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Editors

Marine Hydrocarbon Seeps

Microbiology and Biogeochemistry of a Global Marine Habitat

Springer

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Foreword

Hydrocarbon seeps are unlike other seafloor ecosystems. Their dependence on fossil carbon sources, strongly reducing redox state, abundant supply of electron donors (hydrogen, sulfide, methane, ammonia), and frequent brine admixture sets them apart. In this book, aficionados of the oily deep provide an overview on hydrocarbon seeps in major marine regions before directing the spotlight onto some of the special microorganisms thriving in these ecosystems. The book opens with an overview on seep microbial ecology in Chap. 1 by S. Emil Ruff, inspired by his publication "Global dispersion and local diversification of the methane seep microbiome," published in 2015 in Proceedings of the National Academy of Sciences of the United States of America. He and his colleagues established the microbial characteristics of seep ecosystems and delineated their differences to other seafloor microbiota. No other benthic microbial ecosystem is so strongly shaped by methane- and sulfur-cycling bacteria and archaea.

Among the bacteria that thrive in hydrocarbon seeps, perhaps none are as diversified and adaptable as the hydrocarbon-degrading sulfate reducers, introduced, and discussed in depth in Chap. 2 by Sara Kleindienst and Katrin Knittel. Taken together, the wide substrate spectrum and environmental tolerance of this group turn these bacteria into effective and ubiquitous catalysts for hydrocarbon oxidation in anaerobic marine sediments.

In the next five Chaps. (3, 4, 5, 6 and 7), the editors of this book and their colleagues, including Samantha B. Joye, Gunter Wegener, Cassandre S. Lazar, and Konstantinos Ar. Kormas draw inspiration from multiple research cruises and introduce hydrocarbon seeps with contrasting characteristics in different geographical regions to highlight some of the inherent variability that make seep habitats and their microbiota such rewarding targets for microbiological and biogeochemical studies. This gallery of seeps opens with introducing a classic site in the Gulf of California, Guaymas Basin, in Chap. 3—an unusual hybrid location that combines characteristics of a mid-ocean ridge hydrothermal vent site and a hydrocarbon seep. Here, sedimentary organic matter in thick sediments covering an active spreading center is transformed into hydrocarbons under high temperature and pressure. The hydrothermally heated mixture of very young petroleum and

hydrothermal energy sources migrates to the sediment surface where it sustains unusually complex microbial communities characterized by extensive thermal tolerance. This chapter also doubles as an introduction to recent advances in alkane utilization and oxidation by novel types of archaea that have been cultured from its hydrothermal sediments, or, that were detected by metagenomic analysis. In contrast to this hydrothermal system, Chap. 4 introduces the most extensive archipelago of cold hydrocarbon seeps on Earth, extending from Florida to Texas along the entire continental slope of the northern Gulf of Mexico. Here, numerous sites represent a wide spectrum of mud volcanoes, seafloor brine lakes, methane hydrate outcrops, and oil seeps that—with few exceptions—remain in the early stages of microbial and biogeochemical surveys and invite further in-depth studies in the future. The widespread hydrocarbon-oxidizing and -assimilating microbial populations in the Gulf of Mexico seeps are of particular environmental significance as they serve as seed banks for hydrocarbon degraders that play a role in natural hydrocarbon remediation, for example, after the Deepwater Horizon oil spill in 2010. A highly unusual seep type in the southern Gulf of Mexico, the Chapopote Asphalt volcano, is singled out in Chap. 5. Instead of gas and liquid hydrocarbon seepage, this site is dominated by the seafloor emergence of slowly flowing, heavily viscous, and chemically weathered asphalt that yet contains sufficient energy sources to sustain its own hydrocarbon seep ecosystem. The habitat surveys are completed by Chaps. 6 and 7 on Mediterranean hydrocarbon seeps, mud volcanoes, and hydrocarbon-rich brine flows, which are embedded in the complex tectonic setting of the Mediterranean Sea, from where they derive some of their distinct qualities.

High concentrations of sulfide, intermixed in the cocktail of reduced gases at seep sites, select for different types of sulfur-oxidizing bacteria, including the highly conspicuous filamentous mat-forming members of the family *Beggiatoaceae.* The filaments are often large enough to be visible to the unaided eye and form extensive white, yellow, and orange-colored mats on the seafloor that coincide with areas of active seepage. At present, these striking bacteria are mostly uncultured; however, the *Beggiatoaceae* are intensively investigated in the context of their habitat. For example, their preferred biogeochemical niche at the sediment–seawater interface is tackled through microprofiler surveys, and physiological experiments are conducted with live mat material. Here, two chapters are devoted to them: In Chap., 8, the two editors of this book summarize and extend current knowledge about the diversity of *Beggiatoaceae* in Gulf of Mexico seeps, while chapter 9, led by Dirk de Beer, opens up a new and previously neglected perspective on the importance of pH and DIC speciation for autotrophic metabolism in *Beggiatoaceae,* using samples collected in Guaymas Basin.

The book concludes with Chap. 10 by Tony Gutierrez and Sara Kleindienst, introducing Stable Isotope Probing (SIP) as a promising and versatile tool to investigate the activities and substrate ranges of hydrocarbon-oxidizing bacteria. SIP elegantly integrates knowledge about the genomic potential of hydrocarbon-oxidizing microorganisms with trophic responses detected in complex mixtures or communities to hydrocarbon availability, using microbial enrichment experiments amended with specific substrates.

Throughout these chapters, all authors have included numerous illustrations and photographs of marine seep ecosystems, keeping in mind that submersible rides and ROV deployments are in short supply, and that many readers have not seen these distinctive seafloor landscapes and microbial habitats in person. Often, images say more than a thousand words; they provide a mental reference and serve as an anchor for the increasingly data-rich studies that are emerging in the productive field of hydrocarbon seep microbiology. An informative and amply illustrated book assists in making the field more accessible because it lowers the "activation energy" barriers that stand in the way of encouraging further interest in deep-sea hydrocarbon seep research. Likewise, this book provides readily accessible background and context for rapidly evolving research "hot spots," for example, the ongoing discoveries of enzymatic pathways of hydrocarbon degradation, the investigation of genomes and metagenomes, the identification of novel hydrocarbon-oxidizing bacteria and archaea, and new insights into stable carbon isotope systematics and molecular structures of metabolites that arise from new findings in the repertoire of microbial degradation of hydrocarbons. For now, this volume provides a useful introduction, anticipating to stimulate further research interest in hydrocarbon seep microbiology and biogeochemistry.

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