Geobiotechnology: A new frontier field of the future scientific drilling

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Abstract: The ongoing studies of the deep subseafloor biosphere have revealed widespread microbial populations as living or surviving forms in the deep subseafloor environments. Explorations of the nature of novel subseafloor life and the habitable fields are, on one hand, substantially important as the basic science, on the other hand, it is currently in high demand for the future scientific drilling that the results are relevant to social issues and industrial applications. Given the needs of social relevance and the scientific backgrounds, a concept of "Geobiotechnology" is proposed for the future scientific drilling.

Introduction: What is the "Geobiotechnology"?

It is widely accepted that microorganisms play major roles on global biogeochemical cycles in the Earth's ecosystem. In the "Applied and Environmental Microbiology" research field, unique characteristics of natural microbial components or communities are sometimes utilized for social and industrial applications such as the bio-remediation of industrial pollutants in soils and aquifers and the bio-reaching of metals and contaminated elements at mines. To increase the gene-expression and metabolic productivity, genetic or enzymatic functions are sometimes re-constructed through molecular recombination techniques. On the other hand, in the "Applied Geosciences" research field, numerous studies have been carried out to identify and retrieve some geologic resources at oil, coal, natural gas and metals. Also, the marine subsurface realms are recently considered as the potential safety place for the long-term CO_2 storage. These two scientific research fields will be able to combine together as "Geobiotechnology" through the future scientific drilling.

Examples of geobiotechnological studies

Previous molecular (DNA) ecological studies of the cored subseafloor sediments suggested that microbial communities in deep marine sediments are composed of phylogenetically diverse uncultured components and may have unique functions that mediate previously unknown biogeochecmial reactions. Hinrichs and his colleagues pointed out from the carbon isotopic studies that some microbial components might be responsible for hydrocarbon-productions via the acetate-based ethanogenesis and propanogenesis (Hinrichs *et al.*, PNAS 2006). Although it is currently unknown what kinds of microbes are responsible for those unique reactions, it may have a great industrial potential to retrieve high-energy products through the natural bio-reactor system.

One of the predominant subseafloor bacterial components is the phylum *Chlrofrexi*, of which members are known to use halogenated organic compounds as the electron acceptor for the anaerobic respiration, so called "dehalogenation". Some isolates from terrestrial environments showed industrially useful activities such as detoxification of chlorinated ethane and bromophenol, which are well-known industrial chemical pollutants. Recently, diverse putative dehalogenase-homologous genes were widely detected from cored sediments, and significant dechlorination and debromination activities were observed during the incubation analysis (see Figure 1: Futagami *et al.*, submitted to AEM). These unique characteristics of subseafloor microbes have great potentials to the industrial applications. Also, the understanding of these microbial functions in nature provides fundamental information to develop useful molecular applications under the appropriate conditions.

Subseafloor microorganisms play important roles on biogeochemical cycles of one-carbon compounds such as CO_2 and CH_4. Previous studies of tracer experiments indicated that metabolic activities of CO_2-consuming autotrophic microbial communities (e.g., homo-methanogenesis rate) are expected to have very low activity in natural sediments, but have strong impact on the biogeochemical cycles in geological time. However, if the activities are artificially stimulated by adding nutrients and active cellular components into the cored sediments, it may turn to be active populations that effectively mediate or enhance reactions of one-carbon components. The microbial functions of methanogenesis, acetogenesis, and autotrophic carbon fixation may be useful to remediate the future CO_2 storage conditions in subseafloor environments such as coal, natural gas, and oil fields.

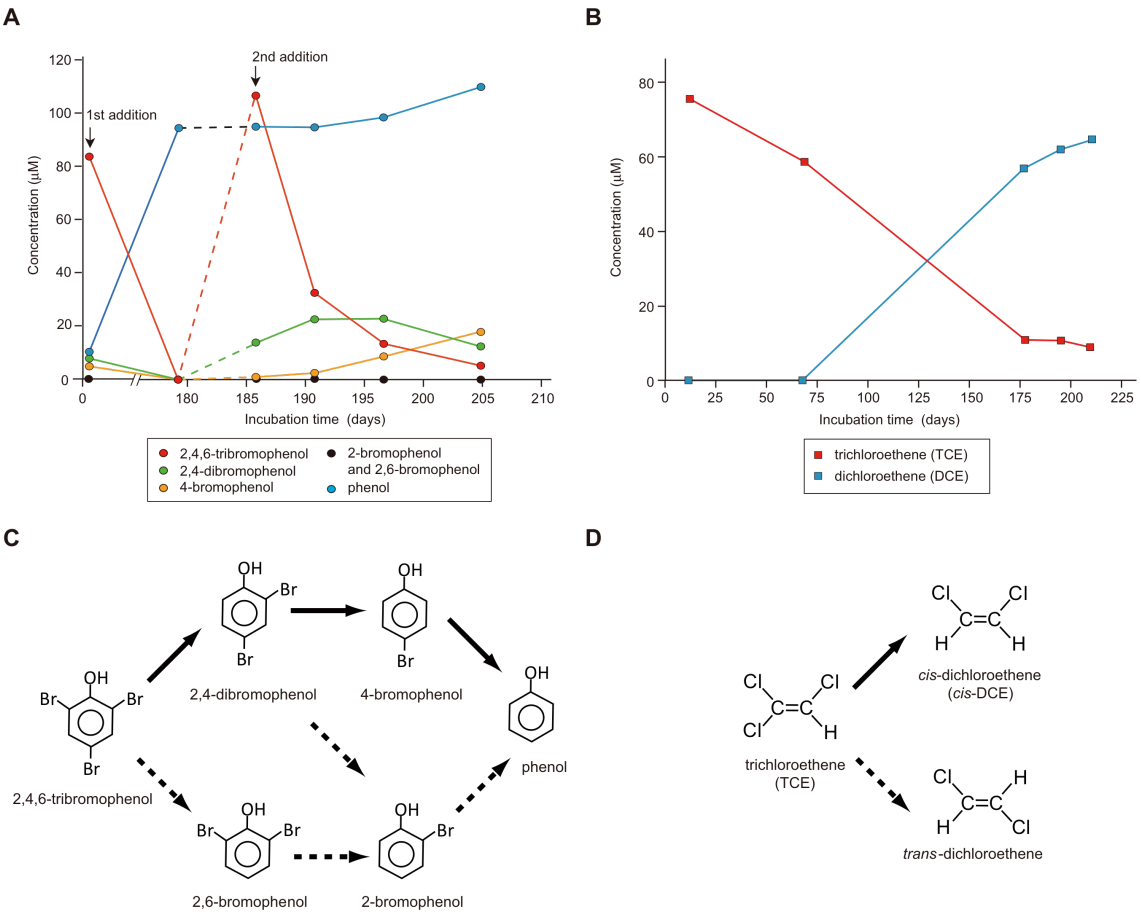

Figure 1. Dehalrespirating activities of subseafloor microbes.

(**A**) Debromination of 2,4,6-tribromophenol (2,4,6-TBP) in a subseafloor sediment slurry at Site C0002 in the Nankai Trough forearc basin (IODP Exp. 315). Arrow indicates the timing of 2,4,6-TBP supplementation. (**B**) Dechlorination of trichloroethene (TCE) in the same slurry sample. Sterilized control sediment slurries did not exhibit the phenol and *cis*-dichloroethene (*cis*-DCE) productions (data not shown). (**C**) Potential debromination pathway of 2,4,6-TBP (solid line), and (**D**) potential dechlorination pathway of TCE (solid line) observed in this incubation experiment. Data are derived from Futagami et al. (in review).

Technological requirements

To perform geobiotechnological research, retrieval of core materials with keeping pressure and anaerobic *in situ* conditions is a crucial point to maintain and monitor the microbial activity in the environment. This is highly relevant to the QA/QC issue and technological developments on the drilling platforms and in onboard/shore-based laboratories. The HYACINTH pressure-coring system has already been developed by GeoTek Ltd. as the third party tool for non-riser drilling platform such as *JOIDES Resolution* (Figure 1). This system also has connectivity with microbiological sampling device (Parkes et al., EM 2009). However, it is currently no high-pressure sampling device available for the deep riser-drilling *Chikyu*, which has a great merit to obtain previously inaccessible high-pressure and gaseous core samples stably at great depths through the blowout-preventer (BOP). The high-pressure devices as well as the sample transfer and tracer-injection system should be developed for the future deep riser-drilling with *Chikyu*. In addition, one of the unique characteristics of *Chikyu* lab-structures is X-ray CT scan. If the high-pressure cores can be transferred into aluminum and/or glass fiber reinforced plastic (GFRP)-based core chamber, we will be able to monitor not only the inner structure but also the penetration of tracers for microbes such as microsphere beads and the permeability without depressurized and destructed conditions. This technological development will significantly contribute to the basic and applied sciences including the "Geobiotechnology".

Figure 2. The HYACINTH core transfer and analysis system.

The photo is provided by Drs. Peter Schultheiss and Melanie Holland, GeoTek, Ltd.