2001-2010 DOE-BES Final Report

Project Title:

“Physiochemical Evidence of Faulting Processes and Modeling of Fluid Flow in Evolving Fault Systems in Southern California”

Principal Investigators:

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Objectives:

This is a collaborative study to quantify formation- and basin-scale fluid flow, submarine gas migration, and diagenetic effects within deforming fault zones in a transpressional setting that is seismically active. The field application emphasis is on faulted basins in southern California.

Project Description:

Our study targets recent (Plio-Pleistocene) faults and young (Tertiary) petroleum fields in southern California. Faults include the Refugio Fault in the Transverse Ranges, the Ellwood Fault in the Santa Barbara Channel, and most recently the Newport-Inglewood in the Los Angeles Basin. Subsurface core and tubing scale samples, outcrop samples, well logs, reservoir properties, pore pressures, fluid compositions, and published structural-seismic sections have been used to characterize the

tectonic/diagenetic history of the faults. As part of the effort to understand the diagenetic processes within these fault zones, we have studied analogous processes of rapid carbonate precipitation (scaling) in petroleum reservoir tubing and manmade tunnels. From this, we have identified geochemical signatures in carbonate that characterize rapid CO₂ degassing. These data provide constraints for finite element models that predict fluid pressures, multiphase flow patterns, rates and patterns of deformation, subsurface temperatures and heat flow, and geochemistry associated with large fault systems.

Summary of Results:

Our earliest studies funded by this DOE grant showed that massive calcite cementation occurred at the two ends of the 24 km long Refugio-Carneros fault (Boles et. al., 2004). The calcite originated from oxidation of methane mixed with calcium from ground water. Crystallization temperatures are shown to be around 100°C and crystallization occurred in the presence of hydrocarbons within the past few hundred thousand years. Modeling by G. Garven demonstrates that the fluids were derived from an overpressured basin and vertical transport distances would have been several kilometers. Further modeling of the system confirmed that fluids were likely derived from the offshore basin rather than the underlying Paleogene strata (Appold et. al., 2007). An analogous study of the Wheeler Ridge thrust fault (Quaternary-Recent age) in the San Joaquin basin shows that calcite cementation was restricted to deeper levels along the fault zone (greater than 2.5 km), but that shallow levels along the fault have

enhanced porosity due to dissolution of minerals (Perez and Boles, 2004). Vertical transport distances were estimated to be about 100 to 750m.

Our studies of the South Ellwood fault (Pleistocene to Recent age), which bounds the north edge of the South Ellwood field, reveal evidence of connectivity between the sea floor and producing wells in the field based on changes in gas seep rate to the sea floor. We estimate permeability on the fault of about 30 millidarcies (mD) (Boles et. al., 2010). The South Ellwood field is currently about 70% of hydrostatic pressure and document sea water incursion down the fault into the reservoir from elevated oxygen, deuterium and sulfate composition within the reservoir and down hole shut-in pressure data for a well adjacent to the fault that shows a tidal signal (see PDF presentation).

In the Los Angeles Basin, we have interpreted an igneous body drilled at the northern end of the Newport-Inglewood fault to be largely a series of surface flows intruded along the fault. We sampled several levels of the igneous body and have processed and dated them by the Ar/Ar method (Prof. Gans laboratory at UCSB). Due to alteration, only one yielded a reliable date, which is 13.6 my +/- 0.7. This is the only know date of igneous activity *within* the basin and corresponds to mid to late Miocene volcanism associated with basin rifting. The date will be incorporated into thermal modeling of hydrocarbon generation associated with local heat sources within the basin.

Studies of carbonate scaling in hydrocarbon production tubing and the formation of speleothems in a manmade tunnel highlight the geochemical signatures in rapidly precipitating (mm/year growth rates) carbonate (Boles, 2004; Giles and Boles, 2007). Results show that isotopically heavy carbon and oxygen result from CO₂ degassing. Furthermore, the oxygen is 1 to 20 per mil heavier than expected for equilibrium. Covariation of carbon/oxygen isotopes occurs with a positive slope. Unexpectedly, unusually coarse crystals of vaterite, a highly unstable polymorph of calcite, were found in some oil field tubing scales that has apparently persisted for several years. This vaterite has extremely light carbon and oxygen composition, indicating a fundamentally different crystallization mechanism compared with calcite (see PDF presentation).

Recent graduate students that have been supported by these DOE funds include PhD student Renee Perez (consultant in Calgary) and MS student Grace Giles (currently with EXXON). Additionally, graduate student Jesse Mosolf was funded to process samples for the Ar/Ar dating of the deep igneous rocks from the Inglewood field. Mentored undergraduate students that have gained valuable laboratory and field sampling experience include: Belinda Roder, currently a graduate student in the Department of Earth and Space Sciences at UCLA and Tim Gross, who has been working as a lab assistant for several months and has been accepted to the Colorado School of Mines.

Abstracts, Papers, and Theses Supported by this Research (last three years):

Boles, J.R. and S. Horner (2003). Fluid conductivity in the South Ellwood Fault: communication between the ocean and a hydrocarbon reservoir at one kilometer depth: 78th Annual Meeting of AAPG Pacific Section, Abstracts with Program, Long Beach, California.

Boles, J.R., Horner, S., and G. Garven (2009) Permeability on the South Ellwood fault, offshore Santa Barbara, California: AGU Fall Meeting, San Francisco, California.

Boles, J.R., Horner, S., and G. Garven (2010) Permeability estimate for the South Ellwood fault: SPE Western Regional Meeting, May 27-29, Anaheim, California. SPE Paper 133613, 9p. (PDF attached).

Boles, J.R., Miller, G. F., and T.D., Wright (2010) Modern oil generation and pyrolysis at >800°C from spontaneous combustion in a landslide of Miocene shale, California: Geol. Soc. Amer. National Mtg., Denver, Colorado.

Camacho, H., Boles, J.R., and G. Garven (2010) Thermal anomalies associated with the Newport Inglewood fault zone, Long Beach Field, California: AAPG National Mtg., New Orleans, LA.

Garven, G., Jung, B., and J.R. Boles (2010). A geohydrodynamic study of the role of faults on petroleum migration in the California borderland basins: 85th Annual Meeting of AAPG Pacific Section, Abstracts with Program, Anaheim, California.

Giles, G.F. and Boles, J.R. (2007). Geochemical signatures of rapid carbonate crystallization in well scales. Water-Rock Interaction. Bullen and Wang (eds). 315-319. (PDF attached)

Jung, B., Garven, G., and J.R. Boles (2009). A geohydrologic modeling study of faults and large-scale multiphase flow and heat transport in the Los Angeles Basin, California: AGU Fall Meeting, San Francisco, California.

Jung, B. (2009). Structural controls on paleohydrology and multiphase flow in the Los Angeles Basin: 17th Hubbert Quorum, USGS Menlo Park Center, Menlo Park, California.

Jung, B. (2011). "Geohydrodynamics of Petroleum Migration and Deep Groundwater Flow in Faulted Sedimentary Basins—A Quantitative Analysis": PhD Thesis, Department of Civil & Environmental Engineering, Tufts University (*in preparation*).

Recent Oral and Poster Presentations on This Research: Prof. Jim Boles

October 2009: Coast Geological Society, Ventura, California.

Dec 2009: AGU Fall Meeting, San Francisco, California.

April 2010: AAPG National Meeting, New Orleans, Louisiana (H. Camacho, presenter).

April 2010: Anadarko Petroleum, Houston, Texas.

May 2010: SPE Western Regional Meeting, Anaheim, California.

August 2010: Venoco Inc., Carpinteria, California

November 2010: GSA Annual Meeting, Denver, Colorado.

Dec 2010: M. King Hubbert Quorum, US Geological Survey, Menlo Park, California.