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Hydrothermally altered biomarkers preserved in marine vents and oil reservoirs

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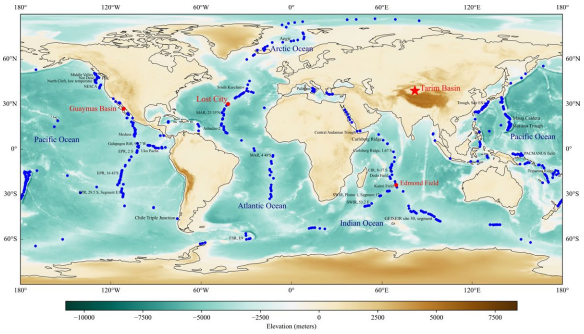

Hydrothermal fluids occur in diverse geological settings worldwide, including mid-ocean ridges, continental rift systems, pre-orogenic and subduction zones, back-arc basins, hot springs, and volcanically active regions (Fig 1). The hydrothermal alteration plays a pivotal role in shaping the molecular and isotopic signatures of organic biomarkers in both commercial oil reservoirs and marine vent systems. This study highlights the widespread occurrence of 25-norhopane in hydrothermal vents and highly mature crude oils, suggesting its potential as a robust indicator of hydrothermal activity. The formation of 25-norhopane likely involves the removal of a methyl group at the C-25 position, a process that may be analogous to biodegradation but driven by hydrothermal conditions. Our results reveal that hydrothermal alteration exerts a stronger influence on polycyclic aromatic hydrocarbons (PAHs) than on saturated biomarkers, likely due to hydrogen-rich fluids promoting the saturation of carbon-carbon double bonds. In particular, MPI (Methylphenanthrene Index) and P/MP (Phenanthrene to Methylphenanthrene ratio) display a significant inverse correlation. Compound-specific isotope analysis (CSIA) of n-alkanes demonstrates an inverse carbon isotopic trend in hydrothermally altered samples, where higher molecular weight n-alkanes exhibit relative enrichment in ^{12}C. This inverse trend contrasts with conventional thermal maturation patterns and provides a unique isotopic fingerprint for hydrothermal alteration. In sedimentary basins, the spatial-temporal configuration of hydrothermal fluids, fault conduits, cap rocks, and original hydrocarbon reservoirs significantly influences the present-day distribution of oil and gas (Fig 2). The interaction between hydrothermal fluids, rocks, and organic matter may also have profound implications for the origin and evolution of life. These processes could have created localized environments rich in organic compounds and energy sources, potentially fostering the emergence and proliferation of early life forms. This study advances our understanding of hydrothermal alteration mechanisms and their impact on biomarker preservation, with implications for reconstructing paleo-hydrothermal environments, refining petroleum exploration strategies, and exploring the geobiological connections between hydrothermal activity and the origins of life.

