Microstructure of Rocks
Porosity and Permeability of Rocks and Vent Deposits

All rocks are porous to some degree – varying from joints in natural rock formations to microcracks and tiny pores in some specimens. Porosity affects fluid transport in rocks and is important to many science and engineering problems, including earthquake and fault studies, oil and gas recovery, reservoir architecture, groundwater contamination control, and nuclear waste deposit monitoring.

The key physical property that affects fluid transport in rock is permeability, or the ability of a rock to transmit fluid. However, to estimate permeability is challenging, because it varies a great deal in different rocks. To make matters more complicated, Earth is a dynamic environment, which means that there are huge variations in pressure, temperature, fluid chemistry and other environmental conditions.

My research focus is to investigate the relationship between permeability and pore structure in a wide range of geological materials, including sedimentary rocks (sandstones and limestones), partially molten rocks (mantle peridotite and harzburgite) and hydrothermal vent mineral deposits. My approach is to use both experimental and theoretical methods to provide better data on rock permeability and to determine how permeability changes under different conditions.

Since arriving at WHOI, I started an exciting collaboration with Meg Tivey, a geochemist and a former DOEI fellow (June 2001 - May 2004). Meg specializes in the study of active seafloor hydrothermal systems, where metal-rich vent deposits form from complex interactions among hot (~350°C) vent fluid, cold (~2°C) seawater, and previously deposited material. These deposits are analogs of ore deposits present on land, and host unusual biological communities, including microorganisms that thrive at high temperatures (up to 120°C).

Like most people who are aware of seafloor hydrothermal vents, I am fascinated by black smokers, white smokers and the amazing creatures that live at vent sites. But a not-so-common aspect of my interest in vent systems is that, to me, it is a natural factory where materials with ever-evolving pore structures are fabricated. Because vent fluids and seawater flow through the changing pores, it is important to accurately estimate permeability of vent deposits and to understand how it affects fluid flow, thus influencing the growth of vent structures and the animals that live there.

Because permeability is closely related to porosity – a physical parameter that is much easier to measure – efforts have been made to establish permeability-porosity relationships. As a DOEI Fellow, in collaboration with Meg, I obtained permeability-porosity measurements and conducted microstructural analyses on three large vent deposits from the Juan de Fuca Ridge (off shore of Washington state). We found that the connections between permeability and porosity can best be described by two different
power law relationships. The difference in the two permeability-porosity relationships reflects different mineral precipitation processes, as pore space evolves within different parts of the vent structures. In one process, angular sulfide grains deposited as aggregates block fluid paths very efficiently. In the other process, amorphous silica coats existing grains and reduces fluid paths more gradually, thereby reducing flow through the structures. These findings are published in our recent paper in the *Journal of Geophysical Research*.

Our results suggest that, while there is not a single “universal” permeability-porosity relationship, there are good correlations between permeability and porosity for some types of samples, particularly when pore evolution processes – the processes that change pore space – are considered. Types of pore evolution processes relevant to vent deposits include precipitation and dissolution, and formation of cracks from thermal cracking. These processes destroy and/or create porosity.

Identifying which processes result in changes in porosity and permeability is accomplished by making microstructural observations, for which we use reflected light microscopy to examine grain size, pore size, pore distribution and connectivity. Identification of different evolution permeability-porosity relationships (EPPRs) provides information about how different portions of vent structures form over time. They also tell us what processes are responsible for changes in porosity and permeability, and, thus, the ease with which fluid flows through parts of the vent deposit.

Based on our success in quantifying permeability-porosity relationships on vent deposits, we plan to conduct further experimental and microstructural measurements on a full range of vent structure types with samples recovered from many different active seafloor vent sites. Our data and observations will be used to identify ranges of permeability and different EPPRs, which we hypothesize will correlate with distinct textures that reflect different physical and chemical processes (e.g., thermal cracking vs. precipitation of blocky grains vs. precipitation of mineral coatings).

Results from my DOE study will be used in models of fluid transport and to examine feedback processes that are crucial in simulating flow within vent structures. Our study will address a key question about many hydrothermal structures – whether there are cascading feedbacks that lead to clogging, or, alternatively, whether the feedback is such that fluid flow is maintained in certain portions of the structures. – *Wenlu Zhu*