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Time-structured early diagenesis drives sediment organic matter stabilization in a tropical lake

TING ZHANG[1], JONATHAN OBRIST-FARNER[2], CYNTHIA KALLENBACH[3], ANTONIN PRIJAC[4] AND PETER M J DOUGLAS[1]

[1]McGill University
[2]Missouri University of Science and Technology
[3]The University of British Columbia
[4]Université du Québec à Montréal (UQAM)

Early diagenesis plays a fundamental role in organic carbon (OC) stabilization in lacustrine sediments, yet its molecular pathways and temporal structure remain poorly constrained, particularly in tropical lakes where eutrophication may obscure primary diagenetic signals. We investigate recent sediments from Lake Izabal (Guatemala) using a 210Pb-constrained age–depth framework integrating bulk organic geochemistry, carbon and nitrogen stable isotopes, inorganic indicators, and temperature-resolved stepwise Py–GC–MS (Fig. 1).

A central-basin core (LZ-C1) records predominantly natural early diagenetic modification, whereas a nearshore core (EP) influenced by eutrophication provides a comparative end-member to distinguish environmental forcing from intrinsic diagenetic transformation. In the central basin, organic matter evolution follows a distinct time-structured trajectory. During the first ~30 years of burial, preferential degradation of isotopically heavier and highly reactive components drives rapid TOC and TN loss and shifts toward lighter $\delta^{13}C_org$ and $\delta^{15}N$ values, consistent with limited mineral protection. By ~100 years, bulk carbon inventories approach apparent stability, while isotopic compositions continue to evolve, indicating progressive internal reorganization of sedimentary carbon pools.

Temperature-resolved Py–GC–MS reveals the molecular basis for this transition (Fig. 2). Early burial stages are dominated by intermediate-temperature (400–500 °C) cracking products derived from intact biomacromolecules. With increasing burial age, these components decline, whereas high-temperature (600–700 °C) pyrolysates enriched in condensed and aromatized structures become increasingly dominant. This shift reflects selective biomacromolecule degradation, microbial reworking, molecular reorganization, and strengthening mineral–organic associations [1,2].

Our results demonstrate that key molecular characteristics of lacustrine source-rock precursors are established during early diagenesis on centennial timescales. Temperature-resolved Py–GC–MS provides a robust framework for resolving early diagenetic pathways and carbon stabilization mechanisms in modern and ancient lake systems.

References

[1] Hobbie & Ouimette (2009), Biogeochemistry 95, 355–371.
[2] Arndt et al. (2013), Earth-Science Reviews 123, 53–86.

Figure 1. Time-structured early diagenetic evolution of organic carbon in Lake Izabal sediments.

Figure 2. Temperature-resolved molecular transformation during early diagenesis.

Depth profiles of pyrolysis product abundance and compositional indices in core LZ-C1 showing a transition from biomacromolecule-derived intermediate-temperature products (400–500 °C) to condensed, aromatized high-temperature products (600–700 °C) with increasing burial age.

