**Reminiscences (from Harold Wollenberg)**

In the early ‘60s, as a grad student in engineering geology at UC Berkleley, I was looking for a thesis project. Fortunately for me, the Lab’s Health Physics department needed someone to find material that could comprise concrete for a thick-walled low-background gamma counting facility. Its main purpose then would be to characterize the distribution of gamma-emitting fallout from atmospheric atomic bomb tests. I was hired, and searched the West for aggregate and cement of the lowest radioactivity. I found aggregate in the form of serpentinite waste rock from an asbestos mine in the Sierra Nevada, which, when combined with cement from Vancouver Island, made 500 tons of the world’s lowest radioactivity concrete. I got my thesis project, and Alan Smith still uses that facility, tucked into the north end of Bldg. 72.

Because of its ultra-low gamma background, the counting facility lent itself to studies of the natural radioelement contents of rocks, an important factor in the earth’s production of heat. I found alliances with members of the U.S. Geological Survey who were studying Earth’s conductive heat flow, leading to several years of field projects incorporating transects of the Coast Ranges and the Sierra Nevada, several by foot, sampling a kilogram of rock every mile. The combined radiogenic heat production - heat flow picture resulted in well-received papers that Al Smith and I authored with USGS colleagues.

Under the leadership of Ed Lofgren, U.C. and the Lab in the mid ‘60s were trying to locate a site for the next large accelerator, to be a mile in diameter. Dick Blumberg, Don Eagling, and I (as an engineering geologist) searched central California for a fairly level area on good bedrock. I’m still convinced that, technically, we had the nation’s best site in the foothills east of Sacramento, but politics dictated that the machine be built at what is now Fermilab. Decades later, I played a similar role in selecting California’s candidate site near Davis for the Supercollider, only to see Texas win the national competition (in what turned out to be a pyrrhic victory).

From 1969 to 1971, I took a leave of absence from the Lab to work for the Danish government, who were searching for uranium ore deposits in Greenland. Besides working in the most spectacular terrain geologically and scenically, I was able to learn Danish in the Greenland field camps and at the Riso lab near Roskilde.

In the early ‘70s, Paul Witherspoon was asked by Andy Sessler and Jack Hollander to lead a group to investigate geoscience techniques for finding viable sources of geothermal energy, and engineering solutions to efficiently harness that resource to produce electricity. Thus the embryo of what was in a few years to become the ESD was conceived by the troika of Witherspoon and Frank Morrison from the College of Engineering, and Ken Mirk of the Lab’s Engineering Division. Since the juiciest geothermal plum, the Geysers Field in northern California, had already been plucked, I was asked by the triumvirate to help locate and geologically characterize sites that weren’t associated with relatively recent volcanism. Hot spring areas in the northern Basin and Range—where there are no volcanics but where the earth’s crust is relatively thin—seemed good targets. The approach we demonstrated in northern Nevada, integrating geology, geophysics, and geochemistry, leading to heat flow drilling, has since been employed by industry to successfully produce geothermal electricity from nonvolcanic sites in the Basin and Range region. The electrical and seismic-geophysical and heat flow methods developed in this project were also used by national geothermal enterprises in Mexico and Central America. A joint project with Mexico's Comision Federal de Electricidad explored the geothermal reservoir near their plant at Cerro Prieto in Baja California. The field technical team, which collected hundreds of line-miles of data in Nevada, was led by Ray Solbau, who became the Division's technical leader for several decades.

Bright students of Witherspoon in hydrology and of Morrison and Tom McEvilly in geophysics, such as Sally Benson, Bo Bodvarsson, Marcelo Lippman and Ernie Majer, did much of their graduate research and ultimately matriculated to full-time Lab scientists in the geothermal projects. Spurred by then E.& E. Division leader Bob Budnitz to enter the radioactive waste isolation sector, the geothermal group metamorphosed into a full fledged Earth Sciences Division in the late '70s. The earth scientists were augmented by young physicists (Yvonne and Chin-Fu Tsang, Karsten Preuss, Joe Wang) challenged to help solve the mysteries of how fluids move through rock that may or may not be porous, fractured, or saturated.

Some of the geothermal projects developed into long-term research sponsored by ERDA's, and then DOE's office of basic energy sciences. The most enjoyable for me were collaborations with Los Alamos' ESD in drilling into active hydrothermal systems at California's Long Valley and the Valles Caldera in New Mexico. The drill cores we recovered furnished juicy (figuratively) material for several publishable papers.

With the impetus of the waste isolation projects, the cadre of geothermal experts began to address the ability of fractured rock to retain high-level waste from commercial reactors. Since there was an important geochemical component to HLW studies, Ian Carmichael from UCB and John Apps, Art White, and Oleh Weres joined the ESD staff.

A component of the HLW program that I found most fascinating was the study of analogues to radioactive waste isolation in potential candidate rock types: granite, salt, and basalt. (At that time, the U.S. had not chosen Yucca Mountain as the candidate site for its repository.) For several years in the mid '80s, our geology-geochemistry group in ESD examined such "natural" analogues as a dike of kimberlite cutting a salt bed, dikes and veins intruding granite, and rhyolite dikes cutting basalt flows. The primary purpose was to see if radioactive and/or trace elements migrated from the once-hot intrusives into the encompassing country rock, a natural simulation of what might happen in a repository if waste canisters leaked. (We were ecumenical about seeking support for projects. The Nuclear Regulatory Commission, not DOE, funded most of our "natural" analogue work.) Perhaps the grandest analogue study was a full-scale geoscience characterization of a fractured granite rock mass at an accessible old mine at Stripa, Sweden. Here long-term monitoring of rock behavior in response to artificial heating was done in collaboration with Swedish scientists, with instrumentation developed and nurtured by the Lab's Real Time Systems Group, led by Gene Binnall. The Stripa Project brought on board rock-physical expertise personified by Neville Cook and perpetuated by Larry Myer. I consider the Stripa work a prototype of lots of the experiments and monitoring done at Yucca Mountain a decade later.

When the U.S. became determined to establish a high-level waste repository in tuff, we collaborated with counterparts at Livermore Lab on heater tests in tuff, at the G-tunnel in Rainier Mesa on the Nevada Test Site. I was especially interested in examining changes in the distribution of uranium in the rock as it responded to a minihydrothermal system caused by the heater.

In the late '80s, it was enjoyable to come full-circle by joining forces with E. and E. Division, personified by Rich Sextro, Tony Nero, and Ken Revzan, in studying the occurrence of radon in rocks, soils, and in people's basements, culminating in the installation of an intensively instrumented test facility simulating a basement in weathered granite in the Santa Cruz mountains.

Maybe because it evolved from the Energy and Environment Division, Earth Sciences has always had what I think of as a geo-environmental underpinning. I enjoyed playing a role in projects in addition to the ones I've described above: (i.e., studies of selenium in agricultural drainage systems in the Central Valley; investigation of radioelement contamination at former uranium enrichment plants; studies at Yucca Mountain; and collaboration with Russian earth scientists on the radio-hydrological situation at Chelyabinsk, Siberia—Russia's version of our Hanford). In all projects, an important factor was the ability of ESD to collaborate enthusiastically with other divisions on the Hill, with departments on the Berkeley campus, and with counterparts at other national labs.

Research is most enjoyable when like-minded people of good will and, perhaps most importantly, with good senses of humor, work together.