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

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S1 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 parent material composed of a mixture of silt-rich marine and alluvial post-glacial deposits (Svendsen et al., 2004). Characteristic to all sampling sites was a landscape with rolling hills and gentle slopes. 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).

S2 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 multicolinearity 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 having the highest explanatory power (Mehmood et al., 2012; Chong and Jun, 2005). Based on the ANOVA results and subsequent Post-hoc tests, the sample pool for PLSR analysis was divided into two horizon clusters, i.e., topsoil horizons (including subducted topsoil) and subsoil horizons (including permafrost horizons), and performed for each site individually.

S3 Density fractionation

Twenty-five g (25 g) of the bulk soil were weighed in duplicates into centrifugation bottles and amended with 125 ml sodium polytungstate (SPT) adjusted to a density of 1.6 g cm^{-3}. After one hour of equilibration, soil samples were dispersed by sonication (LABSONIC ultrasound homogenizer, Sartorius Stedim Biotech GmbH) using an energy input of 60 J ml^{-1} (Cerli et al., 2012). As most of the soil samples had a plastic soil structure with little or absent aggregation, we did not distinguish "free" and "occluded" particulate OM but separated the total particulate material as "light fraction" (LF) from the "heavy fraction" (HF), which contained OM associated with minerals. After sonication, the suspension was allowed to settle for one hour and thereafter centrifuged at 3,000 × g for 20 minutes. The floating LF was transferred on a quartz fibre filter (Whatman GF 6) placed in a Büchner funnel connected to a vacuum pressure device. The LF material was rinsed with deionised water until the electric conductivity of the cleaning solution was < 50 µS cm^{-1}. The HF pellet was resuspended in deionized water and centrifuged at 6,000 × g for up to 60 minutes to remove residual SPT. The procedure was repeated until the electric conductivity dropped below 50 µS cm^{-1}. Both, the LF and HF materials were freeze-dried for further analyses. The separation of soil into light (LF) and heavy (HF) fractions was performed with an average dry mass recovery of 93.9 ±3.5%, and the vast majority (96.9 ± 6.6%) of the soil was recovered as HF. Within these two fractions, the recovery was 85.2 ± 15.9% of the initial soil OC, and 89.7 ± 15.7% of the initial TN. During density fractionation, substantial amounts of soluble OC and TN were mobilized by the SPT solution (termed 'MoF'). From that, 80.3 ± 12.3% OC was released from HF and 19.7 ± 12.3% from LF (Fig. S3).

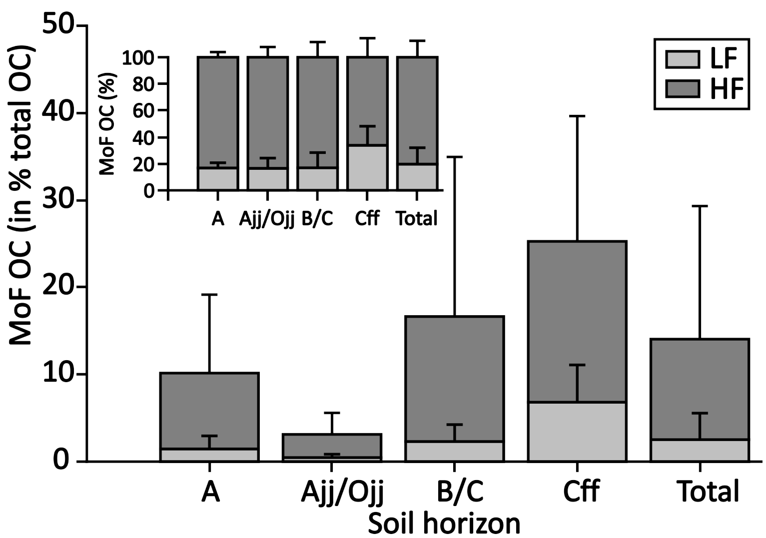


Fig. S 1: Contribution of LF and HF to the total proportion of mobilizable OC (MoF-OC) during density fractionation. Values derived from measurements of DOC in rinsing solutions. The values were expressed as percentage of the respective fraction to the total MoF-OC pool (inner bar chart) and percent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

S4 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 hyroxides 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.

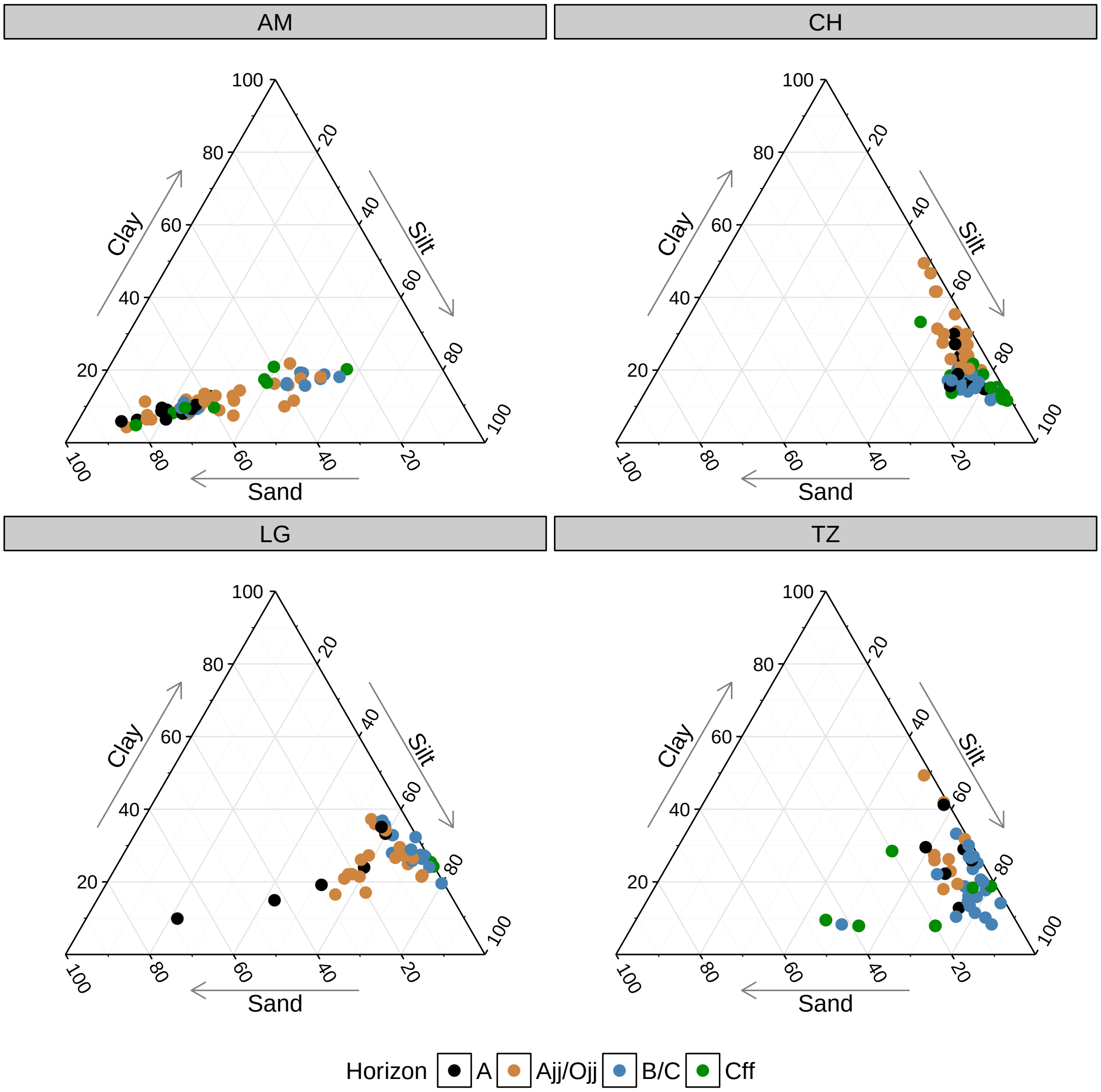


Fig. S 2: Texture composition (in %) from mineral soil horizonsacross the sampling locations in the Siberian Arctic. Texture classes according to the FAO (Food and Agriculture Organization) system.

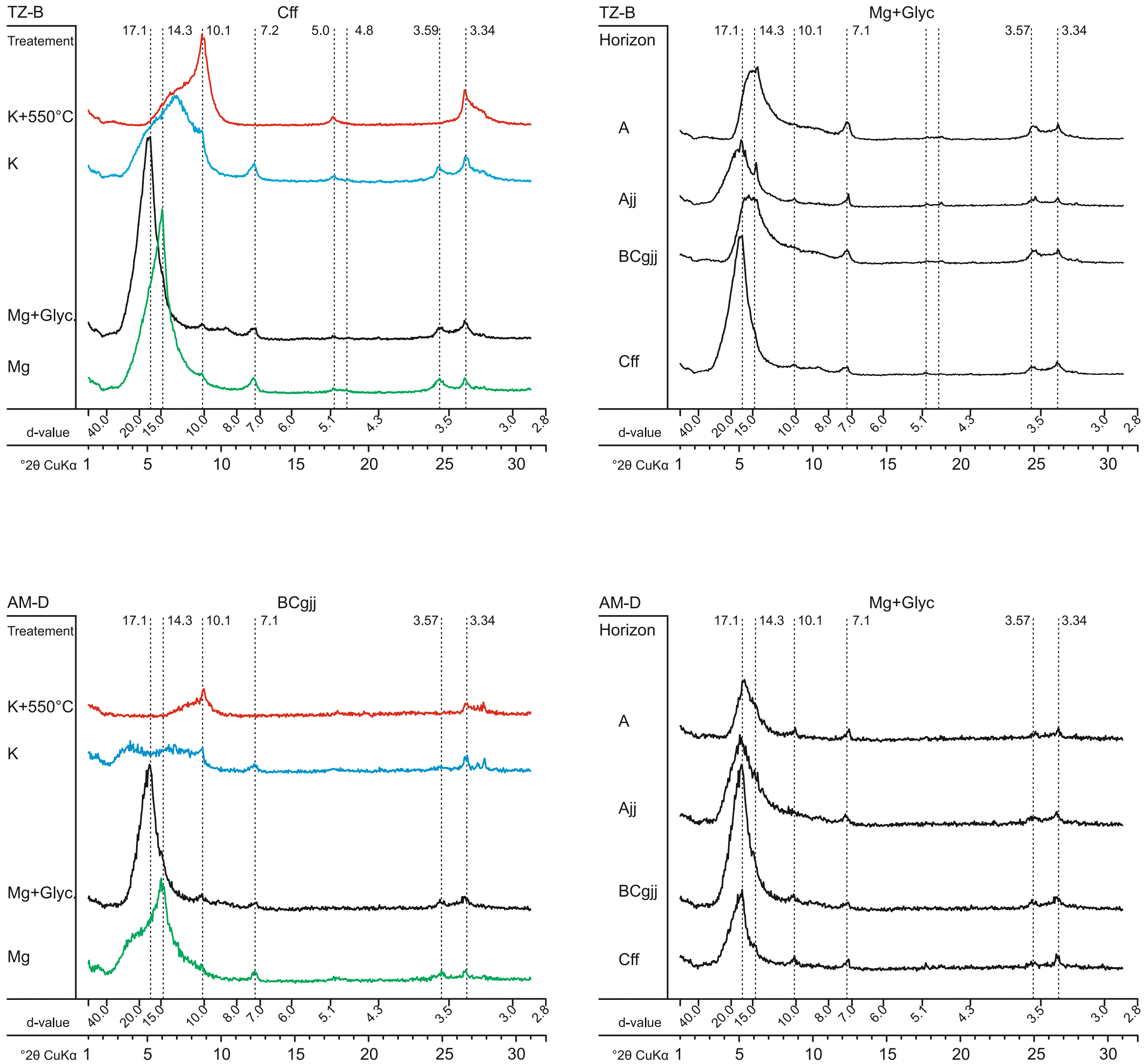


Fig. S 3: X-ray diffraction pattern of the clay sized fraction across the Siberian sampling sites (TZ-Tazowskiy, AM-Ari-Mas, LG-Logata, Cherskiy). The left panel shows the different treatments (Mg-saturated, Mg-saturated and ethylene glycol solvated, K-saturated, K saturated heated to 550°C) for one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

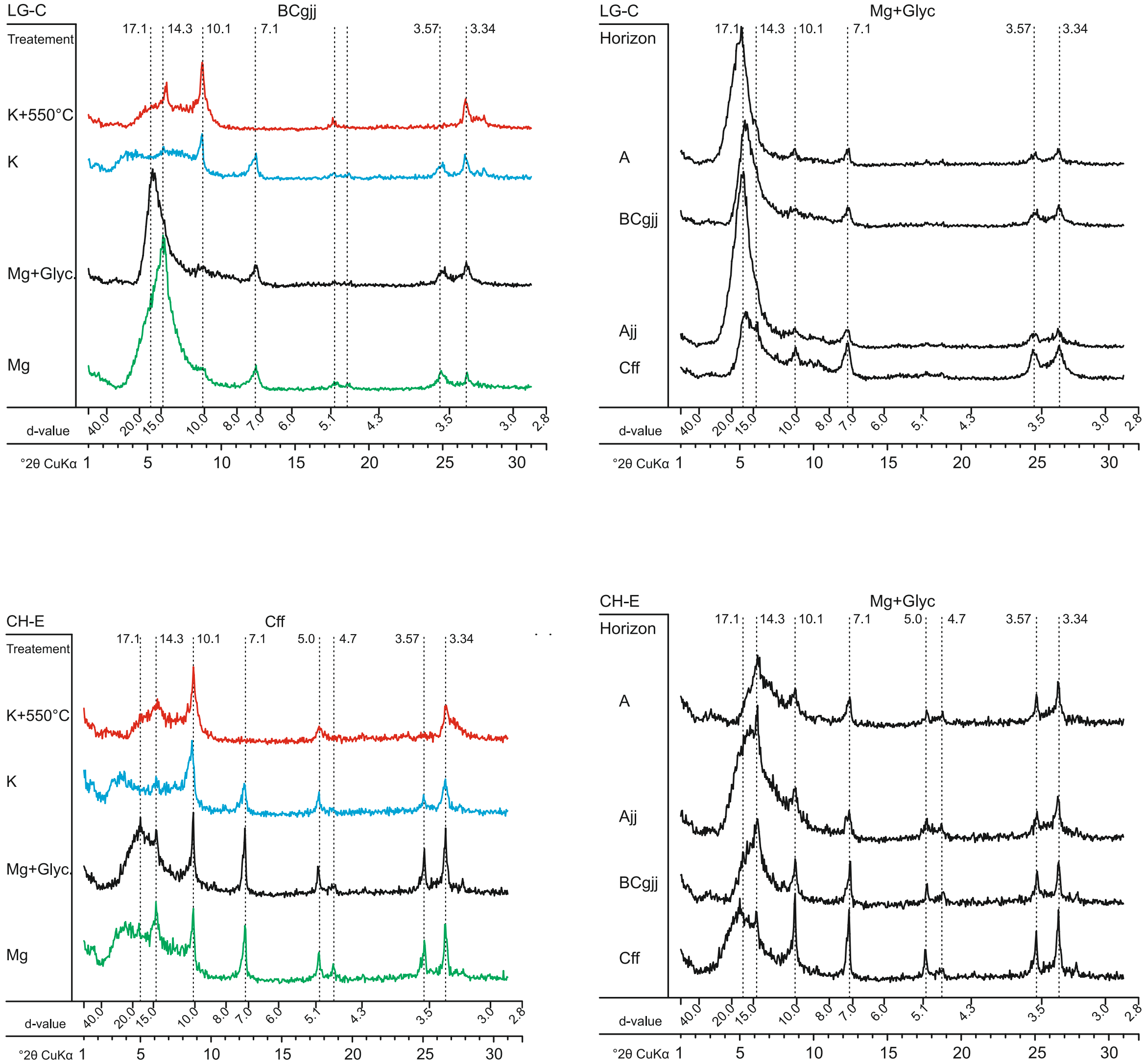


Fig. S 4: Continued figure from the previous page.

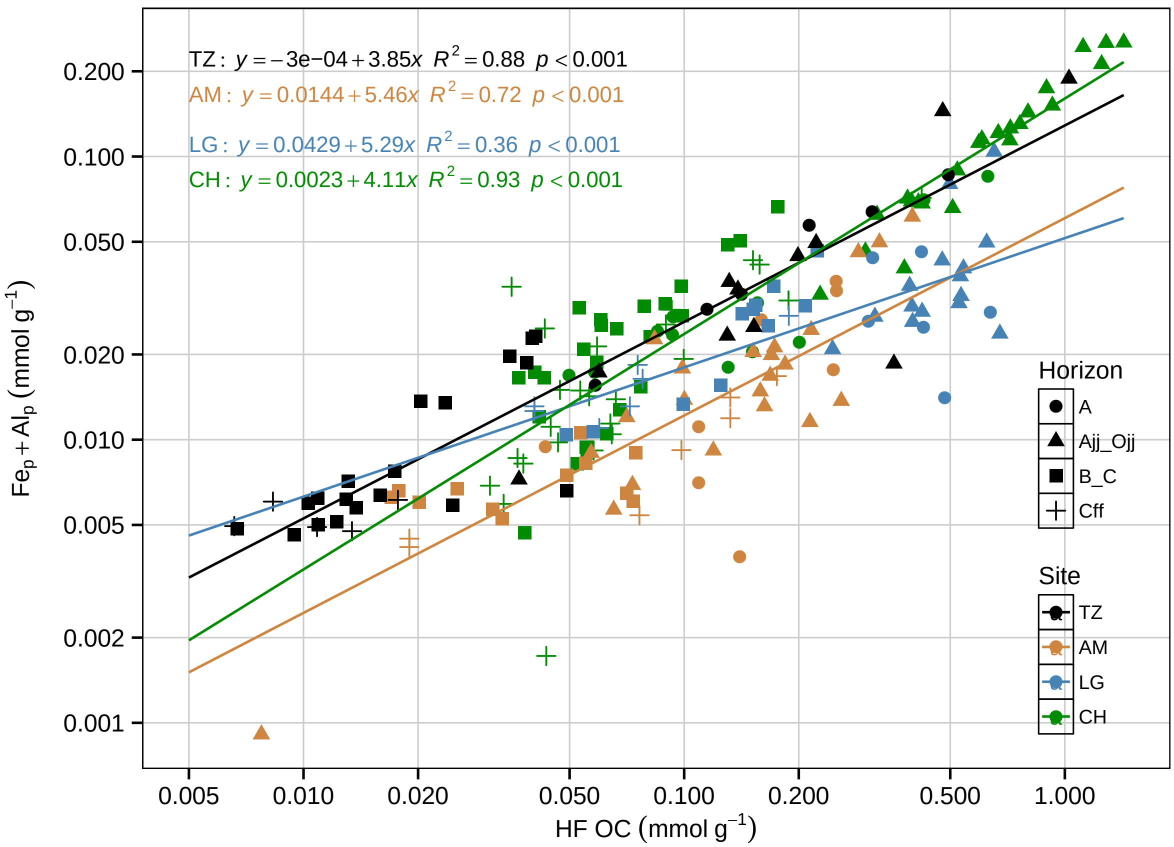


Fig. S 5: Relation between organically complexed Fe and Al and mineral bound OC (HF-OC) across the different sampling locations. Note, both axes are on a log scale.

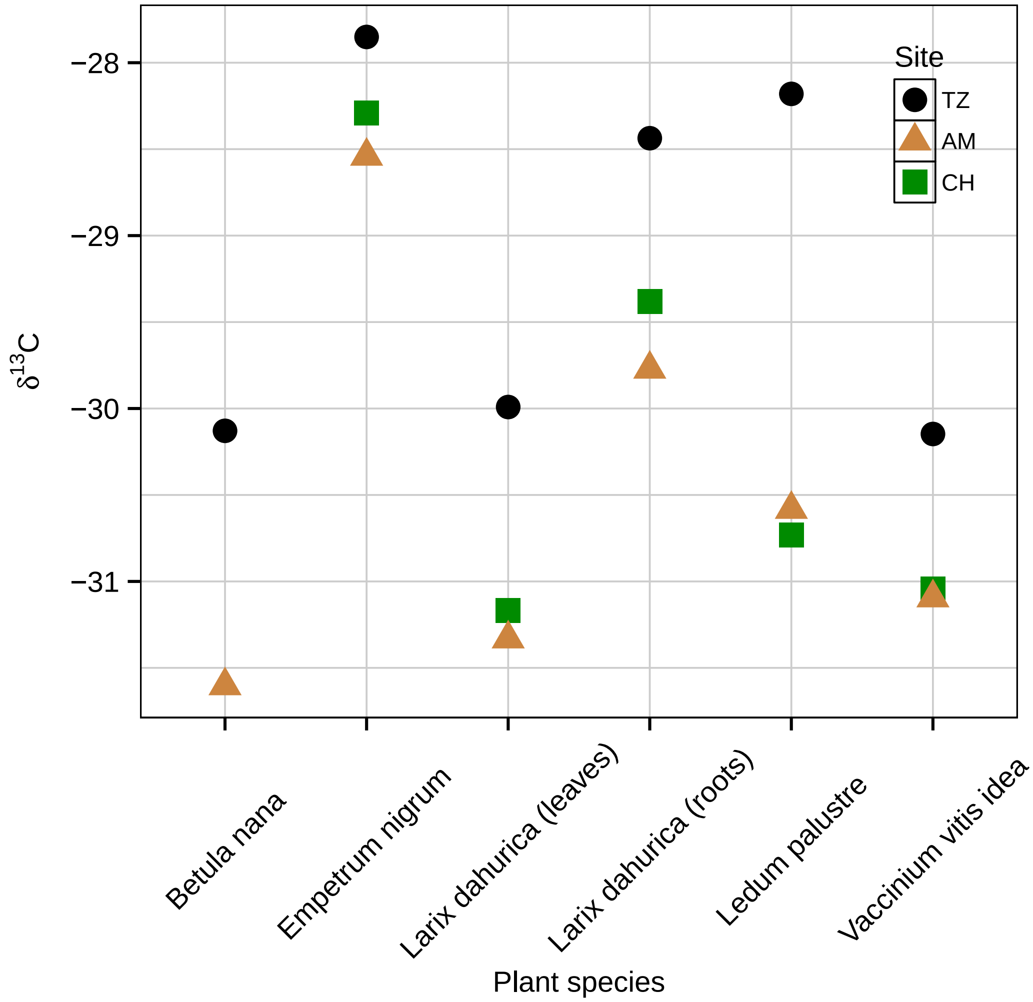


Fig. S 6: Carbon isotopic composition in individual plants from different sampling location in West Siberia (TZ), Central Siberia (AM), and eastern Siberia (CH). The higher δ^{13}C ratios in western Siberia continue in OM from soil samples of these sites and suggest isotope discrimination by plants at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

Table S 1: Soil pH and exchangeable cations across the four sampling locations (TZ, AM, LG, CH) and soil horizons (following a depth gradient)

		pH (H_2O)			CEC_{eff}		BS		Ca		Mg		K		Na		Al		Fe		Mn		
Site	Horizon	Mean	SD	N	Mean cmol$_c$	SD kg^{-1}	Mean %	SD	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	Mean cmol$_c$	SD kg^{-1}	N
CH	O	5.08	0.30	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	5.50	0.33	12	23.28	3.26	43.14	5.26	5.90	1.70	3.88	0.70	0.21	0.04	0.13	0.04	12.40	1.51	0.77	0.15	0.20	0.12	11
	Ajj/Ojj	5.82	0.49	26	32.75	3.50	53.13	7.32	11.96	3.16	4.94	0.84	0.31	0.08	0.37	0.48	14.13	1.51	1.05	0.14	0.59	0.45	18
	B/C	6.13	0.63	25	21.71	2.04	42.62	7.18	5.55	1.19	3.28	0.46	0.21	0.09	0.17	0.11	11.65	1.97	0.85	0.31	0.21	0.13	18
	Cff	7.15	0.95	26	24.26	2.89	57.38	9.01	8.83	2.09	4.37	0.89	0.25	0.05	0.58	0.49	9.12	2.27	1.12	0.48	0.57	0.23	16
AM	O	6.65	0.62	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	6.51	0.49	12	21.76	7.18	61.09	11.14	8.81	3.43	4.55	2.91	0.11	0.08	0.27	0.45	7.33	2.28	0.69	0.20	0.27	0.33	6
	Ajj/Ojj	6.97	0.64	29	25.33	6.21	64.97	8.49	10.99	3.00	5.15	2.15	0.10	0.05	0.29	0.37	8.09	2.87	0.70	0.24	0.14	0.11	17
	B/C	7.32	0.37	15	28.25	4.07	65.27	6.72	11.26	3.57	6.69	1.49	0.20	0.06	0.47	1.02	9.11	1.22	0.51	0.11	0.19	0.11	8
	Cff	7.84	0.51	16	26.84	8.84	71.69	10.27	12.75	6.00	6.60	2.60	0.16	0.07	0.24	0.36	6.17	2.56	0.94	0.68	0.39	0.23	12
LG	O	5.69	0.65	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	5.63	0.34	9	27.92	6.24	72.30	7.20	12.30	3.64	6.39	1.44	0.56	0.16	1.01	1.19	6.92	2.27	0.74	0.08	0.48	0.08	5
	Ajj/Ojj	6.40	0.45	20	38.36	4.67	78.11	5.66	20.41	3.65	8.84	1.59	0.42	0.07	0.42	0.52	7.33	1.64	0.95	0.17	0.65	0.59	14
	B/C	6.71	0.57	16	29.04	2.90	69.97	5.23	12.43	1.17	7.26	1.23	0.41	0.13	0.13	0.04	7.87	2.13	0.93	0.11	0.42	0.37	14
	Cff	6.89	0.50	14	32.21	3.15	78.73	3.36	15.43	1.62	8.38	1.76	0.62	0.14	0.96	0.61	5.71	1.00	1.10	0.09	1.54	0.30	12
TZ	O	4.82	0.56	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	5.27	0.43	6	25.98	3.55	44.91	6.43	7.60	1.28	3.44	0.60	0.15	0.05	0.45	0.67	13.75	2.65	0.59	0.12	0.10	0.04	6
	Ajj/Ojj	5.90	0.64	18	29.19	3.96	50.33	10.74	10.13	2.92	4.36	1.40	0.12	0.04	0.16	0.02	13.76	3.48	0.65	0.16	0.05	0.03	13
	B/C	6.67	0.51	24	22.50	3.99	55.48	10.16	8.11	2.22	4.07	1.28	0.13	0.04	0.22	0.29	9.52	2.56	0.45	0.15	0.13	0.12	15
	Cff	7.26	0.16	14	19.35	4.45	65.66	2.58	8.08	1.96	4.34	1.25	0.19	0.10	0.16	0.05	6.17	1.35	0.41	0.07	0.30	0.22	11
All Sites	O	5.24	0.66	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	5.80	0.63	39	24.36	5.15	52.57	13.64	8.03	3.30	4.38	1.78	0.24	0.17	0.39	0.66	10.62	3.51	0.71	0.15	0.24	0.21	28
	Ajj/Ojj	6.32	0.74	93	31.23	6.65	61.43	13.31	13.22	5.04	5.76	2.29	0.24	0.15	0.32	0.41	10.86	3.96	0.85	0.25	0.37	0.45	62
	B/C	6.63	0.67	80	24.74	4.55	56.39	13.36	8.83	3.42	5.01	2.03	0.24	0.14	0.21	0.42	9.73	2.53	0.71	0.29	0.24	0.24	55
	Cff	7.28	0.74	70	25.68	6.77	67.56	10.92	11.14	4.41	5.83	2.36	0.30	0.20	0.50	0.53	6.99	2.39	0.92	0.50	0.70	0.54	51
	Total			312																			196

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.

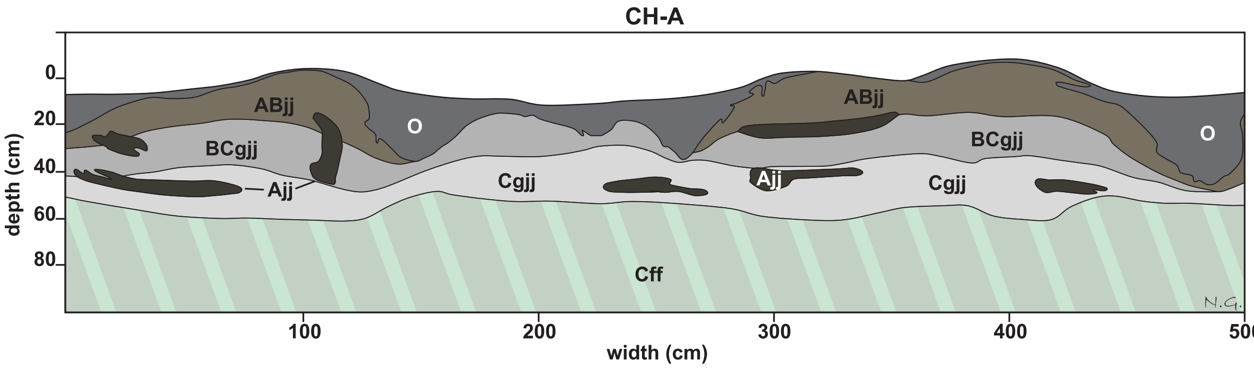
Site	Horizon	Fe_d (mg g^{-1}) Mean	SD	Fe_o (mg g^{-1}) Mean	SD	Fe_p (mg g^{-1}) Mean	SD	Ald (mg $^{-1}$) Mean	SD	Alo (mg g^{-1}) Mean	SD	Alp (mg g^{-1}) Mean	SD	Fed-Feo (mg g^{-1}) Mean	SD	Feo/Fed Mean	SD	N
CH	A	11.94	1.61	5.93	1.74	0.66	0.45	1.30	0.35	1.45	0.34	0.41	0.21	6.01	1.09	0.49	0.10	10
	Ajj/Ojj	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	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	25
	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	26
AM	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	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	28
	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	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	11
LG	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	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	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	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	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	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	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	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	6
All sites	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	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	95
	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	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	48
	Total																	244

Table S 3: Contribution of the different soil fraction (LF, HF, MoF) to the total OC and TN concentration at different sampling locations. 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.

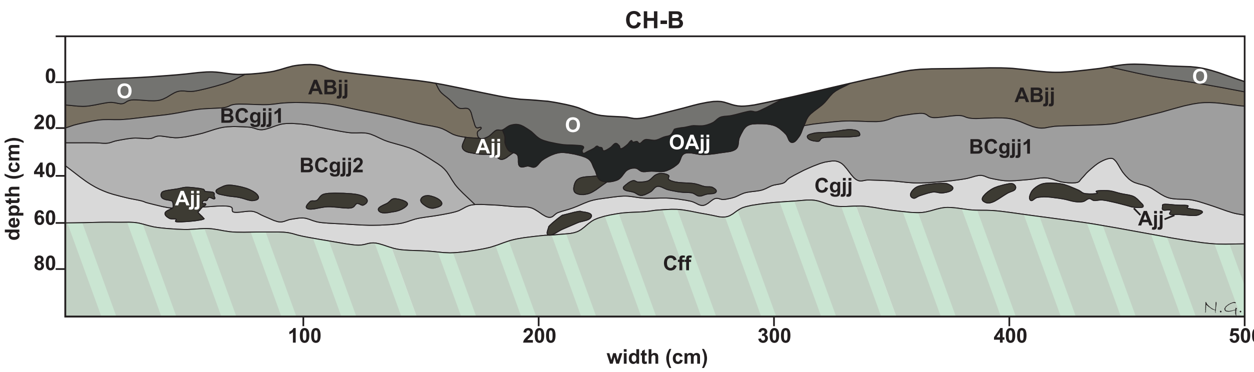
		Bulk (mg g^{-1})		Bulk			LF (mg g^{-1})				HF (mg g^{-1})				MoF (mg g^{-1})			Fractions	
		OC		TN			OC		TN		OC		TN		OC		TN		
	Horizon	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	N
CH	O	245.71	66.16	10.43	1.94	15	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	42.36	43.44	2.41	2.03	12	7.04	5.18	0.21	0.17	21.14	19.55	1.57	1.22	8.79	12.57	0.41	0.30	11
	Ajj/Ojj	100.74	56.07	6.01	2.68	26	35.87	42.31	1.46	1.77	66.05	29.29	4.88	1.94	7.24	3.73	0.55	0.38	23
	B/C	13.15	5.27	1.11	0.27	25	1.58	0.69	0.05	0.03	8.30	3.83	0.97	0.66	3.43	3.68	0.29	0.19	25
	Cff	19.74	20.65	1.44	0.88	26	2.90	2.67	0.13	0.12	10.10	9.44	1.61	1.56	5.62	13.70	0.33	0.34	25
AM	O	211.62	127.64	7.14	3.94	3	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	41.07	27.71	2.36	1.33	11	12.61	16.45	0.47	0.59	19.65	10.17	1.37	0.59	3.07	4.34	0.21	0.24	10
	Ajj/Ojj	39.23	37.95	2.23	1.85	38	19.25	25.60	0.84	0.96	19.87	11.07	1.43	0.76	5.29	10.82	0.16	0.15	25
	B/C	6.83	3.15	0.52	0.22	17	1.21	0.76	0.05	0.03	5.08	2.46	0.47	0.18	0.63	0.30	0.04	0.03	13
	Cff	15.12	11.88	1.00	0.68	20	5.90	6.69	0.30	0.32	10.97	6.02	0.84	0.41	2.20	2.10	0.15	0.01	10
LG	O	209.90	57.02	8.82	1.91	6	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	71.09	21.90	4.37	1.50	10	17.68	14.29	0.74	0.70	47.86	13.54	3.20	0.85	3.80	2.69	0.32	0.17	7
	Ajj/Ojj	85.32	32.26	4.92	1.06	25	23.52	15.02	1.08	0.71	48.51	10.16	3.25	0.51	7.60	6.43	0.45	0.38	16
	B/C	17.89	7.38	1.29	0.46	19	3.90	1.79	0.15	0.07	13.93	5.98	1.17	0.33	2.55	0.91	0.17	0.07	13
	Cff	14.63	16.68	1.08	0.75	31	3.22	3.36	0.11	0.12	8.84	4.75	0.80	0.25	10.43	20.86	0.56	0.97	14
TZ	O	235.68	68.56	7.04	1.33	7	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	35.38	25.18	1.93	0.99	6	8.51	7.69	0.22	0.21	22.57	14.35	1.50	0.72	4.29	3.65	0.20	0.11	6
	Ajj/Ojj	42.36	47.86	2.27	1.95	18	12.15	26.68	0.34	0.77	24.45	22.95	1.66	1.22	12.49	17.76	0.55	0.66	12
	B/C	3.30	2.08	0.34	0.12	24	0.63	0.69	0.02	0.01	2.28	1.37	0.34	0.09	0.72	0.36	0.04	0.03	21
	Cff	1.74	0.62	0.26	0.11	14	0.20	0.12	0.01	0.00	1.23	0.38	0.25	0.07	0.36	0.20	0.06	0.03	11
All sites	O	233.93	66.59	9.10	2.36	30	–	–	–	–	–	–	–	–	–	–	–	–	–
	A	48.11	33.56	2.81	1.78	40	11.10	12.04	0.40	0.49	26.50	18.19	1.84	1.12	5.69	8.38	0.29	0.23	34
	Ajj/Ojj	65.47	50.82	3.78	2.56	107	23.96	30.98	0.99	1.24	40.16	27.94	2.86	1.93	7.74	9.89	0.43	0.43	76
	B/C	10.16	7.39	0.82	0.49	85	1.70	1.52	0.06	0.06	7.03	5.41	0.73	0.54	2.12	2.61	0.18	0.17	72
	Cff	14.22	16.56	1.04	0.81	91	3.41	4.34	0.15	0.19	8.63	7.60	0.99	1.04	4.42	11.63	0.29	0.47	60
	Total					353													242

Table S 4: Comparison of bulk OC stocks (in kg m^{-2} to 100 cm soil depth, mean ± 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.

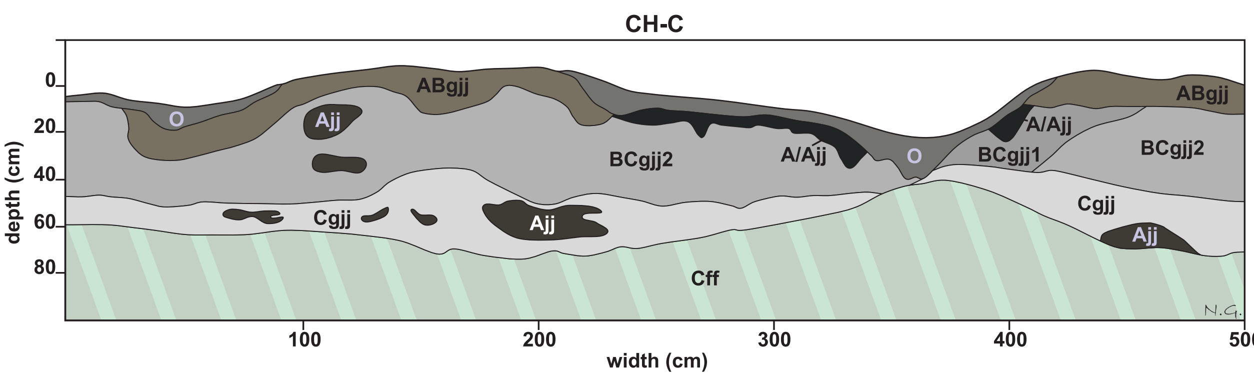
Study	Site	Land Cover	Area of the total lanscape (%)	0-100 cm	Organic layer	Mineral layer	Active layer	Permafrost layer
1	CH D-F	Tussock tundra		28.5 ± 6.0	4.7 ± 5.7	23.8 ± 5.1	16.5 ± 5.9	12.0 ± 4.5
2	Shalaurovo	Tussock tundra	46.5	29.0 ± 4.0	4.4 ± 2.5	24.6 ± 2.8	22.0 ± 5.9	7.0 ± 4.9
1	CH A-C	Grass tundra		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



(a)

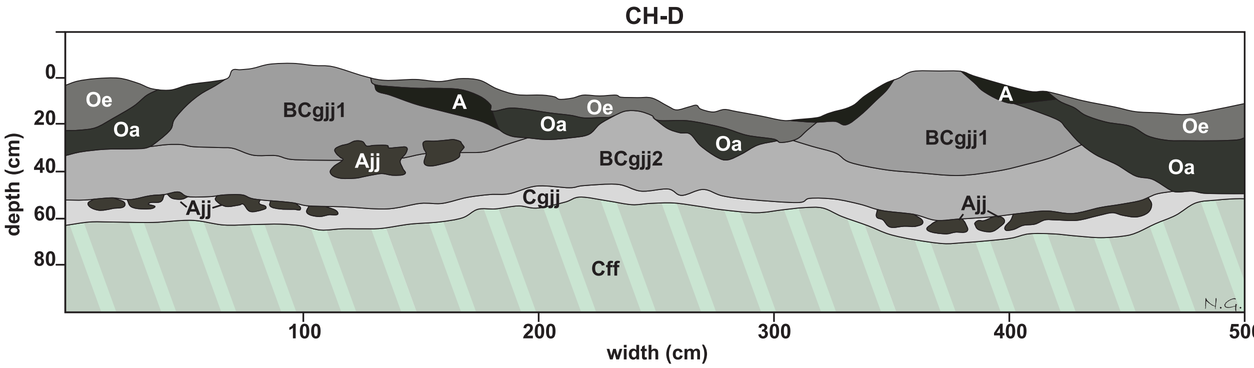


(b)

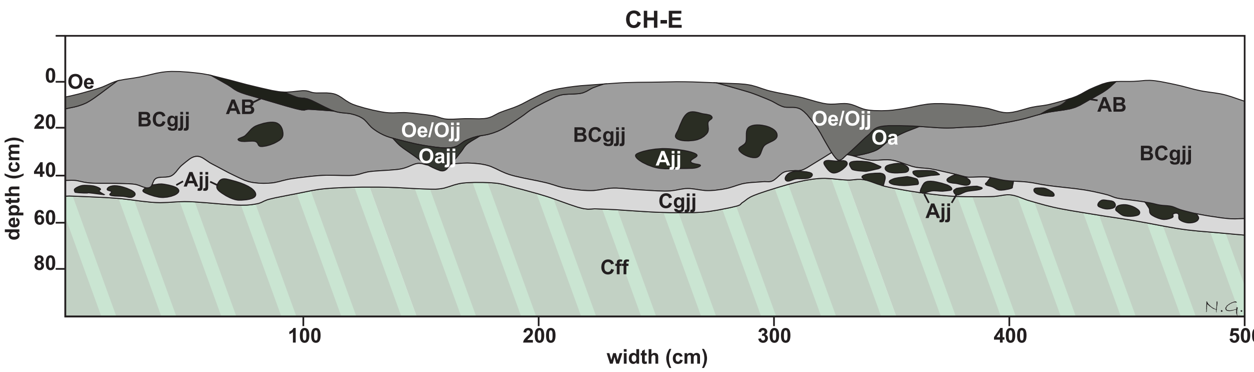


(c)

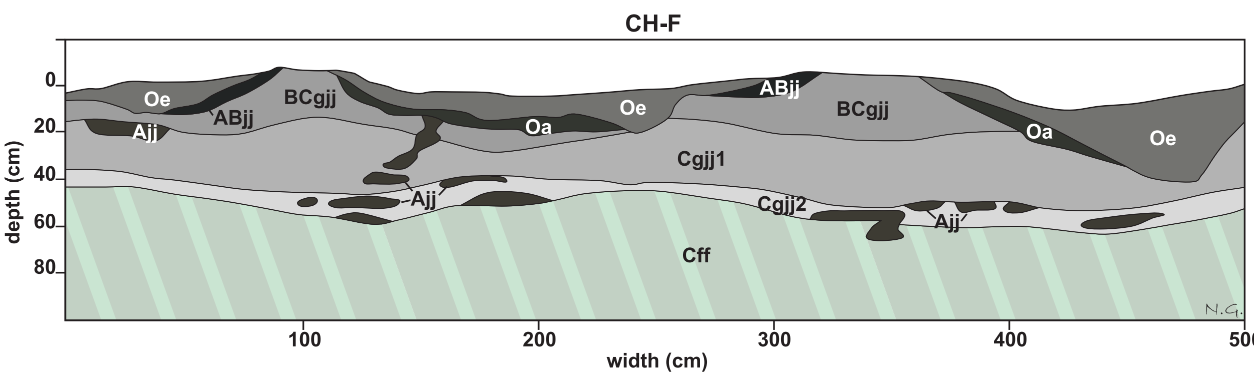
Fig. S 7: Profile sketches from the four sampling sites across Siberia (CH, AM, LG, TZ). All sketches were drawn by AutoCAT2010 and the areas of designated soil horizons were used to calculate OC and TN stocks up to one meter soil depth.


CH-D
0
20
40
60
80
depth (cm)
Oe
Oa
BCgjj1
A
Oe
Oa
Oa
BCgjj2
Ajj
Ajj
Cgjj
Ajj
BCgjj1
A
Oe
Oa
Cff
N.G.
100
200
300
400
500
width (cm)

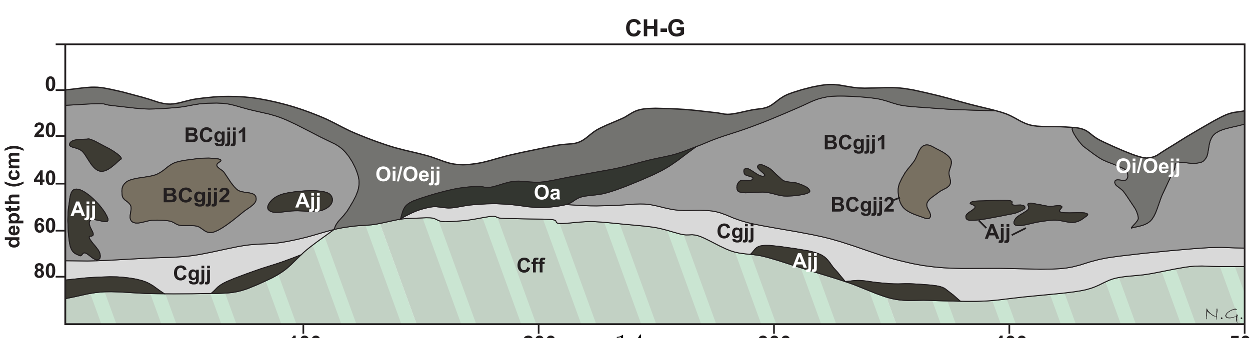
(d)


CH-E
0
20
40
60
80
depth (cm)
Oe
BCgjj
AB
Oe/Ojj
Oajj
BCgjj
Ajj
Ajj
Oe/Ojj
Oa
AB
BCgjj
Cgjj
Ajj
Cff
N.G.
100
200
300
400
500
width (cm)

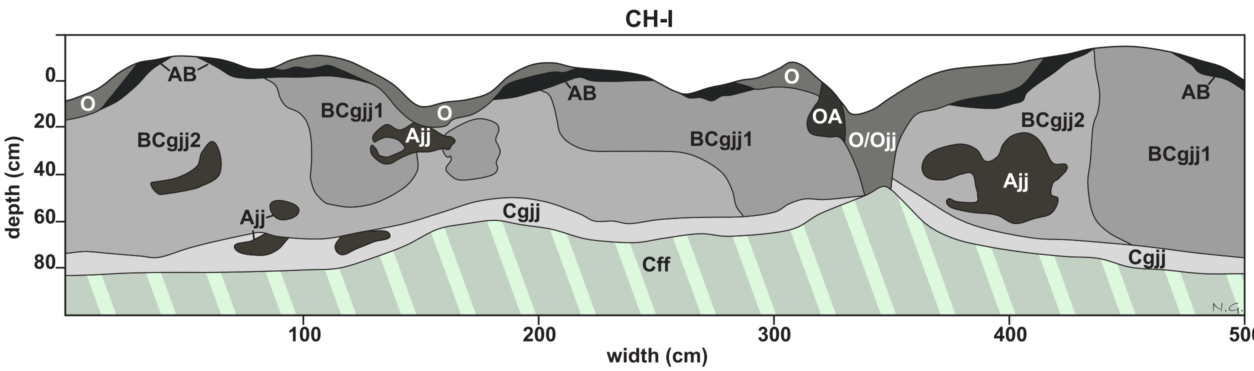
(e)


CH-F
0
20
40
60
80
depth (cm)
Oe
ABjj
BCgjj
Ajj
Oa
Oe
ABjj
BCgjj
Oa
Oe
Cgjj1
Ajj
Cgjj2
Ajj
Cff
N.G.
100
200
300
400
500
width (cm)

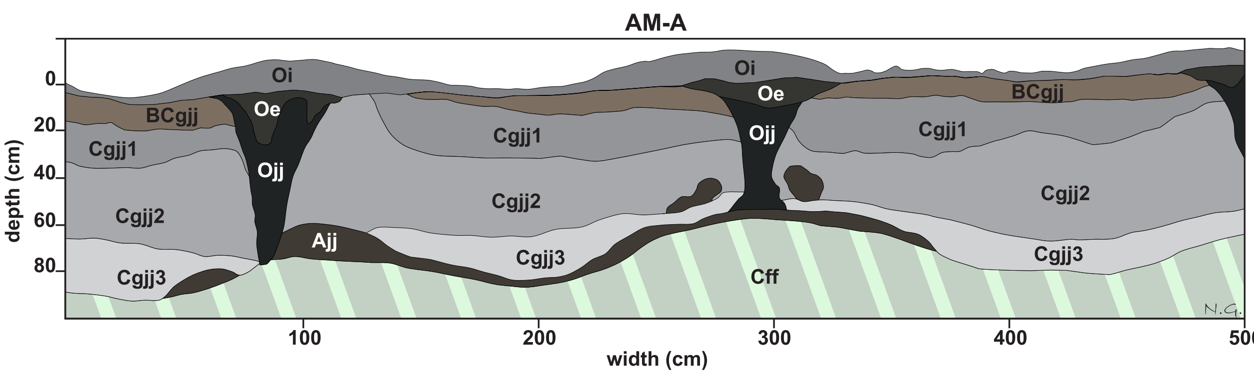
(f)


CH-G
0
20
40
60
80
depth (cm)
BCgjj1
BCgjj2
Ajj
Ajj
Oi/Oejj
Oa
Cgjj
Cff
BCgjj1
BCgjj2
Cgjj
Ajj
Ajj
Oi/Oejj
N.G.
100
200
300
400
500
width (cm)

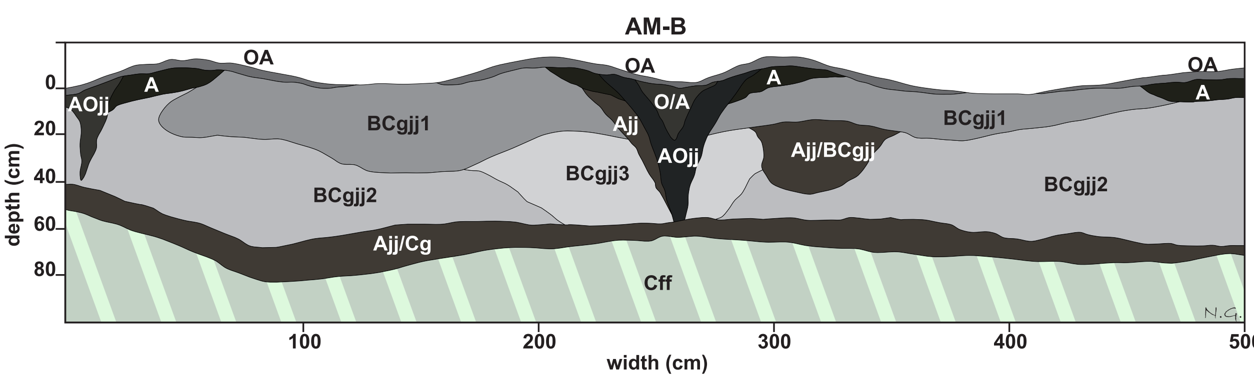
(g)


CH-I
O
AB
BCgjj1
O
AB
O
OA
O/Ojj
BCgjj2
AB
BCgjj2
Ajj
BCgjj1
BCgjj1
Ajj
Ajj
Cgjj
Cff
Cgjj
depth (cm)
0
20
40
60
80
100
200
300
400
500
width (cm)
N.G.

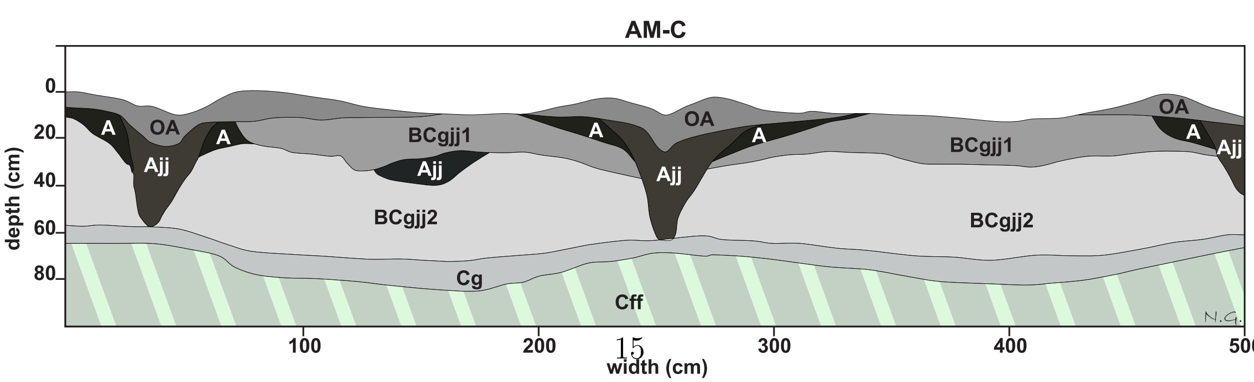
(h)


AM-A
Oi
Oi
Oe
Oe
BCgjj
BCgjj
Cgjj1
Ojj
Cgjj1
Cgjj1
Ojj
Cgjj2
Cgjj2
Cgjj2
Ajj
Cgjj3
Cgjj3
Cgjj3
Cff
depth (cm)
0
20
40
60
80
100
200
300
400
500
width (cm)
N.G.

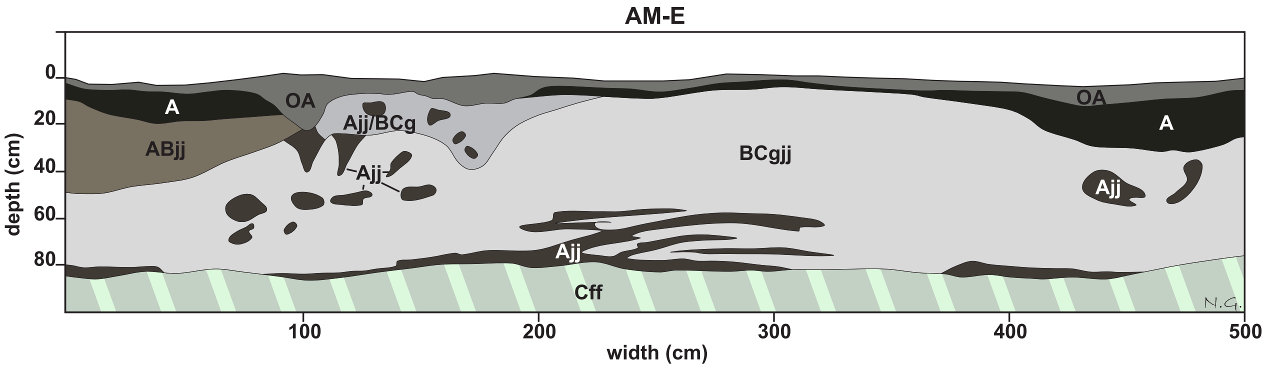
(i)


AM-B
OA
OA
OA
A
A
A
AOjj
O/A
BCgjj1
BCgjj1
Ajj
AOjj
Ajj/BCgjj
BCgjj3
BCgjj2
BCgjj2
Ajj/Cg
Cff
depth (cm)
0
20
40
60
80
100
200
300
400
500
width (cm)
N.G.

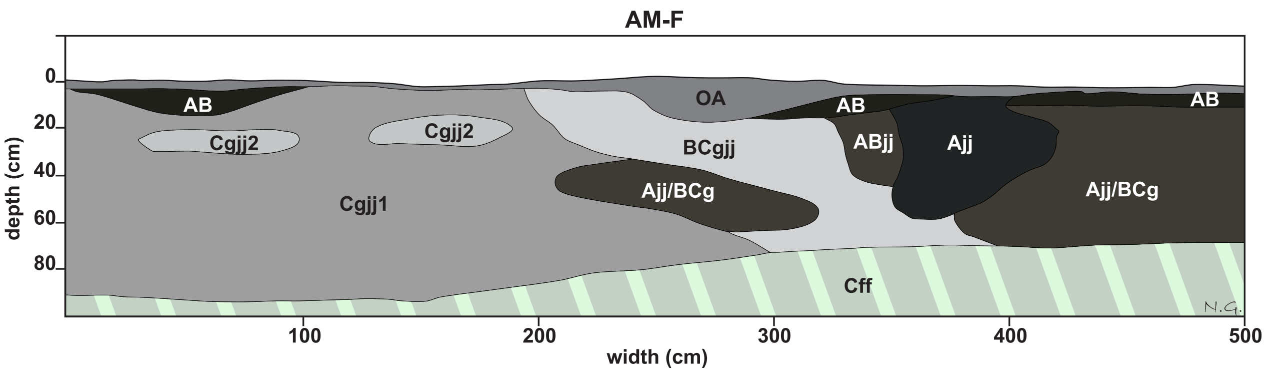
(j)


AM-C
OA
OA
OA
A
A
A
A
A
Ajj
BCgjj1
Ajj
Ajj
BCgjj1
Ajj
BCgjj2
BCgjj2
Cg
Cff
depth (cm)
0
20
40
60
80
100
200
300
400
500
width (cm)
N.G.

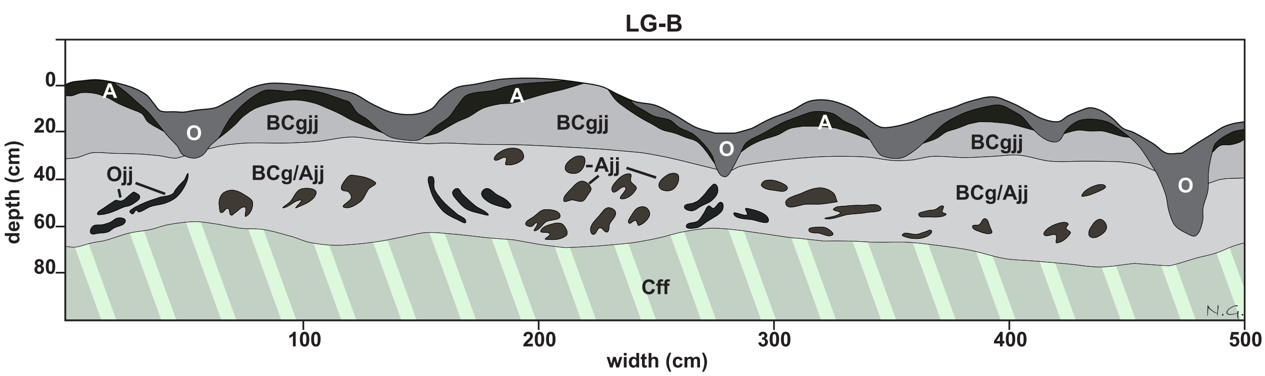
(k)


AM-E
0
20
40
60
80
depth (cm)
A
OA
ABjj
Ajj/BCg
Ajj
BCgjj
OA
A
Ajj
Ajj
Cff
N.G.
100
200
300
400
500
width (cm)

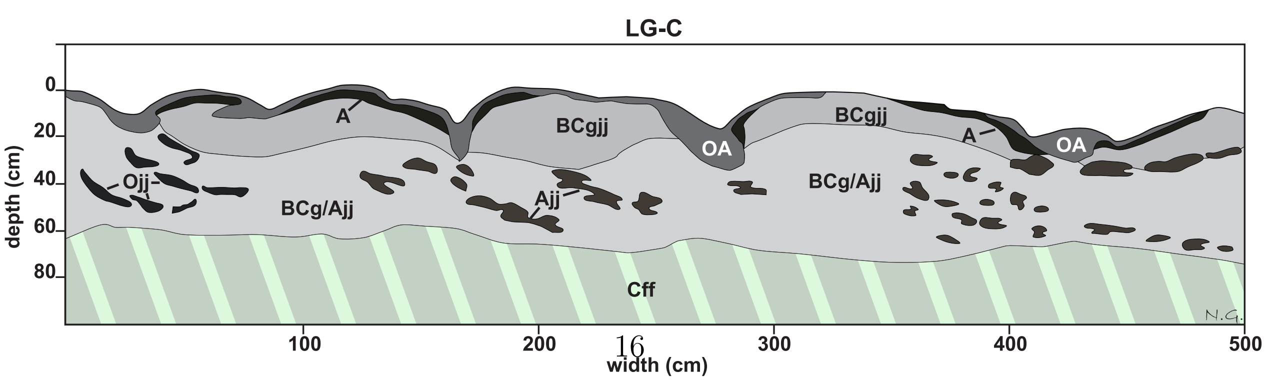
(l)


AM-F
0
20
40
60
80
depth (cm)
AB
Cgjj2
Cgjj2
Cgjj1
OA
BCgjj
Ajj/BCg
AB
ABjj
Ajj
AB
Ajj/BCg
Cff
N.G.
100
200
300
400
500
width (cm)

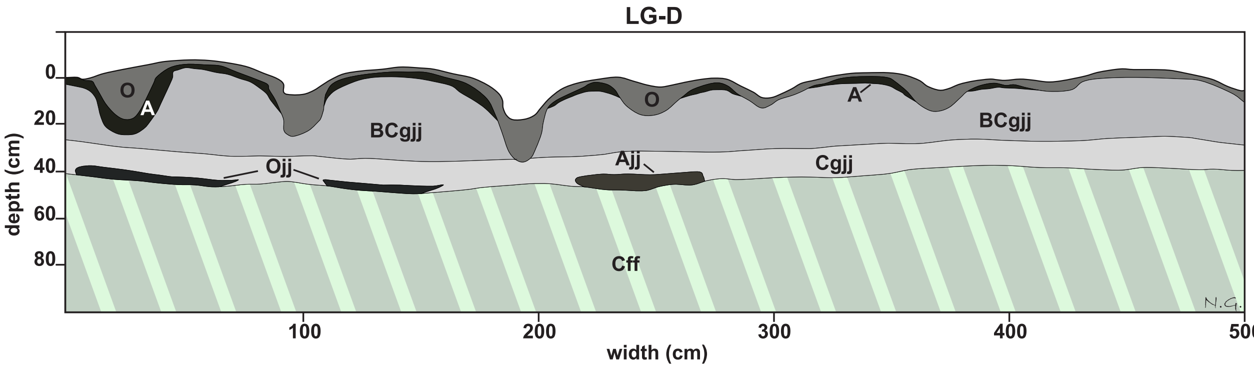
(m)


LG-B
0
20
40
60
80
depth (cm)
A
O
BCgjj
A
BCgjj
O
A
BCgjj
Ojj
BCg/Ajj
Ajj
BCg/Ajj
O
Cff
N.G.
100
200
300
400
500
width (cm)

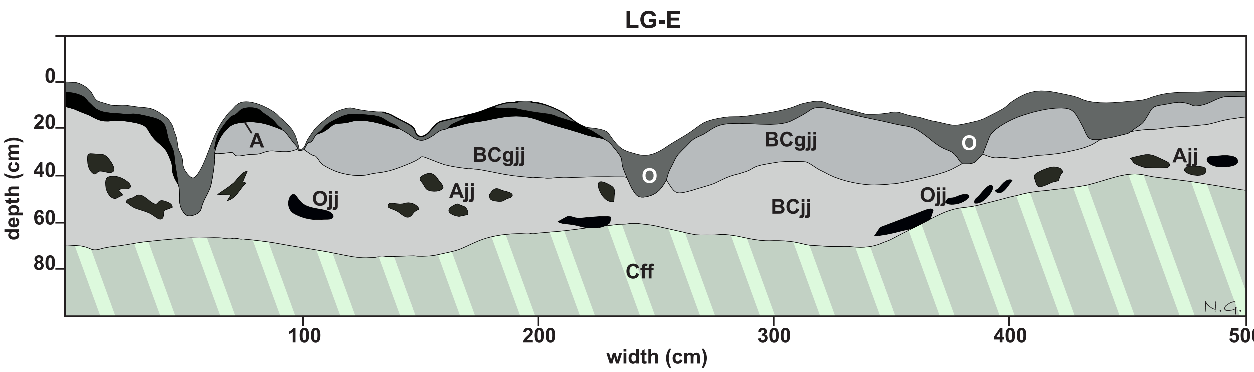
(n)


LG-C
0
20
40
60
80
depth (cm)
A
BCgjj
OA
BCgjj
A
OA
Ojj
BCg/Ajj
Ajj
BCg/Ajj
Cff
N.G.
100
200
300
400
500
width (cm)

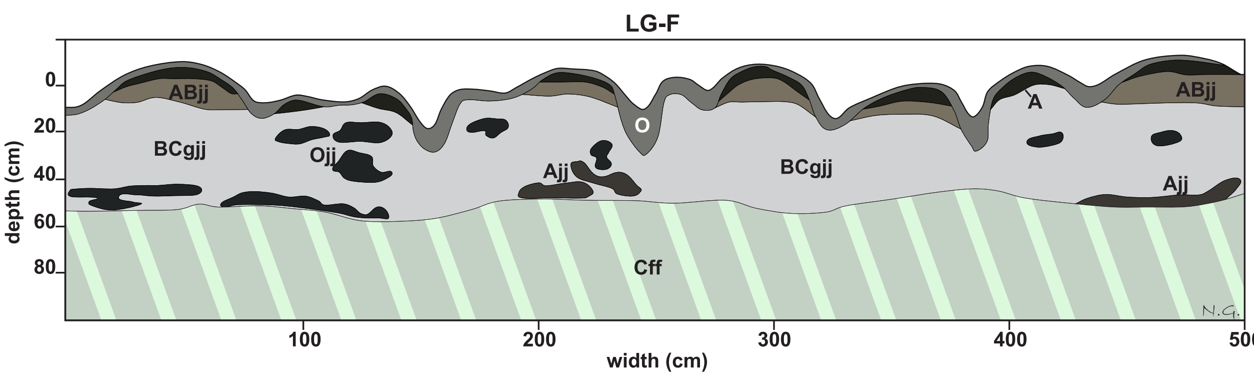
(o)


LG-D
depth (cm)
0
20
40
60
80
O
A
BCgjj
Ojj
Ajj
A
Cgjj
BCgjj
Cff
N.G.
100
200
300
400
500
width (cm)

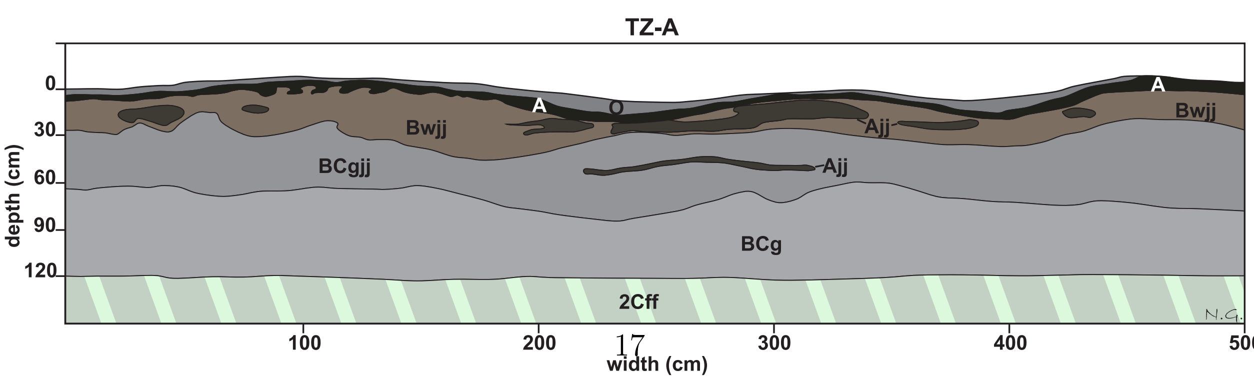
(p)


LG-E
depth (cm)
0
20
40
60
80
A
BCgjj
O
BCgjj
O
Ajj
Ojj
Ajj
BCjj
Ojj
Cff
N.G.
100
200
300
400
500
width (cm)

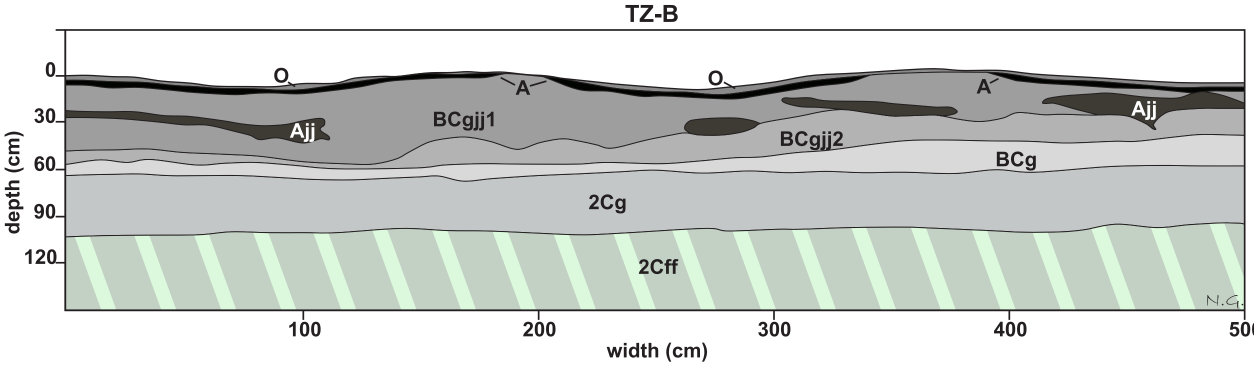
(q)


LG-F
depth (cm)
0
20
40
60
80
ABjj
BCgjj
Ojj
O
Ajj
BCgjj
A
ABjj
Ajj
Cff
N.G.
100
200
300
400
500
width (cm)

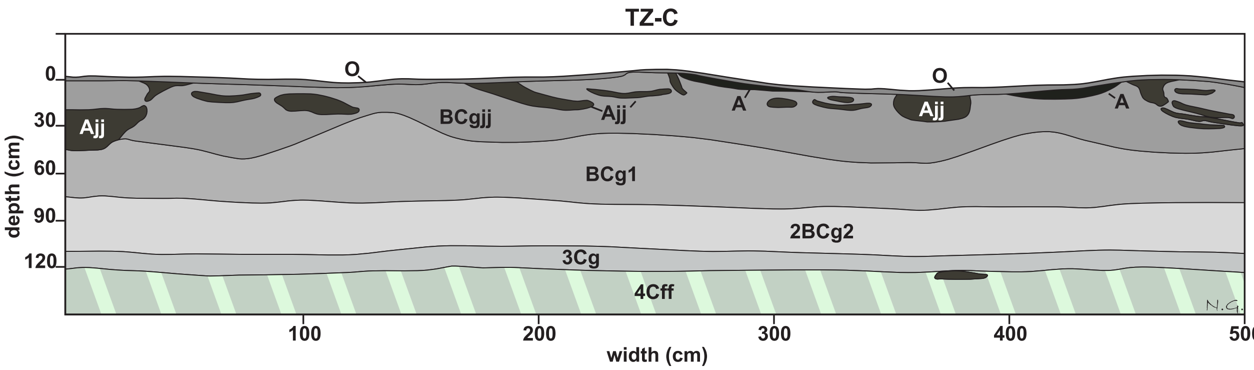
(r)


TZ-A
depth (cm)
0
30
60
90
120
A
O
Bwjj
Ajj
A
Bwjj
BCgjj
Ajj
BCg
2Cff
N.G.
100
200
300
400
500
width (cm)

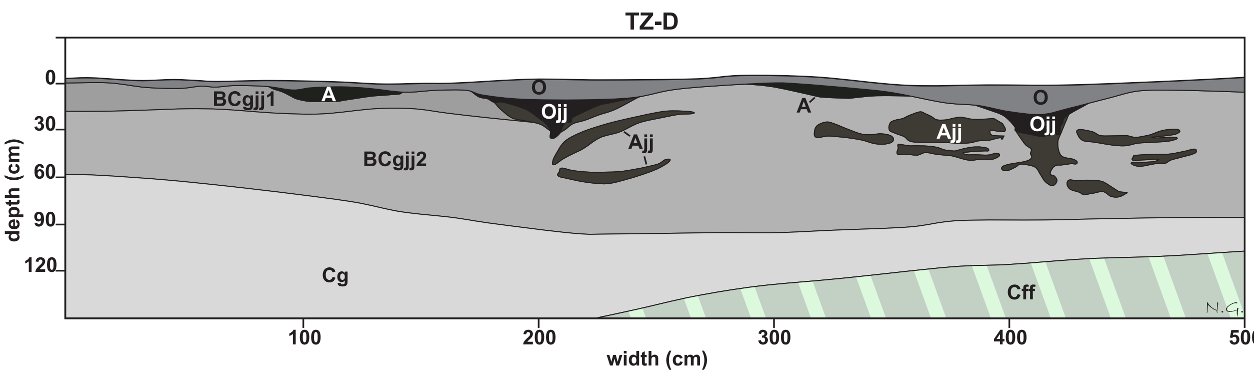
(s)


TZ-B
O
A
O
A
Ajj
BCgjj1
BCgjj2
Ajj
BCg
2Cg
2Cff
depth (cm)
0
30
60
90
120
100
200
300
400
500
width (cm)
N.G.

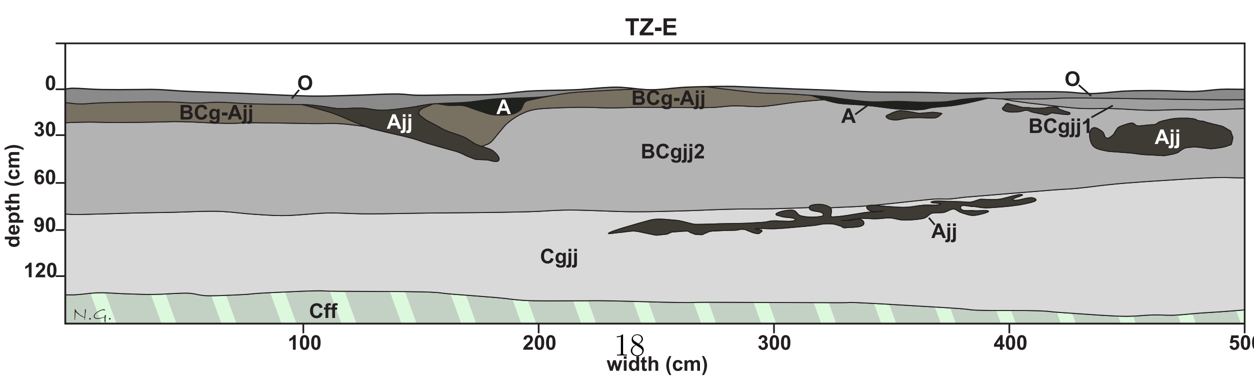
(t)


TZ-C
O
O
A
Ajj
A
Ajj
BCgjj
Ajj
BCg1
2BCg2
3Cg
4Cff
depth (cm)
0
30
60
90
120
100
200
300
400
500
width (cm)
N.G.

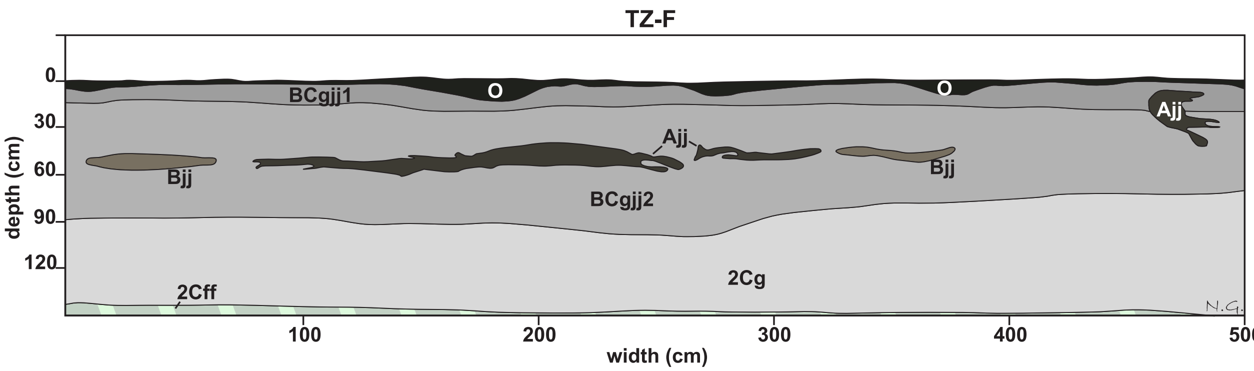
(u)


TZ-D
O
O
BCgjj1
A
Ojj
A
Ajj
Ojj
Ajj
BCgjj2
Cg
Cff
depth (cm)
0
30
60
90
120
100
200
300
400
500
width (cm)
N.G.

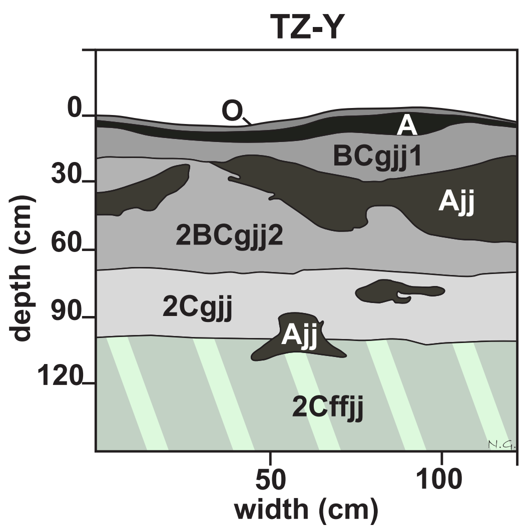
(v)


TZ-E
O
O
BCg-Ajj
A
BCg-Ajj
Ajj
A
BCgjj1
Ajj
BCgjj2
Ajj
Cgjj
Cff
depth (cm)
0
30
60
90
120
100
200
300
400
500
width (cm)
N.G.

(w)



(x)



(y)

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

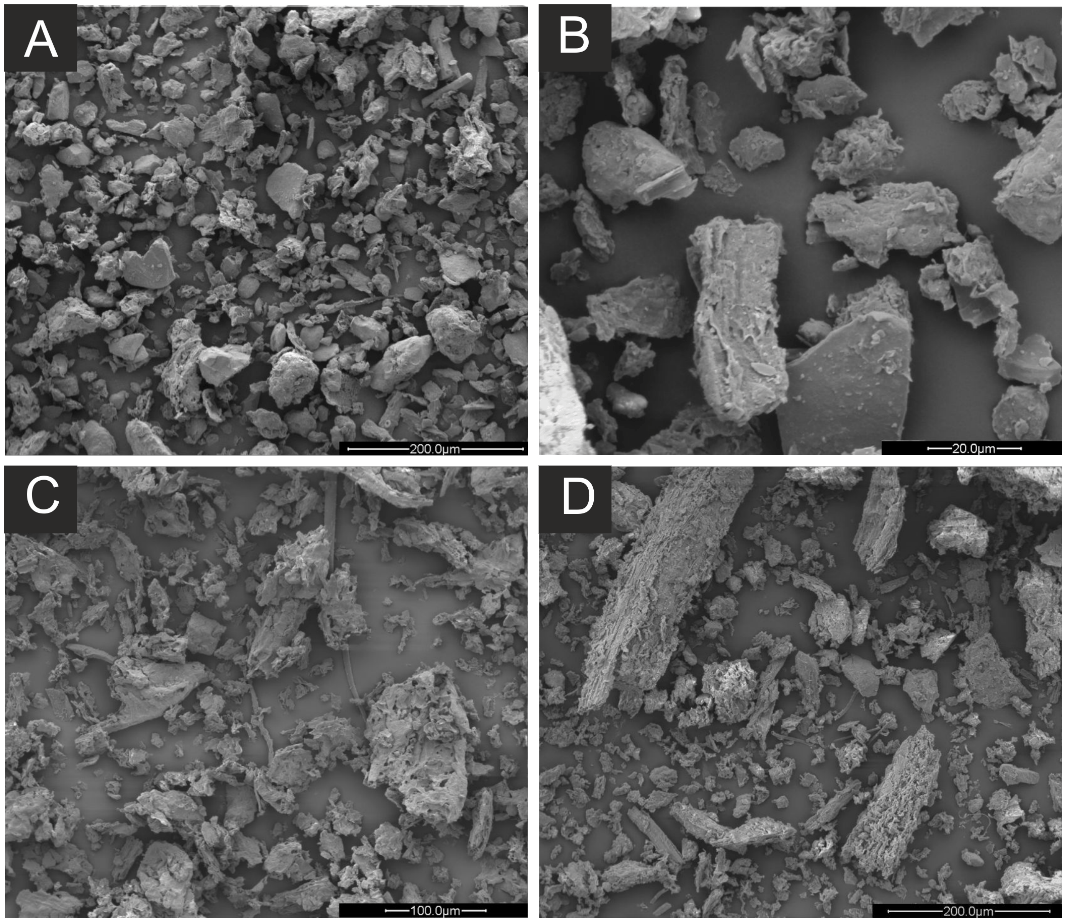


Fig. S 8: Scanning electron images from the HF of an A horizon (A) and an Ajj horizon from 80 cm depth (B). The related LF images from these horizons are shown in C and D.

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