Research

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Motivation and Scope of Problems:

I have spent much of my career performing research with an academic perspective and approach, yet applied to problems put forth by my supporting funding agencies and companies. In the past, a major source of funding for me was the U.S. Department of Energy, Basic Energy Sciences Program. That program has the overarching goal of improving fundamental understanding the Earth for energy and environmental applications. I see that program as a potential source of funding for my research in the future, since I continue to have interest in areas consistent with their programmatic interests. When this type of funding can be obtained this provides flexibility to work on problems of broad importance and applicability to a wide range of geologic problems.

As one example, in late 2007 the DOE released a statement of Basic Research Needs for the Geosciences. In this document, the primary focus is on the development of new technology for geologic sequestration of the vast amounts of CO_2 produced by extraction and use of fossil fuels. This is motivated by the fact that worldwide energy consumption is projected to double by mid-century and much of this will be accommodated by fossil fuels. Thus, we face serious challenges as we meet global energy needs and at the same time must reduce emissions of greenhouse gases to the atmosphere. To reduce the atmospheric impact of this fossil energy use, they recognize that it is necessary to capture and sequester a substantial fraction of the produced CO_2. Most plans envision that subsurface rock formations will be used for the storage this vast volume of CO_2.

The problem is that rock formations are composed of complex natural materials and were not designed by nature as storage vaults for CO_2. Therefore, fundamental improvements are needed in our understanding a range of problems concerning subsurface rock properties.

It is worth pointing out that, although the DOE program described above is driven by the single-minded goal of sequestering CO_2 in rock formations, the range of topics and the research required to attain this goal have much broader significance.

In fact in this application, as stated by the DOE report, the fundamental crosscutting challenge is to understand the properties and processes associated with complex and heterogeneous subsurface porous rock formations, the equally complex fluids that may reside within and flow through those formations, and the tectonic stress as perturbed by pore fluid pressure fluctuations. These are the same challenges to understanding the genesis and distribution of ore deposits, the coupling of tectonic stress, pore pressure, fluid flow and deformation needed to construct models of subsiding basins due to fluid withdrawal, and to understanding aspects of the earthquake mechanism.

In addition to the government-funded research, I have worked on several applied research projects funded directly by industry, both during my time at MIT and in my position at New England Research. Our current working group within MIT continues to seek support for projects relating seismic exploration and key industry needs such as flow and transport characterization. I play an active role in this planning. I see fostering old and gaining new industry contacts as a key focus in seeking new research funds.

In my new research projects and proposals I would consider aspects of the following:

- **Integrated characterization, modeling, and monitoring of geologic systems.** This includes methods for joint inversion of coupled process models that represent nonlinearities, scale effects, and uncertainties.
- **Mapping and machine learning.** Understanding natural patterns and processes through computer analysis of map data with both spatial and temporal components for assessment of natural resources and risk from natural and environmental hazards.
- **Simulation of multi-scale geologic systems.** This includes consideration of how to couple information across scales, that is account for the effects of small-scale processes on larger scales or the microscopic basis of macroscopic complexity for physically-based upscaling.
- **Dynamic imaging of flow and transport.** Use of laboratory physical modeling to image the interactions of physical fields, elastic waves, and electromagnetic perturbations with fluid-filled porous media.
- **Fluid-induced rock deformation.** Work toward developing improved models for the coupling of chemical, mechanical, and hydrological effects.
- **Personal instrumentation.** Development of inexpensive and portable geophysical and environmental sensors allowing meso-scale mapping, imaging, and analysis of natural, urban, and agricultural settings.
- **Building energy flows.** Application of analogs between electrical circuit components and energy flows in buildings. Provide tools for simple monitoring and modeling of energy budgets and comfort in new and retrofitted conventional and passive solar buildings.

Approach and Methods Employed:

My strongest areas of expertise are the physical properties of fractured and otherwise heterogeneous rock and the application of geophysical methods to mining, energy, and environmental problems. In this work I draw on a broad range of physical science disciplines - including geology, geophysics, physics, materials science, hydrology, fluid and heat transport, and chemistry - to develop the fundamental understanding required for robust and practical results. I typically combine field geologic and geophysical studies and mapping, experimental geophysics in the laboratory, computer modeling, and theoretical work. Field work typically involves fracture, fault, and structure mapping projects where the results are placed in the context of theoretical models. I often use experimental methods, whether laboratory, bench-top, or small demonstration field scale to develop insight and to check and calibrate models. For this experimentation, unique personal technical skills I have applied are manufacturing and prototyping using machining, metalwork, and casting, analog and digital electronics design and assembly, and integration of micro-controllers into instrumentation. I have experience in design and construction of ELF and VLF radio receivers and antennas, design and construction of field magnetometers and electrical resistivity meters, and in radio remote control of instrumentation and data logging on unmanned aerial vehicles, as well as laser imaging and ranging equipment design, assembly, and use. I use time series analysis, image analysis and processing, and numerical modeling for study of elastic, electrical, and fluid transport processes, and use scaling statistics such as fractals to characterize and develop models for geological heterogeneity and scale dependence of geophysical processes.