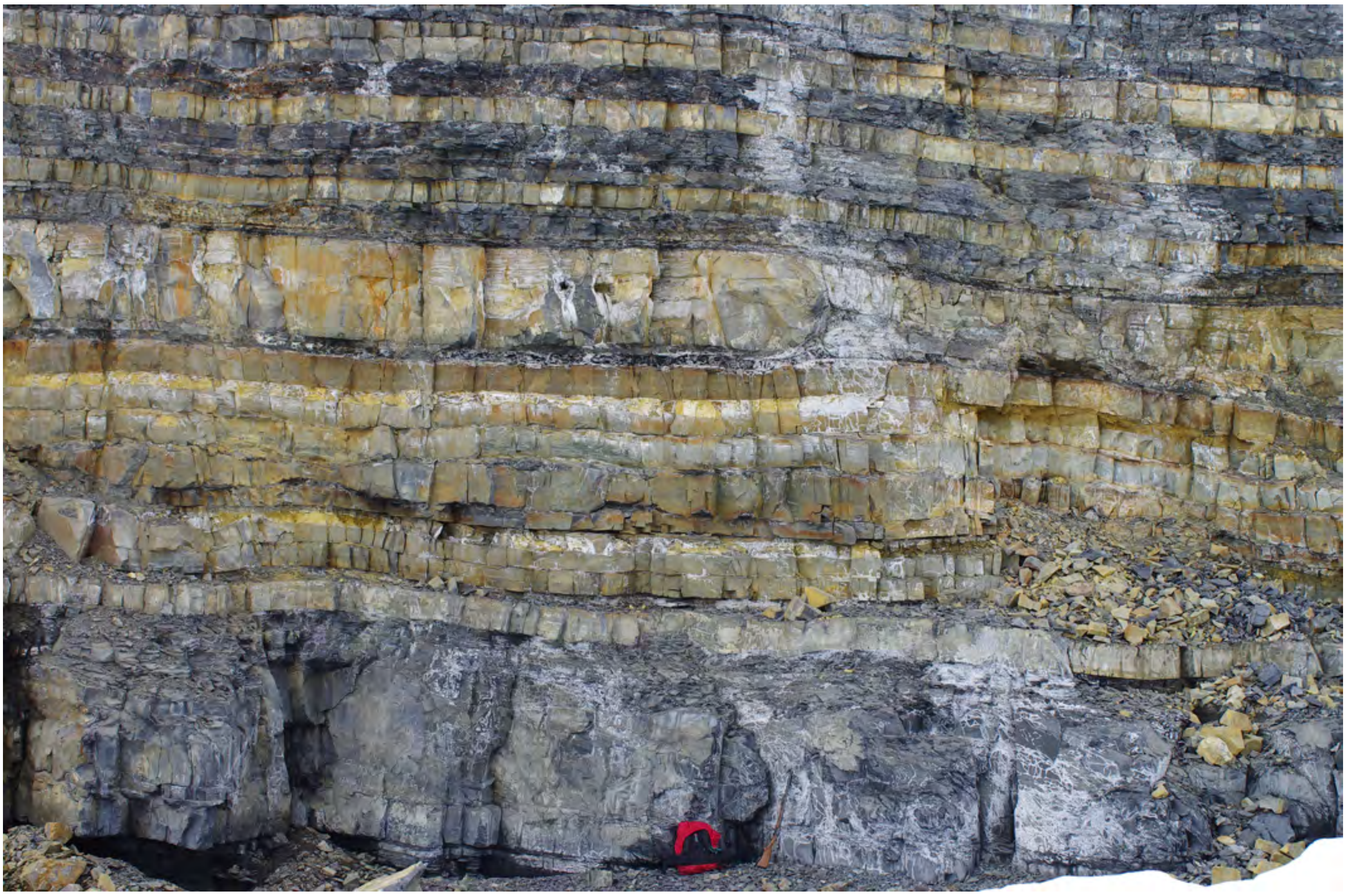

Figure S19. Fragment of the key section (70 m to north from point 104, see Figure 3 in the paper). Thick (2.3 m) diamictite (muddy sandstone) bed is at the base of cliff. Middle part of the photograph shows sandstone package; note lenticular bed in the lower half of it. This member is overlain by intercalation of light-coloured sandstones and dark packages, the latter contain rather thick diamictitic sandstones. Visible in this picture part of the sequence corresponds to interval from ‘pole 1’ to middle part of ‘pole 5’ (Fig. 24 in the paper).

Figure S20. Fragment of laminated package in thick diamictitic sandstone bed. Photograph is about 1 m high.

Figure S21. Pseudonodules (ball-and-pillow structure) of laminated sandstone (light grey) in muddy sandstone.

Figure S22. The uppermost part of the Ordovician section, visible on Bennett Is. (near site 102). Rocks are coloured in the weathering crust and brecciated in the fault zone. This fault acts as boundary between Paleozoic rocks and Lower Cretaceous basalts.

Figure S23. Siliciclastic turbidites exposure in the upper reaches of Lagernaya River, formed due to erosion by subglacial(?) water flow.

Figure S24. Middle Ordovician sandstones and shales, overlain by Lower Cretaceous basalts (near site 249). Westernmost Ordovician exposure. Rocks are coloured in the Cretaceous weathering crust.

Figure S25. Sedimentary structures in sandstone bed of the Upper Unit. Middle part (with thin horizontal lamination) and upper part (with climbing ripples deformed by slump folds) are typical for the Bouma Tb and Tc divisions for low-density turbidity currents. Lower part of the bed consists of more coarse particles and could be formed by high-density current.

Figure S26. Convolute lamination and load marks in sandstone bed.

Figure S27. Horizontal lamination and climbing ripples in Middle Ordovician sandstone (Upper Unit).

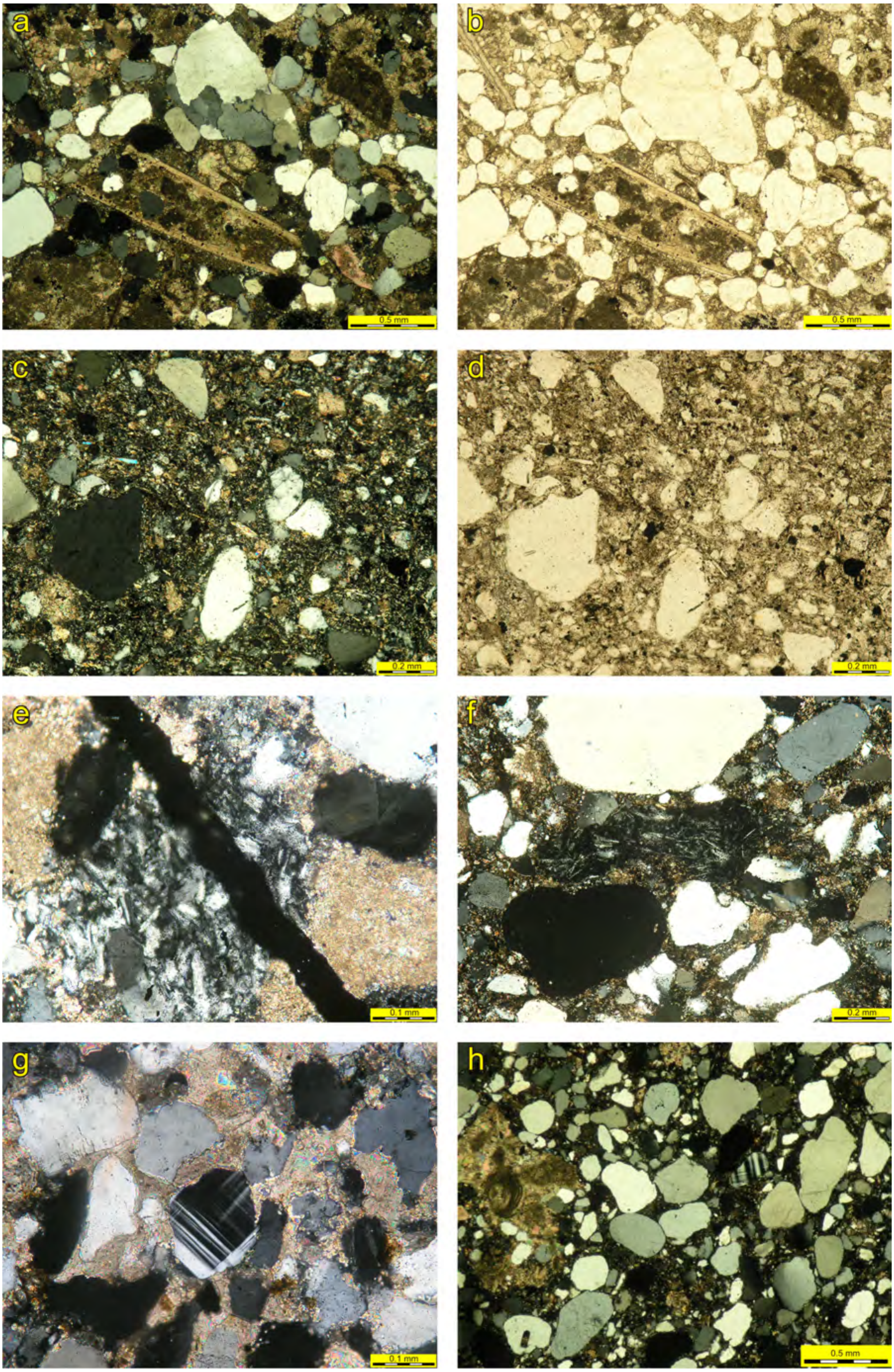

Figure S28. Microphotographs of rocks from the Siliciclastic turbidite Unit. (a, b) Poorly sorted sandstone with abundant carbonate material (clasts and cement). Large quartzite fragment and carbonate bioclast are at the centre. a – cross-polarized light, b – plane-polarized light. (c, d) Diamictitic sandstone with large amount of fine-grained matrix containing white mica. Note the great range in particle sizes. c – cross-polarized light, d – plane-polarized light. (e) Dacite(?) fragment in sandstone with crossed polars. (f) Basaltic rock fragment in muddy sandstone (cross-polarized light). (g) Fresh microcline in sandstone with carbonate cement (cross-polarized light). (h) Poorly sorted diamictitic sandstone with crossed polars. Note rounded quartz grains, microcline (center right) and limestone fragment (left).

Figure S29. Rhythmic intercalation of carbonate siltstone and shale in the Lower Ordovician of NE Taimyr (Kluevka River, middle reaches). Top is on the right.

Figure S30. Carbonate sandstone bed with sole marks, horizontal lamination in the lower and middle part and cross-lamination near the top. Lower Ordovician, NE Taimyr (Kluevka River basin, middle reaches).

Figure S31. Flute casts on the bottom of carbonate siltstone. Upper Cambrian – Lower Ordovician, NE Taimyr (Stanovaya River basin, upper reaches).

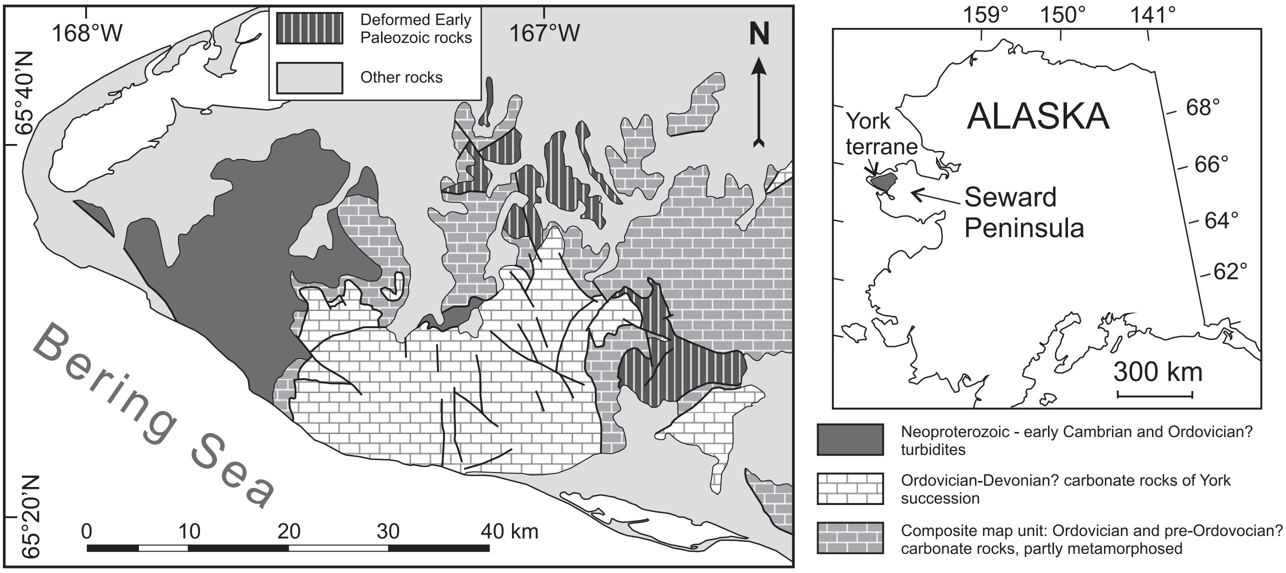

Figure S32. Simplified geological map of western and central parts of the York terrane and the geographic location of that terrane within Alaska (modified from Dumoulin et al., 2002, 2014). Most of rocks mapped as composite unit are definitely Ordovician and likely formed as part of York succession (Dumoulin et al., 2014).