

Alluvial Facies Architecture and the Role of Climate and Tectonics in  
Basin-Fan Systems, Death Valley, California

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# **Alluvial Facies Architecture and the Role of Climate and Tectonics in Basin-Fan Systems, Death Valley, California**

## Abstract

Pull-apart basins are common structural features in strike-slip regimes that have significant petroleum potential. **In non-marine environments, facies architecture in pull-apart basins is controlled by tectonics and climate.** Much attention has been focused on syntectonic facies architecture, frequently because distinguishing the relative roles of climate and tectonics is difficult to discern beyond the last 1 Ma because of basin response time. **The difficulty lies in finding an erosion-sedimentation system with excellent (1) exposure, (2) age control and (3) a nearby tectonically inactive basin with an excellent climatic record is preserved.** I propose that a series of measured stratigraphic sections, which are temporally linked by tephrochronology and paleomagnetism, will allow a 3D reconstruction of the Pliocene-Pleistocene depositional environment and facies architecture of the Death Valley pull-apart basin. **Comparison of the Death Valley record with the tectonically inactive Searles Lake basin to the west and oceanic records of climate change will provide a test of the relative influences of tectonics and climate on sedimentation in a tectonically active pull-apart basin.** The results of this project will influence the interpretation of hydrocarbon reservoir lateral continuity in pull-apart basins, basin response to climatic and tectonic forcing, structural interpretation of late stage pull-apart basin evolution, and provide a framework for stratigraphic correlation in the western US. **This project will build upon previous undergraduate research projects and support at least three additional undergraduate projects.**

## Introduction

Pull-apart basins are common structural features in strike-slip regimes that have significant petroleum potential (Christie-Blick and Biddle 1985; Sylvester 1988). Exploiting the hydrocarbon potential of pull-apart basins is dependent upon understanding the potential reservoir lithofacies (i.e., coarse clastic alluvial-fan deposits) vs. confining lithofacies (i.e., fine lacustrine deposits) architecture (e.g., Carter, 2003). An inherent problem in studying pull-apart basin facies architecture is that these basins are frequently buried (Reijs and McClay 2003) and lateral correlation is difficult (Faulkenberry and Buffler, 1999). As a result, most of what is known about lithofacies architecture in pull-apart basins is inferred from seismic data (e.g., Hurwitz et al. 2002), laboratory models (e.g., McClay and Dooley 1995) or the sparse locations where 3-D exposure is good (Crowell 1974; Reijs and McClay 2003).

In the short fluvial basin-fan environments common to non-marine pull-apart basins, tectonics and climate are the most important forces controlling lithofacies architecture (e.g., Castelltort and Van Den Driessche, 2003). Differentiating between tectonic and climatic forcing in the stratigraphic record is difficult because of the inherent response time between a tectonic or climatic event and expression of that event in the stratigraphic record (See Castelltort and Van Den Driessche, 2003 and references therein). Modeled and field data from geomorphic studies indicate that the minimum response time of basin-fan systems to tectonics is >100 ka to 2.5 Ma for basin sizes ranging from 3 to 40 km in length (Tucker and Slingerland, 1996; Allen and Densmore, 2000; Whipple, 2001). In contrast, climate change produces a fluvial system response in less than a few thousand years (Fernandes and Dietrich, 1997; Tucker and Slingerland,

1997). The response time is an important reason why demonstrating and distinguishing the relative influence of climate vs. tectonics beyond the last 1 Mya has proven difficult (Leeder, 1997). Still another issue is the magnitude of the basin-fan system to tectonic or climatic perturbations.

Based on the discussion above, to effectively discriminate between climate and tectonics in the stratigraphic record requires (1) two nearby (same latitude; <200 km distance) basins, one tectonically active and the other tectonically inactive; (2) a high resolution climate record in the tectonically inactive basin; (3) high resolution geochronology ( $\pm 100$  ka) in both basins; and (4) evidence that the tectonically active basin contained short to medium size drainage basins. A successful study would also require (5) 3D exposures in order to examine the fluvial system proximal and distal from the paleo-basin and (6) span a time frame that includes both rapid climate changes and sustained interglacial and/or glacial periods.

All of these conditions are uniquely met in Death Valley where, the Pleistocene-Holocene deformation has provided 3D exposures of Pliocene sediments deposited in earlier stages of the Furnace Creek pull-apart basin. Wright et al. (1999) showed that Pliocene sediments of Furnace Creek basin were locally derived. West of Death Valley is the tectonically inactive Searles Valley where cores provide a climatic record for the last ~3.5 Ma (Jannik et al. 1991; Smith 1991). In addition, worldwide compilation of Pliocene climate provides a record of rapid climate change as well as sustained glacial and interglacial climates (Figure 2) during the late Pliocene (Shackleton et al., 1995; Dowsett et al., 1999). The late Pliocene-early Pleistocene geochronology is provided by tephrochronologic and paleomagnetic studies that have established a robust

geochronology for the Death Valley stratigraphy that is correlative to Searles Valley cores (Knott et al. 1999; Sarna-Wojcicki et al. 2001). These tephra beds are well preserved at multiple locations throughout Death Valley, and when combined with paleomagnetism, provide geochronologic resolution of  $10^4$ - $10^5$  years.

I hypothesize that measured stratigraphic sections, which are temporally linked by tephrochronology, paleomagnetism and radiometric dating will allow a 3D reconstruction of the Pliocene-Pleistocene depositional environment and facies architecture of the Death Valley pull-apart basin. Based on the facies distribution, conformity of the sections and comparison to the tectonically inactive Searles basin, inferences may be made regarding the relative influences of climate and tectonics on facies distribution.

### Proposed Study

I propose that undergraduate students and I measure a series (4-7) of stratigraphic sections in the late Pliocene to early Pleistocene Furnace Creek pull-apart basin of Death Valley. These sections will be located in the middle to southeastern portion of the Furnace Creek basin (Figure 1). Areas surrounding the sections will be mapped at 1:12,000 scale as well. Facies in each section will be described and appropriate samples collected for tephrochronologic, paleomagnetic, and  $^{40}\text{Ar}/^{39}\text{Ar}$  analysis.

These stratigraphic sections will be located both proximal and distal (>10 km) to the basin bounding faults, thus providing a nearly complete section through the basin. Tephra beds ranging in age from ~3.5 Ma to ~2 Ma have been found at several locations in the Furnace Creek basin deposits (See Sarna-Wojcicki et al., 1999 for a

review). The tephra beds will provide excellent time-stratigraphic marker beds from section to section and allow correlation to the climatic record from the Searles Valley and oceanic records. Local mapping studies by CSU Fullerton undergraduates have confirmed at least three locations where ~3.3 Ma tephra beds crop out and have been tentatively identified (Hathaway, 2004; Ebbs, in prep; David, in prep). Several earlier studies have identified evidence for facies changes in the Furnace Creek deposits, including evidence of a lake (Blair and Reynolds, 1999; Knott and Sarna-Wojcicki, 2001). However, these studies lack either precise geochronology or facies descriptions.

### Methods

Geologic mapping and measuring stratigraphic sections will be completed using standard methods. Tephrochronology uses the chemical composition of glass shards in tephra layers to correlate tephra beds over great distances (Sarna-Wojcicki and Davis 1991). When found in stratigraphic sequences with other tephra layers and combined with paleomagnetism, tephrochronology is a precise and accurate time-stratigraphic technique. Volcanic glass will be concentrated from the tephra beds using wet sieving, magnetic and heavy liquid separation techniques. Once concentrated, glass shards will be analyzed for major element composition using the electron microprobe at UCLA. Minor and trace element compositions will be measured using the laser ablation ICP-MS at CSU Long Beach.

Paleomagnetic samples will be collected and analyzed by Dr. Joseph Liddicoat at the UC Santa Cruz paleomagnetism laboratory. Radiometric dating of tephra beds will be conducted at the US Geological Survey  $^{40}\text{Ar}/^{39}\text{Ar}$  lab at Menlo Park, California under the guidance of Dr. Robert Fleck.

## Undergraduate Student Involvement

Undergraduate students at CSU Fullerton will be key participants in this project (Table 1). Students will map the local geology, measure the section, collect samples and evaluate geochronologic data as part of their senior thesis. In addition, students will perform the laboratory preparation of samples and participate in electron microprobe and LA-ICP-MS analyses when practical. The students will consult with myself as well as scientists at UCLA, CSULB, USGS and Barnard College when interpreting the results.

Based on recent past successes, undergraduate students involvement in this type of research is both educationally and scientifically productive. Two students (Veva Ebbs and Jeffrey Hathaway) are completing similar, fruitful studies of the northern Furnace Creek basin (northernmost Kit Fox Hills) with intramural funding. Hathaway (2004) has described curvilinear normal faults and fault parallel folding consistent with simple shear deformation along a propagating flower structure. Previous hypotheses have suggested that these faults are initially linear and are then deformed. Hathaway's data is the first that we are aware of that describes normal fault structures that have an initial curvilinear form. Ebbs (in prep) has found previously unknown tephra beds that are geochemically similar to Upper Glass Mountain tephra beds (0.8 – 1.2 Ma); however, these tephra beds are stratigraphically below the 3.35 Ma Mesquite Springs tuff. Both of these studies will be presented at the Geological Society of America Cordilleran Section meeting (April 2005) and both students have elected to continue their education in graduate school.

A third student (Bryan David) has begun a collaborative study with USGS scientists examining another 3.35 Ma section located to the southeast and closer to the basin boundary. The studies of all three of these students will be cornerstones for the proposed project. This proposal will likely support at least 3 other undergraduate student theses.

### Links to Other Studies

The USGS has recently completed a 5-year mapping project of the central Death Valley project, which includes the proposed project area. The proposed study will build upon this regional mapping compilation by providing detail stratigraphic data. Graduate and undergraduate students at Caltech under the direction of Dr. Brian Wernicke have been mapping the Nova Basin, which crops out on the western margin of Death Valley and includes late Pliocene deposits and tephra beds.

### Possible Outcomes and Significance

This project will examine significant knowledge gaps identified by previous studies by others. The outcomes are described below in the form of possible publications that would be co-authored with undergraduates and form the basis of meetings presentations.

- **Basin Response to late Pliocene to early Pleistocene Climate Change, Furnace Creek Basin, Death Valley, California.** *The hypothesis/problem to be tested:* Is climatic and/or tectonic forcing is discernible in small to medium sized fluvial basin-fan systems in Pre-Quaternary deposits. *Significance:* Study of basin-fan response time is an important data gap in the study of fluvial systems (Castelltort and Van Den Driessche, 2003). Much of the knowledge of these systems is < 1 Ma (Leeder, 1997)



and from longer drainage systems (i.e., Searles Lake) and therefore may not be as sensitive to climate change as the Death Valley record.

- **3D Facies Architecture of a Pull-Apart Basin, Furnace Creek Basin, Death Valley, California.** *Hypothesis/problem to be tested:* What is the 3D distribution of lithofacies in pull-apart basins? *Significance:* Knowledge of the connectivity of reservoir facies impacts hydrocarbon flow and recovery. With establishment of the facies architecture and geochronology, collaborative studies of the sequence stratigraphy, palynology and microfossil (e.g., ostracodes) could then be initiated.
- **Late Pliocene- Early Pleistocene Tephrostratigraphy of the Western US.** *Hypothesis/problem to be tested:* Based on Ebbs' preliminary findings and other studies in the region (Sarna-Wojcicki et al. 2001), Plio-Pleistocene eruptions were substantially more frequent and their chemical composition very similar to middle Pleistocene eruptions. Analysis of the Death Valley tephra deposits for major, minor and trace element composition will substantially improve the stratigraphic record in the western US and allow basin to basin correlation of Pliocene stratigraphic sections. *Significance:* These data would assist in correlating basin deposits throughout the western US, which influences climate models and stratigraphic correlation. Dowsett et al. (1999) noted that many of the terrestrial records used in their modeling of Pliocene climate have poor geochronology; this study would substantially improve the mid continent record.
- **Paleogeography and Kinematics of a Late Stage Pull-Apart Basin.** *Hypothesis/problem to be tested:* Field observations and laboratory models indicate that pull-apart basins evolve in stages (McClay and Dooley 1995); however, there

are few examples of the later stage kinematics (see Rejis and McClay, 2003 and references therein). The tephra marker beds identified in this study will allow a paleographic reconstruction of the Pliocene Furnace Creek and Pleistocene-Holocene Death Valley pull-apart basin. *Significance:* These results will add to a fundamental understanding of pull-apart basin evolution, which will impact models of structural hydrocarbon traps in pull-apart basins.

#### Impact on Faculty Member and Students

Faculty: This research will be performed in Knott's tephrochronology with sample preparation lab at CSUF. These funds would help to establish a credible lab for tephrochronology functioning at CSUF. Establishment of this lab and utilization of the LA-ICP-MS facility at CSU Long Beach should lead to other collaborations and opportunities for undergraduates to participate in research.

Students: These research funds would provide support for undergraduate thesis projects for several students. Most CSUF students are from groups under-represented in the sciences supporting their own education. This financial support allows students to concentrate on research without reduced financial hardship. The intramural grant funding has produced three undergraduate theses with publishable results. These funds and the exposure to research were an important factor that encouraged two students (both single parents; one also a woman) to enroll and a third (Native American) to contemplate graduate study.

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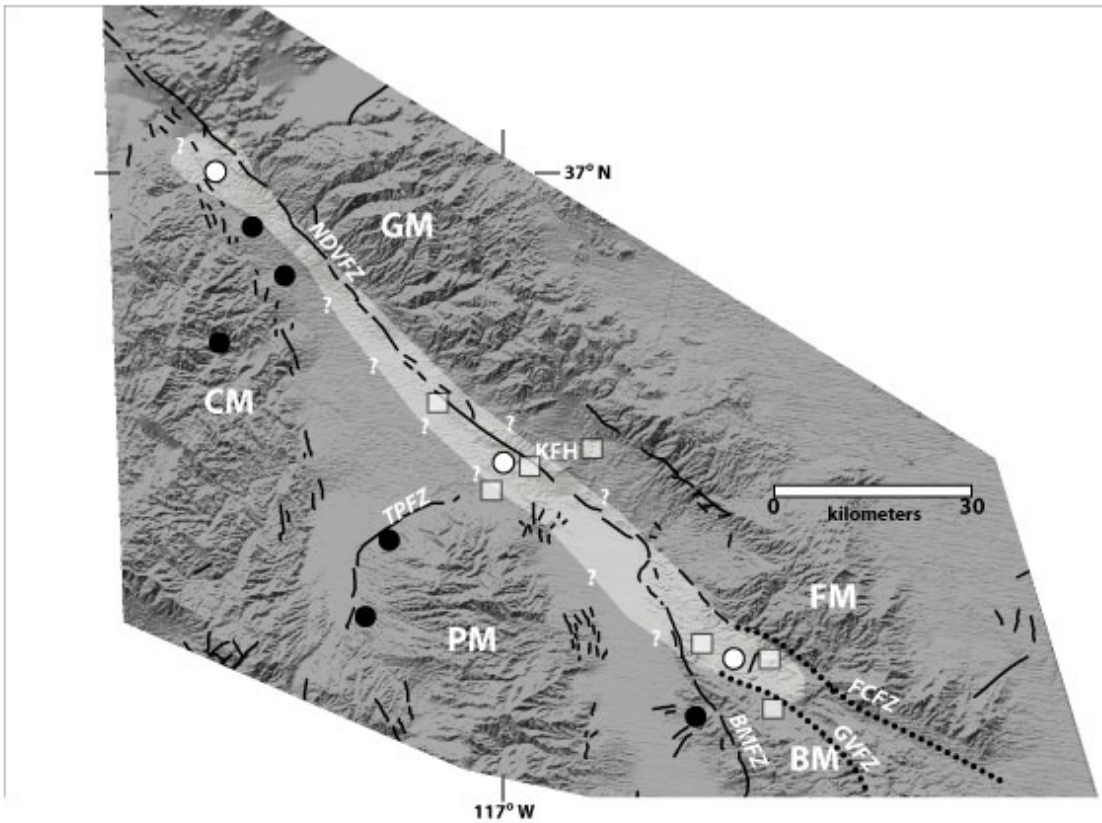
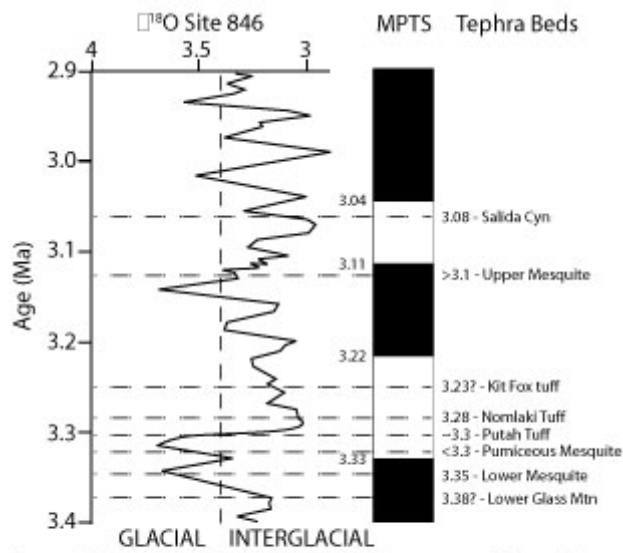


Figure 1 - Map of northern Death Valley showing the distribution of the Furnace Creek basin about 3.2 Ma along with Quaternary fault traces (black lines). White squares indicate proposed locations of measured stratigraphic sections. White circles indicate locations where late Pliocene tuffs are interbedded with lake sediments. Black circles indicate where late Pliocene tuffs are interbedded with alluvial-fan deposits. The shaded area is the aerial extent of the postulated lake. Major geographic features are: Black Mountains (BM), Cottonwood Mountains (CM), Death Valley (DV), Funeral Mountains (FM), Grapevine Mountains (GM), Panamint Mountains (PM) and Kit Fox Hills (KFH). Major fault zones are: the Black Mountains (BMFZ), Furnace Creek (FCFZ), Grandview (GVFZ), Northern Death Valley (NDVFZ), and Towne Pass (TPFZ). Shaded relief base map derived from digital elevation model.



**Figure 2** - Diagram showing benthic oxygen isotope record from ODP Site 846 (Shackleton et al., 1995), magnetic polarity time scale (Berggren et al., 1995), PRISM2 climate model (Dowsett et al., 1999), and tephra beds already identified in the Funeral Formation and elsewhere in Death Valley (Sarna-Wojcicki et al. 2001). Reverse polarity chrons (white) are the Kaena and Mammoth with boundary ages to left. After Dowsett et al., (1999).

**Table 1 – Tentative Schedule**

	<b>STUDENT GROUP 1</b>	<b>STUDENT GROUP 2</b>	<b>Y E A R</b>
Sept 05-Dec 05	Reconnaissance Work		<b>1</b>
Jan 06	Recruit Student(s) Mapping/Measuring and sampling sections in Furnace Creek area		
Feb 06-Aug 06	Initial Results (EM/LA- ICP- MS/Paleomag/ <sup>40</sup> Ar/ <sup>39</sup> Ar)		
Sept 06-Dec 06	Compilation of data and writing Additional sampling to fill data gaps	Recruit Second Student(s)	<b>Y E A R</b>
Jan 07	Complete writing	Mapping/Measuring and sampling sections in Kit Fox Hills area	
Feb 07-Aug 07	Presentation of results at Cordilleran Section meeting of GSA	Initial Results (EM/LA- ICP- MS/Paleomag/ <sup>40</sup> Ar/ <sup>39</sup> Ar)	
Sept 07-Dec 07		Compilation of data and writing Additional sampling to fill data gaps	<b>Y E A R</b>
Jan 08		Complete writing	
Feb 08- May 08		Presentation of results at Cordilleran Section meeting of GSA	
June –Aug 08	Writing		<b>3</b>