Subsidence associated with active growth faulting on the Mississippi Delta: Displacement rates and steering of the Mississippi River

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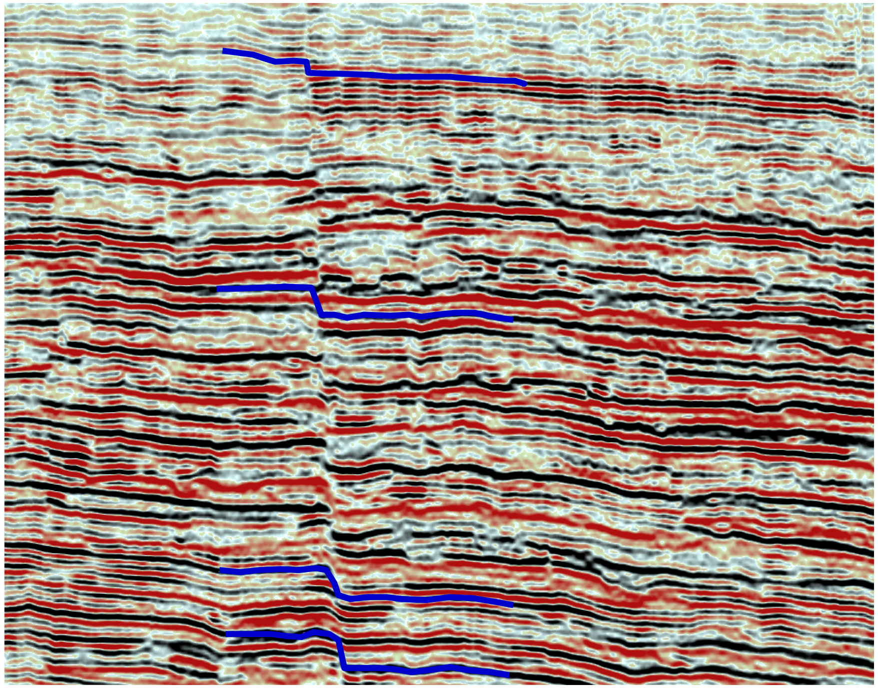

Long-Term Estuary Assessment Group

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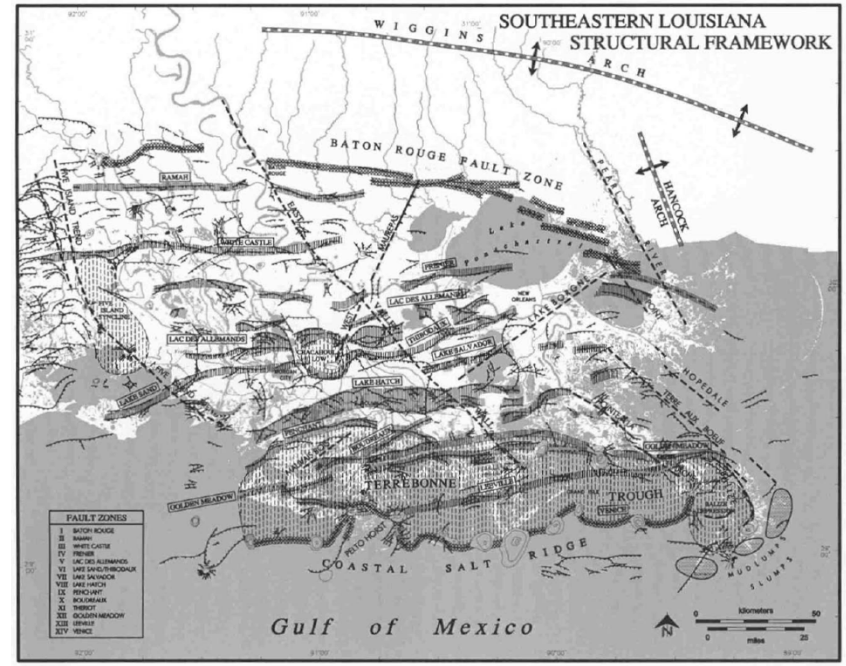
Big Questions

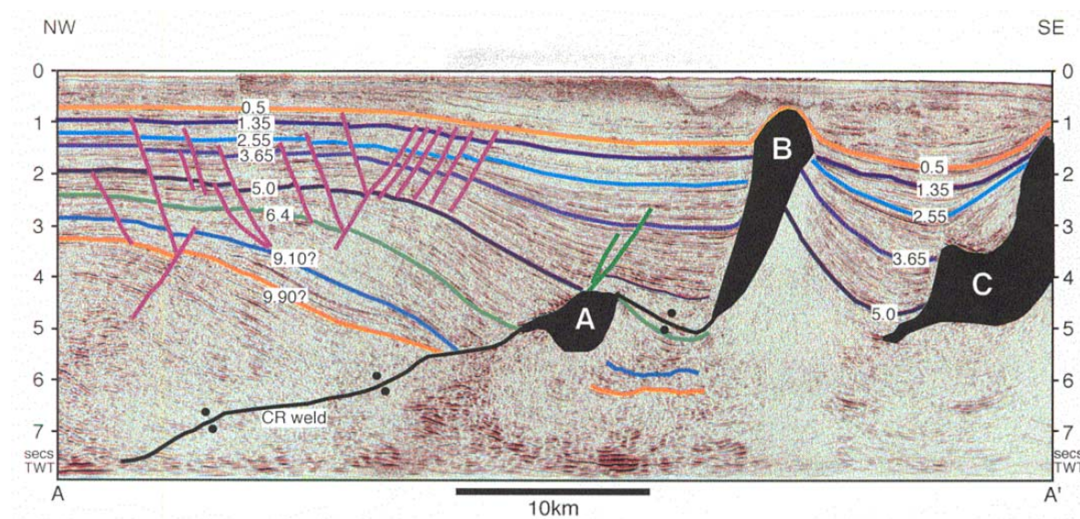
1) What are the short and long term displacement rates and lateral gradients in displacement for growth faults on the lower Mississippi Delta?
2) What controls the ability of growth faults and other mechanisms for creating lateral subsidence gradients to steer channels?
3) Is there evidence that the modern day Mississippi River is being steered by growth faults?
4) Is there evidence for steering of paleo-Mississippi Delta Top channels by growth faulting?

Many growth faults have been identified in SE LA from surface geomorphology &/or subsurface data



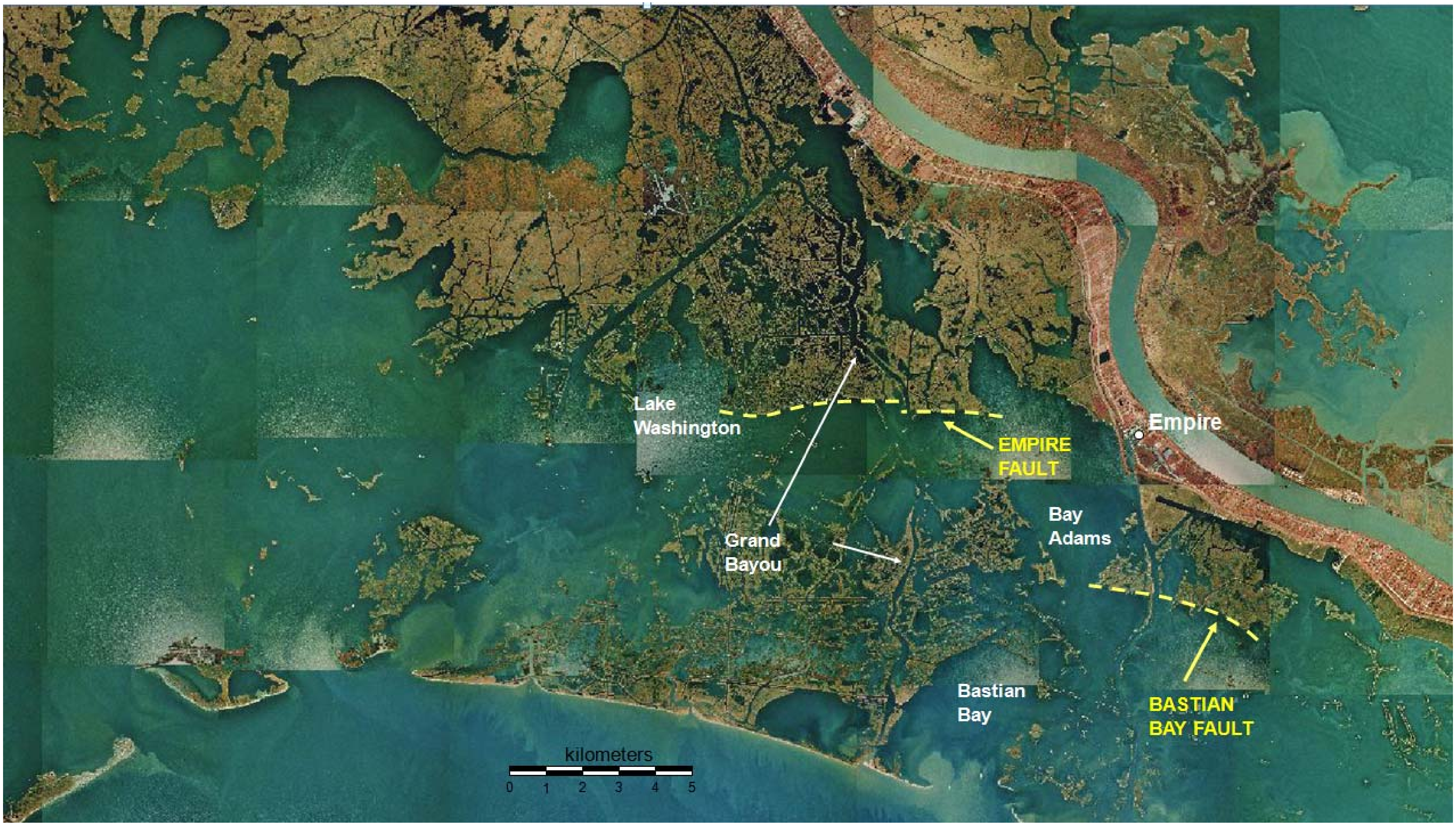
Gagliano (2003)

Growth faults associated with movement of the Louann Salt in response to loading through the Quaternary



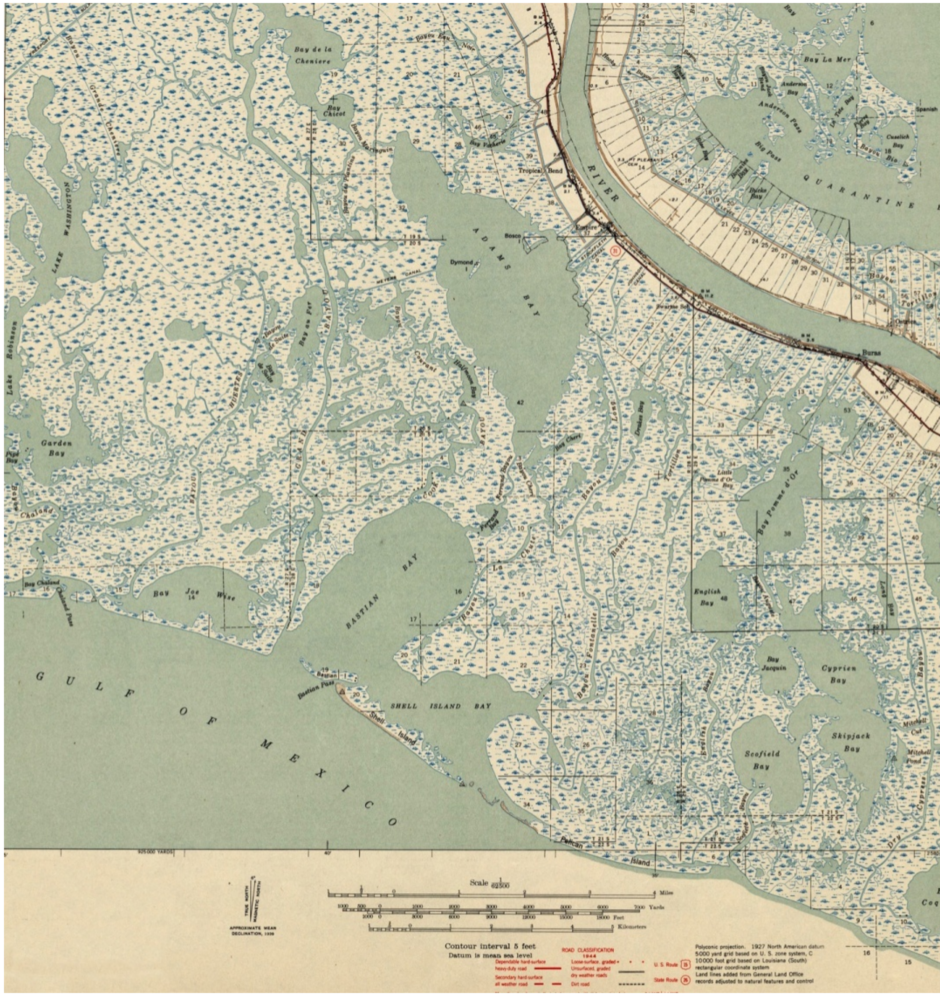
Trudgill, 2004

Empire & Bastian Bay Faults, Plaquemines Parish, Louisiana



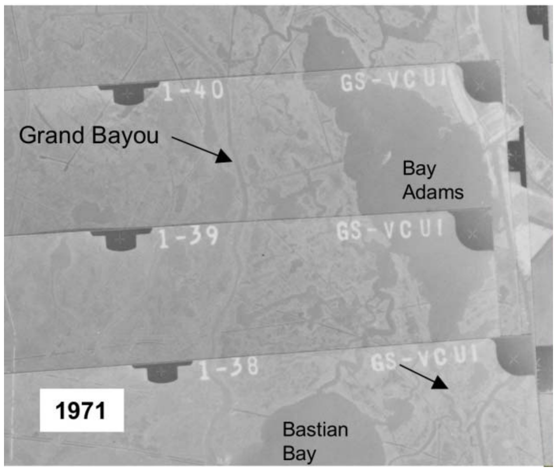
Empire & Bastian Bay Faults, Plaquemines Parish, Louisiana

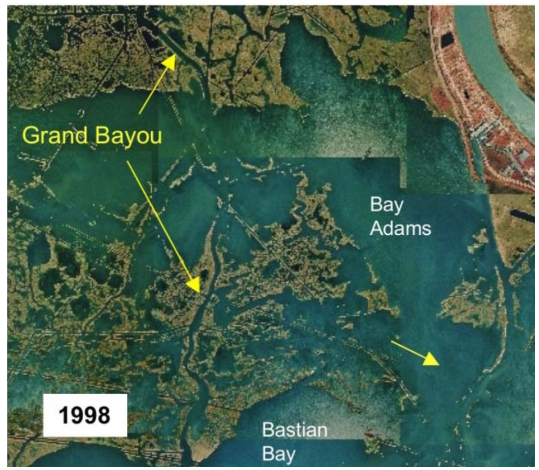
No obvious topographic expression of either fault seen on 1945 USGS Quadrangle.



Empire Fault (**1976-1978**)
vertical displacement = **1.1 m**

Bastian Bay Fault (**1974-1975**)
vertical displacement = **1.4 m**

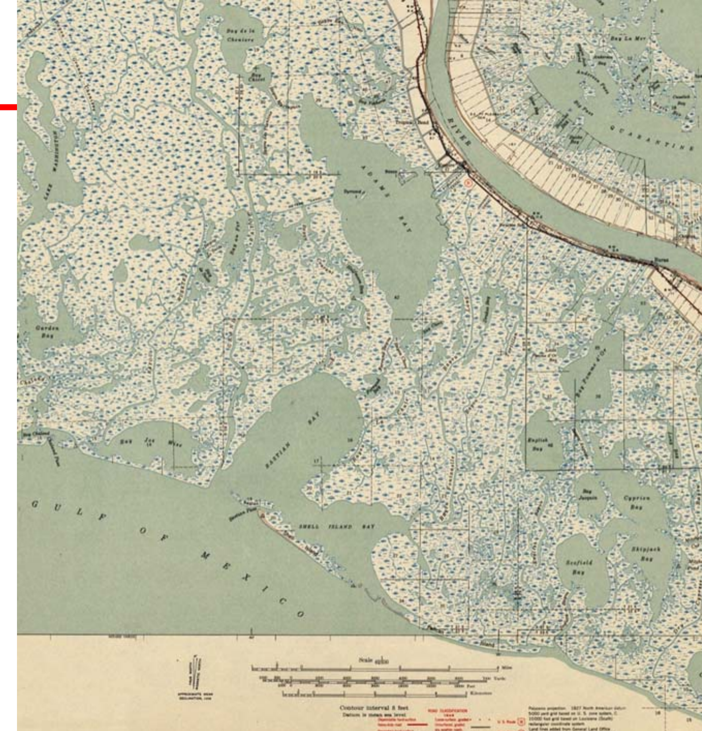




Empire Fault: Active Vertical Displacement Rate = **360 mm/yr**

Bastian Bay Fault: Active Vertical Displacement Rate = **690 mm/yr**

Displacements reported in Gagliano et al. (2003) and Martin (2006)



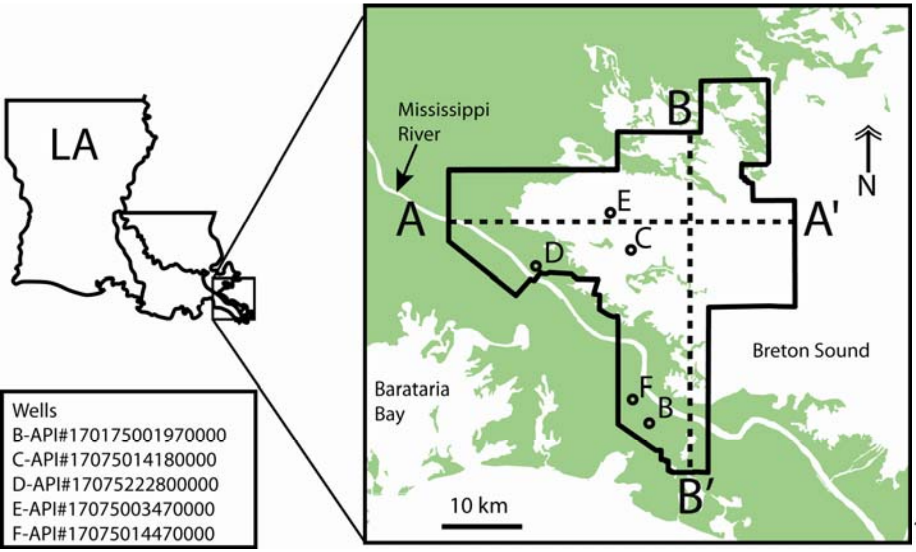
Evidence For Long-Term Slip on Growth Faults

Seismic Volume and Well Data Provide Best Possible Resolution of:

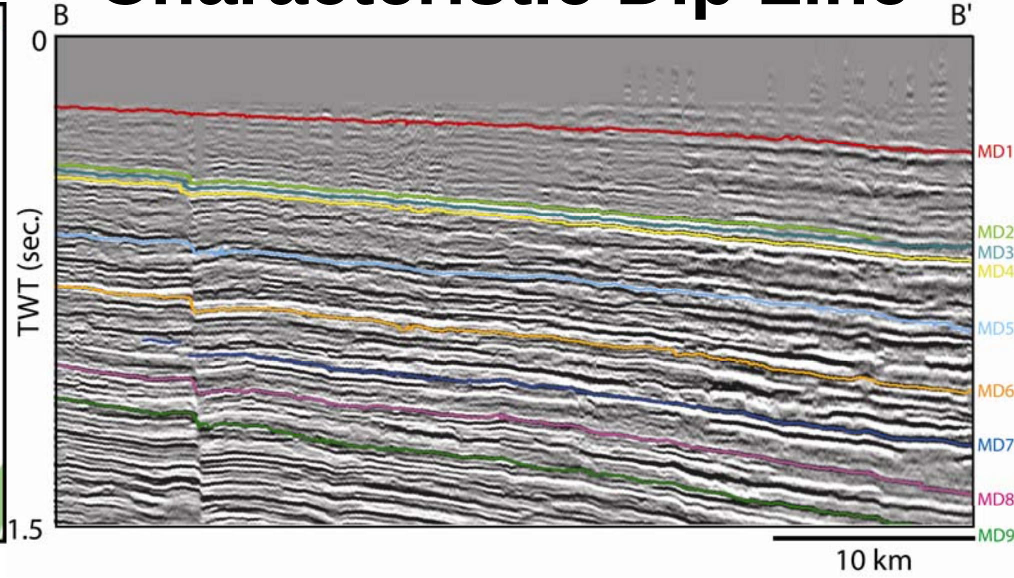
1) Spatially Varying Subsidence Field

2) Long- & Short-Term Subsidence Rates

3) Arrangement of Channel-Fills

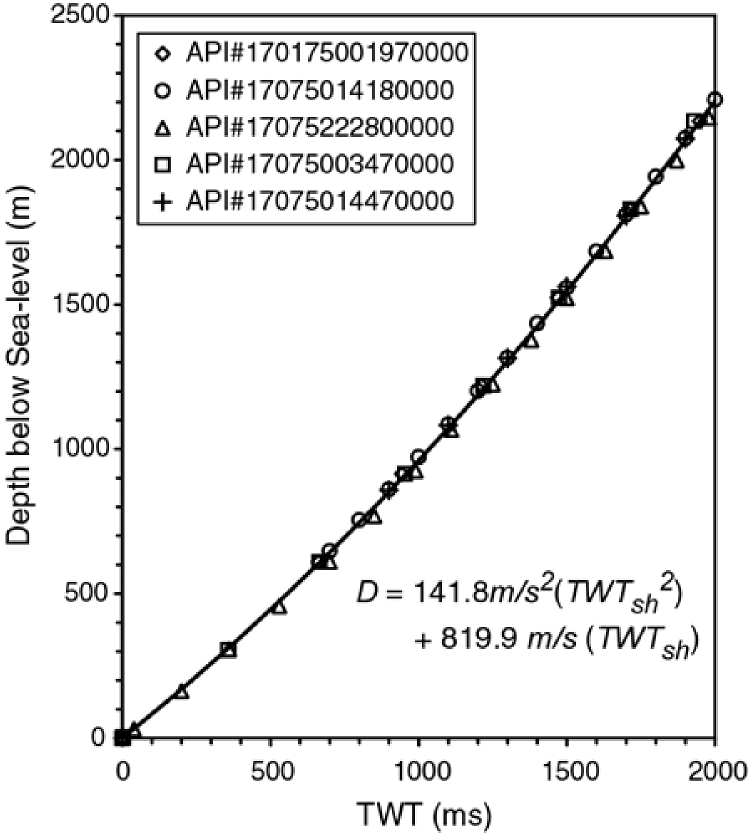


Characteristic Dip Line



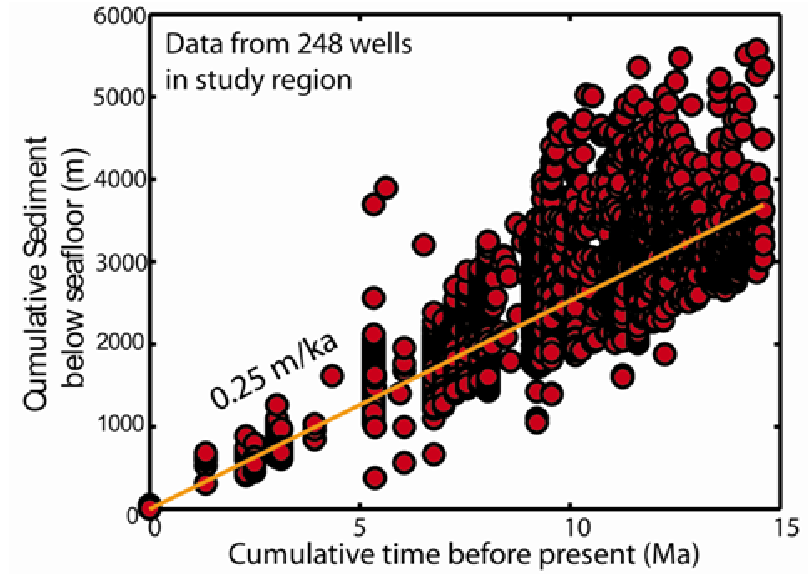
Necessary Data for Basin Analysis

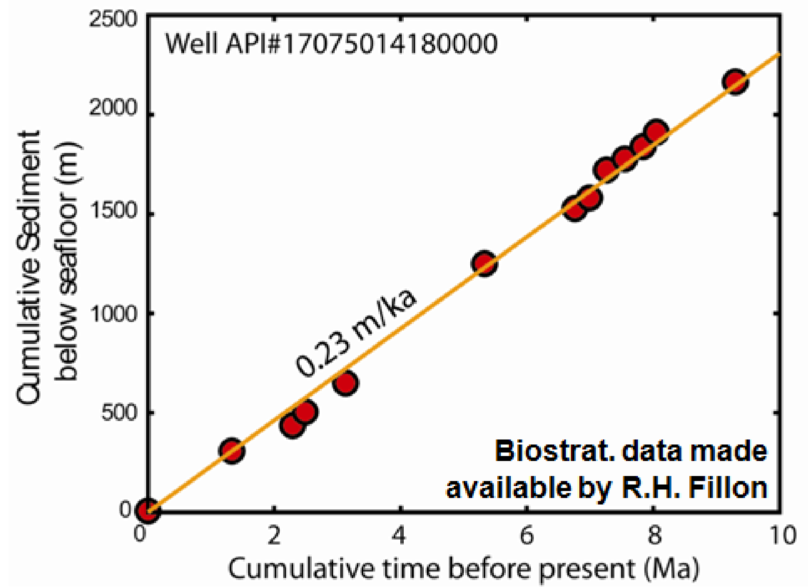
Time-Depth Curve

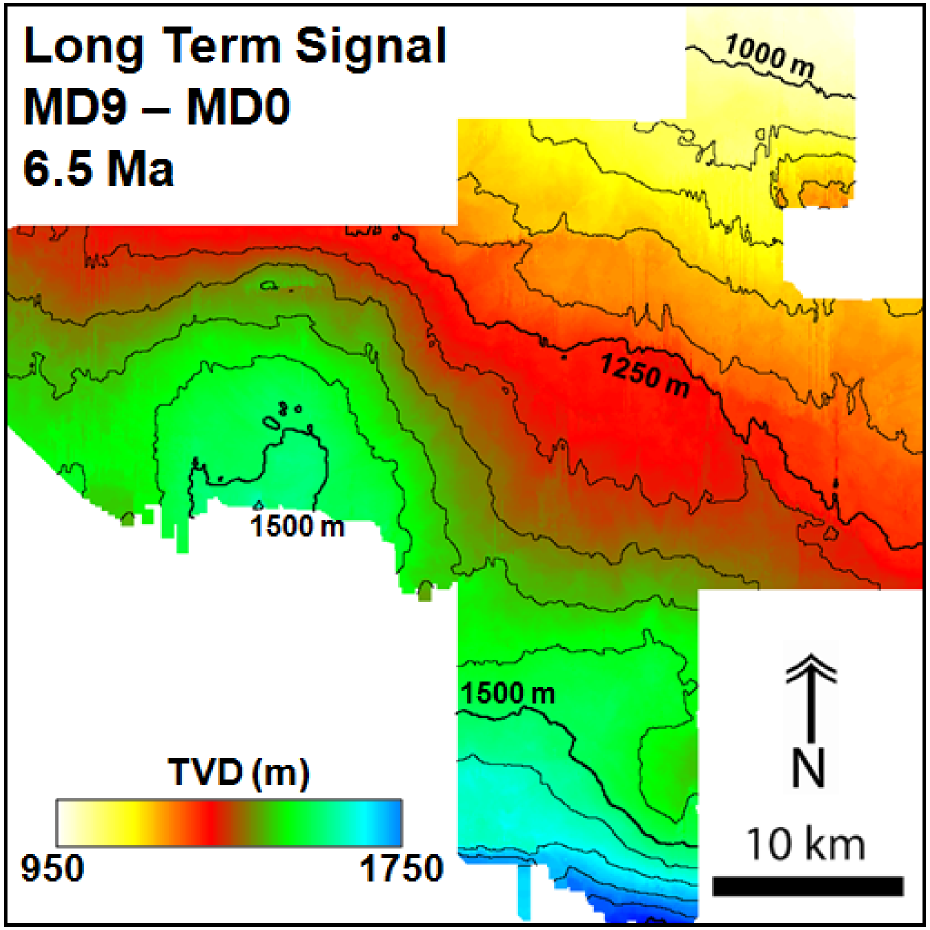


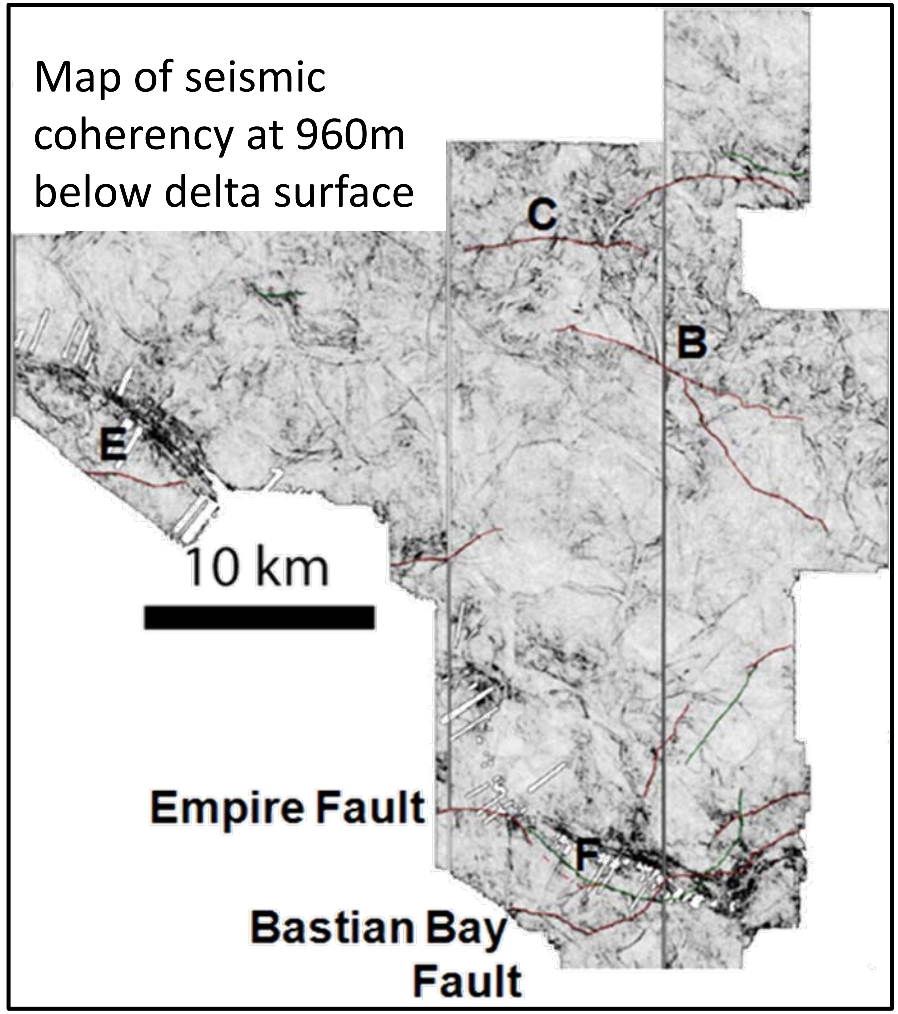
Microfossil assemblages divide the last 9 My into 12 discrete time intervals with average subsidence /sedimentation rates = 0.23 m/ka.

Age-Control from Biostrat. Dates





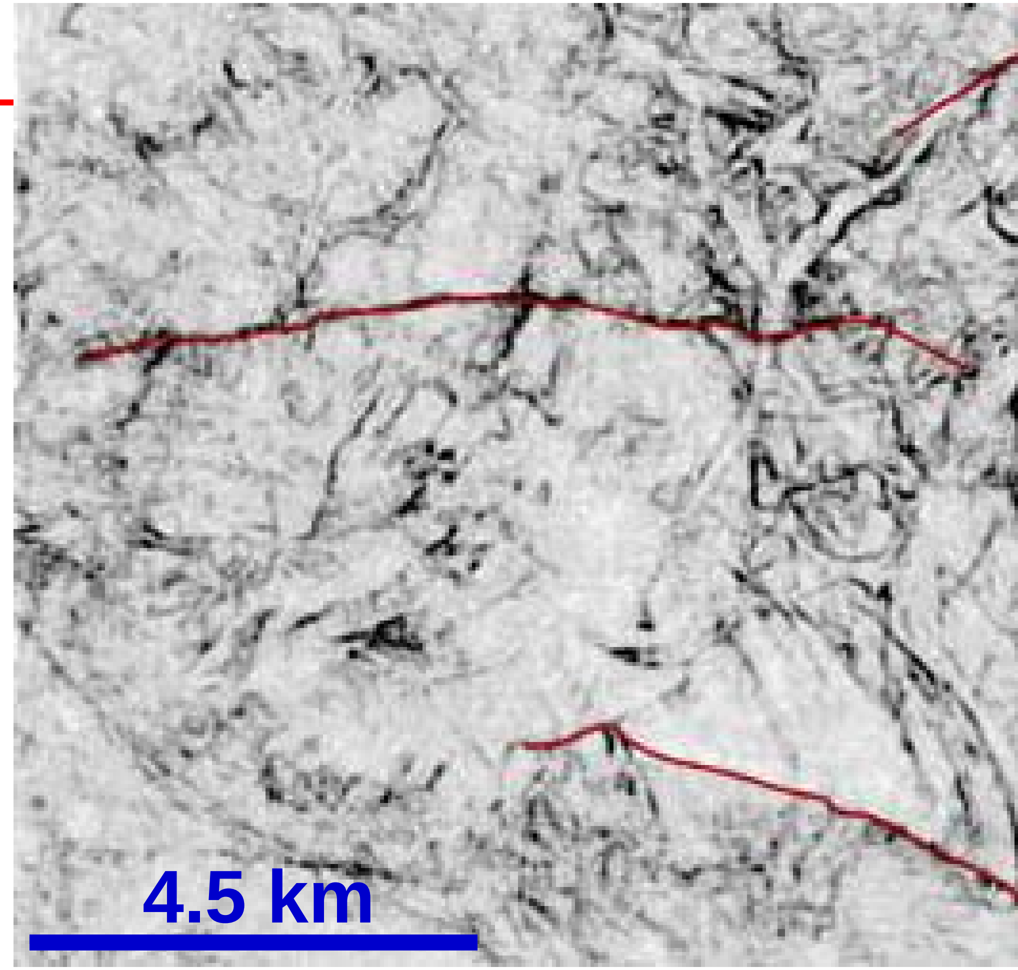


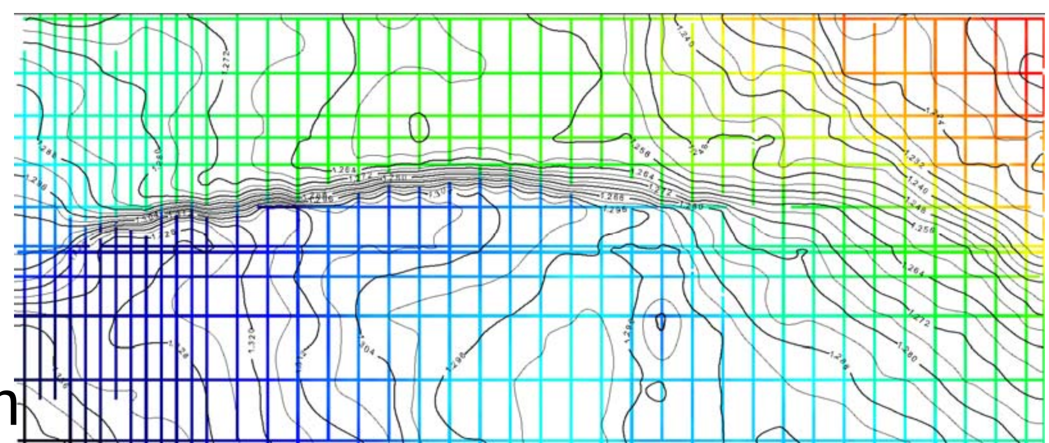


Average spatial change in subsidence at ~ 1500 m depth is ~ 1 – 3 m/km. Superimposed on this trend is high gradient changes is subsidence associated with growth faults.

Individual Growth Faults in Seismic Volume on Mississippi Delta:

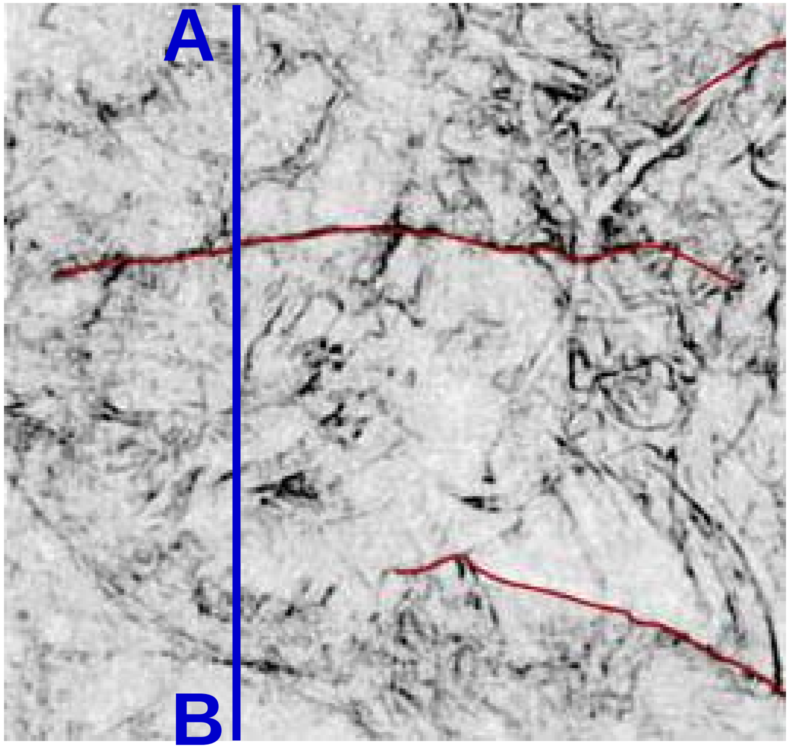
1) Are ~ 10 km in Length
2) Accumulate Spatially Varying Vertical Displacements

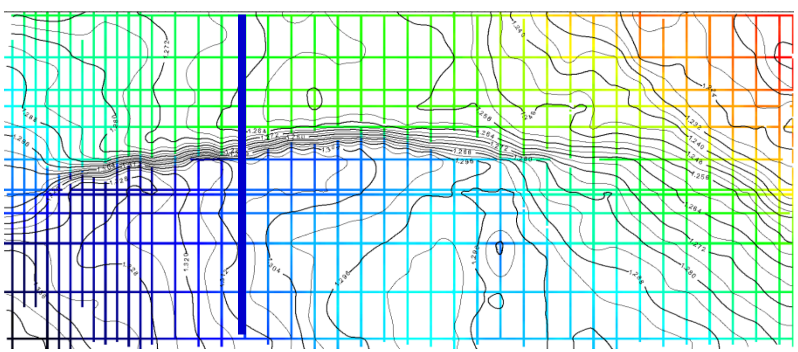




Contour Interval = 9.5 m

Vertical Displacement on Growth Fault

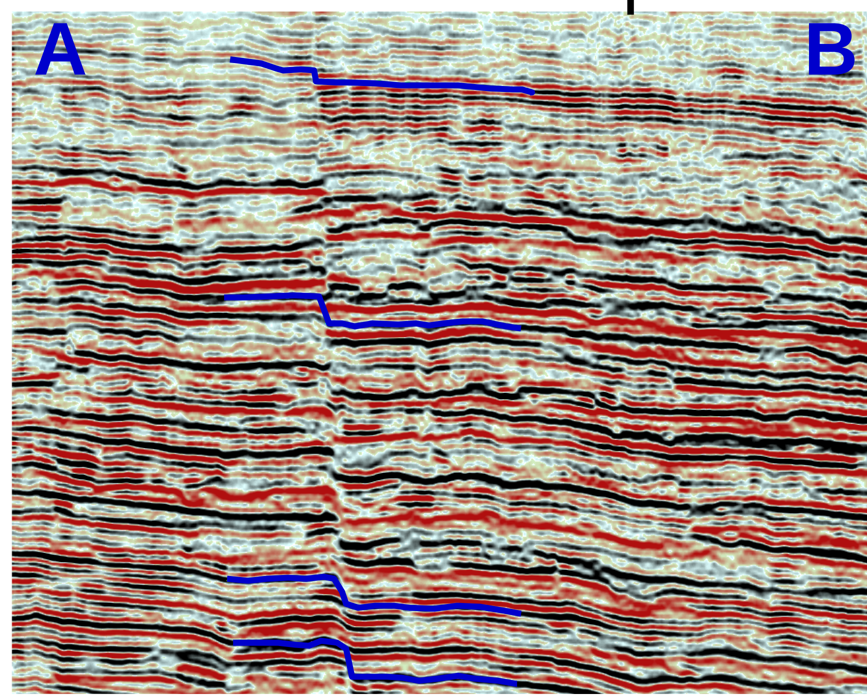


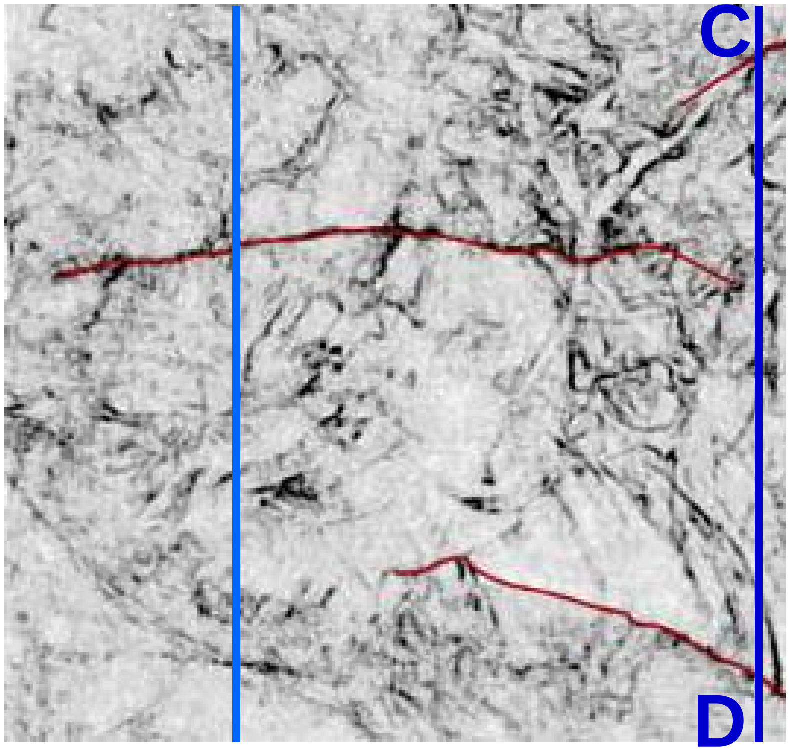


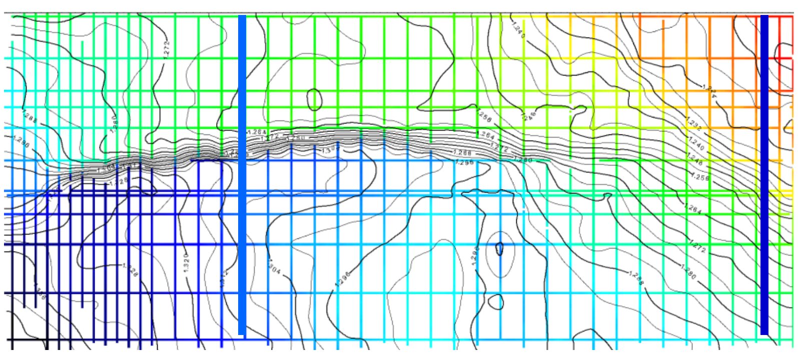
C.I. = 9.5 m

4.5 km

Increasing Displacement with Burial Depth

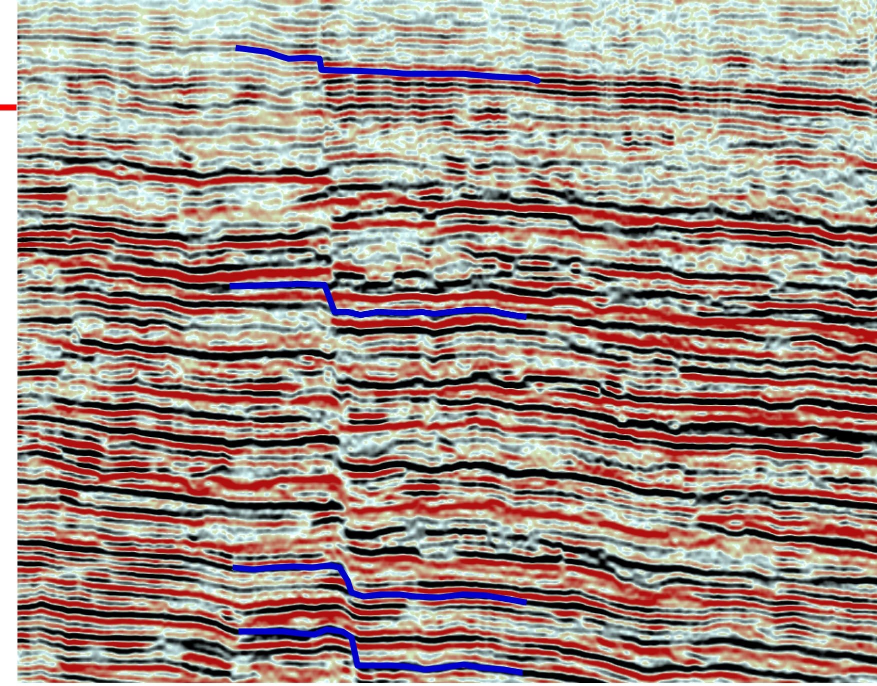




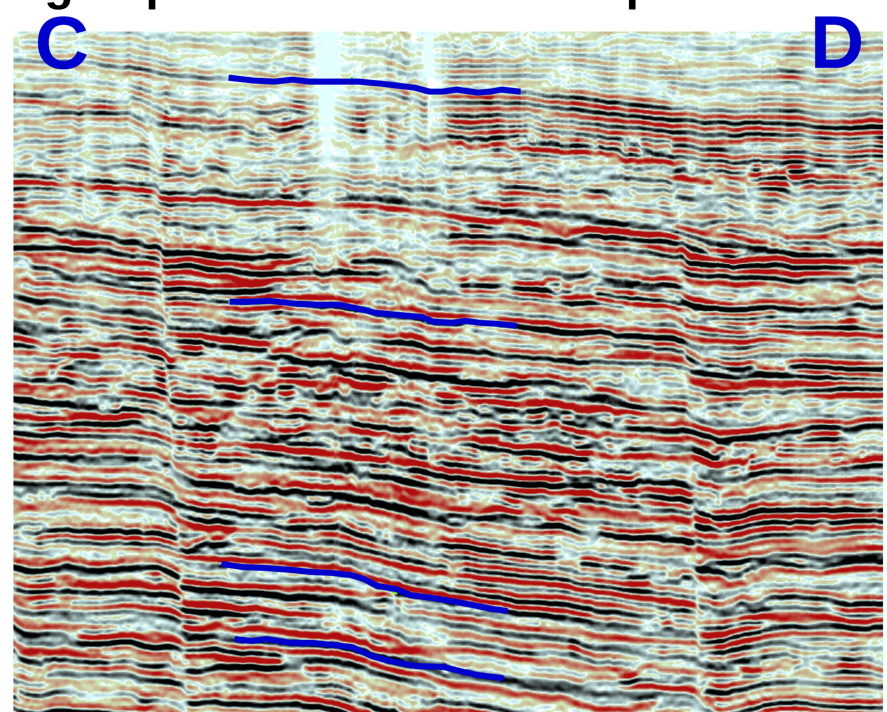


C.I. = 9.5 m

4.5 km

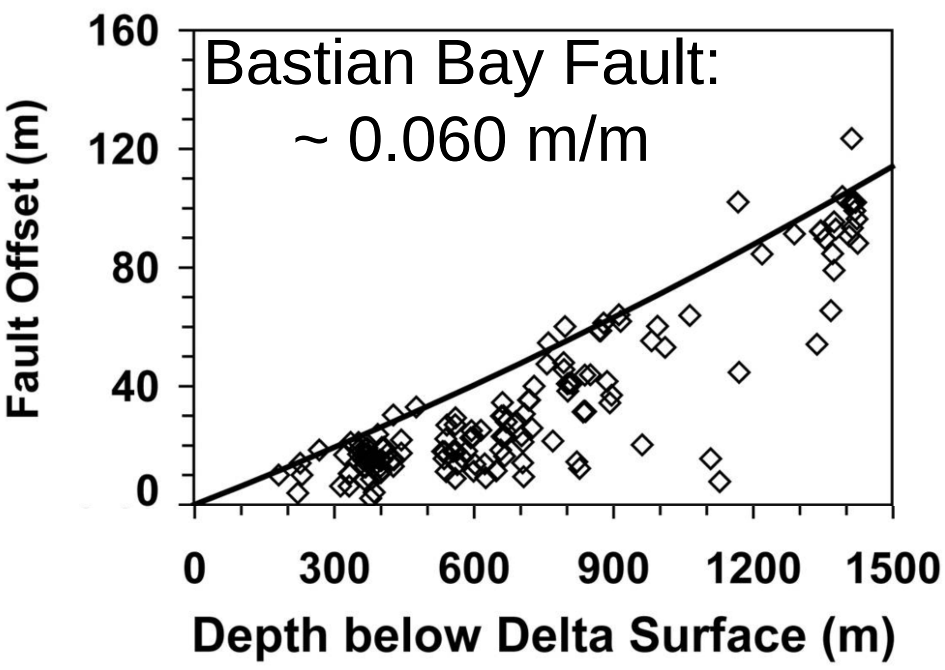


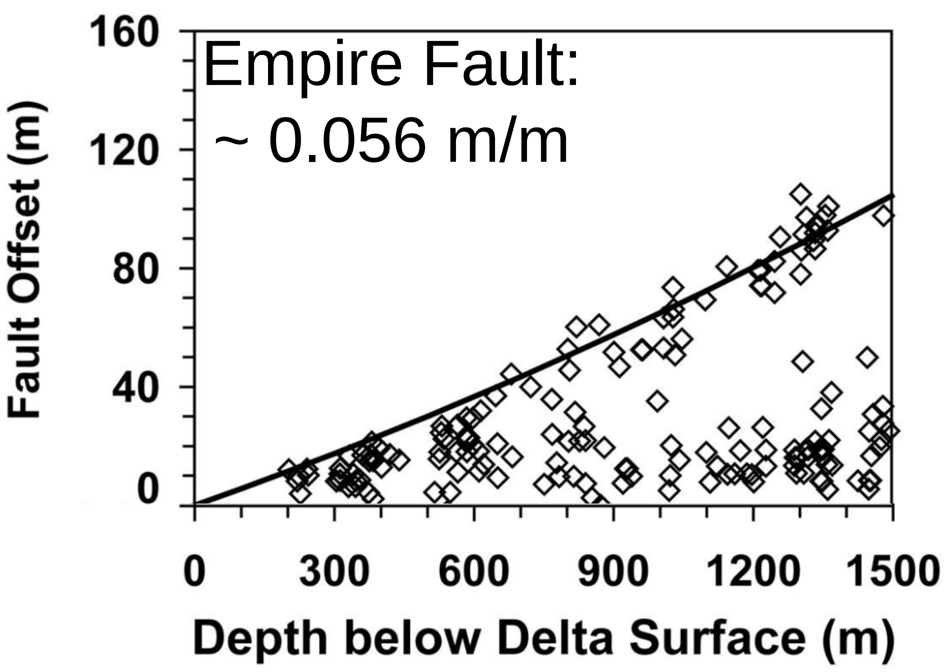
Large Spatial Gradient in Displacements



Long-Term Rates of Growth-Fault Displacement:

Accurate Estimate requires:
(1) Measure of Displacement as a Function of Burial Depth

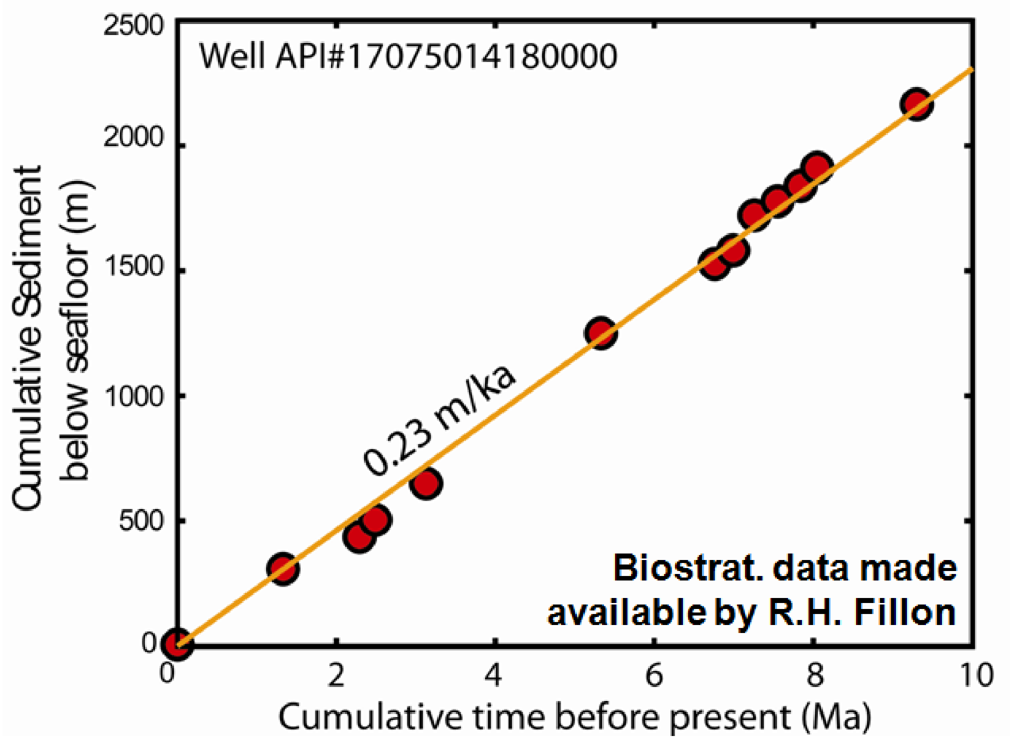


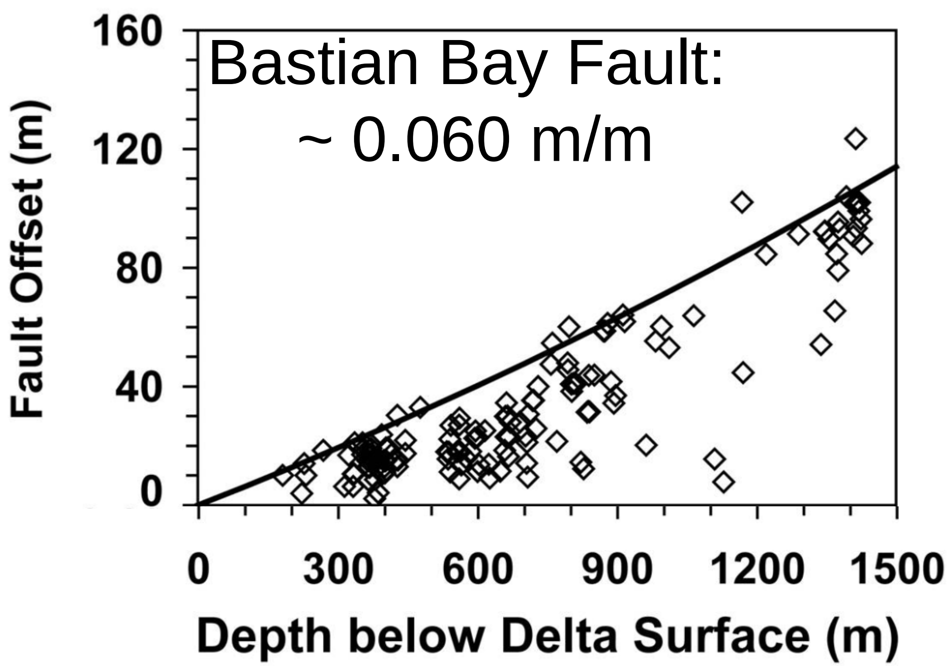


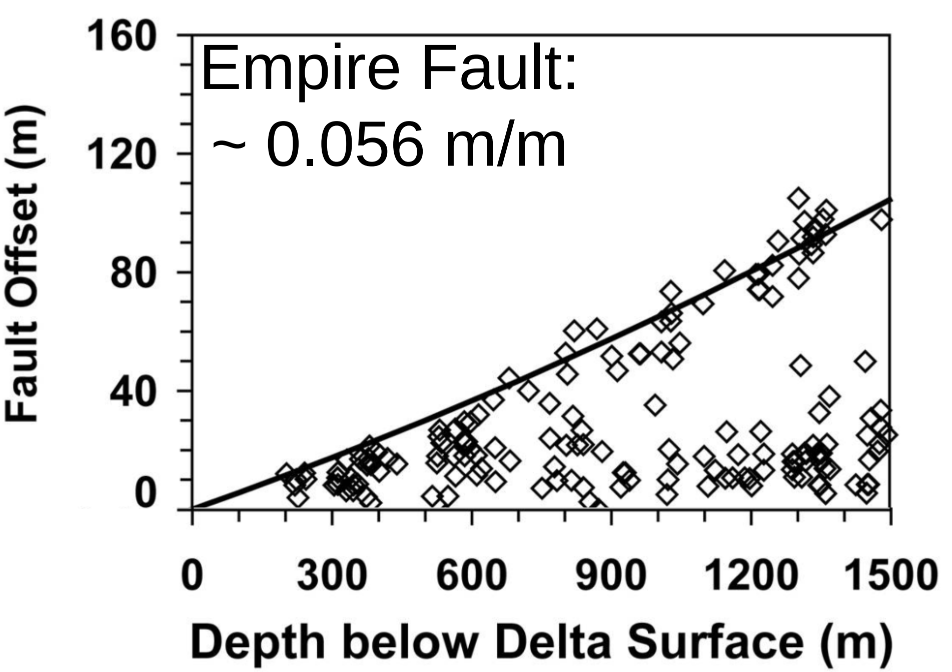
Long-Term Rates of Growth-Fault Displacement:

Accurate Estimate requires:
(1) Measure of Displacement as a Function of Burial Depth;

(2) Measure of Long-term Burial Rate





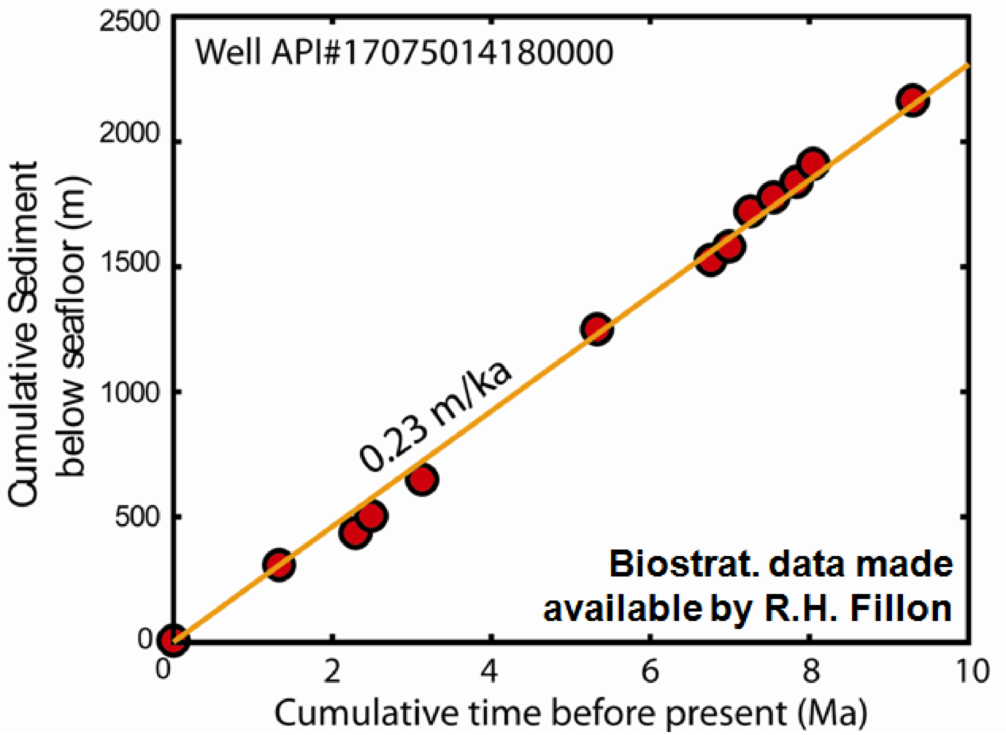


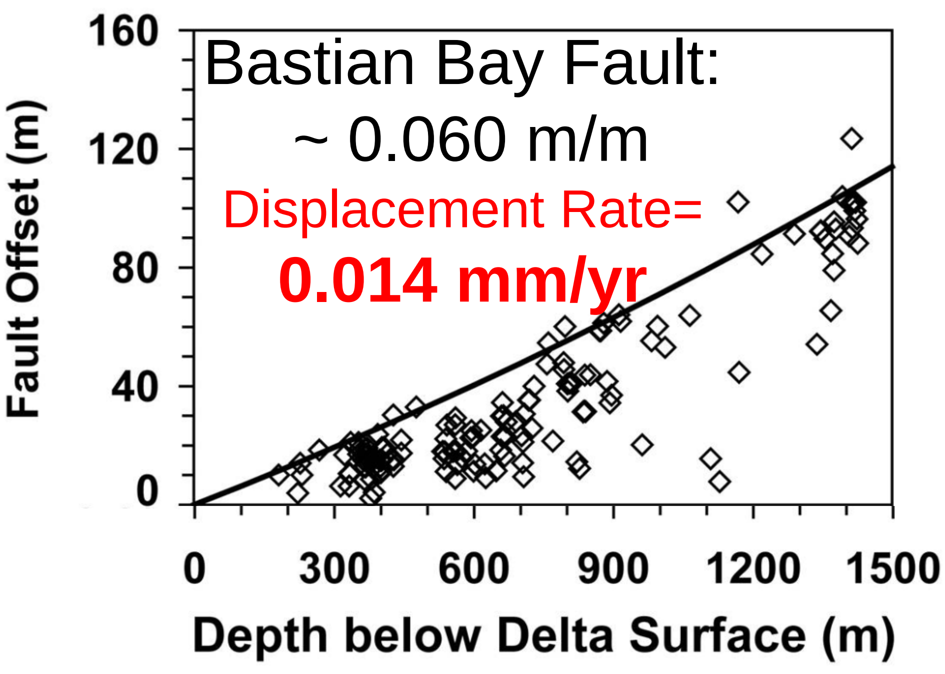
Long-Term Rates of Growth-Fault Displacement:

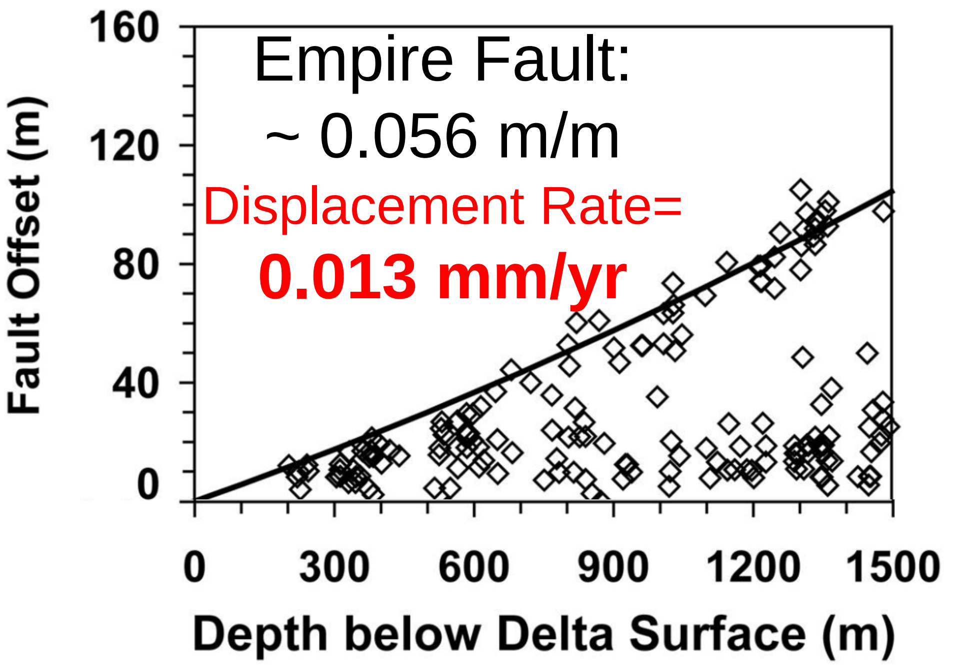
Accurate Estimate requires:
(1) Measure of Displacement as a Function of Burial Depth;

(2) Measure of Long-term Burial Rate

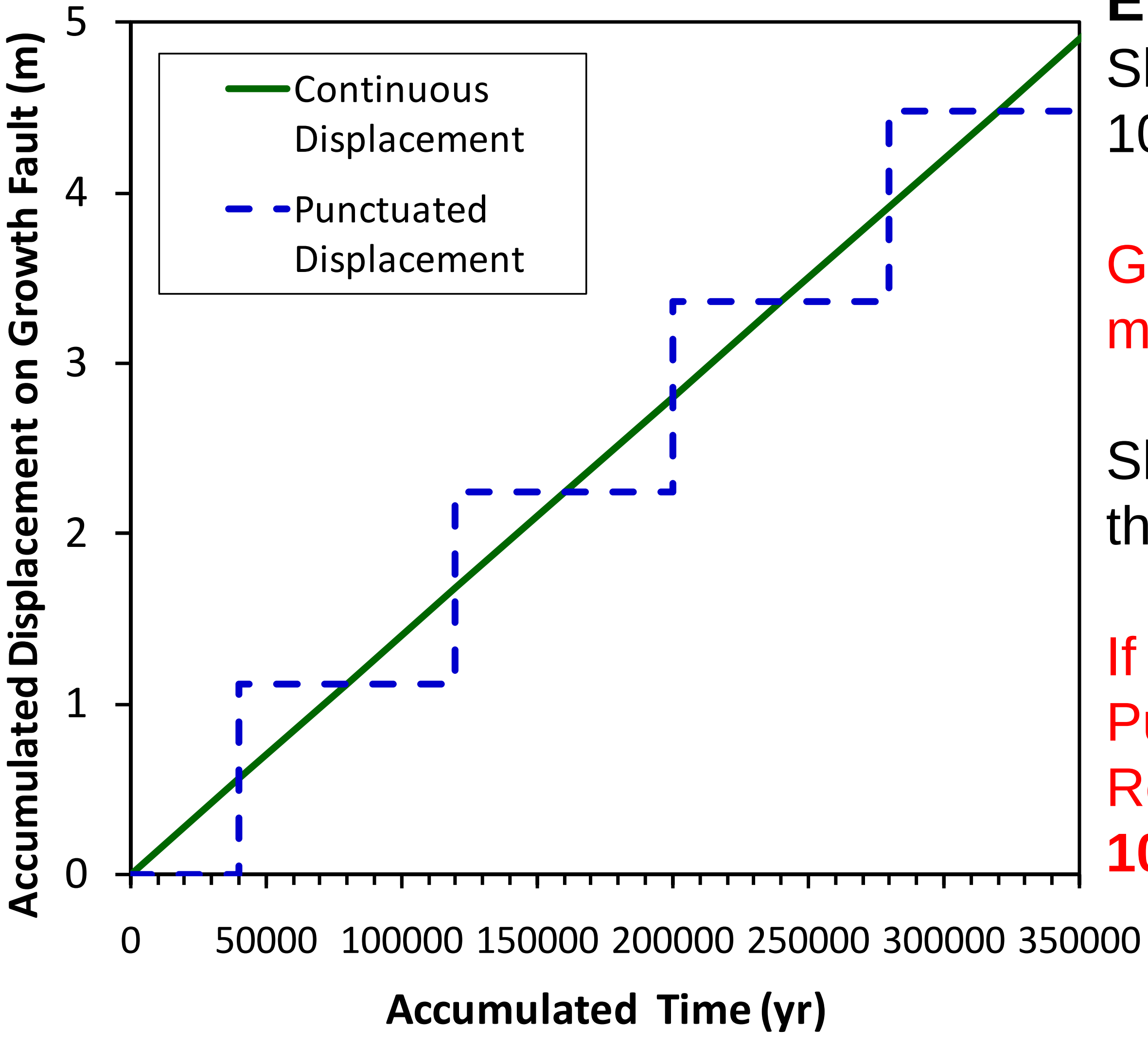
Displacement Rate = (1) x (2)







How do we describe temporal history of fault movement?



Empire & Bastian Faults:

Short-term Offset Rates = 10^2 mm/yr

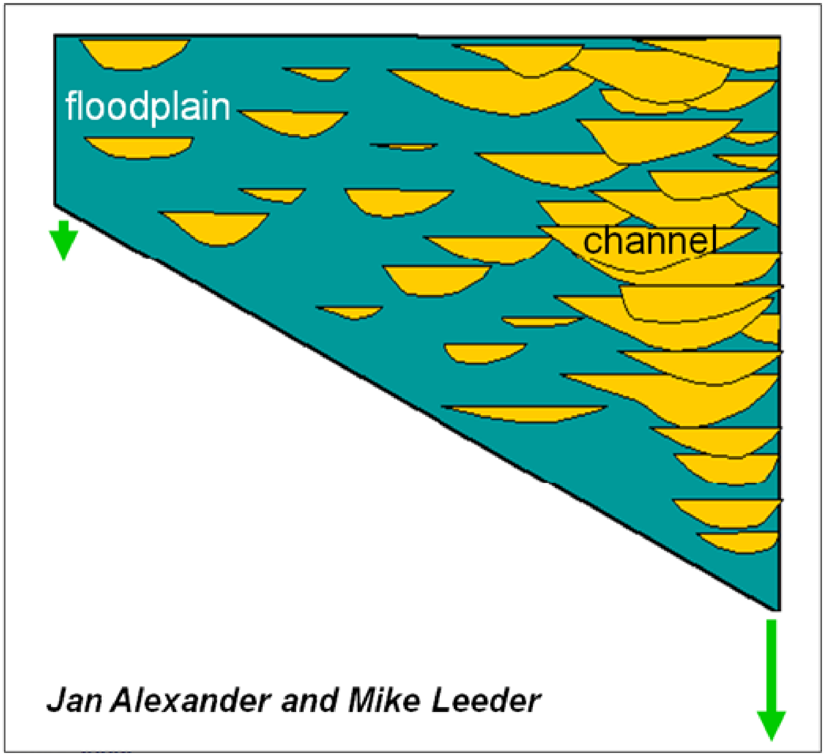
Geologic Offset Rates = 10^{-2} mm/yr

Short-term is 10^4 x greater than Long-Term Rate.

If all Fault Movement is Punctuated, a Characteristic Recurrence Interval is **10^4 to 10^5 years.**

Steering of Channels Resulting from Lateral Subsidence Gradients

Flow is orthogonal to image plane



Enhanced channel stacking in regions of high subsidence

- If channels are steered by tectonics, then subsidence (or uplift) distribution can be used to predict channel-prone areas

  Tectonic dominated

- Conversely, in the absence of steering, channel distribution is unrelated to distribution of subsidence

  Sediment dominated

<u>When is a system tectonic vs. sediment dominated?</u>

When is a system tectonic vs. sediment dominated?

Tectonic time scale

•Time which cross stream slope exceeds downstream slope

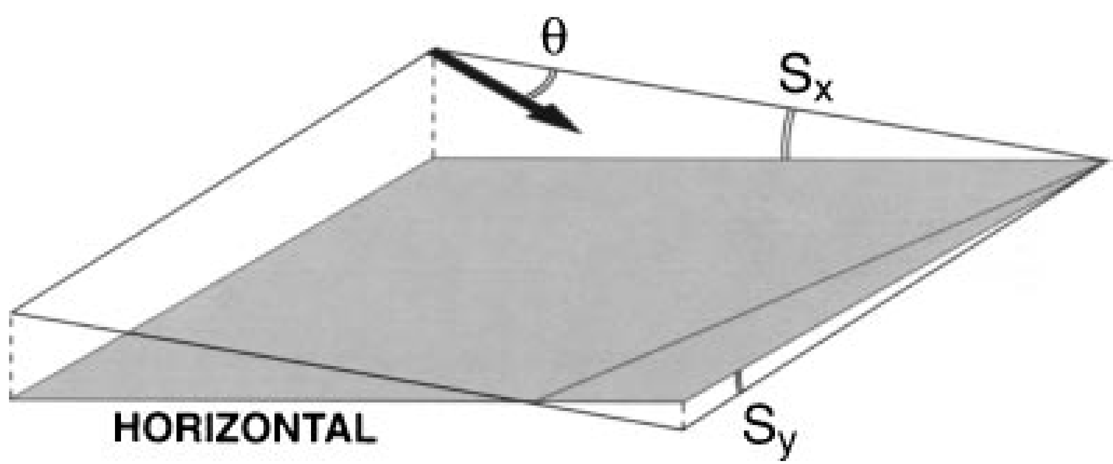
$$T_t = S_x\left(\frac{\partial S_y}{\partial t}\right)^{-1} = S_x\left(\frac{\Delta\sigma}{L_y}\right)^{-1}$$

Channel time scale

•Time needed for the channels to visit most (e.g. 90%) of the basin surface at least once

$$T_c = \frac{B_t - B_w}{v_c} \approx \frac{B_t - B_w}{q_s / h}$$

$$\frac{S_x}{S_y} < 1$$



$$\boxed{T_* = \frac{T_c}{T_t}}$$

Overall control:

$T_* \rightarrow 0$: fast channels, slow tectonics: sediment dominated

$T^* \rightarrow \infty$: slow channels, fast tectonics: tectonic dominated

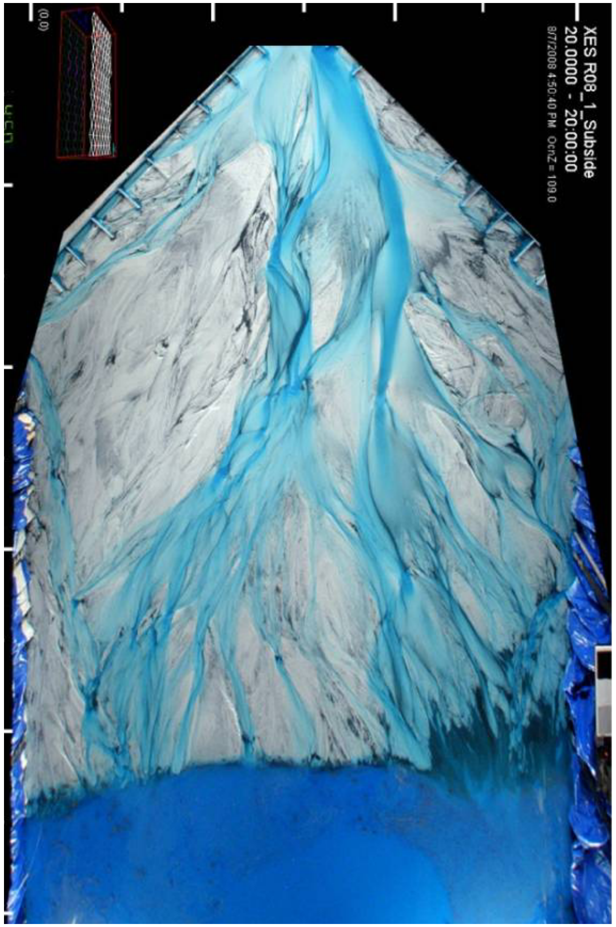
Theory from Sheets (2004) and Kim et al., 2010

Experimental Proof of Concept

T* = 1.1

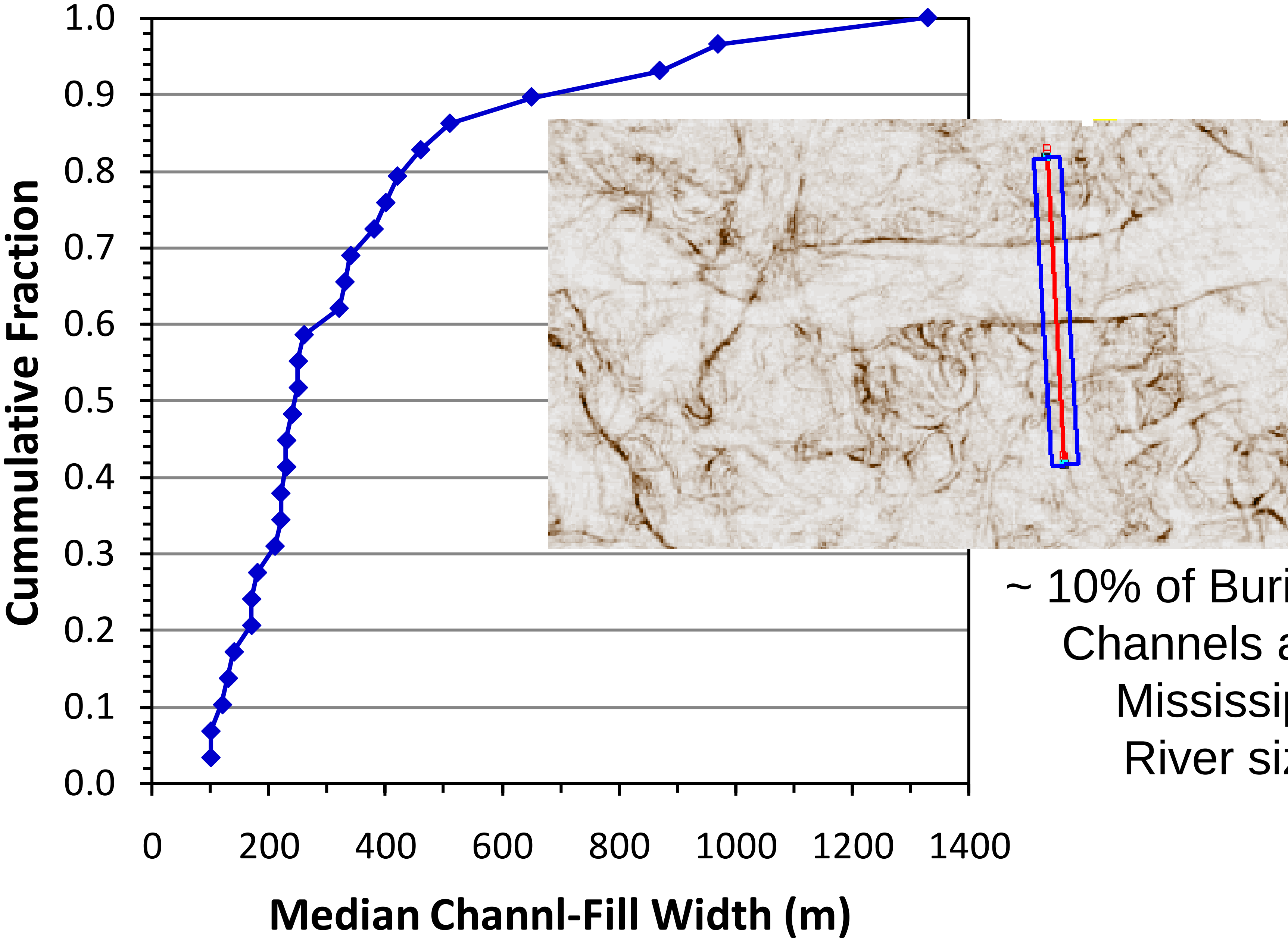
Kim et al., 2010

T* = 0.3



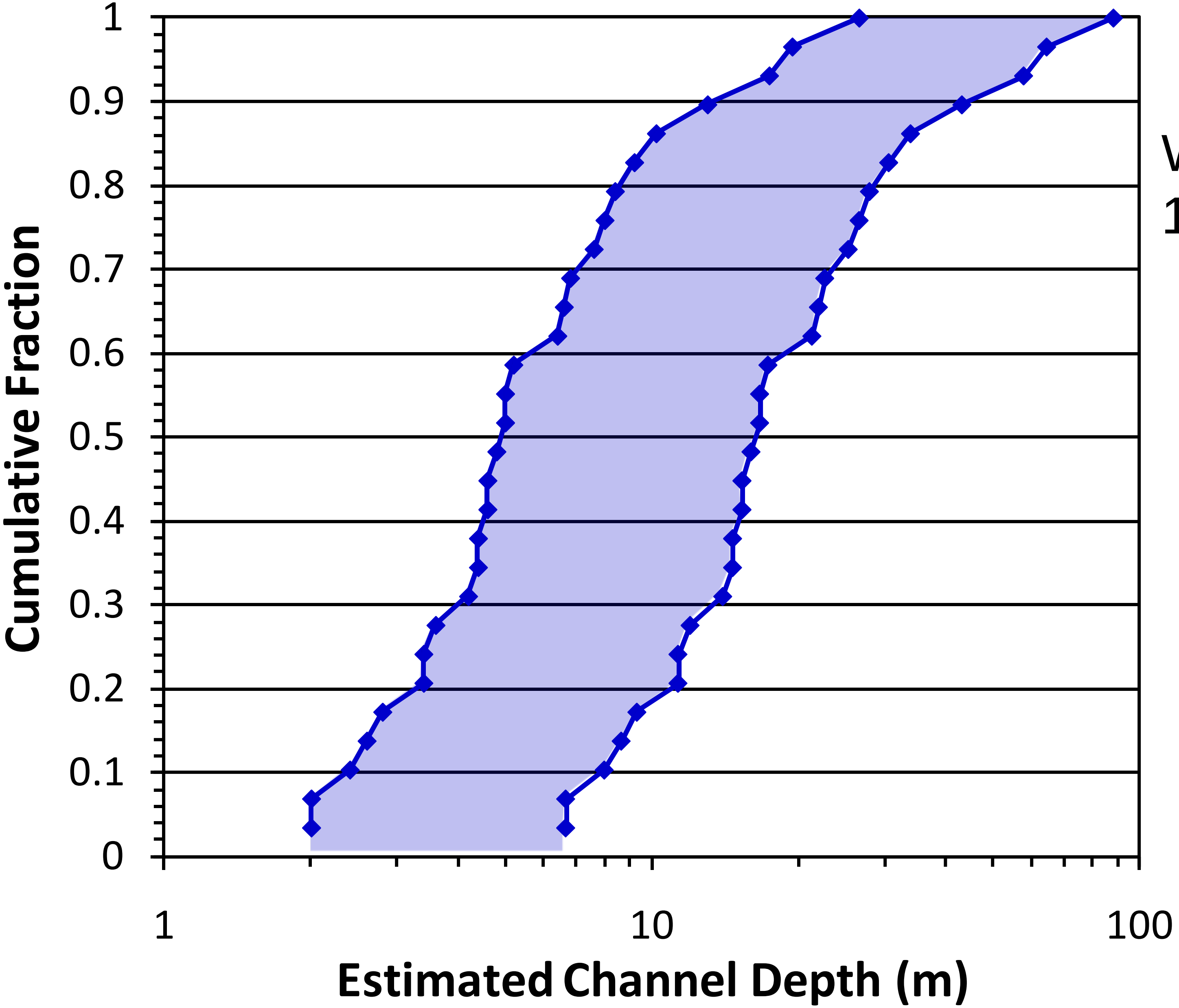
Straub et al., in prep.

Distribution of Channel Widths Estimated from Channel-Fills



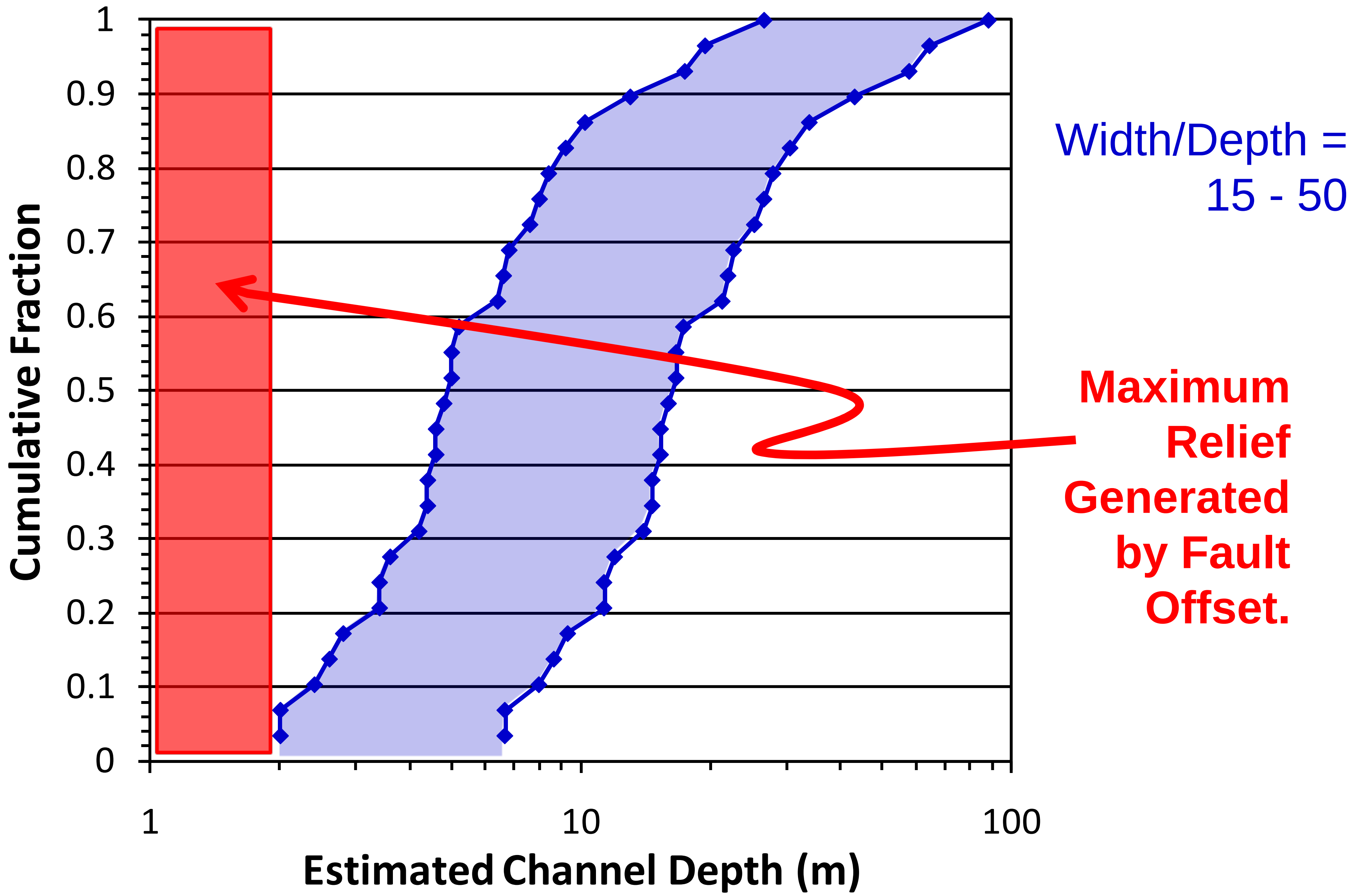
~ 10% of Buried Channels are Mississippi River size.

Distribution of Channel Depths Estimated from Channel Widths

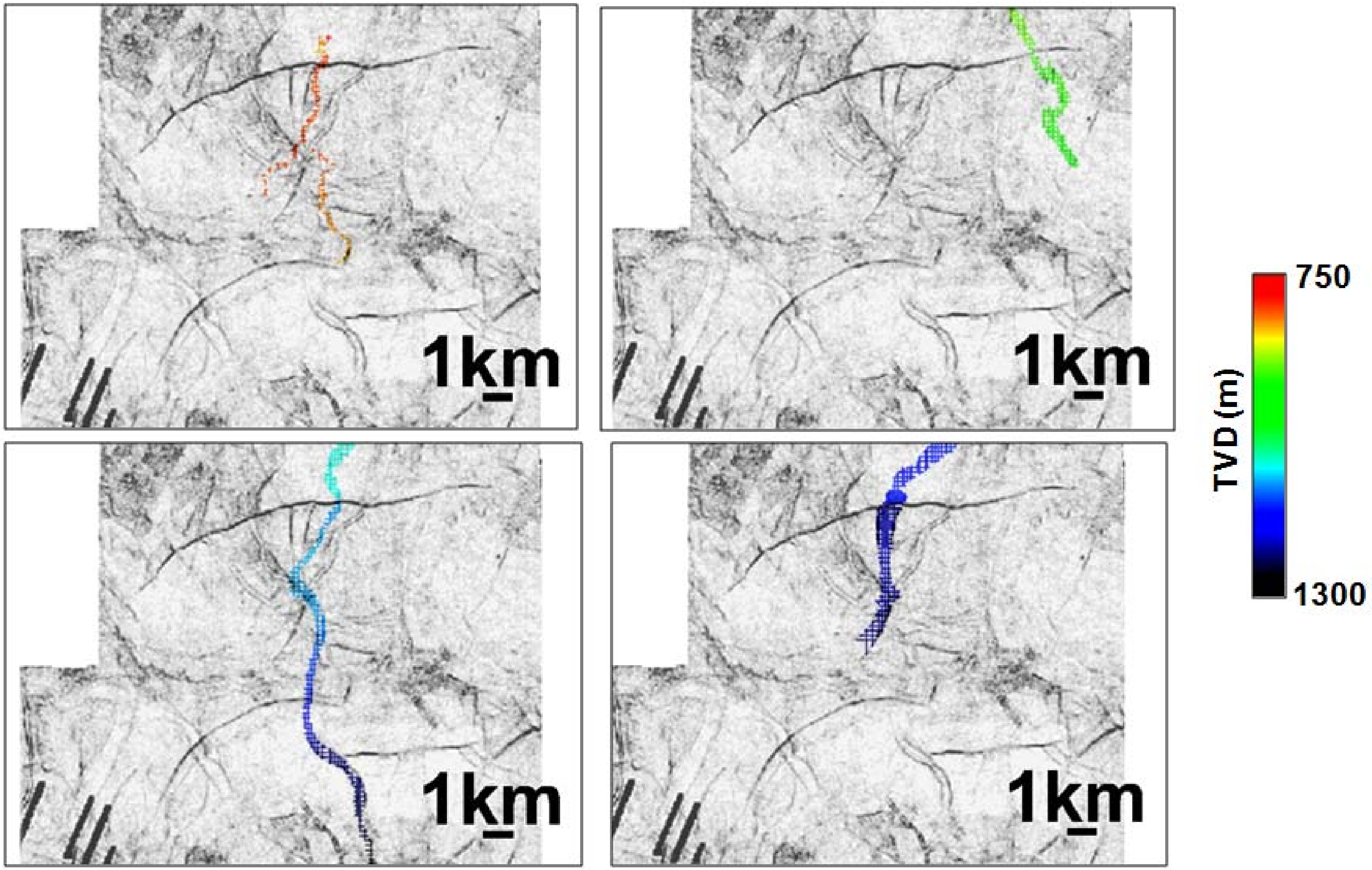


Width/Depth =
15 - 50

Distribution of Channel Depths Estimated from Channel Widths



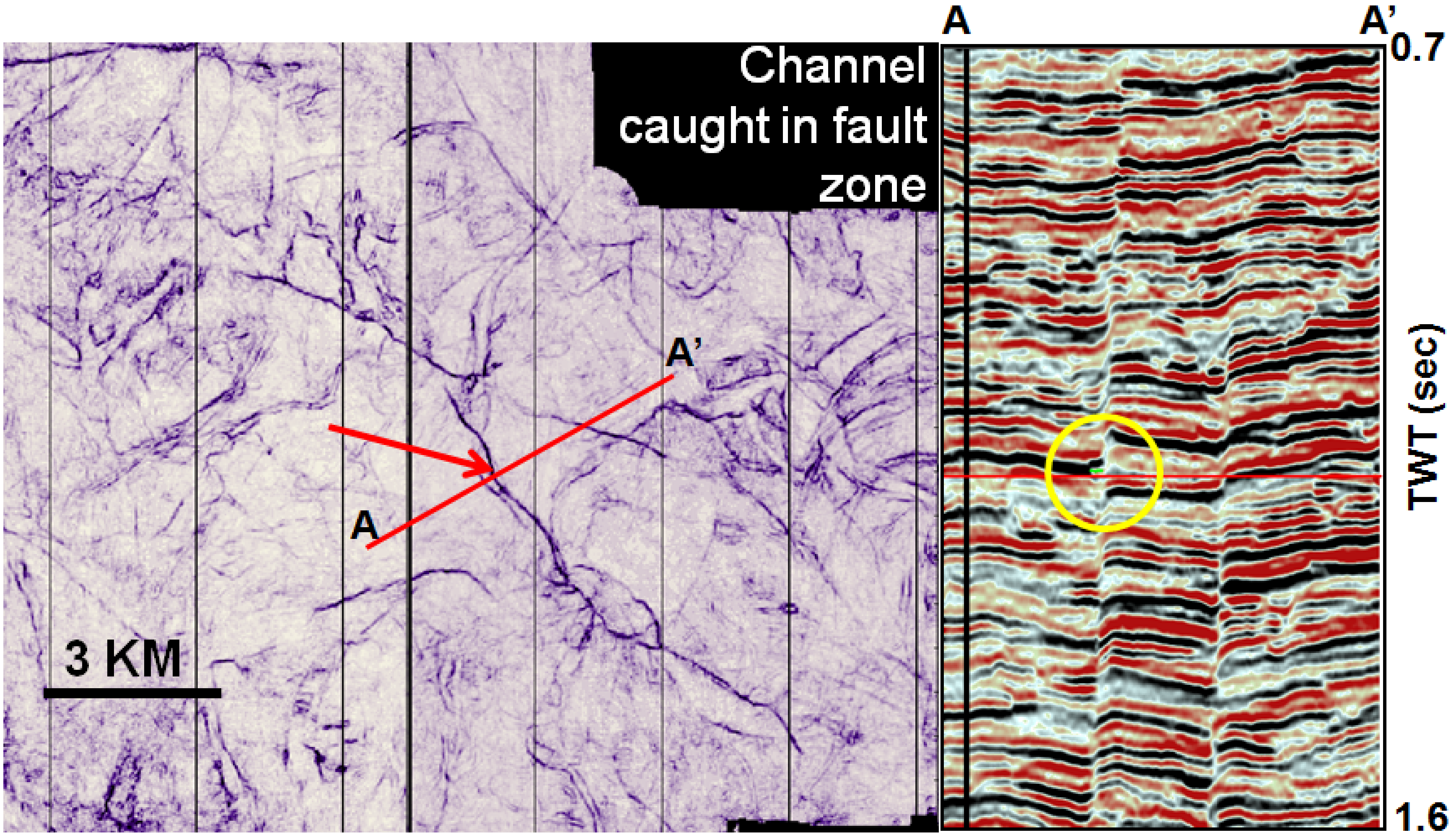
Subsurface Evidence



Channels are insensitive to active growth faults

- Have mapped 54 channels across 6 active growth faults
- 0 channel fills exhibit change in width &/or depth across faults
- Only 2 channels are clearly redirected by faults (*extremely weak attractors*)

Rare example of channel steered by fault



How does our theory do with real data?

Long Term :

$$T_t = S_x \left(\frac{\partial S_y}{\partial t} \right)^{-1} = S_x \left(\frac{\Delta \sigma}{L_y} \right)^{-1} \sim 30{,}000 \text{ yrs}$$

$S_x = 1.4 \times 10^{-5}$ m/m

$$\left(\frac{\partial S_y}{\partial t} \right)^{-1}_{\text{@ 6.5 Ma surface}} = 2.2 \times 10^{9} \text{ yrs}$$

$T_C \sim 5{,}000\text{-}10{,}000$ yrs

Estimate of T_c based off maps of Mississippi Delta lobes by Fisk (1954)

$T_* = 0.1 - 0.4$ ⟶ Channel dominated (Would not expect steering)

Short Term (punctuated movement on faults)

$$T_t = S_x \left(\frac{\partial S_y}{\partial t} \right)^{-1} = S_x \left(\frac{\Delta \sigma}{L_y} \right)^{-1} \sim 1 \times 10^{-3} \text{ yrs}$$

$S_x = 1.4 \times 10^{-5}$ m/m

$$\left(\frac{\partial S_y}{\partial t} \right)^{-1} = 100 \text{ yrs}$$

For 1 m offset developing in 10 yrs

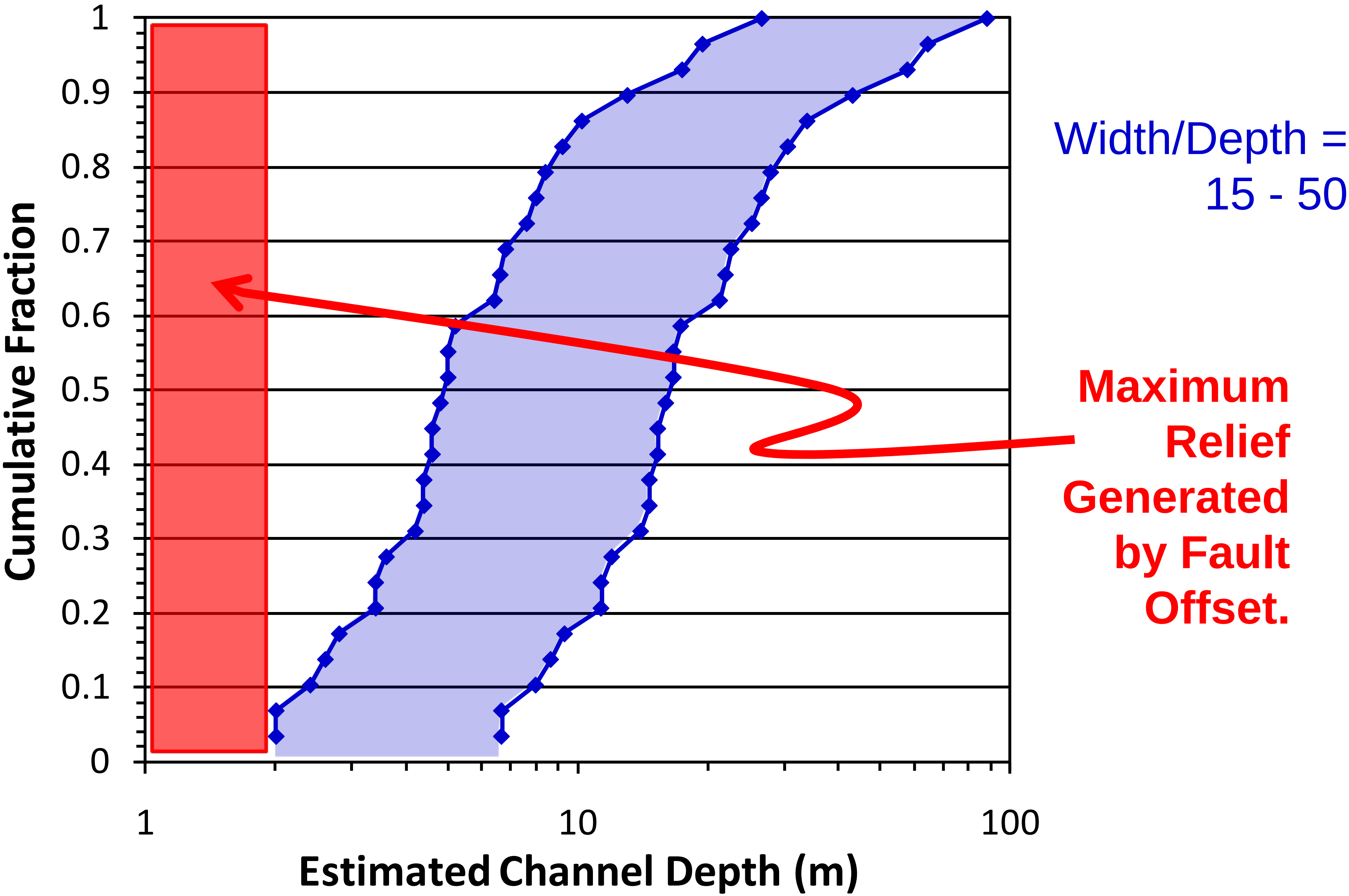
$T_C \sim 5{,}000\text{-}10{,}000$ yrs

Estimate of T_c based off maps of Mississippi Delta lobes by Fisk (1954)

$T_* \sim 1 \times 10^{-6}$ ⟶ Tectonic dominated

If channel is near a fault when slip event occurs an ability to steer is present, however these events are rare!

Reason 2 for no steering: Hard to steer channels if relief associated with faults never exceeds depth of channels



Summary

1) Subsidence associated with structural deformation is ongoing
2) Movement on growth faults appears to be punctuated (short term slip rates can be 5 orders of magnitude greater than long term rates)
3) Ratio of channel to tectonic time scales accurately predicts ability of tectonics to steer channels in laboratory experiments.
4) Most mapped channel bodies in Mississippi Delta stratigraphy are insensitive to active growth faults. Likely due to low *T** value for Mississippi Delta and deep channels relative to topography generated by active faulting.