

Supplementary Information for

Biogeochemical explanations for the world's most phosphate-rich lake, an origin-of-life analog

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Supplementary Note 1

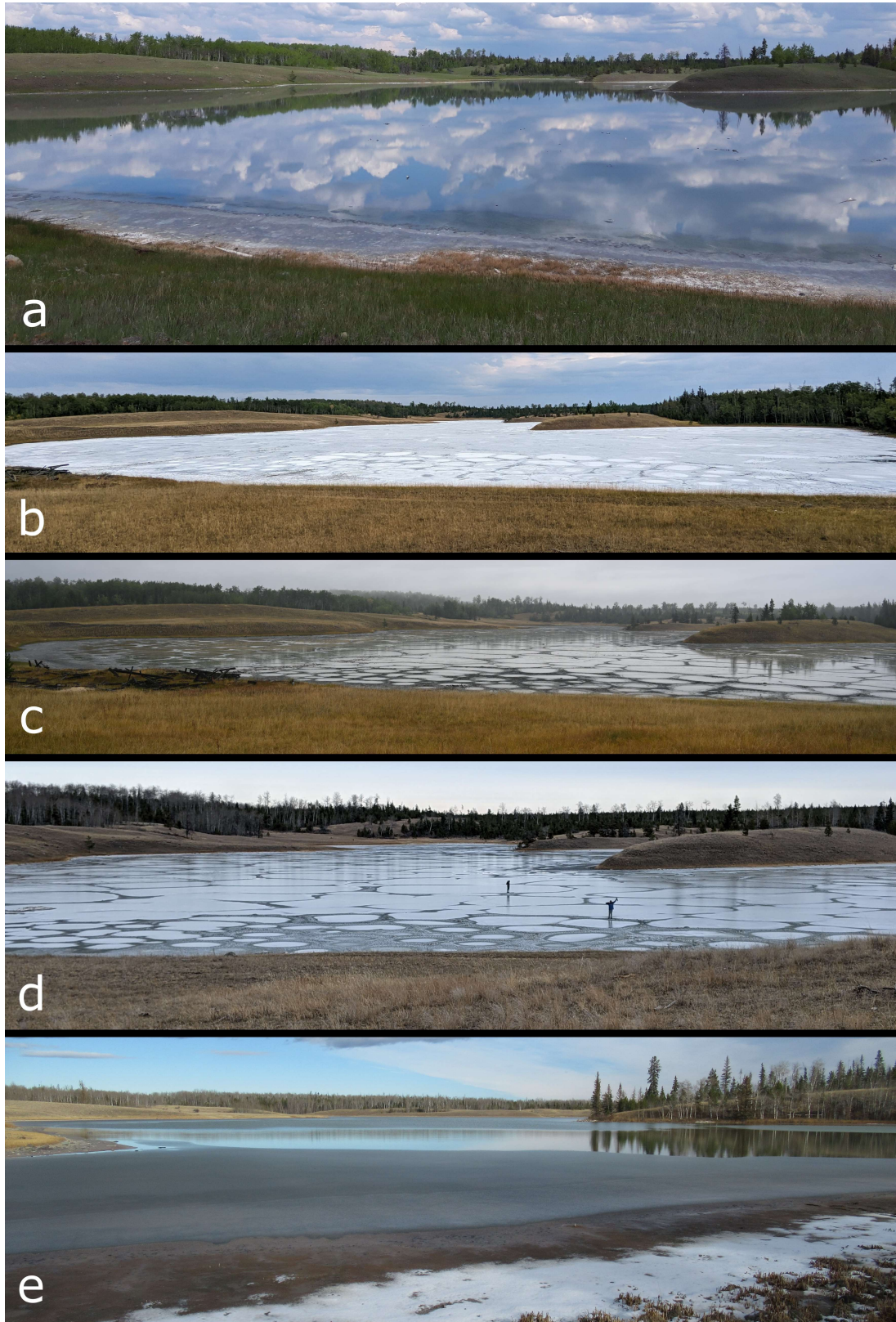
Supplementary Figs. 1–6

Supplementary Tables 1–3

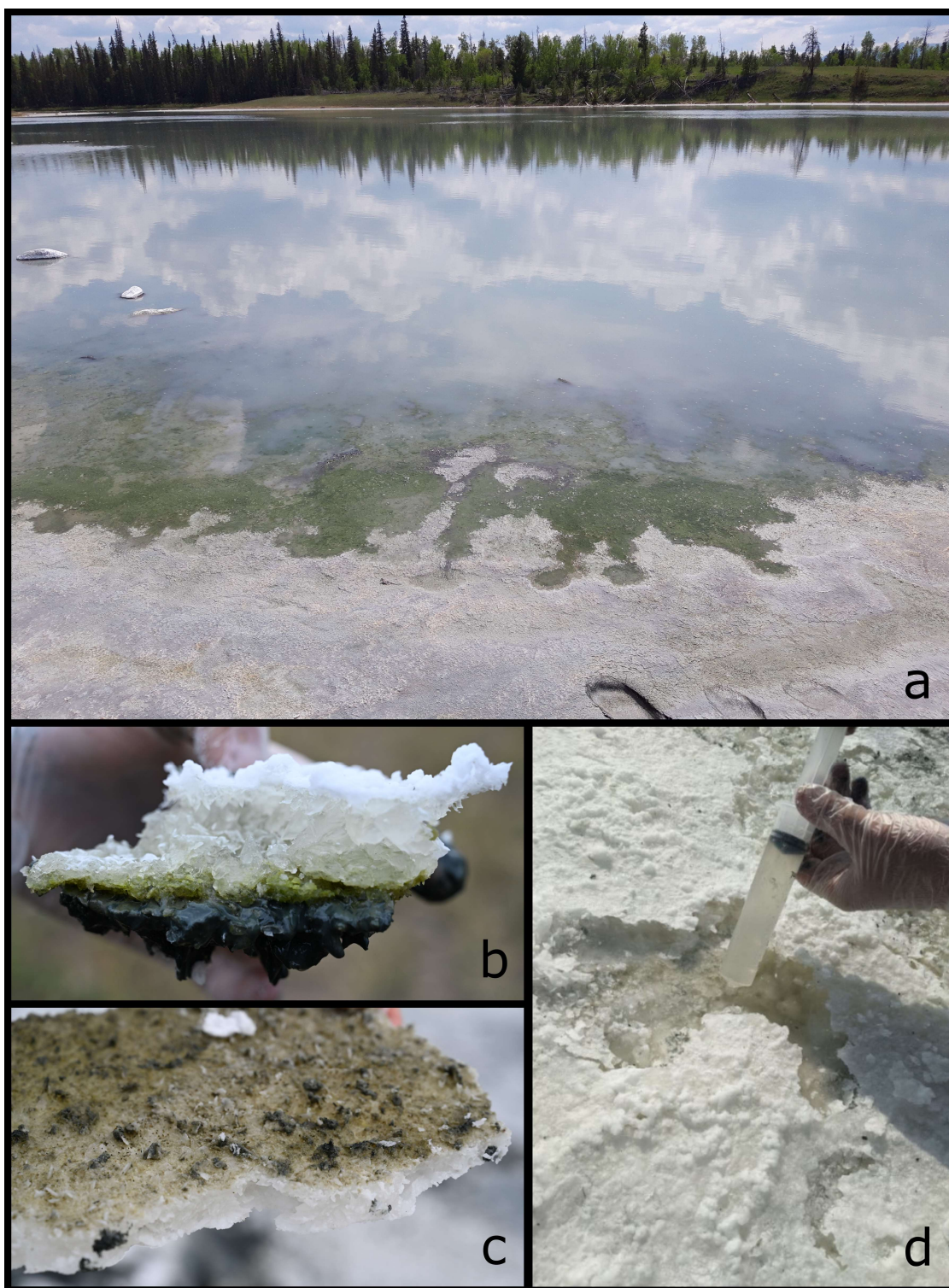
Supplementary Notes

Supplementary Note 1: Seasonal variations in chlorophyll *a*

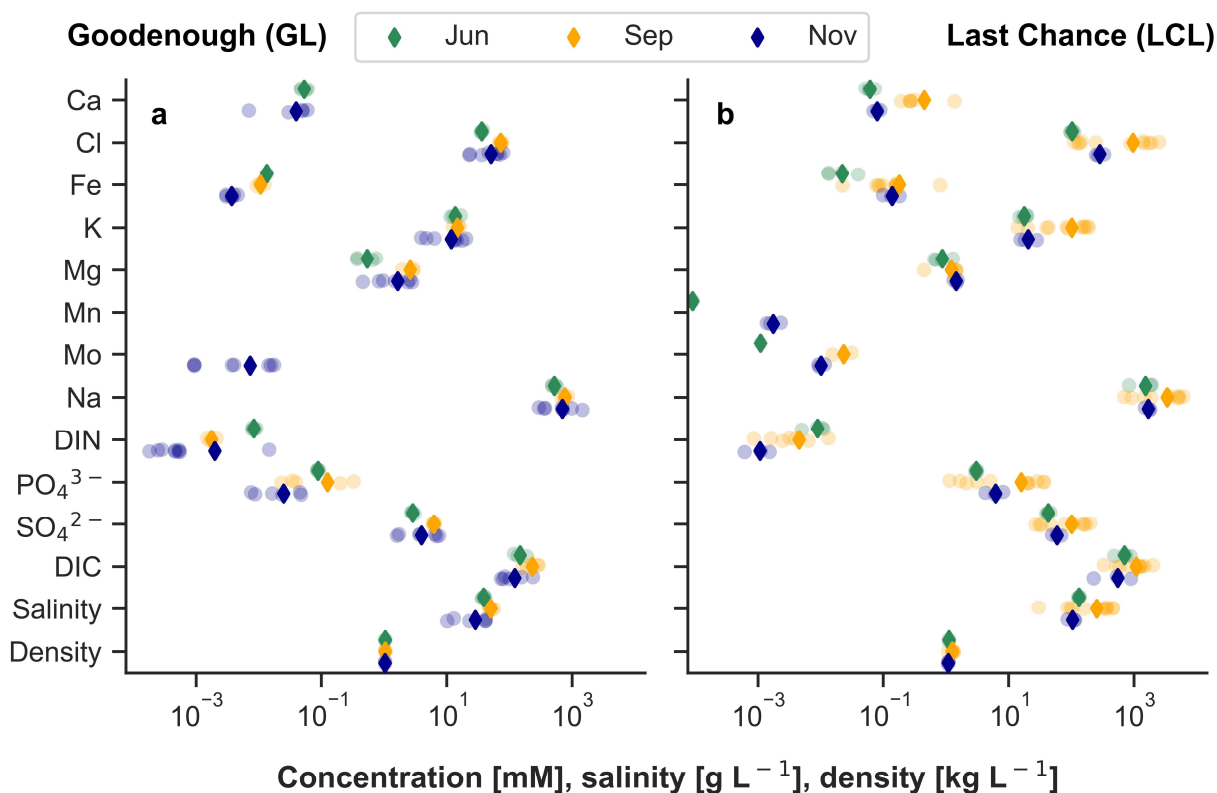
Chlorophyll (Chl) *a* strongly varied seasonally. Minimum values in June suggest that we sampled the tail-end of the spring bloom (Supplementary Table 2). The low Chl *a* concentrations in GL suggested that photosynthesis occurred primarily in the microbial mat surfaces. In LCL, the Chl *a* maximum in September may suggest a concentration of phytoplankton as evaporation proceeds, which is consistent with visual observations of a green layer underneath the September salt crust (Supplementary Fig. 1). The low Chl *a* concentrations in LCL absent evaporative concentration in September are consistent with low biological productivity due to N-limitation (see Results and Discussion). In the absence of strong benthic phototrophic activity as in GL, this implies low biological productivity in the overall LCL system.



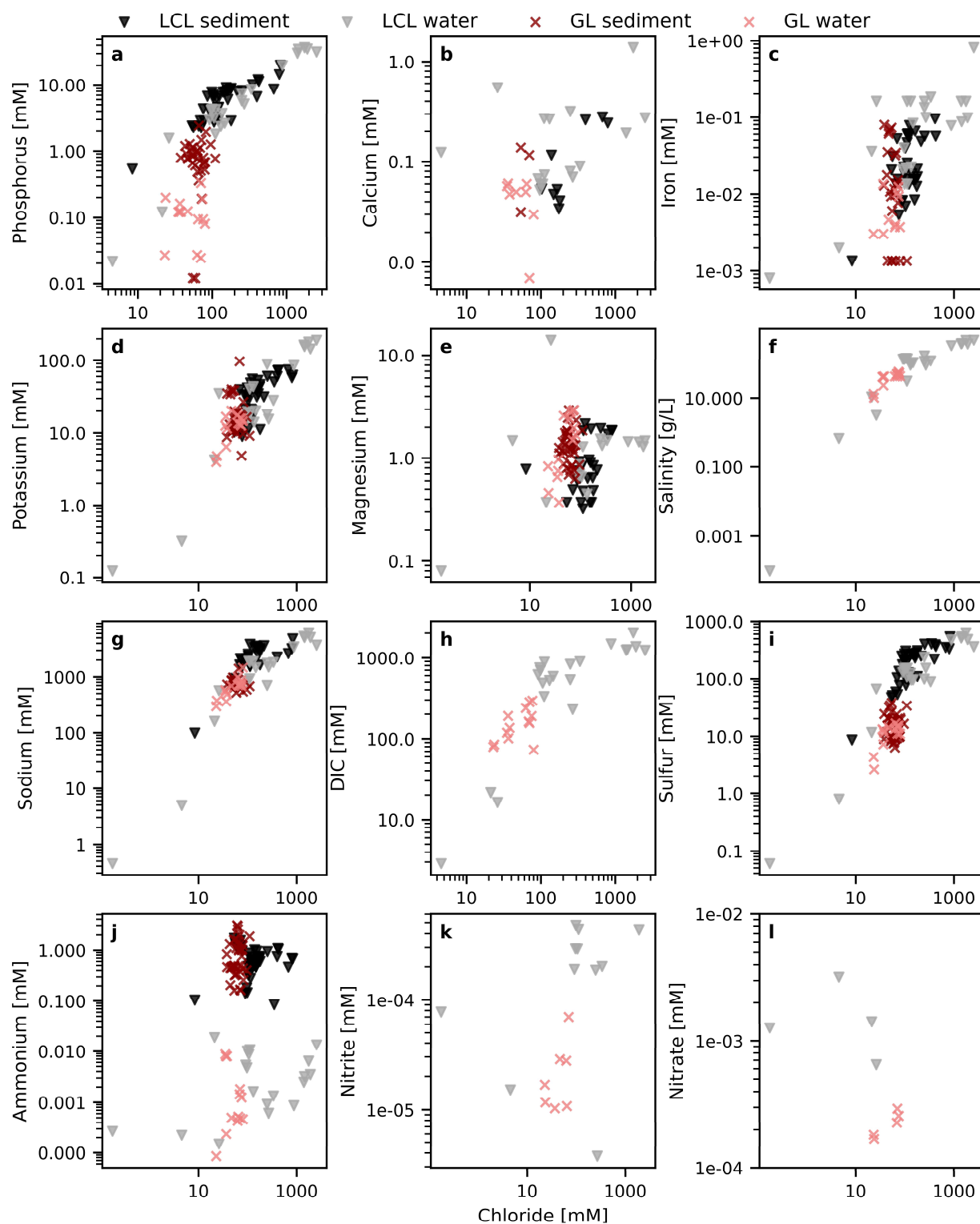
Supplementary Fig. 1. Photos of Last Chance Lake (LCL) and Goodenough Lake (GL) field sites. Last Chance Lake in (a) June 2022, (b) September 2022 pre-rain (photo credit: Andrew Shumway), (c) September 2022 near the end of a major rain event, (d) November 2021. (e) Goodenough Lake in November 2021. Panel d shows people for scale.



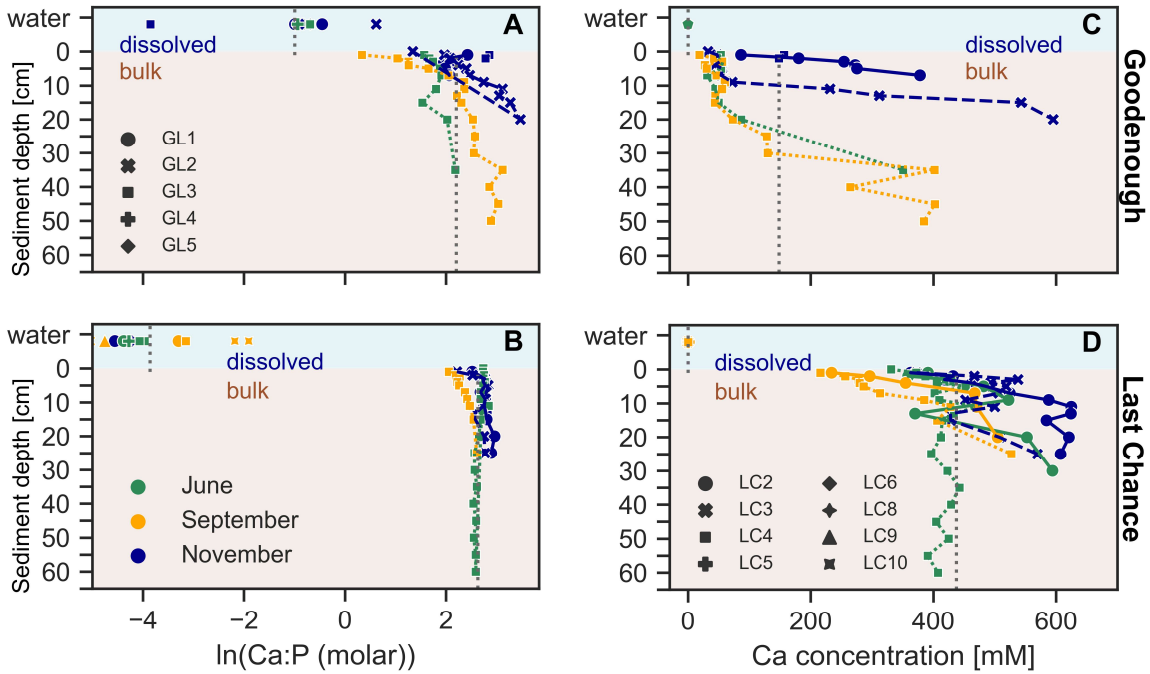
Supplementary Fig. 2. Photos of salt crusts and biofilms of Last Chance Lake. (a) Green biofilms at the fringes of the lake in June 2022; also note the opaqueness of the water behind the biofilms. (b) Green biomass apparently concentrated between salt crust and black sediment, sampled near the spring in September 2022 (hand for scale). (c) Salt crust without green biomass sampled further from the spring in September 2022 (scale similar to **b**). (d) Highly concentrated brine sampled from cavities in the lake's salt crust in September 2022 after carefully removing the upper crust with metal tools (hand for scale; photo credit: Megan Gialluca).



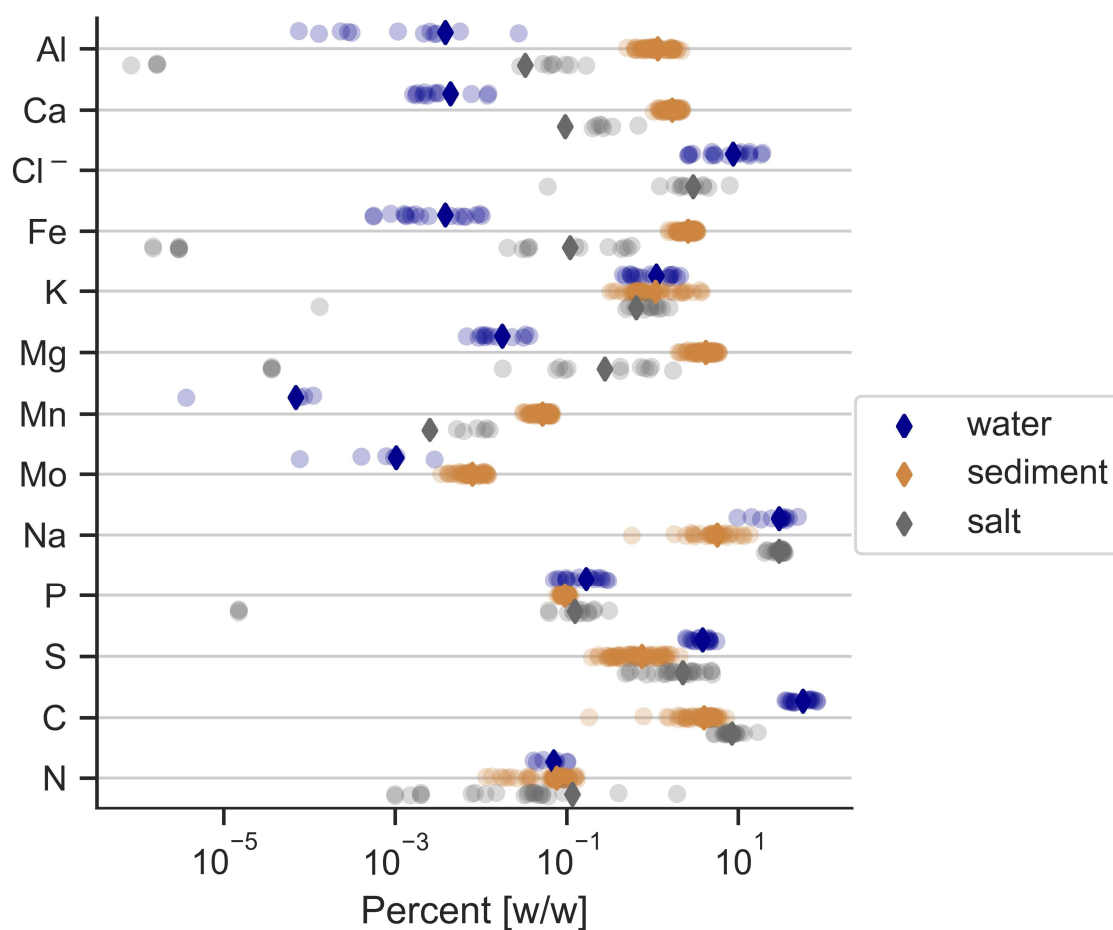
Supplementary Fig. 3. Concentrations of selected ions, salinity and density of lake water across seasons. This figure shows variability of individual measurements for which seasonal means are shown in Table 1 for (a) Goodenough Lake, and (b) Last Chance Lake.



Supplementary Fig. 4: Concentrations of selected dissolved elements and ions in water and sediment porewater of each lake plotted against the concentration of the salinity-proxy chloride. (a) Phosphorus, (b) calcium, (c) iron, (d) potassium, (e) magnesium, (f) salinity, (g) sodium, (h) DIC, (i) sulfur, (j) ammonium, (k), nitrite, (l) nitrate.



Supplementary Fig. 5. Calcium and phosphorus in lake water and sediment porewater. (a, b) Ca:P ratios, and (c, d) Ca concentrations are shown dissolved in the water column (blue background) and total Ca and P in bulk sediment (brown background). Different marker styles refer to sampling stations in Fig. 1 and the legend also applies to Fig. 3.



Supplementary Fig. 6. Relative concentrations (percent [w/w]) of different ions and elements in Last Chance Lake water, sediment, and evaporites (salt). Percent [w/w] concentrations are shown for solids i) dissolved in water (relative to total dissolved solids), ii) in bulk sediments (relative to dry sediment weight), iii) in bulk salts (relative to dry salt weight).

Supplementary Table 1. Phosphate concentrations and salinities in soda lakes with documented phosphate concentrations $\geq 1\text{mM}$ but also including the well-studied Mono Lake.

Lake	Location	Highest phosphate [mM]	Salinity [g/L]	Sampling month	Ref.
Last Chance Lake	British Columbia, Canada	38	265	September	¹
Last Chance Lake	British Columbia, Canada	4.4		May	²
Last Chance Lake	British Columbia, Canada	37	358	September	this study
Goodenough Lake	British Columbia, Canada	1.4	42.9	September	¹
Goodenough Lake	British Columbia, Canada	0.4		May	²
Goodenough Lake	British Columbia, Canada	0.33	49.0	September	this study
Owens Lake	California, USA	13.6	470	August	³
Albert Lake	Oregon, USA	2.5	78	November	⁴
Searles Lake	California, USA	20	310	February	⁵
Lake Eyre	South Australia	3.8	300	December	⁶
Wadi Natrun	Egypt	6.8	394	August	⁷
Mono Lake	California, USA	0.35-0.45	80-86.5	August	⁸

Supplementary Table 2. Mean values of chlorophyll (Chl) *a* ($\mu\text{g L}^{-1}$) as well as sensor measurements of dissolved O_2 ($\mu\text{mol L}^{-1}$), pH and turbidity (FNU) by season for each lake.
Error margins represent the standard deviation of replicate seasonal measurements.

Lake	Month	O_2	pH	Turbidity	Chl <i>a</i>
Good-enough	Jun	258 ± 10.9	10.0 ± 0.0902	4.7 ± 0.58	1.0 ± 0.62
	Sep	398 ± 107	10.3 ± 0.0173	0.80 ± 0.20	7.5 ± 4.0
	Nov	211 ± 13.9	10.2 ± 0.0465	9.7 ± 1.0	39 ± 4.8
Last Chance	Jun	107 ± 59.2	10.1 ± 0.0577	270 ± 76	2.1 ± 1.5
	Sep	-	-	-	87 ± 30
	Nov	-	-	-	23 ± 7.4

Supplementary Table 3. Mineral composition of sediments (0–55 cm depth) and evaporites from Last Chance and Goodenough Lake based on X-ray diffraction. Sediments were analyzed after gravity-exclusion of the clay phase. Errors indicate the standard deviation based on *n* evaporite or sediment samples from the same lake. Minerals occurring at $\geq 1\%$ [w/w] in 50% of samples or at $\geq 5\%$ in more than 1 sample are included here.

Minerals	Last Chance Lake		Goodenough Lake	
	% in sediments <i>n</i> = 11	% in evaporites <i>n</i> = 18	% in sediments <i>n</i> = 7	% in evaporites <i>n</i> = 6
Plagioclase feldspar (anorthite, $\text{CaAl}_2\text{Si}_2\text{O}_8$)	38.5 $\pm$ 13.4			
Plagioclase feldspar (albite, $\text{NaAlSi}_3\text{O}_8$)	31.5 $\pm$ 20.3		30.2 $\pm$ 11.5	
Dolomite, $\text{CaMg}(\text{CO}_3)_2$	22.3 $\pm$ 8.21		17.9 $\pm$ 8.16	
Mica, $\text{NaAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$	19.2 $\pm$ 3.44		8.85 $\pm$ 1.63	
K-feldspar (anorthoclase, $(\text{Na,K})\text{AlSi}_3\text{O}_8$)	17.6 $\pm$ 1.64		12.7 $\pm$ 10.7	
Diopside, $\text{MgCaSi}_2\text{O}_6$	12.7 $\pm$ 2.65		7.36 $\pm$ 4.79	
Ankerite, $\text{Ca}(\text{Fe,Mg})(\text{CO}_3)_2$	7.70 $\pm$ 1.45		12.7 $\pm$ 6.10	
Quartz, SiO_2	3.05 $\pm$ 1.23		5.2 $\pm$ 4.61	
Vesuvianite**, $\text{Ca}_{19}\text{MgFe}_2\text{Al}_{10}(\text{Si}_{18}\text{O}_{70})(\text{OH})_8$			13.3 $\pm$ 5.47	
Andalusite**, Al_2SiO_5			8.30 $\pm$ 2.49	
Thermonatrite*, $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$		66.1 $\pm$ 20.5	40.2 $\pm$ 24.3	77.8 $\pm$ 21.7
Trona, $(\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O})$		18.2 $\pm$ 9.83		17.3 $\pm$ 20.0
Burkeite, $\text{Na}_6(\text{CO}_3)(\text{SO}_4)_2$		12.9 $\pm$ 5.29		3.40 $\pm$ 0.00
Nahcolite, NaHCO_3		5.57 $\pm$ 4.54		4.30 $\pm$ NA
Thenardite, Na_2SO_4		3.94 $\pm$ 5.42		1.73 $\pm$ 0.44
Halite, NaCl		2.96 $\pm$ 2.67	2.20 $\pm$ 0.68	2.13 $\pm$ 0.79

*Noting that primary natron ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) would dehydrate to thermonatrite because of sample preparation for XRD.

**These minor phases are matches in the XRD analysis but require further investigation beyond the scope of this paper (e.g., petrographic studies). Andalusite is a metamorphic phase generally not associated with low-silica igneous rocks, although Renaut and Stead⁹ do report observing “metamorphic rocks” within the muddy sediment matrix of Last Chance Lake. Vesuvianite is also an unusual phase but can be generated by contact metamorphism with lavas.

Supplementary References

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