



Supplement of

Storage and transformation of organic matter fractions in cryoturbated permafrost soils across the Siberian Arctic

N. Gentsch et al.

Correspondence to: N. Gentsch (gentsch@uni-hannover.ifbk.de)

Supplement of: Organic matter storage and transformation in cryoturbated permafrost soils across the Siberian Arctic

S 1 Study area

The east Siberian sampling sites were located along the Kolyma River north of Cherskiy. The climate in the Cherskiy (CH) region is characterized by extreme continentality with a mean annual temperature (MAT) of -10.7°C and a mean annual precipitation (MAP) of 272 mm (http://meteo.infospace.ru/wcarch/html/e_day_stn.sht?num=78). While the northern sampling sites (CH A-C) are located in the typical tundra, the southernmost sampling sites (CH G-I) resided already in the transition zone from southern to forest tundra (Table 1). This area has never been glaciated during the Pleistocene (Astakhov, 2008), and the parent material consists of aeolian, fluvial, and alluvial sediments covering granitic bedrock from a Cretaceous batholith intrusion (Patyk-Kara and Postolenko, 2004). As we aimed at investigating comparable soils affected by cryoturbation (Gelisol order, Turbel suborder; Soil Survey Staff (2010)) along the Siberian gradient, we excluded sites belonging to the “Yedoma Suite” (Dutta et al., 2006; Schirrmeister et al., 2008).

Two study sites reside in the typical tundra zone on the Taimyr Peninsula in central Siberia. Ari-Mas (AM) and Logata (LG) were located 70 and 180 km north-west of Chatanga. The climate in the interior Taimyr Peninsula (Chatanga meteorological station) is extremely continental with a MAT of -12.6°C and a MAP of 278 mm. The Taimyr Peninsula was glaciated several times during the Quaternary but remained periglacial through the last glacial maximum. At AM, the sampling sites resided on sand- and silt-rich fluvial-marine sediments derived from sea transgression during the Eemian interglacial (Svendsen et al., 2004). The LG sites were located on marine deposits from a Kara Sea transgression after the Early Weichelian glaciation (Svendsen et al., 2004). The northern sampling site on the West Siberian Plain near Tazovsky (TZ) is located in the southern tundra (TZ A-C) while the southern sampling site (TZ D-F) is in the transition zone to forest tundra. The climate is under a stronger influence of the arctic sea, with a MAT of -8.3°C MAT and a MAP of 452 mm. The landscape is gently hilly and the parent material composed of a mixture of silt-rich marine and alluvial post-glacial deposits (Svendsen et al., 2004). According to the formula of Gorczynsky (Blüthgen and Weischet, 1980), the index of continentality increased from meteorological stations in Tazovsky ($K = 57$) over Chatanga ($K = 61$) to Cherskiy ($K = 68$).

S 2 PLSR Statistics

Interactions of OC with soil mineral parameters were studied with partial least squares regression (PLSR) analysis. This approach has proven as insensitive to multicollinearity effects or if the number of predictors exceed the number of observations (Carrascal et al., 2009). The PLSR technique constructed latent factors by linear combinations between predictor and response variables such that the original multidimensionality is reduced to a lower number of orthogonal factors (Carrascal et al., 2009). In line with Carrascal et al. (2009), we only report “significant” latent factors which explain $> 5\%$ of the original variance. Variable importance in the projection (VIP) values were used as indicator for the weight of each predictor on the result matrix. In general, VIP values > 1 indicate an above average influence on the response variable and, thus, represent the variable

1 having the highest explanatory power (Mehmood et al., 2012; Chong and Jun, 2005). Based on
 2 the ANOVA results and subsequent Post-hoc tests, the sample pool for PLSR analysis was divided
 3 into two horizon clusters, i.e., topsoil horizons (including subducted topsoil) and subsoil horizons
 4 (including permafrost horizons), and performed for each site individually.

5 S 3 Density fractionation

6 Twenty-five g (25 g) of the bulk soil were weighed in duplicates into centrifugation bottles and
 7 amended with 125 ml sodium polytungstate (SPT) adjusted to a density of 1.6 g cm^{-3} . After one
 8 hour of equilibration, soil samples were dispersed by sonication (LABSONIC ultrasound homoge-
 9 nizer, Sartorius Stedim Biotech GmbH) using an energy input of 60 J ml^{-1} (Cerli et al., 2012). As
 10 most of the soil samples had a plastic soil structure with little or absent aggregation, we did not
 11 distinguish “free” and “occluded” particulate OM but separated the total particulate material as
 12 “light fraction” (LF) from the “heavy fraction” (HF), which contained OM associated with miner-
 13 als. After sonication, the suspension was allowed to settle for one hour and thereafter centrifuged
 14 at $3,000 \times g$ for 20 minutes. The floating LF was transferred on a quartz fibre filter (Whatman GF
 15 6) placed in a Büchner funnel connected to a vacuum pressure device. The LF material was rinsed
 16 with deionised water until the electric conductivity of the cleaning solution was $< 50 \mu\text{S cm}^{-1}$. The
 17 HF pellet was resuspended in deionized water and centrifuged at $6,000 \times g$ for up to 60 minutes to
 18 remove residual SPT. The procedure was repeated until the electric conductivity dropped below
 19 $50 \mu\text{S cm}^{-1}$. Both, the LF and HF materials were freeze-dried for further analyses.

20 Separation of soil into light (LF) and heavy (HF) fractions was performed with an average dry
 21 mass recovery of $93.9 \pm 3.5\%$, and the vast majority ($96.9 \pm 6.6\%$) of the soil was recovered as HF.
 22 Within these two fractions, the recovery was $85.2 \pm 15.9\%$ of the initial soil OC, and $89.7 \pm 15.7\%$
 23 of the initial TN. During density fractionation, substantial amounts of soluble OC and TN were
 24 mobilized by the SPT solution (termed ‘MoF’). From that, $80.3 \pm 12.3\%$ OC was released from
 25 HF and $19.7 \pm 12.3\%$ from LF (Fig. S3).

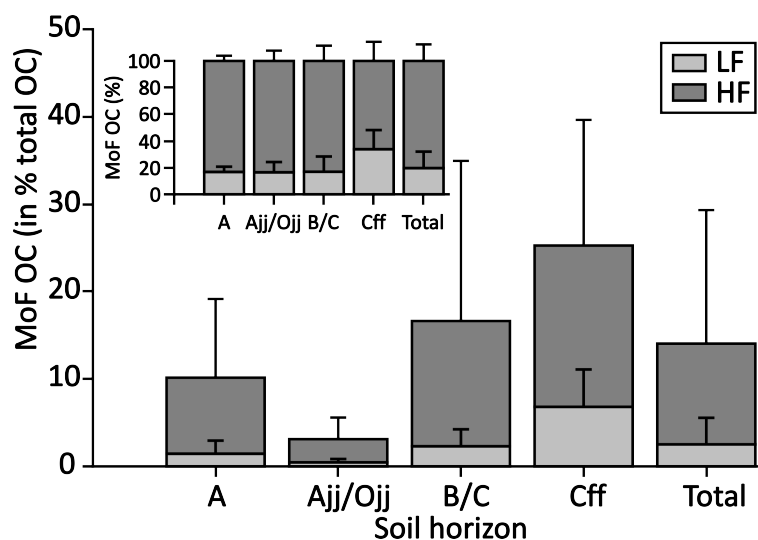


Fig. S 1: Contribution of LF and HF to the total proportion of mobilizable OC (MoF-OC) during density fractionation. Values derived from measurements of DOC in rinsing solutions. The values were expressed as percentage of the respective fraction to the total MoF-OC pool (inner bar chart) and percent MoF-OC related the total OC concentration.

S 4 Mineral composition and transformation

Soils in the Kolyma region developed from sediments of aeolian origin and clay mineral transformation in this region is primarily ascribed to the degradation of illite and chlorite under formation of randomly interstratified illite-smectite and chlorite-smectite (Alekseev et al., 2003). Soils at CH contained an assemblage of 1:1 and 2:1 clay minerals dominated by illite, chlorite, and kaolinite, with increasing abundance of smectite and interlayered smectite minerals within the transient layer. In contrast to the east Siberian sites, the shallow marine-alluvial deposits in west and central Siberia were almost entirely dominated by the 2:1 clay mineral smectite which is in line with previous reports about soils from the Taimyr Peninsula (Sokolov et al., 2004; Vasil'evskaya, 1980) and northwest Siberia (Mahaney et al., 1995). The smectites at our study sites likely originated from smectite-bearing sediments of paleosols from the Siberian Tap Province (Rossak et al., 1999; Svendsen et al., 2004).

The eastern and western Siberian soils showed an advanced state of soil development compared to their central Siberian counterparts. This was indicated by smaller amounts of exchangeable Mg^{2+} and Ca^{2+} in coincidence with higher proportions of Al^{3+} at the exchange complex, thus reflecting a stronger degree of weathering and higher leaching losses of nutrients (Table S1). The release of Al^{3+} partially result in the formation of Al hydroxide interlayers in smectite as is evident from the XRD pattern in the topsoil (Fig S2). Incipient “chloritization” by polymerization of Al hydroxides in the interlayer of smectite (Wilson, 1999) is considered to be very likely under the present pH of 4.7 to 5.7 (Rich, 1968). But only in the east Siberian sites, with highest contents of total (Fed > 1%) and well crystalline (Fe_d – Fe_o) pedogenic Fe oxides, the soil development led to the formation of larger amounts of sesquioxides. The high Fe_o contents and activity ratios (Fe_o/Fe_d) of 0.4 to 1.0 suggest a strong redox influence in the soils with continuous mobilization and immobilization of Fe (Cornell and Schwertmann, 2003). Further crystallization of Fe oxyhydroxide is likely impeded by high amounts of OM (Eusterhues et al., 2008) such as present in subducted topsoils, leading to the overall enrichment of poorly crystalline Fe forms in mineral horizons.

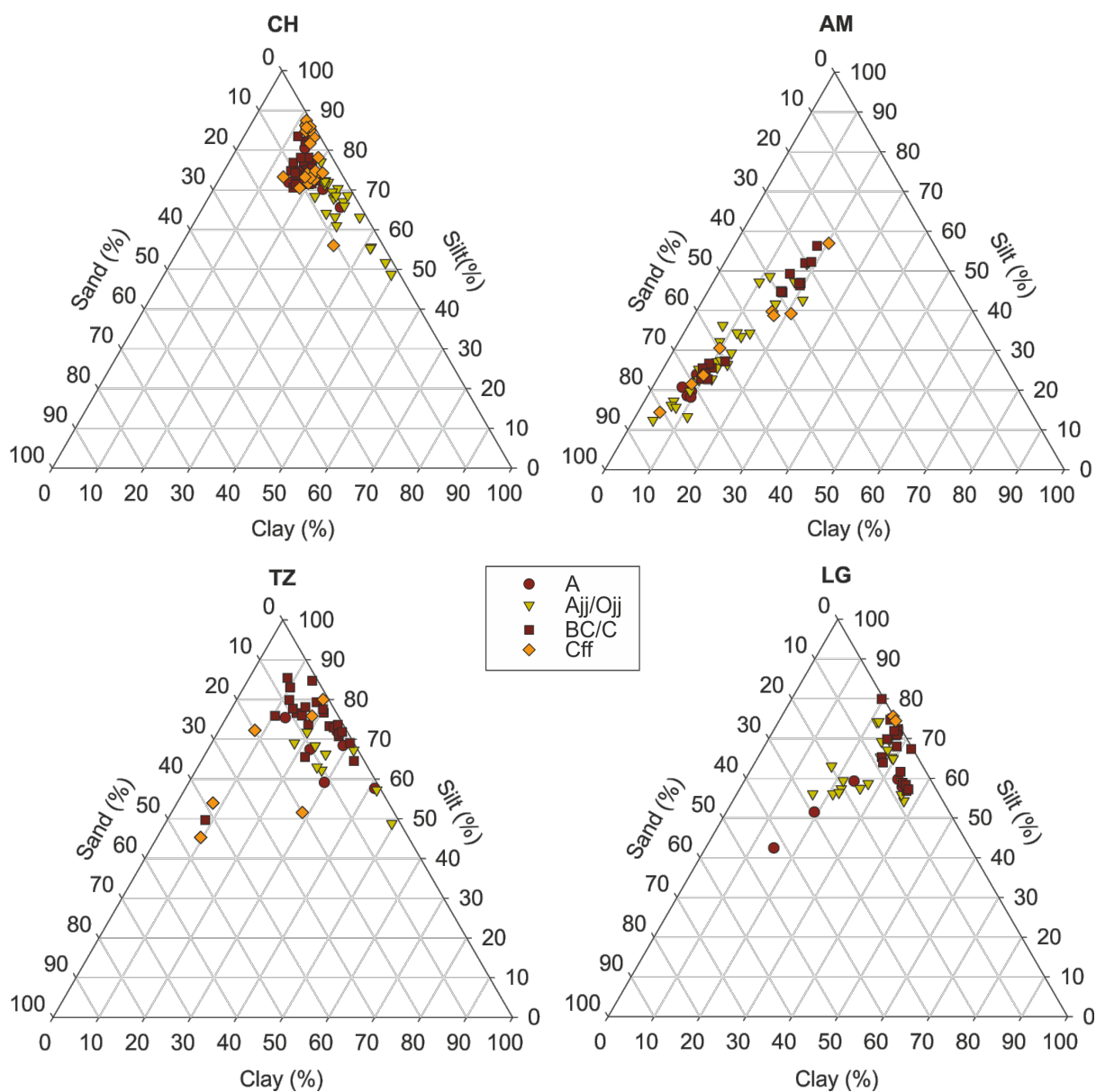


Fig. S 2: Texture composition in mineral soil horizons from four sampling locations across the Siberian Arctic. Texture classes according to the FAO (Food and Agriculture Organization) system.

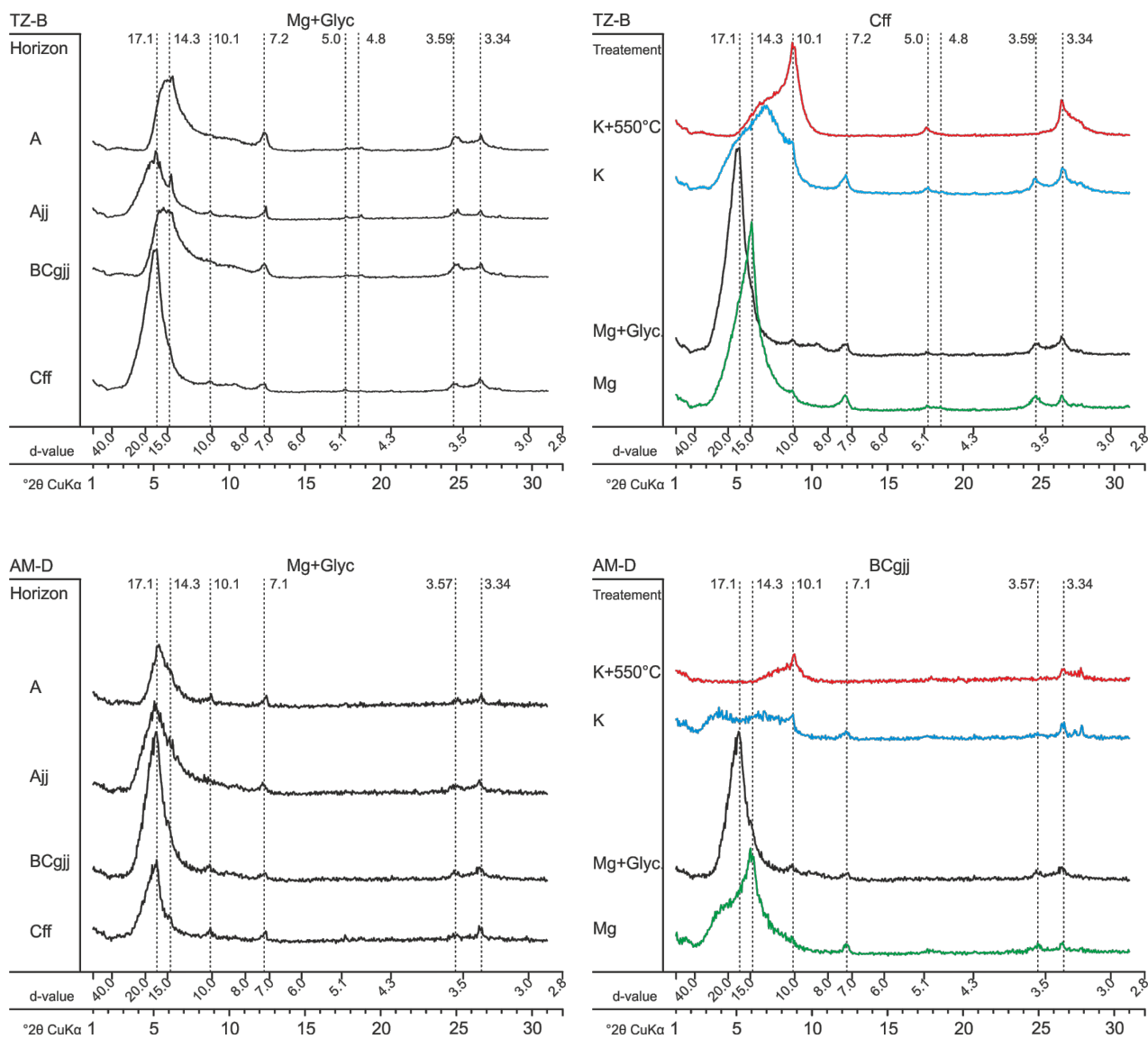


Fig. S 3: X-ray diffraction pattern of the clay sized fraction across the siberian sampling sites (TZ-Tazowskiy, AM-Ari-Mas, LG-Logata, Cherskiy). The left graphs showing the Mg-saturated ethylene glycol solvated from topsoil horizons (A) following a depth gradient to the permafrost (Cff). The right graphs showing the different treatments (Mg-saturated, Mg-saturated ethylene glycol solvated, K-saturated, K saturated heated to 550°C) for one of the respective samples from the left.

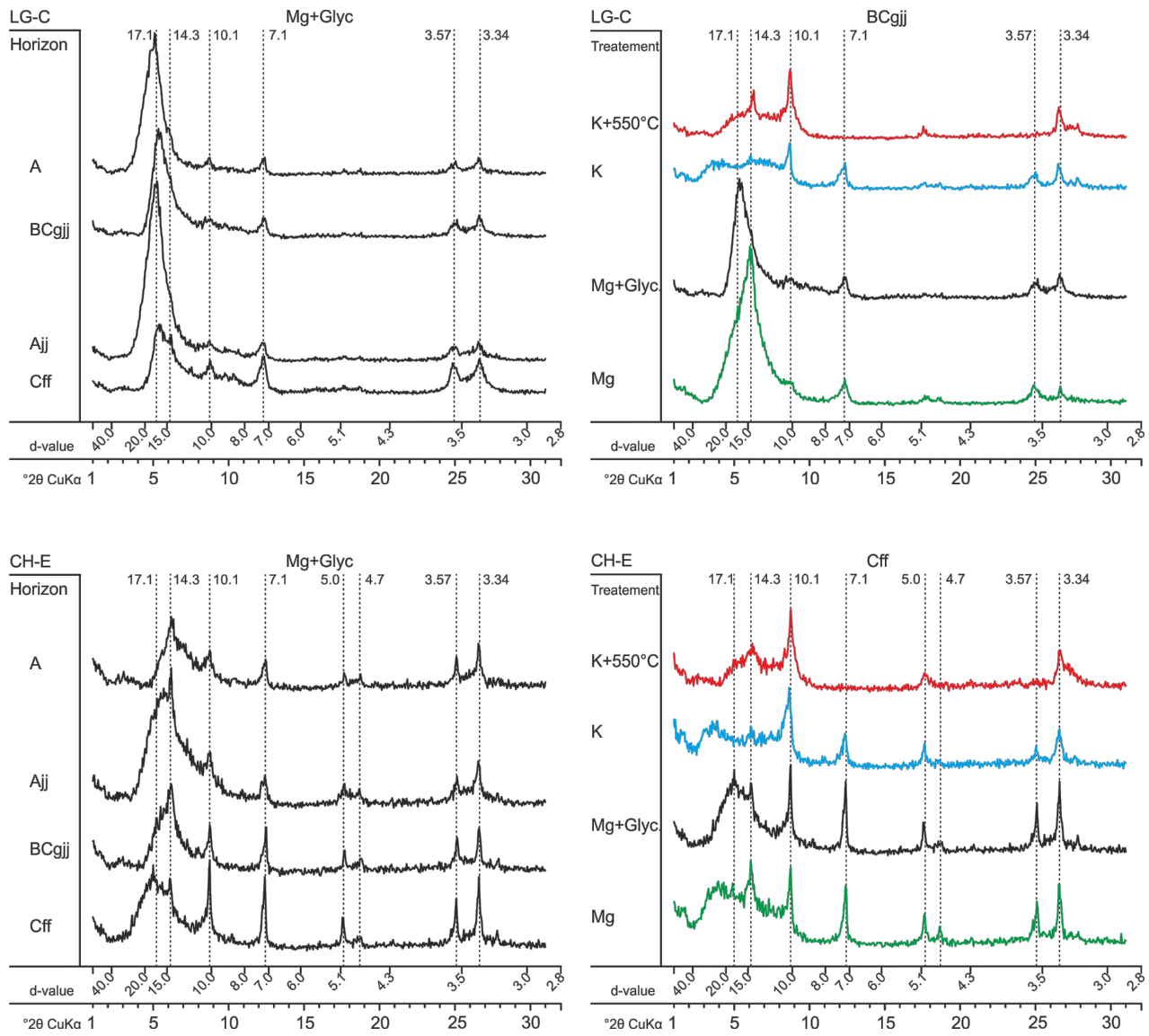


Fig. S 4: Continued figure from the previous page.

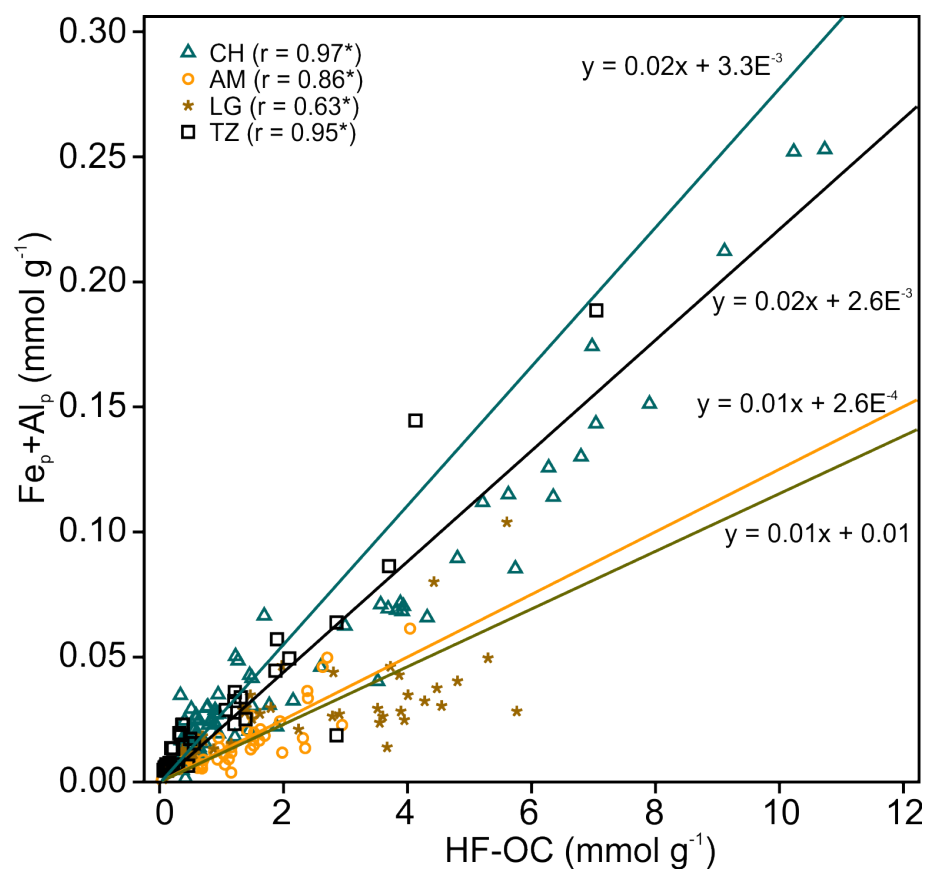


Fig. S 5: Relation between organically complexed Fe and Al and mineral bound OC (HF-OC) across the different sampling locations. The reported Pearson correlation coefficients (r) include topsoil and subsoil horizons ($*p < 0.001$).

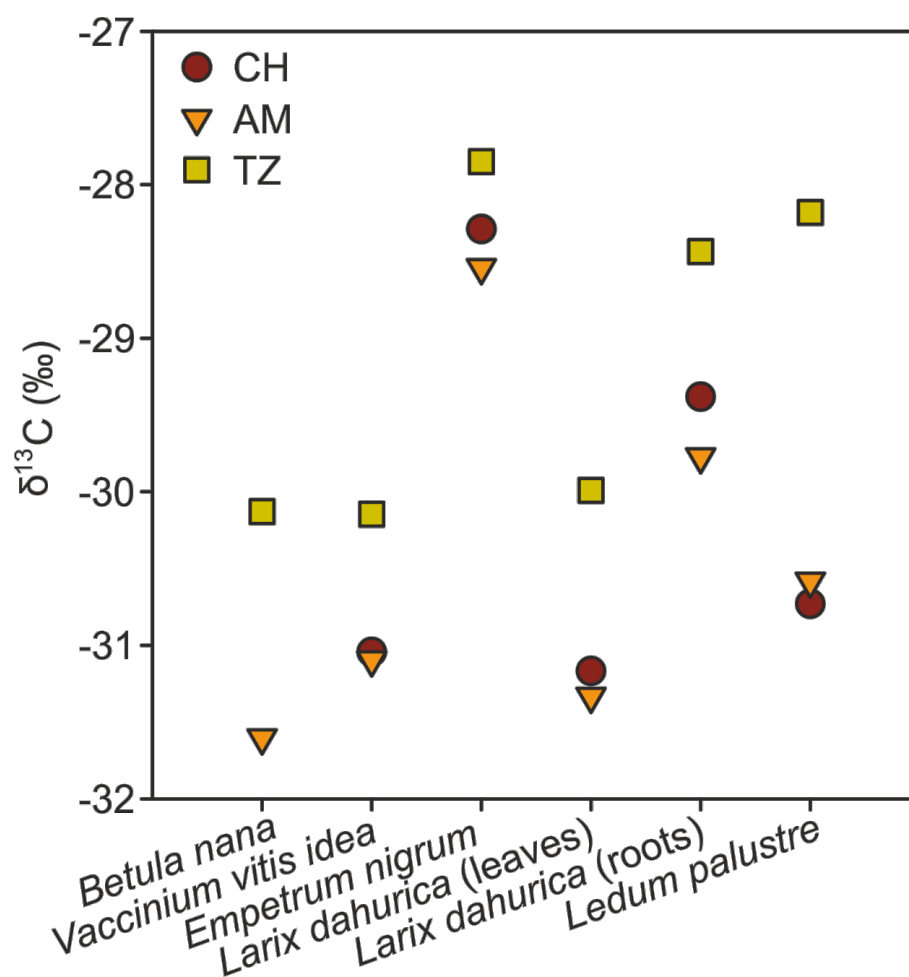


Fig. S 6: Carbon isotopic composition in individual plants from different sampling location in West Siberia (TZ), Central Siberia (AM), and eastern Siberia (CH). The higher $\delta^{13}\text{C}$ ratios in western Siberia continue in OM from soil samples of these sites and suggest isotope discrimination by plants at sites of stronger continentality (AM, CH, see above).

Table S 2: Concentrations of dithionite (Fe_d), oxalate (Fe_o) and pyrophosphate (Fe_p) extractible iron (Fe) and aluminum (Al). Mean values, standard deviation (SD) and the number of samples (N) were given with respect to soil horizons and sampling location in the Siberian Arctic.

Site	Horizon	Fe _d (mg g ⁻¹)			Fe _o (mg g ⁻¹)			Fe _p (mg g ⁻¹)			Ald (mg g ⁻¹)			Alo (mg g ⁻¹)			Alp (mg g ⁻¹)			Fed-Feo (mg g ⁻¹)			Feo/Fed			Fep+Alp/Fed+Ald		
		Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
CH	A	11.94	1.61	5.93	1.74	0.66	0.45	1.30	0.35	1.45	0.34	0.41	0.21	6.01	1.09	0.49	0.10	0.08	0.04	10								
	Ajj/Ojj	12.89	5.02	10.46	6.06	3.93	2.88	2.00	0.58	2.60	0.61	1.25	0.53	2.53	2.36	0.79	0.20	0.33	0.13	26								
	B/C	10.50	2.19	6.33	2.75	0.75	0.69	0.92	0.21	1.22	0.25	0.27	0.10	4.58	2.44	0.65	0.40	0.10	0.08	25								
AM	Cff	9.75	2.66	6.97	2.33	0.74	0.58	0.75	0.28	1.14	0.36	0.18	0.16	2.85	3.82	0.77	0.28	0.09	0.06	26								
	A	3.00	0.33	2.12	0.52	0.59	0.30	0.46	0.22	0.63	0.25	0.26	0.18	0.88	0.27	0.70	0.11	0.24	0.12	7								
	Ajj/Ojj	3.57	1.20	2.30	0.91	0.60	0.42	0.59	0.42	0.83	0.36	0.24	0.22	1.29	1.03	0.65	0.20	0.21	0.11	28								
LG	B/C	4.02	0.83	1.84	0.67	0.16	0.04	0.39	0.10	0.94	0.27	0.11	0.03	2.18	0.82	0.46	0.16	0.06	0.01	14								
	Cff	4.02	1.33	2.15	0.35	0.31	0.23	0.30	0.11	0.77	0.13	0.10	0.03	1.87	1.19	0.57	0.15	0.10	0.06	11								
	A	6.53	1.56	4.46	1.58	1.11	0.31	0.71	0.17	0.89	0.30	0.38	0.13	2.08	1.74	0.69	0.21	0.21	0.05	5								
	Ajj/Ojj	6.91	2.52	5.19	2.69	1.56	1.10	0.67	0.23	0.80	0.23	0.30	0.11	1.73	1.34	0.74	0.19	0.26	0.11	23								
	B/C	8.50	1.24	5.28	1.23	0.99	0.50	0.56	0.18	0.90	0.20	0.22	0.09	3.22	1.36	0.63	0.15	0.14	0.07	13								
	Cff	8.53	2.54	4.29	0.82	0.73	0.26	0.35	0.08	0.65	0.10	0.10	0.02	4.36	0.81	0.50	0.08	0.12	0.06	5								
TZ	A	5.62	0.69	3.86	0.88	1.11	0.82	1.52	0.52	1.84	0.66	0.74	0.35	1.76	0.80	0.69	0.14	0.25	0.14	6								
	Ajj/Ojj	6.16	1.13	4.68	1.56	1.13	1.32	1.84	0.92	1.87	1.09	0.83	0.88	1.51	0.94	0.75	0.16	0.17	0.13	18								
	B/C	4.66	1.01	2.74	0.73	0.27	0.32	0.76	0.27	0.84	0.27	0.21	0.29	1.92	0.93	0.60	0.16	0.09	0.11	21								
	Cff	4.51	1.64	2.35	0.66	0.15	0.03	0.48	0.13	0.56	0.14	0.07	0.01	2.16	1.14	0.54	0.10	0.05	0.02	6								
	A	7.39	3.85	4.27	1.96	0.82	0.53	1.03	0.54	1.23	0.60	0.44	0.28	3.11	2.45	0.62	0.16	0.18	0.12	28								
	Ajj/Ojj	7.59	4.70	5.68	4.70	1.97	2.27	1.26	0.87	1.50	0.99	0.67	0.65	1.80	1.63	0.73	0.19	0.25	0.13	95								
All sites	B/C	7.22	3.19	4.25	2.55	0.54	0.58	0.71	0.29	1.00	0.30	0.22	0.18	3.11	2.00	0.59	0.27	0.09	0.08	73								
	Cff	7.71	3.40	5.01	2.83	0.59	0.50	0.56	0.29	0.93	0.36	0.14	0.13	2.69	2.96	0.67	0.24	0.09	0.06	48								
	Total																				244							

Table S 4: Comparison of bulk OC stocks (in kg m^{-2} to 100 cm soil depth, mean \pm SD) from this study (study 1) to Palmtag et al. (in press) (study 2), and Palmtag et al. (in preparation) (study 3). The investigated soil profiles from study 1 were representative for tussock tundra and grass tundra from study 2, together covering 64% of the total landscape area. At the AM and LG sites, soil profiles from study 1 were representative for wet and dry uplands from study 3, together representing 47% and 48% of the total landscape area.

Study	Site	Land Cover	Area of the total landscape (%)	0-100 cm	Organic layer	Mineral layer	Active layer	Permafrost layer
1	CH D-F	Tussock tundra		28.5 ± 6.0	4.7 ± 5.7	23.8 ± 5.1	16.5 ± 5.9	12.0 ± 4.5
2	Shalaurovo	Tussock tundra	46.5	29.0 ± 4.0	4.4 ± 2.5	24.6 ± 2.8	22.0 ± 5.9	7.0 ± 4.9
1	CH A-C	Grass tundra		18.4 ± 3.3	2.7 ± 2.9	15.7 ± 2.5	13.1 ± 3.2	5.4 ± 0.7
2	Shalaurovo	Grass tundra	17.5	21.3 ± 3.9	2.3 ± 0.9	19.0 ± 4.4	17.0 ± 3.0	4.5 ± 2.6
1	AM	Upland wet/dry		21.1 ± 5.4	1.6 ± 1.5	19.5 ± 5.5	14.7 ± 4.4	6.4 ± 5.9
3	Ari Mas	Upland wet	7.5	18.6 ± 1.7	5.5 ± 2.2	13.1 ± 0.6	12.7 ± 1.4	5.9 ± 1.3
3	Ari Mas	Upland dry	39.6	14.6 ± 5.8	2.0 ± 0.6	12.6 ± 5.9	13.4 ± 5.5	1.2 ± 1.2
1	LG	Upland wet/dry		24.4 ± 7.0	1.5 ± 0.9	22.9 ± 7.4	15.4 ± 3.4	9.0 ± 6.4
3	Logata	Upland wet	11.5	28.7 ± 0.0	2.2 ± 0.4	26.5 ± 0.4	15.7 ± 1.3	13.0 ± 1.3
3	Logata	Upland dry	36.3	24.5 ± 8.2	1.9 ± 0.9	22.6 ± 8.3	18.8 ± 8.5	5.8 ± 3.8

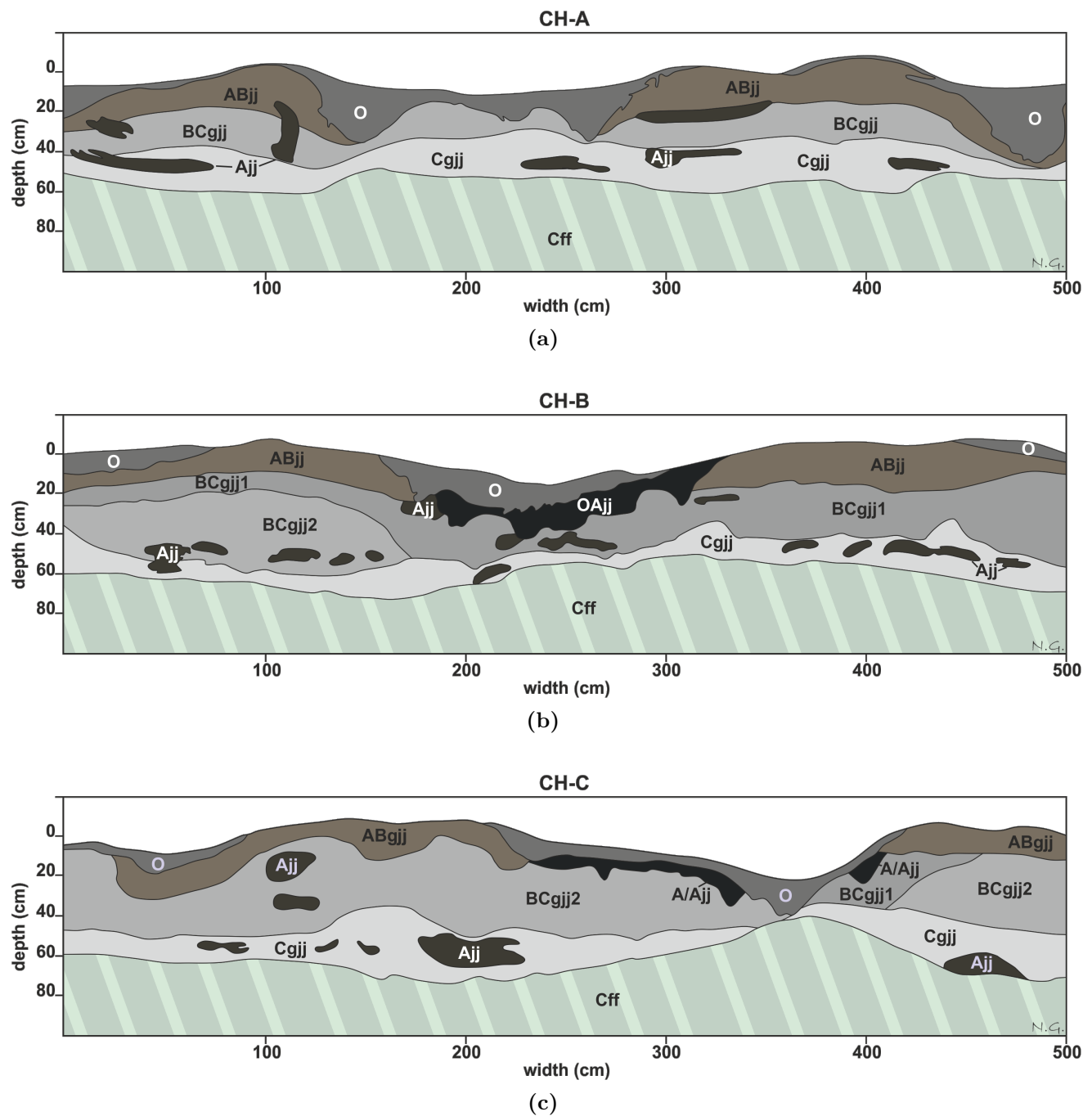


Fig. S 7: Profile sketches from the four sampling sites across Siberia (CH, AM, LG, TZ). All sketches were drawn by AutoCAT2010 and the areas of designated soil horizons were used to calculate OC and TN stocks up to one meter soil depth.

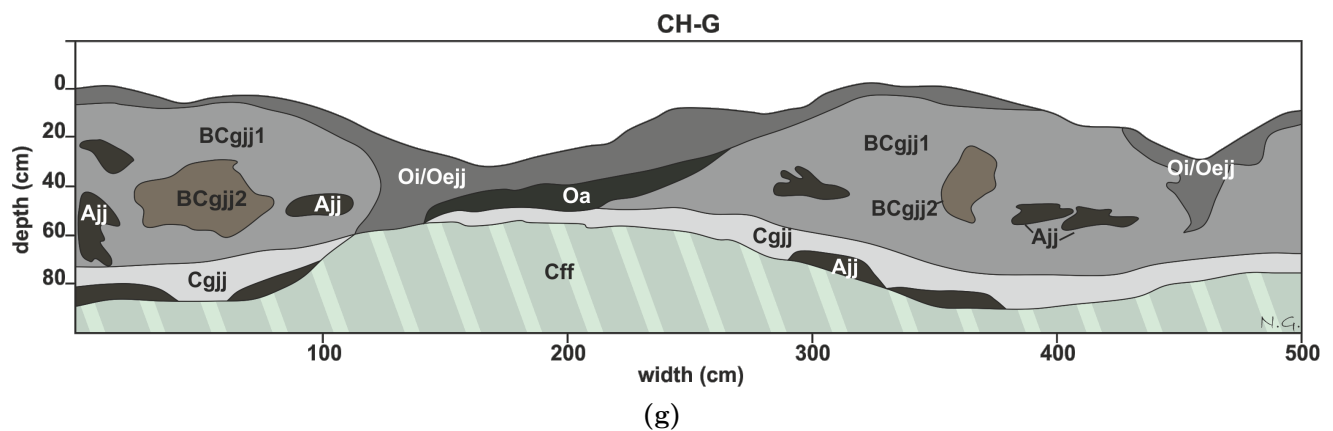
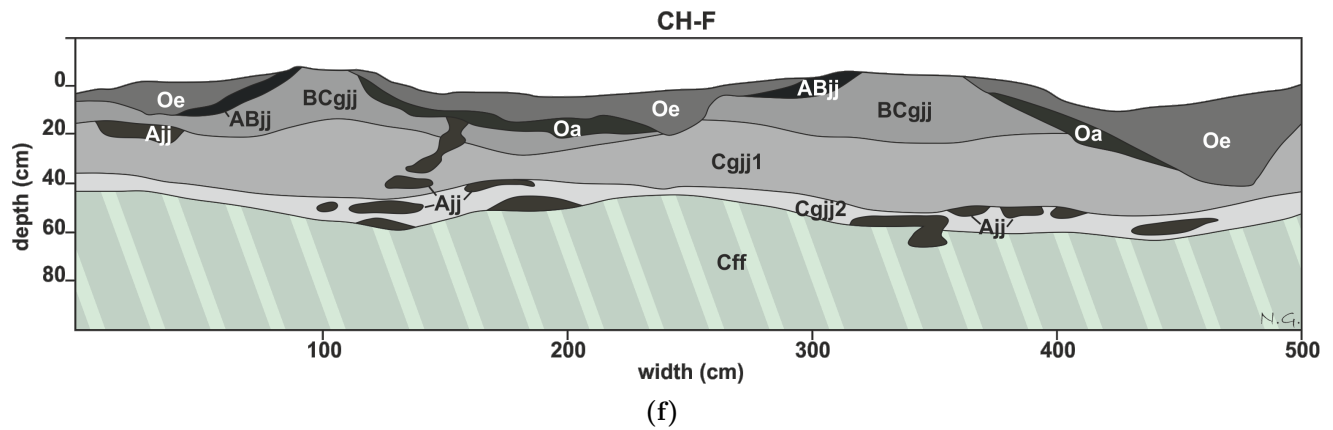
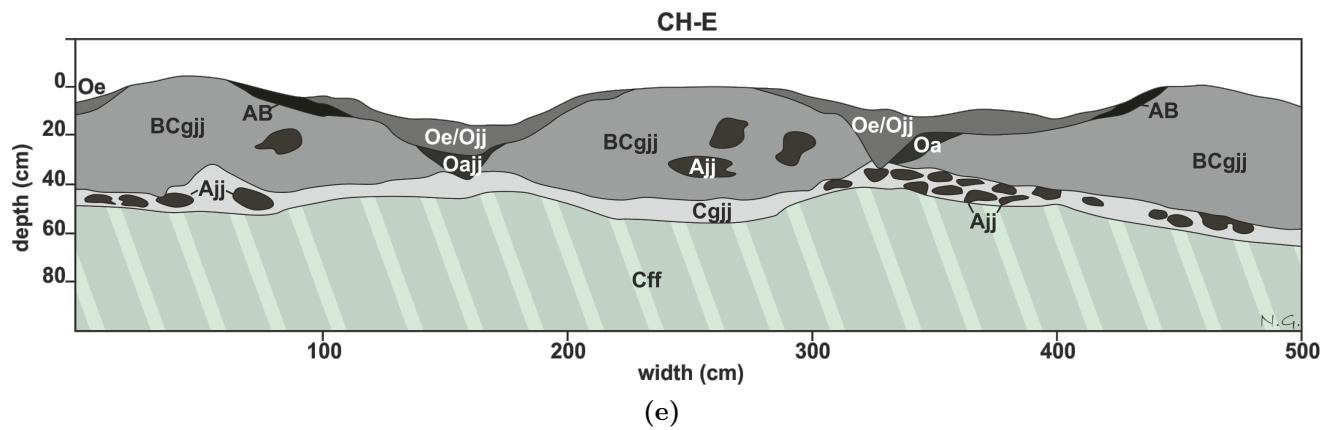
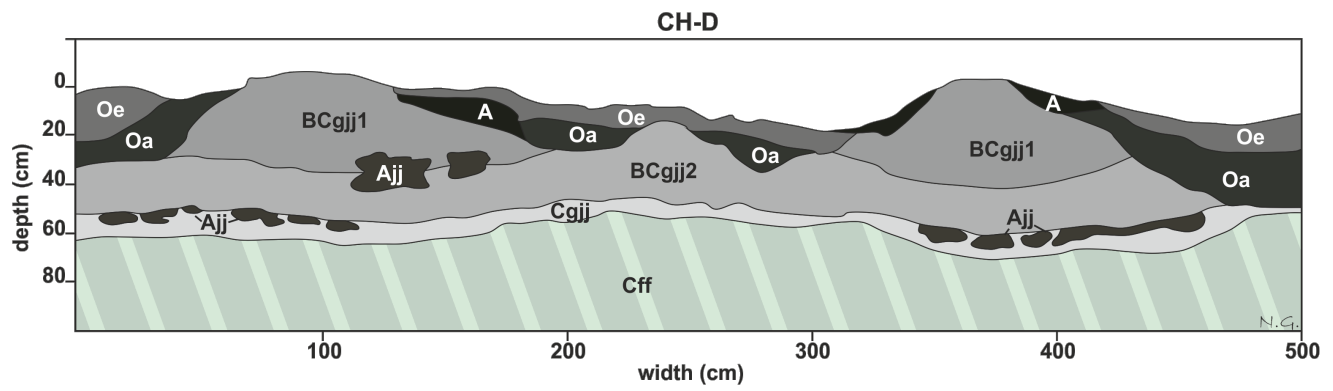


Fig. S 7: Continued figure from the previous page.

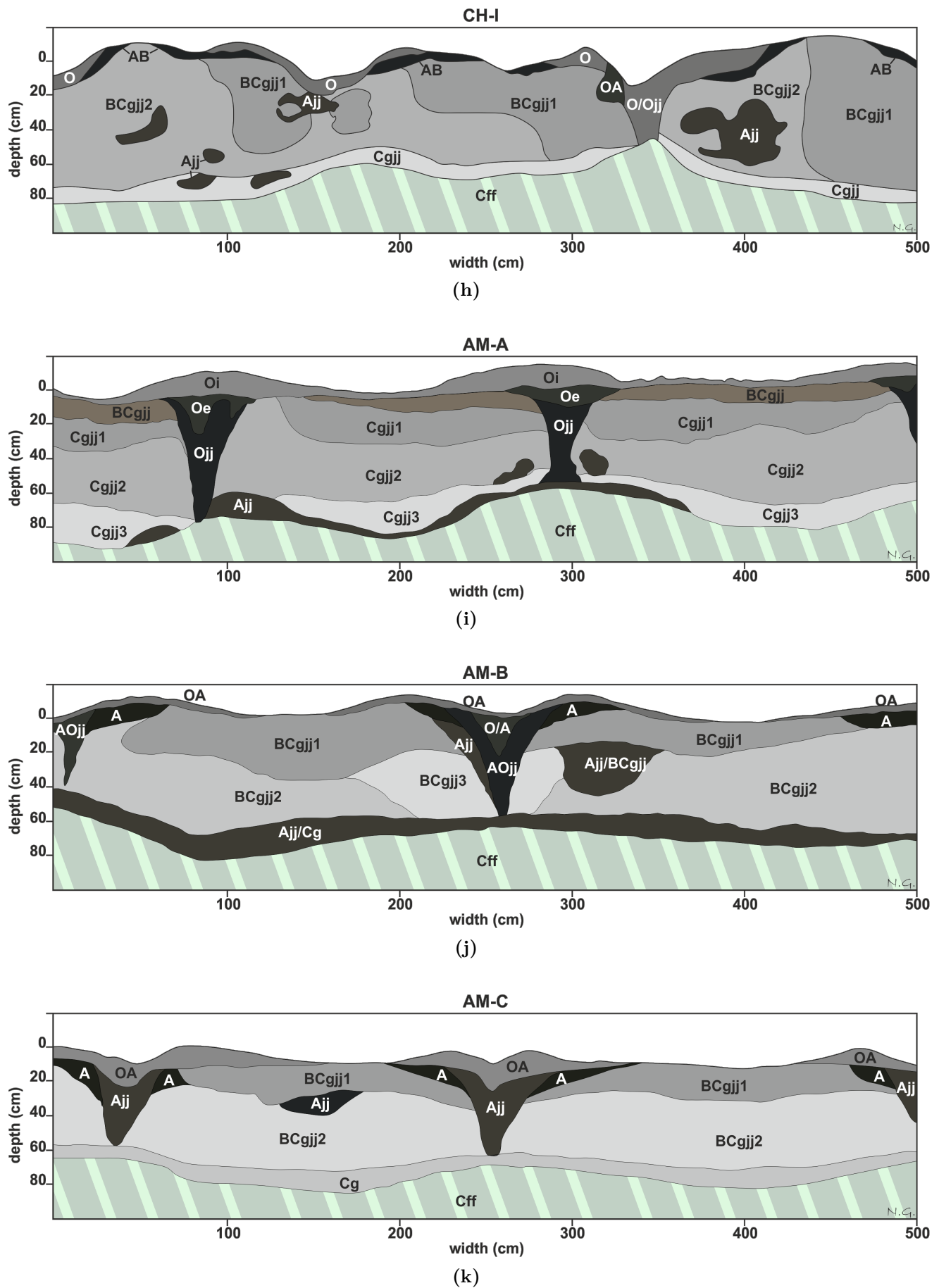


Fig. S 7: Continued figure from the previous page.

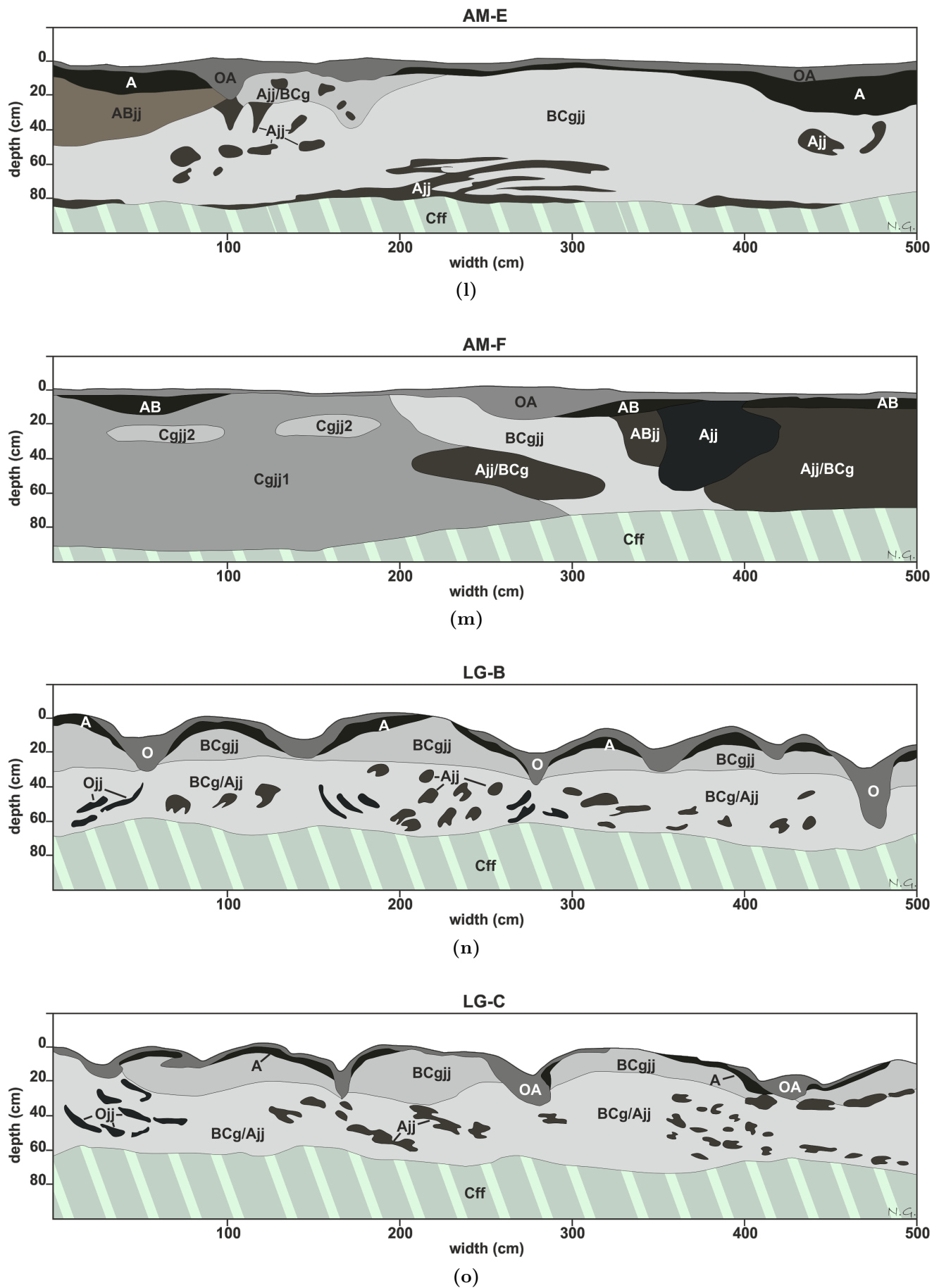


Fig. S 7: Continued figure from the previous page.

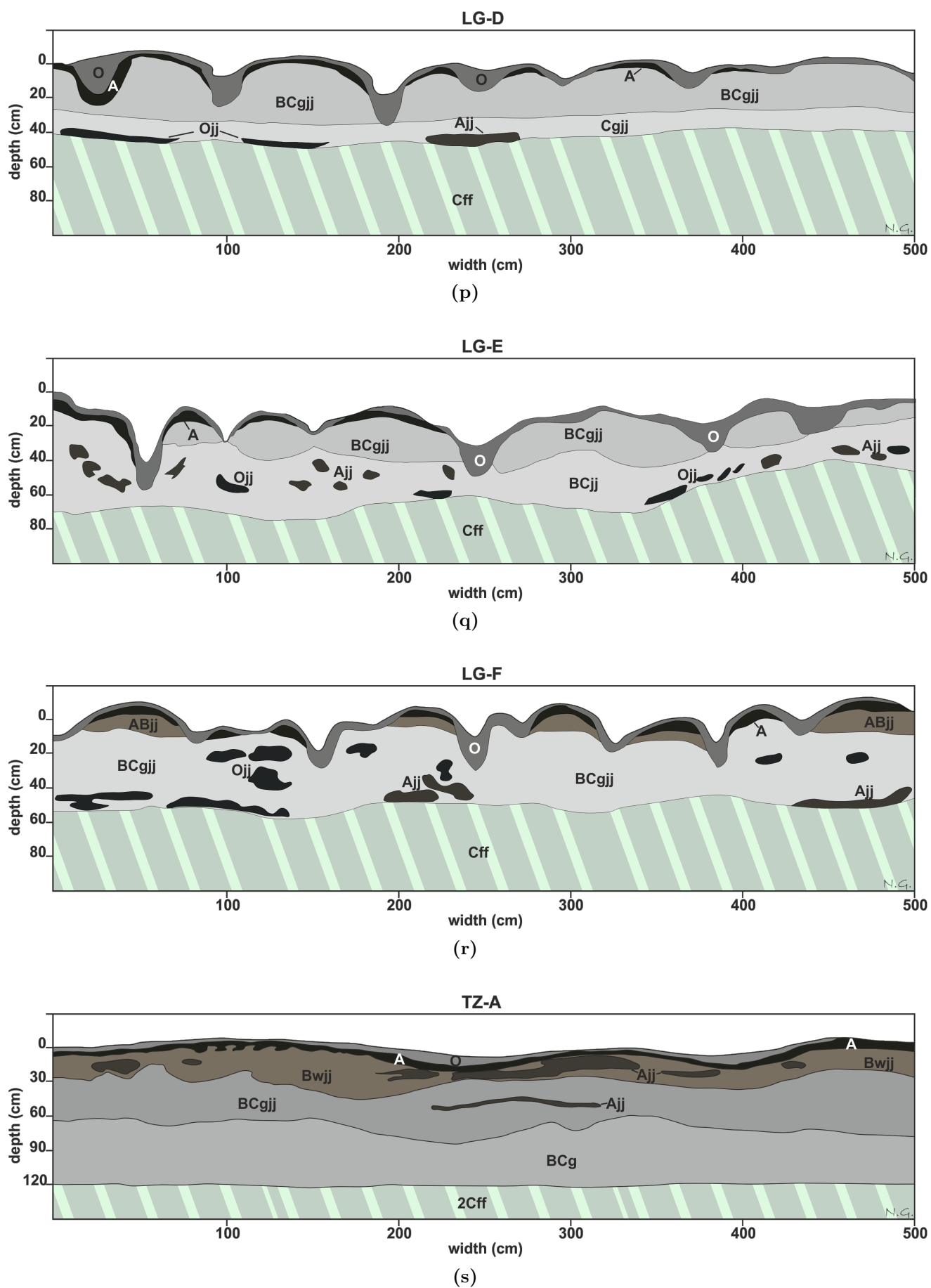


Fig. S 7: Continued figure from the previous page.

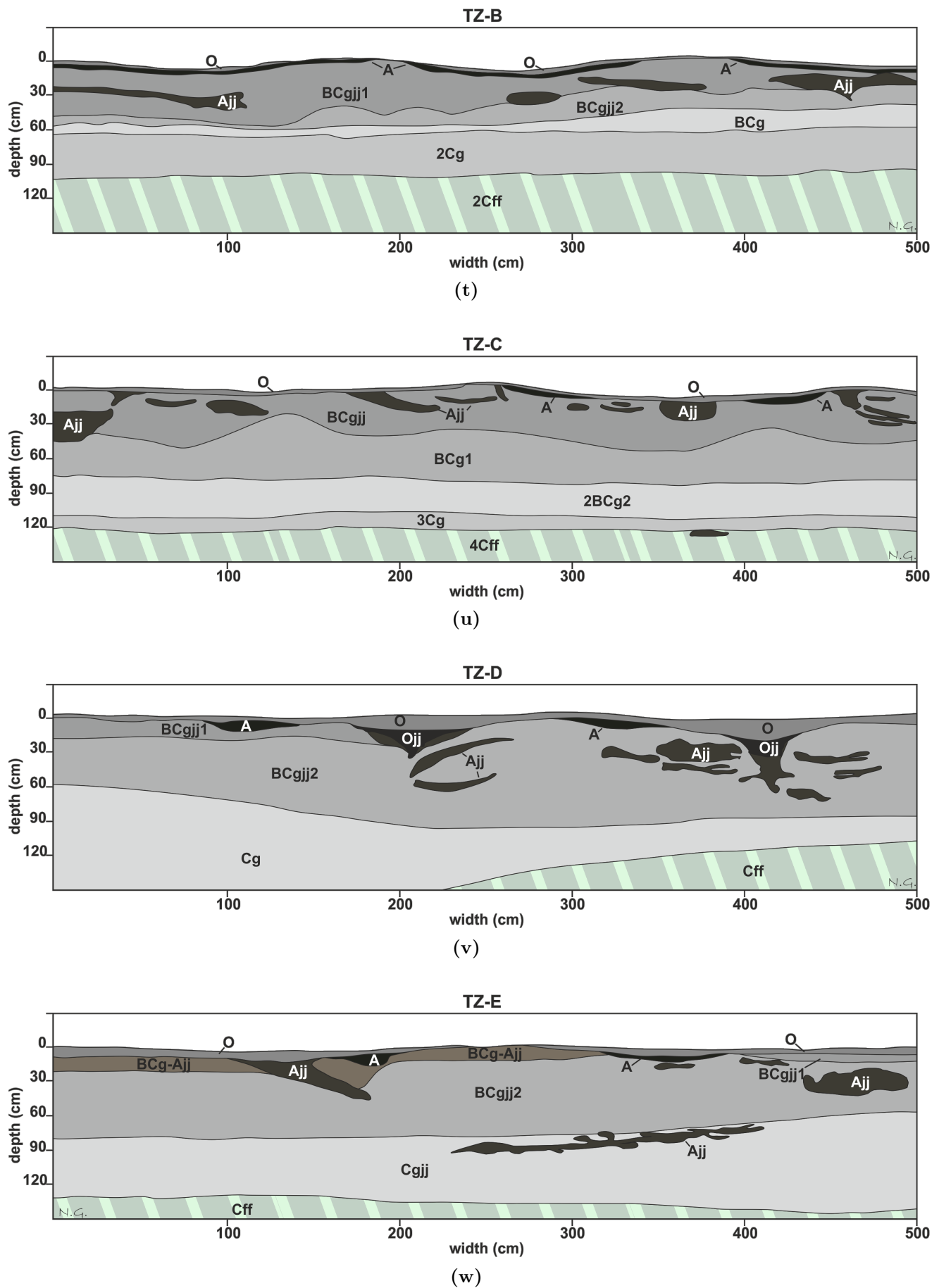


Fig. S 7: Continued figure from the previous page.

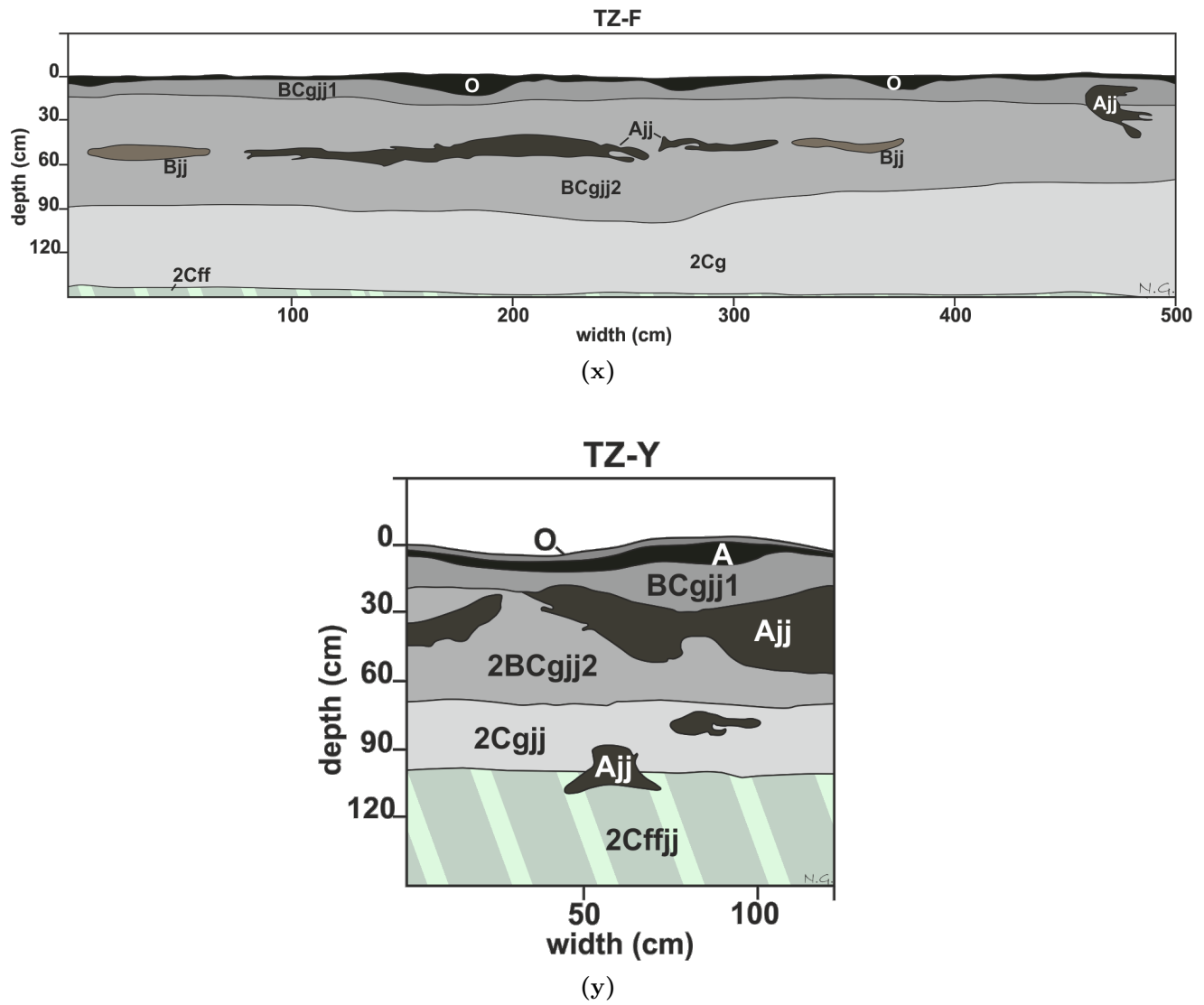


Fig. S 7: Continued figure from the previous page.

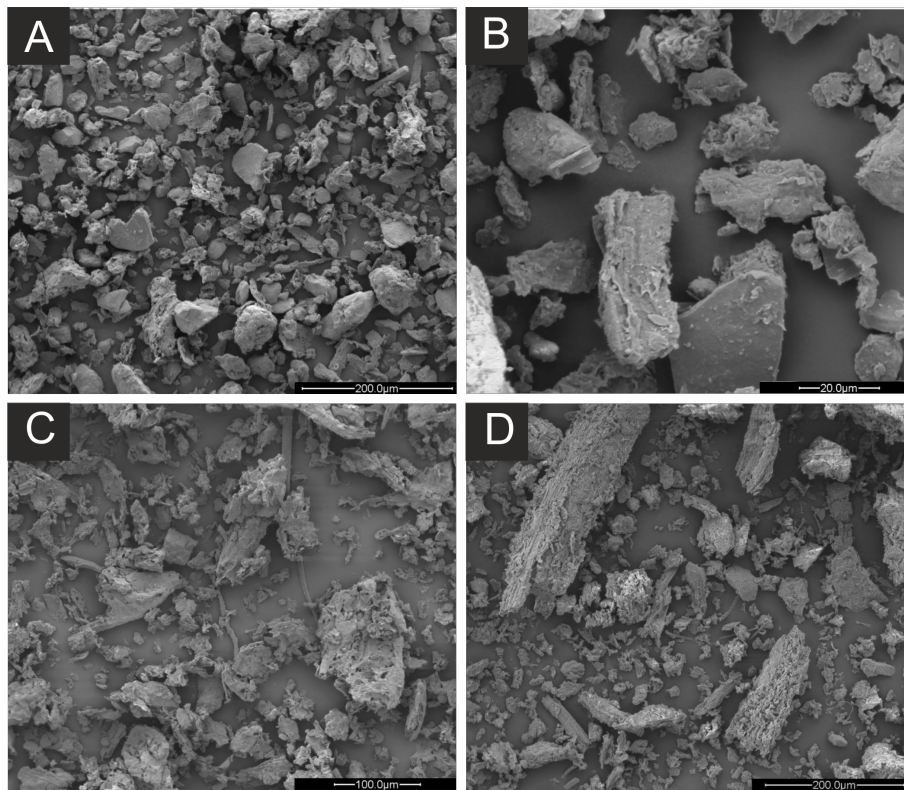


Fig. S 8: Scanning electron images from the HF of an A horizon (A) and an A_{jj} horizon from 80 cm depth (B). The related LF images from these horizons are shown in C and D.

References

- Russia's Weather Server - Weather Archive - Cherskii, Russian Federation, URL http://meteo.infospace.ru/wcarch/html/e_day_stn.sht?num=78.
- Alekseev, A., Alekseeva, T., Ostroumov, V., Siegert, C., and Gradusov, B.: Mineral Transformations in Permafrost-Affected Soils, North Kolyma Lowland, Russia, *Soil Sci. Soc. Am. J.*, 67, 596–605, 2003.
- Astakhov, V.: Geographical extremes in the glacial history of northern Eurasia: post-QUEEN considerations, *Polar Research*, 27, 280–288, 2008.
- Blüthgen, J. and Weischet, W.: *Allgemeine Klimageographie*, De Gruyter, 1980.
- Carrascal, L. M., Galván, I., and Gordo, O.: Partial least squares regression as an alternative to current regression methods used in ecology, *Oikos*, 118, 681–690, 2009.
- Cerli, C., Celi, L., Kalbitz, K., Guggenberger, G., and Kaiser, K.: Separation of light and heavy organic matter fractions in soil - Testing for proper density cut-off and dispersion level, *Geoderma*, 170, 403–416, 2012.
- Childs, C. W.: Ferrihydrite: A review of structure, properties and occurrence in relation to soils, *Z. Pflanzenernaehr. Bodenk.*, 155, 441–448, 1992.
- Chong, I.-G. and Jun, C.-H.: Performance of some variable selection methods when multicollinearity is present, *Chemometrics and Intelligent Laboratory Systems*, 78, 103–112, 2005.
- Cornell, R. M. and Schwertmann, U.: *The iron oxides: Structure, Properties, Reactions, Occurrences and Uses*, WILEY-VCH, 2003.
- Dutta, K., Schuur, E. A. G., Neff, J. C., and Zimov, S. A.: Potential carbon release from permafrost soils of Northeastern Siberia, *Global Change Biology*, 12, 2336–2351, 2006.
- Eusterhues, K., Wagner, F. E., Häusler, W., Hanzlik, M., Knicker, H., Totsche, K. U., Kögel-Knabner, I., and Schwertmann, U.: Characterization of Ferrihydrite-Soil Organic Matter Coprecipitates by X-ray Diffraction and Mössbauer Spectroscopy, *Environmental Science & Technology*, 42, 7891–7897, 2008.
- Hubberten, H. W., Andreev, A., Astakhov, V. I., Demidov, I., Dowdeswell, J. A., Henriksen, M., Hjort, C., Houmark-Nielsen, M., Jakobsson, M., Kuzmina, S., Larsen, E., Lunkka, J. P., Lyså, A., Mangerud, J., Möller, P., Saarnisto, M., Schirrmeister, L., Sher, A. V., Siegert, C., Siegert, M. J., and Svendsen, J. I. J. I.: The periglacial climate and environment in northern Eurasia during the Last Glaciation, *Quaternary Science Reviews*, 23, 1333 – 1357, quaternary Environments of the Eurasian North (QUEEN), 2004.
- Mahaney, W. C., Michel, F. A., Solomatin, V. I., and Hütt, G.: Late Quaternary stratigraphy and soils of Gydan, Yamal and Taz Peninsulas, northwestern Siberia, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 113, 249–266, doi:10.1016/0031-0182(95)00056-R, URL <http://www.sciencedirect.com/science/article/pii/003101829500056R>, 1995.

- Mehmood, T., Liland, K. H., Snipen, L., and Sæbø, S.: A review of variable selection methods in Partial Least Squares Regression, *Chemometrics and Intelligent Laboratory Systems*, 118, 62–69, 2012.
- Palmtag, J., Hugelius, G., and Kuhry, P.: Above- and below-ground carbon storage from two sites in Taymyr Peninsula, Cryosphere, in preparation.
- Palmtag, J., Hugelius, G., Lashchinskiy, N., Tamsdorf, M. P., Richter, A., Elberling, B., and Kuhry, P.: Storage, landscape distribution and burial history of soil organic matter in contrasting areas of continuous permafrost, Arctic, Antarctic, and Alpine Research, in press.
- Patyk-Kara, N. and Postolenko, G.: Structure and Cenozoic evolution of the Kolyma river valley, eastern Siberia, from its upper reaches to the continental shelf, *Proceedings of the Geologists' Association*, 115, 325–338, 2004.
- Reid-Soukup, D. and Ulery, A. L.: Smectites, in: *Soil Mineralogy with Environmental Application*, edited by Dixon, J. B. and Schulze, D. G., Soil Science Soc. of America, 2002.
- Rich, C.: Hydroxy interlayers in expansible layer silicates, *Clays Clay Miner*, 16, 15–30, 1968.
- Rivkina, E., Gilichinsky, D., Wagener, S., Tiedje, J., and McGrath, J.: Biogeochemical activity of anaerobic microorganisms from buried permafrost sediments, *Geomicrobiology Journal*, 15, 187–193, 1998.
- Rossak, B. T., Kassens, H., Lange, H., and Thiede, J.: Clay Mineral Distribution in Surface Sediments of the Laptev Sea: Indicator for Sediment Provinces, Dynamics and Sources, in: *Land-Ocean Systems in the Siberian Arctic*, edited by Kassens, D. H., Bauch, D. H. A., Dmitrenko, D. I. A., Eicken, D. H., Hubberten, P. D. H.-W., Melles, D. M., Thiede, P. D. J., and Timokhov, P. D. L. A., pp. 587–599, Springer Berlin Heidelberg, 1999.
- Schirrmeister, L., Kunitsky, V. V., Grosse, G., Kuznetsova, T. V., Derevyagin, A. Y., Wetterich, S., and Siegert, C.: The Yedoma Suite of the Northeastern Siberian Shelf Region Characteristics and Concept of Formation, in: *Proceedings of the 9th International Conference on Permafrost*, edited by Kane, D. and Hinkel, K., University of Alaska Fairbanks, Institute of Northern Engineering, 2008.
- Soil Survey Staff: *Keys to Soil Taxonomy*, United States Department of Agriculture-Natural Resources Conservation Service, Washington, DC, 11 edn., 2010.
- Sokolov, I. A., Ananko, T. V., and Konyushkov, D. Y.: The Soil Cover of Central Siberia, in: *Cryosols*, edited by Kimble, J. M., pp. 303–338, Springer Berlin Heidelberg, 2004.
- Svendsen, J. I., Alexanderson, H., Astakhov, V. I., Demidov, I., Dowdeswell, J. A., Funder, S., Gataullin, V., Henriksen, M., Hjort, C., Houmark-Nielsen, M., Hubberten, H. W., Ingólfsson, Ó., Jakobsson, M., Kjær, K. H., Larsen, E., Lokrantz, H., Lunkka, J. P., Lyså, A., Mangerud, J., Matiouchkov, A., Murray, A., Möller, P., Niessen, F., Nikolskaya, O., Polyak, L., Saarnisto, M., Siegert, C., Siegert, M. J., Spielhagen, R. F., and Stein, R.: Late Quaternary ice sheet history of northern Eurasia, *Quaternary Science Reviews*, 23, 1229 – 1271, *quaternary Environments of the Eurasian North (QUEEN)*, 2004.

- Vasil'evskaya, V. D.: Soils of Taimyr Peninsula., Moscow University Soil Science Bulletin, 35, 1–9, 1980.
- Wattel-Koekkoek, E. J. W., Buurman, P., Van Der Plicht, J., Wattel, E., and Van Breemen, N.: Mean residence time of soil organic matter associated with kaolinite and smectite, European Journal of Soil Science, 54, 269–278, 2003.
- Wilson, M. J.: The origin and formation of clay minerals in soils: past, present and future perspectives, Clay Minerals, 34, 7–7, doi:10.1180/000985599545957, 1999.