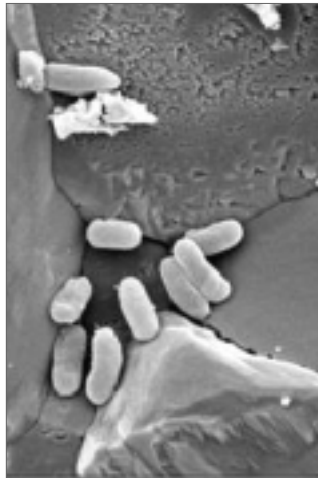

Bedrock Bioremediation Center

2001 - 2002 Annual Report



Message from the Director

I am pleased to report that the Bedrock Bioremediation Center (BBC) has just finished its third year of research and its first year of active outreach. There have been some noteworthy research accomplishments and exciting outreach efforts for the BBC this year. Some highlights are provided below.

This fall, the BBC completed its first well cluster – a group of wells in which at least two are hydraulically connected. With the final cluster borehole installed, testing is now underway to confirm the hydraulic connectivity of the wells. The newly completed well cluster will allow BBC researchers to test bioremediation technologies *in situ*. The process of selecting a bioremediation technology suitable for testing at the BBC field site will soon begin.

Using their BBC field data, BBC hydrologists developed a software application called HYTESTS, which estimates hydraulic conductivity (K) and storage coefficients (S) from flow rate-drawdown time data. This application was presented at the Fractured Rock Aquifers 2002 Conference in Denver, CO. HYTESTS is currently being converted from its original DOS format to a Windows application. This new format will soon be available on the BBC website (www.bbc.unh.edu).

The BBC has initiated its outreach efforts by providing short courses and workshops to federal and state regulators, as well as private sector engineers, scientists, and consultants. The Center has developed a short course entitled *Bioremediation – An Option Worth Considering?* which has been presented to New Hampshire Department of Environmental Services employees and U.S. Air Force personnel, as well as New England area engineers, scientists, and consultants. The Center's workshop entitled *Innovative Approaches for Bedrock Site Characterization* has been presented to New England, New York and New Jersey state and federal regulators as well as consultants. In the future, the BBC plans to offer these programs in other regions of the country that are also plagued by bedrock groundwater contamination.

This year, the BBC has undergone an organizational change. The Center has been incorporated into the University of New Hampshire's new Contaminant Monitoring and Remediation Center (CMRC). Along with the BBC, the CMRC also houses the Storm Water Research Center.

In closing, the Bedrock Bioremediation Center would like to thank the USEPA for its funding, Dr. Mary Gonsoulin (USEPA Project Officer; Ada, OK), and its Research Advisory Board for their guidance and support of our research. We would also like to thank all those who continue to show support and interest in the BBC's research and outreach program. We look forward to working with you in the coming years.

Sincerely,



Nancy E. Kinner, Director
Bedrock Bioremediation Center
University of New Hampshire
Durham, New Hampshire

The Bedrock Bioremediation Center (BBC) at the University of New Hampshire (UNH) specializes in multidisciplinary research on bioremediation of organically-contaminated bedrock aquifers. The Center is comprised of a consortium of faculty from the University's Environmental Research Group (ERG) and the UNH Departments of Civil Engineering, Earth Sciences, and Microbiology. The Center has received four years of funding through U.S. Environmental Protection Agency (USEPA) appropriations.

The BBC is staffed with a Director, Principal Investigators from the UNH Departments of Civil Engineering, Earth Sciences, and Microbiology, a Postdoctoral Research Associate, two Research Scientists, and a Research Technician. The Center also has Master's and Doctoral level graduate students participating in its research efforts.

The BBC's USEPA Project Officer is Dr. Mary Gonsoulin who is a Microbiologist at the R.S. Kerr Environmental Research Center in Ada, OK. Dr. Gonsoulin reviews and approves the BBC's yearly work plans and provides guidance on the BBC's research efforts. The BBC also seeks Dr. Gonsoulin's approval for major work scope and procedural changes as they arise.

The Center's Research Advisory Board is composed of both state and federal regulators; experts in the fields of microbiology, hydrogeology, and geology; and individuals with in-depth knowledge of the BBC's field site. Board members represent the U.S. Environmental Protection Agency, U.S. Air Force, U.S. Geological Survey, and NH Department of Environmental Services. The purpose of the Board is to provide input and guidance on the BBC's research plans and findings. The Advisory Board meets annually with BBC researchers and staff to discuss the Center's accomplishments and proposed research.



Advisory Board member Dr. Frank Chapelle of the USGS and BBC Director Dr. Nancy Kinner.

The Problem

Remediation of contaminated bedrock aquifers, particularly those in competent bedrock, is generally regarded as technically impractical. In the case of bedrock cleanup, bioremediation is one of the few technologies that can potentially work because it uses naturally-occurring microorganisms to degrade the contaminants *in situ*. The acceptance of bioremediation by regulators as an alternative for bedrock remediation is complicated by the fact that little research has been performed in this area and there are few sites where controlled demonstrations have been conducted. This has occurred because:

- (1) it is hard to design pilot tests *in situ* unless the researchers have extensive experience working in bedrock environments,
- (2) it is much harder to document results because monitoring is difficult in bedrock, and
- (3) there are no established sites where new and innovative bioremediation technologies can be evaluated by independent (third party) researchers.

Bedrock contamination presents a perversely difficult problem for regulators. In soil and unconsolidated subsurface environments, the choice regulators face is whether to permit a lower cost passive treatment option rather than require the more expensive active treatment. In bedrock situations, however, the choice at present is whether to require the expense of an unproven treatment technology or natural attenuation. In some *de minimus* situations, this may be acceptable, but in cases where the contaminants may travel great distances and permanently pollute essential drinking water supplies, it is unwise.

Hence, the conundrum for using bioremediation in contaminated bedrock aquifers is that regulators will not sanction it until independent verification occurs, and innovative applications of bioremediation will not be proposed by consultants or developed by vendors/entrepreneurs unless they believe that regulators will accept them.



The BBC is headquartered in the Environmental Technology Building on UNH's entrepreneurial campus in Durham, NH. (Photo by Joseph St. Pierre.)

Introduction

The BBC is well positioned to address this problem. BBC researchers have worked with regulators on bioremediation applications in soil/unconsolidated subsurface environments and have regulators' confidence that they make independent evaluations of bioremediation. In addition, the BBC's Advisory Board has several members from regulatory agencies.

The BBC has an established research team of UNH- and externally-based scientists and engineers able to address unanswered questions concerning bedrock bioremediation applications. The Center has a chlorinated contaminant field site where carefully controlled pilot tests can be conducted to evaluate *in situ* bioremediation technologies.

The BBC also has state-of-the-art research facilities in the Environmental Technology Building at UNH. The BBC has the expertise in drilling and monitoring to produce well-documented data to evaluate the success of *in situ* pilot tests of bioremediation technologies. In addition, the Center is an effective instrument for technology transfer of information about bedrock bioremediation to regulators and consultants. BBC researchers are well known for their teaching abilities and have run several acclaimed workshops for regulators and consultants. The BBC produces technical presentations and reports that discuss how a technology works, its advantages/disadvantages, appropriate applications, and protocols for construction and monitoring.

Finally, the Center also provides advisory services so that regulators and consultants can receive help from BBC researchers on specific applications of bedrock monitoring and bioremediation.

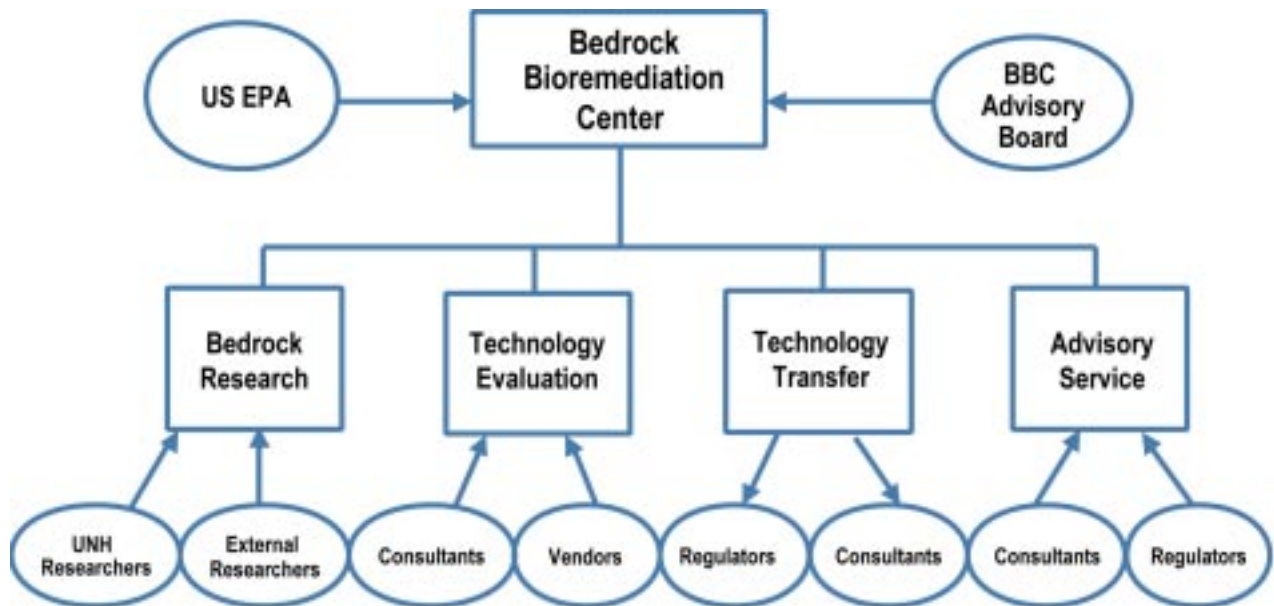
The BBC is positioned to play a significant role in bridging the gulf between regulators responsible for public welfare and environmental protection, and consultants and vendors, helping to remove barriers to effective and appropriate applications of bioremediation in bedrock aquifers.

Focus

The BBC has four main focus areas:

- ▶ Bedrock Research,
- ▶ Technology Evaluations,
- ▶ Technology Transfer, and
- ▶ Advisory Services.

Each of these areas will be discussed at greater length in subsequent sections of this report.



The Bedrock Bioremediation Center's focus in bedrock monitoring and bioremediation.

BBC Research Partners

The BBC has established its chlorinated solvents research site at Site 32 of the Pease International Tradeport (formerly the Pease Air Force Base) in Portsmouth, NH. The BBC is working at Pease under a Federal Facilities Agreement (FFA) between the U.S. Air Force (USAF), NH Department of Environmental Services (NHDES), U.S. Environmental Protection Agency (USEPA), and the Pease Development Authority (PDA).

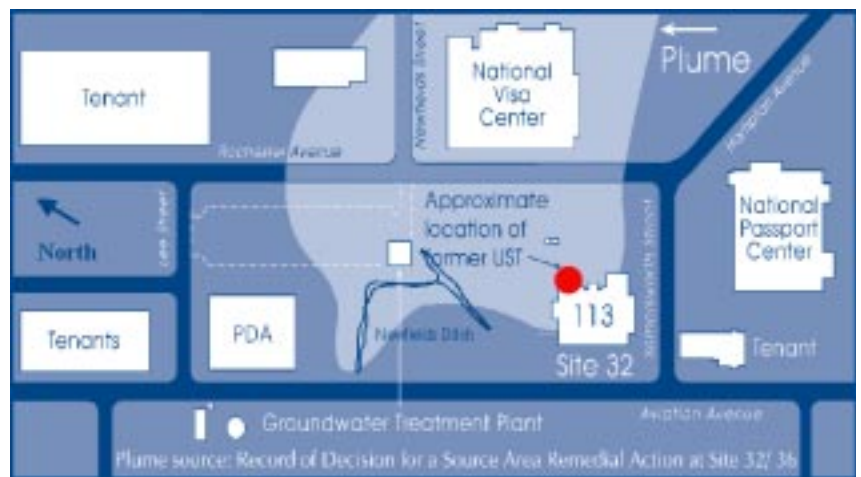


BBC Field Site

The original source of contamination at Site 32 was an overflow of trichloroethylene (TCE) from a 1,200-gallon waste storage tank located underground near Building 113. The TCE was used as part of a degreasing operation to maintain equipment at the former USAF Base. TCE, which is more dense than water, migrated down through the overburden soil and into the bedrock. Concentrations of TCE in the 100,000 ppb range were detected. The plume migrated away from the site with the groundwater moving into the highly fractured (weathered) bedrock and the deeper, less fractured (competent) bedrock. Chemical analysis of the groundwater flowing through the fractures in the bedrock indicates that TCE is being degraded, most likely by naturally-occurring microbes, to dichloroethylene (DCE) and vinyl chloride (VC). As part of the Record of Decision (ROD), groundwater from the most highly contaminated zone (immediately beneath the discharge) is being pumped continuously to the surface and treated to remove the chlorinated organic contaminants. The rest of the plume, which is migrating away from the source area, underlies the U.S. Visa Office building and is moving beneath a red maple wetland. The USAF must monitor the plume indefinitely for chemical constituents that will indicate whether natural attenuation is occurring and the chlorinated contaminants are being biodegraded to acceptable byproducts (e.g., CO₂).

The long-term objectives of the BBC's bedrock research program are to:

1. Improve and develop characterization techniques for groundwater flow and fracture patterns. Without this it will be difficult to implement and monitor bioremediation.
2. Develop and apply innovative microbial and molecular techniques to accelerate and monitor *in situ* bioremediation.
3. Develop field and laboratory methods to determine bioremediation rates.
4. Test and evaluate remediation technologies for organically polluted aquifers.
5. Transfer information learned through research to regulators and consultants.



The plume at the BBC's field site.

Activities at the Chlorinated Solvent Field Site

BBC researchers have developed unique drilling procedures to obtain and process 4-inch diameter cores that contain intact, representative, microbial populations. These procedures allow for the option of maintaining and examining cores under anoxic conditions. Using these procedures, the BBC installed five bedrock boreholes. Each borehole was installed with telescoping casing through the overburden and fractured bedrock in an effort to isolate the overburden and the shallow weathered bedrock zones from the competent bedrock below.

Borehole video logging, omni-directional borehole radar, acoustic and optical televiewer, heat pulse flow meter, natural gamma, caliper, single-point resistivity, and fluid temperature/resistivity analyses were performed on each completed borehole. In addition, the BBC was able to use its drilling parameter recorder (DPR) system during the advancement of three of the boreholes. The DPR is a computerized system that automatically collects data from a series of transducers installed on conventional drilling equipment. The data include information on the advance rate, down-thrust and pull-up pressures, rod torque, rotation rate, mud/water pressure and flow, depth, and time. Data from the DPR, video logs, and geophysical logs were used to select fracture zones in each borehole for further study. These fracture zones were the focus of the groundwater sampling and hydraulic testing conducted in each borehole.

One of the main goals of the BBC is to conduct *in situ* tests of bioremediation technologies in bedrock. In order to do this under controlled site conditions, the BBC has developed the concept of constructing well clusters. A well cluster can serve as an *in situ* reactor consisting of at least two or three boreholes connected by at least one common fracture or dominant hydraulic connection. Within the cluster, the connecting fracture(s) serves as an *in situ* reactor. One upgradient well is linked hydraulically to one or two downgradient wells by this fracture. In this way, for example, amendments can be added in the upgradient well and their effect downgradient can be monitored. The challenge of installing a cluster is in locating the wells so that hydraulic communication exists between them. The task is problematic because of the complex nature of fracture networks, the difficulty in tracking fracture orientations and the distance they travel, and the uncertainty in hydraulic gradients.

The BBC has developed a protocol for drilling and testing a well cluster. In this protocol, the proposed well locations are based on as much data as can be obtained and refined from existing studies and wells including the successively installed BBC boreholes. The latest three wells the BBC has installed complete the first well cluster. At this time, testing to confirm hydraulic connectivity is being conducted.



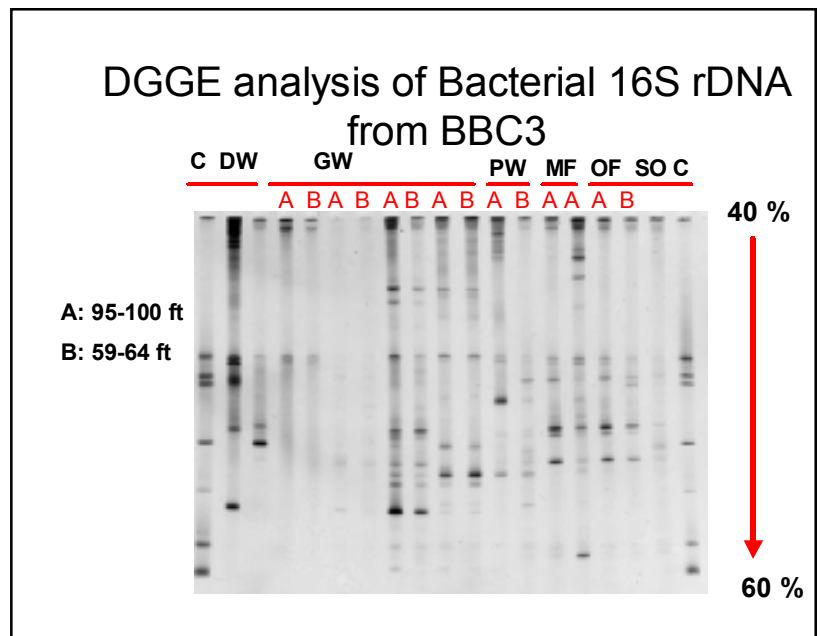
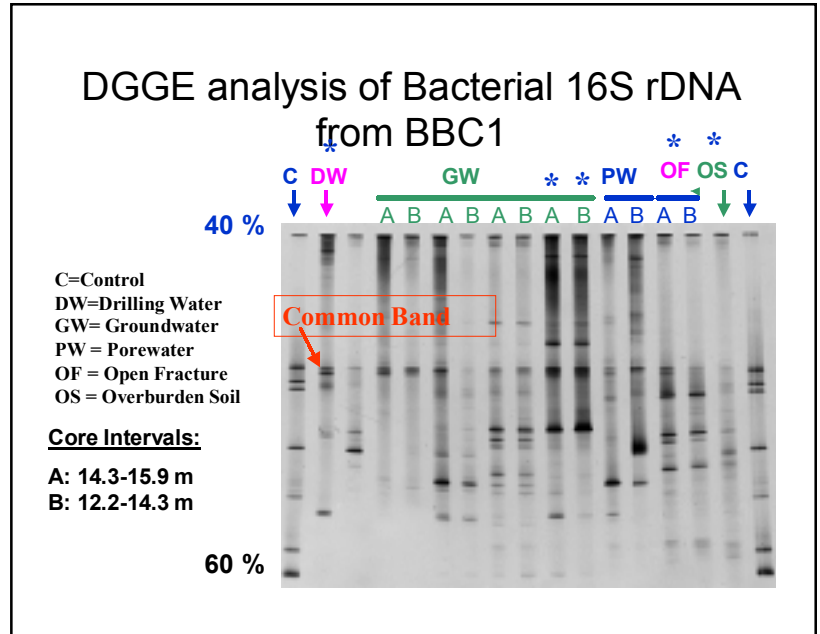
Drilling parameter recorder mounted on a drill rig.

Microbial Characterization

The primary goal of the microbial characterization component of the BBC project is to identify TCE-degrading prokaryotic populations (i.e., Bacteria and Archaea) associated with the fracture faces or residing in the groundwater of the contaminated bedrock. All prokaryotes have a large 16S rRNA gene that is 1500 base pair units long and codes for a large polynucleotide that is part of the small subunit of the ribosome. Base pairs are the individual segments of the DNA (adenine, guanine, cytosine, thymidine). The exact order of the base pairs codes for the enzymes the microorganisms can manufacture. The enzymes that are produced, in turn, dictate the metabolic (degradative) reactions the microorganism can perform. Each species of the Bacteria and Archaea has a unique sequence for its 16S rRNA gene. BBC researchers are identifying the microorganisms present in the Site 32 bedrock using the sequences of the 16S rRNA gene. The microbial community structure is being analyzed by denaturing gradient gel electrophoresis (DGGE), which allows for large numbers of samples to be analyzed simultaneously.

Based on the chemical analysis of groundwater samples from two BBC wells, primers were designed for several specific phylogenetic groups of prokaryotes that may act as key players in the Site 32 bedrock aquifer. These groups include iron-reducers, sulfate-reducers, methanogens, methylotrophs, dehalorespirers, ammonia oxidizers and others. Primers were designed for functional genes including dissimilatory sulfate reductase and methyl CoM reductase. Microbial populations in the contaminated bedrock fracture surfaces and in the groundwater are being quantified using real-time PCR. This technique can quantify unique metabolic groups of microbes. Most probable number (MPN) PCR is also being used to qualitatively study the microbial populations. The results from these PCR methods are being compared to each other and to *in situ* hybridization results.

The BBC has initiated work on fluorescent *in situ* hybridization (FISH). A FISH protocol was optimized for two probes, one for sulfate-reducing bacteria and one for a general Eubacterial probe. It was initially hoped that FISH could be performed directly on rock samples from the BBC cores, allowing a direct count of bacteria present on the fracture surfaces. However, the rock samples autofluoresce at the same wavelength as the fluorochromes used with the FISH probes. As a result, all present FISH work has been focused on analyzing groundwater samples. More probes are being developed to target other relevant groups of bacteria involved with *in situ* TCE degradation.



Fracture Characterization

The Center's initial research focused on open bedrock fractures. However, experiments during drilling showed that the water used to cool the bit and remove the cuttings was scouring microorganisms from these surfaces. Further experimentation confirmed that the scour is incomplete leaving some cells remaining that can be used to determine the populations present but not their abundance.

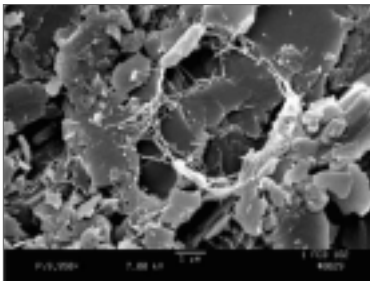
More recently, one of the most interesting results has been the identification of microbial populations extracted from the surface of partially sealed mineralized fractures (PSMF) or microfractures. Unlike the open fractures, microfractures do not appear to be affected by the scouring associated with drilling activity. Because microfractures are tighter in nature, the flow of groundwater through them is less than that through an open fracture. The prevalence of microfractures, however, makes them significant contributors to groundwater flow.

BBC researchers have been working to better understand the relationship between contaminated microfracture surfaces that are frequently weathered and contain secondary minerals and the ecology and metabolic activity of adherent microbial populations. Methods have been developed to allow for microfracture surface characterization using scanning electron microscopy (SEM) for spatial description of bacteria and secondary mineral morphology, energy dispersive analysis of x-rays (EDX) and x-ray photoelectron spectroscopy (XPS) for spatial mapping of elements, XPS for speciation and depth profiling, secondary ion mass spectrometry (SIMS) for ion mass frag-

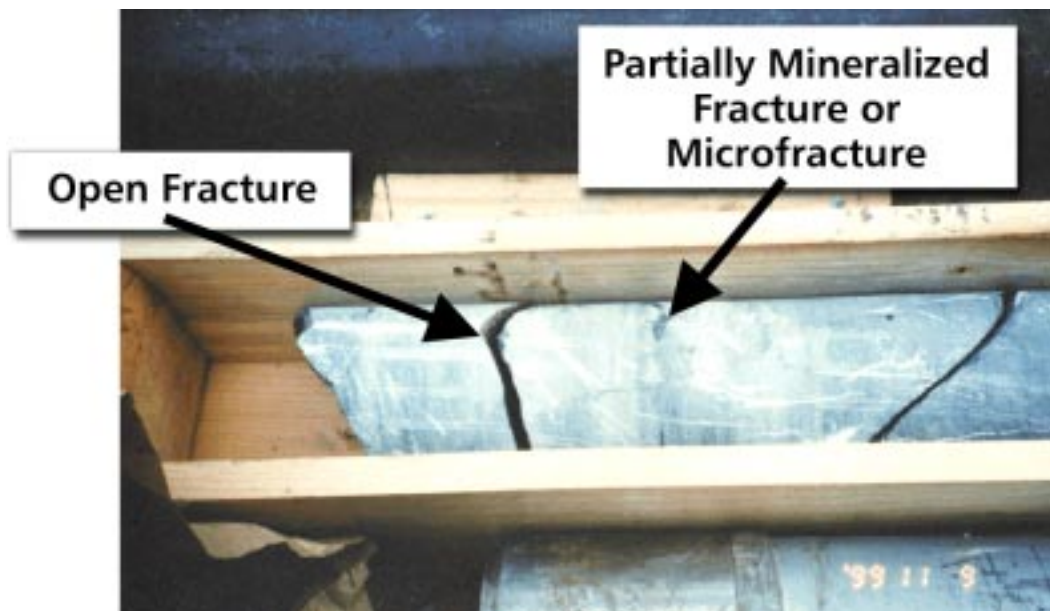
ment finger printing, and x-ray powder diffraction (XRPD) for secondary mineral characterization. Microfracture samples have been collected from three of the five BBC boreholes.

Preliminary examination of the fracture surfaces with petrography and XRPD has shown that a number of different secondary mineral groups are present, most abundantly quartz, carbonate (typically calcite), phyllosilicate (chlorite), iron hydroxide (limonite?), and sulfide (pyrite), and rarely zeolite (clinoptilolite). SEM shows that fracture surface coatings vary in thickness (on the order of microns) and appear to be complex three dimensional structures containing secondary mineral structure and organic material. Some preliminary geochemical modeling of pore waters from regions including the microfractures suggests that microfracture surface minerals do control major ion pore water chemistry.

Static secondary ion mass spectrometry (SIMS) was used to characterize the top atomic layers of select microfracture surfaces. Both positive and negative ion fragments were collected under Ga bombardment in atomic mass unit ranges from 0 to 100. Mass fragment fingerprints suggest that an organic carbon layer covers the heterogeneous mineral surfaces of the microfractures. Inorganic elements are in general agreement with element composition found with other spectroscopies. Of particular interest were chlorinated one- and two-carbon fragments typical of fingerprints when TCE, DCE or VC are analyzed by SIMS, suggesting that chlorinated solvents are partitioned to the organic carbon adsorbed layers on the microfracture surfaces.



SEM micrograph of a fracture showing complex secondary mineral formation surface. An adherent bacterium with extracellular material is present.



Bedrock core with an open fracture and a partially mineralized fracture (microfracture).

Hydraulic Characterization

The fundamental goal of the BBC's hydraulic studies is to better understand the hydraulic characteristics and connections within the competent bedrock at Site 32. To achieve this goal, hydraulic information from existing USAF wells and BBC wells continue to be gathered and analyzed. These data allow the quantification of hydrogeologic parameters and geologic interconnections. In addition, climatic variables (precipitation, atmospheric pressure, and temperature) are concurrently measured.

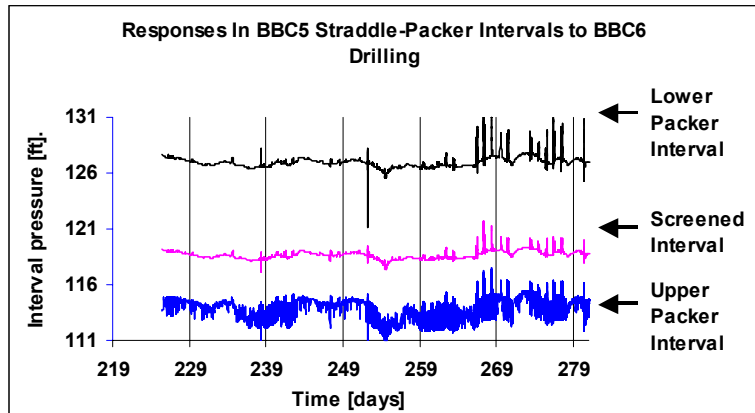
For a recent study, the objective of hydraulic testing was to estimate hydraulic parameters in the bedrock wells (hydraulic conductivity – K; storage coefficient – S) at depths of selected fractures with various methods (physical and analytical). In a single bedrock well, 100 slug tests were conducted at 12 different intervals. In addition, pumping tests were also performed in these same intervals. There were obvious differences in the hydraulic signals and the interpretation of the resulting data of the slug and pumping tests. Slug tests yielded hydraulic conductivity estimates almost an order of magnitude higher than pumping tests. We hypothesize that small fractures induced by drilling and the natural microfractures are hydraulically active for slug tests and not for pumping tests. These results were presented at the Fractured Rock Aquifers 2002 Conference in Denver, CO.

From this study, a software application called HYTESTS was developed to estimate hydraulic conductivity (K) and storage coefficients (S) from flow rate-drawdown time data. HYTESTS has been posted as a shareware program on the BBC website (www.bbc.unh.edu). In addition, HYTESTS was presented as a poster at the Fractured Rock Aquifers 2002 Conference in Denver, CO.

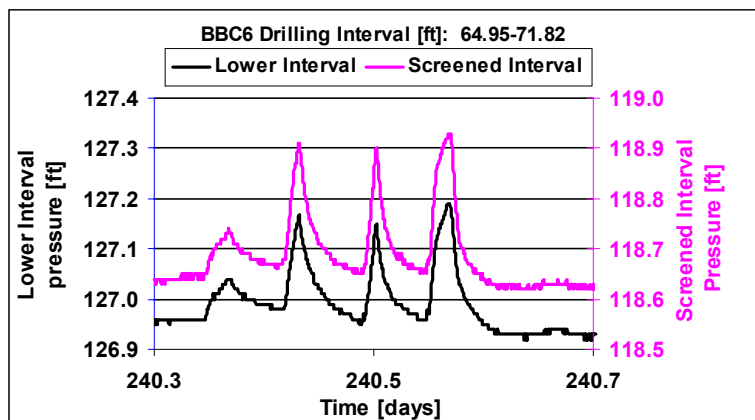
We have also experimented with large magnitude slug signals in the slug tests in order to generate responses in nearby wells, thereby developing large-scale hydraulic parameters. The results look promising, and wells as far away as 200 feet are yielding information from slug tests.



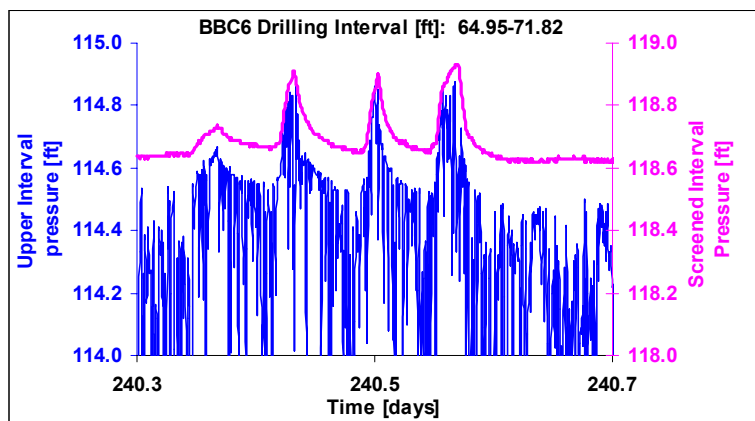
Straddle-packer system used for BBC hydraulic testing.



During the drilling of BBC6, a nearby well (BBC5) was fitted with a straddle-packer (screened interval at 121 to 127 feet below ground). Pressure transducers monitored the pressures within, above, and below the screened interval. These pressure readings reflect the hydraulic connections of the two wells by measuring the water level (pressure) responses in BBC5 due to the use of drilling water in BBC6. This figure displays the relative transducer data for all days of drilling.



The measured responses of the lower and screened BBC5 packer intervals on drilling day 240. On this day, BBC6 was at a depth of 64.95-71.82 feet below ground. The figure shows that hydraulic responses were felt at all BBC5 depths and synchronously.



Significant responses in the upper levels of BBC5 during BBC6 drilling on day 240. On that day, BBC6 was drilling into the top of the competent rock. These responses illustrate steeply dipping fractures and possibly a strong porous media characteristic to the bedrock within short distances.

Bioremediation Technologies Evaluations

One long-term objective of the BBC is to test bioremediation technologies *in situ* under carefully monitored conditions. This work requires the completion of one or more well clusters, each of which has confirmed connectivity between at least two wells. The BBC has recently completed the installation of the third borehole in its first well cluster. This cluster is being tested to determine the extent of connectivity between the wells in question.

With its newly completed well cluster in place, the BBC will soon begin work with the private sector and USEPA to identify possible bioremediation technologies for testing. These will be brought before the BBC's Research Advisory Board, the USAF, and NHDES before any final decision is made as to which technology will be tested.

The scope of the BBC project offers an opportunity for researchers to conduct smaller scale evaluations of new technologies and/or standard field methods. While such evaluations are not the primary focus of the BBC's research, the Center's established field site does provide a unique opportunity to examine questions that other field operations are not able to address.

Evaluation of Borehole Sampling Methods

As part of the Center's research efforts, an experiment was designed to help BBC researchers evaluate the reliability and accuracy of various methods of sampling bedrock well water. In this experiment, groundwater from a single bedrock well was sampled at ten intervals with five different technologies: straddle-packers (twice), low flow pumping, diffusion bag samplers, HydraSleeve™, and a ported FLUTE™. The water samples were analyzed for chlorinated volatile organic compounds and the analytical results compared for each zone



UNH graduate student Gonzalo Pulido-Silva removes diffusion bag samplers from a BBC borehole.

and for each sampling method. Personnel requirements, time demands, and costs for each sampling method were also compared.

A statistical comparison of well water sampling methods, based on cis-1,2-dichloroethene analytical results, indicates significant differences between the results obtained by the various sampling methods. Personnel requirements ranged between 1 person, for both the HydraSleeve™ and the diffusion bags samplers, and 3 people for the FLUTE™; equipment costs ranged from \$250 for the HydraSleeve™ to approximately \$25,000 for the straddle-packer system; and sample collection time ranged from 1 hour for the FLUTE™ to up to 32 hours for the straddle-packer system. The results of this experiment were presented at the Fractured Rock Aquifers 2002 Conference in Denver, CO and are available on the BBC's website (www.bbc.unh.edu).

Drilling Parameter Recorder Evaluation

As part of the research site's bedrock characterization, a drilling parameter recorder (DPR) was used to provide continuous monitoring of the drilling advance for each borehole. Drilling parameter recorders are computerized systems that monitor a series of transducers installed on conventional drilling equipment and automatically collect data on advance rate, down-thrust and pull-up pressures, rod torque, rotation rate, mud/water pressure and flow, depth, and time. The data are displayed in real time in digital form and as hard copy and are stored on an electronic medium for further analysis.

Carefully logged cores collected by the BBC at Site 32 summarized lithologic variability, fracture attitude, spacing, and fracture surface types, and provided the basis for comparison with the DPR logs, acoustic televiewer and video logs. Comparisons of the results from these methods helped determine how they could be used most effectively (separately or in combination) to maximize information about lithology and fracture patterns in a bedrock aquifer. Data collected by the DPR significantly enhanced the quality of information obtained from the BBC boreholes and have the potential to lead to improvements in drilling equipment and techniques. Such advances can increase efficiency and productivity, help control the drilling process, improve rock recovery, and provide real-time data about the rock formation.

The DPR system provides real-time geological profiling and the preliminary results clearly show that it can accurately detect fractures. DPR protocols are currently being developed that will provide *in situ* characterization rapidly and cost-effectively, thus limiting the need for coring during rock investigations.

	Packer Oct	Packer Aug	Low Flow	Hydrasleeve	DBS	Flute Day 1	Flute Day 8	Flute Day 122
Packer - Aug	NO	-						
Low Flow	NO	NO	-					
Hydrasleeve	YES	YES	YES	-				
DBS	YES	NO	NO	YES	-			
Flute Day 1	YES	YES	YES	NO	YES	-		
Flute Day 8	YES	YES	YES	YES	NO	YES	-	
Flute Day 122	YES	YES	YES	YES	YES	YES	YES	
Flute Day 133	YES	YES	YES	YES	YES	YES	YES	YES

Comparison of well sampling methods - paired t-test differences.

Technology Transfer

In accordance with its goal to transfer information on bioremediation to both regulators and consultants, the BBC has sponsored several workshops and courses during the past year. The result of these outreach efforts by the BBC is a private and public sector better informed about the current state-of-the-art in bedrock monitoring and remediation, as well as a heightened awareness and use of the BBC's services/knowledge base.

In October 2001, the BBC sponsored a short course for New Hampshire regulators entitled *Bioremediation – An Option Worth Considering?* This course was presented to an audience of approximately 50 NHDES employees. After receiving much positive feedback following this short course, the BBC offered the course to approximately 25 New England area engineers, scientists, and consultants in November 2001.

Also in October 2001, BBC Principal Investigator Thomas Ballestero presented a one week short course entitled *Desenvolvimento de Água Subterrânea em formações de Rochas Fraturadas* (Groundwater Development in Fractured Rock Formations) at Universidade Federal do Ceará, Brazil.

In May 2002, the BBC sponsored a workshop entitled *Innovative Approaches for Bedrock Investigations and Remediation*. This workshop was presented to an audience of approximately 70 state and federal regulators, including participants from the U.S. Environmental Protection Agency, NH Department of Environmental Services, MA Department of Environmental Protection, ME Department of Environmental Protection, RI Department of Environmental Management, VT Department of Environmental Conservation, and CT Department of Environmental Protection.

After much positive feedback from these regulators, the BBC sponsored a similar workshop entitled *Innovative Approaches for Bedrock Site Characterization* for New England area consultants in September 2002. This workshop was presented to an audience of approximately 55 engineers, scientists, and consultants. The workshop was approved for 5 Massachusetts Licensed Site Professional and 6 Connecticut Licensed Environmental Professional continuing education credits.

During May and June 2002, BBC Principal Investigator Thomas Ballestero presented a two week short course entitled *Taller Nacional Sobre Diseño de Redes de Monitoreo* (Design of Ground Water Monitoring Networks) to 40 groundwater professionals in Bogotá, Colombia. This short course was given at INGEOMINAS (Colombian Geological Survey).

In October 2002, Nancy Kinner, the BBC's Director, and Thomas Ballestero, BBC Principal Investigator, presented *Bioremediation – An Option Worth Considering?* to employees at The Air Force Center for Environmental Excellence (AFCEE) at the San Antonio, TX.

In addition to their workshops and short courses, BBC researchers have presented talks and/or posters at several conferences. BBC presentation materials for the current year's conferences are available on the BBC website (www.bbc.unh.edu).

During the Fractured Rock Aquifers 2002 Conference in Denver, CO in March 2002 BBC researchers made two conference presentations and one poster presentation. Presentation titles included: Comparison of Bedrock Well Water Sampling Methods; Characterization of Fractured-Rock Aquifers Using Drilling Parameters; and Hydraulic Tests in a Fractured Bedrock Formation.

In September, the BBC co-sponsored the 2002 International Symposium on Subsurface Microbiology in Copenhagen, Denmark. Four conference presentations were made by BBC researchers. Presentation titles included: Protists in TCE Contaminated Saturated Bedrock; Microbial Tracer Studies During Drilling In Saturated Bedrock; Community Profiling of TCE-Contaminated Saturated Bedrock; and Preliminary Microbial and Spectroscopic Investigations on Microfracture Surfaces from TCE-Contaminated Kittery Formation Bedrock.

In October, the BBC co-sponsored the 2002 National Ground Water Association FOCUS Ground Water Conference in Burlington, VT. At this conference, the BBC sponsored one of the conference sessions and BBC-affiliated speakers gave a total of six conference presentations. Presentation titles included: General Considerations in Bedrock Bioremediation; Geology and Hydrogeology of the BBC Field Site, Pease International Tradeport, Southeastern New Hampshire; Well Drilling and Core Recovery at the UNH Bedrock Bioremediation Center Test Site; Mineral-Microbial Interaction on Microfracture Surfaces; Characterization of Fractured-Rock Aquifers Using Drilling Parameters; A Comparison of Slug Tests and Pumping Tests in Fractured Rock; and Identifying Microbial Communities Using Fluorescent *In Situ* Hybridization.

Advisory Services

Another outreach effort made by members of the BBC's research team is that of providing advisory services to regulators and consultants. Some BBC researchers have provided third party advisory services to groups evaluating bioremediation as an option at specific sites. For example, BBC's Director, Nancy Kinner, and Principal Investigator, Thomas Ballestero, are advising NH Department of Environmental Services on the first two applications of bioremediation in New Hampshire: the Dover Landfill Superfund site and the Cardinal Landfill in Farmington, NH.

Regulator and Consultant Workshops



*Innovative Approaches For
Bedrock Site Characterization*

Highlights of Next Year's Activities

A number of activities for the Center will be occurring as part of the BBC's Year IV Workplan.

Well Cluster Connectivity Confirmation

Monitoring and analysis of well/fracture interconnectivity will be conducted at the BBC's newly completed three well cluster. The hydraulic testing of BBC4, BBC5, and the newly installed BBC6 will establish the dominant interconnected zones, and perhaps identify individual fractures, linking the wells in this cluster.

Microbial Community Characterization

Identification and characterization of the microbial community within the bedrock groundwater and core fractures will continue. Molecular techniques, SEM, FISH, real-time PCR, and MPN PCR will be used.

Microcosm Development

This year, permeameter-based reactors developed by the BBC will be tested. The data from these microcosms and the more traditional serum bottle-based microcosms will be compared in concurrent experiments. The purpose of the side-by-side monitoring is to determine the efficacy of the biodegradation rate data collected from each of the methods. These rates will be compared to *in situ* biodegradation rates determined in the BBC's well cluster.

Microfracture Surface Study

Bedrock microfracture surfaces will continue to be studied in an effort to determine the relationship between the rock minerals and the ecology and metabolic activity of the adherent microbial community.

Technology Transfer Workshops

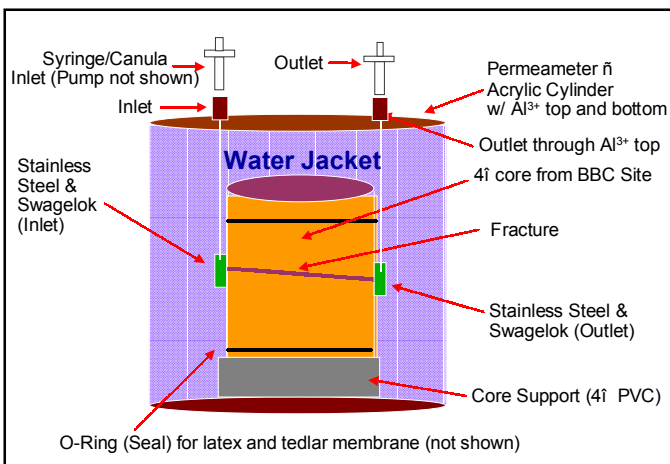
Technology transfer workshops for regulators in New York and New Jersey will be held in November 2002. These workshops will be based on the *Innovative Approaches for Bedrock Site Characterization* workshop. The BBC is also planning workshops in the southeastern U.S. with states that are interested in such technology transfer initiatives on bedrock.

Technology Evaluation

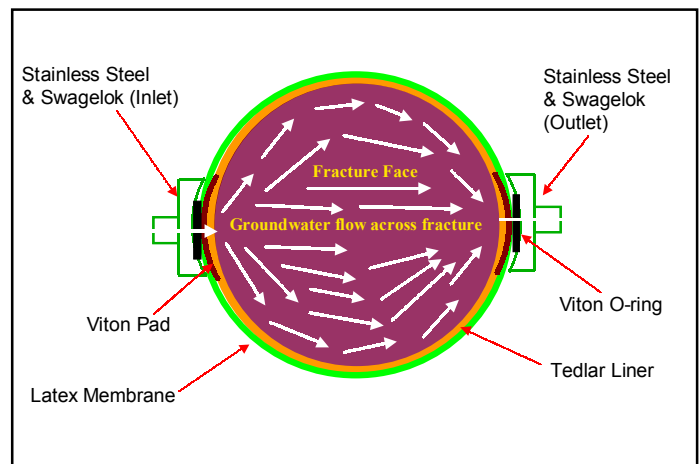
The BBC research team, in conjunction with the Research Advisory Board, USAF, USEPA, and NHDES, will determine what technology is to be tested in the completed well cluster. The Center will solicit proposals for technologies that could be tested in the well cluster. It is anticipated that technology testing will begin late in Year IV and continue into subsequent years.

USEPA Site Characterization Guidance Document

Based on feedback from regulators who attended the May 2002 workshop and from regulators and consultants calling the BBC technical advisory service for assistance, there is a pressing need for a guidance document on cost effective, reliable, and useful methods of site characterization for contaminated bedrock sites. Not only are practitioners and regulators unfamiliar with the available site characterization technologies, but there is also a need for a "checklist" of information that must be known prior to deciding on a course of action (e.g., remediation, monitoring). The BBC will write a peer-reviewed guidance document for USEPA that focuses on how to characterize contaminated bedrock sites. The guidance document will be a "hands-on," how-to document that will be used by consultants and regulators faced with characterizing and monitoring bedrock sites.



Section View Permeameter (Type 1)



Plan View Permeameter (Type 1)

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