Using High-Resolution Basin Analysis to Unravel Complex Fault Kinematics, Understand Tectonic Events and Address Climate Change in the Central Basin and Range

Melissa (Lisa) Lamb, University of St. Thomas, Sue Beard, USGS, Hickson Thomas, University of St. Thomas, Paul Umhoefer, Northern Arizona University

Introduction

The Lake Mead Area is a key area to study extensional processes (e.g., Anderson (1971; Wernicke and Axen, 1988) as well as the evolution of the Colorado River and Grand Canyon (e.g., Karlstrom et al., 2014). Much work in this area focused on structural analysis and thermochronolgy (e.g., Reiners et al., 2000; Dubendorfer, 1988) but Beard (1996) recognized the need to study the complex stratigraphy as well. The Horse Spring Formation (HSF) records hanging wall deposition prior to and during the main phase of extension from ~17 to ~8 Ma. Ranging from >25 to ~12 Ma, the HSF consists of a variable mix of carbonates, siliciclastics, tuffs, and evaporites that formed in small basins of varying size. The deposits have been subsequently beautifully exposed by down-cutting of Colorado River tributaries, possibly due to establishment of the Colorado River in the area at 5-6 Ma. We set out to define and characterize these basins in detail to reconstruct the complex faulting and tectonic evolution of the area and to address the following questions:

How does extension in a wide rift proceed?
How does the hanging wall break-up?
- **Progression spatially, from east to west?**
- **Different styles of faulting through time?**
- **Continuous through time or punctuated?**

How do climate change and evolving topography affect sedimentation in a major extensional orogen?

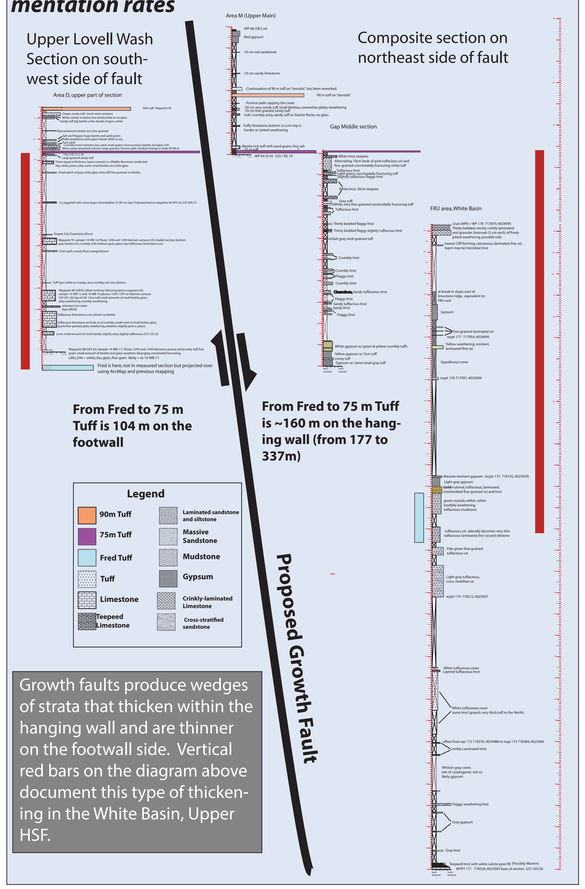
Because the HSF stratigraphy is so variable in terms of lateral and vertical facies, it can be hard to map across faults, but this complexity is actually advantageous: separate basins and subbasins have their own unique characteristics that can be used to unravel deformation. Numerous tuffs allowed us to create a detailed chronostratigraphy: we probed 216 tuff samples for geochemical fingerprinting and dated 22 samples using $^{40}Ar/^{39}Ar$ geochronology. We measured over 60 detailed sections and, in the highly variable areas, walked out beds to document lateral changes. We mapped at 1:5,000 and 1:10,000 scales and conducted paleocurrent and provenance analyses. Finally, we ran 715 lacustrine carbonate samples for stable O and C isotope analyses.

With this huge integrated dataset, we defined a number of sedimentary basins and determined many of the faults that created them, as well as the timing of faulting. We identified growth faults at two different times within the HSF and began to distinguish tectonic and climatic signals in the stratigraphic record. We are creating a step-by-step tectonic reconstruction of the entire area from 18 Ma to present. Our structural analyses have benefitted greatly from the multidisciplinary, detailed approach. It has also been a very successful tool for engaging students (undergraduates and M.S.) in research at all scales.

Selected Examples of our Work to Date

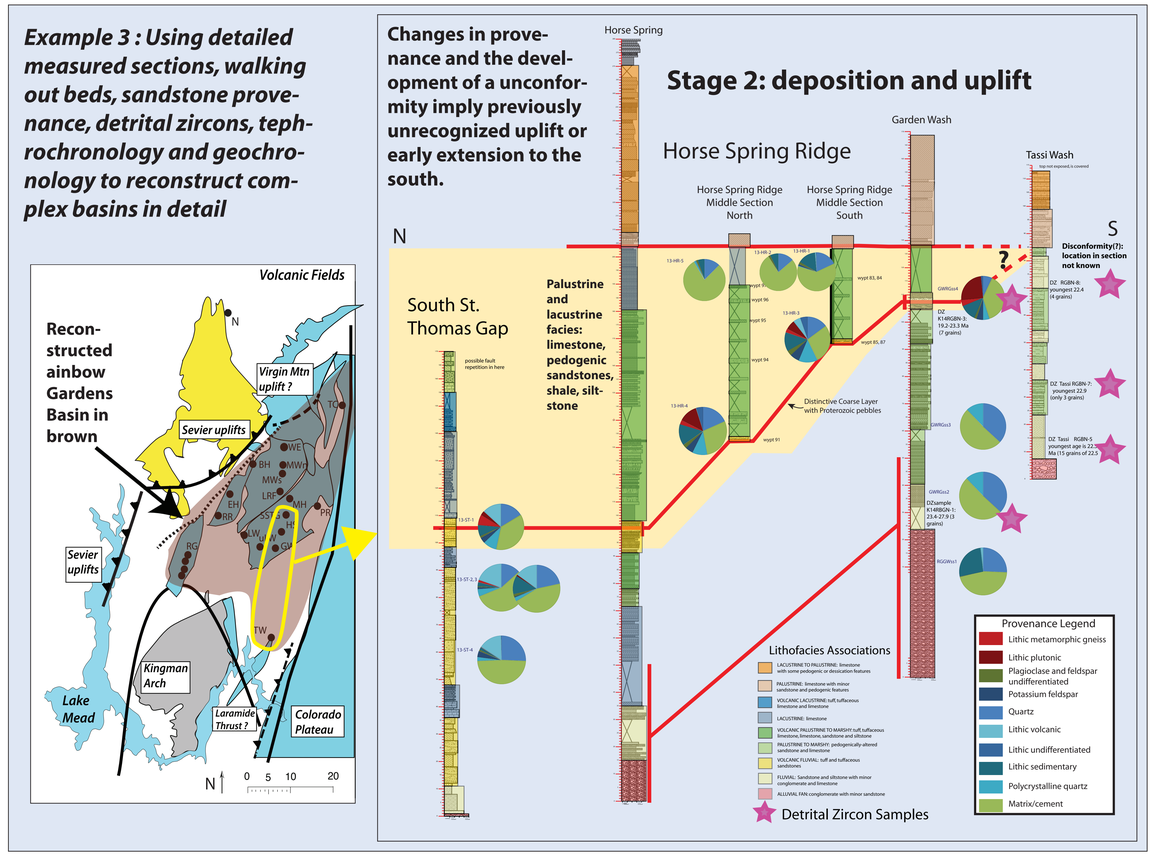
Because the Horse Spring Formation was deposited in a series of basins that were dismembered during several episodes of faulting, outcrops are found throughout the Lake Mead region. During several field seasons and over 20 undergraduate and M.S. student projects, we carefully documented the facies and faulting in each region in order to reconstruct the basins and timing of each stage of deformation. Below are four examples of this work.

Example 1: Using detailed measured sections, mapping, tephrochronology and geochronology to find and determine the timing of growth faulting and sedimentation rates

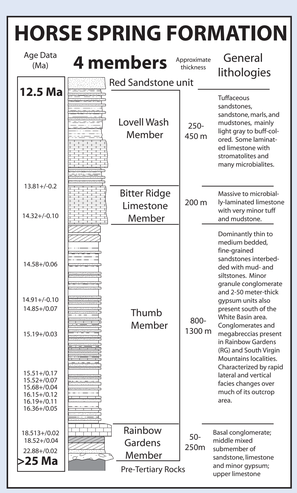


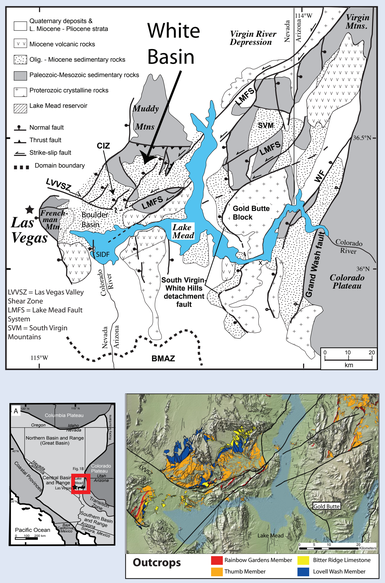
Growth faults produce wedges of strata that thicken within the hanging wall and are thinner on the footwall side. Vertical red bars on the diagram above document this type of thickening in the White Basin, Upper HSF.

Example 3 : Using detailed measured sections, walking out beds, sandstone provenance, detrital zircons, tephrochronology and geochronology to reconstruct complex basins in detail



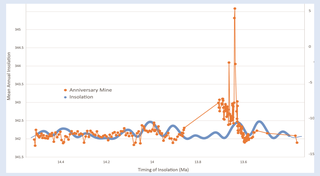
Lake Mead Area: complex mix of normal and strike-slip faults





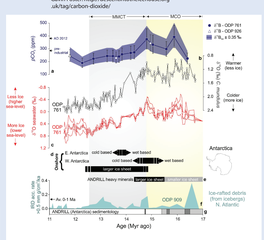
Example 2: Climate and tectonics

We are trying to unravel the interplay of climatic and tectonic factors on sedimentation by comparing the laterally and vertically highly-variable HSF facies and our stable isotope data to global climate data sets. Isotopic variation within thick, uniform lacustrine deposits are likely the result of Milankovitch-scale solar insolation cycles. Other stratigraphic changes may be linked to a major middle Miocene global cooling event, including the mid-latitude aridification of continents. At the same time, tectonics and extensional faulting control the location and geometry of basins.



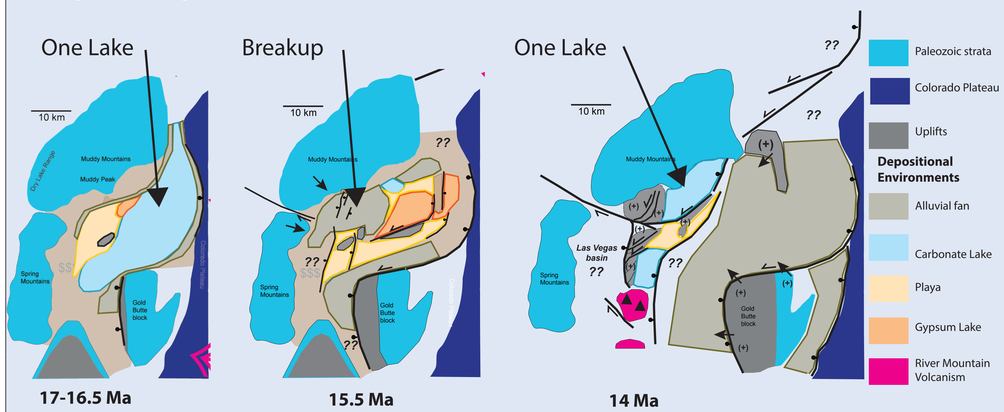
HSF oxygen variations vs solar insolation variations for this latittude

HSF oxygen variations vs global marine oxygen variations (Zachos, 2001).



The middle Miocene encompasses the Miocene Climatic Optimum (MCO) and the Middle Miocene Climate Transition (MMCT), a major rapid global cooling event. Cycles within this cooling may have contributed to the stratigraphic cycles we see.

Example 4: simplified reconstructions, based on detailed ArcGIS reconstructions



17-16.5 Ma | 15.5 Ma | 14 Ma

We are organizing all of our student and faculty mapping into one ArcMap project so that we can create detailed palinspastic reconstructions, moving tens of individual polygons at each time step from 18 Ma to present. Our initial work suggests that deformation is continuous from 17 to 12 Ma but comes in pulses, with changing rates through time. We see two cycles of the formation of a long-lived lake created by a single major fault followed by the breakup into subbasins on many faults.