

Influence of Water and Sediment Supply on the Completeness of the Stratigraphic Record and the Construction of Stratigraphic Surfaces in Alluvial Fans and Deltas*

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Abstract

Stratigraphy contains the most complete record of information necessary to quantitatively reconstruct paleolandscape dynamics for the majority of Earth history, but this record contains significant gaps over a range of time and space scales. These gaps result from stasis on geomorphic surfaces and erosional events that remove previously deposited sediment. Building on earlier statistical studies, we examine stratigraphic completeness in three controlled laboratory experiments where topography of aggrading deltas were monitored at high temporal and spatial resolution. The three experiments cover unique combinations in the absolute magnitudes of sediment and water discharge in addition to generation of accommodation space through base-level rise. This analysis centers on the influence of three time scales: 1) the time at which a record is discretized (t), 2) the time necessary to build a deposit with mean thickness equivalent to the maximum roughness on a surface (T_c), and 3) the time necessary for channelized flow to migrate over all locations in a basin (T_{ch}). We find that stratigraphic completeness increases as a function of t/T_c but decreases as a function of T_c/T_{ch} , over the parameter space covered in the experiments. We also examine how absolute curvature changes as a function of measurement window for geomorphic and stratigraphic surfaces and how to relate them to each other. We find that high curvature features on deltaic geomorphic surfaces (i.e. channels) are preferentially transferred to the stratigraphic record and that their stratal boundaries are crafted during erosional events. In addition, the width of the geomorphic channels can be estimated from the stratigraphy by identifying a scale break in the plot of mean absolute slope of stratigraphic surfaces vs. measurement window.

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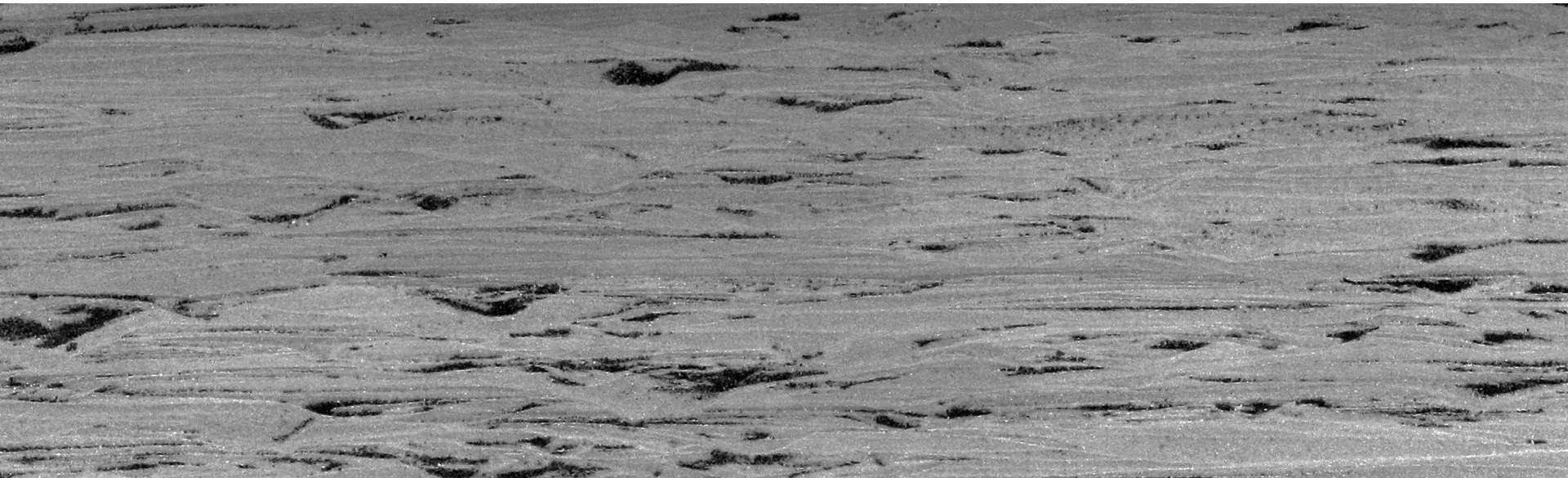
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Influence of water and sediment supply on the completeness of the stratigraphic record and the construction of stratigraphic surfaces in alluvial fans and deltas



Kyle M. Straub & Christopher Esposito

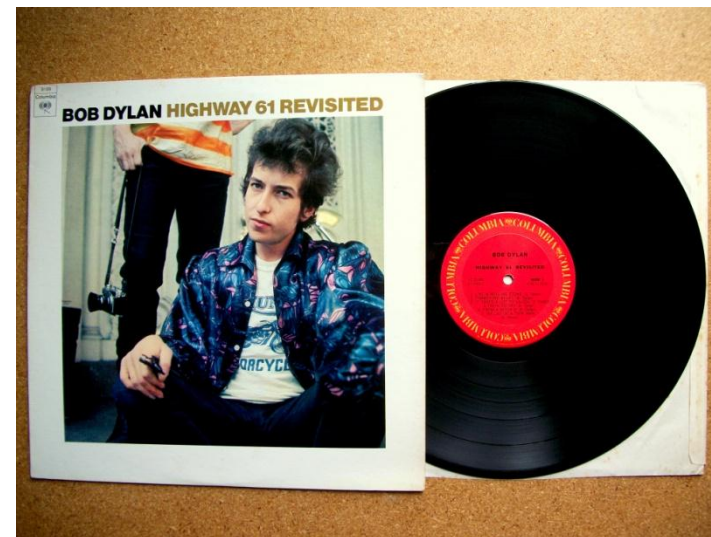


Stratigraphy: A great record?



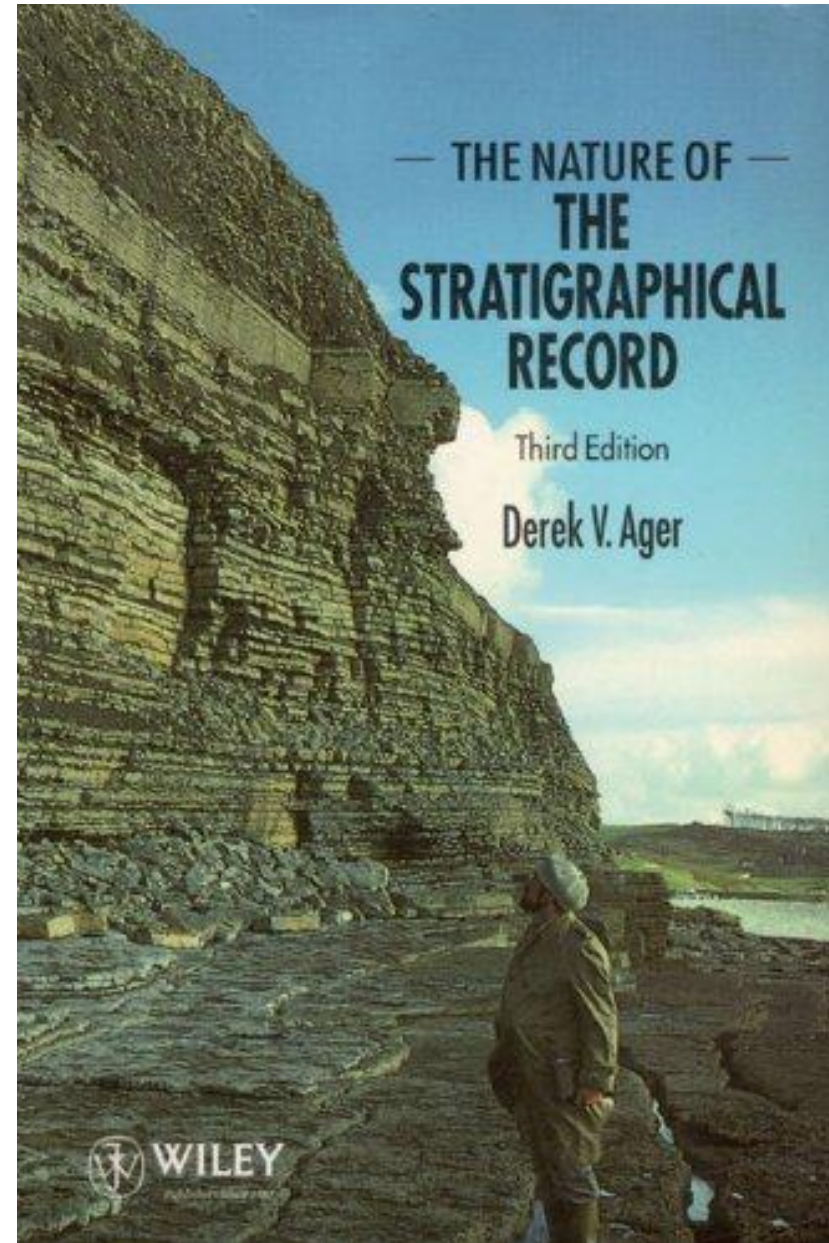
Alluvial basins contain the most complete record of information necessary to quantitatively reconstruct paleolandscape dynamics across many time scales

- National Research Council, 2009



Stratigraphy: More gaps than record

- "The stratigraphic record is a lot of holes tied together with sediment. It is as though one has a newspaper delivered only for the football results on Saturday and assumes that nothing at all happened on the other days of the week"
- "... the history of any part of the Earth, like the life of a soldier, consists of long periods of boredom and short periods of terror"
- "When discussing continuous sedimentation one should note the temporal resolution over which they are referring."



1st Edition: 1973

Developing Ager's ideas into quantitative theory

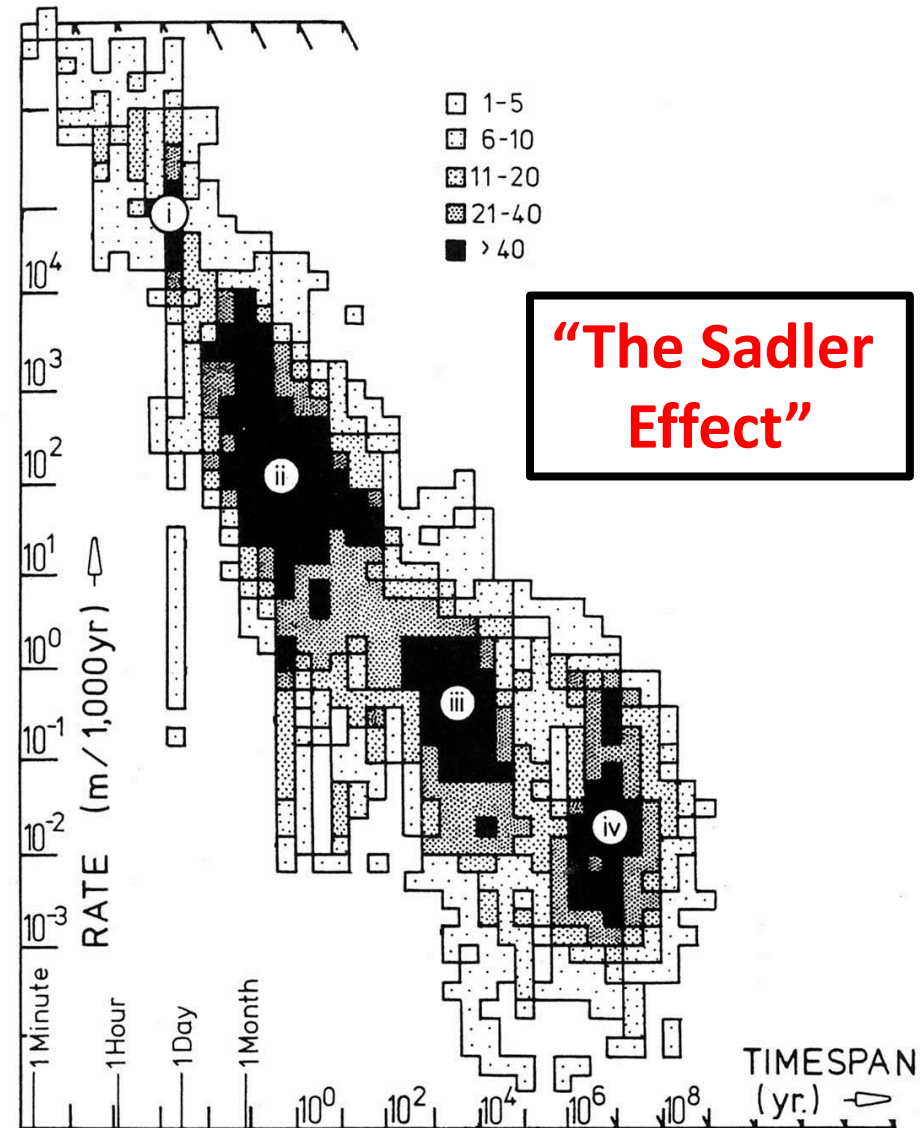
Peter Sadler



David Strauss

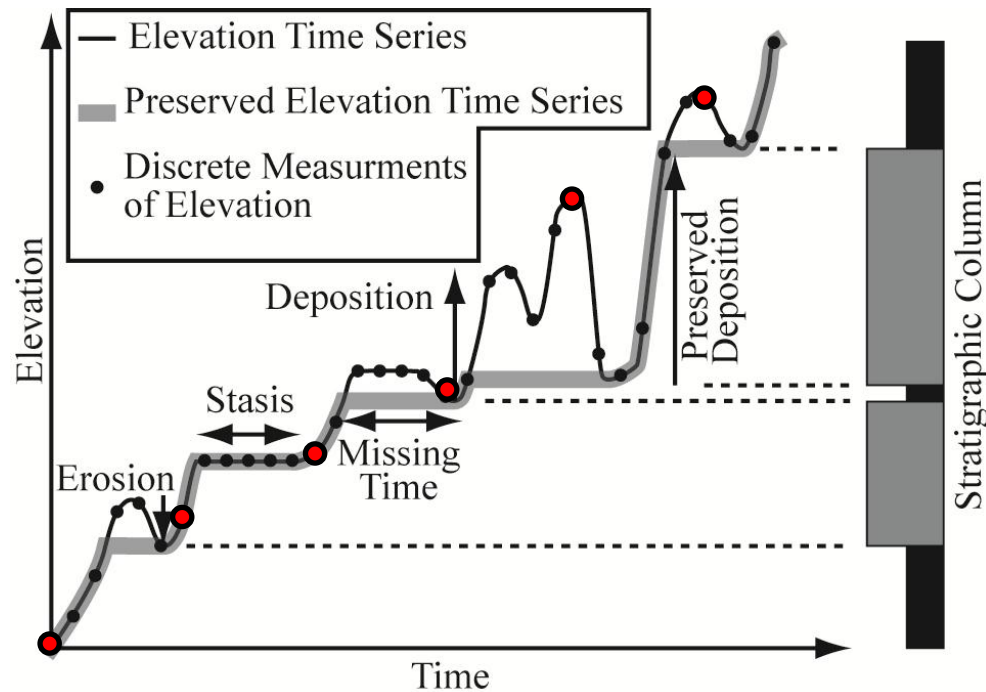


Sadler and Strauss start working together in the late 1980's to develop predictive theory to explain observation that deposition rate is a function of time-span of measurement. This also leads to stratigraphic completeness theory.



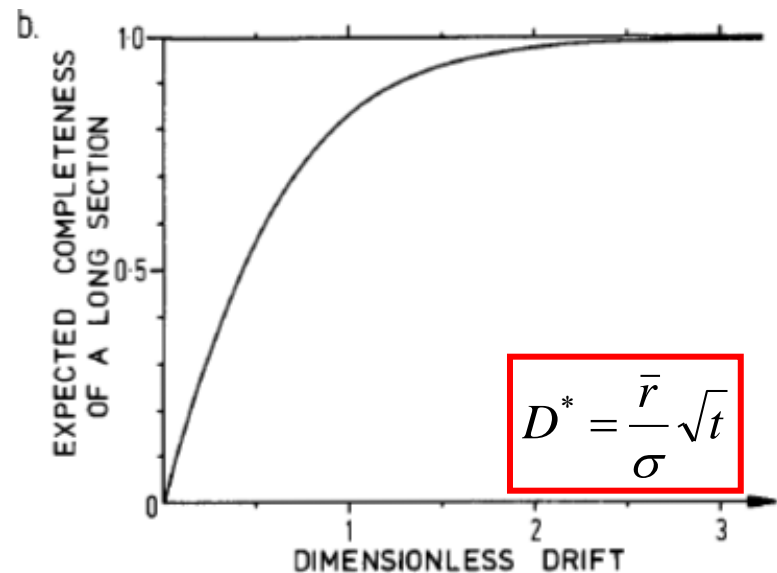
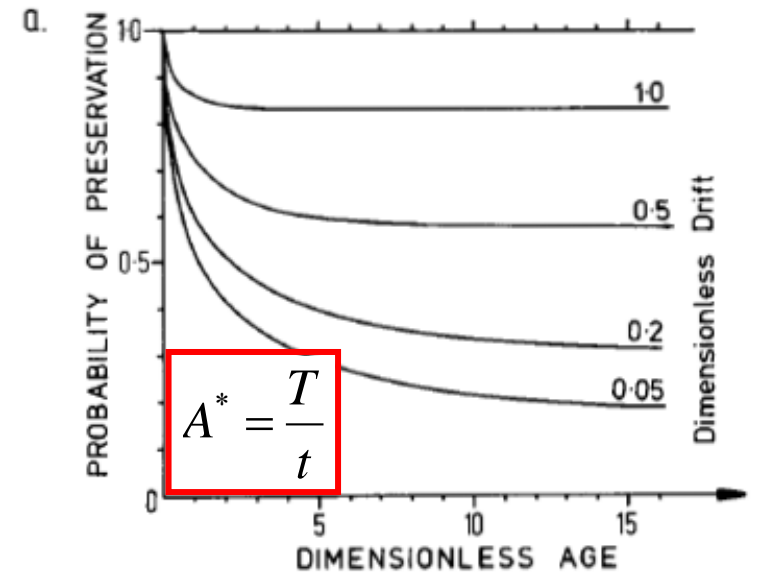
Sadler, Peter M., Sediment accumulation rates and the completeness of stratigraphic sections, *Journal of Geology*, 89 (5), p. 569-584, 1981.

Definition of Problem

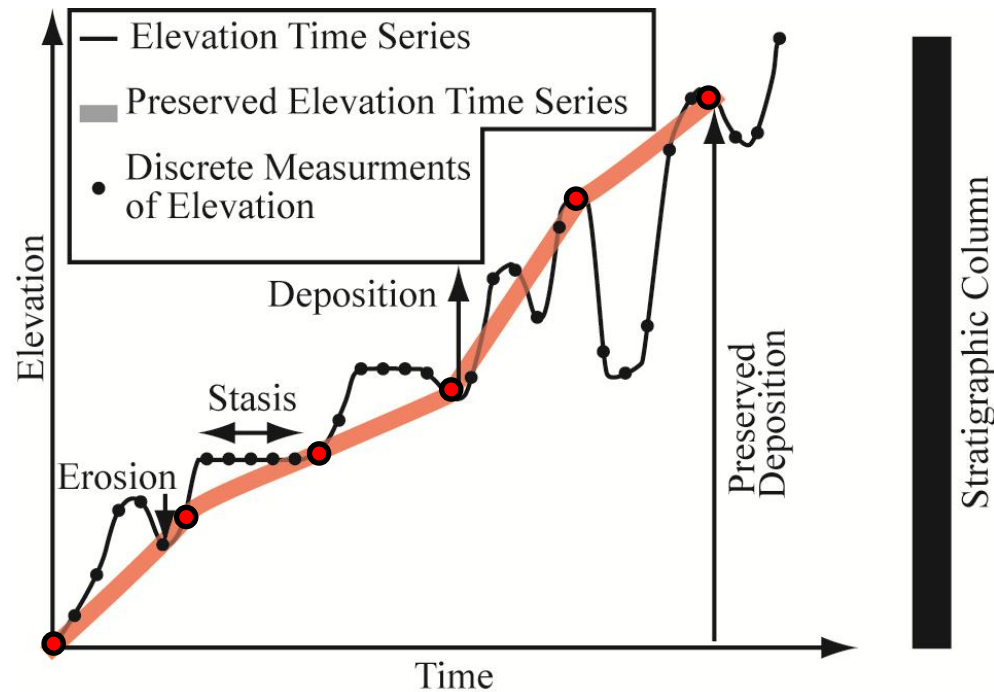


Strauss and Sadler [1989] and Sadler and Strauss [1990] developed theory for prediction of stratigraphic completeness through analysis of global compilations of sedimentation rate and stochastic deposition models.

We aim to build on this earlier work by exploring process-based controls on completeness.

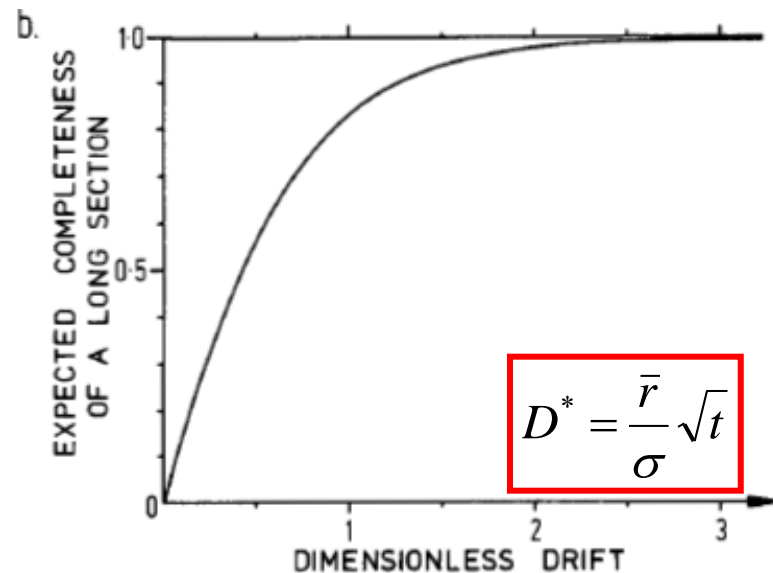
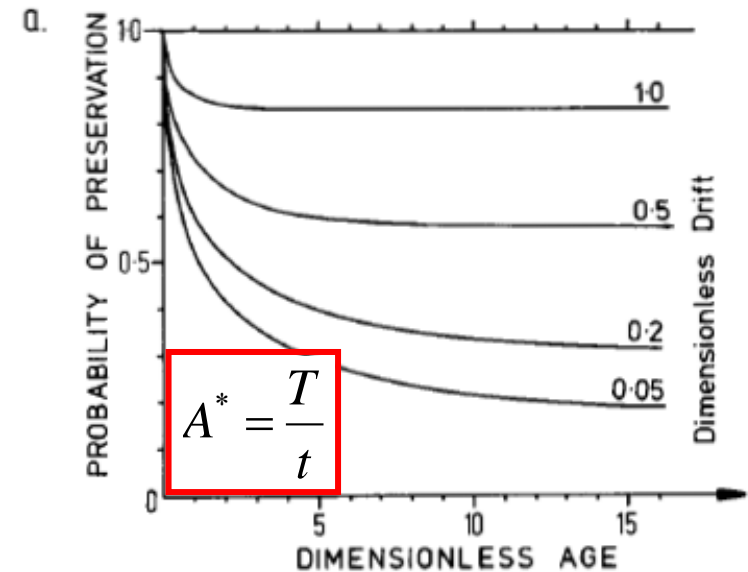


Definition of Problem

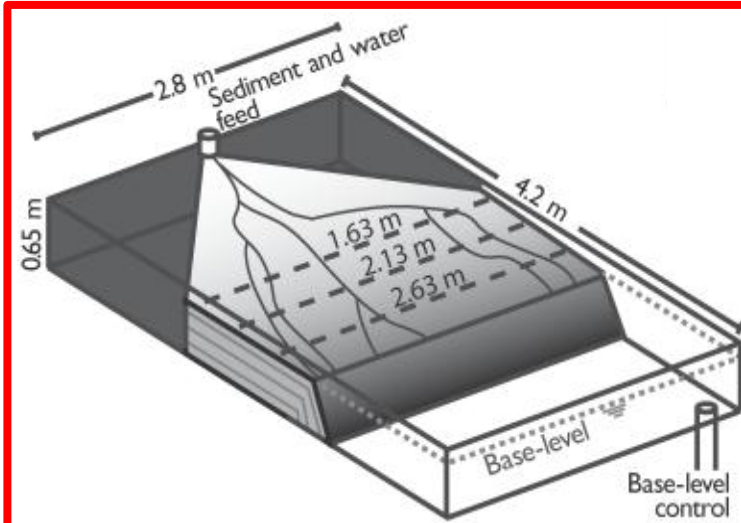


Strauss and Sadler [1989] and Sadler and Strauss [1990] developed theory for prediction of stratigraphic completeness through analysis of global compilations of sedimentation rate and stochastic deposition models.

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Experimental setting



Measurement:

Topography sampled every 2 minutes along 3 strike transects.

Total run time: 1250 – 2500 minutes

The “unreasonable effectiveness” of stratigraphic and geomorphic experiments

Paola et al., 2009

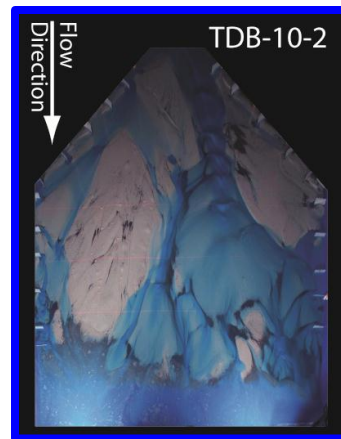
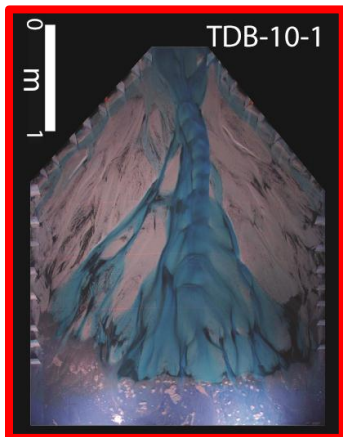
TDB-10-1 (Control)

Sediment Discharge: 0.011 L/sec - **X**

Water discharge: 0.451 L/sec - **Y**

Base-level rise rate: 5 mm/hr - **Z**

$Q_w:Q_s$ - **40:1**



TDB-10-2 (2x Q_w , 2x Q_s)

Sediment Discharge: 0.022 L/sec - **2X**

Water discharge: 0.902 L/sec - **2Y**

Base-level rise rate: 10 mm/hr - **2Z**

$Q_w:Q_s$ - **40:1**

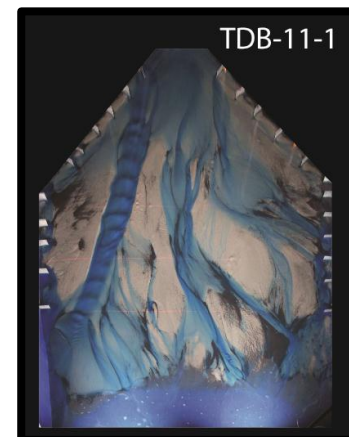
TDB-11-1 (2x Q_w , 1x Q_s)

Sediment Discharge: 0.011 L/sec - **X**

Water discharge: 0.902 L/sec - **2Y**

Base-level rise rate: 5 mm/hr - **Z**

$Q_w:Q_s$ - **80:1**



Stratigraphy = topography + **kinematics** + net deposition

kinematics

T_{ch} = Channel Time scale

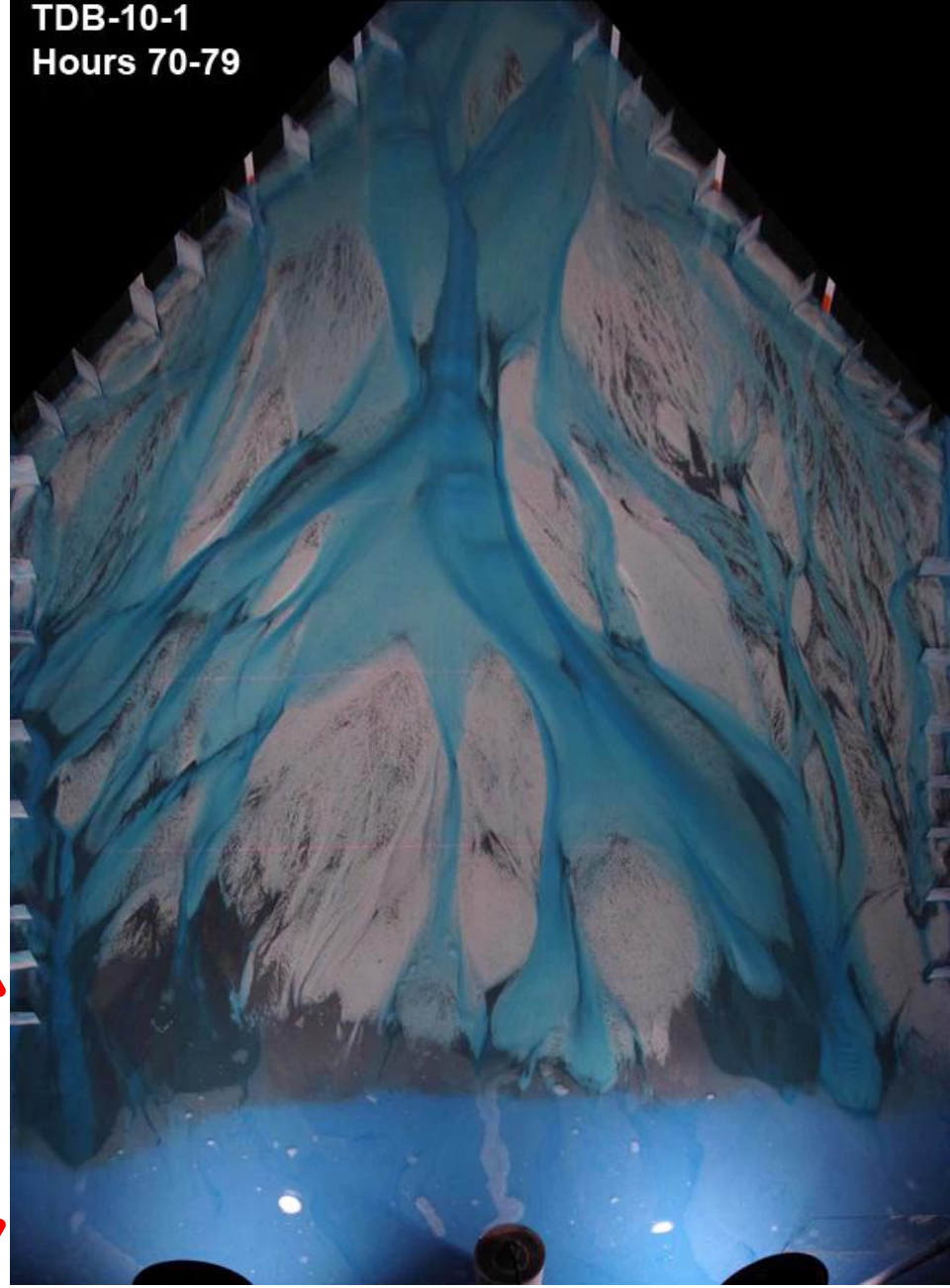
How do we quantify this?

T_{ch} = Time for flow to visit 95%
of delta-top area (Cazanacli et al., 2002)

[Click to view movie](#)

1 m

TDB-10-1
Hours 70-79

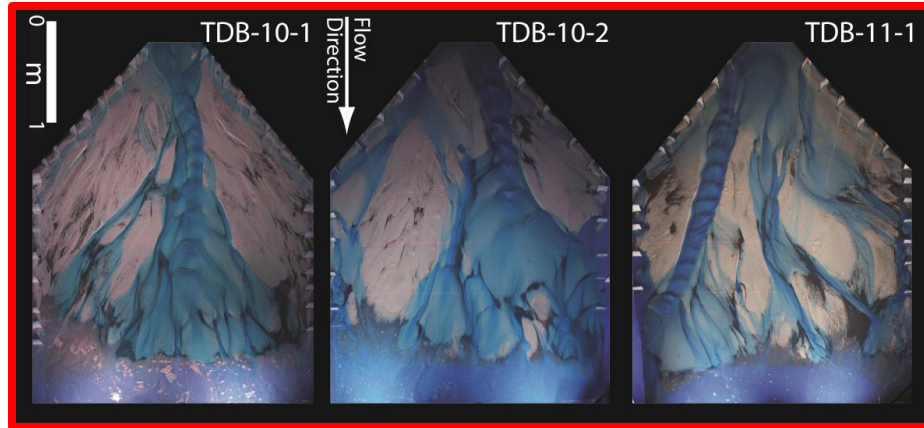


Stratigraphy = topography + **kinematics** + net deposition

kinematics

T_{ch} = Channel Time scale

How do we quantify this?

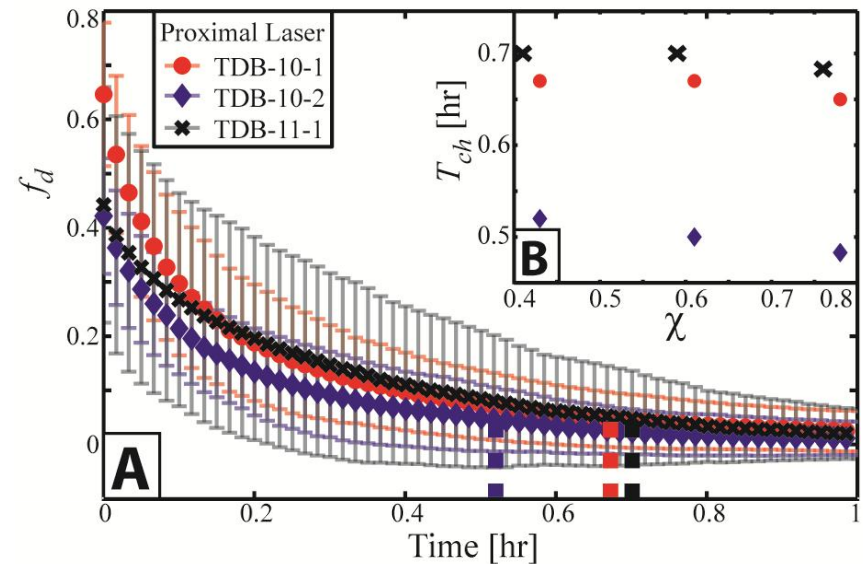


T_{ch} = Time for flow to visit 95%
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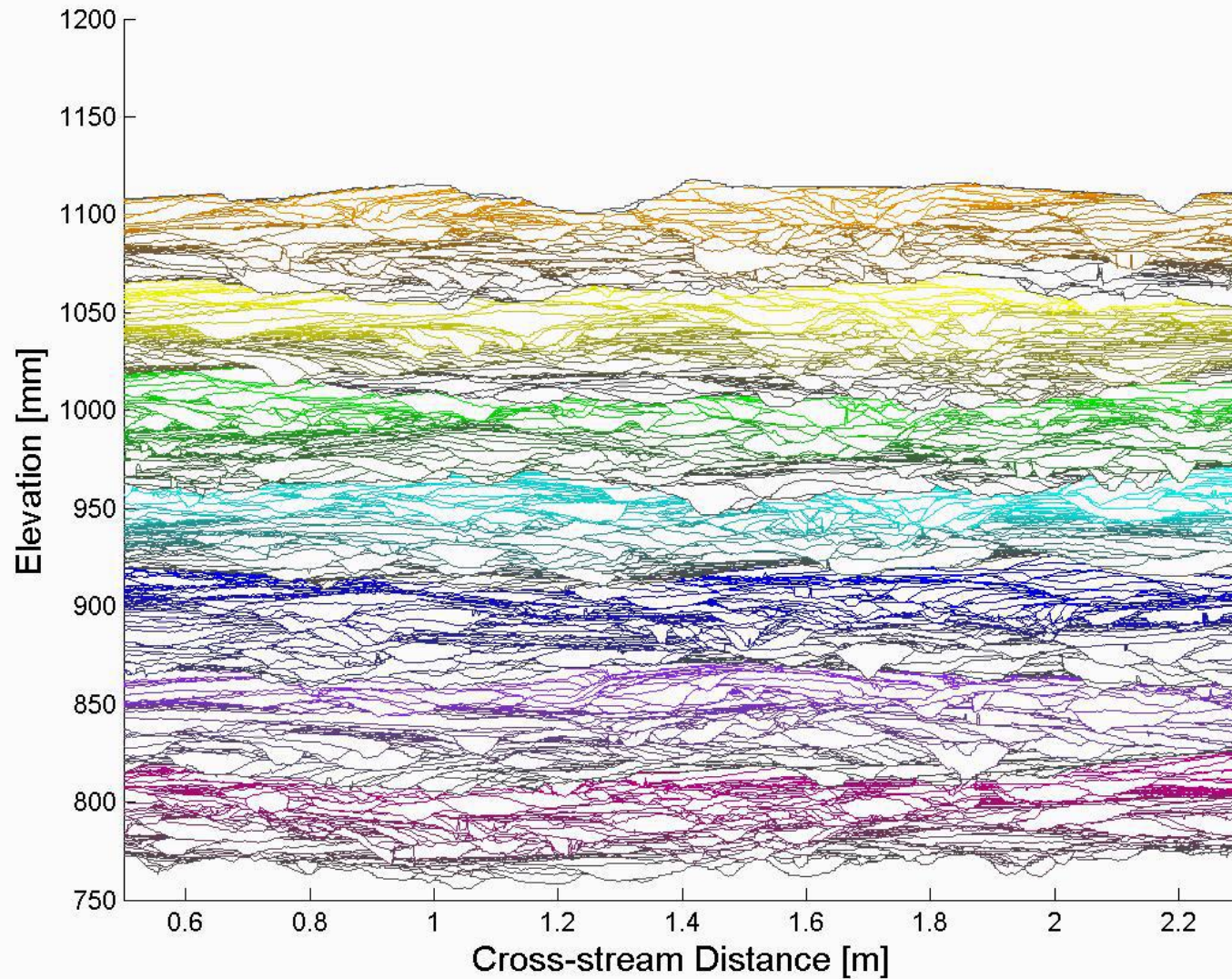
Control – TDB-10-1

2x Q_w , 2x Q_s – TDB-10-2

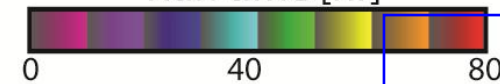
2x Q_w , 1x Q_s – TDB-11-1



Stratigraphy = topography + kinematics + net deposition

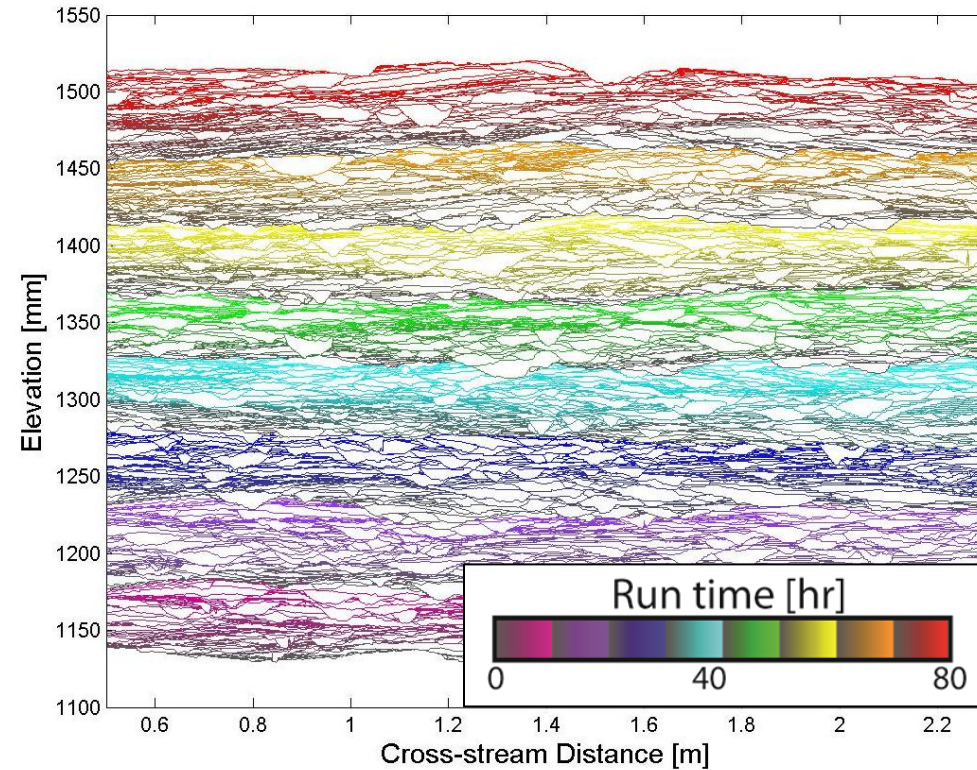


Run time [hr]



[Click to view movie](#)

Stratigraphy = topography + kinematics + net deposition



topography + net deposition

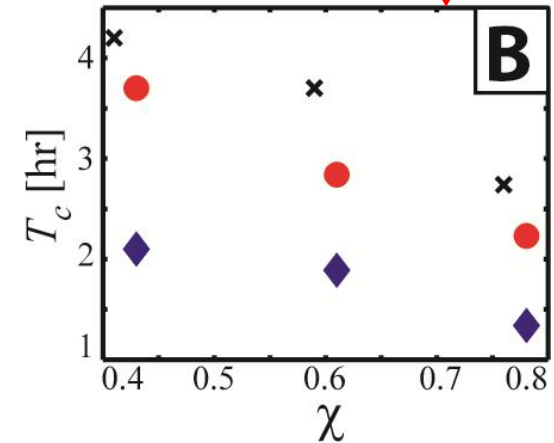
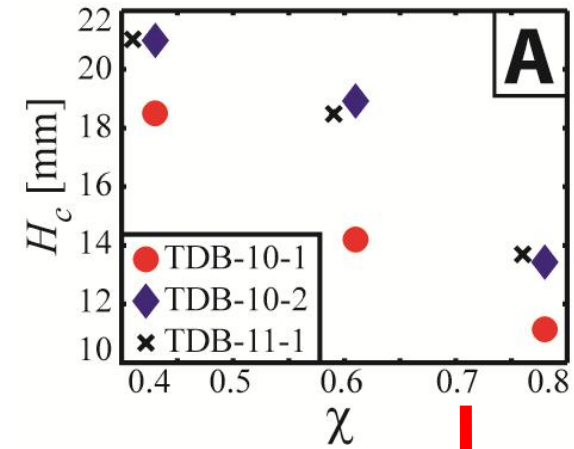
$$T_C = \frac{l}{\bar{r}}$$



Roughness Length Scale



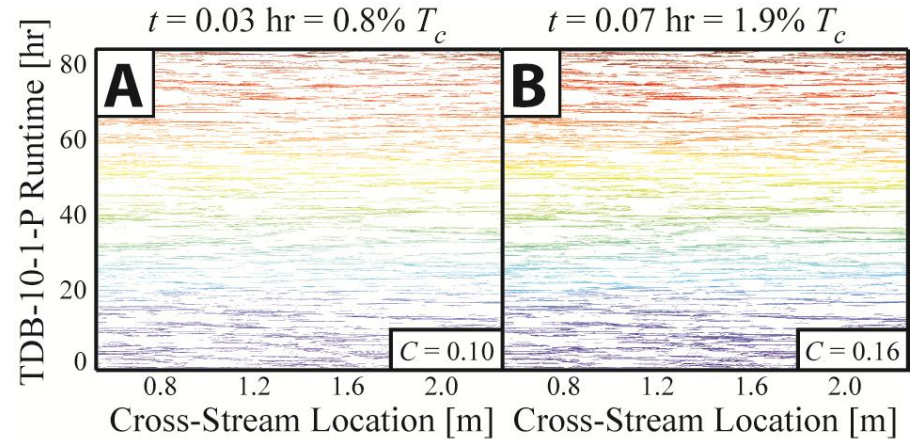
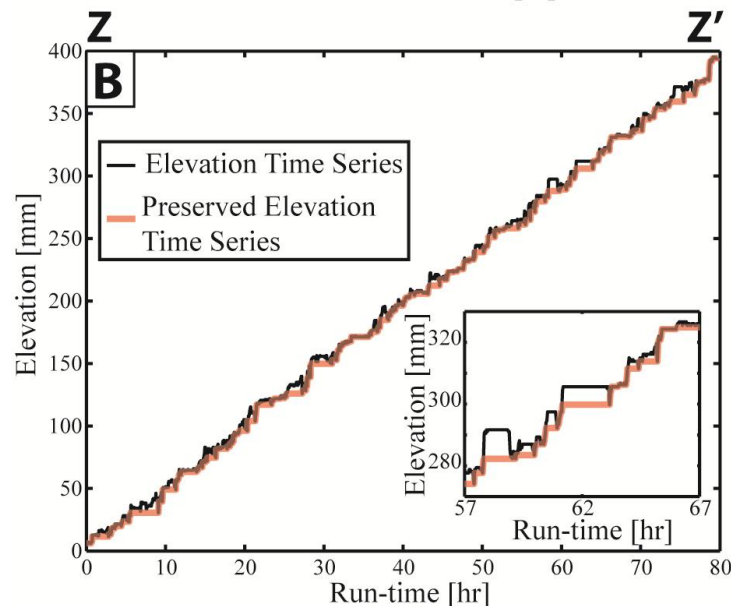
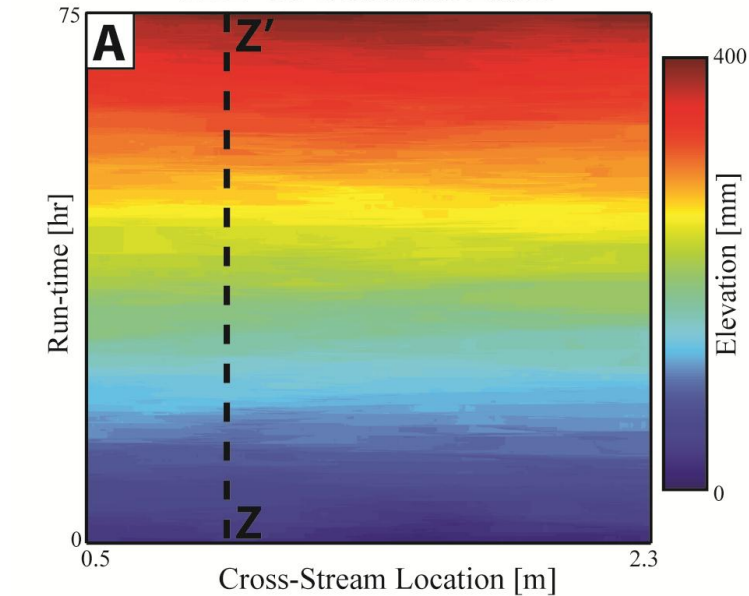
**Long-term
Aggradation Rate**



**T_C is time from generation
of surface until it gets frozen
in the stratigraphic record**

Measuring Stratigraphic Completeness

TDB-10-1 Medial Laser



$$C = \frac{nt}{T}$$

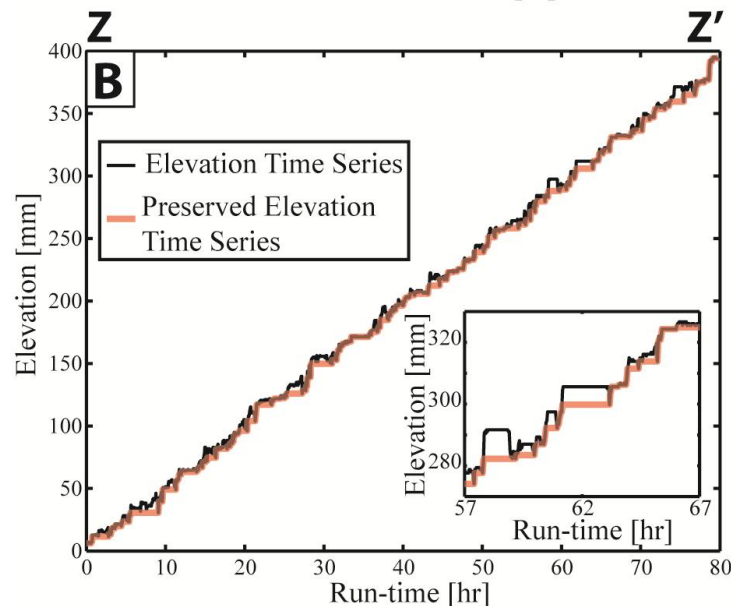
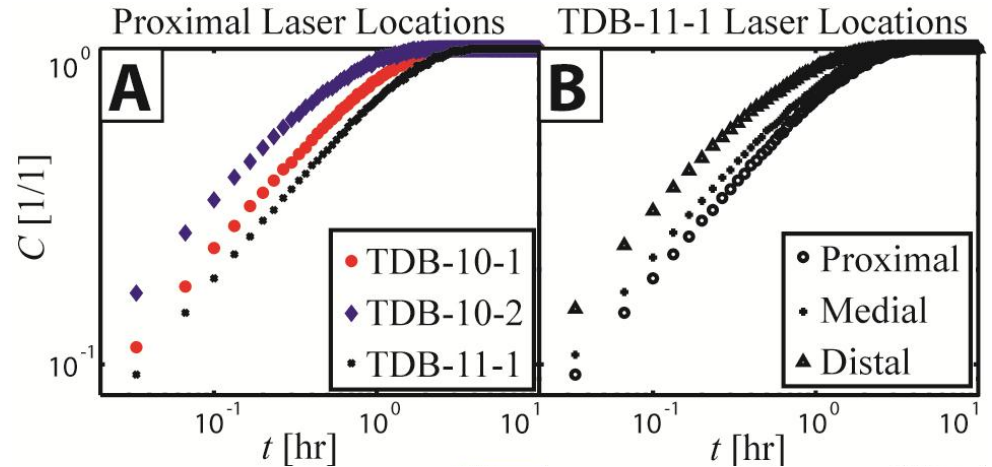
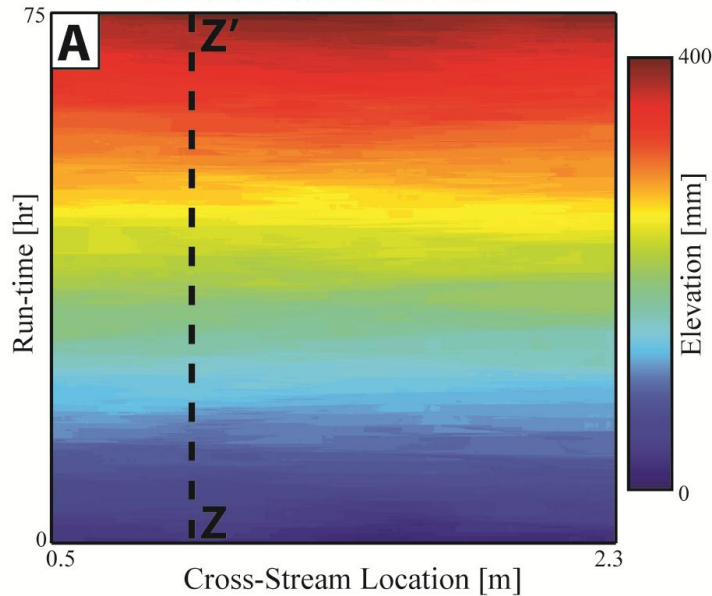
n = number of intervals that leave a record

t = time scale that record is discretized

T = total length of record

Measuring Stratigraphic Completeness

TDB-10-1 Medial Laser



$$C = \frac{nt}{T}$$

n = number of intervals that leave a record

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Combining T_{ch} and T_c

$$T^* = \frac{T_c}{T_{ch}} \rightarrow T^* = \frac{H_c v_c}{\bar{r}(B_t - B_w)}$$

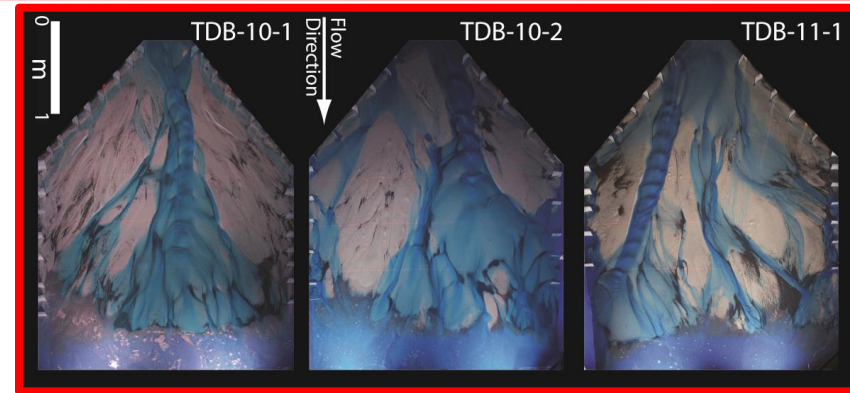
High

Each spot on a delta is frequently visited by flow during a period of duration T_c

T^*

Low

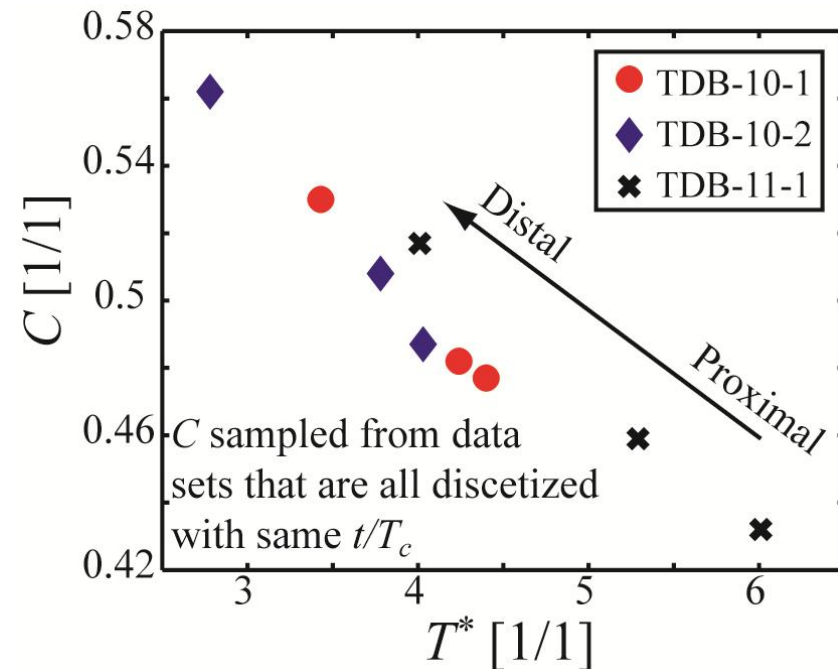
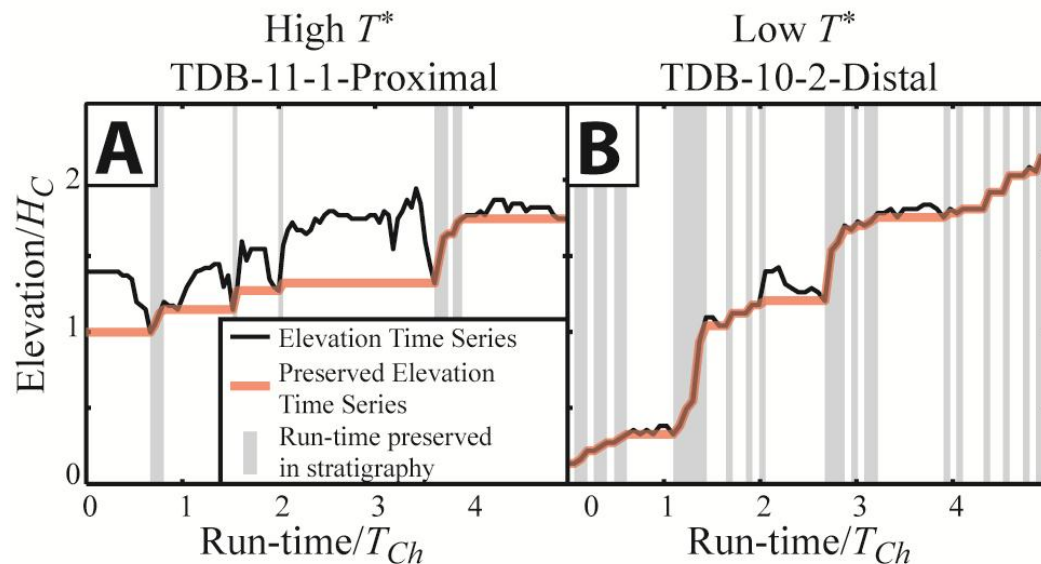
Each spot on a delta is infrequently visited by flow during a period of duration T_c



TDB-10-1
Control

TDB-10-2
 $2x Q_w, 2x Q_s$

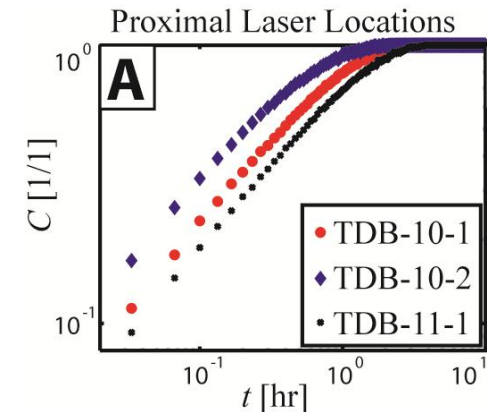
TDB-11-1
 $2x Q_w, 1x Q_s$



A Good Record, but of what?

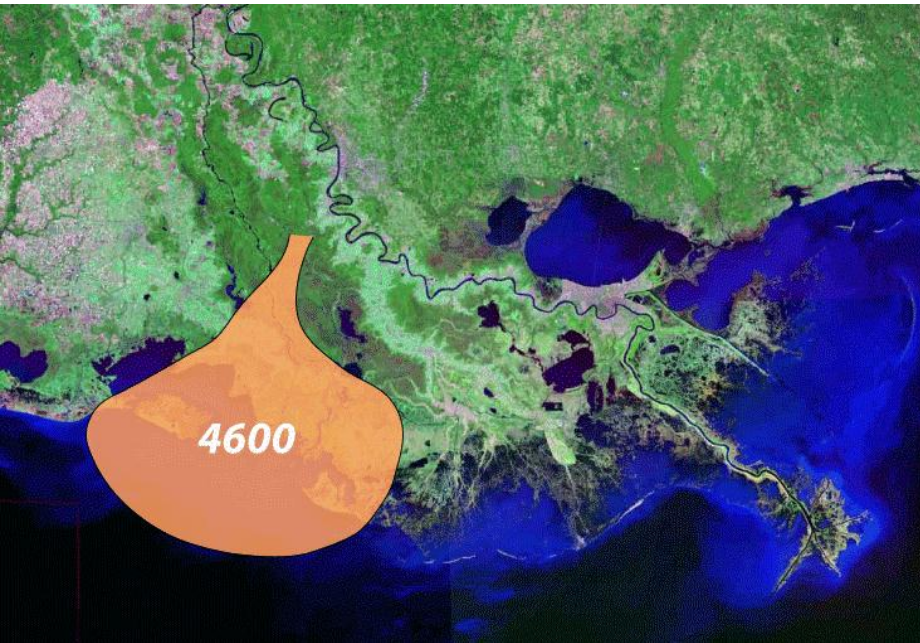


Proxy (climate) records disconnected from sediment routing system and/or sampling of taxa for studies of ecological succession: Best preserved in systems with lowest possible T_c , so that the system reaches perfect completeness in shortest possible time



Stratigraphic Completeness in the field

Channel time scale



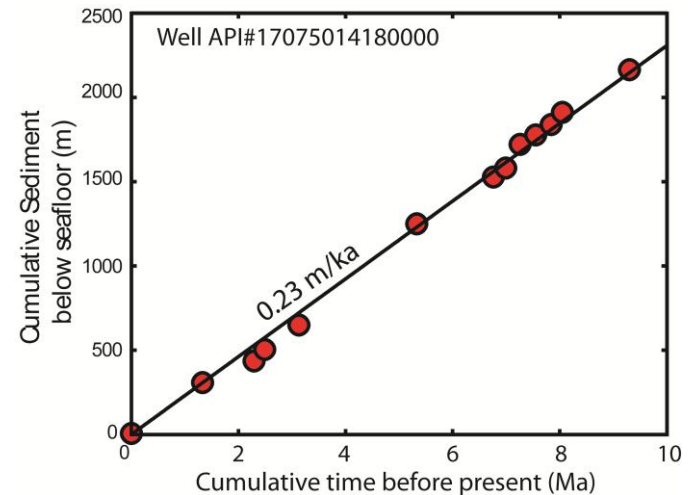
Back of the envelope estimate using the amount of time associated with construction of the sub-delta lobes that currently comprise delta plain from Törnqvist et al. (1996)

$$T_{ch} = 7.5 \text{ kyrs}$$

Compensation time scale

Channel Depth of Lower Mississippi River: 30 m

Long-term sedimentation rate:
0.23 m/k.y. (Straub et al., 2009)

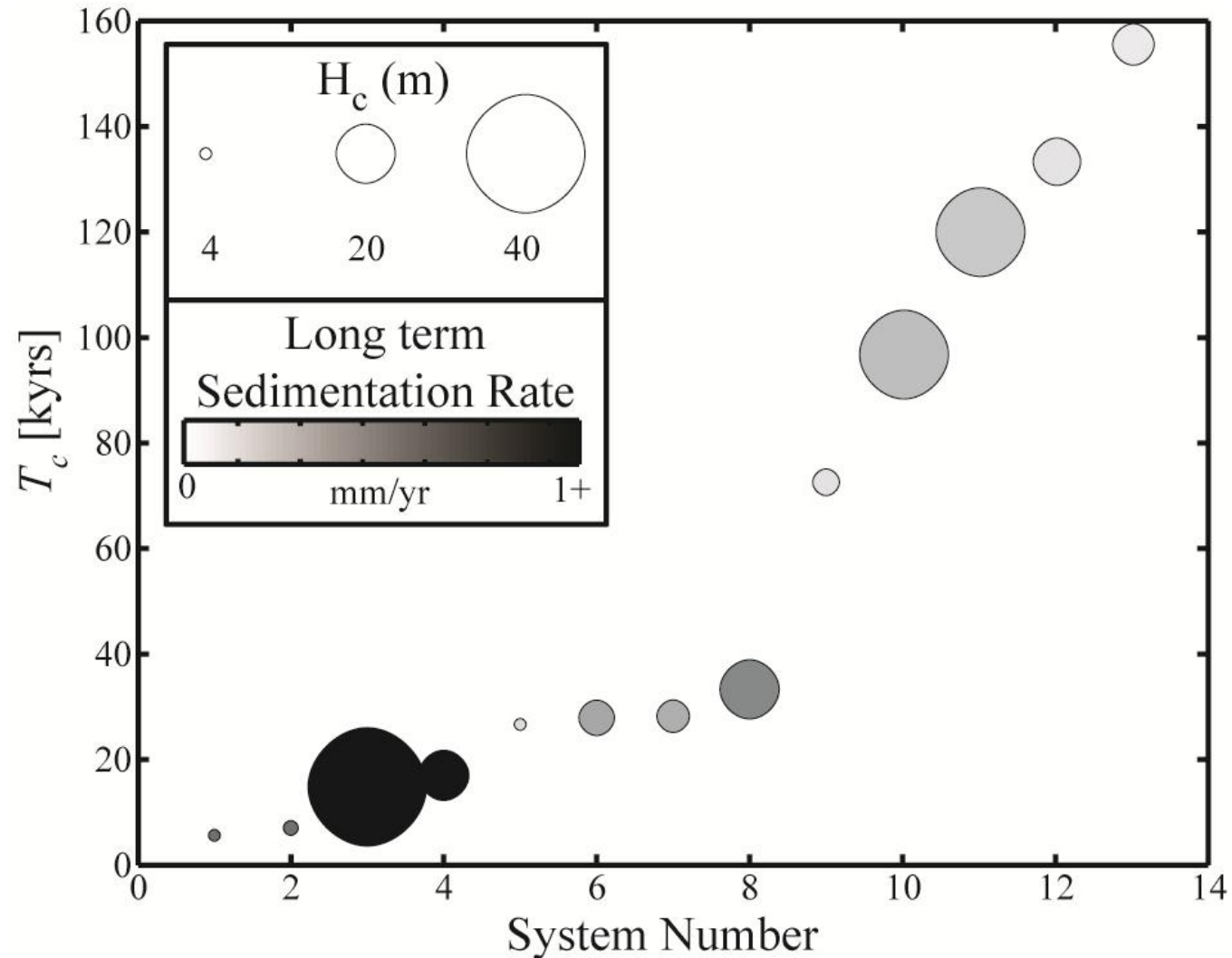


$$T_c = \frac{l}{\bar{r}} \quad \Rightarrow \quad 115,000 \text{ yrs}$$

$$T^* = \frac{T_c}{T_{ch}} \sim 15$$

Calculated autogenic time-scale (T_c) is long in comparison to many allogenic time-scales (e.g. Milankovitch Cycles)

Autogenic time scales in the field



Calculated autogenic time scale (T_c) is long in comparison to many allogenic time-scales (e.g. Milankovitch Cycles)

Stratigraphy: The Best Record We Have...



- Stratigraphy does contain the most complete record of Earth history available to us, but...
- A proper understanding of the processes associated with its generation and the limits associated with the record's fidelity (**imposed by gaps in the record and autogenic processes**) are necessary to accurately decode this record