Supplementary material

Supplementary tables

Table S1. Detailed information of lake cores.

Lake	Composite core depth[1]	Overlapping cores		Tephras classified[3]							Notes[4]
Name (label)	(mbl)	Label[2]	(mbl)	Tu	Ma	Op	Mm	Wh	Rr	Rk	
Ngāroto (S1)	0.05–4.30	S1-A-1	0.02–2.35		i	d	i		i	i	1
		S1-A-2	1.84–4.20						ds		
		S1-A-3	0.05–1.91	d	d	d	i				
		S1-A-4	2.04–4.15								
Mangakaware (S2)	0.00–3.19	S2-A-1	0.00–3.18	d	i	i	i	i	i	i	2
		S2-A-2	0.00–1.86		i	i	i	i	i	i	
		S2-B-1	0.00–0.84	i	i						
Maratoto (S3)	0.00–3.80	S3-A-1	0.00–3.80	i	ds	i	i	i	i	i	2, 3
		S3-A-2	0.00–3.10	d	i	i	i	i	i	i	
		S3-A-3	0.10–2.80	d	d	d	i	ds	i	i	
		S3-B-1	0.00–1.40						i	i	
		S3-B-2	0.00–1.40						i	i	
		S3-C-1	0.00–3.15	d	i	i		i	i	i	
		S3-C-2	0.00–1.75	i	i	i	i	i	i		
		S3-C-3	0.00–1.63	i	i	i	d	ds	i	d	
		S3-D-1	0.00–2.39	i	i	i	i	i	i	i	
		S3-E-1	0.00–1.93	i	i	i		i	i	i	
		S3-F-1	0.00–1.70	d	i	i	i	i	i		
		S3-G-1	0.00–1.83	d	i	i		i	i		
		S3-G-2	0.00–2.40	i	ds	i		i	i	i	
		S3-G-3	0.50–2.67	i	i	i	i	i	i	i	
		S3-H-1	0.00–3.12		i	d	i	i	i	d	
		S3-H-1	0.00–2.64	i	i	d		d	i		
		S3-H-1	0.00–2.17	i	d	i		i	i	i	
		S3-I-1	0.75–2.96	i	i	i		i	i	i	
		S3-J-1	0.50–1.93		i	d			i		
		S3-J-2	0.50–2.82	i	i	i	i	i	i	i	
		S3-K-1	0.00–2.03	i	i	i	i	i	i	d	
		S3-L-1	0.00–2.60	i	ds	i		ds		i	
Rotoroa (C1)	0.11–3.06	C1-A-1	0.11–1.67	i	i	i					4
		C1-A-2	1.26–3.46	i	i	i	i	i	i	i	
	0.00–3.17	C1-B-1	0.00–1.72	i							5
		C1-B-2	1.00–2.15	i	i	i	i	i	ds		
	1.00–3.03	C1-C-1	1.00–2.25					i	ds		
		C1-C-2	1.40–3.03						ds		
	0.00–3.35	C1-D-1	0.00–1.77	i	i	i	i				
		C1-D-2	1.50–3.93	i	i	i	i	i	ds	i	
	0.00–1.76	C1-E-1	0.00–1.75	i	i	ds	d	ds	ds		
	0.00–1.83	C1-F-1	0.00–1.17	i	i	i	i	i			
		C1-F-2	0.10–1.76	i	ds		d	i	ds	i	
	0.00–3.98	C1-G-1	0.00–2.21	i	i	i	i				
		C1-G-2	2.00–4.08			i	i	ds	ds	i	

Table S1. *(continued)*

Lake	Composite core depth[1]	Overlapping cores		Tephras classified[3]							Notes[4]
Name (label)	(mbl)	Label[2]	(mbl)	Tu	Ma	Op	Mm	Wh	Rr	Rk	
Rotokaeo (C2)	0.10–4.04	C2-A-1	0.10–1.56	i	i						4
		C2-A-2	1.00–3.24	ds	ds	i	ds	ds	d		
		C2-A-3	2.50–4.65			i	i	i	ds	ds	
Waiwhakareke (C3)	0.13–4.37	C3-A-1	0.13–1.87	i	i	i					4
		C3-A-2	1.00–3.16	i	i	ds	d	i	i		
		C3-A-3	2.50–4.75	i	d		i	i	i	i	
Rotokauri (C4)	0.03–6.94	C4-A-1	0.03–2.04	ds	d						1
		C4-A-2	1.95–4.10	ds	i	i	i	d			
		C4-A-3	3.53–6.71					d	ds	i	
		C4-A-4	0.58–3.70	i	i	i	i	d			
		C4-A-5	3.55–5.95					i	ds	i	
Kainui (N1)	0.05–4.02	N1-A-1	0.00–2.10	i	i	i		i	ds	i	2
		N1-A-2	0.00–2.90	i	i	i		i	ds	i	
		N1-B-1	0.05–1.88								1
		N1-B-2	1.54–4.14	i	i	i	i	i	ds	ds	
		N1-B-3	0.07–3.17	i	i	i	i	d	d		
		N1-B-4	1.04–3.41	i	i	i	i	i	d		
Rotokaraka (N2)	1.00–6.57	N2-A-1	1.00–3.65	i		d		ds	ds		2
		N2-A-2	2.00–4.36		d	d		i	ds	i	
		N2-A-3	4.00–5.74						ds	i	
		N2-A-4	3.00–4.95					i	ds	i	
Leeson's Pond (N3)	1.51–4.56	N3-A-1	3.00–5.70	i				ds	ds	i	2
		N3-A-2	3.00–5.30	i		i		ds	ds	i	
		N3-A-3	1.50–2.70	i	d	i					

mbl–metre below lake bed; Tu = Tuhua tephra; Ma = Mamaku tephra; Op = Opepe tephra; Mm = Mangamate tephra; Wh = Waiohau tephra; Rr = Rotorua tephra; Rk = Rerewhakaaitu tephra

[1]Composite cores were created from information of one or more overlapping cores; an example for Lake Rotokaeo (C2) is provided in supplementary Fig. S1.

[2]The letters A to L (forming the middle part of the core labels) represent different coring locations within the central part of a lake, whereas the last digit in the label denotes a core taken at a specific coring location. Note that the core labels for Maratoto (S3) were changed from those used in the original publication to align with the nomenclature used for later coring as follows (old labels in brackets follow Green and Lowe (1985) and unpublished core logs): S3-A-1 (4,1a), S3-A-2 (4,1b), S3-A-3 (4,1d), S3-B-1 (4,1h), S3-B-2 (4,1i), S3-C-1 (5,1a), S3-C-2 (5,1b), S3-C-3 (5,1c), S3-D-1 (6,1a), S3-E-1 (7,1a), S3-F-1 (1Nb), S3-G-1 (5Wb), S3-G-2 (5Wc), S3-G-3 (5Wa), S3-H-1 (5Ec), S3-H-2 (5Eb), S3-H-3 (5Ea), S3-I-1 (6Wa), S3-J-1 (6Eb), S3-J-2 (6Ea), S3-K-1 (7Wa), S3-L-1 (7Ea).

[3]Tephra layers were classified as "soft-sediment deformation structures present" (ds), "intact" (i), and "discontinuous" (d). Cells that were left empty denote that the respective tephra layers were not cored or identified in the sediment core. Examples of classified tephra layers are provided in supplementary Fig. S2.

[4]Notes: (1) cored in 2016; (2) published by Lowe (Lowe 1988); (3) published Green and Lowe (1985); (4) cored in 2020; (5) cored in 2022.

Table S2. Sampling list of lake cores.

Lake	Overlapping cores		Sampling		
Name (label)	Label[2]	(mbl)	Depth	Stratigraphy	Type
Ngāroto (S1)	S1-A-1	0.02–2.35	1.12	Ma	gs
			1.91	Rr	gs
			2.05	Rk	gs
	S1-A-2	1.84–4.20	1.85	Rr*	gs
Rotoroa (C1)	C1-A-1	0.11–1.67	1.30	Lake sediment	al
			1.37	Tu	gs
			1.42	Ma	gs
	C1-A-2	1.26–3.46	2.06	Tu	gs
			2.14	Ma	gs
			2.79	Lake sediment	al
			2.91	Wh	gs
			3.11	Rr	gs
			3.31	Rk	gs
Rotokaeo (C2)	C2-A-1	0.10–1.56	1.53	Tu	gs
			1.59	Ma	gs
			1.68	Lake sediment	al
	C2-A-2	1.00–3.24	1.46	Tu	gs
			1.54	Ma	gs
			2.92	Lake sediment	al
			3.12	Rr	gs
	C2-A-3	2.50–4.65	2.53	Tu	gs
			3.53	Rr	gs
			3.83	Rk	gs
			3.89	Lake sediment	al
Waiwhakareke (C3)	C3-A-1	0.13–1.87	1.38	Tu	gs, bd
			1.44	Ma	gs
			1.50	Lake sediment	al
	C3-A-2	1.00–3.16	1.67	Lake sediment	bd
			1.89	Tu*	gs
			1.97	Ma*	gs
			2.09	Lake sediment	bd
			2.75	Wh*	gs
			3.06	Lake sediment	al
	C3-A-3	2.50–4.75	3.21	Wh	gs
			3.40	Lake sediment	bd
			3.62	Rr*	gs, bd
			3.90	Lake sediment	bd
			4.17	Lake sediment	al
			4.23	Rk*	gs

Table S2. *(continued)*

Lake	Overlapping cores depth		Sampling		
Name (label)	Label[1]	(mbl)	Depth	Stratigraphy[2]	Type[3]
Rotokauri (C4)	C4-A-1	0.03–2.04	1.75	Lake sediment	bd
			1.92	Tu*	gs
			2.12	Tu*	gs
	C4-A-2	1.95–4.10	2.07	Lake sediment	oc
			2.20	Ma	gs
			2.46	Lake sediment	bd
	C4-A-3	3.53–6.71	3.93	Lake sediment	oc
			3.98	Rr	gs
			4.03	Lake sediment	oc
	C4-A-4	0.58–3.70	1.68	Lake sediment	oc
			1.74	Tu	gs
			1.87	Lake sediment	oc
	C4-A-5	3.55–5.95	3.72	Wh	gs
			4.03	Rr*	gs
			4.42	Rk	gs
Kainui (N1)	N1-B-2	1.54–4.14	2.08	Tu	gs
			2.16	Ma	gs
			2.96	Wh	gs
			3.08	Lake sediment	bd
			3.21	Rr*	gs
			3.43	Lake sediment	bd
	N1-B-3	0.07–3.17	2.08	Tu	gs
			2.15	Ma	gs
	N1-B-4	1.04–3.41	2.29	Tu	gs
			2.42	Ma	gs
			3.22	Wh	gs

[1]See description to supplementary Tab. S1.

[2]Sampling was performed on lake sediment or on specific intact tephra layers (Tu = Tuhua tephra; Ma = Mamaku tephra; Op = Opepe tephra; Mm = Mangamate tephra; Wh = Waiohau tephra; Rr = Rotorua tephra; Rk = Rerewhakaaitu tephra). The asterisk indicates that sampling was performed on liquefied tephra layers.

[3]Differerent types of samples were taken: al = Atterberg limits; bd = Bulk density; gs = Grain size; oc = Organic content. See description in the Methods section for further details.

Supplementary figures

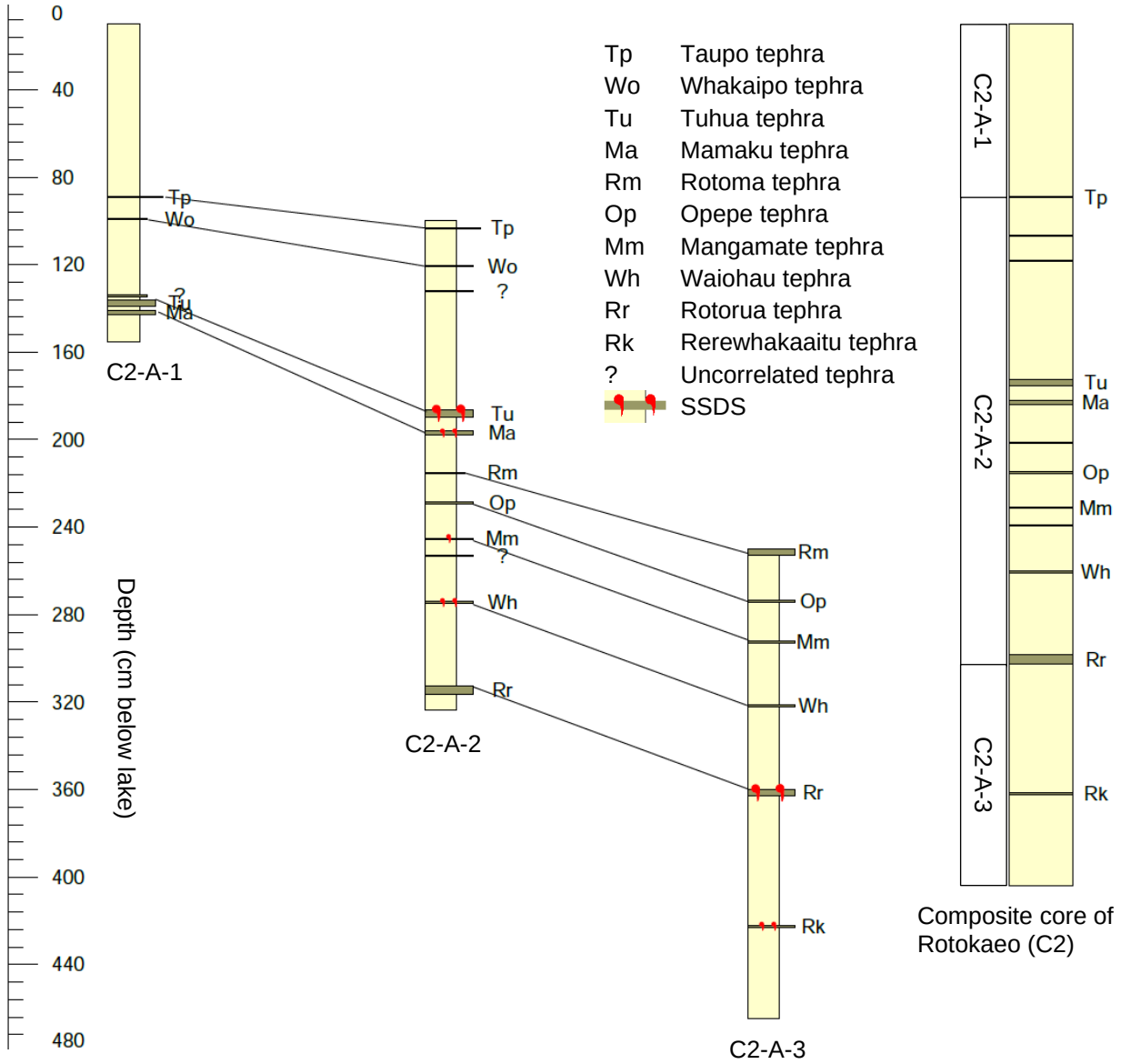

Fig. S1. Example for construction of composite core at Lake Rotokaeo (C2). The composite core was created by stacking three overlapping cores (i.e., C2-A-1, C2-A-2, C2-A-3), being well-correlated (connected from one to another) based on distinctive tephra layers present in the cores in different superpositions. The tephra layers are not located at exactly the same absolute core depths mainly because of local variability in the lake sediments. This variability resulted in depth offsets for some tephra layers. The depth scale of cores was kept constant.

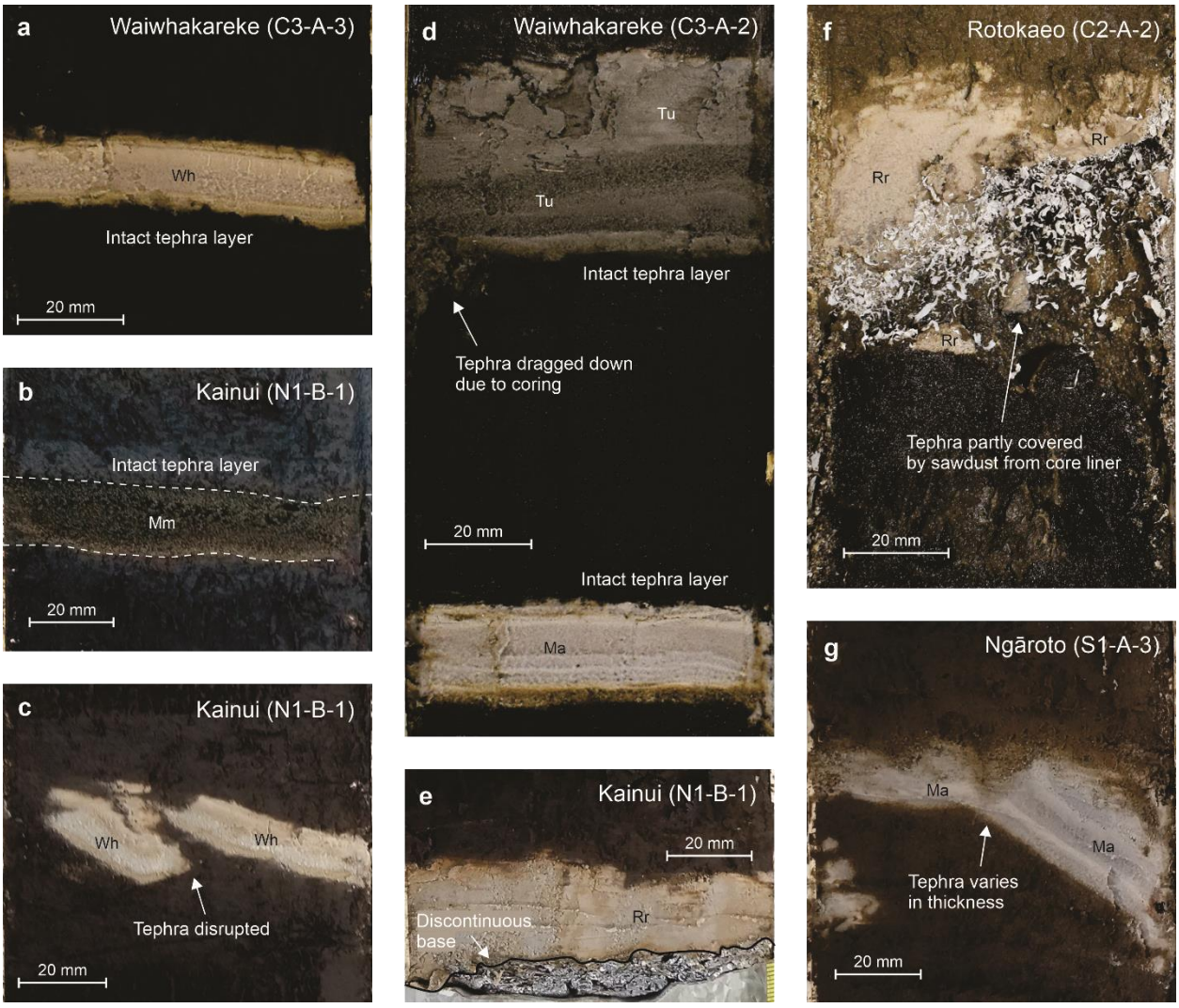

Fig. S2. Examples of tephra layers intercalated in lake sediment. (a-b, d) Tephra layers being classified as "intact". Small artefacts due to the coring process may be present (i.e., a tephra is dragged down along the coring barrel). (c, e-g) Tephra layers being classified as "discontinuous". Tephras were either disrupted (c), exhibited a discontinuous base (e), were not entirely exposed (f), or significantly varied in thickness (g).

References

Green JD and Lowe DJ (1985) Stratigraphy and development of c. 17 000 year old Lake Maratoto, North Island, New Zealand, with some inferences about postglacial climatic change. New Zealand Journal of Geology and Geophysics 28(4): 675-699. https://doi.org/10.1080/00288306.1985.10422541

Lowe DJ (1988) Late Quaternary volcanism in New Zealand: towards an integrated record using distal airfall tephras in lakes and bogs. Journal of Quaternary science 3(2): 111-120. https://doi.org/10.1002/jqs.3390030202