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Exploring the limits of deep subseafloor geosphere-biosphere interactions through scientific ocean drilling

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Over the course of half a century, one of the milestone discoveries that have accomplished by scientific ocean drilling is the discovery of microbial life deep beneath the ocean floor–the deep subseafloor biosphere. Since the first deep biosphere-dedicated Ocean Drilling Program (ODP) Leg 201 off Peru in 2002, numerous microbiological and biogeochemical studies at various oceanographic and geological locations have been integrated into scientific ocean drilling, demonstrating that there are indeed living life forms that have persisted and/or survived under geophysically and energetically challenging sedimentary and crustal environments over millions of years. Accumulating molecular ecological data at regional to planetary scales suggest that subseafloor microbial communities consist mainly of uncultured and hence physiologically unknown species that are evolutionary far distinct from the cultivable microbes living in high-energy habitats on the Earth's surface. On-going international community effort including aseptic sampling and multidisciplinary analytical technologies for the deep subseafloor biosphere is underpinning our knowledge of the functionality of vastly distributed microbial life within the Earth planetary interior; e.g., during the Integrated Ocean Drilling Program (IODP) Expedition 329 in 2010, using the drilling vessel JOIDES Resolution, the presence of dissolved oxygen and aerobic microbial communities was observed in the entire sediment column of the ultra-oligotrophic South Pacific Gyre, suggesting no limits to microbial life in the open ocean sedimentary environment. During the IODP Expedition 337 off Shimokita Peninsula, Japan in 2012, the riser-drilling technology of the drilling vessel Chikyu demonstrated that indigenous microbial life occurs in coal-bearing sedimentary environments down to $\sim$2.5 km below seafloor, which anaerobic functionality long plays biogeochemical roles in carbon cycling in situ. In 2016, the International Ocean Discovery Program (IODP) Expedition 370 aimed to explore the temperature limit of the deep subseafloor biosphere in the Nankai protothrust zone off Cape Muroto, Japan, and daily helicopter-sample transportation from offshore (the Chikyu) to the onshore laboratory (Kochi Core Center) was successfully accomplished for the state-of-the-art microbiological processing using super-clean technologies. Consequently, as the community effort, these technological and scientific challenges to explore the deep subseafloor frontiers are elucidating the global picture of the deep subseafloor biosphere, establishing a new foundation of how Earth's planetary sub-systems are systematically connected with each other and coevolve as a system from the past to the future, and even deciphering our intrinsic question of what is life in the universe.