Bio-Soils Interdisciplinary Science & Engineering Initiative

"Meeting Societal Needs through International Transformative Research"

NSF Final Report on 2007 Workshop
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Executive Summary

The interaction of biological materials with geotechnical processes has long been ignored by geotechnical engineering, and its importance is just beginning to be realized. In the 2006 report from the National Academy of Sciences entitled "Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation" the role of biological processes in soil behavior is identified as a technical area that has not been accounted for and is cited as a critical research thrust and opportunity for the future. Biological materials are unique by their innate characteristics of being self-active and re-growing within geotechnical soil matrices. The biological alteration of the mechanical behavior of soils is thus a potential novel path for directed manipulation and improvement of soils.

The soil environment is known to be exceptionally complex and heterogeneous in structure. Such complexity is essential to support plant and animal life by providing an intricate particle-pore matrix that consists of solid, liquid and gas phases for the effective cycling and storage of nutrients. This same complex soil matrix is also the fundamental "building block" for geotechnical engineering. With our increased understanding of soil microbial life this biological activity and its products can be harnessed to provide new innovative solutions for geotechnical problems as well as provide explanation for observed geosystem performance. To address and explore this opportunity, integration of the sciences and engineering is necessary. The complexity of the processes cannot be sufficiently addressed within a single discipline.

The goal of the workshop was to bring together experts from a spectrum of traditional disciplines (e.g. geotechnical engineering, environmental engineering, geosciences, microbiology, soil science, biology) that are leaders in their field, are creative and innovative, and have a personal interest in exploring this new interdisciplinary field. This was accomplished by holding a workshop with about 50 participants, about 50% US and 50% International participants, which was jointly funded by multiple NSF programs and by the EPSRC in the United Kingdom.

The workshop was organized in a manner that gradually progressed build from developing a mutual foundation of understanding of different disciplines, to sharing current research and brainstorming about new opportunities, to identifying the necessary "action items", or developmental steps, required to mature this field. An informal environment and activities that fostered discussion, brainstorming, and free sharing of ideas was incorporated into the agenda.

The primary research outcomes of the workshop were significant and far-reaching. The primary "state variables" controlling bio-soil processes within each respective traditional discipline were identified and their maturity level assessed. This resulted in identification of substantial research needs in the following overarching interdisciplinary engineering and hard science areas: spatial heterogeneity, soil fabric and pore space architecture, fluid movement and transport, upscaling of biological processes, biological community composition and distribution among others. Further, interdisciplinary participant groups identified significant scientific merit and potential broader impacts in bio-soil controlled applications for mechanical property control, hydraulic flow control, subsurface remediation and waste treatment, energy and carbon sequestration, and agricultural soil-plant interactions.

The emergence of this new interdisciplinary field also necessitates education pedagogical change. Training of students and academicians for interdisciplinary research requires a significant departure from the predominant current education approach wherein an individual becomes highly specialized in scientific/engineering niche. Instead, a "renaissance" education, wherein an individual can speak the technical language of several disciplines but is specialized in a specific area, is necessary. Several ideas of education reform to meet this need were discussed and identified.

At the workshop's conclusion there was overwhelming consensus that a new interdisciplinary field at the cross-roads of biological and soil processes is emerging and it will have a substantial impact on society. In effect, the workshop itself has enabled the primary "chapters", or topics, of this "book" to be identified and outlined. Hard science and engineering research over the next several decades in the research and education areas identified herein is necessary to begin maturing this new field. To that end, one objective of the outcome of this workshop is the formation of a funded research initiative led jointly by NSF and EPSRC.

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Context

In the 2006 report from the National Academy of Sciences entitled "Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation" the role of biological processes in soil behavior is identified as a technical area that has not been accounted for, and in many cases neglected, in geotechnical engineering practice over the past decades (National Research Council 2006). It also identifies the role of biological processes to be a high research priority as advancement in this field will not only provide new insights and understanding of soil behavior, but also new engineering techniques, methods, and solutions that utilize natural process and are environmentally sensitive. Pilot studies are currently beginning performed to validate these predictions with respect to both improved understanding and new engineering techniques.

The converse need also exists in the sciences. The behavior, modeling, and design of materials studied by engineers are necessary to better understand biological processes. For example, soil scientists know that soil compression during agricultural treatment initiates a fundamental shift in biological processes, which creates conditions harmful to plant roots and an environment that is conducive to the release of greenhouse gasses. However, they have yet to be able to quantify this relationship – and geotechnical engineers likely can contribute to solving this problem. Through considering a series of these types of examples, it becomes clear that scientists – geologists, soil scientists, microbiologists, bioengineers, and others – would benefit from interactions with geotechnical engineers as well.

The intersection of geotechnical engineering with the natural and biological sciences is envisioned to form a new interdisciplinary area referred to herein as "Bio-Soil Interactions and Engineering". Both fields are primed for collaborative studies. Scientists have move well past the days of observation alone, and are now capable of controlling the rate, magnitude, etc. of biological processes. Geotechnical engineering understanding of soil behavior at the micro-nano scale has matured to where biological processes can no longer be ignored and to where the interaction between soil and biological processes could be understood and utilized.

For these reasons the workshop was both timely and necessary. The workshop is envisioned to be the first of a series of workshops in the coming years aimed at maturing the interdisciplinary field of "Bio-Soil Interactions and Engineering" from a vision with great promise to an established research area that is producing significant science and engineering advancements that are relevant to real-world problems. These activities would be supported strongly by dedicated research initiatives and programs. With this initial workshop designed to formative – developing collaborations, research ideas, visions for future research, funding opportunities – it is anticipated that a second workshop will be the foundation in support of the maturation of this new interdisciplinary community that lies at the interface between science and engineering.

Motivation

A number of technical and professional factors motivated organization of this workshop. The motivations listed below are far from inclusive and only presents initial ideas by the organizers prior to the workshop (which were greatly expanded by the workshop). The potential breadth of societal impact and depth of interdisciplinary research realized by the workshop is presented subsequently.

The harnessing and use of biological processes in engineering have significantly advanced society.

Society has directly benefited from research advances in which biological processes were instrumental in providing viable solutions to long-standing engineering problems. New solutions have provided more efficient, environmentally friendly, and/or economic solutions relative to traditional treatments that utilize man-made materials. An example of this is Microbial Enhanced Oil Recovery (MEOR), where microbial activity has been used to either mobilize adsorbed oils or to plug large pore spaces via calcite cementation, which in turn enable additional production of oil from a well before abandoning it. Other examples include the stabilization of metals including radioactive wastes, development of biological shields for zonal remediation of hazardous wastes or reactive landfill liners, environmental stabilization of contaminated soils, encapsulation of hazardous, reactive materials, and other contaminants in natural soils and acid mine tailings. However, the changes that occur in soils from the geotechnical aspect are often not investigated due to the focus on environmental remediation.

Biological processes influence the performance of geotechnical systems.

Natural biological processes have been shown to alter the properties and behavior of both natural soil deposits and of man-made soil deposits created during construction. One of the most common examples of this is "bio-engineering" techniques that are implemented for near surface stabilization of slopes (Gray and Sotir 1996). Live vegetative materials, or fascines, are integrated into the slope surface and their natural anchoring systems – roots – provides additional stability, enabling construction at higher slope grades than that possible with conventional construction techniques. Less widely recognized is the role that biological processes can have in the failure of geotechnical systems. For example, Mitchell and Santamarina (2005) cited biologic activity as a critical component in the 1984 embankment failure of Carsington Dam in Derbyshire, England, and in the long term stability of a high rock pile near an open pit mine in northern New Mexico.

Geotechnical processes influence natural biological processes.

Largely unrecognized by geotechnical engineers is the influence geotechnical construction processes can have on biological processes. For example, soil compression during agricultural treatment (compaction by a smooth drum roller in geotechnical terminology) initiates a fundamental shift in biological processes (from aerobic to anaerobic metabolism), which creates conditions harmful to plant roots and an environment that is conducive to the release of greenhouse gasses (Flynn *et al*., 2005). Soil compression (due to mechanical compaction) also alters the balance between water stress and mechanical impedance that roots experience, affecting plant growth.

Understanding of nature has matured to where these biological processes can be controlled.

The biological sciences have advanced well beyond on the age of observation. Today many biological processes have been characterized and understood to a degree that the process can be controlled. Some examples include the microbial degradation of organic matter in waste waters, the use of microorganisms in the bioremediation of hazardous substances in groundwater, soils, and air, creation of bioreactors, microbial activity controlling agricultural and food production, etc.

There is potential to replace manufactured materials used in many geosystems with natural treatment processes that will provide economic and environmental benefits.

In recent decades the frequency and volume of manufactured materials, such as geosynthetics and grouts, introduced into the subsurface as part of geotechnical systems has increased dramatically. The addition of these materials, while beneficial from an engineering performance perspective, might not necessarily be advantageous for the environment. For example, materials for grouting, which can create artificially high *in situ* pH levels, have in some cases contaminated the subsurface and lead to toxic conditions. Examples of this include paralysis of cows in Sweden, contamination of groundwater in France resulting human death, and threatening of aquatic fish habitat in the Sacramento River. Alternative, natural biologically – based treatment methods could meet the same engineering requirements without environmental concerns.

A workshop for scientists and engineers from different disciplines provides an opportunity to stimulate new understanding.

The role of biological processes in the engineering behavior of soils, and vice-versa, are inherently interdisciplinary questions. If experts remain within the confines of their traditional disciplines and do not engage beyond their discipline minimal progress can be made in exploring and developing this field. A forum such as a workshop that brings these people together has the strong potential to stimulate new understanding of old problems as well as new discoveries. For example, the embankment failure of Carsington Dam (cited above) was unexplainable considering only geotechnical aspects, but can be explained when biological processes are also considered. Similarly, soil scientists hypothesize that the surfactants that roots produce alter rates of soil water uptake, but without geotechnical understanding they have not been able to quantify if this is indeed the case and whether it affects soil strength. Furthermore, exposure to other disciplines will also expose experts to the research and analysis tools in other fields that may be useful for their research.

Biological Processes in Geotechnical Engineering is a "high priority" for the National Academy of Sciences.

In the 2006 report from the National Academy of Sciences entitled "Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation" the role of biological processes in geotechnical engineering will be cited as a critical research thrust and opportunity for the future (National Research Council (2006). The recognition of the role of biological processes has also been recently highlighted in the ASCE G-I GeoStrata (2005) magazine, which dedicated the September/October 2005 issue to "Bio-Geo: In-situ Processes".

Recent research studies demonstrate the role of biological activity in geosystem performance and the ability to modify soil properties with biological processes.

The emerging importance of the role of biological process in geotechnical engineering has been highlighted by an ASCE journal paper by Mitchell and Santamarina (2005) in which the authors establish a foundation for this new area. They sequentially define and describe "biological constituents, characteristics, and processes within a soil", provide "examples of how microbiological conditions and processes may influence engineering properties and behavior of earth materials", review "geomicrobiological processes that appear particularly promising for further study", and identify "relevant references to aid in obtaining in-depth background and understanding of many of the points". The recent publication of a paper such as this (with basic definitions) emphasizes the infancy of this field and simultaneously highlights the increasing recognition of the importance of this emerging field.

Recent laboratory studies by interdisciplinary groups have demonstrated that biological processes can be harnessed and used to modify the behavior of soil. DeJong et al. (2006), using the microorganism *Bacillus pasteurii*, successfully cemented a loose sand specimen with calcite (Figure 1a). Testing of the specimens revealed that the strength of the soil had been substantially improved and that specimen collapse under shear was prevented (Figure 1b). Banagan et al. (2005) explored the improvement of soil properties using bio-films, observing and increase in strength and a decrease in permeability.

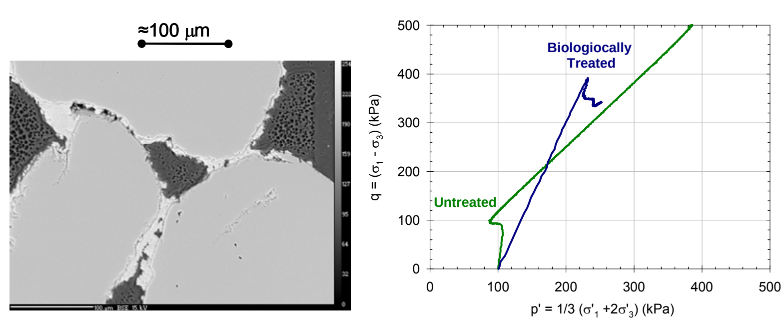

Figure 1: (a) SEM image of microbially induced calcite cementation by *Bacillus pasteurii* and (b) improved shear response of biologically treated sand.

Objectives & Atmosphere

A series of objectives were identified during planning of the workshop. While this workshop is standalone, it is envisioned that it will be the first of a series of workshops that will lead the exploration and development of this new field. Recognizing also that this field is relatively "young", the objectives of the workshop are intended to be more "vision casting" than "culminating conclusions". With this context, the following objectives were identified and guided the planning:

- Cross-pollination of knowledge and ideas among traditional disciplines
- Identify and define the boundaries of opportunities given current knowledge
- Visualize the future opportunities and scope of the field
- Establish inter-disciplinary network for developing future research partnerships
- Identify opportunities for collaborative research
- Identify specific engineering and hard science research needs
- Develop agenda for establishing a new funding initiative and/or program
- Identify reform required for educational development of undergraduate and graduate students with interest and expertise in this new field.

To hold a successful "visioning" workshop the chairpersons worked to create an atmosphere that is stimulating, creative, and secure. Stimulation occurred through interdisciplinary presentations and discussions. Creativity was stimulated through brainstorming exercises, having presenters propose far-reaching ideas, and seeded questions. Finally, given the highly exploratory and visioning nature of the workshop, a secure environment where people could propose "radical" ideas that can be assessed by other disciplines was fostered.

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Identification of participants for the workshop considered individual expertise, creativity, and curiousity as well as a target distribution across all participants with respect to technical backgrounds, career stages, and diversity. The achieved distribution among NSF funded US attendees was as follows:

- 18% junior academicians, 52% senior academicians, 26% graduate students / post-docs, 4% national labs scientist
- 39% females, 61% males
- 22% minorities (Hispanic, African American, Native American)

Logistics

Website: http://www.sil.ucdavis.edu/

When: April 1-4, 2007

Where: MIT Endicott House (http://www.mitendicotthouse.org/)
The workshop was held at the MIT Endicott House, an all inclusive conference facility. The entire workshop was held on the 25 acre grounds, including lodging, meals, and meetings. The MIT Endicott House is located in Dedham, Massachusetts, just 30 minutes from downtown Boston.

Schedule

The schedule format over the three day workshop was designed with two primary objectives. The first objective was to familiarize and educate all participants in relevant activities occurring within the traditional disciplines of geotechnical engineering, microbiology, geochemistry, environmental engineering, and soil science. The second objective was to facilitate interdisciplinary activities in which the current state of discipline maturity was assessed and the potential of bio-soil interactions and engineering applications was explored. The detailed workshop schedule is shown in Appendix C. Presentations given throughout the workshop are presented in Appendix D.

Synthesis of Discipline Specific Research Activity

Synthesis of discipline specific presentations occurred through three primary formats: keynote lectures, oral presentations, and poster presentations.

Two keynote evening lectures presented overarching research needs, concepts, and ideas. These were: “New Frontiers in Geotechnical Engineering, Challenges and Opportunities” by James K. Mitchell (given by Ed Kavazanjian) and “Bioengineering Soils” by Iain Young. The former provided a historical perspective on development of geotechnical engineering and summarized the National Academy of Science (2006) report which outlines the future of geotechnical engineering. The latter presentation provided a significant societal motivation, urged consideration of soil as a finite resource (like coal), and outlined the utility and potential of microbial activity.

Three one-half day sessions, in which three twenty minute oral presentation were followed a poster session, served to synthesize current research activity and interest among all participants. The session themes were nominally geotechnical engineering, microbiology and geochemistry, environmental engineering and soil science. The oral and poster presentations for each session are listed in Appendix D.

Extensive group discussion occurred following the oral presentations and following the poster presentations. Discussions were guided considering two questions: “What have I seen/learned that is of relevance to what I do?” and “What do I do that is of relevance to what I have seen/learned?”. Within the exploratory spirit of the workshop these discussions were unbounded, serving to stimulate discussions of ideas, observations, interdisciplinary similarities, and potential applications.

Synthesis of Interdisciplinary Measurement & Process Monitoring Methods

The diversity among participants with respect to discipline (i.e. microbiology vs. geotechnical engineering vs. soil science) and research approach (i.e. experimental vs. modeling vs. analytical) stimulated a session in the afternoon of the second day in which all interested participants presented a five minute "nugget" highlighting a research tool that may have interdisciplinary appeal. This session was led by a twenty minute presentation by Mike Humphreys entitled "Designing Multifunctional Grasslands" in which the benefits of genome sequencing enabled guided breeding of plants for improved drought tolerance. A listing of all presentations made is provided in Appendix D.

The nugget presentations were remarkably diverse, ranging from new instrumentation (e.g. Raman confocal microscopy, shear wave velocity measurements, geocentrifuges), to microbial diversity (e.g. community diversity and durability), to bioremediation analytical tools, to benchscale system models, to natural microbial potential (e.g. conductive nanowires), to geochemical system modeling.

Two primary observations, or themes, formed through this session. First, the quantity and diversity of tools available is sufficient for much of the bio-soil ideas being explored in the workshop. Second, the aspects within each traditional discipline that prove most challenging to measure and model are similar among the various disciplines. For example, upscaling of a particular behavior from a controlled laboratory setting to a 1 m^3 volume of a natural soil sample is very complex.

Assessment of Discipline Maturity and Needs

With an enhanced understanding of discipline research interests and the broader idea of using biological processes to control the engineering behavior of soils, participants were charged to assess the maturity and needs of their respective discipline. To accomplish this, participants were grouped into the following discipline areas:

- Geotechnical Engineering
- Environmental Engineering
- Geochemistry and Biogeochemistry
- Microbiology and Biology
- Agriculture and Soil Science

Each group considered soil as an open reactor system to deliver and control specific engineering properties and functions. They identified the primary "state variables", the first-order factors, for their discipline that must be assessed/understood/quantified to determine if a proposed bio-soil process would be feasible/effective. After ranking these variables in order of priority, the "maturity" (i.e. level of understanding, ability to measure and quantify, ability to model) of each state variable was assessed on a scale of 1 (low) to 5 (high). After each group completed the exercise participants reassembled and shared their respective assessments.

The "state variables" ranked with low "maturity" effectively list the primary hard science and engineering research needs in each respective discipline. These should/could be considered among the primary research needs for each respective discipline.

A summary of each discipline's self assessment follows:

Geotechnical Engineering

- Microstructure and fabric (3.5),
- Mineral-fluid interactions (2.5),
- Bulk response (4),
- Fluid movement (4.5),
- Surface characteristics/interface (1),
- Long term effects (2),
- Heterogeneities (2),
- Process control/by-products (2)

Environmental Engineering

- Redox,
- Pore Distribution,
- Kinetic Controls,
- Chemical Constituents,
- Biological Functions (Spatial & Temporal),
- Geological,
- Hydraulic Conductivity,

- Temperature,
- Water Content/Multiphase,
- Capillarity/Surface Tension (very important),
- Colloid Transport, Functional State?,
- Average Good Predictor?,
- Geo/Chemo/Bio Transfer

Geochemistry & Biogeochemistry

- Chemical composition and gradients:
  - mineralogy (5),
  - fluid (5),
  - pH (5),
  - redox status (3),
- Physical structure:
  - pore space (4),
  - fluid content (4);
- Spatial distribution and dynamics (2),
- Reaction rates (2),
- Transport rates (3),
- Genetic potential and expression of function (2),
- Possible metabolic controls on geochemical pathways: molecular expression (1), resulting mass transformation (1),
- Microbial signaling (1)

Microbiology & Biology

- e- donors / acceptors (3),
- Physical environment (pH, ion strength, particle size distribution, geochemical minerals, etc) (-),
- Specific rate reactions of interest (0-4),
- Key metabolic reactions (1-3),
- Community architecture (composition, distribution) (3),
- Inhibitors (1),
- Biomass and turnover (3),
- Localisation of activities cross-scale (scale dependent)

Agriculture & Soil Science

- Water content (4),
- Organic matter (2),
- Nutrient status (4),
- Plants (2),
- Stability (4),
- Heterogeneity (1),
- Water quality (2),
- Contamination (2),
- Biodiversity (4),
- Sealing (hydraulic conductivity) (5)

Overarching State Variables

From these discipline specific assessments several overarching "state variables" were present, most of which were ranked with a relatively low level of maturity (i.e. level of understanding, ability to measure and quantify, ability to model). These included:

- Heterogeneity – microbial community, soil/pore gradation, spatial
- Soil Structure and Pore Space Distribution – characteristics of pore space within which biological processes occur
- Fluid Movement and Transport – fluid, microbial, and nutrient movement in the pore space
- Up-Scaling – upscaling from μm to m scale while maintain science/engineering rigor
- Biodiversity - microbial community composition and distribution

These overarching state variables are generally understood at the micro-scale with some level of idealization (e.g. uniform soil gradation, limit microbial diversity) and at the macro-scale in terms of average bulk properties (e.g. sandy soil, aerobic microbial dominant).

In order to control biological processes for engineering purposes at the macro-scale (tens of cubic meters), the micro-scale processes must be up-scaled in a rigorous manner that successfully captures the relevant hard science and engineering.

The overarching state variables are the primary interdisciplinary research needs that must be addressed to realize the benefits of controlling biological processes for engineering purposes at the full scale. As such, they require significant hard science and engineering research and should be primary research issues for existing as well as future research funding initiatives.

Identification of Interdisciplinary Research Opportunities

Following synthesis of the respective disciplines, participants regrouped to brainstorm and envision the range of potential applications the control of bio-soils processes could be used for. In each group there was at least one representative from the disciplines of geotechnical engineering, environmental engineering, geochemistry and biogeochemistry, microbiology and biology, and agriculture and soil science. Five groups were formed to explore the following potential application/impact areas:

- Mechanical Control
- Hydraulic Control
- Remediation and Waste Treatment
- Energy and Carbon Sequestration
- Soil-Plant Interactions

Each group was charged to identify specific potential applications, the critical state variables for the general application, the primary questions that must be answered, the measurement and monitoring requirements, and other relevant issues. As expected given the creative level of this exercise, the results from each group differed somewhat in format.

As evident below, specific and significant opportunities in each application area and the primary hard science and engineering research required to accomplish them were identified. A summary of each application group's ideas follows:

Mechanical Control

- **Applications:**
  - Infrastructure,
  - Geological Hazard and Mitigation,
  - Global Warming Issues
- **State Variables**
  - Strength,
  - Stiffness,
  - Volume Change Properties,
  - Hydraulic Conductivity,
  - Durability,
- **Process Control Variables:** Chem and Bio, Pressure and Temperature
- **Hard Science:** How to control soil as bio reactor
  - Understand and Model biological and chemical processes in soil and their impacts on the micro structural features
  - Understand the impact of the micro structural features on the Physical Properties
  - Characterization of the system, including heterogeneity
  - Control subsurface-environment (pH, simulate procedures), growth, propagation of the processes
- **Hard Engineering**

- Bridge scale gap to translate micro to macro and macro to micro
  - Macroscopic explained by microscopic science
  - Heterogeneity/Variability
- **Measurements and Monitoring**
  - Site characterization; process monitoring; long term behavior
  - Tools:
    - geophysics: tomographic methods
    - geochemistry: ground water and pore water chemistry
    - geomicrobiology: presence, activity, and abundance
  - Need to improve resolution of existing tools, sensors, and models

Hydraulic Control

- **Applications**
  - Decrease Permeability:
    - salt water intrusion;
    - waste water retention;
    - CO_2 subsurface repositories;
    - Enhanced oil/gas recovery;
    - Sealing in construction, and over the life of structures;
    - Preventing leakage of reservoirs;
    - Bioremediation: slow, direct, or contain contaminant plumes;
    - Creating underground water/fuel storage silos;
    - Prevention of piping/erosion: manipulation of flow length
  - Increase Permeability:
    - Maintenance of drainage;
    - Enhanced oil/gas recovery;
    - Geothermal energy extraction;
    - Maintenance of wells;
    - Increase permeability of clay layers;
    - Bioremediation: increase permeability of clay layers;
    - Recovery from oil shale;
    - Emergency release from levees;
    - Sustainable urban drainage;
    - Pore pressure management;
    - Drainage for landslide prevention;
    - Increased infiltration capacity caused by fire
- **State Variables**
  - Mixed community reaction kinetics;
  - Genetic potential;
  - Surface characteristics;
  - Pore structure: porosity and fractures;
  - Interaction: Spatial distribution, and Scaling/ averaging/risk;
  - Formation, Function, and Persistence
- **Hard Science**
  - Turn on/off metabolic processes
  - Biofilm growth:

        - spatial issues,
        - why is it formed,
        - what supports biofilm growth,
        - exploiting predation,
        - what is the role of soil in biofilm growth,
        - understanding mixed community dynamics
    - Chemical signaling
    - Developing adhesion properties
    - Scaling
    - Spatial heterogeneity
    - Pore structure, tortuosity
    - How can the pure culture science be extended to the system level
    - Back-engineering of clogged aquifers
    - Controlled transport
    - Persistence

Remediation & Waste Treatment

- **Applications**
    - Realizing the genetic potential of soil for novel manufacturing
    - Lower energy consumption
    - Closed-loop treatments
    - Pre-emptive design
    - Joined up thinking: multidisciplinary training
    - Performance assessment from first principles
    - Engagement with global strategies
- **Hard Science**
    - Quantifying uncertainty in relation to sensitivity and risk
    - Scaling laws for parameters and process models
    - Interpreting mass transformation potential from gene expression
    - In-situ visualization/assessment of microbial activity
    - Conceptualization of systems to initiate modeling
    - Predictive models
    - Relating complex Bio-Geo-Hydro-Micro systems to collapsed simple variables
- **Measurement and Monitoring**
    - Improved monitoring strategy:
        - Low-cost, long-term, automated monitoring
        - Non destructive, in-situ, real time, spatially distributed
        - Biogeophysics: monitoring biochemical and geochemical systems non-invasively and remotely fot temporally questions
    - Efficient data processing
    - Molecular methods for gene expression in dirty systems

Energy & Carbon Sequestration

- **Applications**
  - Carbon sequestration
    - To significantly increase the level of carbon sequestration.
    - Can we engineer the system such that microbes will nucleate CaCO3 into a granular mass?
    - Engineer a way to matrix the soils to transfer carbon into a more reduced, deeper environment
  - Nuclear Power
    - A GHG-free power source- zero carbon emission
- **Hard Science Questions**
  - What are the controls on the transfer of reduced organic carbon into mineral carbon- hydrology, precipitation, etc.?
    - How can we manipulate these processes such that we can tip the balance into a carbonate precipitate.
    - What limits the turnover, and what is the availability of calcium?
    - What are the metal delivery systems that may accelerate the process of carbon capture
    - Can we get a handle on the microbial/geomicrobial chemical processes in action
    - What availability of biomass near the subsurface is there for us to use?
    - Evaluation of the kinetic controls of the system
  - What can we do to the natural pedogenic functions to allow us to capture CO_2?
    - Can we stabilise the reduced C such that when it re-oxidises, it goes into deeper reservoirs rather than being released back into the atmosphere.
    - What is the process and mechanisms that transfers or pumps down the captured carbon (from atmosphere through photosynthesis), converts it to organic carbon and moves to depth where it is mineralised.
    - Need to research the link between top metre and solid bedrock in terms of biogeochemical processes
- **Monitoring and Measurements**
  - Scale Concerns: Monitor small changes in the flux in the shallow soils- would be very small compared with the natural C fluxes in and out of the soil

Soil-Plant Interactions

- **Applications**
  - Create wealth;
  - Meet Kyoto Targets;
  - Water Framework Directive;
  - Soil Framework Directive;
  - Traceability and audit of supply chain (*Liability, unforeseen consequences*);
  - Stay at the front of GM technology *(transfer genes to traits, functional response);*
  - Biodiversity action plans;
  - Coastal protection;
  - Flood protection;
  - Olympics, Commonwealth games
- **State Variables**
  - Soil Carbon - Robust spatial-temporal assessment framework
  - Plants - Finding the *potential* in the genome
  - Heterogeneity - Change of culture for uncertainty, embrace complexity
  - Contamination - Reliably predating bioavailability and degradation
  - Water quality - Scale, complexity, delivery across scales
  - Greenhouse gases - Improved N use efficiency, reduced methane
- **Hard Science**
  - Predictive capacity for controlling plant-soil interactions to give societal outcomes
    - Systems approach
  - Genes for traits and function
    - Ability to test, assess heterogeneity
    - Determine full environmental risks, interactions (*proper* trials)
    - Flood and runoff control
  - Functional soils for cities
    - Desired outcomes, clean water, clean air, amenities
    - Sustainable urban draining systems
    - Cities as ‘ecosystems’
- **Contribution from the Geotechnical Engineer?**
  - Engineered watersheds for clean water; infiltration control for landfill applications; control of heat island performance; crime reduction; multi-functional control; integrated landscape design

Assessment of Education Needs and Opportunities

Realization of the applications and execution of the hard science and engineering research described in the prior sections necessitates education improvements. Workshop participants were divided into two groups to evaluate educational needs, with one group examining undergraduate education needs and the second group examining graduate education needs.

The overall consensus was that training of students and academicians for interdisciplinary research requires a significant departure from the predominant current education approach wherein an individual becomes highly specialized in a scientific/engineering niche. Instead, a "renaissance" education, wherein an individual can speak the technical language of multiple disciplines but is specialized in a specific area, is necessary.

The following summarizes the ideas/issues to be raised/addressed/considered:

Undergraduate Education

Interdisciplinary education at the undergraduate level must be integrated within a curriculum that is already impacted and stretched. Science and engineering majors at most universities have among the greatest unit requirements/restrictions for degrees. As a result, adding additional content is not a realistic option. Additional material could only be added as replacement material or within an alternative/elective class.

The primary objective at the undergraduate level was to expose students to multiple disciplines and inter-disciplinary research to broader their scientific view and appeal to their interests. It was determined that rigorous interdisciplinary training is best accomplished at the graduate level and therefore the objective at the undergraduate level is more towards educating students regarding this opportunity.

Alternative mechanisms for introducing more life science content into engineering curricula and visa versa identified include:

- Bio-Chem-Geo-Civil Seminar series: A one/two unit course in which professors from multiple disciplines each lecture for one/two weeks providing an introduction to their respective discipline.
- Bio-Chem-Geo-Civil Course: A full technical elective course that is taught by three/four professors from the disciplines of biological sciences, chemistry, geosciences, and civil engineering. The course, for example, could focus on soil samples and characterizing them from all discipline perspectives – microbial community, chemical stability/oxidation, geological formation process, hydraulic flow properties, and strength and compressibility.
- Research Internships: Significant interdisciplinary education occurs very effectively through one-on-one interactions. Undergraduate students should be immersed in the laboratory to perform research alongside graduate students and/or professors.

Graduate/Post-graduate Education

The education structure for graduate/post-graduate education differs significantly between the US and the UK systems. In the US, students take up to 50 course unit hours (1 unit = 1 contact hour per week for 10 weeks on quarter system or 14 weeks on semester system) as part of their doctoral education. In the UK, students are not required to take additional course work for their doctoral degree, though an increasing number of students are taking some courses. Participants agreed that an interdisciplinary course series (two to thee courses) would be a format amenable to both education structures.

The following characteristics were identified as being important for any graduate education model being considered:

- Core Competency Training: Inter-disciplinary training/education is intended to substantially broader one's capabilities, but it does not replace the necessity of being a specialist in a specific technical area.
- Multi-Language Training: Students must become sufficiently familiar with other disciplines such that they can interact intelligibly with discipline specific individuals (e.g. biological, chemists, geologists, geotechnical engineers) and can identify and understand what they do know and what they don't know.

The following formats were identified as being potentially effective in interdisciplinary training at the graduate level:

- Journal Paper Discussion Group: An informal setting in which researchers from various disciplines come together and discuss journal papers related to the interdisciplinary research problem of interest.
- Bio-Chem-Geo-Civil Seminar series: A one/two unit course in which professors from multiple disciplines each lecture for one/two weeks providing an introduction to their respective discipline. This could include assigned journal/text readings.
- Bio-Chem-Geo-Civil Course Sequence: A full technical elective course series that is taught by several professors from the disciplines of biological sciences, chemistry, geosciences, and civil engineering. Different models representative of this format were identified by program participants. Namely:
    - INRA Subsurface Graduate Program (http://ssgp.boisestate.edu/Default.htm): The Subsurface Science Graduate Program (SSGP) is a long-term collaborative effort by the universities of the Inland Northwest Research Alliance (INRA) to enhance research and education in the subsurface sciences.
    - Exploring Interfaces through Graduate Education and Research (EIGER) (http://www.eiger.geos.vt.edu/): The EIGER Program at Virginia Tech, supported by NSF IGERT funding through 2010, focuses on graduate research in the areas of 1) interdisciplinary environmental interface science, as studied by physical scientists and engineers, and 2) human interfaces within interdisciplinary scientific and engineering teams, as studied by behavioral scientists. Ten departments in four colleges are involved in this project which will support 27 Ph.D. students over its lifetime.

- Science/Engineering/MBA Degree: A combined technical and business graduate degree program designed to equip student competent in implementing bio-based solutions in industry. This idea was driven through recognition of the need for research to be realized in industry.
- Doctoral Training Degree: In the UK centers are being formed that support doctoral training degrees. These degrees programs are coursework only doctoral programs designed to equip students who are intent on working in industry. This program is appealing due to the large number of course hours that would be available for interdisciplinary training.

Road Map of Future Activities

Workshop participants concluded that the broad field of "Bio-Soil Interactions and Engineering" is at its inception. In many respects, the table of contents for the field has been outlined, and now research must be performed to being exploring the field and to write the chapters of the book. To this end a series of activities are underway and planned, including:

- Completion of NSF Workshop Report: The workshop report will be edited by reviewed participants and then be submitted to NSF and EPSRC and distributed on-line.
- Review Articles in Reviewed Journals: Work is underway by the organizers to submit a technical synthesis of the workshop outcomes in a widely disseminated journal (i.e. Science or Environmental Science and Technology) as well as in discipline trade magazines such as Civil Engineering.
- 2nd UK Participants Workshop: The UK participants held a second meeting on July 6, 2007 to reconnect and strategize for future funding. Program directors from EPSRC, BBSRC, and NRC were in attendance.
- Presentation at NSF to Project Managers: On August 22, 2007 a presentation was given at NSF to program directors by Jason DeJong and Kenichi Soga.
- The UK organizers (Kenichi Soga, Richard Whalley, and Steven Banwart) reviewed the bio-soils initiative activities and presented four UK consortium proposals for funding consideration.
- Bio-Soils Initiative Panel at Geo-Congress 2008: A panel session is being organized at Geo-Congress 2008 in New Orleans to further disseminate results from the workshop and to engage more people in the research activities. The session will consist of a brief overview of the workshop outcomes and subsequent US-UK activities, followed by short presentations from researchers actively engaged in the field and a period of audience-panel discussions.

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Appendix A. Participant Biographies

Akram Alshawabkeh
Sookie S. Bang
Steven A. Banwart
Glyn Bengough
Simon Bottrell
Scott J. Brandenberg
Susan E. Burns
Laurie Caslake
Jason DeJong
Cassandra Fowler
Vicent Gomez-Alvarez
April Z. Gu
Michael Harbottle
Philip M. Haygarth
Mike Humphreys
Stephan Jefferis
Robert M. Kalin
Edward Kavazanjia, Jr.
Thomas L. Kieft
Matthew Kuo
Ning Liu
Jonathan R. Lloyd
David Manning
Brian Martinez
John McDougall
Steve P. McGrath
James K. Mitchell
W.O. Molendijk (Waldo)
Brina Mortensen
Douglas C. Nelson
Klaus Nüsslein
R. Jane Rickson
Mary J.S. Roth
J. Carlos Santamarina
Robert W. Smith
Patricia Sobecky
Kenichi Soga
Douglas L. Stewart
Ian Thompson
Julio R. Valdes
W.H., van der Zon (Willem)
Richard Whalley
Iain M. Young

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):

Electrokinetic and Electrolytic processes in soil, soil and groundwater remediation, Electrolytic enhancement of bioremediation, fate and transport of contaminants in soil and groundwater

Synthesis of Research Activities Relevant to Workshop:

1. Evaluation of oxygen generation and transport by direct electric currents (water electrolysis and electroosmotic transport) and its impact on the biological activities in clays.
2. Evaluation of enhanced aerobic transformation of phenanthrene (polycyclic aromatic hydrocarbon) in soils by electrokinetic enhanced bioremediation
3. Evaluation of enhanced anaerobic dehalogination of PCE in clays by electro-injection of lactate
4. Assessment of transport process and impact of electrolytic and electrokinetic phenomena on microbial activities in soils

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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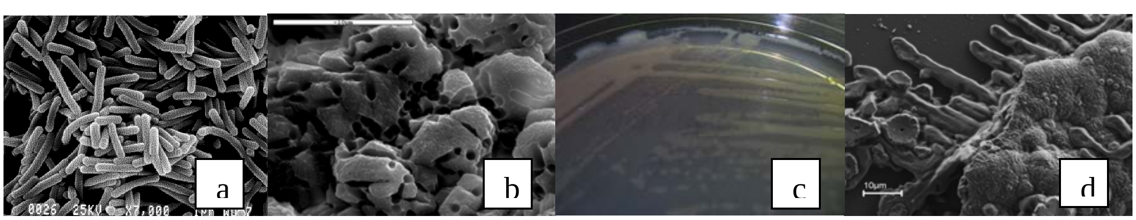
Research Expertise:
Environmental Microbiology and Biotechnology: Microbiologically enhanced crack remediation; development of genetically engineered biosealant; genomics of biomass-degrading extremophiles; and characterization of novel thermostable enzymes

Synthesis of Research Activities Relevant to Workshop:
Long-term research of Dr. Bang at the South Dakota School of Mines and Technology (SDSM&T) focuses on the application of a microbial metabolic byproduct, calcite ($CaCO_3$), in crack remediation (NSF/CMS-9412942, -9802127). Microbial-induced calcite precipitation involves a series of complex biochemical reactions, including participation of *Bacillus pasteurii*, urease (urea amidohydrolase; EC 3.5.1.5), and high pH. The research efforts have been expanded to an international collaboration between the SDSM&T and the Curtin University of Technology, Perth, Australia, complementing two campuses' expertise and laid a major groundwork for the application of molecular recombinant technology in microbiologically enhanced crack remediation (NSF/INT-0002608). Currently, efforts are being made to develop genetically engineered microorganisms capable of producing both inorganic and organic polymers for crack remediation (NSF/CMS-0301312).



(a) SEM image of *B. pasteurii*
(b) SEM image of calcite precipitation induced by *B. pasteurii*
(c) Mucoid colonies of a recombinant microorganism, *Pseudomonas aeruginosa* 8821(pUBU1)
(d) SEM image of calcite and alginate polymer produced by *P. aeruginosa* 8821 (pU

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise: Reactive processes in soil and groundwater with an emphasis on interfacial processes including biodegradation within biofilm communities and the biological weathering of minerals.

Synthesis of Research Activities Relevant to Workshop:
My research track record is in methods to predict reaction rates for complex field systems from more fundamental laboratory data and theoretical principles. Key results include one of the first successful predictions of field weathering rates for rock and minerals from lab data[1]. More recently I have applied numerical simulation methods to complex biodegradation processes[2] and collaborated on advanced computational methods to simulate reactive transport processes in groundwater[3]. I am PI for the £1.4M Sheffield Cell-Mineral Interface Research Programme, with EPSRC and BBSRC funding across 5 departments linking nanosciences with engineering biofilms and groundwater remediation engineering. This programme was expanded in 2005 with award of a £1.74M NERC Consortium Grant to study from molecular- to soil profile- scale the role of mycorrhizal fungi in symbiosis with their host plants to influence soil formation. Linking with USA partners and the British Geological Survey, this grant established the Worldwide Universities Weathering Science Consortium (www.wun.ac.uk/wsc/). I am a member of the UK Nanotechnologies Environmental Risk Assessment Task Force and am a Council member of the European Association of Geochemistry.

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[1] Malmström M., Destouni G, Banwart S. and Strömberg B. (2000). Resolving the scale-dependence of mineral weathering rates. *Environmental Science and Technology, Vol.34*, No. 7, 1375-1377.
[2] Watson I., Oswald S.E., Mayer K.U., Wu Y. and Banwart S.A. (2003). Modelling kinetic processes controlling hydrogen and acetate concentrations in an aquifer-derived microcosm. Environ. Sci. Technol., 37, 3910-3919.
[3] Watson I.A., Oswald S.E., Banwart S.A., Crouch R.S. and Thornton S.F. (2005). Modelling the dynamics of fermentation and respiratory processes in a groundwater plume of phenolic contaminants interpreted from laboratory- to field-scale. *Environ. Sci. Technol., Vol. 39*, No. 22, 8829-8839.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise: Root-soil interactions; mechanics of root growth; root anchorage & slope stabilization;

Synthesis of Research Activities Relevant to Workshop:

- Effects of soil physical conditions on root growth. Here, my interest is in the physical stresses experienced by roots growing in soil, with a particular focus on the effects of soil strength (mechanical impedance) and structure.
- New methods of measuring and screening root systems, including electrical capacitance.
- Border cell and exudate production by roots and their physical and biological roles in the rhizosphere.
- Bioengineering slopes with root reinforcement. We are studying how roots mechanically support soil slopes. We are trying to unravel how root length density & orientation, root branching, and root strength contribute to soil reinforcement.
- In-vivo imaging and analysis of root cell expansion. This work aims to develop powerful methods to analyze root growth responses to environmental perturbations. Confocal microscopy and computer vision techniques are being developed to track the growth of living root cells.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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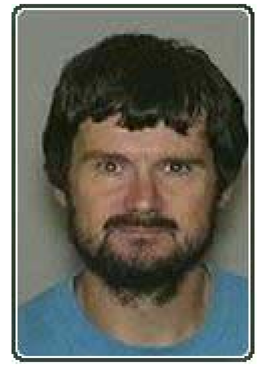

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Research Expertise (2-3 lines of key phrases): Geochemistry, Contaminant Hydrogeology, Stable Isotopes, Groundwater Tracing, Subsurface Microbiology, Contaminant Biodegradation.

Synthesis of Research Activities Relevant to Workshop:

Investigation of in-situ subsurface biodegradation (principally of organic contaminants) involving:

- stable isotope abundances of contaminant species, in situ;
- chemical concentration and isotopic changes to electron acceptor species used in biodegradation;
- microcosm and mesocosm studies of biodegradation potential and controls and limitations on biodegradation capacity.

Investigation of fate of contaminants in the environment using stable isotope tracers, both natural abundance differences and through artificially labeled tracer experiments.

Use of inherent differences in isotopic compositions to distinguish sources of contaminants and natural from anthropogenic sources of solutes.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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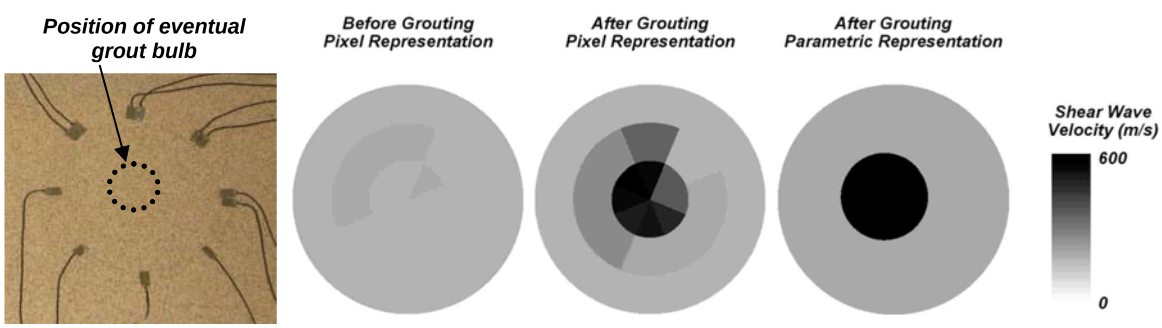
Research Expertise (2-3 lines of key phrases):
My primary area of expertise involves pile foundations in liquefied and laterally spreading ground. An emerging area of interest for me is site investigation using geophysical methods such as bender elements and ultrasonic transducers.

Synthesis of Research Activities Relevant to Workshop:
I collected shear wave velocity measurements along multiple ray paths using bender elements embedded in a sand model. These measurements were collected before and after a cement slurry was injected into the sand to form a grout bulb. Tomographic inversion of travel time measurements identified a high shear wave velocity anomaly in the center of the array, which indicates the presence of the grout bulb. Such methods show potential for identifying spatial and temporal variations in soil stiffness that can be caused, for example, by cementation of sand particles due to biological processes.



Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):
Geoenvironmental engineering, engineered materials, physical and chemical behavior of soils, cone penetration testing, fundamental behavior of clay minerals

Synthesis of Research Activities Relevant to Workshop:

Our group focuses on the investigation into the fundamental behavior of clay minerals through the manipulation of surface properties. Recent work has focused on engineering the interfacial properties of montmorillonite through cation exchange of inorganic cations with quaternary ammonium organic cations. Manipulation of the density of the organic coating and the structure of the organic cation facilitates study of the physical and chemical interaction forces on the clay minerals, and allows us to control the clay's hydraulic conductivity, intrinsic permeability, compressibility, and interface frictional strength. Depending on the choice of cation, the interfacial friction can be decreased (thin film lubricating regime), or can be increased through electrostatic and chemical bonding.

In addition to changes in the governing frictional forces, alteration of the organic phase on the clay surface also changes its interaction with organic contaminants in the pore fluid. The structure and the density of the organic cation coating controls the sorptive behavior of the soils, which can be engineered to exhibit either partitioning or adsorptive behavior.

Of additional interest are the trends we have demonstrated between chemical adsorption and frictional interaction between the engineered montmorillonite. Our work has shown that increasing levels of friction are paralleled by decreasing levels of contaminant uptake for one of the organic cations studied (benzyltriethylammonium).

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):
Broadly, my research focuses on the bacterial response to adverse environmental conditions… biotransformation of environmental mercury, reduction of perchlorate, biofilm formation, quorum sensing.

Synthesis of Research Activities Relevant to Workshop:
I have had a SGER grant with Prof. Mary Roth (Civil Engineering) to test whether sand strength could be improved by the addition of *Flavobacterium johnsoniae,* a biofilm-forming bacterium.

Tests were performed using a vane shear device, which measures the combined cohesive and frictional strength of the soil (in kPa). A box model was built that permits liquid flow through a main sand compartment with sampling ports stationed vertically and horizontally. Liquid CYE containing *F. johnsoniae* was added to the box model to a final height of 21.5 cm, followed by sterile Ottawa 30 sand to a height of 24.1 cm. After eight days, samples were extracted and stained with SYTO-9 and Alexa Fluor 633, and examined under a confocal microscope. Sand strength was measured at seven locations and two depths (depth 1 = 10.8 cm and depth 2 = 20.3 cm from the top of the box model) using a vane shear. The staining procedure confirmed that both bacteria and an exopolysaccharide matrix were present in the box model when the vane shear was used to test the soil. The average increase in strength was 35.6% and 114.5% over the baseline strength test with the addition of *F. johnsoniae*, at depth 1 and 2, respectively. This shows that the addition of *F. johnsoniae* increased the cohesion and strength of the saturated Ottawa sand.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):
- bio-mediated soil improvement
- experimental laboratory methods
- soil and soil-structure interface behavior
- subsurface characterization & in situ testing

Synthesis of Research Activities Relevant to Workshop:
- use of *Bacillus pasteurii* to mediate calcite precipitation in granular soils
- monitoring of cementation process with non-destructive methods (bender elements, etc.)
- control of monotonic and cyclic shear response of treated soil
- control of permeability with bio-treatment (primarily reductin)
- treatment integrity (coherence) during stress loading and unloading
- treatment permanence (longevity) of treated soil
- upscaling of treatment process from cm to m scales

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise:
Graduate student working in the area of geomicrobiology and its application to soil mechanics.

Synthesis of Research Activities Relevant to Workshop:
Studying the effect of microbial processes on the mechanical properties of soil. The overall research project is evaluating three candidate mechanisms for use in soil improvement; mineral precipitation, mineral transformation, and biopolymers and biofilms. My research is currently focusing on mineral transformation: the transformation of one type of mineral to another through biological activity. In particular, I am looking at the transformation of smectite to illite. We hope to show that smectite, a clay mineral that has high volume change potential, can be changed to illite, a clay mineral with a lower volume change potential, at room temperature and atmospheric pressure through anaerobic microbial processes, as reported in the geology literature. Initial results have shown that the plasticity index of a local (Phoenix, Arizona) expansive soil can be decreased by more than 60% by treating it anaerobically with *Shewanella Oneidensis MR-1* and nutrient broth for 15 days. Corresponding decreases in swell potential and the application of the mineral transformation process to other expansive soils are being studied.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise:

Microbial Ecology, Community Characterization, Soil Diversity, Molecular Techniques

Synthesis of Research Activities Relevant to Workshop:

I'm currently a postdoctoral research fellow at the University of Massachusetts - Amherst (Klaus Nüsslein, advisor). My academic training is in Microbial Ecology and I have always been interested in the study of soil microbial populations and their interactions with environmental factors. My dissertation research examines the microbial community composition in recent volcanic deposits in Kilauea Hawaii (Klaus Nüsslein, advisor), and determined the extent to which community structure varied spatially within the volcano (FEMS Microbiol Ecol 60 [2007] 60-73). As part of my post-doctoral experience I would be interested in studying the distributions and variations of microbial populations in the environment and relate the diversities to ecological functions.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise:
Biological nutrient removal, bioremediation and microbial ecology in natural and engineered biological treatment systems

Synthesis of Research Activities Relevant to Workshop:
Current research interestes:

- Identifying and Analyzing the Microorganisms At Subsurface capable of transforming heavy metals and Relating Their Abundance and Growth Rates with Transformation Rates of metals.
- Bioremediation of compounds of emerging concern such as endocrine disruptors.
- Heavy Metal Reduction and Precipitation by Induced Electrolytic Corrosion of Iron in Soils and Groundwater
- Optimization of sampling strategies for groundwater remediation.

Previous research on bioremediation:

Gu, A.Z, H.D. Stensel, J. Pietari, and S. Strand, "Vinyl Bromide as a Surrogate for Determining Vinyl Chloride Reductive Dechlorination Potential," *Environmental Science & Technology*, 37(19) 4410-4416 (2003).

Gu, A.Z., B. Hedlund, J. Staley, S. Strand, and H.D. Stensel, "Analysis and Comparison of the Microbial Community Structures of Two Enrichment Cultures Capable of Reductively Dechlorinating TCE and cis-DCE," *Environmental Microbiology*, V6(1), 45-54 (2004).

Walker, C.B., A.Z. Gu, H.D. Stensel, and S.E. Strand. A Biological Method for Synthesizing ^{14}C-Vinyl Chloride, *J Label Compd Radiopharm*, 47: 1–8 (2004).

Gu, A.Z., H. Smidt, J.T. Staley, D.A. Stahl, S.E. Strand, and H.D. Stensel. An Anaerobic VC-Enriched Consortium is Dominated by Novel Flexibacter Species. American Society for Microbiology, 102nd General meeting, Salt Lake City, Utah, May, 2002.

Gu, A.Z. Assessment of Reductive Dechlorination of Vinyl Chloride and Characterization of Enrichments that Grow on Vinyl Chloride as the Sole Carbon and Energy Source. Ph.D. Dissertation, University of Washington, Seattle, WA, (2003).

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Michael Harbottle
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Research Expertise (2-3 lines of key phrases):

Enhancing biodegradation, contaminant transport and soil strengthening using electrokinetics; assessment of sustainability of remediation; biodegradation in soil/cement systems; contaminant tracking in soil and plants using magnetic resonance imaging.

Synthesis of Research Activities Relevant to Workshop:
(keep profile to 1 page total…fine to include images, etc.)

Encouraging biodegradation in soil/cement: In-situ stabilization/solidification (S/S) has the disadvantage that contaminants remain on site and may come to pose a risk once more if/when the system breaks down in the future. We attempted to tackle this by seeing if organics in the soil/cement matrix were susceptible to biological attack. We studied two grouts (involving high pH Portland cement and a phosphate cement at a more moderate pH) and also considered the use of compost addition as a repository within the S/S matrix where contaminant and degraders could be 'sheltered' from the rather hostile environment of the soil/cement itself. Experiments indicated a loss of contamination from the high pH system, particularly with added compost.

Electrokinetics to enhance biodegradation of organics: we used an electric field and associated electrokinetic phenomena in an effort to improve the bioavailability of an organic contaminant in soil. Conditions under regularly-reversed field were found to enhance production of $^{14}CO_2$ from radiolabelled contaminants.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Philip M. Haygarth
Position/Title: Professor
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Research Expertise (2-3 lines of key phrases):
Phil Haygarth's research is on soil and water biogeochemistry and aims to understand the key biological, physical and chemical processes of colloid and nutrient release from soils to waters. The main focus is concentrated on phosphorus, although work on nitrogen and carbon and associated 'colloids' is also conducted.

Synthesis of Research Activities Relevant to Workshop:
The research provides a scientific framework for rationalising and understanding the transfers of nutrients, including colloid-associated material, from fine-scale mechanistic processes in the soil-plant system, through to potential impacts in catchments and surface waters. The niche is the multi-scaled 'transfer continuum' that involves an interdisciplinary systems-based approach from the rhizosphere to small catchment scale. Agricultural soils and catchments have the most direct strategic and the work also has importance for EU water quality, with potential to assess scenarios for land and catchment function under climate change scenarios.

The key top level question is to ascertain the extent to which fine scale reductionist advances in soils and plant science can make a functional difference at the catchment scale. Key current research aims are:

1. To isolate the soil biological processes that are responsible for nutrient release, as a result of rhizosphere hydrological pulsing (wetting and drying).
2. To characterise and quantify colloid release from grassland systems.
3. To determine the extent to which grass plants control localised hydrological balances in the rhizosphere that may impact on the water balance (flooding) and potentially control and nutrient fluxes.
4. Determine the characteristics of organic P in UK soils and catchments.
5. To undertake relevant strategic research for the UK government to construct cost effective means of managing and mitigating diffuse pollution.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: **Dr. Mike Humphreys**
Position: Team Leader: Grasses Traits & Varieties Programme
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Institution: Institute of Grassland & Environmental Science (IGER)
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http://www.iger.bbsrc.ac.uk/SGF/
http://www.iger.bbsrc.ac.uk/SAGES2/sages2.html

Research Expertise:

Ryegrass – Fescue species cytogenetics. Natural and synthetic grass hybrids. Genetics of resistance to drought, cold, or salinity. Novel traits for improved grassland sustainability. Development of molecular markers to "dissect" and target genes for key traits. Androgenesis and microspore rergeneration for increased gene expression and variation.

Synthesis of Research Activities Relevant to Workshop:

Dr Mike Humphreys, who is a cytogeneticist and Leader of The Grass Traits and Varieties Programme at IGER developed the methodologies used for transfer of genes for abiotic stresses from fescue species *Festuca pratensis* (2x), *F. glaucescens* (4x) and *F. arundinacea* (6x) into ryegrass species *Lolium multiflorum* or *L. perenne* (2x). He was also co-ordinator of the EU FPV Programme SAGES (2001-03) involving 9 scientific and industrial partners in the UK, Norway, Poland and France. *Lolium* genotypes together with genetic markers tagged to introgressed *Festuca* genes were developed for winter hardiness, drought resistance, water-use-efficiency, and root development (http://www.iger.bbsrc.ac.uk/SAGES2/sages2.html). The SAGES web-site provides new information on the requirements for European grassland systems for the future and evaluates the potential of novel genotypes described therein as safeguards against climate change and for improved crop-sustainability. Dr Mike Humphreys developed species-specific markers (sequence-tagged-sites (STS), simple-sequence-repeats (SSRs), amplified-fragment-length-polymorphism (AFLPs) each assigned close to the *Festuca* genes responsible for the *Festuca* traits. These enable the transfer and assembly of selected gene combinations across generations in cultivar development. Dr Humphreys is a Co-Investigator in the recently funded BBSRC project "Selecting genes for function: Exploiting genetic diversity in grasses to manage the biophysical interactions in grassland soils" involving partners at IGER North Wyke, Rothamsted Research, and Lancaster University which uses outcomes of the SAGES project aimed at improving soil hydrology both under periods of water deficit and surplus. Dr Humphreys has researched the grasses within the *Lolium-Festuca* complex for 28 years and is the author of 135 publications including a manuscript accepted recently by Genetics which described the first comparative mapping of traits associated with abiotic stresses in *Festuca* and other monocot crop species. He has a number of invited reviews on abiotic stress in grasses and on grassland sustainability in books and in a recent New Phytologist Tansley Review entitled "A changing climate for grassland research" one of the top 20 most read publications in New Phytologist.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Stephan Jefferis
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Department/Group: University/Institution:
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Director and Board Chairman, Cybersense Biosytems Ltd
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Research Expertise (2-3 lines of key phrases):
Qualifications in natural sciences, chemical engineering, civil engineering and law.
Applied research focused on the interactions of chemistry and/or microbiology with construction works including tunnelling, piling, grouting, cut-off walls and other geotechnical processes.

Synthesis of Research Activities Relevant to Workshop:
Over 35 years experience in the investigation and resolution of unusual materials and environmental problems including:

- Investigation and management of natural chemical and microbiological processes which from time to time occur at a scale sufficient to threaten the viability of construction projects;
- performance of materials in complex and aggressive environments;
- the development of in-ground technologies for control of contaminant migration, passive barriers and permeable reactive barriers;
- management of chemical and nuclear waste legacies;
- development of polymer slurry systems for excavation support and slurry tunneling
- use of chemical and cementitious grouts for ground improvement and radioactive and toxic waste solidification;
- risk assessment and risk perception in relation to environmental issues;
- concepts of sustainability applicable to geotechnical engineering;
- impact of pollution events such as major spills and fires on the environment.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Professor Robert M. Kalin BSc, MSc, PhD, CEnv, FICE
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DOB: 1 July 1961

Career Interests

Professor Kalin's research interests are focused on Environment Science and Engineering to underpin the global sustainability agendas. His work ranges from site specific biogeochemistry of contaminated land and groundwater (including engineering design of remediation methods), development of new enhanced in-situ remediation methods that manage sustainable risk, to hydrogeology and palaeohydrology of local to regional scale groundwater systems, and study of global biogeochemical cycles and climate change.

Research Output

Professor Kalin is currently author on over 130 peer review publications that cover a wide range of topics including environmental engineering, geological sciences, water resources, climate change and medical research. During the past decade many students have completed under his supervision.

Engineering Experience

Prof. Kalin is a Chartered Environmentalist (CEnv) and a Fellow of the Institution of Civil Engineers (UK). During the past decade of University-Industrial collaborations Professor Kalin has been partner to or is currently leading research valued over £14M, including full-scale demonstration of novel and world-leading technology / approach at sites in GB (12), N. Ireland (6) and Ireland (3).

Development of 'Engineering for Sustainability' Vision

One of the seven UN Millennium Goals is Sustainable Environmental Development including the move to a carbon neutral society. This is a core concept that most of the World aims to address in the Decade 2005 to 2015. Prof. Kalin through his RAEng Chair clearly acknowledges the Millennium Goals and aims to make a significant impact to help humanity achieve sustainability through three complementary topics:

- **i. Water Resource Management**
- **ii. Urban Redevelopment for a Carbon Neutral Society**
- **iii. Environmental Forensics and rebuilding of Environmental Capital.**

His research on sustainable environmental development is driven by an engagement with interdisciplinary focused problem solving and knowledge transfer, drawing in particular on the insights of environmental science and engineering and extending across research endeavours found in other disciplines (eg. Environmental planning, environmental governance, paleo-ecology, environmental economics, environmental law, agriculture and land use change). The RAEng Chair involves research which explores the organization and interaction of complex past and present, natural and human communities at a range of spatial scales. His vision looks to the past to understand the roots and causes environmental damage and considers what measures require establishing to regenerate environmental capital we need to *'keep the promise'* of the UN Millennium Goals for the future of humanity on this planet.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Edward Kavazanjian, Jr.
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Department/Group: Department of Civil and Environmental Engineering
University/Institution: Arizona State University

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Research Expertise:
Geotechnical engineering, including geotechnical analysis and design for infrastructure projects, ground improvement, geotechnical earthquake engineering, and design and construction of waste containment systems.

Synthesis of Research Activities Relevant to Workshop:
My current research interest in this area involves employing geomicrobiological processes for improvement of the physical properties of soil. Three different categories of geomicrobiological processes that can potentially be employed for soil property improvement are being studies: mineral precipitation, mineral transformation, and bio polymer growth. The mineral precipitation work is focusing on inducing precipitation and cementation in granular soils to mitigate liquefaction potential, improve foundation bearing capacity, and facilitate tunneling and excavation in running and flowing sands. Three different anaerobic precipitation mechanisms are being evaluated: ureolysis, denitrification, and sulfate reduction. The mineral transformation work is focusing on transformation of smectite to illite under anaerobic conditions at room temperatures to mitigate the swelling of expansive soils. Preliminary results have shown a significant reduction in plasticity index in a local (Phoenix, Arizona) expansive soil after just 14 days of anaerobic treatment.. Potential applications of biopolymers that may be investigated include groundwater control and mitigation of liquefaction potential.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Thomas L. Kieft
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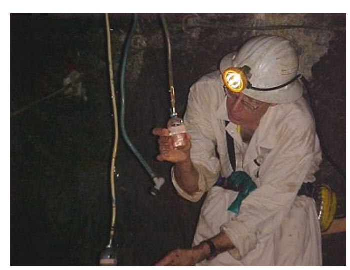
Research Expertise: microbiology of arid and semiarid soils, soil microbial activities; microbiology of subsoils, vadose zones, and deep subsurface ecosystems

Synthesis of Research Activities Relevant to Workshop:
My studies of soils have been on water relations of soil microorganisms, i.e., the influence of soil water potential on microbial activities; the microbiology of arid and semiarid soils, especially as related to desertification; and long-term starvation survival of microbes. My interests in soils led me to research in the subsurface, i.e., into the vadose zones underlying soils, to saturated aquifer sediments and fractured rock environments, and most recently to the deepest parts of the continental biosphere that have been explored to date. As part of a team of microbiologists and geochemists, I have been studying deep fracture water environments accessed via gold mines in South Africa that are >3 km deep and in a molybdenum mine in Colorado that is proposed as a national Deep Underground Science and Engineering Laboratory. I've also studied lichens, which rarely get the respect they deserve. I have been involved in undergraduate research and education, serving as a mentor in NSF Research Experiences for Undergraduates in South Africa (http://geomicro.utk.edu/) and New Mexico (http://infohost.nmt.edu/~reu/).

Sevilleta NWR, New Mexico

Rhizoplaca chrysoleuca



sampling at 3 km depth

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):
Considering the possible role living organisms (burrowing invertebrates, bacteria and microbes) play in formation of deep sea 'crusts' observed in offshore site investigations off the Angolan coast and within the Gulf of Guinea through processes of suction, de-structuring and binding of clay.

Synthesis of Research Activities Relevant to Workshop:
At water depths of greater than two kilometres, surface sediments generally comprise 'muds' of very low shear strengths. However, in some locations off the Angolan coast and within the Gulf of Guinea, thin 'crusts' of up to one metre thickness and 15kPa shear strength are present. These crusts would seem more at home at a sediment depth of 10m rather than 0.5m, but no erosion is thought to have taken place. At present, no clear understanding has been formed as to the origins of this crust however it is generally accepted that the increase in shear strength is not the product of over-consolidation through the removal of material from the seabed. My PhD research under Professor Malcolm Bolton will consider the following hypotheses for increased shear strength:

- Mucus binding of sediment passing through gut of invertebrates expelled as pellets, and mucus-lined burrows
- Suction caused by the de-structuring of clay agglomerates by bacterial or biological activity, or by burrowing invertebrates 'pumping' water while feeding
- Generation of exocellular polysaccharide secretions by bacteria/microbes
- Organic matter allowing 'favourable' clay orientations during sedimentation
- Bioturbation by micro and meio-fauna causing either direct compaction of surrounding sediment, or far-field effects below depth of life

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise (2-3 lines of key phrases):

Soil compositional and structural characterization using electromagnetic waves; Time domain reflectometry for determination of water content, specific surface area and pore fluid salt concentration; Relationships between EM properties and engineering properties.

Synthesis of Research Activities Relevant to Workshop:

My research focuses on soil and site characterization uisng electromagnetic waves. Electromagnetic waves can be a very useful tool for studying the interactions of soils and biomass because of their non-destructive nature.
In my study, I proposed a new model to relate EM properties of soils to their components and structure, through which the influences of water content, pore fluid salt concentration, flocculation, clay percentage, clay mineralogy and temperature on soil EM properties can be quantified and predicted.
The model also provides a valualbe means to study the effects of micro-organism on soil structure and components. For example, some micro-organisms tend to faciliate the flocculation of clay particles without significantly changing the pore fluid electrical conductivity. This process can be studied by monitoring the EM properties of bio-treated soils, through which how much and how fast the soil structure changes can be determined. By establishing the relationship between the changes in soil structure and the changes in hydraulic conductivity and strength, the optimal environment for micro-organisms to make the fastest changes in soil properties can be identified and the best way to use micro-organisms to treat soils can be determined.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Prof Jonathan R Lloyd
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Research Expertise (2-3 lines of key phrases):
Geomicrobiology, metal-microbe interactions, microbial physiology, subsurface microbiology, molecular ecology and bioremediation.

Synthesis of Research Activities Relevant to Workshop:

My research focuses on the mechanisms, environmental impact and biotechnological application of microbial metal reduction in natural and engineered environments. This research portfolio is highly multi-disciplinary and is built upon strong collaborations with mineralogists, geochemists, radiochemists and biologists in several universities and National Laboratories in Europe and N. America. Financial support is from NERC, EPSRC, BBSRC, the European Union, the US Department of Energy, the US National Science Foundation and several companies.

Selected recent references

Lear, G., Song, B., Gault, A.G., Polya, D.A. and J.R. Lloyd (2007) Molecular Analysis of Arsenate-Reducing Bacteria within Cambodian Sediments Following Amendment with Acetate. Applied and Environmental Microbiology 731041-1048

Ahmed, M. F., S. Ahuja, M. Alauddin, S. J. Hug, J. R. Lloyd, A. Pfaff, T. Pichler, C. Saltikov, M. Stute, and A. v. Geen. (2006). Ensuring Safe Drinking Water in Bangladesh. Science 314 1687 - 1688.

Coker, V.S., A. G. Gault, C. I. Pearce" G. van der Laan, N. D. Telling' J. M. Charnock" D. A. Polya, J. R. Lloyd (2006) XAS and XMCD evidence for species dependant partitioning of arsenic during microbial reduction of ferrihydrite to magnetite: implications for arsenic mobilization in reducing aquifers. ES&T 40 7745-7750

Burke, I.T., Boothman, C., Lloyd, J.R., Livens, F.R., Charnock, J.M., McBeth, J.M., Mortimer, R.J.G. and Morris, K. (2006) Redoxidation behaviour of technetium, iron and sulfur in estuarine sediments. ES&T 40 3529 – 3535

Renshaw, J.C. Laura J. C. Butchins, Francis R. Livens, Iain May, John M. Charnock and Jonathan R. Lloyd (2005) Bioreduction of uranium: environmental implications of a pentavalent intermediate. Environmental Science and Technology 39 15 5657-5660

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise:

Mineral-water reactions in biologically-active systems including soils, sediments, aquifers, petroleum reservoirs and landfill sites.

Synthesis of Research Activities Relevant to Workshop:

I'm particularly interested in the precipitation of carbonate minerals in systems that are biologically-driven. This interest started with work on calcite precipitation within sanitary landfills, where scale formation and clogging fouls leachate management and pumping systems. It encompassed gathering evidence to support the validity of using limestone aggregate (geotechnical properties willing) in drainage systems. My work has moved on to investigate carbonate mineral precipitation within soils and water treatment systems, partly through microbial precipitation in connection with soil stabilization, and now in connection with carbon sequestration in soil systems.

With EPSRC funding (Instrument Development Fund) I have developed a unique thermal analysis system coupled to on-line stable isotope analysis that gives simultaneous determination of C isotope ratios and mass loss – it is useful for investigating composite samples that are not amenable to separation, ideal for samples from soils and related environments where biological processes generate nanoscale intergrowths.

Manning, D. A. C. Calcite precipitation in landfills: an essential product of waste stabilization. Mineralogical Magazine, 65, 603-601, 2001

Lopez-Capel, E, Abbott, GD, Thomas, KM, & Manning, D. A. C. Coupling of thermal analysis with quadrupole mass spectrometry and isotope ratio mass spectrometry for simultaneous determination of evolved gases and their carbon isotopic composition. J Anal Appl Pyrol 75, 82-89, 2006

Bamforth, S. M., Manning, D. A. C., Singleton, I., Younger, P. L. and Johnson, K. L. Manganese removal from mine waters – investigating the occurrence & importance of manganese carbonates. Appl Geochem, 21, 1274-

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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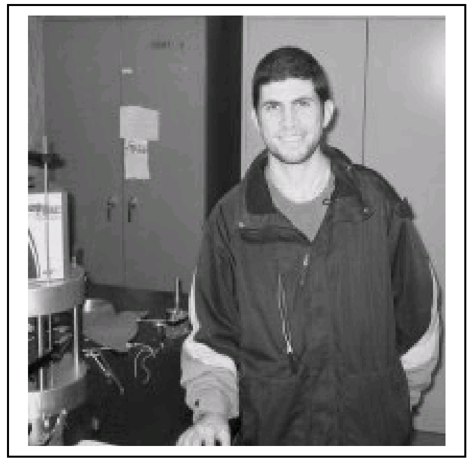

Research Expertise:

- Monotonic/Cyclic Direct Simple Shear Testing
- Interface Direct Shear Testing

Synthesis of Research Activities Relevant to Workshop:

My research focuses on the monotonic and cyclic shear strength of biologically treated granular soils. Through a series of cyclic Direct Simple Shear tests, we hope to develop a controlled solution to enhance the behavior of granular soil under monotonic and cyclic loading. Currently, I am focusing on designing methods of injecting cultured bacteria into DSS samples before the shearing phase. *Bacillus pasteurii* will be the bacteria used to mediate calcite cementation within the sample. A monitoring system will be developed, with use of bender elements, to track the cementation level within the sample.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Dr John McDougall

Position/Title: Lecturer in Geotechnical Engineering

Department/Group:
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University/Institution:
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Research Expertise (2-3 lines of key phrases):
Geomechanics of non-conservative or degrading soils
Hydraulic-biodegradation-mechanical analysis and constitutive modelling
Landfilled waste behaviour

Synthesis of Research Activities Relevant to Workshop:
John McDougall has active research interests in unsaturated and decomposing soils but has gained international recognition for his innovative work on the engineering analysis and hydro-bio-mechanical modelling of landfill behaviour. His work has attracted research funding from UK funding councils, government agencies and other bodies. Recent contracts cover work to develop a graphical user interface for his HBM landfill model. John is currently working with a Golder Associates on two UK Government contracts. On the first, the HBM model is being used to investigate the long-term consequences of 'failsafe' landfill management and on the second, long-term landfill settlement.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Professor Steve P. McGrath
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Department/Group: Agriculture and Environment
University/Institution: Rothamsted Research

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Research Expertise (2-3 lines of key phrases):

- Phytoremediation
- Soil contaminants
- Environmental chemistry
- Bio-indicators of pollution, focusing on heavy metals and persistent organic pollutants
- Biogeochemistry of trace elements in soils, microbes and plants
- Biological impacts of waste disposal
- Soil remediation

Synthesis of Research Activities Relevant to Workshop:
Steve is an internationally recognised authority on the chemical forms of pollutants in soils, their uptake and fate in plants and effects on soil microorganisms, and is Programme Leader of the Soil Protection and Bioremediation Research at Rothamsted, comprising 15 researchers. Recent interests include soil remediation by physical and biological means and risk assessment of pollutants. He has also contributed recently to relating the chemical forms (speciation) of metals present in soils to uptake by biota and the development of biotic ligand models for toxicity and their application in soils.
He has published over 200 papers in international refereed journals, in a total of over 350 publications including books and review papers and is on the ISI Highly Cited Researchers list, putting him among the top 0.5% of researchers in environment and ecology worldwide. Other awards and achievements include:

- Appointment in 2001 as a Special Professor in the School of Biosciences in Nottingham University.
- Editorial positions for the international journals: Plant Cell and Environment, Journal of Environmental Quality and Soil Biology and Biochemistry.
- He is a partner is many international research programs including those of the EU, UNEP, UNIDO, IAEA and FAO.
- Appointed to the Committee on toxicants and pathogens in biosolids applied to land of the National Academy of Sciences, Board of Environmental Studies and Toxicology, USA, 2001-2002.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: James K. Mitchell
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Department/Group: CEE/Geotechnical
University/Institution: Virginia Tech

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Research Expertise (2-3 lines of key phrases): Soil composition and structure and interrelationships with soil engineering properties and behavior; coupled flows and time effects in soils; influences of chemical, mineralogical, and biological processes on soil composition and mechanical properties

Synthesis of Research Activities Relevant to Workshop:

Primary research activities focused on experimental and analytical studies of soil behavior related to geotechnical problems, admixture stabilization of soils, soil improvement and ground reinforcement, physico-chemical phenomena in soils, environmental geotechnics, the stress-strain time behavior of soils, in-situ measurement of soil properties, and mitigation of ground failure risk during earthquakes. Has supervised the dissertation research of 75 Ph.D. students and authored more than 350 publications on these topics, including "Fundamentals of Soil Behavior," third edition by Mitchell and Soga published in May 2005, several state-of-the-art papers and guidance documents on soil stabilization, waste containment, ground improvement and earth reinforcement. Served during the 1960's and early 1970's as the National Aeronautics and Space Administration's Principal Investigator for the Soil Mechanics Experiment, which was a part of Apollo Manned Missions 14-17 to the Moon. Recent research has included studies of electrical response properties of soils and the role of biological factors in soil engineering properties and behavior.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Website:

Research Expertise:
- Risk management & assessment
- Civil Engineering
- Engineering Geology
- Mining engineering

Synthesis of Research Activities Relevant to Workshop:
Design & soil investigations
- Monitoring strategies
- Soil- and groundwater investigations, non-destructive in-situ as well as laboratory testing
- Design topics on improvement of the sub surface soil and embankments for railways and motorways
- Design aspects of underground structures such as large diameter tunnels
- Design of large, vibration resistant, foundations
- Risk management of large scale civil projects
- General geo- and rock mechanics

Soil improvements
- Grouting and injections of soil,
- Geological processes, diagenesis
- Formation and weathering of minerals and rock.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Brina Mortensen
Position/Title: Graduate Student
Department/Group: Civil & Environ. Engineering
University/Institution: University of California, Davis

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Research Expertise:

- microbial induced cementation of sand

Synthesis of Research Activities Relevant to Workshop:

My current research project involves the use of *Bacillus pasteurii* to induce calcite precipitation in granular soils. The calcite precipitation is a response to the increase in pH within the soil environment due to the metabolic processes of the *Bacillus pasteurii.* The change in stiffness of the soil from the cementation process is monitored using shear wave velocities obtained with the use of bender elements. The change in strength of the soil, the integrity of the cementation, and the response to shear loading is studied using triaxial equipment and bender elements. In addition, the influence of different pore fluids and soil types on the cementation process will be studied using rigid cells under confinement.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Douglas C. Nelson
Position/Title: Professor and Chair
Department/Group: Section of Microbiology
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Website:

Research Expertise:
Prokaryotic diversity. Ecology, physiology, and genetics of bacteria, with special emphasis on aerobes and anaerobes of the sulfur cycle. Microbial methylation of inorganic mercury in marine and freshwater sediments.

Synthesis of Research Activities Relevant to Workshop: I have been recently introduced to the topics surrounding use of bacteria for bio-stabilization of soils and am attending this workshop to learn more. Based on my knowledge and experience in areas of microbial diversity, physiology and ecology I hope to be able to contribute to the discussions.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Klaus Nüsslein, Ph.D.
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University/Institution: University of Massachusetts

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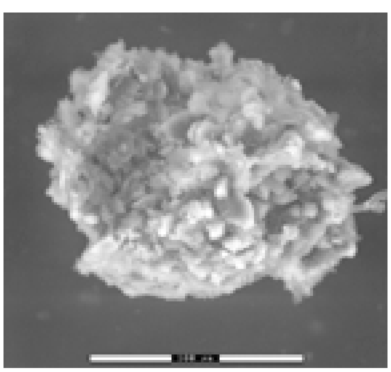
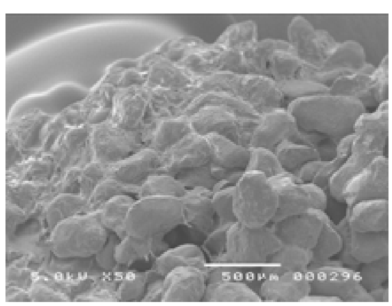
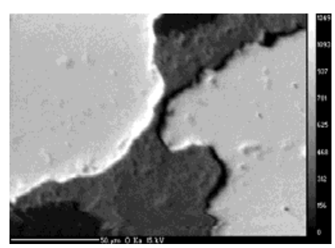
Research Expertise (2-3 lines of key phrases):

- Microbial community structure over the continuum of environmental conditions: regulation and adaptation of microbial community structure and function to external stress factors.
- Biogeochemical aspects that drive interactions among bacterial communities in extreme environments.
- The use of molecular techniques in the analysis of microbial community structure.

Synthesis of Research Activities Relevant to Workshop:
(keep profile to 1 page total…fine to include images, etc.)

Soil Microenvironments: Functional niches for the soil nitrogen cycle across the size range of all soil microaggregates. 	*Soil Stability (collaboration with DeJong)*:	
	Sand solidification with bacterial in situ cementation. 	Elemental Map showing biocementation at sand grain contact. 

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Dr. R. Jane RICKSON
Position/Title: Senior Lecturer in Soil Erosion & Conservation
Department/Group: National Soil Resources Institute, Department of Natural Resources, School of Applied Sciences.
University/Institution: Cranfield University

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Research Expertise (2-3 lines of key phrases):
Use of vegetation for erosion control and slope protection (soil bioengineering); soil erosion processes; soil erodibility; use of geotextiles and soil conditioners for erosion control. Experimentation in erosion research, especially use of rainfall simulators.

Synthesis of Research Activities Relevant to Workshop:
Research at Cranfield University investigates linkages between life sciences and engineering, especially related to the role of above- and within-ground biology in agricultural, geotechnical and civil engineering. We are particularly interested in the effects of living organisms on soil structure, erodibility and slope stability. For example, we have been investigating the role of vegetation in slope stabilisation and erosion control ("bioengineering") for several years. In this we consider the engineering properties of the canopy, stem, roots and stand of vegetation in terms of changing hydrological, hydraulic and mechanical properties of soil and other slope forming materials. The aim of this work is to incorporate living components into traditional civil and geotechnical engineering design and installations.

At a smaller spatial scale, we have investigated the role of soil microbiology on soil structure and stability. We have researched the relationships between land management practice (e.g. tillage), soil biology (notably microbial communities and their distribution within the soil), and soil susceptibility to erosion and runoff generation. In addition to this, in the future we hope to investigate the role of incorporated natural fibres to increase soil strength and improve hydrological properties.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Mary J.S. Roth
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Website:

Research Expertise (2-3 lines of key phrases): Reliability-based design, retaining wall structures, use of geophysical methods for geotechnical projects, geophysical testing in karst, use of bacteria to stabilize loose sands.

Synthesis of Research Activities Relevant to Workshop: It was hypothesized that the addition of biofilm-forming bacteria would provide some cohesion between sand particles and increase resistance to liquefaction failure in loose, saturated sand deposits. Using two different preparations of sand and two strains of bacteria, Flavobacterium johnsoniae UW101 (expected to form a bio-film) and Flavobacterium johnsoniae UW102.92 (expected to simply attach to the sand), the large strain strength of loose sand was tested. Significant activities related to this research included: design and construction of bench-scale box model with sampling ports and the ability to apply a small gradient for flow through the sand, development of protocol for identifying bacteria cells and the presence of a biofilm using epiflourescence microscopy in conjunction with a confocal microscope, and use of undergraduate research students from both civil engineering and biology. Statistically significant increases (15 to 87 percent) in baseline strength were found with both strains of bacteria. However, the box model became contaminated after multiple trials and additional testing with specific bacteria types became impractical. Work has begun using the box model with indigenous bacteria gathered from local streams.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: J. Carlos Santamarina
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USA

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Research Expertise:
- soil behavior
- experimental methods
- wave based characterization

Synthesis of Research Activities Relevant to Workshop:
- Geometrical and mechanical limits to bioactivity in soils
- Fluid stiffness control: gas generation
- Skeletal stiffness control: cementation
- Hydraulic conductivity control: clogging in radial flow
- Soils bio-engineering

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Robert W. Smith
Position/Title: Distinguished Professor of Subsurface Science
Department/Group: Biological and Agricultural Engineering
University/Institution: University of Idaho – Idaho Falls

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Research Expertise:
Biogeochemistry of terrestrial subsurface systems, Geologic carbon sequestrations, Application of geocentrifuge techniques to vadose zone reactive transport

Synthesis of Research Activities Relevant to Workshop:
Dr. Smith is a biogeochemist with 25 years experience contributing to and leading interdisciplinary research and engineering projects focused on the fate and mobility of contaminants in subsurface environments. Prior to joining the University, his research focused on U.S. Department of Energy's subsurface science issues at Hanford, WA (Basalt Waste Isolation Project, Pacific Northwest National Laboratory), and Idaho National Laboratory. Dr. Smith is a principal investigator in the Environmental Remediation Science Program and a past principal investigator in the Environmental Management Science and the Natural and Accelerated Bioremediation Research Programs. He has published 33 reviewed papers, organized and served as editor the "Scientific Basis for Nuclear Waste Management XXIII" symposium, and given over 70 presentations at scientific meetings. Currently, Dr. Smith is exploring the applicability of centrifuge techniques to investigate biogeochemical processes under variably saturated vadose zone conditions and the geologic sequestration of carbon dioxide in deep mafic rock hosted aquifers.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Patricia Sobecky
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University/Institution: Georgia Institute of Technology

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Research Expertise (2-3 lines of key phrases):
Environmental microbiology and microbial ecology, molecular microbial ecology, plasmid ecology, horizontal gene transfer and bioremediation of soils

Synthesis of Research Activities Relevant to Workshop:

We are applying microbiological and molecular ecology approaches to address microbial activities in systems ranging from the horizontal gene transfer of metal stress genes among bacteria in radionuclide and heavy metal contaminated subsurface environments to determining the metabolically active microbial populations present in deep sea sediments and gas hydrates. A list of recent relevant publications is provided below.

Martinez, R.J., Wang, Y., Raimondo, M.A., Coombs, J.M., Barkay, T., and P.A. Sobecky. 2006. Horizontal gene transfer of P_{IB}-type ATPases among bacteria isolated from radionuclide- and metal-contaminated subsurface soils. Appl. Environ. Microbiol. 72:3111-3118.

Martinez, R.J., Mills, H.J., S. Story, P.A. Sobecky. 2006. Prokaryotic diversity and metabolically active microbial populations in sediments from an active mud volcano in the Gulf of Mexico. Environmental Microbiology 8(10):1783-1796.

Mills, H.J., R.J. Martinez, S. Story and P.A. Sobecky. 2005. Characterization of microbial community structure in Gulf of Mexico gas hydrates: a comparative analysis of DNA- and RNA-derived clone libraries. Appl. Environ. Microbiol. 71:3235-3247.

Mills, H.J., R.J. Martinez, S. Story, and P.A. Sobecky. 2004. Identification of members of the metabolically active microbial populations associated with *Beggiatoa* species mat communities from Gulf of Mexico cold-seep sediments. Appl. Environ. Microbiol. 70:5447-5458.

Mills, H.J., C. Hodges, K. Wilson, I.R. MacDonald and P.A. Sobecky. 2003. Microbial Diversity in Sediments Associated with Surface Breaching Gas Hydrate Mounds in the Gulf of Mexico. FEMS Microbiol. Ecol. 46:39-52.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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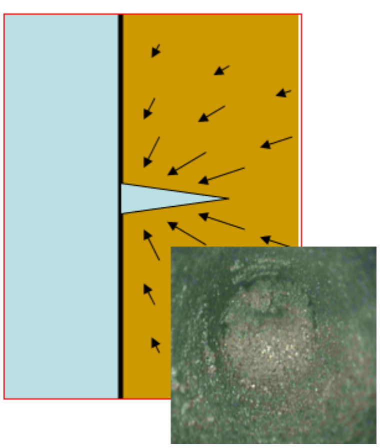
Research Expertise: Geotechnical engineering, Environmental geotechnics, Underground infrastructure monitoring and assessment, Wellbore stability for oil/gas/methane hydrate recovery

Synthesis of Research Activities Relevant to Workshop:
I previously worked on bio-surfactants for cleaning up contaminated soils. I am currently interested in applications of microbiology to geotechnical engineering. Possible applications include (i) microbial enhanced oil/gas recovery, (ii) bio-reinforcement to reduce load applied to wellbore casing and to prevent formation of fractures from the wellbore, (iii) bio-stabilisation to prevent sand production into wellbore, (iv) self-healing of underground infrastructure, and (v) bio-sealing and bio-reinforcement of soils to minimise degradation of underground infrastructure.



Prevent sand production into wellbore?

Acid attack by bacteria action on cast iron tunnel lining?

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Douglas I. Stewart
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University/Institution: University of Leeds

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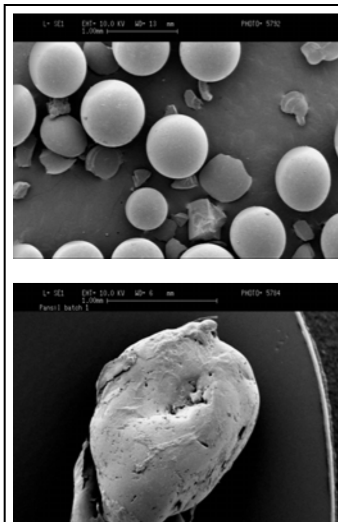
Research Expertise: Environmental Geotechnics, including; remediation of contaminated groundwater; the causes and impacts of chromate release from chromium ore processing residue disposed in the near surface environment; effect of humic materials on Cu^{2+} mobility in contaminated soils; application of molecular techniques to characterize microbial populations in soils with microbially-induced metal reduction.

Synthesis of Research Activities Relevant to Workshop:
As an engineer my aim is to understand factors controlling the performance of in-situ techniques so that they can be developed for deployment on site.
Long-term performance of permeable reactive barriers (PEREBAR), EU FP5. This project involved determining the performance of novel resins for treating uranium contaminated groundwater. It showed the importance of contaminant speciation in determining the outcome of any attempt to treat contaminated groundwater. It also highlighted the value of geochemical modelling in understanding that speciation, particularly where potential complexing ligands such as carbonate are present.
Bio-stimulation for the in-situ treatment of metal contaminated groundwater, Royal Society, UK. Currently there is no economically viable treatment for chronic contamination problems arising from long-term industrial use because equipment intensive technologies are very costly when treatment times are long. Injection of a harmless organic molecule into contaminated aquifers as an electron donor to promote the growth of indigenous metal reducing microbes can result in the immobilization of some inorganic contaminants (e.g. CrO_4^{2-}, UO_2^{2+} and TcO_4^-). This pilot study is investigating microbially mediated chromate reduction in neutral and alkaline soil-water systems characteristic of chromium ore processing residue disposal sites.



New PRB materials for treating uranium contaminated groundwater

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: Ian Thompson
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University/Institution: University of Oxford

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Research Expertise (2-3 lines of key phrases):

- Environmental Biotechnology, linking microbiology with engineering.
- Bioremediation, industrial waste treatment, community manipulation.
- Bacterial diversity and theoretical ecology.

Synthesis of Research Activities Relevant to Workshop:

Bacterial Diversity and Functionality

Employment of a range of phenotypic and genotypic methods for understanding microbial diversity in soils, in particularly in chemically contaminated sites. This includes nutrient assimilation and fatty acid methods, and molecular profiling methods such as PCR-DGGE. In addition, the employment of cutting edge technologies such as the combined deployment of Raman Microscopy and Stable Isotope Probing to identify, down to the single cell level, functional active components of the community.

Manipulation of microbial communities for soil clean-up

Once the degradation capability of the soil microbial community has been determined to then stimulate and manipulate clean-up activities. This includes the deployment of cross-disciplinary approaches such as phytoremediation, addition of macro-organisms (earthworms), electrokinetics and ultrasound to stimulate soil clean-up rates. The kind of contaminants of interest include BTEX, naphthalene, PCP and mustard gas.

Theoretical microbial ecology

Establishing a sounder theoretical base for understanding the phenomenal diversity within microbial communities. A gram of soil can contain in excess of 10^9 individuals consisting of tens of thousands of genotypes. In order to move from the observational, case-by-case and site-by-site approach, we need to develop theories and models (such as species area relationships in macro-ecology) in microbial ecology, and in deed have made tentative start in this respect.

1. Brevia article: Larger islands house more diverse bacterial communities. *Science* (2005), **308**, 1884.
2. Bacteria and island biogeography. *Science* (2005) **308**, 1998-1999.

Global change

To manipulate key microbial populations, such as the methane and ammonium oxiders to control the emission of methane and other VOC from landfill and other soil sites.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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University/Institution: San Diego State University

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Research Expertise:

Granular materials: breakage, engineered mixtures, controllable filters.
Particle migration through perforations and tortuous networks: clogging and flushing
Experimental geomechanics.

Synthesis of Research Activities Relevant to Workshop:

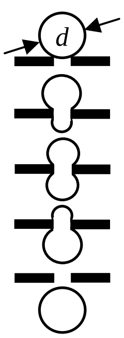

Fig. 1.

In geomechanics, filtration, clogging, and flushing processes are analyzed assuming that the filtrate is composed of rigid particles. This assumption is particularly flawed when the filtrate is composed of "bio-particles", such as bacteria and zooplankton. Indeed, bio-particles are flexible and/or shear-able. For example, the assumption that a particle with size d will be retained by a pore throat with size d_o when $d > d_o$ is not necessarily valid for bio-particles (**Fig. 1**). Similarly, the transport and entrapment of multiple bio-particles through and within a perforation or a tortuous network is affected by the particles' shear-ability and/or flexibility. For instance, bio-particle shearing during filtration creates more filtrate; the increase in filtrate particle concentration leads to clogging. Filtration and flushing problems concerning bio-particles include clogging of perforated drains and soils in geotechnical infrastructure, permeability reductions in pavement subgrade, and removal of invasive plankton species from ballast water.

A flexible filtrate calls for a filter with controllable pore microstructure. Current research efforts sponsored by NSF and NOAA are directed towards engineering stress-controlled filters using mixtures of rigid and compressible filter particles[1]. Compressing the filter via external stresses enhances filtration and filter unclogging is realized by flushing the filter while it is un-compressed (**Fig. 2**).

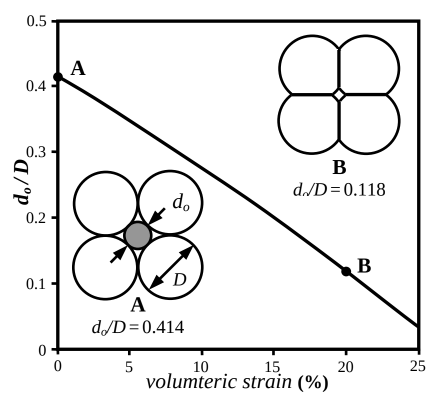

Fig 2. Controllable filter matrix.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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Research Expertise:

- Farmacochemistry, (biochemisty & Organic chemistry)
- Analytical chemistry,
- Chemical-engineering,
- Material sciences.
- Environmental engineering
- Clay mineralogy

Synthesis of Research Activities Relevant to Workshop:

Strengthening of soils by means of biochemical reactions

Biogrout research programme where bacteria are used to strengthen soil. Research topics are:

Proces of calcite formation in sand (urease reaction)

Clean reaction, Calcite production without ammonium production

Silicate production to strengthen peat by means of a combined chemical and biochemicalreaction)

Clogging of soils, called Biosealing,

where through a biological process erosion of soil is initiated and clogging is achieved.

From refuse to re-use:

Sustainable landfill

Dredging sludge

Materials,

Classical Civil Engineering materials such as Silicate injections, grout injections, cut off walls and bentoniet uses.

Directional drilling

Bio-Soil Interactions and Engineering Workshop
Participant Profile

Name: **Richard Whalley**
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Department/Group: **Soil Physics Group**
University/Institution: **Rothamsted Research**

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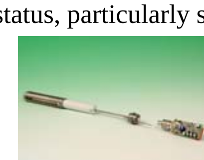
Research Expertise:
Development of robust sensors to measure matric potential in the field. Response of plants to abiotic stresses that arise because of soil drying, especially soil strength. Effect of plant root activity on soil hydraulic properties.

Synthesis of Research Activities Relevant to Workshop:
I have developed and used a number of novel techniques that allow the effects of soil strength and water stress on plant growth to be investigated independently of each other. A key result from this work has been to identify that in a drying soil mechanical impedance is likely to be the key stress that limits the extension of the root system rather than low matric potential.

A laboratory system to simulate the effect of high soil strength on plant growth. Roots growth in either confined or unconfined sand, so strength can be increased with out changing soil hydraulic properties or soil aeration

I have developed sensing methods to measure the soil's physical status, particularly soil matric potentials.

A prototype porous matrix sensor to measure matric potential. A model of hysteresis has been implemented so that the appropriate calibration curve is updated, depending on if the soil is wetting or drying



These sensors are well suited to agriculture, or long term monitoring applications, because they cover a wider range of matric potentials than standard water-filled tensiometers and the need no maintenance. I am interested in developing new and novel sensing technologies to measure/sense the internal stresses in soil and then relate these to the pressures the roots need to exert to expand cavities.

In current work we are interested in developing a more general understanding of the mechanism responsible for the generation of soil structure by plant roots. Rothamsted has a number of long term experiments that allow the effect of soil management on soil physical properties to be explored.

Bio-Soil Interactions and Engineering Workshop
Participant Profile

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University/Institution: Abertay

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Website:www.simbios.ac.uk;

Research Expertise:
Soil biophysics.
Quantification of mineral-microbe interfaces.
x-ray micro-tomography.

Synthesis of Research Activities Relevant to Workshop:
I am active in three research areas relevant to the workshop.
[1] Functional quantification of heterogeneous structures - the use of fractal geometry and other mathematical techniques to quantify clustering properties and pore connectivities in heterogeneous media. Using such quantification to predict water flow, retention and stability of porous biomaterials.
[2] Microbial movement and activity in soil: chemotaxis & signalling - How soil physical conditions affect microbial dynamics (bacteria, nematodes, fungus). Examining the effect of structural change and microbial activity (nutrient flows, predator~prey interactions). The origin of heterogeneity with respect to biological inputs.
[3] Using science to develop solutions for practical problems in the environment. For example, the link between soil microbes and the playability of golf courses.

I am particularly interested in developing sustainable multidisciplinary research projects. My research group (Scottish Informatics Mathematics Biology & Statistics- SIMBIOS) is highly multidisciplinary with staff covering theory, experiments, physics and biology. The core of the current work is soil ecosystems, but recently has developed into biomedical applications.
I am Research Director of the Abertay Centre for the Environment (ACE) which interacts with industrial partners in the area of environmental legislation and research: http://www.ace.abertay.ac.uk/

I am a Director of Sensation which is an active and successful science Centre in Dundee: http://www.sensation.org.uk/

Appendix B. Workshop Schedule

Sunday, April 1, 2007

2:00 – 4:30 pm	Arrival & check-in at MIT Endicott House Facility
4:30 pm	Welcome reception (EH - Gun Room)
5:30 pm	Dinner, Vision & Scope, Introductions (EH - Living Room)
7:00 pm	***Evening Lectures: "Current Boundaries and Needs of Our Disciplines"*** (EH - Living Room) o Moderators Jason DeJong & Kenichi Soga o Lecturers: Jim Mitchell & Iain Young
8:30 – 10:00 pm	Cash Bar (EH - Gun Room)

Monday, April 2, 2007

8:00 am Breakfast (EH - Dining Room)

9:00 am **Geotechnical Engineering Lectures** (BC – Lecture Hall)
- Moderator: Julio Valdez
- Lecturers: Stephan Jefferis, Carlos Santamarina, Willem van der Zon

10:30 am **Geotechnical Engineering Poster Presentations** (BC – Seminar A & B)
- Poster Presenters: Scott Brandenburg, Jason DeJong, Michael Harbottle, Ed Kavazanjian, John McDougall, Waldo Molendijk Mary Roth, Kenichi Soga, Julio Valdez,
- Other participants consider the following questions:
  - What have I seen/learned that is of relevance to what I do?
  - What do I do that is of relevance to what I have seen/learned?

11:30 am **Geotechnical Engineering Workshop Discussion** (BC – Lecture Hall)
- Moderator: Julio Valdez & Carlos Santamarina

12:00 pm Lunch (Dining Room)

2:00 pm **Microbiology & Geochemistry Lectures** (BC – Lecture Hall)
- Moderator: Jon Lloyd
- Lecturers: Thomas Kieft, Sookie Bang, Ian Thompson

3:30 pm **Microbiology & Geochemistry Poster Presentations** (BC – Seminar A & B)
- Poster Presenters: Steven Banwart, Philip Bennett, Simon Bottrell, Laurie Caslake, Jon Lloyd, Ferran Garcia-Pichel, Doug Nelson, Klaus Nüsslein, Patricia Sobecky

4:30 pm **Microbiology & Geochemistry Workshop Discussion** (BC – Lecture Hall)
- Moderator: Jon Lloyd

5:00 pm Break

6:00 pm Dinner (EH - Living Room)

8:00 – 10:00 pm Cash Bar (EH - Living Room)

Tuesday, April 3, 2007

8:00 am	Breakfast (EH – Dining Room)
9:00 am	**Soil Science & Geoenvironmental Lectures** (BC – Lecture Hall) o Moderator: Robert Smith o Lecturers: Dave Manning, Akram Alshawabkeh, Bob Kalin
10:30 am	**Soil Science & Geoenvironmental Poster Presentations** (BC – Seminar A & B) o Poster Presenters: Glyn Bengough, Susan Burns, April Gu, Phil Haygarth, Mike Humpherys, Steve McGrath, George Redden, Jane Rickson, Robert Smith, Doug Stewart, Richard Whalley
11:30 am	**Soil Science & Geoenvironmental Workshop Discussion** (BC – Lecture Hall) o Moderator: Robert Smith
12:00 pm	Lunch (EH – Dining Room)
2:00 pm	**Process Monitoring & Measurements – the Interdisciplinary Toolbox** (BC – Lecture Hall) o Moderator: Susan Burns o Lecturers: Mike Humpherys & all participants with 3-5 minute "nugget" presentation
4:00 pm	**Brainstorming Sessions in Research Interest Groups** (BC – Lecture Hall, Seminar A, B, & C) o Discussion Facilitators: TBD
6:00 pm	Dinner (EH – Living Room)
8:00 – 10:00 pm	Cash Bar (EH – Gun Room)

Wednesday, April 4, 2007

8:00 am	Breakfast (EH – Dining Room)
9:00 am	**Synthesis of Research Opportunities** (BC – Lecture Hall) o Moderators: Jason DeJong & Kenichi Soga o Lecturer: Richard Fragaszy
10:30 am	Refreshment break
11:00 am	**Synthesis of Educational Opportunities** (BC – Lecture Hall) o Moderators: Mary Roth & Steve Banwart o Discussion Points: ▪ Overview of IGERT Education Program at Virginia Tech ▪ Education needs by discipline ▪ Education needs at K-12, undergrad, and graduate levels
12:30 pm	Lunch & Closing Remarks (BC – Dining Hall)
1:30 - 2:00 pm	Check-out & Depart

Appendix C. Discipline Presentations

Geotechnical Lectures:

James K. Mitchell (given by Ed Kavazanjian), "New Frontiers in Geotechnical Engineering, Challenges and Opportunities"

Stephan Jefferis, "A problem derived perspective to promote pro-active management"

J. Carlos Santamarina, "Biological Considerations in Geotechnical Engineering"

Willem van der Zon, "BioGrout, Past-Present-Future"

Geotechnical Presentations:

Scott Brandenburg, "A Bender Element System for Measuring Shear Wave Velocities in Centrifuge Models"

Jason DeJong, "Microbially Induced Calcite Cementation to Improve Soil Behavior"

Michael Harbottle, "Biodegradation of stabilized/solidified (S/S) organic contaminants, and Electrokinetic enhancement of biodegradation."

Michael Harbottle, "Recent Research Projects Related to Bio-Soils Interactions"

Ed Kavazanjian, "Biological Improvement of Soils"

John McDougall, "Hydro-bio-mechanical (HBM) modeling"

Waldo Molendijk, "SmartSoils, Soils on Demand"

Mary Roth, "Increasing Sand Strength with Bacteria… the engineer's perspective"

Kenichi Soga, "Living Organisms: Are they the Original Ground Engineers"

Julio Valdez, "Stress – Controlled Filtration"

Stephan Jefferis, "ROTAS – A new field analytical tool to measure the total toxicity of soil"

J. Carlos Santamarina, "Influence of Microorganisms in Soil Behavior"

Ning Liu, "Soil & Site Characterization using Electromagnetic Waves"

Microbiology & Geochemistry Lectures:

Iain Young, "Bioengineering Soils"

Thomas Kieft, "Assessing Abundance, Activities, and Biodiversity in Engineered Soils"

Sookie Bang, "Selective Cementation Induced by Microbial Activities"

Ian Thompson, "Sustainable Clean-up of Contaminated Soils"

Microbiology & Geochemistry Posters:

Steven Banwart, "FTIR micro-spectroscopy and potentiometric titrations to characterize the interactions occurring at the bacterial cell – solid interface"

Steven Banwart, "The Cell-Mineral Interface Research Programme"

Steven Banwart, "Quantitative Measurement of Colloid & Microbe Transport in Unsaturated Sand at Meso-Scale using UV-Fluorescence Imaging"

Steven Banwart, "The Multi-Factorial Analysis of Cell-Mineral Interactions in Diverse Systems"

Philip Bennett

Simon Bottrell, "Stable Isotopes and other Tracers in Contaminant Hydrogeology and Biodegradation"

Laurie Caslake, "Increasing Sand Strength with Bacteria… the biologist's perpective"

Jon Lloyd, "Solid-state Biotechnology: Nano-spinel synthesis by FE(III)-reducing bacteria"

Jon Lloyd, "Experimental studies of FE(III) mineral reduction by Geobacter"

Ferran Garcia-Pichel

Klaus Nüsslein

Patricia Sobecky, "Aerobic Uranium U(VI) Bioprecipitation by Metal Resistant Bacteria Isolated from Radionuclide – and Metal – Contaminated Subsurface Soils"

Soil Science & Geoenvironmental Lectures:

Dave Manning, "Engineering Soils to Capture Carbon"

Akram Alshawabkeh, "Electrochemical Methods for Enhanced Bioremediation"

Bob Kalin, "Engineering Soil/Bio Interaction, The soft touch…"

Soil Science & Geoenvironmental Posters:

Glen Bengough, "Mechanical stabilization of slopes by plant root systems"

Susan Burns, "Coupled Mechanical and Chemical Behavior of Bentonite Engineered with a Controlled Organic Phase"

Ferran Garcia-Pichel, "Rope-building microbes as erosion-control engineers"

April Gu, "A VC-Mineralizing Consortium is Dominated by Novel *Flixibacter* Species"

Phil Haygarth, "Biological effects on catchment scale processes"

Phil Haygarth, "A conceptual model describing the effects of soil wetting and drying on phosphorus biogeochemistry"

Phil Haygarth, "Evidence for diurnal fluctuations in dissolved phosphorus concentration in a small moorland river"

Mike Humphreys, "Grass Roots to Improve the Management of Soil-Water"

Bob Kalin, "In-Situ Enhanced Soil Treatment for Biodegradation"

Davis Manning, "Multidimensional characterization of soil carbon pools using stable isotope and quadrupole mass spectrometry couple to thermal analysis"

Steve McGrath, "Soil Pollution Assessment and Remediation"

George Redden, "BSSC-1042: Calcium carbonate precipitation along solution-solution interfaces in porous media"

Robert Smith, "Microbially Facilitated Calcite Precipitation for Remediation of Strontium-90 (EMSP Project 87016)"

Robert Smith, "*In situ* stabilization of ^{90}Sr by microbially facilitated calcite precipitation"

Doug Stewart, "Stimulation of microbially-mediated chromate reduction in alkaline COPR contaminated soils"

Richard Whalley, "Soil-root Interactions"

Appendix D. Interdisciplinary Measurement & Monitoring Presentations

Measurement & Monitoring Lectures:

Mike Humphreys, “Designing Multifunctional Grasslands”

Measurement & Monitoring Nugget Presentations:

Ian Thompson, “Application of Raman Confocal Microscopy for Soil Microbiology”

Klaus Nüsslein, “Microbial Community Activity”

David Manning, “Thermal Analysis with Simultaneous Evolved Gas and Stable Isotope Analysis: A Nugget to Describe a Unique Facility”

Ferran Garcia-Pichel, “Rio Mesquites, Main Drainage Course of Cuatro Ciénegas, MX”

April Gu, “Tools in Bioremediation”

Cassandra Fowler, “Mineral Precipitation”

Steve Banwart, “Model Laboratory Systems”

Bob Smith, “Geocentrifuge Studies of Flow and Transport in Porous Media”

J. Carlos Santamarina, “Bio-Geophysics”

Scott Brandenburg, “A Bender Element System for Measuring Shear Wave Velocities in Centrifuge Models”

Bob Kalin, “Conductive Nanowires – Permeable Column Stimulate Ox/Redox Precoesses”

George Redden, “Stimulation of Injection of a Supersaturated Solution using Smoothed Particle Hydrodynamics”

John McDougall, “Modelling: Another Tool in the Kit”

Steve McGrath, “Phytoremediation of Arable Sludge Soils”

Willem van der Zon, “BioSealing Hypothesis”

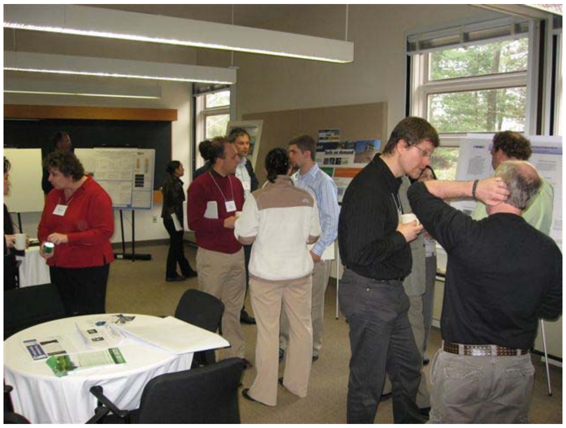
Appendix E. Photographs from Workshop

MIT Endicott House

US-UK Participants

Presentations

Plenary Sessions & Discussions



Poster Sessions

Recooperation