Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric: Phase III

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LONG-TERM GOALS

Program goals were to provide a better quantitative and mechanistic understanding of chemical processes that occur in fine-grained coastal and continental margin sediments. The focus of this phase of our work was to examine mineralogical controls on microbial habitation of coastal sediments.

OBJECTIVES

Objectives of this phase of our work focused on analyzing data from our laboratories and from the literature in terms of addressing two fundamental questions: (1) What are the controlling physical, chemical, and mineralogical factors in the adaption of different microbial communities to their host sediments and (2) does the specificity of distinctly different microbiological consortia for different mineral substrates that we have seen in the laboratory carry out into the natural environment.

APPROACH

This work was part of a three institution coalition working to gain a quantitative and mechanistic understanding of chemical mass transfer in coastal marine sediments. Efforts at the Scripps Institution of Oceanography (SIO) during this fiscal year focused on the impact of mineralogy on sediment microbiology. Collaborators at the Naval Research Laboratory at the Stennis Space Center (Drs. Y. Furukawa, D. Lavoie, and associates) were focused on field and microfabric aspects of the overall program, and collaborators at the Georgia Technological University (Drs. Philippe van Cappellan, C. Koretsky, and associates) were responsible for combining these results into the computational part of the program.

At Scripps, collaborations were carried out with the participation of microbiologist Dr. B. Tebo and his laboratory. It is in this laboratory that most of the work in this phase was carried out. For the microbiological studies, anaerobic and anaerobic conditions were imposed in either Fe-reducing or Sreducing environments. Gel electrophoresis, DNA sequencing, and other standard molecular biological techniques were used to determine microbial community structure.

WORK COMPLETED

Research supported by ONR permitted the construction and implementation of reactors in which microbial consortia could be cultured under anaerobic conditions using mineralogical media as substrates. With these, culture experiments were carried out using pure samples of the most common minerals in fine-grained marine coastal sedimentary environments, including bays, estuaries, and harbors. Minerals used were: montmorillonite, illite, chlorite, kaolinite, and quartz. Microbial populations used in the experiments came from marine sediments near shore at the Scripps Institution of Oceanography, with a single sampling being used as the source for all enrichment cultures. Using identical experimental parameters, that differed only in the type of mineral used as the geological substrate in each reactor, stable anaerobic microbial enrichments were produced from a single natural sample for sulfate-reducing and iron-reducing conditions. Resulting microbial cultures were subjected to standard molecular biological techniques, including PCR amplification of the 16S small subunit ribosomal genes, denaturing gradient gel electrophoresis (DGGE), DNA sequencing, and phylogenetic analysis to determine the composition of the resulting microbial communities and to compare community composition and diversity between reactors. Results showed a definite preference for different members of the original microbial populations to thrive in different mono-mineralogic substrates.

More extensive determination of the microbial communities of the anaerobic experiments are still yet to be made, but we expect these to be completed within the next fiscal year. Also be completed are more detailed mesocosm measurements of biological mediation of toxic chromium in marine sediments. These are presently being carried out under funding of the EPA. Also to be completed are three manuscripts presently under preparation on the impact of organic matter occluding sediment pores on geochemical fluxes, a microfabric model for organic matter preservation, and the results of our microbiological experiments on mineral-microbe interaction and specificity.

RESULTS

The primary conclusions reached in this phase of our program was that minerals with similar structures, but with different chemical compositions physical interactions with water and its dissolved constituents, promote the growth of different bacterial species in anaerobic sedimentary environments (Tables 1 and 2). This held true for anaerobic microbial consortia that regardless of whether they were Fe-reducing or sulfate-reducing communities.

Of additional interest were staining studies using Ruthenium Red. These were carried out to try and determine the extent to which mucco-polysaccharide fibrils (i.e., biofilm) was excreted by the microbial communities into the sediment matrix. Results of this effort show that a volume of exocellular material is excreted that far exceeds that of the microbial inhabitants and that this material acts to bind together sediment particles, even in granular sediments such as sands and silts, significantly increasing sediment cohesivity.

Table 1. Major differences in microbial communities that originate from the same initial microbial innoculant for each model sediment. Results are presented for the sulfate-reducing microbial enrichments.

Mineral	Mineral Composition and Structural Formulae	Microbial Biodiversity Differences (% DNA Similarity)
Quartz	SiO_2	desulfovibrio acrlicus (97%)
Kaolinite	$Al_2Si_2O_5(OH)_4$	desulfomicrobium spp. (95%) escambium hypogeium baculatum desulfobacterium macestii (95%)
Chlorite	$(Fe,Mg)_3Fe_3(AlSi_3)O_{10}(OH)_8$	desulfomicrobium spp. (95%) escambium hypogeium baculatum
Illite	$K_{0.8}Al_{1.9}(Al_{0.5}Si_{3.5})O_{10}(OH)_2$	No interpretable data
Smectite	$K_{0.3}Al_{1.9}(Si_4)O_{10}(OH)_2*4.5H_2O$	desulfovibrio spp. (87%)

Table 2. Major differences in microbial communities that originate from the same initial microbial innoculant for each model sediment. Results are presented for the iron-reducing microbial enrichments.

Mineral	Mineral Composition and Structural Formulae	Microbial Biodiversity Differences (% DNA Similarity)
Quartz	SiO_2	clostridium thermoplarium (93%) shewanella alga (99%)
Kaolinite	$Al_2Si_2O_5(OH)_4$	shewanella alga (98%)
Chlorite	$(Fe,Mg)_3Fe_3(AlSi_3)O_{10}(OH)_8$	vibrio spp. (95%) clostridium spp. (91-96%) thermopalarium dysprosium shewanella alga (97-98%)
Illite	$K_{0.8}Al_{1.9}(Al_{0.5}Si_{3.5})O_{10}(OH)_2$	acinetobacter spp. (95%) shewanella putrifaciens (94%)
Smectite	$K_{0.3}Al_{1.9}(Si_4)O_{10}(OH)_2*4.5H_2O$	shewanella alga (99%)

IMPACT/APPLICATION

The impact of this phase of our research is that it demonstrates that there is a specificity of different microbial corsortia for different mineral substrates. This finding now allows us to explore the possibility of designing long-term stable microbial consortia that can be put onto the seafloor and remain in place for remdediation of underwater toxic contaminants. These results suggest that, through the selective use of specific mineralogical substrates, the competitiveness of microbiological communities created for specific bioremediation programs will be enhanced over natural consortia. This indicates that designer microbial consortia, genetically engineered for specific bioremediation purposes, will have an increased longevity in subaqueous environments and will be able to remain at underwater locations at which remediation needs to occur. Because most of the clay minerals used are abundant and relatively inexpensive to obtain, this creates the possibility of highly cost-effective long-term microbial remediation of underwater contaminant sites, something that up to now has eluded us.

TRANSITIONS

Starting as a purely geochemical study of biogeochemical fluxes in fine-grained sediments, the scope and impact of this work has now expanded into the fields of molecular biology and microbial remediation of toxic metals and organic compounds. In terms of collaborations, it has increased the collaboration by bringing in the microbiological laboratory of Dr. Bradley Tebo at the Scripps Institution of Oceanography. It has also created a collaboration between Dr. B. Ransom and Dr. R. Naviaux, a mitochondiral RNA specialist at the University of California Medical School. Together Drs. Naviaux and Ransom are investigating the DNA adsorbed onto specific minerals in coastal sediments and examining the results in terms of lateral gene transfer and microbiological mutations.

RELATED PROJECTS

This grant formed the basis for a ONR ASSERT grant of the same name and with the same P.I.s that consisted of a collaboration between the Scripps Institution of Oceanography, the Naval Research Laboratory at the Stennis Space Center, and the Georgia Technological University for the purpose of quantifying chemical mass transfer in fine-grained coastal marine sediments. A continuing effort is now in place to publish the results of these studies.

PUBLICATIONS

Ransom, B., Kastner, M., Tebo, B., Obrastova, A. (2000) Organic matter in fine-grained continental margin sediments: Occurrence and impact on sediment physical properties and geochemical fluxes. EOS Trans. AGU*,* 81 (48).

Obraztsova,A., Ransom,B., Arias,Y.M.,Kastner,M., and Tebo,B.M. (2001) Mineralogical controls on microbiological diversity. American Society of Limnology and Oceanography Meeting, Albuquerque, New Mexico Programs and Abstracts. p. 105.