Biogeophysics Chapman Con.: Exploring the Geophysical Signatures of Microbial Processes in the Earth

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Geophysical methods have the potential to detect and characterize microbial growth and activity in subsurface environments over different spatial and temporal scales. Recognition of this potential has resulted in the development of a new sub-discipline in geophysics called 'Biogeophysics', a rapidly evolving Earth science discipline that integrates environmental microbiology, geomicrobiology, biogeochemistry, and geophysics to investigate interactions that occur between the biosphere (microorganisms and their products) and the geosphere. Biogeophysics research performed over the last decade has confirmed the potential for geophysical techniques to detect microbes, microbial growth/biofilm formation, and microbe-mineral interactions.

The unique characteristics of geophysical datasets (e.g. non-invasive data acquisition, spatially continuous properties retrieved) present opportunities to explore geomicrobial processes outside of the laboratory, at unique spatial scales unachievable with microbiological techniques, and possibly in remote environments such as the deep ocean. In response to this opportunity, the American Geophysical Union (AGU) hosted the Chapman Conference on Biogeophysics with a mission to bring together geophysicists, biophysicists, geochemists, geomicrobiologists, and environmental microbiologists that are leaders in their field and have a personal interest in exploring this new interdisciplinary field or are conducting multidisciplinary research with potential impact on biogeophysics in order to define the current state of the science, identify the critical questions facing the community and to generate a roadmap for establishing biogeophysics as a critical subdiscipline of earth science research. The Biogeophysics Chapman Conference was held October 13-16, 2008, in Portland, Maine (http://www.agu.org/meetings/chapman/2008/fcall/).

About sixty participants participated in five sessions designed to address the following five questions: (1) What are the direct geophysical signatures of microbial cells and biofilms? (2) How do microbe-mineral transformations generate geophysical signatures as a result of changes to the physicochemical properties of the grain-fluid interface? (3) What geophysical signatures are associated with the generation of microbial-driven redox chemistry? (4) How can Biogeophysics be used to improve understanding of biogeochemical processes in natural and anthropogenic environments? (5) Could Biogeophysics ultimately contribute to exploration of microbial activity in extreme environments such as the deep ocean?

Forty oral presentations were spread across these five sessions that took place over a 3.5 day period. Plenary speakers reviewed 'exploiting microbe-electrode interactions for environmental restoration (Derek Lovley, University of Massachusetts), 'voltammetric solid state (micro) electrodes as in situ chemical sensors to understand microbial processes' (George Luther, University of Delaware) and 'the mystery of deep subsurface microorganisms' (Bo Barker Jørgensen, University of Aarhus). An evening poster session (fourteen presentations) provided a forum for enthusiastic discussion around some of the more controversial biogeophysics research conducted in recent years, such as biologically maintained geobatteries and electrical properties of biofilms..

This Chapman Conference catalyzed a unique communication between geophysicists, biogeochemists and microbiologists to explore the opportunities for research presented by linking geophysical signals with microbial processes in the Earth. Although the existence of these geophysical signals was reinforced by many of the presentations, it was clear from the enthusiastic discussions around each talk that the mechanisms generating these signals remain uncertain. For example, some of the mechanisms invoked by geophysicists to explain natural sources of electrical current in the earth (measured with the self potential geophysical technique) are based on microbiological research suggesting that microbes can facilitate electronic conduction over large spatial scales via connections of appendages. As the electronic conduction of such appendages is still a subject of intense research at the nanoscale, some participants felt that it was premature to be suggesting that electronic conduction via microbes could be invoked to explain field-scale geolectrical signatures. This issue led to more focused discussions around the source mechanisms of self potentials in general, with a lively debate developing over whether large self potential signals repeatedly observed over contaminated sites of active microbial degradation even necessitated the presence of an electron conductor.

Similar discussions also developed around presentations on electrical and seismic signals associated with microbial processes as observed in laboratory experiments performed by multiple research groups. Although geophysical signals resulting from microbial activity were again demonstrated, mostly conceptual models were invoked to explain these signals. The Chapman Conference thus highlighted the need for efforts to progress from observation-monitoring of biogeophysical signatures (the primary research of the last ten years) to the development of modeling approaches required to validate source mechanisms. Although advances in this arena have been made for cellular suspensions (e.g. dielectric spectroscopy in biophysics research for medical practices), discussion during this meeting highlighted that a porous medium represents a much harder modeling challenge. The complexity of the situation results from the fact that, in addition to the possible geophysical response associated with microbes/biofilms themselves (the target of experiments on cellular suspensions), biogeochemical alteration of the pore fluid chemistry and pore structure must be accounted for. These latter two effects are incompletely understood and very hard to constrain experimentally. There is a need for in-situ pore-scale imaging and quantitative analyses of these dynamic processes.

Other discussions developed around the techniques themselves, with questions raised about the sensitivity and resolution of geophysical measurements and whether some of the small signals faithfully recorded in the laboratory could be accurately recorded in field environments. However, presentations were given on recent research at field sites (where bioremediation monitoring strategies are being investigated) producing data consistent with laboratory findings. Also on instrumentation aspects, substantial discussion developed around the possible implementation of micro-electrodes (voltammetry), as used highly successfully to probe sulfur redox chemistry in the deep oceans, could be adopted in conjunction with geophysical surveys to better understand sulfide chemistry induced by microbial processes occurring in the near surface. Unlike geophysical techniques, these methods are sensitive to the geochemical conditions at the immediate vicinity of the electrode. In addition to exploring sulfur cycling in natural environments e.g. occurring in wetlands, the application of these voltammetric techniques for improving understanding of bioremediation processes associated with sulfate reducing bacteria was explored. In fact, presentations on a simpler electrodic method, relying on sensitivity of the electrode to aqueous chemistry at the point of measurement based on a galvanic cell effect, were presented for studies conducted at bioremediation sites. The linkage between small scale voltammetry (where speciation can be resolved) and these simpler galvanic cell electrodic techniques formed another focus of extensive discussion.

Perhaps the most fascinating discussions were motivated by the talks considering the ultimate possibility of adopting geophysical techniques as investigative techniques for detecting microbial processes in extreme environments such as the deep ocean (e.g., identifying microbial hot zones in gas hydrates in permafrost and deep marine environments; diversity of microbial life around hydrothermal vents), deep within ice sheets (identifying discrete signatures of microbial activity in ice) or even on other planets. The existence of life in extreme environments was the subject of one plenary talk (Jørgensen). Consensus was reached that this presents a research opportunity in the long-term but that much fundamental research (and instrumentation development) would be needed before such exploration could occur. The opportunity is evidenced by the fact that dielectric spectroscopy tools are being developed for future exploration on Mars. However, the challenge continues to be whether or not there are "unique" bio-signatures that can be readily identified from the geophysical data.

Scientists from Europe, Israel and China traveled to engage North American colleagues in this highly focused 3.5 day meeting. The group included an approximately equal mix of microbiologists, biogeochemists and near surface geophysicists. Thirty early career scientists (graduate students or graduates within 7 years of receipt of their PhD degree) received full travel awards from National Science Foundation (NSF). Multiple NSF divisions/programs (Marine Geology and Geophysics, Geobiology & Low Temperature Geochemistry, Ocean Drilling Program, Arctic Natural Sciences, Antarctic Earth Sciences, Antarctic Organisms & Ecosystems, Geomechanics & Geomaterials, Hydrologic Sciences, and Geophysics) and the United States Department of Energy (DOE) contributed to this support, a testimony to the interdisciplinary topic of the meeting. We are optimistic that this Chapman conference (and its deliverables, to include a review paper currently in preparation) will act as a catalyst for accelerated agency-supported research, in the emerging field of biogeophysics.

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