Ecological disturbance in tropical peatlands prior to marine Permian-Triassic mass extinction

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Sample processing

To avoid the possibility of variable transport capacity associated with the different processes that led to the facies variations, only samples from mudstones were processed. Forty-two unweathered samples in total were processed using acid maceration techniques. Firstly, we broke the original bulk samples (~40 g of each sample, Table DR2) into 1.5-2 cm pieces before acid treatment with the smaller pieces or powdery removed. Then, treatment with cold hydrochloric acid (36% HCl) removed carbonate, and samples were then rinsed with ultrapure water. Subsequently, treatment with cold concentrated hydrofluoric acid (39% HF) for 24 h removed silicates, and then were rinsed with ultrapure water again. Acid treatments were repeated twice. The process was completed with a final treatment in cold HCl for 24 h to avoid calcium fluoride precipitation. Finally, samples were rinsed with ultrapure water until a neutral pH was achieved. The residue was sieved over a 100-μm-mesh screen and both size fractions were collected. The >100 μm size fractions of all samples were analyzed using a binocular microscope and the numbers of charcoal particles observed were quantified to represent charcoal abundance. Selected samples of charcoal were examined using a scanning electron microscope (SEM) to confirm their identification as charcoal. The < 100 μm size fractions was quantified by evenly dispersing the organic particles in a known quantity of water. A known volume was then pipetted and made into slides using standard palynological techniques. The palynofacies analysis of each sample was conducted, quantifying the abundance of pollen and spores, plant cuticle, amorphous organic matter and coalified particles.

For bulk organic carbon isotope analyses, 35 samples were selected from the ZK4703 core section. Each sample was crushed to fine powder (< 200 mesh), and ~2 g of powder was weighed and placed

into a centrifuge tube. The powdered samples were reacted with 4 mol/L HCl for 24 h to remove carbonate, then rinsed with ultrapure water repeatedly until neutralized, and finally dried at 35℃. For cuticles and charcoal organic carbon isotopes analyses, 23 and 19 samples were selected, respectively. The $\delta^{13}C_{org}$ values of the treated samples were obtained using an elemental analyzer (EA) coupled with an isotope ratio mass spectrometer (Thermo Finnegan DeltaV) at the China University of Geosciences (Wuhan). The results were calibrated using USGS standards: USGS40 ($\delta^{13}C$ = –26.39 ‰) and UREA ($\delta^{13}C$ = –37.32 ‰). The analytical precision of $\delta^{13}C_{org}$ was better than ±0.2 ‰. Organic carbon isotope values are given in per mille relative to VPDB. For total organic carbon (TOC) analyses, about ~4 g of powdered sample was put into the 30 mL tube, then 50% HCl was injected to dissolve carbonate minerals. After multiple centrifugal and lyophilization, the residue was analyzed for total organic carbon (TOC). A Multi EA 4000-analyzer was used for TOC and total sulfur concentrations (TS) determination at the China University of Geosciences (Wuhan), yielding an analytical accuracy of 1.5% and 2% of the reported values, respectively. Major element abundances of ZK4703 samples were determined by an Inductively Coupled Plasma source mass spectrometer with Agilent 7700e at Wuhan SampleSolution Analytical Technology Co. Ltd. For the samples from ZK4703, Hg content was measured using a LECO AMA254 mercury analyzer at the China University of Geosciences (Wuhan). Data reliability was assured by use of international standard 502-685 with Hg concentration of 40 ± 8 ppb, and analytic precision was within 5%. For the samples from Chinahe, Hg content was measured using a Lumex RA-915 Portable Mercury Analyzer with PYRO-915 Pyrolyzer at the University of Oxford. The machine was calibrated before use with standards of NIST2587 with Hg concentration of 290±9 ppb, analytic precision was within 6%.

Studied sections

Chinahe section (26.13077°N, 104.35637°E) is located in Chinahe Village of the Tianba town, 30 km southeastern of Xuanwei City. It comprises a continuously exposed outcrop of the upper part of the Xuanwei Formation, the Kayitou Formation and the lower part of the Dongchuan Formation. The successions within the Xuanwei Formation were deposited chiefly in an alluvial-plain to fluvial and lacustrine environments. The *Gigantopteris* flora commonly ranges to immediately above the last occurrence of coal in the Xuanwei Formation. The Kayitou Formation is similar to the underlying Xuanwei Formation, mainly comprising grey-green mudstone and sandstone. The difference between the Kayitou and Xuanwei formations is that the former contains no coal beds. The rocks of the Kayitou Formation, in ascending order, are green sandstone, siltstone, and mudstone in the lower part, brownish-yellow-green siltstone, and mudstone in the middle part, and purple-red siltstone increasing

in proportion upwards in the upper part. The Dongchuan Formation is characterized by a thick succession of purple-red siliciclastic sandstone, siltstone and mudstone.

The ZK4703 core (25.54151°N, 104.28994°E), was drilled in Anzichong Viliage of Dahe Town, 15 km south of Fuyuan County, Qujing City. It comprises a continuously successions of the Xuanwei Formation, the Kayitou Formation and the Dongchuan Formation. The Xuanwei Formation lies unconformably on the Emeishan basalts and consists mainly of siliciclastic sandstone beds with intercalations of organic-rich mudstone and coal beds. Large pieces of *Gigantopteris* leaves are commonly observed in the core. The Kayitou Formation is similar to the underlying Xuanwei Formation, but shows no coal beds. The Dongchuan Formation is characterized by a thick succession (over 500 m thick) of purple-red siliciclastic sandstones, siltstones and mudstones.

Hg/TOC, Hg/Al and Hg/TS

Hg can be associated with the TOC, sulfide or clay fractions. In the present study, we measured the TOC, Al and S contents of ZK4703 section to assess the effect of organic matter burial, redox condition and clay abundance on the Hg enrichment. ZK4703 core has low total sulfur contents, mostly < 0.15% which is too low to evaluate. They show no covariation with Hg concentrations. The Al contents varies little and the correlation with Hg concentrations is poor (R^2=0.1358, P=0.03), indicating that Hg fluctuations are not controlled primarily by clay content. The TOC concentrations average ~1.3% in the Xuanwei Formation and ~0.4% in the Kayitou Formation. After normalizing Hg concentrations by TOC values, there is no significant correlation (Chinahe, R^2=0.0032, P=0.68; ZK4703, R^2=0.0384, P=0.25), suggesting that Hg peaks are not linked to organic matter scavenging. The strong noncorrelative trends of Hg, TOC, and Al through time suggest that the Hg anomalies are not linked to increased organic matter burial and/or clay abundance.

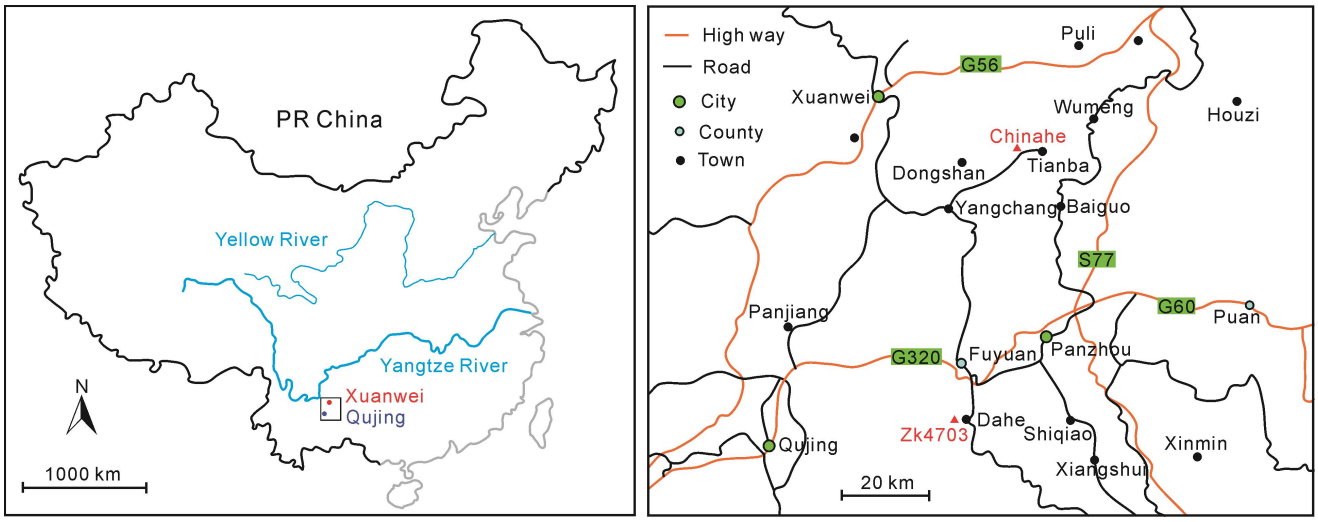

Figure DR1. Location map of the studied section. Chinahe section (26.13077°N, 104.35637°E) is located in the Chinahe Viliage of the Tianba town, Xuanwei City. ZK4703 core (25.54151°N, 104.28994°E), drilled in Anzichong Viliage of Dahe Town, Qujing City.

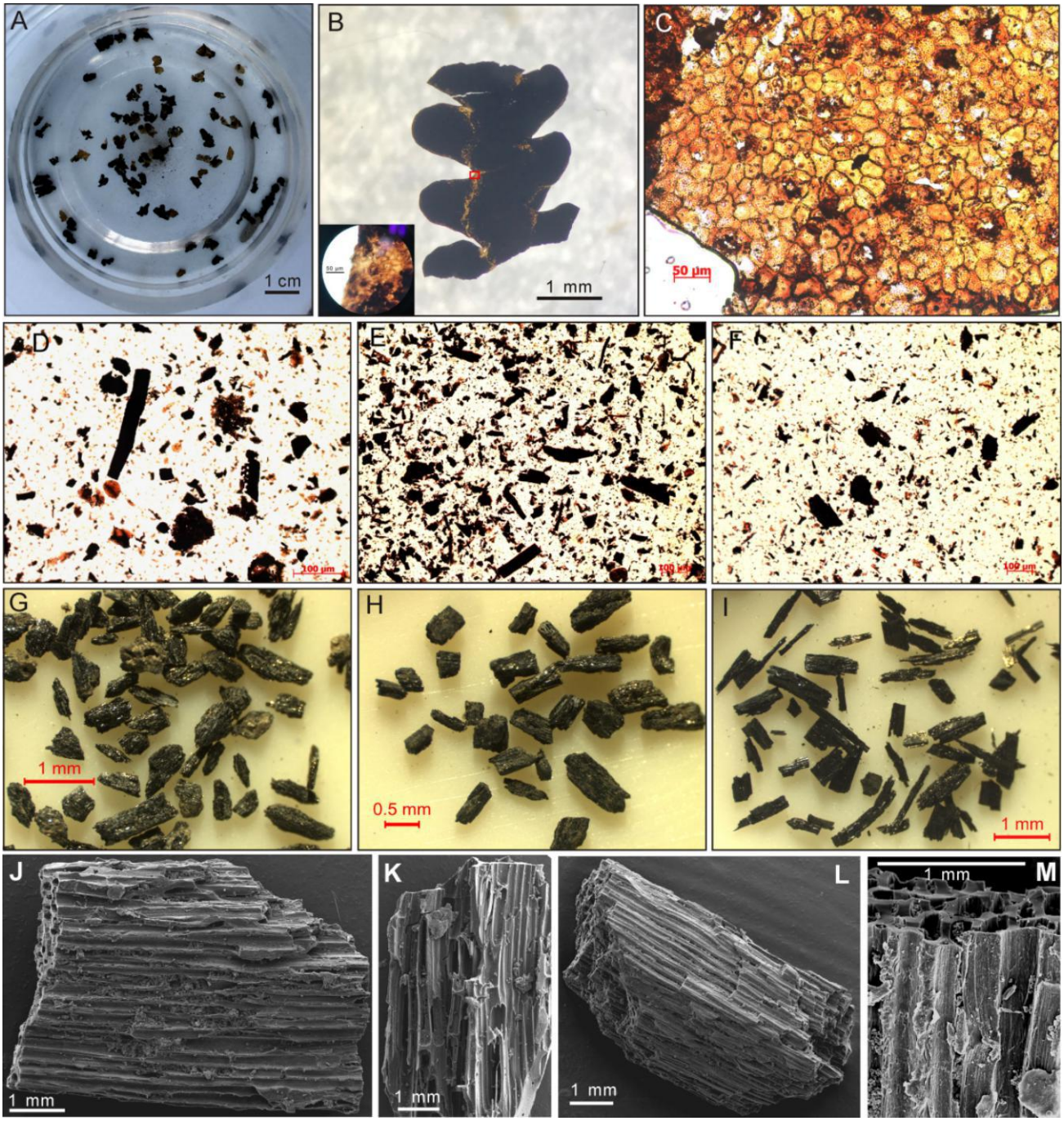

Figure DR2. Cuticle and charcoal particles under binocular microscope and SEM.

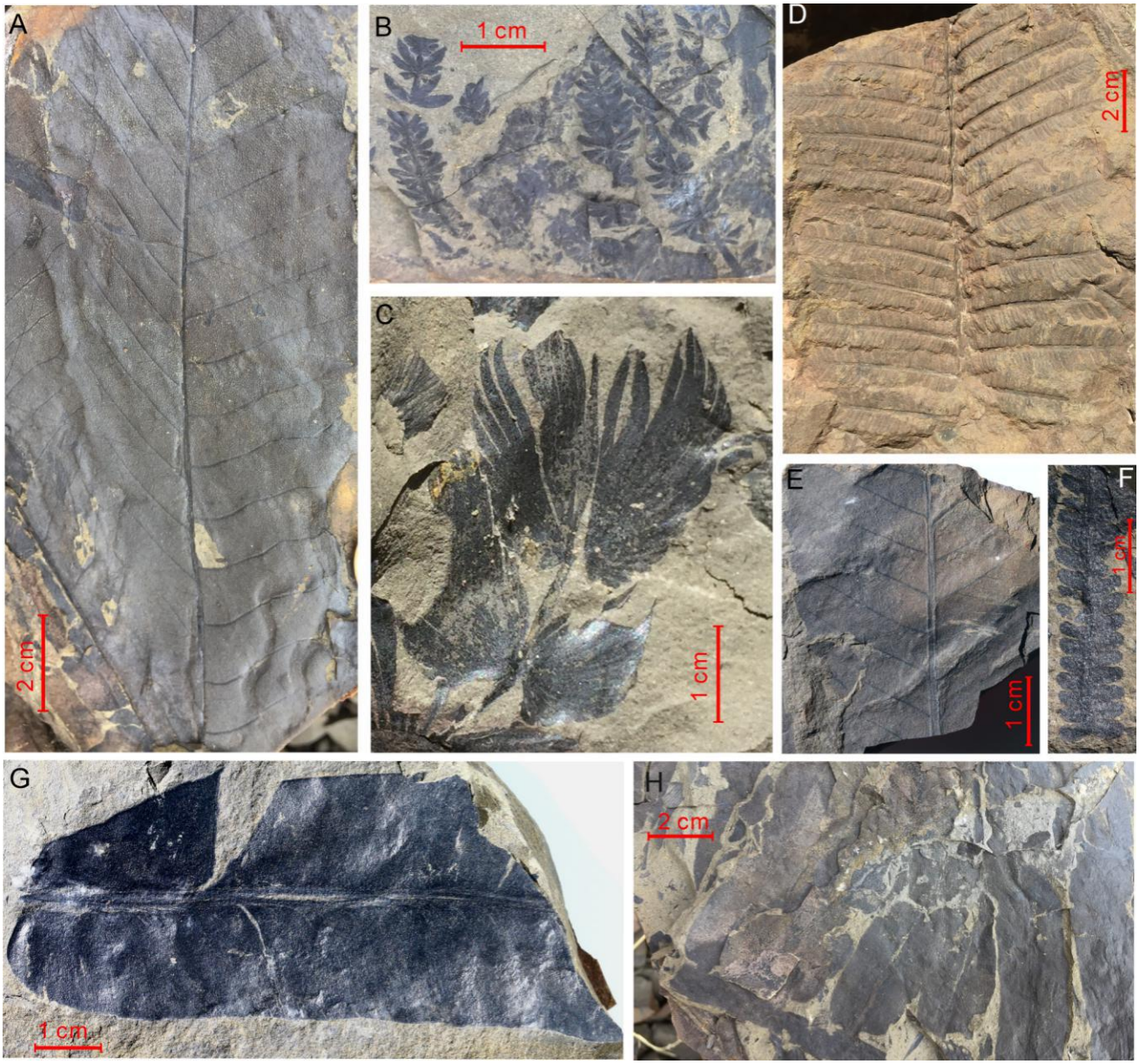

Figure DR3. Typical *Gigantopteris* flora from the Xuanwei Formation of the Chinahe section. A: *Gigantopteris dictyophylloides*; B: *Annularia pingloensis*; C: *Lobatannularia* sp.; D: *Pecopteris marginata*; E: *Gigantonoclea guizhouensis*; F: *Pecopteris* sp.; G: *Compsopteris contracta*; H: Abundant plant leaf fossils preserved on the same bedding surface

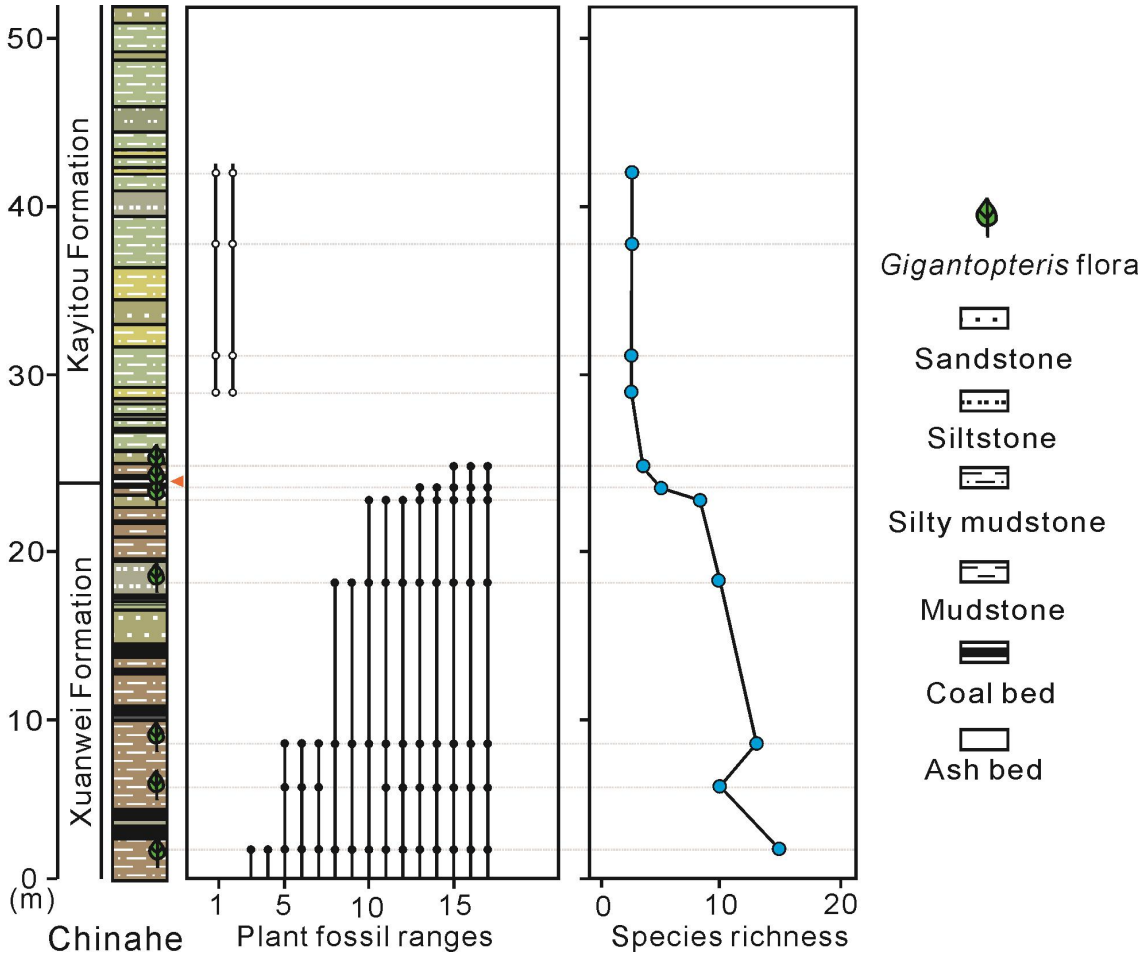

Figure DR4. The plant fossil ranges and species richness of the Chinahe section. 1. *Peltaspermum* sp.; 2. *Annalepis* sp.; 3. *Compsopteris contracta*; 4. *Fascipteris densata*; 5. *Cladophlebis permica*; 6. *Annularia pingloensis*; 7. *Compsopteris* sp.; 8. *Lobatannularia heianensis*; 9. *Pecopteris marginata*; 10. *Lobatannularia cathaysiana*; 11. *Pecopteris guizhouensis*; 12. *Rajahia guizhouensis*; 13. *Gigantonoclea* sp.; 14. *Stigmaria* sp.; 15. *Gigantonoclea guizhouensis*; 16. *Gigantopteris dictyophylloides*; 17. *Pecopteris* sp..

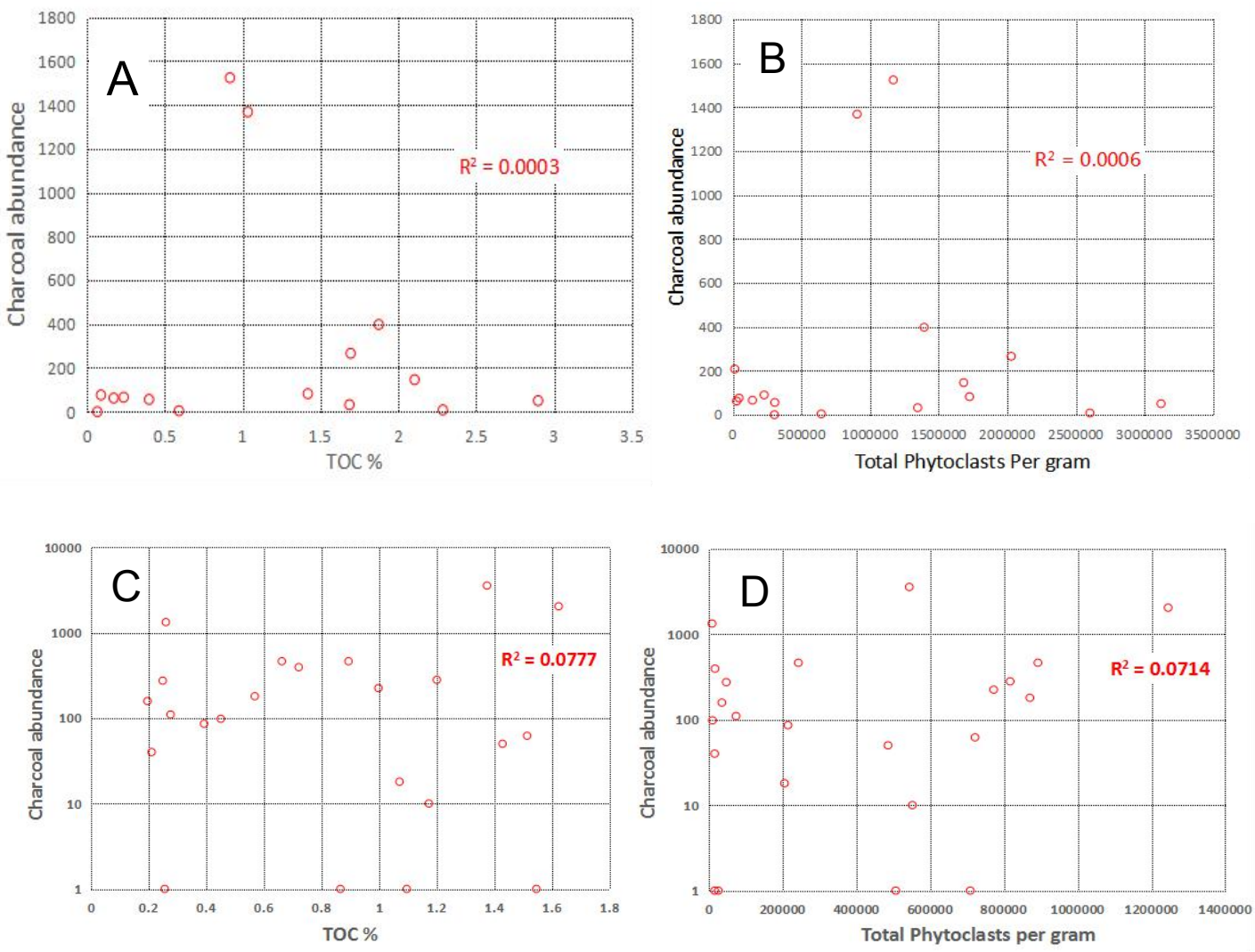

Figure DR5. Charcoal abundance (charcoal particles per 100 g) versus TOC and charcoal abundance versus phytoclasts abundance, showing variations in preserved phytoclasts and TOC show little correlation with the variations in charcoal abundance. A, B: Chinahe; C, D: ZK4703.

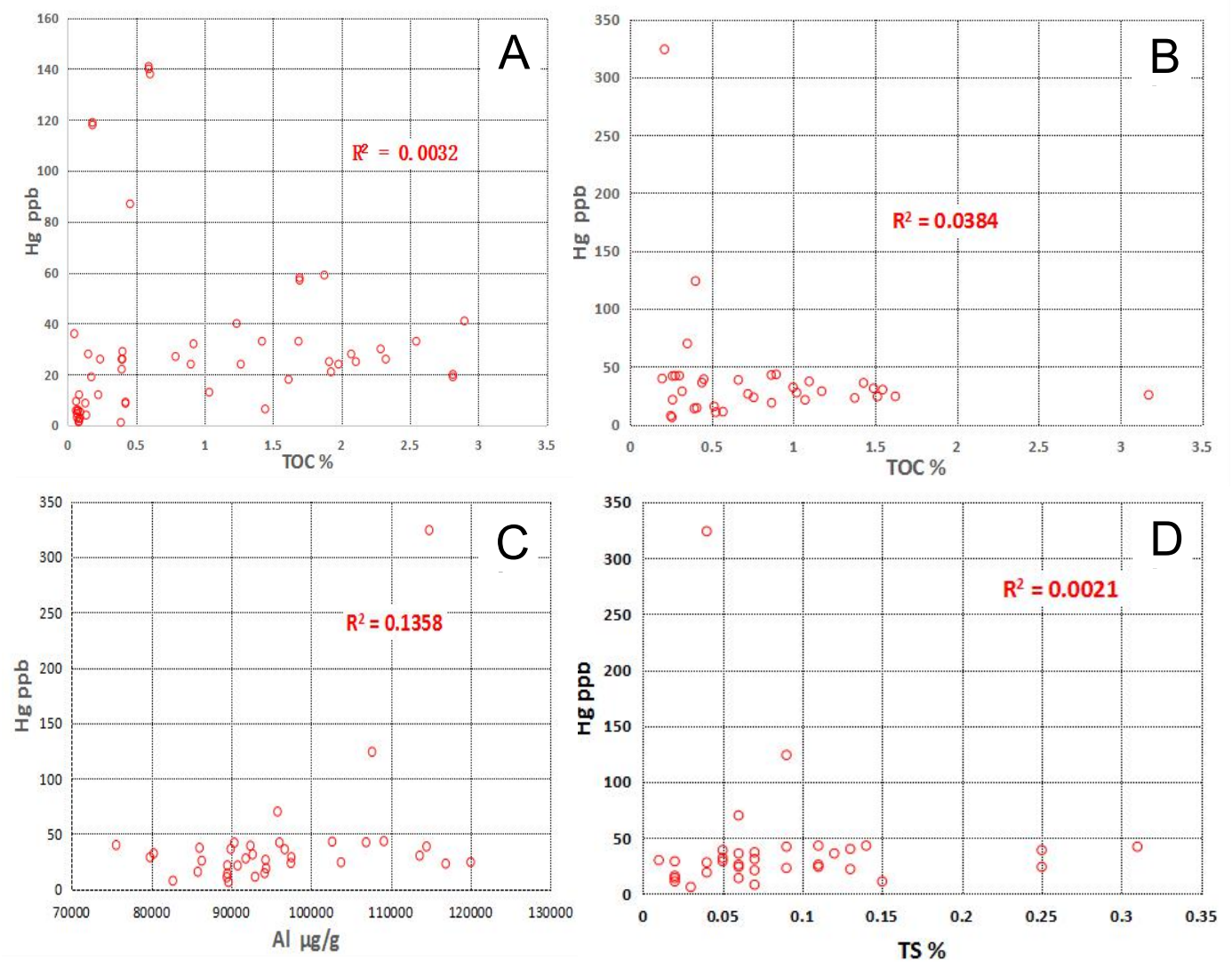

Figure DR6. A: Hg content versus TOC at Chinahe, showing weak correlation; B: Hg content versus TOC at ZK4703, showing weak correlation; C: Hg content versus Al content at ZK4703, showing weak correlation; D: Hg content versus TS at ZK4703, showing weak correlation.

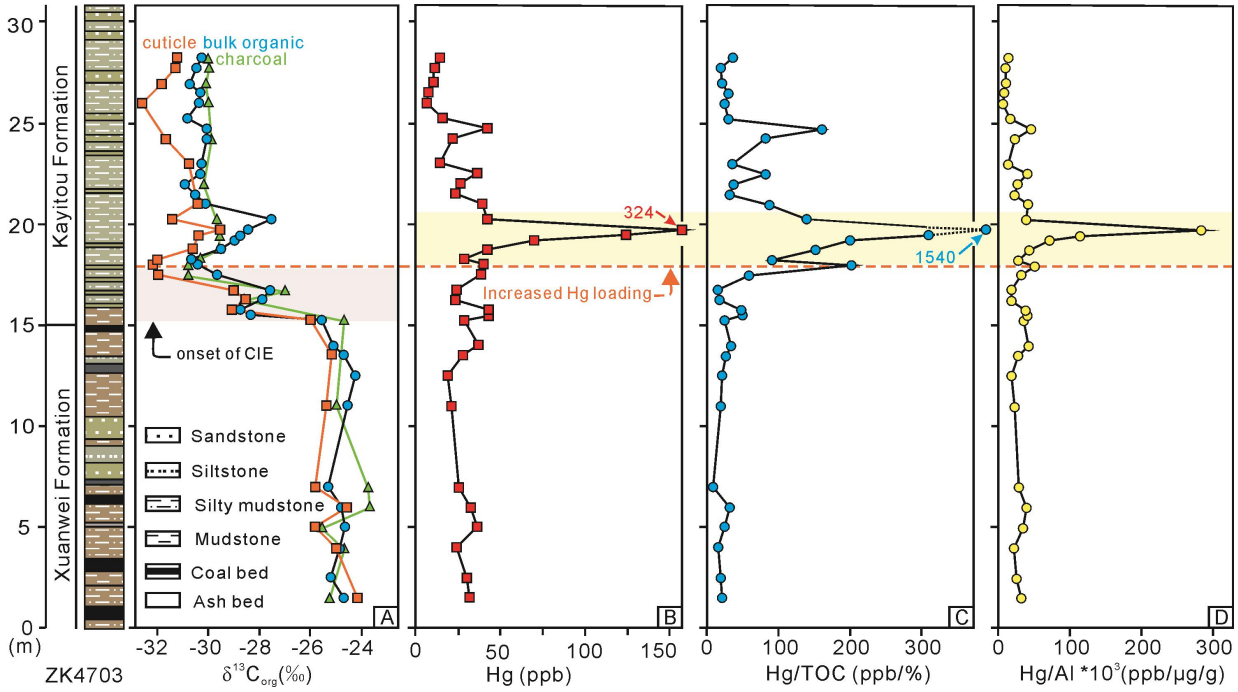

Figure DR7. Organic carbon isotopes, Hg concentration, Hg/TOC and Hg/Al ratios in the ZK4703 core sections.

Table DR1. Hg, TOC, TS, Al, organic carbon isotopes and charcoal abundance (particles per 100 g bulk rock) data from ZK4703.

Sample	Height (m)	Hg (ppb)	TOC %	TS %	Al μg/g	Hg/TOC (ppb/%)	Hg/Al*10^3 (ppb/ μg/g)	Organic carbon isotope (%)			Charcoal abundance
								Bulk OM	Cuticles	Charcoal	
ZK-3	1.50	31	1.49	0.07	928	21	34	-24.67	-24.20	-25.15	440
ZK-5	2.50	30	1.55	0.01	1136	20	27	-25.18	N	N	0
ZK-8	4.00	24	1.51	0.06	1038	16	23	-24.81	-24.93	-24.68	62
ZK-10	5.00	36	1.43	0.12	967	25	37	-24.65	-25.79	-25.57	50
ZK-12	6.00	32	1.00	0.05	803	32	40	-24.81	-24.53	-23.70	224
ZK-14	7.00	26	3.17	0.06	863	8	29	-25.30	-25.81	-23.73	280
ZK-16	9.00	N	N	N	N	N	N	N	N	N	28
ZK-17	11.00	21	1.07	0.07	908	20	24	-24.52	-25.35	-25.09	18
ZK-19	12.00	N	N	N	N	N	N	N	N	N	0
ZK-20	12.50	19	0.87	0.04	944	22	20	-24.23	N	N	N
ZK-21	13.00	N	N	N	N	N	N	N	N	N	8
ZK-22	13.50	28	1.02	0.04	918	27	30	-24.68	N	N	N
ZK-23	14.00	37	1.10	0.07	860	34	43	-25.07	N	N	0
ZK-25	15.00	N	N	N	N	N	N	N	N	N	708
ZK-26	15.25	29	1.17	0.05	798	25	36	-25.55	-25.99	-24.70	10
ZK-27	15.50	43	0.86	0.14	1027	50	41	-28.33	N	N	N
ZK-28	15.75	43	0.89	0.11	1091	48	39	-28.72	-29.13	N	462
ZK-29	16.00	N	N	N	N	N	N	N	N	N	1394
ZK-30	16.25	23	1.37	0.09	1169	17	20	-27.87	-28.58	-28.65	N
ZK-31	16.50	N	N	N	N	N	N	N	N	N	2482
ZK-32	16.75	24	1.62	0.25	1200	15	20	-27.57	-29.08	-27.01	2034
ZK-33	17.00	N	N	N	N	N	N	N	N	N	38
ZK-34	17.25	N	N	N	N	N	N	N	N	N	462
ZK-35	17.50	39	0.66	0.25	1145	58	34	-29.64	-31.94	-30.79	372
ZK-37	18.00	40	0.20	0.13	756	203	53	-30.40	-32.18	-30.77	158
ZK-39	18.25	29	0.32	0.02	975	90	29	-30.67	-32.01	-30.30	216

ZK-41	18.75	42	0.28	0.31	960	152	44	-29.49	-30.53	-29.58	110
ZK-42	19.25	70	0.35	0.06	958	200	73	-28.90	N	N	24
ZK-43	19.50	124	0.40	0.09	1077	310	115	-28.50	-30.29	-29.51	N
ZK-45	19.75	324	0.21	0.04	1148	1540	282	-28.44	-29.42	N	40
ZK-47	20.25	42	0.30	N	1069	140	39	-27.54	-31.37	-29.68	152
ZK-49	20.75	N	N	N	N	N	N	N	N	N	98
ZK-50	21.00	39	0.45	0.05	924	87	42	-30.10	-30.33	N	N
ZK-51	21.25	N	N	N	N	N	N	N	N	N	280
ZK-52	21.50	24	0.76	0.11	975	31	24	-30.50	N	N	N
ZK-53	21.75	N	N	N	N	N	N	N	N	N	394
ZK-54	22.00	26	0.72	0.11	943	37	28	-30.92		-30.20	N
ZK-55	22.25	N	N	N	N	N	N	N	N	N	40
ZK-56	22.50	36	0.44	0.06	899	82	40	-30.31	N	N	N
ZK-57	22.75	N	N	N	N	N	N	N	N	N	34
ZK-58	23.00	14	0.41	0.06	942	35	15	-30.27	-30.69	N	N
ZK-63	24.25	22	0.26	0.13	895	83	25	-30.05	-31.64	-29.85	N
ZK-65	24.75	42	0.26	0.09	904	162	46	-30.04	N	N	N
ZK-67	25.25	16	0.51	0.02	858	30	18	-30.82	N	N	310
ZK-70	26.00	6	0.26	0.03	897	25	7	-30.36	-32.58	-30.05	670
ZK-72	26.50	8	0.25	0.07	827	31	9	-30.30	N	N	274
ZK-74	27.00	11	0.52	0.02	895	20	11	-30.74	-31.81	-30.10	34
ZK-77	27.75	11	0.57	0.15	930	20	12	-30.46	-31.37	-29.71	180
ZK-79	28.25	14	0.39	0.02	895	36	15	-30.27	-31.34	-29.99	86

Table DR2. Hg, TOC, organic carbon isotope values and charcoal abundance (particles per 100 g bulk rock) data from Chinahe.

Sample	Height (m)	Hg (ppb)	TOC (%)	Hg/TOC (ppb/%)	Organic carbon isotope (%)		Charcoal abundance
					Bulk OM	Charcoal	
CNH-02+0	2.5	27	0.79	34	-24.23	N	4
CNH-03+0.1	3.5	N	N	N	-24.23	N	N
CNH-03+1	4.4	33	1.42	23	-24.54	-23.71	82
CNH-03+2	5.4	24	1.26	19	-24.48	N	N
CNH-03+3.8	7.2	21	1.92	11	-25.49	-24.45	282
CNH-03-0.7	8.7	18	1.61	11	-24.42	N	N
CNH-04+1.3	10.7	41	2.90	14	-24.30	-23.59	50
CNH-04-0.6	11.9	25	1.91	13	-23.94	N	N
CNH-05+0.2	12.3	N	N	N	-24.17	N	N
CNH-05+0.3	12.4	28	2.07	14	-24.02	N	N
CNH-06+0.1	13.3	N	N	N	-23.66	N	N
CNH-06-1	15.3	33	1.69	20	-24.90	N	32
CNH-07+0.2	16.5	24	0.90	27	-24.55	-25.07	N
CNH-07+1.2	17.5	20	2.81	7	-25.20	N	90
CNH-08+0.1	18.7	N	N	N	-25.46	N	N
CNH-08-0.3	19.7	8.6	0.42	20	-25.29	N	N
CNH-09+0.3	20.3	1.1	0.39	3	-25.55	N	52
CNH-09+1.2	21.2	24	1.98	12	-25.29	N	N
CNH-09-0.9	21.55	N	N	N	-25.24	N	N
CNH-10+0.1	22.55	6.4	1.44	4	-25.33	-23.76	380
CNH-10+0.4	22.85	13	1.03	13	-25.23	-24.10	1368
CNH-11+0.1	23.05	N	N	N	-25.12	N	N
CNH-12+0.2	23.55	26	2.32	11	-26.81	-24.33	90
CNH-12+0.5	23.85	25	2.10	12	-26.74	-25.57	146
CNH-12+0.75	24.10	N	N	N	N	-26.37	N
CNH-12+1	24.35	33	2.55	13	-26.52	-26.70	704

CNH-12+1.3	24.65	40	1.23	32	-26.43	-25.59	294
CNH-12+1.6	24.95	32	0.92	35	-27.51	-26.73	1524
CNH-13+0	25.25	30	2.29	13	N	-26.72	8
CNH-13+0.7	25.95	57	1.69	34	-27.18	-28.60	266
CNH-13+1.1	26.35	59	1.87	31	-26.97	-27.23	395
CNH-13+1.2	26.45	N	N	N	-28.40	N	N
CNH-13+1.5	26.75	141	0.59	238	-30.14	-29.71	4
CNH-13+2.3	27.55	87	0.46	191	-28.31	N	6
CNH-14+0.1	28.85	29	0.40	73	-28.61	N	56
CNH-14+0.8	29.55	22	0.39	56	-28.48	N	N
CNH-14+1.75	30.5	19	0.17	110	-27.68	N	62
CNH-14+2.25	31.00	28	0.15	187	-27.44	N	N
CNH-14-0.1	32.05	119	0.18	658	-28.15	-28.98	178
CNH-15+0.6	32.75	12	0.22	54	-28.73	-29.73	92
CNH-15+1.6	33.75	12	0.08	145	-27.74	N	92
CNH-15+2.8	34.95	26	0.24	110	-29.61	-30.25	66
CNH-15-0.3	36.55	N	N	N	-28.61	N	N
CNH-16+0.3	37.15	8.7	0.13	68	-29.05	N	N
CNH-16+1.3	38.15	N	N	N	-28.95	-30.57	N
CNH-16+2.3	39.15	4	0.13	30	-30.32	N	N
CNH-18+0.2	46.55	2.9	0.09	32	-30.84	N	76
CNH-18+2	48.35	N	N	N	-28.95	N	N
CNH-18+3.4	49.75	5.9	0.08	76	-27.97	N	46

Table DR3. Palynofacies analysis data from ZK4703, quantifying the abundance of pollen and spores, plant cuticle, amorphous organic matter and coalified particles.

Sample	Weight (g)	Counts taken across slide transect							Total phytoclasts in transect	Total phytoclasts in slide	Total phytoclasts in bulk sample	Total phytoclasts /g
		Wood	Cuticle	Charcoal	Spore & Pollen	AOM	Fungal	Coalified material				
ZK-2	46.0	23	15	75	5	6	0	301	425	3400	34871795	758082
ZK-5	39.8	36	12	21	29	15	0	133	246	1968	20184615	506642
ZK-8	39.1	8	5	39	4	77	0	211	344	2752	28225641	721699
ZK-10	38.2	59	4	6	13	0	0	144	226	1808	18543590	485816
ZK-12	39.0	29	6	1	8	0	0	69	113	904	30133333	772254
ZK-15	44.4	34	3	6	19	0	0	74	136	1088	36266667	816817
ZK-17	40.6	18	3	4	11	1	0	67	104	832	8320000	205078
ZK-19	39.5	12	3	1	0	1	0	53	70	560	28000000	708861
ZK-23	39.3	9	4	49	2	46	0	141	251	2008	1004000	25580
ZK-26	41.3	1	3	10	0	3	0	40	57	456	22800000	551791
ZK-28	40.0	12	4	17	10	3	0	51	97	776	9700000	242682
ZK-30	38.6	12	6	18	6	2	0	61	105	420	21000000	543478
ZK-32	39.5	5	2	34	3	3	0	76	123	984	49200000	1245254
ZK-34	39.2	45	2	7	20	0	0	101	175	1400	35000000	892174
ZK-37	39.2	44	7	32	18	4	0	241	346	2768	1384000	35333
ZK-41	39.6	16	4	11	76	0	0	623	730	5840	2920000	73737
ZK-45	40.1	3	0	1	3	0	0	310	317	2536	634000	15818

ZK-49	39.2	3	0	3	2	0	0	184	192	1536	384000	9803
ZK-53	41.3	35	1	11	20	3	0	489	559	4472	688000	16675
ZK-63	40.6	11	1	65	3	11	0	216	307	1228	151138	3721
ZK-65	44.4	69	16	156	61	40	0	285	627	5016	385846	8688
ZK-69	40.7	20	2	10	2	0	0	488	522	4176	642462	15770
ZK-73	39.4	11	2	162	4	15	0	272	466	3728	1864000	47298
ZK-77	39.3	43	14	41	9	0	0	64	171	1368	34200000	870450
ZK-79	39.2	10	0	44	8	0	0	43	105	840	8400000	214559
ZK-83	38.8	5	0	212	3	0	0	90	310	1860	186000	4794

Table DR4. Palynofacies analysis data from Chinahe, quantifying the abundance of pollen and spores, plant cuticle, amorphous organic matter and coalified particles.

Sample	Weight (g)	Counts taken across slide transect							Total phytoclasts in transect	Total phytoclasts in slide	Total phytoclasts in bulk sample	Total phytoclasts/g
		Wood	Cuticle	Charcoal	Spore & Pollen	AOM	Fungal	Coalified material				
CNH-3+1	50.1	0	1	32	0	0	0	291	324	1296	86400000	1724551
CNH-4+1.3	50.4	0	0	19	0	0	0	276	295	2360	157333333	3121693
CNH-6-1	51.0	3	0	21	0	0	0	137	161	1288	68693333	1346928
CNH-9+1.2	50.6	0	0	87	0	0	0	321	408	3264	130560000	2580237
CNH-10+0.4	50.1	0	0	2	2	0	0	166	170	1360	45333333	904857
CNH-12+0.5	50.6	2	0	45	3	0	0	121	171	1368	85120000	1682213
CNH-12+1.6	50.5	3	0	132	0	0	0	280	415	3320	59022222	1168757
CNH-13+0-1	50.6	7	0	86	23	0	0	371	487	3896	121208889	2603074
CNH-13+0-2		0	0	2	0	0	0	11	13	104	346667	
CNH-13+0-3		9	1	31	14	0	0	326	381	3048	10160000	
CNH-13+0.3-1	50.4	0	0	4	3	0	0	48	55	55	183333	226918
CNH-13+0.3-2		7	5	123	47	0	0	240	422	3376	11253333	
											11436667	
CNH-13+0.7-1	51.0	2	2	81	40	0	0	234	359	2872	102115556	2029560
CNH-13+0.7-2		1	3	21	31	0	0	205	261	2088	1392000	
											103507556	

CNH-13+1.1	50.2	1	0	9	16	0	0	97	123	984	69973333	1393891
CNH-13+1.5	50.4	0	1	8	11	0	0	94	114	912	32426667	643386
CNH-13+1.9-1	50.4	6	2	56	7	0	0	321	392	3136	8362667	479506
CNH-13+1.9-2		1	3	10	9	0	0	104	127	1016	15804444	
											24167111	
CNH-14+0.1	50.2	0	0	8	2	0	0	76	86	688	15288889	304560
CNH-14+1.75	50.1	0	0	16	0	0	0	232	248	1984	1322667	26401
CNH-15+2.6	51.2	5	1	14	16	0	0	304	340	2720	7253333	141667
CNH-16+1.3	50.9	0	1	2	0	0	0	78	81	648	648000	12731
CNH-18+0.2	50.3	2	0	10	5	0	0	65	82	656	2186667	43472
CNH-18+5.3	50.9	0	0	11	2	0	0	218	231	1848	1848000	36306
CNH-20+1	50.3	0	0	19	2	0	0	101	122	976	15182222	301833
CNH-21+1.5	50.1	0	0	15	0	0	0	120	135	1080	720000	14371