Ernest Orlando Lawrence Berkeley National Laboratory

Earth Sciences Division Research Summaries 2004-2005

A Perspective from the Division Director

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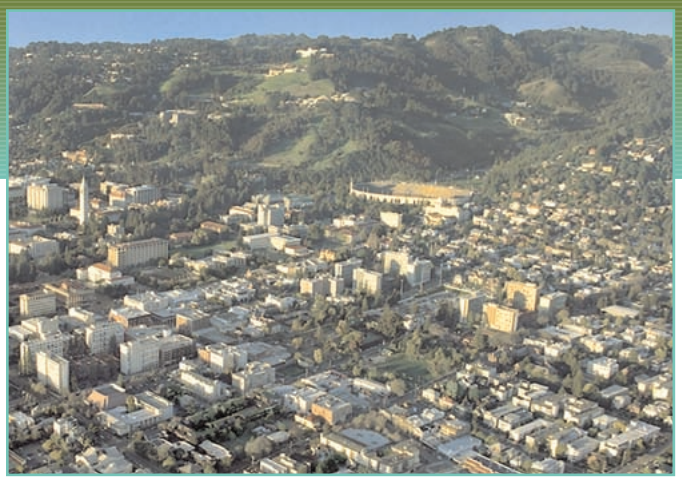

Research in earth and atmospheric sciences is becoming increasingly important in light of the energy, climate change, and environmental issues facing the United States and the world. The development of new energy resources other than hydrocarbons and the safe disposal of nuclear waste and greenhouse gases (such as carbon dioxide and methane) are critical to the future energy needs and environmental safety of this planet. In addition, the cleanup of many contaminated sites in the U.S., along with the preservation and management of our water supply, remain key challenges for us as well as future generations. In order to address future energy and environmental issues, we think that it is critical to integrate the earth sciences and disciplines in a timely fashion. This will involve focusing on fundamental, crosscutting science common to many energy and environmental issues. A primary focus will be the characterization, imaging, and manipulation of fluids in the earth. This addresses many DOE applications, from environmental restoration to energy extraction and optimization.

The Earth Sciences Division (ESD) of the Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is currently addressing many of the key technical issues described above. Our total staff of over 200 scientists, UC Berkeley faculty, support staff and guests—performing world-acclaimed fundamental research in hydrogeology and reservoir engineering, geophysics and geomechanics, geochemistry, microbial ecology, and environmental engineering—provide the foundation for all of our programs. Building on this scientific foundation, we perform applied earth science research and technology development to support the Department of Energy in a number of its program areas, namely:

- Fundamental and Exploratory Research—fundamental research to provide a basis for new and improved energy and environmental technologies
- Nuclear Waste—theoretical, experimental, and simulation studies of the unsaturated zone at Yucca Mountain, Nevada
- Energy Resources—collaborative projects with industry to develop or improve technologies for the exploration and production of oil, gas, and geothermal reservoirs
- Environmental Remediation—innovative technologies for locating, containing, and remediating metals, radionuclides, chlorinated solvents, and energy-related contaminants in soils and groundwaters
- Climate Change and Carbon Management—geologic sequestration of carbon dioxide, carbon cycling in the oceans and terrestrial biosphere, and regional climate modeling, the cornerstones of a major new divisional research thrust related to understanding/mitigating the effects of increased greenhouse gas concentrations in the atmosphere

In this document, we present summaries of many of our current research projects. While it is not a complete accounting, it is representative of the nature and breadth of our research effort. We are proud of our scientific efforts, and we hope that you will find our research useful and exciting. Note that sound health and safety practices are critical to all our research.

This report is divided into five sections that correspond to the major research programs in the Earth Sciences Division:

- Fundamental and Exploratory Research
- Nuclear Waste
- Energy Resources
- Environmental Remediation
- Climate Change and Carbon Management

These programs draw from each of ESD's disciplinary departments: Ecology, Geophysics, Geochemistry, and Hydrogeology. Short descriptions of these departments are provided as introductory material. A list of publications for the period from January 2004 to September 2005, along with a listing of our personnel, are appended to the end of this report.

ACKNOWLEDGMENTS

We gratefully acknowledge the support of our major sponsors in the Department of Energy, which include the Office of Science, the Office of Fossil Energy, the Office of Energy Efficiency and Renewable Energy, the Office of Civilian Radioactive Waste Management, and the Office of Environmental Management. We also appreciate the support received from other federal agencies such as the Bureau of Reclamation, the Department of Defense, the Environmental Protection Agency, and NASA. Lastly, we must also acknowledge and thank our industrial collaborators, who provide both financial and in-kind support through various partnership projects, and who bring additional ideas, data, and experience to ESD.

Earth Sciences Division Operations and Facilities

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OUR ORGANIZATION

Management (and Name) Changes

In 2001, the Earth Sciences Division (ESD) Director G.S. (Bo) Bodvarsson developed a strategic succession plan that rotates on an approximately three-year term for department head appointments. This plan, an important priority for ESD, will prepare our current and future leaders (who make up our Division Council) for management responsibilities. The program head appointments are indefinite.

During the 1st quarter of 2004, Susan Hubbard was appointed Environmental Remediation Program Head (formerly held by Terry Hazen). By the 4th quarter of 2005, Kurt Nihei, the Geophysics Department Head, completed his appointment and additionally, Mike Hoversten stepped down as the Energy Resources Program Head. Ernie Majer is currently acting in both positions, and a search is currently under way for candidates to assume these roles.

Additionally, in early 2004, Bo tasked the Division Council to come up with new department names that were short, to the point, and easy to remember. They are as they appear now on the Organizational Chart (refer to p. ii).

New Laboratory Leadership

In August 2004, the new Berkeley Lab Director, Dr. Steven Chu (Nobel Laureate in Physics), took office. By early 2005, the Earth Sciences Division moved organizationally into a new Associate Laboratory Directorate (ALD) called "Life and Environmental Sciences," which includes the Life Sciences and the Genomics Divisions. Regardless of how we are organized, we continue to collaborate with the other divisions outside of this new ALD assignment. These include Physical Biosciences, Environmental and Energy Technologies, Engineering, and Physics Divisions. For more information on Berkeley Lab's organization, please visit http://www.lbl.gov.

OUR SAFETY-CONSCIOUS WORK ENVIRONMENT

The ESD approach to safety includes Berkeley Lab's Integrated Safety Management model. This model identifies the individual employee as the first person accountable for his or her own health and safety, augmented with a Division Safety Coordinator who in turn works with a Berkeley Lab Environmental Health and Safety Liaison, to maintain an open line of communication with Berkeley Lab's Environmental Health and Safety Division. Because ESD has a matrix structure, the employee works with both supervisors and principal investigators to identify, manage, and elevate issues to the ESD Safety Coordinator, Department Head, and Division Director. Additionally, the ESD Safety Committee meets regularly to discuss ESD and Berkeley Lab issues.

In August 2004, Jil Geller was appointed the new ESD Safety Coordinator. Tim Kneafsey was assigned as the new ESD Safety Committee Chair. Since this time, ESD's safety program has continued to grow with increased visibility, awareness, and proactive communication. We also revamped our Health and Safety website (at http://www-esd.lbl.gov/ESDEHS/index.html), giving it a new look and easy access to forms, reports, and other key documents developed by our staff.

Safety will always be a top priority for ESD. We attribute the success of our safety program to all our staff, which has been very cooperative and pro-active in resolving safety issues, providing suggestions on improvements to safety practices, and implementing changes that result in a safer work environment.

TRAINING AND DEVELOPMENT

EHS26 for Managers & Supervisors is a safety training class that was initially developed for Berkeley Lab's Operations Department (known as EHS20). ESD participated in a successful pilot program for EHS26 to refocus ESH concepts to scientific divisions. This class provided a forum to discuss real-life case studies and emphasize ESD's Integrated Safety Management.

ESD Mentoring & Supervising was a class developed by Chin-Fu Tsang and Susan Hubbard. Bodvarsson and the Division Council feel that mentorship is an important role for supervisors and senior staff scientists, to ensure succession planning and maintain the livelihood of ESD's scientific mission for Berkeley Lab. This course covered all aspects of mentoring and supervising, from hiring a new employee, helping the employee develop into capable and independent scientists, and mentoring employees to help find their place in ESD and identify professional opportunities.

TECHNOLOGY TRANSFER

In recent years, the ESD has successfully licensed several of its software codes, such as Tough-Fx and Tough-Fx / Hydrate Software and EM2D_INV. These codes and others are available for purchase through Berkeley Lab's Technology Transfer Department. ESD is continuing to identify and develop more technologies that can be licensed. To learn more about Earth Sciences and Berkeley Lab's available licensed technology, go to http://www.lbl.gov/Tech-Transfer/

The LBNL Award for Excellence in Technology Transfer is given by Berkeley Lab's Technology Transfer Department and recognizes inventors whose technologies, by virtue of being licensed to the private sector, bring significant benefit to society.

Inventors/ Developers/ Contributors	Technology	ESD Department (unless in parenthesis)
2005 LBNL Award for Excellence in Technology Transfer		
Greg Newman	EM2D_INV	Geophysics
Hoi-Ying Holman	A Reflectance-Absorption Spectroscopy Device To Evaluate Abnormal Tissue	Ecology
George Moridis, Stefan Finsterle, Michael Kowalsky, Karsten Pruess	Tough-Fx and Tough-Fx / Hydrate Software	Hydrogeology
2004 LBNL Award for Excellence in Technology Transfer		
Chris Doughty, Frank Hale (NERSC), Chin-Fu Tsang	Bore II Software	Hydrogeology (National Energy Research Scientific Computing Center--NERSC)

A DIVERSE WORKFORCE

One of ESD's primary goals is to create a supportive environment to attract, nurture, and retain the most qualified and diverse workforce, including under-represented group members. Working closely with Berkeley Lab's Workforce Diversity Office and the Center for Science and Engineering Education (CSEE), we have created a working Diversity Plan, within which we continually evaluate and identify the necessary tools to support and enrich our workforce.

As mentioned in the Training and Development Section, we recently provided our staff with a Mentoring and Training course. This is a great step in creating an avenue for ways to retain staff through the career development process. Additionally, a Verbal Communications course was developed to nurture our staff whose native language is not English. This course is currently in development to include other Berkeley Lab divisions that have recently expressed interest in participating.

ESD FACILITIES /CENTERS

Center for Computational Seismology

The Center for Computational Seismology (CCS), which focuses on geophysical computing research, maintains a state-of-the-art computing environment in support of various seismological and geophysical research programs, in particular the development of new methods for imaging the subsurface and its processes, and methods for visualizing results. A wide variety of modern software and hardware is developed and maintained to support this high-level research. In addition to the many "in-house"-developed codes (3-D modeling, forward and inverse codes, etc.), we use a wide variety of commercially supported packages, including CogniSeis Focus (interactive 3-D seismic processing), Baker-Atlas SEISLINK (VSP and cross-well imaging), GeoQuest GXII (interactive raytrace modeling for surface and borehole data), Lynx (geologic modeling), Earthvision (Dynamic Graphics) AVS (3-D visualization), and the complete Promax/Landmark processing and modeling software.These packages provide a powerful modeling base upon which we build our specialized codes.

Our facilities support research focused on subsurface imaging, using active and passive sources at scales ranging from meters to whole-Earth dimensions. Research activities include the processing and interpretation of vertical seismic profiles (VSP) for fracture detection and fault delineation, induced seismicity associated with energy resources, seismic reflection imaging, single well and crosshole seismic profiling for 2- and 3-D imaging, fracture detection between wells, and processing/analysis of micro-earthquake data for imaging of geothermal fields. The hardware facilities include multiple Exabyte tape drives, over 8000 Gbytes of hard drive storage, a 24-inch color Versatec plotter, a 36-inch HP color plotter, and multiple X-terminals and workstations. We have recently upgraded our computer system to the new SUN series 4-CPU server, with10 GByte of memory and 4 Tera bytes of disk. We also recently acquired a "pc cluster" with 128 nodes (2 cpu per node) at 3.6 GHz and 4 Gbyte memory per node. In addition, the CCS facility is linked to the National Energy Research Supercomputing Center at Berkeley Lab, which hosts a variety of supercomputers available for use.

Geophysical Measurements Facility

Our field work is supported by the Geophysical Measurements Facility (GMF), a DOE-supported facility designed to develop and maintain a variety of geophysical and geoscience instrumentation and measurement equipment. For example, research on piezoelectric sources and borehole sensor arrays, as well as high-frequency seismic recording, has been supported by GMF for over 10 years. GMF is the focal point for an extensive inventory of complex scientific equipment used for Berkeley Lab projects, with responsibility for the maintenance, upgrading, training, and field operations of this hardware. GMF will allow for management of the full complement of sophisticated field instrumentation and associated support vehicles necessary to test and develop a piezoelectric multi-source phased array. GMF maintains a state-of-the-art multidisciplinary field instrumentation facility in support of various environmental, geophysical, and hydrogeological research programs at Berkeley Lab. This facility also assists in development of new instrumentation and field methods for investigating the subsurface and its processes by providing professional in-field technical support for scientific staff and management of the complex and varied field studies required in scientific research programs. The GMF includes electronic and mechanical technicians and shop facilities, field support vehicles, (including wireline and recording trucks), and a three borehole test facility.

Soil and Rock Properties Laboratory

At Berkeley Lab's Soil and Rock Properties Lab, electrical resistivity, ultrasonic wave propagation, and hydraulic conductivity can be measured in a triaxial cell equipped to measure all these parameters simultaneously. Confining and axial stresses are set independently to represent in situ states of stress. The cell is designed to handle samples from 3-inch-diameter Shelby tubes, using sample transfer techniques developed from geotechnical practice. The sample is jacketed with a flexible membrane, either latex, viton or teflon, depending on the sample texture and fluid composition. Sample length is determined by considerations of ultrasonic wave attenuation and the extent of stratification of the core. Typically, samples of approximately 5 cm lengths are used, although different lengths can be accommodated. The advantage of making these measurements simultaneously on the same sample is that disturbance from sample transfer between test cells, a particular concern for unconsolidated samples, is avoided. The endcaps of the test cell contain 1 MHz piezo-electric crystals for P- and S-wave transmission and receiving, flow ports, and pressure ports. Porous aluminum plates between the sample and the endcaps provide even flow distribution over the sample cross section.

Electrical resistivity is measured by the four-electrode technique. Both faces of the aluminum plates are gold coated. Electrical current is driven through the outside faces, and voltage drop is measured from the inside faces; a GenRad 1692 RLC Digibridge supplies current and measures voltage drops at five test frequencies varying from 100 Hz to 100 kHz. P-wave and S-wave propagation (velocity and attenuation) is measured by the pulse-transmission technique.

Voltage pulses are generated by Cober Model 605P High Power Pulse Generator (Cober Electronics, Stamford, Connecticut), and data are acquired via a 40 MHz Gagescope data acquisition board (Gage Applied Sciences Inc., Montreal, Quebec) installed in a PC. Hydraulic conductivity is measured either by the constant head method for more permeable samples, or by the falling head method for tighter samples. Differential pressure across the column is measured with variable reluctance transducers (Validyne, Northridge, CA). When possible, site water is used for the hydraulic conductivity measurements to avoid dispersion of clays. Otherwise, test water is generated based upon a chemical analysis of the site water.

In addition to the above facilities, a high resolution x-ray facility (linear x-ray and CAT scan) and NMR imaging facility was added in 2000 for detailed core studies and simultaneous flow and transport studies. In 2003, further capability was added by linking these studies with ultra-high-resolution tomographic work at Berkeley Lab's Advanced Light Source.

For more information on CCS, GMF, or the Rock Lab, please contact Ernest L. Majer, phone: 510-486-6709, elmajer@lbl.gov

Berkeley Lab Center for Environmental Biotechnology Core Facility

The core microbiology facility of Berkeley Lab is in the Center for Environmental Biotechnology, located in Building 70 and 70A. The 11-laboratory unit, which occupies a total area of 6,000 ft^2, is set up for Class II, Type A/B3 molecular, microbiology, and tissue culture work. Level 1 quality and safety assurance procedures are in place. The following work-specific equipment and instruments are available in this facility:

- Omnilog Phenotypic Microarray System with Computer
- Lietz Laser Con Focal Microscope with digital imaging
- Affymetrix Gene Microarray Processor 3000
- 6 SterilGARD II 6-foot vertical laminar-flow, biological-safety cabinet (Baker)

- 2 Avanti J-25 high performance centrifuge (Beckman)
- 6 Extremophile Fermentors (3 L capacity)
- 2 Coy Anaerobic Chambers double wide with microscope and incubators
- 2 Fermentor BioFlow III (New Brunswick)
- DU 640 UV/VIS scanning spectrophotometer (Beckman)
- Ultra-low temperature freezer (Revco)
- 2 Axioskop RLF for DIC, phase contrast, and epifluorescence with microphotography (Zeiss)
- 2 Integrated SpeedVac (Savant)
- GeneAmp PCR system 9600 (Perkin-Elmer)
- Expedite 8909 DNA synthesizer (PerSeptive Biosystems)
- Model 377 ABI Prism automated DNA sequencer (Perkin Elmer)
- CHEF DRII pulsed field electrophoresis equipment (Bio-Rad)
- MIDI identification system (Hewlett Packard)
- High sensitivity MSD mainframe for the HP 6890 GC (Hewlett Packard)
- BIOLOG microbial identification system (BIOLOG)
- Environmental shakers with photosynthetic light banks (New Brunswick)
- Alliance HPLC system with a 996-photodiode array detector and a 474 scanning fluorescence detector (Waters)

Other support equipment and installations are also available—such as autoclave, DI-water, refrigerators, freezers for low temperature storage of temperature-sensitive materials, balance, ice-maker, shakers, incubators, magnetic stirrer, hotplates, microcentrifuges, computers, different electrophoresis boxes and power supplies, and fume hoods. The core facility also has access to the Environmental Measurement Laboratory at Berkeley Lab.

The core microbiology facility preserves and maintains laboratory strains and wild-type strains isolated from environmental samples, microbial genomic DNA, plasmids, and cloned genetic material. We also have three glove boxes and several incubators that allow us to work with anaerobic microorganisms and microaerophiles.

For more information concerning the Center for Environmental Biotechnology Core Facility, please contact Terry Hazen, phone: 510-486-6223, e-mail: TCHazen@lbl.gov

Center for Isotope Geochemistry

The Center for Isotope Geochemistry (CIG), Lawrence Berkeley National Laboratory, and Department of Geology and Geophysics, University of California, Berkeley, is directed by Donald J. DePaolo. The Center has fully equipped radiogenic, noble gas, light stable isotope, cosmogenic radionuclide laboratories and an adjunct environmental measurements laboratory for organic and inorganic chemistry.

Ash deposits formed during the climactic eruption of the Long Valley volcanic system near Mammoth Lakes, California. This ash was deposited about 750,000 years ago by an enormous eruption that formed the Long Valley depression. The area is still volcanically active, and researchers at CIG are studying the volcanic formations of Long Valley to try to determine whether there can be another catastrophic eruption. Researchers are also monitoring the helium isotope ratios in carbon dioxide-rich volcanic gas that is presently escaping from the ground near Mammoth Mountain; the escaping gas is coming from magma deep in the ground.

The analytical facilities of CIG are designed to provide the capabilities for measuring isotopic and trace element concentrations of rocks, minerals, and groundwater. These measurements can be used to deduce the age of groundwater, the flow directions, the rate at which the groundwater chemistry changes by reaction with surrounding rocks, and also the age and origin of the rock units themselves.

Current effort is concentrated on Sr, Ca, O, C, He, Ne, Ar, Xe, Pb, and Nd isotopic ratios, and on problems of mass transport in fluid-rock systems, interpretation of past global climatic change, crustal magmatic and tectonic processes, and Quaternary geochronological methods. A mathematical basis for the application of isotopic measurements of fluids and rocks to the field-scale parameterization of hydrological systems is a major effort of CIG. Modeling is accompanied by systematic measurements of relatively simple natural systems, and by improved sampling and measuring techniques. Emphasis in development is on microsampling of geological materials, on high-precision measurement of the small amounts of recovered material, and on rapid, automated low-blank chemical separation of trace elements. Other efforts of the Center are aimed at geochemical techniques for dating and correlation of sedimentary and volcanic rocks, and for understanding the time scales and mechanisms of crustal processes such as extensional faulting, mountain building, and volcanism. All efforts are aimed at improved characterization of natural rock and fluid systems.

For more information concerning the Center for Isotope Geochemistry, please contact: B. Mack Kennedy, Center for Isotope Geochemistry, phone: 510-486-6451, e-mail: bmkennedy@lbl.gov

SECURE EARTH

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Over the past two years, ESD has focused efforts on an initiative called "Scientific Environmental/Energy Crosscutting Underground Research" (SECURE Earth, or SE), initially developed in partnership with Idaho National Laboratory and since expanded to a multilaboratory university and industry initiative at Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory (LLNL). The overall goal of SE is to achieve timely solutions to critical national problems associated with the earth's subsurface, to accelerate subsurface science research, and ultimately, identify how research leads to improvements in understanding and prediction (as well as ultimately reducing risk). Crosscutting scientific thrust areas have been identified as follows: energy, CO_2 sequestration, environmental cleanup, water, geothermal energy, and nuclear waste disposal.

Efforts prior to and during 2004 focused on briefing the U.S. Department of Energy, Office of Basic Energy Sciences (BES)/Biological and Environmental Research (BER) at the director level. A number of major milestones were also reached in 2004: (1) the formation and meetings of a multidisciplinary/multi-institutional advisory panel; (2) the expansion of the initiative development by including Pacific Northwest National Laboratory and Oak Ridge National Laboratory; (3) the organization of a two-day meeting at the National Academy of Sciences to "roll out" the initiative to many federal agencies and industry; and (4) the presentation of the SE initiative to a variety of research groups and possible sponsors.

The primary conclusions of the National Academy were that this is a worthwhile initiative, and that the DOE/OS, National Science Foundation, National Aeronautics and Space Administration, and U. S. Geological Survey are initiating a process to carryout a "decadal study" in the earth sciences, similar in scale, which justified and identified the need for such projects as the Superconductor Super Collider. This is a very significant achievement, in that never before has such a study been carried out for the geosciences.

Efforts in 2005 focused on preparing for and holding a national workshop in September to define the crosscutting scientific thrust areas of the initiative. Colorado School of Mines hosted this workshop in Golden, Colorado, September 12–13, 2005, with attendance by scientists from around the country (and supported by the various national laboratories). Also conducted were briefings and talks about SE at several national conferences (American Geophysical Union, Geological Society of America, International Society for Subsurface Microbiology) to inform the geoscience community, as well as, gaining grassroots support within the community. The outcome of the September workshop was a detailed listing of the crosscutting scientific thrust areas, which included facilities and technologies needed to accomplish the goals of SE. This list is not meant to be a list of scientific needs, but rather are the nucleus of an overall science plan that is needed to meet the goals of SE.

It is now clear that the fundamental concept of SE has become widely accepted. Notably, Berkeley Lab Director Dr. Steven Chu, in his comments to an ESD-wide meeting, stated that "addressing critical energy and environmental problems will probably have a larger societal impact than curing cancer. Now we just have to convince Congress of that."

The official SECURE Earth web site (http://wwwesd.lbl.gov/SECUREarth/ index.html) is located at Berkeley Lab and contains current information about the initiative.