[PS]Tectonic and Geomorphic Controls on Cyclic Lacustrine and Fluvial Deposition*

Richard Langford[1], Katherine Giles[1], and Xiaowey Li[1]

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Abstract

New Aptian and Albian pre-salt reservoirs and sources in South Atlantic margin basins underscore the importance of lacustrine systems in the generation and trapping of hydrocarbons. However, few outcrop analogs reveal in detail the distribution of facies and their relationship to structures within similar lacustrine basins. Aptian strata of West Texas include a thick (up to 1 km) section of lacustrine beds, separated by thin fluvial intervals. The exposures cover an area of at least 1,700 km, however, the margins are not exposed and the lake may have been much larger. In the Indio Mountains of West Texas, thrusts have juxtaposed three 6-9 km long exposures, each parallel to the Aptian rift margin and originally spaced 4 and 12 km apart. This provides a 3-dimensional exposure of the lacustrine stratigraphy. Carbonate nodule-rich shales with discontinuous limestones dominate the lacustrine sediments. Shales contain ostracods, gastropods and charophyte algae and contain widely dispersed, but thin lenses of microbial limestone. The shale and limestone intervals are separated by channelized sandstones and conglomerates. Key features relevant to petroleum reservoirs and sources are: 1) The lake probably initiated in the deeper basins of the rift and onlapped onto intra-basinal highs, 2) However, the wide spread shales and interstratified incised fluvial sandstones in all fault panels require a lake with a broad, relatively flat bottom that infilled rift basins as the lake expanded, 3) Cyclic deposition reflects repeated incursions by a fluvially-dominated delta into a, shallow, low relief lake, resulting in cyclical shallowing-upward, parasequence-like architecture. Most fluvial deposition was from an axial stream that lay to the southeast. However, monomict conglomerate channel fills must have been deposited from sources from nearby rift flank uplifts, 4) Channels are concentrated within 1 – 4km wide, channel-rich belts oblique to basin margins and did not shift throughout deposition of the formation. This requires structural localization of the axial drainages, probably by transfer zones separating rift segments.

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Booth 15A

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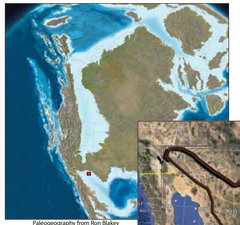
Background

Aptian and Albian lacustrine systems have become important targets for petroleum exploration in the last few years (Neumann et al., 2003; Beglinger et al., 2012; Mello et al, 2013). These paleo-lakes were located in rift basins associated with the break-up of Pangaea (REF) and have been identified as both important source rocks and, more recently reservoirs.

Tectonic Setting



Paleogeography from Ron Blakey
Northern Arizona Geology http://jan.ucc.nau.edu/

During the Middle Cretaceous (Aptian and Albian a rift basin formed, extending from the Gulf of Mexico to Southern California along the present US-Mexico Border.

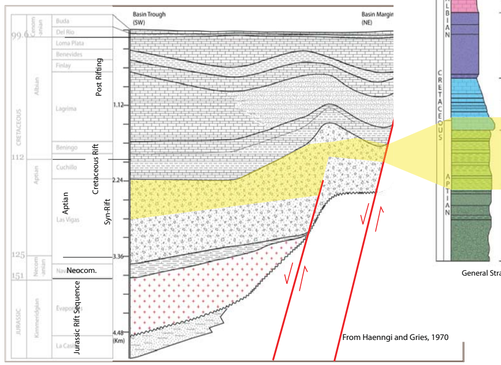
The rift fill is largely Aptian through Cenomanian, and is over 5 km deep in the center of the Rift.

The study area is highlighted in the red Square and was located along the northeast flank of the rift in the segment known as the Chihuahua Trough.

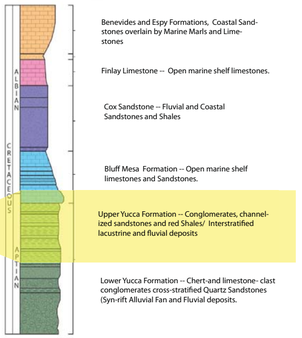
Tectonics of the Chihuahua Trough

Rifting from Middle Jurassic to Early Late Cretaceous (End of Cenomanian)
5 km of Cretaceous strata in deepest basins.
Jurassic Evaporites
Early Cretaceous Conglomerates and coarse Sandstones
Late Cretaceous fluvial and shallow marine.

Stratigraphy



From Haenngi and Gries, 1970



Benevides and Espy Formations, Coastal Sandstones overlain by Marine Marls and Limestones

Finlay Limestone -- Open marine shelf limestones.

Cox Sandstone -- Fluvial and Coastal Sandstones and Shales

Bluff Mesa Formation -- Open marine shelf limestones and Sandstones.

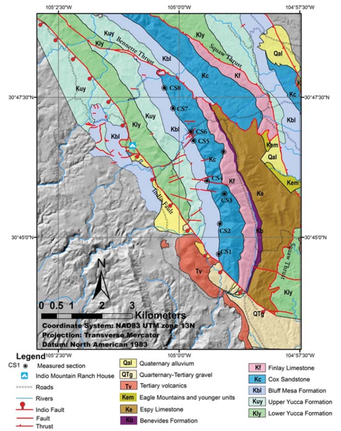
Upper Yucca Formation -- Conglomerates, channelized sandstones and red Shales/ Interstratified lacustrine and fluvial deposits

Lower Yucca Formation -- Chert-and limestone- clast conglomerates cross-stratified Quartz Sandstones (Syn-rift Alluvial Fan and Fluvial deposits.

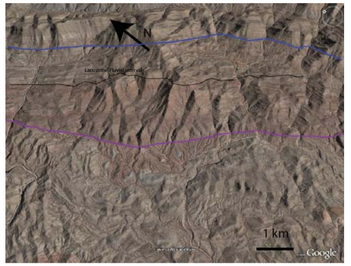
General Stratigraphic Section (from Page 2012)

Early Trinity Laramide Deformation

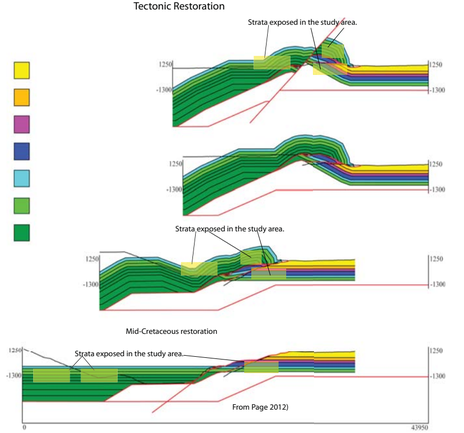
The stratigraphy of the Indio Mu includes over 2.5 km of section. The basal unit is the Lower Yucca formation, the base of which is not exposed. This contains over 800 m of alluvial fan and fluvial strata. In wells immediately to the southeast, over 2 km of this interval are preserved. This is overlain by the upper yucca lacusrine and fluvial deposits, which are the subject of this study and are highlighted in yellow. This interval includes up to 700 meters of interstratified lacustrine mudstones and sandstones and fluvial channel sandstones. An abrupt transgression at the base of the overlying Bluff Mesa formation records marine transgression of the study area.
From Haenngi and Gries, 1970



The geologic map of the area exhibits two Northeast dipping thrust sheets dipping to the Northeast. Although the dips suggest movement to the southeast, Kinematic indicators and structural relationships require northeast transport. The range as a whole is interpreted as a



Tectonic Restoration



Seth Page (2012 performed a 2-D restoration across the study area. Restoration required significant thickening of the Yucca and Bluff Mesa Formations. His model restoring the thrust faults resulted in an 18 km displacement of the upper thrust plate, which includes the basin-center strata. The, basin-margin strata is preserved in the lower thrust plate as a large duplex.

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Depositional Environments.

Typical outcrop of red lacustrine mudstones. with thin interbedded sandstones

Stromatolitic domes in a convex upward bed, onlapped by lacustrine mudstones.

Conglomerate composed of eroded nodules from the lacustrine shales found in fluvial channels within the lacustrine intervals

Irregular carbonate nodules. Most are micritic, but septarian, laminated and radial fans of calcite crystals are also present

Erosional contact at base ov channel incised into underlying lacustrine mudstones

horizontal lamination

Trough cross-bedding

Stromatolitic laminae

Nodules

Burrows

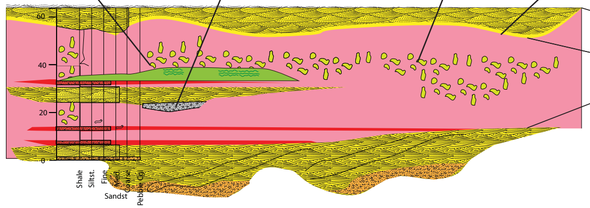
Stromatelite (wavy or domal features)

Conglomerate of reworked nodules

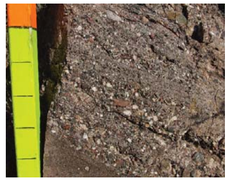
Brown-burrowed sandstone beds Thin, laterally continuous, beds wave and current ripple cross-strata

Chert Pebble Conglomerate Trough cross-stratified and Horizontally bedded

Quartz sandstone with chert grains and pebbles



Typical outcrop pattern of alternating fluvial and lacustrine intervals. These are 20 m thick each.



Chert-pebble conglomerate lenses contain well-rounded clasts of chert and more angular limestone clasts, indicating two source areas outside the rift.

The stratigraphic section above is a short piece of a section through the basin-center thrust plate interval of the Upper Yucca Formation.

The key elements are the alternating channel sandstones and laterally extensive red and variegated mudstones.

Channel sandstones (yellow and orange) are white and light gray and contain gravel bars composed of 2 to 5 cm diamter well rounded chert clastsndar the base (Orange). The sandstones exhibit large troughs cross strata (in this section up to 1.3 m thick) that become thinner and finer-grained towards the top. The sands are quartsoze with up to 12% chert grains and in some channels abundant coarse carbonate grains. Many channels, particularly those in the basin-ceneter plate exthibit well-defined lateral accretion bedding and are interpreted to represent deposits of meandering stream channels 2-5 m deep and 50 to 150 m across that flowed across the rift basin.

The pink and red interval represents the red and variagated mudtsones with interbedded biotrubated and ripple cross-stratified laterally continuous fine-grained standstones. the brown sandstones can be present throughout the mudstone intervals, but are most common in the basal 1.5 meters. When not bioturbated, the brown sandstones exhibit well-defined wave and current ripples. The almost ubiquitous burrows are both horizontal and vertical, and range from 0.3 to 1.0 cm in diamteter. Poorly preserved meniscae are sometimes present. In the study area as of yet, only estracodes have been found in these strata. However, 25 km to the northwest, thes same strata yield gastropods, pelycopods and charophyte algae. Key features are the abundant nodules and algal stromatolites and stromatolite bearing sandstones (See Li and Giles companion poster to this on Wednesday).

The mudstones are interpreted as deposits of extensive, shallow, fresh/brackish water lakes that extended across the 25 km extent of the rift that was invertedinto the thrust plates we see today.

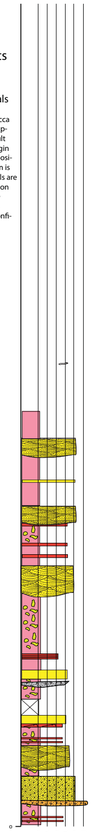
A large broken nodule from one fo the rred mudstones exposing the interior. Septarian concretion overgrown with large radiating calcite crystals. Nodule is 50 cm diameter.

The effects of Major Faults

Thickening of Lacustrine intervals

Complete sections through the upper Yucca formation show the section expands by approxmately 200 % in the Basin Center Fault block In both basin center and Basin Margin blocks cycles of fluvial and lacsturine deposition are evident. Another key observation is that lacusrine nodules and fluvial channels are foune in every outcrop. It seems evident on inspection that the lacusrine intervals are thicker in the basin-center outcrop. This proves to be statistically valid at a 95% confidence interval.

Onlap of Basal Indervals.



Nodules

Burrows

Conclomerate of reworked nodules

Brown-burrowed sandstone beds Thin, laterally continuous, beds wave and current ripple cross-strata

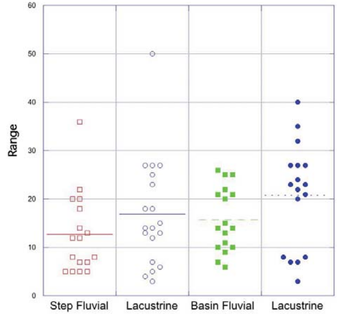
Chert Pebble Conglomerate Trough cross-stratified and Horizontally bedded

Quartz sandstone with chert grains and pebbles

Key Depositional Observations

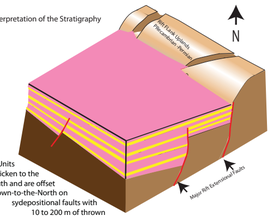
As illustrated by the sections on the left, shallow lacusrine and fluvial envronments form outcrops that extend across both structural blocks. The coninuity of fluvial and lacustrine intervals implies a very broad low relief depositional envrionment. The one good modern geometric analog might be the Omo River and Northern Lake Turkana basin, where a meandering stream and associated lake fill a 30 km wide rift basin.

Fluvial vs Lacustrine Thickness in Basin Margin and Basin-center Outcrops



Plots of unit thickness show that lacutrine intervals are more varied in thickness, with a greater mean thickness than the fluvial intervals. Measured sections in the fluvial units average 12 m in the basin margin plate and 14 m in the basin center plate. Because of the erosional bases of the fluvial intervals, the thickness of measured sections exagerates the variation in true thickness. Two populations are evident, One that averages 10 m thick and another that averages 20 m thick. Field observations show that the individual channels average 3 to 5 m thick and that multi-story sandstones account for the thicker intervals. A very think lacusrine interval in the top of the section skews the results for the lacusrine beds, However, even not including these units, the basinal lacustrine units average 4 meters thicker.

Structural Interpretation of the Stratigraphy



Thickening is accomodated though onlap and thichening of shales. Fluvial sandstones are inferred to have formed relatively quickly and formed thin intervals that planed of structural highs. Deformation during lacusrine intervals allowed thickening in subsiding blocks as these were protected from intermittant erosion.

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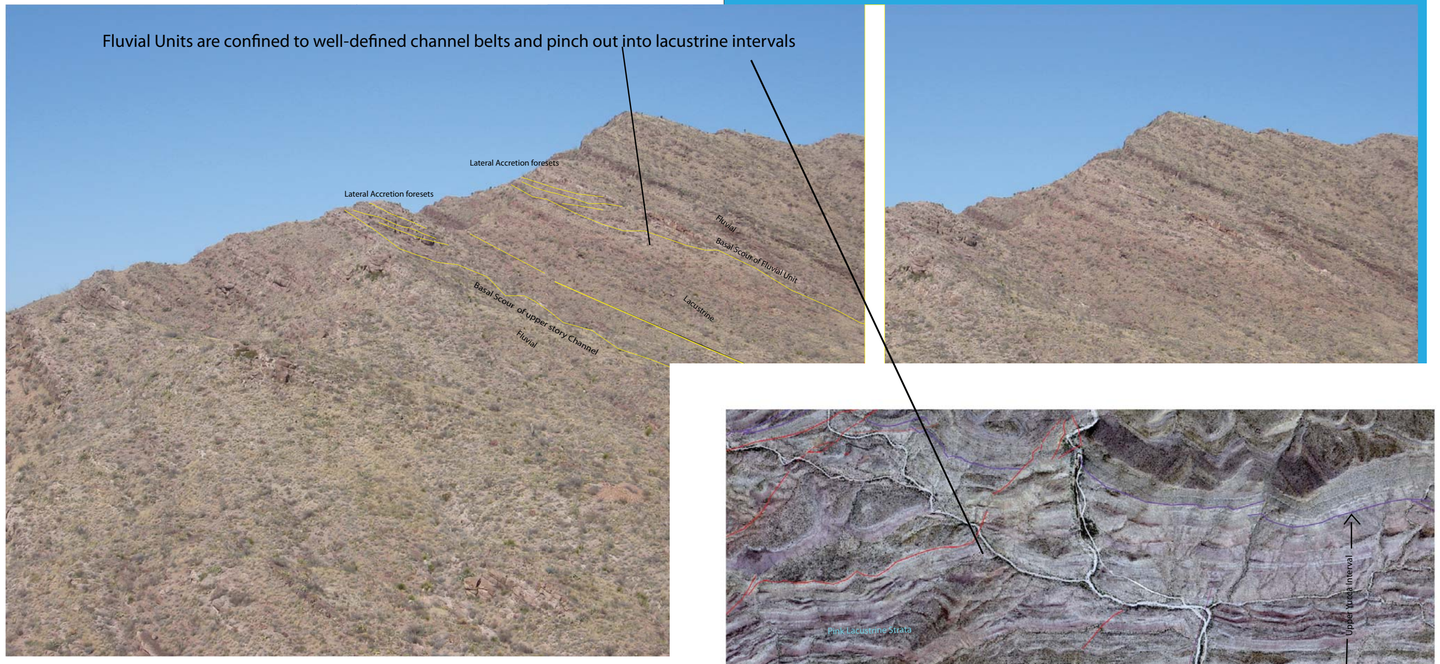
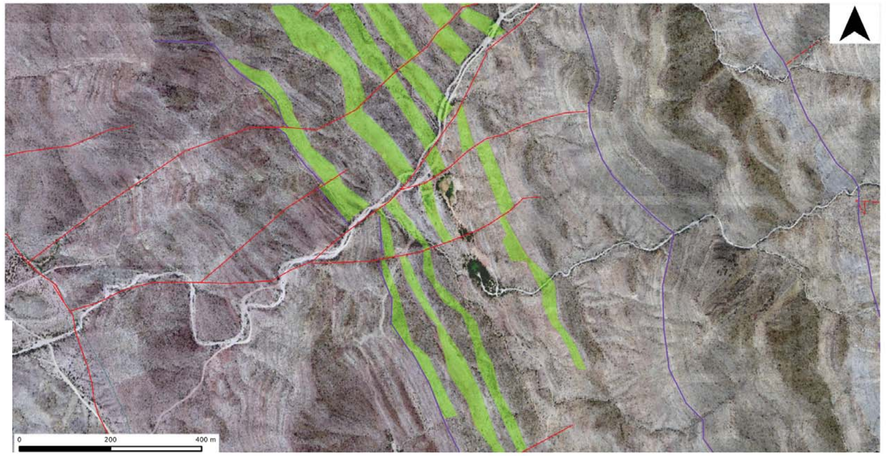


Effects of Syndepositional Faults



Individual faults cannot be correlated across the syndepositional faults. The above map shows how lacustrine intervals, highlighted in green cannot easily be correlated across a complex of syndepositional faults. However, the Base of the Upper Yucca formation, which is marked by the appearance of the first lacustrine beds can be correlated with the typical down-to-the -northwest sense of slip. Dips across the fault, and therefore apparent thicknesses are similar. Note how the lacustrine units thicken across the fault and accommodate thickening within the unit.

Summary

1. Although previously interpreted as marginal marine, the fauna and stratigraphy strongly imply a lacustrine setting

2. Fluvial intervals are interstratified with the lacustrine beds.
   Fluvial units incise into, and sometimes though the lacustrine intervals.
   Isolated fluvial channels are found within the lacusrine intervals.
   Wide, tabular and lenticular fluvial deposits exhibit lateral accretion and are interpreted as deposits of meandering channels.
   Channels form multi-story, laterally stacked fluvial complexes that separate thicker intervals of lacustrine strata.

3. Lacusrine units are 5-120 meters thick and contain burrowed sandstones, and abundant and varied carbonate nodules.
   Algal stromatolites and algal beds form isolated complex upward sandstones and sandy carbonates within the lacustrine units.
   Isolated fluvial channels are found within the lacustrine intervals.
   The association with fluvial units and widespread continuity suggests deposition in an extensive, but shallow lake.
   Associated charophyte algae, gastropods and pelecypods suggest fresh-to brackish water, as does the absence of evaporites.

4. Syndepositional faults shaped deposition, with thicker lacustrine strata on the down thrown blocks.
   The section doubles in thickness across a cryptic, buried major rift fault.
   Smaller cross-faults localize and restricted lacustrine deposition.
   Fluvial intervals do not expand across the faults, whereas lacusrine intervals become thicker.

5. Fluvial channels are found in belts that are probably controlled by syndepositional deformation. Thick fluvial strata pinch out laterally into lacustrine strata over several hundred meters at the margins of the fluvial belts.

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