Progress Report: LEO Isotope Hydrogeology Station
(Submitted April, 2003; prepared by Valerie Schultz)

Project: Paleohydrogeology of a Part of the Alleghenian Thrust Belt in West Virginia

Participants:
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Introduction

We have been investigating paleo-fluid flow in the Appalachians during the Alleghenian thrusting (one of the times when Africa and North America collided). It is believed that this even had a major impact on the formation of the large oil reservoirs and mineral deposits along the front of the thrusting. In the Stable Isotope Chemistry Lab, we've been looking at the isotopic composition of some vein and rock samples in an attempt to test several theories about the fluid rock interaction in a specific portion of West Virginia. The exact field and analytical experiments to be undertaken have been guided by specific hypotheses generated by the more regional work by Dr. Mark Evans (University of Pittsburgh) and Carolyn Brown (a M.S. student in EES, Lehigh University), and we have communicated with these other researchers throughout our project.

Hydrologic regimes in orogenic belts show complex evolution in response to transitions in structural style (affecting permeability), topographic relief, and contributions from surficial and deeper-sourced fluid reservoirs over extended periods of geologic time. Popular fluid flow models have included the tectonic "squeegee" model, in which fluids mechanically expelled at depth in actively deforming thrust wedges are transported updip along thrust structures, and models incorporating topography- and buoyancy-driven recharge and mixing. However, many questions remain concerning the evolution and pathways of fluids during orogenesis, particularly at regional scale. Field-based structural, petrologic, and geochemical studies of orogenic fluid flow suggest differing styles and sources of deep crustal fluid infiltration during compressional and extensional stages in orogenic belts. Numerical models suggest relationships, between orogen geometry and directions and magnitudes of large-scale fluid flux, which are largely untested against field studies. The current study evaluates this set of problems, through examination of stable isotope signatures in deformed thrust belt rocks, exposed just east of the Appalachian Structural Front in West Virginia.

Four formations were studied, from varying structural levels, in the course of our work between January 2002, and April 2003, to determine the paleohydrology of the area. They are the Black River, Trenton, Tonoloway, and Helderburg Formations. They are limestones of Ordovician, Silurian, and Devonian ages, respectively. The location of the study area is in the Valley and Ridge Province, West Virginia. Limestones ($CaCO_3$) were used because the $\delta^{18}O$ and $\delta^{13}C$ values can be analyzed simultaneously using standard laboratory methods for extractions and mass spectrometry. These isotopes indicate the ancient isotope compositions of the waters in this area (i.e., fluid inclusions from mountain building events), and thus provide evidence regarding paleofluids.

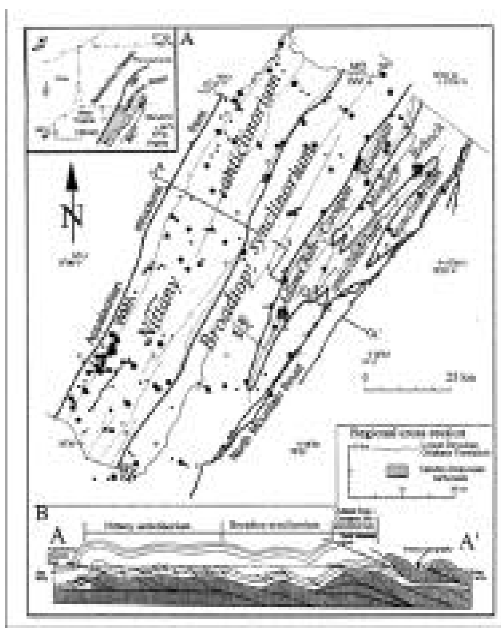

Figure 1: Study Area. From Evans and Battles 1999.

Brief Summary of Results (see posters, PowerPoint presentations on this web site)

The Black River and Trenton Formations have vein $\delta^{18}O_{V\text{-}SMOW}$ values ranging from +23 to +24.8‰, while the $\delta^{13}C_{V\text{-}PDB}$ values range from –14 to +0.25‰. The $\delta^{18}O$ values for host-rocks at this locality are rather uniform, ranging from +23.7 to +24.3‰, but the same samples have $\delta^{13}C$ values widely ranging from –1 to –12‰. The vein data appear to lie along a linear array, with large (up to 1 meter wide) veins having low $\delta^{18}O$ and low to moderate $\delta^{13}C$ values, and smaller veins having high $\delta^{18}O$ and moderate to high $\delta^{13}C$ values (neither vein type shows much overlap with values for host-rocks at the same locality). Data for the Tonoloway Formation from two localities show contrasting isotopic patterns. In the data collected by N. Castle and A. Stern (Spring, 2002), there is a distinct separation between data for the vein and data for host rock samples. The vein $\delta^{18}O$ values range from +21.8 to +22.4‰, with $\delta^{13}C$ values ranging from –0.5 to –0.27‰, and the host rock $\delta^{18}O$ values range from +22.5 to +22.7‰ with $\delta^{13}C$ values ranging from –0.3 to –0.25‰. The data collected by N. Castle and V. Schultz (Fall, 2002) do not show this separation, and there is little difference between the data for veins and the data for host rock samples. In that dataset, the overlapping vein and host rock $\delta^{18}O$ values together range from +22.4 to +23.4‰, while the $\delta^{13}C$ values range from –3.1 to –1.3‰. The C-O isotope data for the Helderberg Formation (from the Fall, 2002) show distinct separation between vein and host rock sample datasets. For the Helderberg locality, vein $\delta^{18}O$ values range from +23.4 to +23.5‰, with the $\delta^{13}C$ values ranging from +4.4 to +4.6‰, and host rock $\delta^{18}O$ values range from +23.9 to +24.3‰ with $\delta^{13}C$ ranging from +4.7 to +4.9‰.

Conclusions

The Helderberg Formation locality appears to represent a part of the Valley and Ridge that behaved as an open system, based on the dataset from the Fall, 2002. This open-system behavior is indicated by the systematic separation in the O-C isotope values for veins and host-rocks (veins are all lower in both $\delta^{13}C$ and $\delta^{18}O$ than their host-rocks). Among the two Tonoloway Formation localities, the first data set (obtained by Andrew

Stern and Nicholas Castle in the Spring, 2002) is consistent with relatively open system behavior, showing significant systematic shifts in isotopic compositions of veins relative to host-rocks. The other data set (obtained by Nicholas Castle and Valerie Schultz in the Fall, 2002) is more compatible with relatively closed-system behavior, with significant overlap in the data for veins and host-rocks. These differences could be due to differing structural evolution, affecting permeability at various scales, at the two Tonoloway localities — such an interpretation is consistent with the findings of Carolyn Brown for a broader region in the same thrust belt. The data for the Black River/Trenton locality are consistent with open-system behavior, and the linear relationship between the O and C isotope compositions of the large and small veins could be explained by the precipitation of calcite from fluids with fixed O-C isotope composition, but over a temperature range.