

An unexplored shallow soda lake in the Tanzanian African Rift: A first biogeochemical characterization

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ABSTRACT

An unexplored shallow soda lake in the Tanzanian African Rift: A first biogeochemical characterization

This study provides the first and preliminary biogeochemical characterization of Lake Magadi, an unexplored shallow soda lake in the Songwe region of Tanzania. The lake exhibited pH, alkalinity and electrical conductivity of 10.155, 760 mEq/L and 47 mS/cm, respectively, indicating that it is among the most extreme soda lakes in the East African Rift Valley and likely worldwide. Na⁺ (1215 mM) predominated over Ca²⁺ and Mg²⁺ (1.40 mM and 0.42 mM, respectively), while Cl⁻ (792 mM) predominated over sulfates (13 mM). The levels of total dissolved inorganic phosphorus (2.7 mM), total dissolved nitrogen (0.51 mM) and dissolved organic carbon (7 mM) indicated a high accumulation of nutrients. The dissolved organic matter was comprised of highly humified, aromatic and large-sized moieties enriched in ¹³C, suggesting an accumulation of highly recalcitrant compounds in the water column. The detection of dissolved methane (~1 μM) indicated microbial methanogenesis was likely released into the anoxic sediments. The water column also exhibited high chlorophyll concentration (0.156 mg/L), with the planktonic primary producers dominated by *Spirulina*-like organisms. In summary, these preliminary results, including its extreme alkalinity, indicate a set of unique biogeochemical properties that make the lake a prime site for future ecological and biogeochemical research on extreme aquatic habitats.

KEY WORDS: soda lakes, East African Rift, biogeochemistry.

RESUMEN

Un lago sódico somero inexplorado en el Rift Africano de Tanzania. Una primera caracterización biogeoquímica.

Este estudio presenta los primeros y preliminares datos biogeoquímicos del lago somero sódico Magadi en la región Songwe en Tanzania en el Rift africano del cual no consta ningún estudio previo. El lago tiene un pH, alcalinidad y una conductividad eléctrica de 10.155, 760 mEq/L y 47 mS/cm que lo sitúan entre las masas de agua más sódicas de todo el Rift y probablemente del mundo. El Na⁺ (1215 mM) predomina sobre el Ca²⁺ y el Mg²⁺ (1.40 mM, and 0.42 mM respectivamente) mientras que el Cl⁻ predomina (792 mM) por encima de los sulfatos (13 mM). El fósforo inorgánico disuelto total (2.7 mM), el nitrógeno disuelto total (0.51 mM) y el carbono orgánico disuelto (7 mM) indican un gran acúmulo de nutrientes. La materia orgánica disuelta incluye compuestos aromáticos, altamente humificados con predominio de moléculas relativamente grandes y enriquecido de ¹³C que sugiere la acumulación en la columna de agua de compuestos altamente recalcitrantes. La detección de metano disuelto (~1 μM) en la columna de agua sugiere la presencia de arqueas metanógenas probablemente en los sedimentos anóxicos. La columna de agua presenta una elevada concentración de clorofila (0.156 mg/L) probablemente debida a la acumulación de cianobacterias del tipo *Spirulina*. En definitiva, estos resultados preliminares, incluyendo su extrema alcalinidad, revelan un conjunto de propiedades biogeoquímicas únicas que convierten el lago Magadi en un lugar privilegiado para futuras investigaciones ecológicas y biogeoquímicas en hábitats acuáticos extremos.

PALABRAS CLAVE: lagos sódicos, rifts oriental africano, biogeoquímica.

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INTRODUCTION

Endorheic saline-alkaline lakes of the East African Rift are ecosystems characterized by unique biogeochemistry and biology. They are renowned for their extremely high pH and alkalinity and for hosting very diverse and hyperactive microbiomes (Fazi *et al.*, 2021) in addition to facilitating the formation of complex evaporitic minerals (Getenet, 2023; Sanz-Montero *et al.*, 2019). Soda-saline water bodies are common and distributed worldwide (Lameck *et al.*, 2023; Pellegrinetti *et al.*, 2023; Boros & Kolpakova, 2018), with their study transcending the fields of aquatic ecology, limnology and promoting investigations of the biosphere under extreme conditions (Banciu & Muntyan, 2015), the origin of life (Cohen *et al.*, 2024) and even astrobiology (Bruschini *et al.*, 2024; Kempe & Kazmierczak, 2022; Butturini *et al.*, 2020, 2025).

Lakes from the East African Rift are very different in size and origin, ranging from the huge tectonic Lake Turkana (the world's largest alkaline lake) to small crater lakes. In between, there are medium-sized tectonic shallow lakes such as Natron, Bogoria, Elementaita, Nakuru, Magadi, Eyasi and Manyara. Most of these lakes have been documented in scientific reports since the 1970s and remain a central topic of ongoing research (Schagerl & Renaut, 2016; Renaut & Owen, 2023). As these studies have noted, the large lakes have been studied extensively, whereas the small lakes, except for Crater Lake Sonachi (Butturini *et al.*, 2020; Fazi *et al.*, 2021), have received little to no attention. For example, Lake Kageinya, a remote lake in the Suguta valley of Kenya's Northern Rift, has been studied only in the paleoclimatic context (Kyalo-Ommo, 2023), while Lake Magadi, a small crater lake in Meru (Kenya), well-known by the local population for trona extraction, has received very little attention. Similarly, Lake Magadi in the south of Tanzania (not to be confused with the well-known Lake Magadi in Kenya) is a shallow playa lake that has never been studied before, despite being an important hotspot for sodium car-

bonate extraction for the local population.

This short note specifically focused on Lake Magadi in the Songwe region of Tanzania, with the main objective of presenting the first preliminary biogeochemical information on this lake following a short visit with students from the Mbeya University of Science and Technology. Beyond presenting novel data, this note aims to contextualize the biogeochemical properties of Lake Magadi with the broader context of the soda lakes from the African Rift and to establish a basis for future research.

MATERIAL & METHODS

Description of the study site

Lake Magadi (8°35'50.06"S, 33° 4'49.57" E, elevation of approximately 833 m a.s.l.) is located in the Songwe region (SW Tanzania), close to Kanga village. The lake is located in the western arm of the Tanzanian rift valley near the eastern part of Lake Rukwa, close to the Lupa fault, 54 km north of Mbeya city (Fig. 1). In this region, the Proterozoic and Archean rocks are covered by Quaternary sediments, including Holocene to Late Pleistocene volcanic deposits (Delvaux, 1989; Fontjin *et al.*, 2012). Lake Magadi is situated in a semi-arid region marked by distinct seasonal patterns, with the rainy season spanning from early December to May and the dry season occurring from June to October, accompanied by temperature fluctuations throughout the year. The lake is permanent, although it dried up in October-November 2019 as a consequence of a severe drought. The surrounding catchment area is marked by sparse vegetation, mainly consisting of shrubs and grasses characteristic of a savanna ecosystem. The lake is almost circular, covers a surface area of around 4.92 km², and has an approximate perimeter of 7.5 km. The lake has no outlet, and its maximum depth is unknown, but it is likely to be lower than 1 meter. The vegetation along the lake edge is almost missing due to the abundant precipitation of trona (Figs. 1 and 2).

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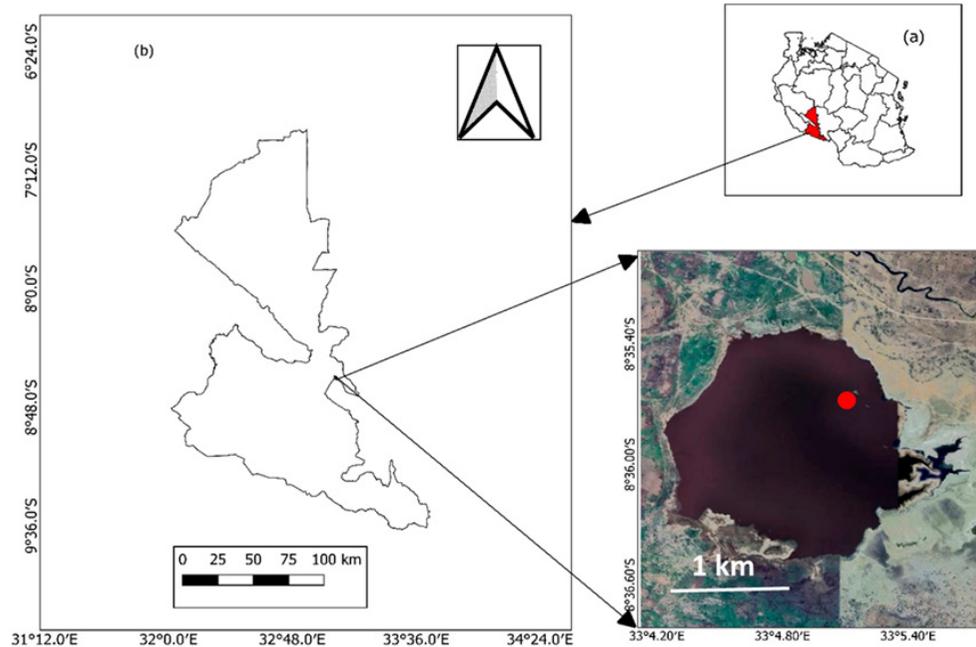


Figure 1. Map of the study area showing (a) the map of Tanzania, (b) the map of the Songwe Region and (c) Lake Magadi (Google Earth image). The red dot indicates the sampling point. *Mapa del área de estudio (a) mapa de Tanzania, (b) mapa de la región de Songwe y (c) Lago Magadi (Imagen de Google Earth), El punto rojo indica el lugar de muestreo.*

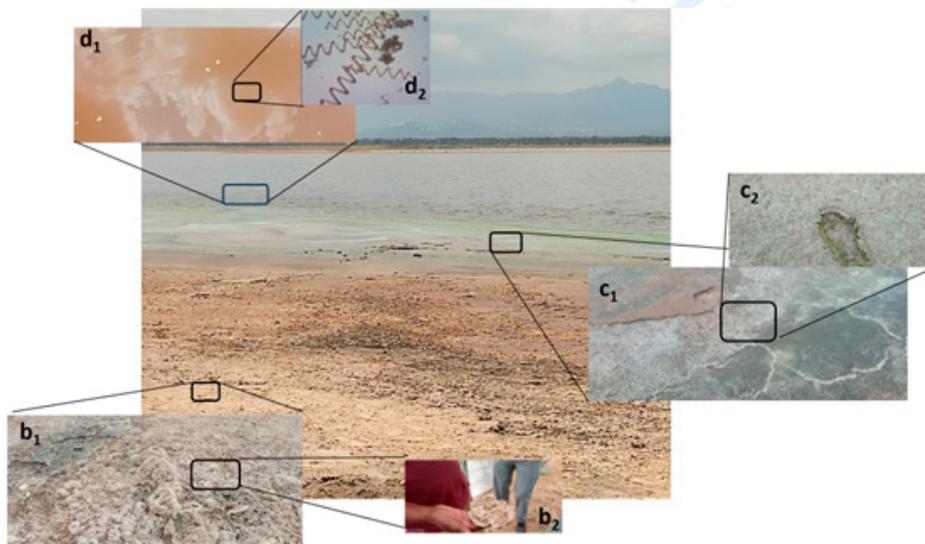


Figure 2. View of Lake Magadi in October 2024. The insets highlight details of the sodium carbonate crust precipitating along the lake edge (b1 and b2 panels), the water-saturated bottom sediment (c1 and c2 panels) and the water column with *Spirulina*-like organisms (d1 and d2). Note in panel c2 the green color along the footprint perimeter indicating a high concentration of chlorophyll in the upper sediments. The photographs are from the authors. The image of the *Spirulina*-like organism (d2) was obtained with a microscope (author: J. Gomà). *Vista del lago Magadi en octubre de 2024. Los recuadros (insets) resaltan detalles de: la costra de carbonato de sódico que precipita a lo largo de los bordes del lago (paneles b1 y b2); el sedimento del fondo saturado de agua (paneles c1 y c2), y; la columna de agua con organismos similares a *Spirulina* sp (d1 y d2). Nótese en el panel c2 el color verde a lo largo del perímetro de la huella, lo que indica una alta.*

Sampling and biogeochemical analysis

Sampling was performed on 11th October 2024 at the end of the dry period. Therefore, the lake level was at a minimum. Water samples were collected at 12:00 noon about 10 m from the edge (water column was approximately 5 cm in depth). Two litres of water were collected. One litre was filtered with combusted Whatman GF/F filters and subdivided into four subsamples and stored at -20 °C. The second litre was also subdivided into four subsamples and stored at -20 °C without filtering. All samples were stored in plastic bottles. A 50-ml aliquot of the filtered sample was preserved unfrozen in a plastic bottle with minimal headspace to test alkalinity. Field measurements were limited to temperature, pH and electrical conductivity (a multiparameter waterproof meter from Hanna Instruments) as well as dissolved methane. A GF/F filter used for water filtering was stored at -20 °C to estimate the planktonic chlorophyll biomass.

Dissolved methane was estimated with the metal semiconductor sensor TGS 2611-E00 (<https://www.figarosensor.com/product/entry/tgs2611-e00.html>; Figaro), following the protocol described by Butturini & Fonollosa (2022). The sensor was calibrated a week before at the Ecology laboratory of the University of Barcelona.

Alkalinity was measured a week later with the filtered unfrozen sample by conducting an acid titration with a 0.1-N H₂SO₄ solution. Due to the presence of a small headspace, the alkalinity value obtained should be considered a rough estimate of the real alkalinity.

The metals (S, Na, K, Mg, Na, Ca, Zn, As, Ni, Pb, Cd, Co, Hg, Fe, Mn, Ba, Sr and Li) were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 3500, PerkinElmer, Waltham, USA) and inductively coupled plasma mass spectrometry (ICP-MS, nexION 350, PerkinElmer, Waltham, USA). The four subsamples were diluted 1/150. Dilution precluded the detection of more diluted metals. Cl, SO₄²⁻ and soluble reactive phosphorus (SRP) were estimated with Spectroquant® colourimetric kits (Merck).

The filtered iced samples were thawed upon

arrival at the laboratory. Aliquots of 25 mL were then acidified at pH 3 with a concentrated solution of HCl to remove the inorganic carbon prior to the analysis of the dissolved organic matter (DOM). DOM is described quantitatively as the concentration of dissolved organic carbon (DOC) and qualitatively through its optical properties. DOC and total dissolved nitrogen (TDN) in the water samples were measured with the TOC-VCSH equipped with a TNM-1 unit (Shimadzu, Japan; detection limit is 0.1 mg/L). The four subsamples were diluted 1/20 to minimize the impact of the salts on instrument function. The description of the DOM optical properties includes absorbance and fluorescence measurements. All the technical details are in Butturini *et al.* (2022). Absorbance values were used to estimate the specific aromaticity at 254 nm (SUVA₂₅₄; Weishaar *et al.*, 2003) and the spectral slope ratio (Sr; Helms *et al.*, 2008). Sr values typically increase upon irradiation and inversely correlate with the molecular weight of the DOM (Helms *et al.*, 2008).

Fluorescence data were used to estimate three DOM qualitative proxies: the fluorescence index (FI), the biological index (BIX) and the humification index (HIX). The FI positively correlates with the accumulation of microbial-derived DOM relative to terrestrial inputs (McKnight *et al.*, 2001). It is the ratio of the fluorescence intensity emitted at 470 nm to that at 520 nm at an excitation wavelength of 370 nm. BIX values positively correlate with the accumulation of recent autochthonous DOM. It is the ratio of the fluorescence intensity emitted at 380 nm to that at 430 nm at an excitation wavelength of 310 nm (Huguet *et al.*, 2009). The HIX is directly related to the accumulation of humic-like substances (Ohno, 2002). It is calculated by dividing the area of the emission spectra between 435 and 480 nm by the sum of the areas of the emission spectra between 435 and 480 nm and between 300 and 345 nm at an excitation wavelength of 254 nm.

Planktonic chlorophyll was extracted from a GF/F filter with 90% acetate for 24 hours under dark conditions and at the laboratory temperature. The extracts were then sonicated for 10 min and filtered with a Whatman GF/F filter. Pigment spectra were collected with a Shimadzu UV-1700 spectrophotometer in the wavelength range of

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Table 1. Summary of the biogeochemical parameters measured at Lake Magadi during sampling. The average and standard deviation values were obtained from four analytical replicates of the same sample. * not replicates. DOC: dissolved organic carbon; TDN: total dissolved nitrogen; SRP: soluble reactive phosphorus. *Resumen de los parámetros biogeoquímicos medidos en Magadi durante el muestreo. Los valores de la media y la desviación estándar se obtuvieron a partir de 4 réplicas analíticas de la misma muestra. * No hay réplicas. DOC: carbono orgánico disuelto; TDN: nitrógeno total disuelto; SRP: fósforo reactivo soluble.*

Parameter	Average ± SD
pH	10.155*
Alkalinity (mEq/L)	760.5 ± 4.12
Cl ⁻ (mM)	792.67 ± 215
SO ₄ ²⁻ (mM)	13.79 ± 0.5
Mg (mM)	0.42 ± 0.02
Na (mM)	1215 ± 7
K (mM)	21.55 ± 0.5
Si (mM)	3.33 ± 0.2
Ca (mM)	1.40 ± 0.2
Zn (μM)	15.39 ± 2
As (μM)	6.87 ± 0.02
Ni (μM)	0.71 ± 0.44
Pb (μM)	0.27 ± 0.03
Hg (μM)	0.16 ± 0.01
Fe (μM)	12.57 ± 0.74
Mn (μM)	0.76 ± 0.1
Ba (μM)	5.39 ± 1.1
Sr (μM)	11.63 ± 0.54
Li (μM)	2.72 ± 1.4
CH ₄ (μM)	0.89 ± 0.05
TDN (mM)	0.51 ± 0.08
SRP (mM)	1.86 ± 0.06
<i>Dissolved organic matter</i>	
DOC (mM)	7.01 ± 1.9
SUVA ₂₅₄	9.18 ± 2.1
FI	0.94 ± 0.004
HIX	0.95 ± 0.0001
Sr	0.75 ± 0.006
d13C-DOC	-9.3075 ± 1.2
Chl-a	
mg/L	0.156*

300 to 1000 nm and using a quartz cuvette with a 1-cm path length. Chlorophyll-*a* concentrations were estimated according to the spectrophotometric models proposed by Ritchie (2006), assuming that cyanobacteria are the most relevant photosynthetic organisms.

RESULTS AND DISCUSSION

Sampling was performed at the end of the dry period. Therefore, the lake level was likely to be at a minimum. Along the lake edge, sediments/rocks were covered by a sodium carbonate (likely trona) precipitate layer that was 1-3 mm thick (Fig. 2). The upper layer of the mineral precipitate showed a laminated structure and the presence of small domes. Its base colour was light grey. However, its hue shifted from dark green to light red, likely due to the influence of benthic chlorophyll, organic matter or dust minerals. We never detected the odour of hydrogen sulfide, which might suggest the presence of sulfate reducers.

The biogeochemical properties of the lake water are summarized in Table 1. The lake exhibited a pH and electrical conductivity of 10.155 and 47 mS/cm, respectively. Among the anions, Cl⁻ and HCO₃⁻ + CO₃²⁻ predominated (792 mM and 760 mEq/L, respectively) over sulfates (13 mM).

Figure 3 describes the relationship between pH and alkalinity in several saline-soda lakes in the East African Rift (Lameck, Skutai & Boros, 2023), showing that Lake Magadi is among the most alkaline lakes in the entire rift and possibly worldwide. However, it should be noted that this finding could be influenced by the fact that sampling was performed during low water conditions. To draw a definitive conclusion on whether the lake is one of the world's most alkaline, it will be crucial to acquire data during its hydrological maximum.

Among the dissolved gases, the data are limited only to dissolved methane, which was present at a concentration of approximately 1 μM. Its presence likely indicates the presence of methanogens within the anoxic sediments at the bottom. However, methane bubbling was not observed during sampling.

The concentration of Na⁺ (1215 mM) was almost two to four orders of magnitude greater than

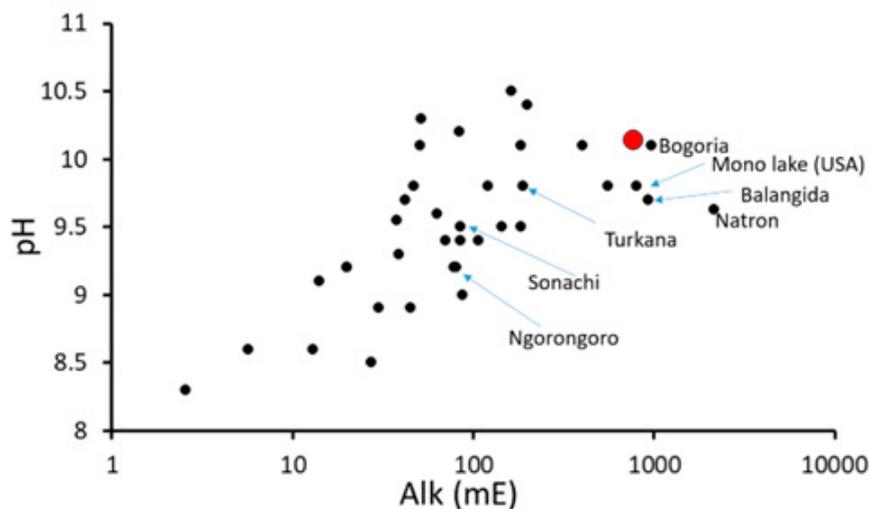


Figure 3. Relationship between pH and alkalinity in several saline-soda lakes from the East African Rift (Lameck, Skutai & Boros, 2023). The large red dot is Lake Magadi. The names of some of the lakes are included. (The graph includes the Mono Lake in the USA). *Relación entre pH y alcalinidad en varios lagos salino-sódicos del Rift de África Oriental (Lameck, Skutai y Boros, 2023). El punto rojo grande representa el lago Magadi. Se incluyen los nombres de algunos lagos (el gráfico incluye el lago Mono en EE. UU.).*

that of K^+ (21.5 mM), Ca^{2+} (1.4 mM) and Mg^{2+} (0.42 mM). Among the metals, the most relevant are Zn (15.4 μ M), Fe (12.6 μ M), Sr (11.6 μ M), As (6.9 μ M) and Ba (5.4 μ M). The concentrations of Hg (0.16 μ M) and Pb (0.26 μ M) were also noticeable. The concentrations of Zn, Fe and Mn in Lake Magadi were roughly half of those measured in Lake Rukwa (Lameck *et al.*, 2024), a large soda lake situated approximately 20 km to the north. By contrast, the concentration of Pb was approximately the same, while that of Sr was almost one order of magnitude greater than that reported for Rukwa (Lameck *et al.*, 2024).

SRP, TDN and dissolved organic carbon (DOC) averaged 1.86 mM, 0.51 mM and 7 mM, respectively.

The concentration of DOC, while two orders of magnitude lower than that of the inorganic fraction, was nonetheless high and in the same range as that reported for other organic-rich endorheic soda/hypersaline waters (Butturini *et al.*, 2020, 2022).

The DOM was highly humified and aromatic (high HIX and $SUVA_{254}$), with a high proportion of large molecules (low Sr) and a low proportion of microbially-derived moieties (low FI and BIX values) compared to other endorheic systems such as Sonachi (a soda lake in Kenya; Butturini

et al., 2020) and Salineta (a hypersaline shallow lagoon; Butturini *et al.*, 2022). Furthermore, the DOM was highly enriched in ^{13}C (Fig. 4). Collectively, this information suggests that the DOM accumulating in the lake is highly degraded and likely to be highly recalcitrant (Fig. 4).

Finally, the chlorophyll concentration in the water column was extremely high, with the planktonic primary producers likely to be dominated by *Spirulina*-like organisms (Fig. 2d2). Although these data are preliminary, they are in line with those reported in old and recent studies performed at Sonachi (Melack, 1982; Fazi *et al.*, 2021), reflecting high primary production. Moreover, the upper layer of the benthic sediments stored a remarkable amount of chlorophyll, indicating that they store primary producers that are likely to have a strong impact on the primary production of the whole ecosystem (Fig. 2, panel c2).

CONCLUSIONS AND PERSPECTIVES

Soda lakes from the East African Rift, which are characterized by a huge amount of dissolved and mineral inorganic carbon as well as an exceptional accumulation of organic matter and highly active microbiomes, harbour a vigorous carbon cycle that has attracted little to no research interest.

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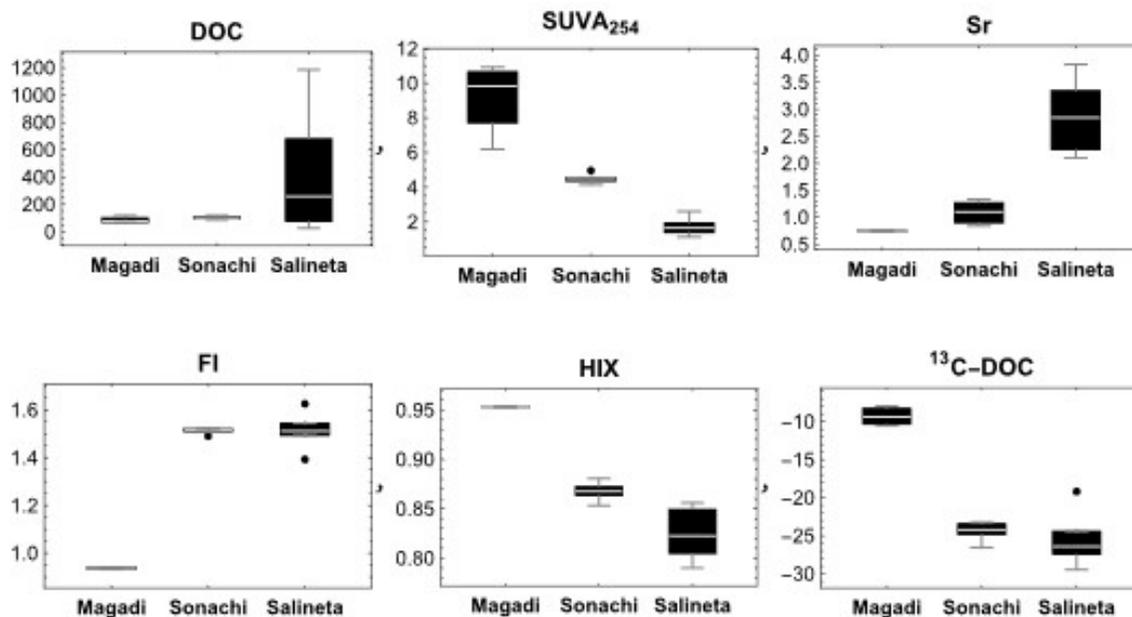


Figure 4. Dissolved organic matter. Box plots are shown of the concentration as well as the optical and isotopic properties of the DOM. The interpretation of the descriptors is in the text. The values from Lake Magadi are compared with those of two organic-rich endorheic systems: Sonachi, a crater soda lake (Butturini et al., 2020), and Salineta, a shallow hypersaline lagoon (Butturini et al., 2022). Black dots represent outliers. *Materia orgánica disuelta. Diagramas de caja de las concentraciones y propiedades ópticas y isotópicas de la MOD. La interpretación de los descriptores se encuentra en el texto. Los valores de Magadi se comparan con dos sistemas endorreicos ricos en materia orgánica: el lago sódico del cráter Sonachi (Butturini et al., 2020) y Salineta, una laguna somera hipersalina (Butturini et al., 2022). Los puntos negros son valores atípicos.*

For instance, there is little that we know about the impact of the microbial processes in sediments on carbon fluxes in the water column. Similarly, there is little information on the air-water exchange of CO₂ and CH₄ in these systems (Fazi et al., 2021), and absolutely nothing is known about the release of other gases such as nitrous oxide and volatile organic compounds. Due to the elevated pH and alkalinity, the dissolved CO₂ is expected to be undersaturated. In addition, along the lake edge, the large surface of sodium carbonate is exposed to the atmosphere. Therefore, soda lakes, in contrast to freshwater ones, should be potential net carbon sinks. However, in-situ field measurements are missing. Moreover, the impact of the production (day)-respiration (night) of benthic sediments (submerged or exposed) on the CO₂ net flux is unknown. Another fundamental gap in knowledge is the information regarding the reciprocal impact between microorganisms and evaporitic minerals. There is no information on the role of microorganisms in mineral formation and speciation or on the role of minerals in microbial community

function and atmospheric gas exchange.

To conclude, given its extremely high alkalinity, elevated pH, shallow water column, and presumed high microbial activity in both the sediments and water column, coupled with the massive precipitation of sodium carbonate along its edge, Lake Magadi offers a compelling case study. It holds the potential to significantly advance our understanding of how mineral-microbe coupling influences the carbon cycle and how these unique extreme systems exchange carbon with the atmosphere.

AUTHOR CONTRIBUTIONS

A.B.: Conceptualization, sample collection, sample analysis, writing-original draft, methodology, analysis, writing-review and editing; A.S.L.: Conceptualization, sample collection, writing-original draft, methodology, analysis, writing-review and editing; A.B.: sample analysis, writing-original draft, methodology, analysis, writing-review and editing; P.F.S.: writing-review and editing.

ETHICAL DECLARATION

The authors confirm that this research was conducted per ethical guidelines and regulations.

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REFERENCES

- Banciu, H. L., & Muntyan, M. S. (2015). Adaptive strategies in the double-extremophilic prokaryotes inhabiting soda lakes. *Current opinion in microbiology*, 25, 73-79. DOI: 10.1016/j.mib.2015.05.003
- Boros, E., & Kolpakova, M. (2018). A review of the defining chemical properties of soda lakes and pans: an assessment on a large geographic scale of Eurasian inland saline surface waters. *PLoS One*, 13(8), e0202205. DOI: 10.1371/journal.pone.0202205
- Bruschini, E., Ferrari, M., Mazzoni, C., Fazi, S., Chiocci, F. L., Mazzini, I., ... & Ammannito, E. (2024). Preliminary spectroscopic investigation of a potential Mars analog site: Lake Bagno dell'Acqua, Pantelleria, Italy. *Planetary and Space Science*, 245, 105893. DOI: 10.1016/j.pss.2024.105893
- Butturini, A., Benaiges-Fernandez, R., Fors, O., &

- Garcia-Castellanos, D. (2025). Potential Habitability of Present-Day Martian Subsurface for Earth-Like Methanogens. *Astrobiology*, 25(3), 253-268. DOI: 10.1089/ast.2024.0100
- Butturini, A., & Fonollosa, J. (2022). Use of metal oxide semiconductor sensors to measure methane in aquatic ecosystems in the presence of cross-interfering compounds. *Limnology and Oceanography: Methods*, 20(11), 710-720. DOI: 10.1002/lom3.10515
- Butturini, A., Herzprung, P., Lechtenfeld, O. J., Alcorlo, P., Benaiges-Fernandez, R., Berlanga, M., ... & Romani, A. M. (2022). Origin, accumulation and fate of dissolved organic matter in an extreme hypersaline shallow lake. *Water Research*, 221, 118727. DOI: 10.1016/j.watres.2022.118727
- Butturini, A., Herzprung, P., Lechtenfeld, O. J., Venturi, S., Amalfitano, S., Vazquez, E., ... & Fazi, S. (2020). Dissolved organic matter in a tropical saline-alkaline lake of the East African Rift Valley. *Water Research*, 173, 115532. DOI: 10.1016/j.watres.2020.115532
- Butturini, A., García-Castellanos, D., Jordi, C., & Ribas, I. (2020). *(In)habitabilidad planetaria: fundamentos de astrogeobiología*. Marcombo. España.
- Cohen, Z. R., Ding, D., Zhou, L., DasGupta, S., Haas, S., Sinclair, K. P., ... & Catling, D. C. (2024). Natural soda lakes provide compatible conditions for RNA and membrane function that could have enabled the origin of life. *PNAS nexus*, 3(3), pgae084. DOI: 10.1093/pnasnexus/pgae084
- Delvaux, D. (1989). The Karoo to Recent rifting in the western branch of the East-African Rift System: A bibliographical synthesis. *Museum Royal African. Central Tervuren (Dép. Géol. Min., Rap. Ann.)*, 1990, 63-83.
- Delvaux, D., Kraml, M., Sierralta, M., Wittenberg, A., Mayalla, J. W., Kabaka, K., ... & GEOTHERM Working Group. (2010). *Surface Exploration of a Viable Geothermal Resource in Mbeya Area, Sw Tanzania*. Part I: Geology of the Ngozi-Songwe Geothermal System.
- Fazi, S., Amalfitano, S., Venturi, S., Pacini, N., Vazquez, E., Olaka, L. A., ... & Butturini, A. (2021). High concentrations of dissolved biogenic methane associated with cyanobacterial blooms in East African lake surface water. *Communications Biology*, 4(1), 845. DOI: 10.1038/

Biogeochemical characterization of an unexplored soda lake

- s42003-021-02365-x
- Fontijn, K., Williamson, D., Mbede, E., & Ernst, G. G. (2012). The Rungwe volcanic province, Tanzania—a volcanological review. *Journal of African Earth Sciences*, 63, 12-31. DOI: 10.1016/j.jafrearsci.2011.11.005
- Helms, J. R., Stubbins, A., Ritchie, J. D., Minor, E. C., Kieber, D. J., & Mopper, K., 2008. Absorption spectral slopes and slope ratios as indicators of molecular weight, source, and photobleaching of chromophoric dissolved organic matter. *Limnology and Oceanography*, 53(3), 955-969. DOI: 10.4319/lo.2008.53.3.0955
- Huguet, A., Vacher, L., Relexans, S., Saubusse, S., Froidefond, J. M., & Parlanti, E., 2009. Properties of fluorescent dissolved organic matter in the Gironde Estuary. *Organic Geochemistry*, 40(6), 706-719. DOI: 10.1016/j.orggeochem.2009.03.002
- Kempe, S., & Kazmierczak, J. (2002). Biogenesis and early life on Earth and Europa: favored by an alkaline ocean?. *Astrobiology*, 2(1), 123-130. DOI: 10.1089/153110702753621394
- Getenet, M., Otálora, F., Emmerling, F., Al-Sabbagh, D., & García-Ruiz, J. M. (2023). Mineral precipitation and hydrochemical evolution through evaporitic processes in soda brines (East African Rift Valley). *Chemical geology*, 616, 121222. DOI: 10.1016/j.chemgeo.2022.121222
- Lameck, A. S., Saeed, O., Justine, P. N., Mwakagile, D., Akos, P., & Boros, E. (2024). Hydrochemical properties and heavy metal concentrations (ecological and human risk) of lake Rukwa. *Environmental Challenges*, 15, 100940. DOI: 10.1016/j.envc.2024.100940
- Lameck, A. S., Skutai, J., & Boros, E. (2023). Review of chemical properties of Inland soda and saline waters in East Africa (Rift Valley region). *Journal of Hydrology: Regional Studies*, 46, 101323. DOI: 10.1016/j.ejrh.2023.101323
- McKnight, D. M., Boyer, E. W., Westerhoff, P. K., Doran, P. T., Kulbe, T., & Andersen, D. T., 2001. Spectrofluorometric characterization of dissolved organic matter for indication of precursor organic material and aromaticity. *Limnology and Oceanography*, 46(1), 38-48. DOI: 10.4319/lo.2001.46.1.0038
- Melack, J. M., Kilham, P., & Fisher, T. R. (1982). Responses of phytoplankton to experimental fertilization with ammonium and phosphate in an African soda lake. *Oecologia*, 52, 321-326.
- Ohno, T. (2002). Fluorescence inner-filtering correction for determining the humification index of dissolved organic matter. *Environmental Science and Technology*, 36(4), 742-746. DOI: 10.1021/es0155276
- Pellegrinetti, T. A., Cotta, S. R., Sarmiento, H., Costa, J. S., Delbaje, E., Montes, C. R., ... & Fiore, M. F. (2023). Bacterial communities along environmental gradients in tropical soda lakes. *Microbial ecology*, 85(3), 892-903. DOI: 10.1007/s00248-022-02086-6
- Renaut, R. W., & Owen, R. B. (2023). *The Kenya Rift Lakes: Modern and Ancient: Limnology and Limnogeology of Tropical Lakes in a Continental Rift*. Springer.
- Ritchie, R. J. (2006). Consistent sets of spectrophotometric chlorophyll equations for acetone, methanol and ethanol solvents. *Photosynthesis research*, 89, 27-41. DOI: 10.1007/s11120-006-9065-9
- Sanz-Montero, M. E., Cabestrero, Ó., & Sánchez-Román, M. (2019). Microbial Mg-rich carbonates in an extreme alkaline lake (Las Eras, Central Spain). *Frontiers in Microbiology*, 10, 148. DOI: 10.3389/fmicb.2019.00148
- Schagerl, M., & Renaut, R. W. (2016). *Dipping into the soda lakes of East Africa* (pp. 3-24). Springer International Publishing. DOI: 10.1007/978-3-319-28622-8_1
- Kyalo-Omamo, M., Junginger, A., Krueger, J., Epp, L. S., Stoof-Leichsenring, K. R., Rohland, S., ... & Tiedemann, R. (2023). Sedimentary ancient DNA of rotifers reveals responses to 200 years of climate change in two Kenyan crater lakes. *Freshwater Biology*, 68(11), 1894-1916. DOI: 10.1111/fwb.14093
- Weishaar, J. L., Aiken, G. R., Bergamaschi, B. A., Fram, M. S., Fujii, R., & Mopper, K. (2003). Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon. *Environmental science & technology*, 37(20), 4702-4708. DOI: 10.1021/es030360x