Results update and works in progress

Kaci Kus

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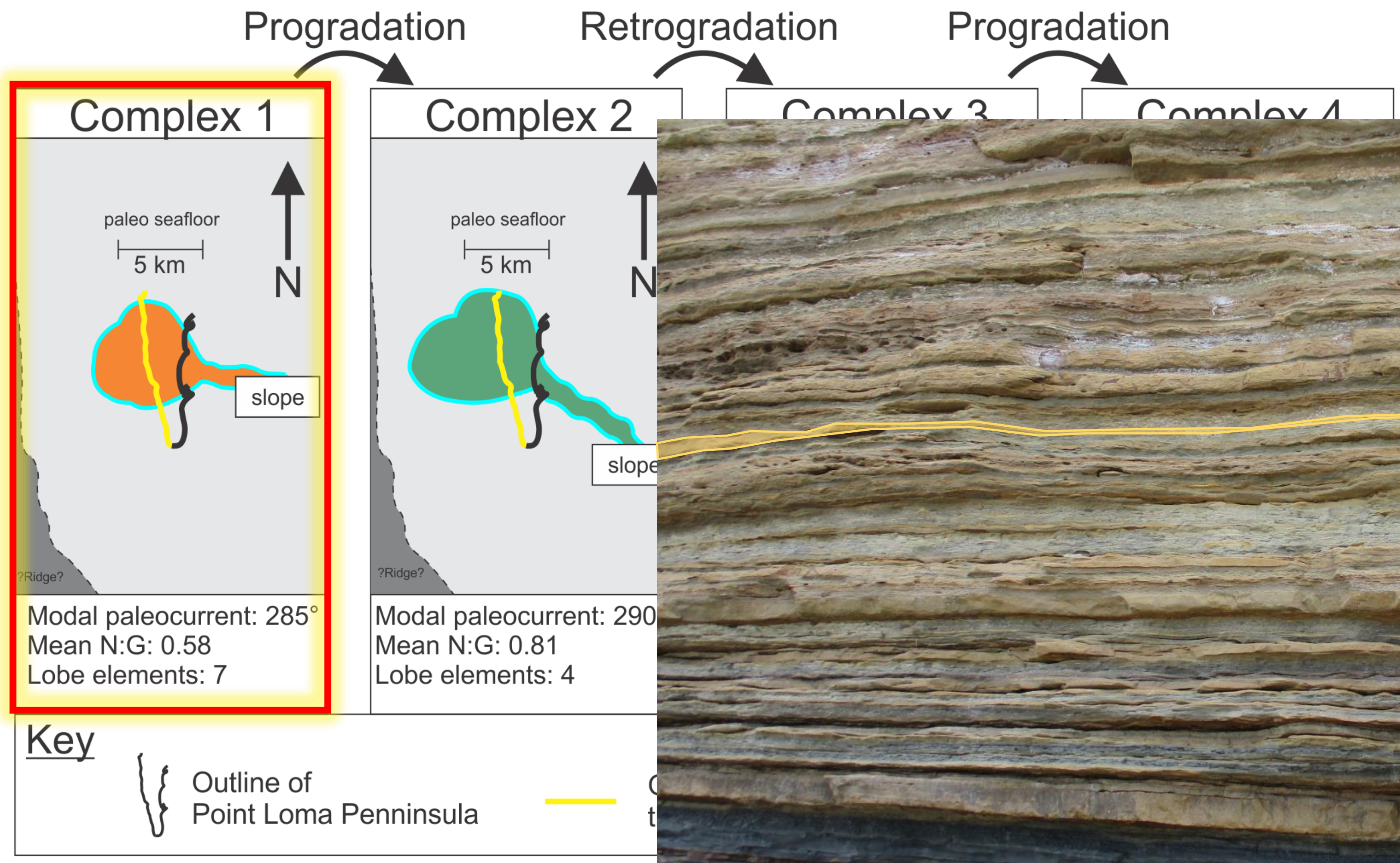
CHEVRON CENTER OF RESEARCH EXCELLENCE
COLORADO SCHOOL OF MINES

Chevron

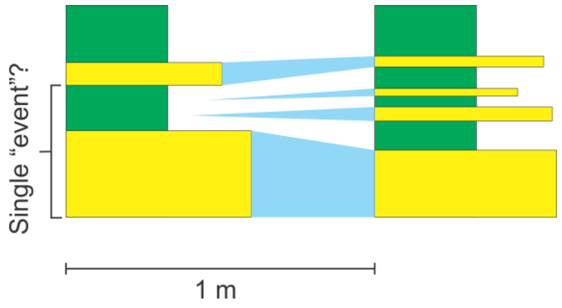
Point Loma Fm. On the Point Loma Peninsula, San Diego



- This study focuses on deposits in Complex 1 of Fleming, 2010

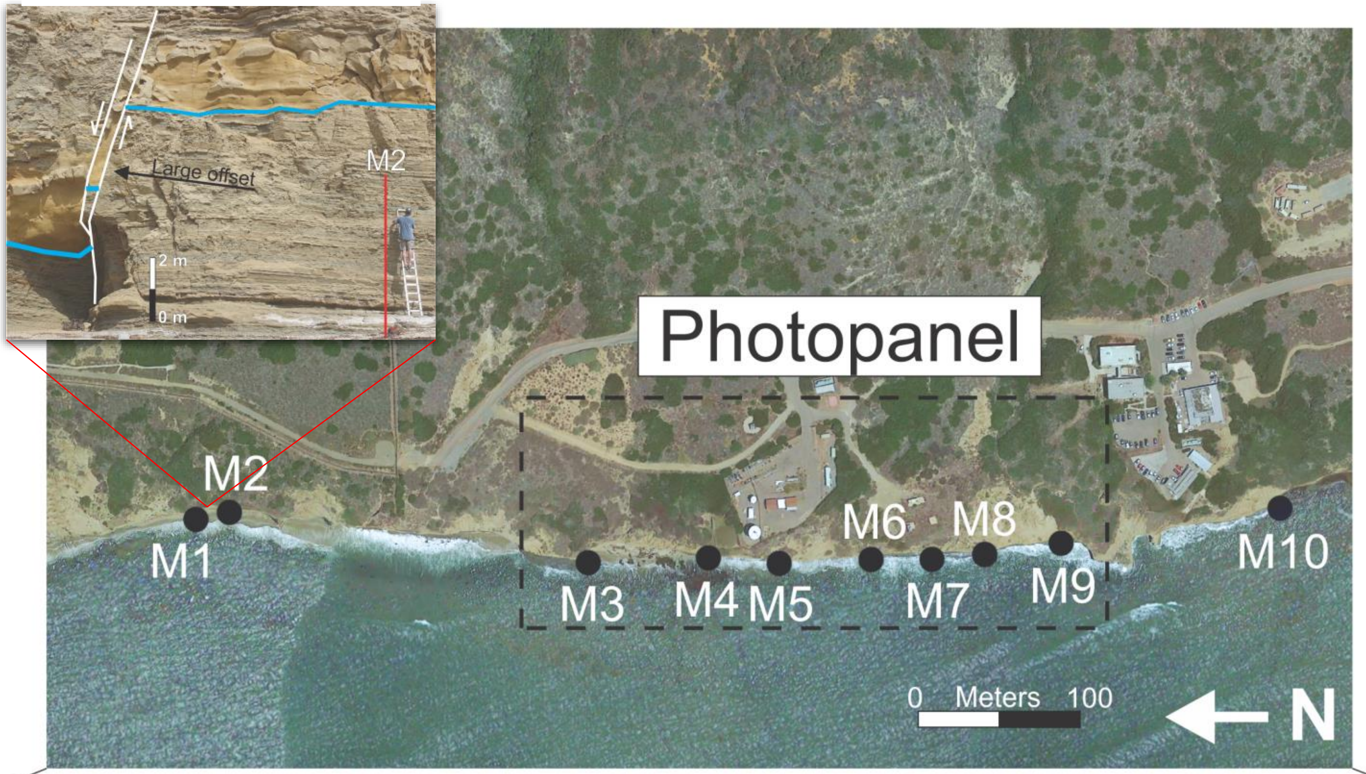
Data set

- 10 measured sections across ~700 m of beach
- Cumulative ~60 m of vertical measured section
- 1,303 “beds”



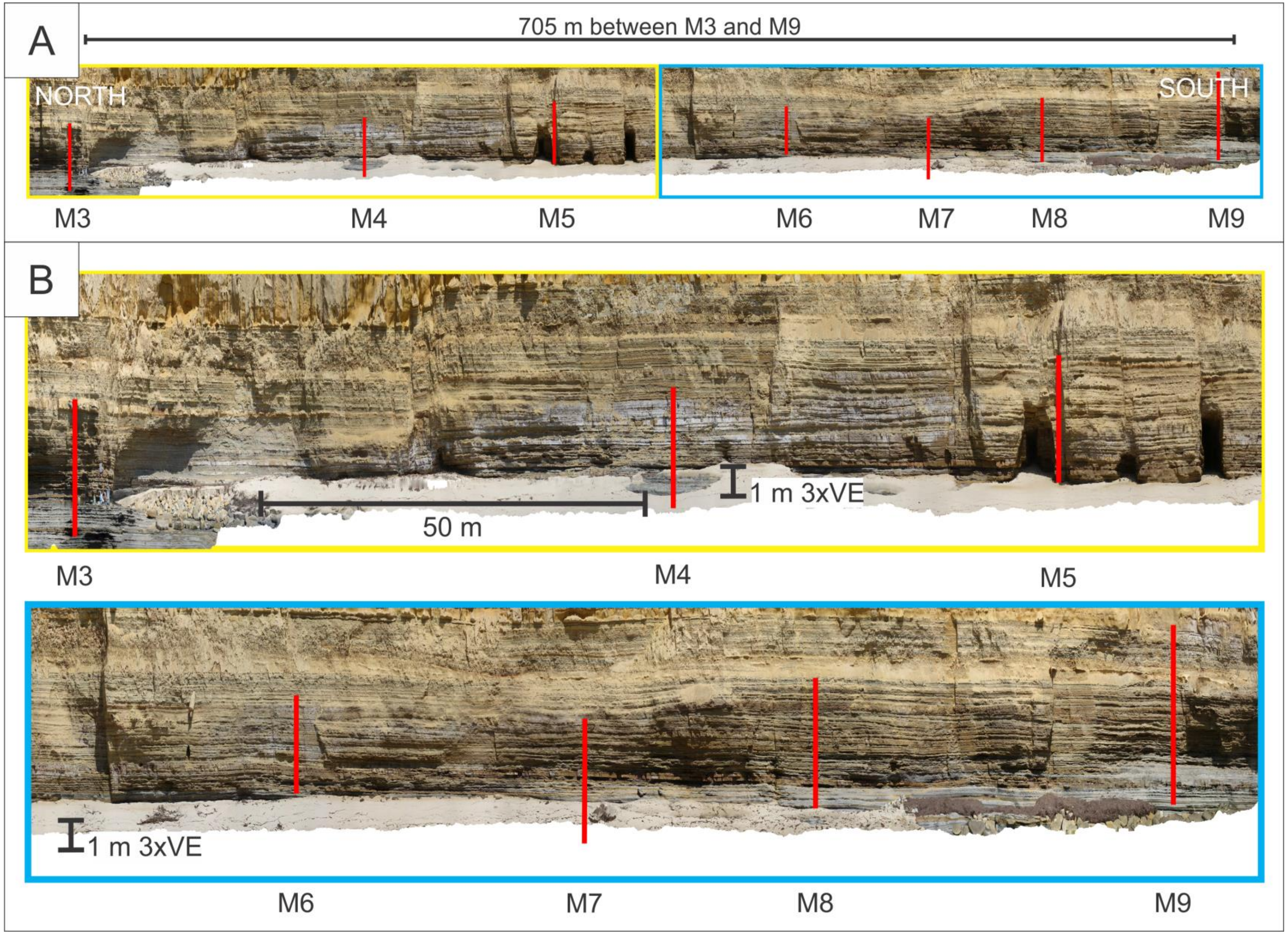
- Majority of correlations are made between M3 and M9

Fault between M1 and M2

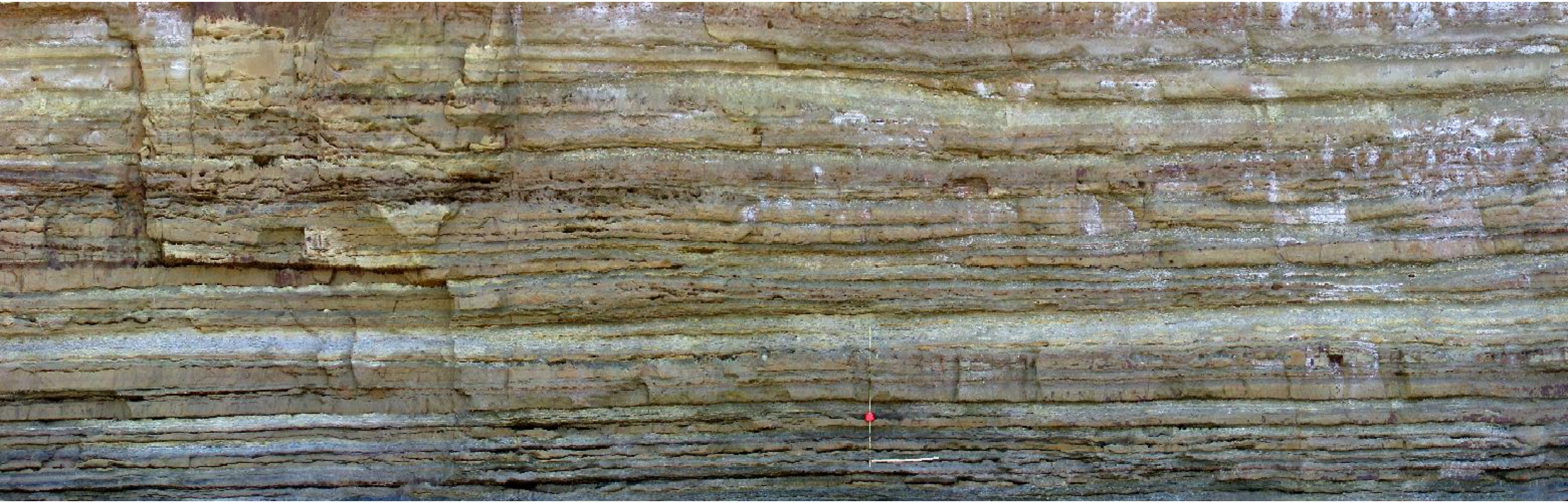


Photopanel from M3 to M9

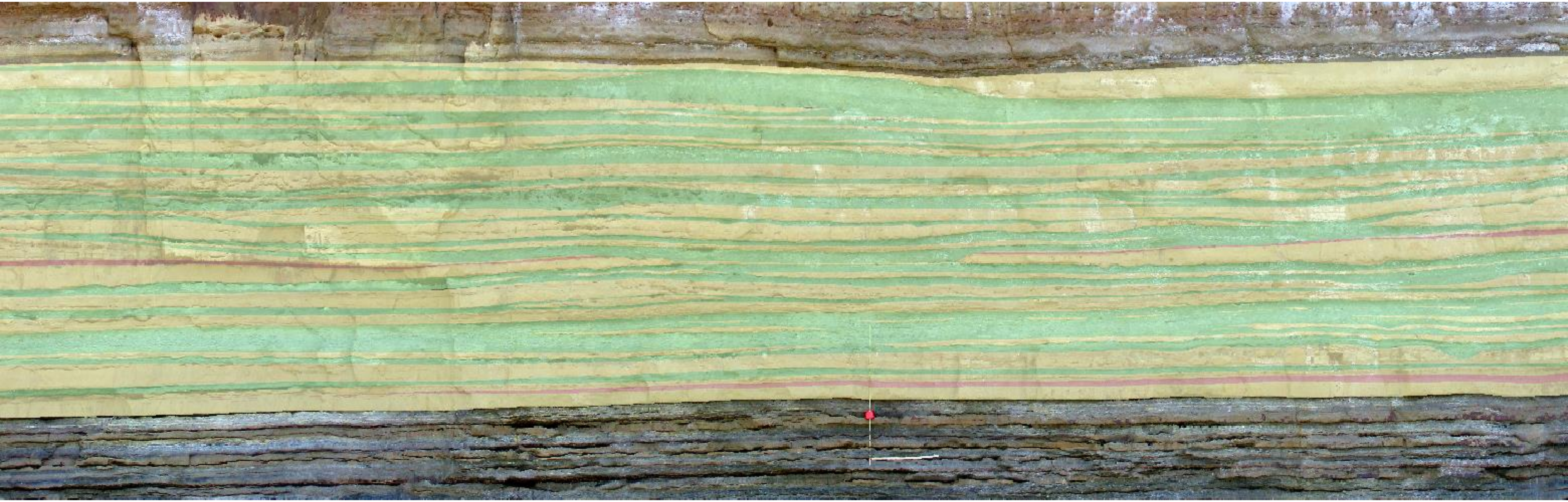
- Outcrop-scale geometries that occur between measured sections
- Traced beds/lithofacies in ArcMap

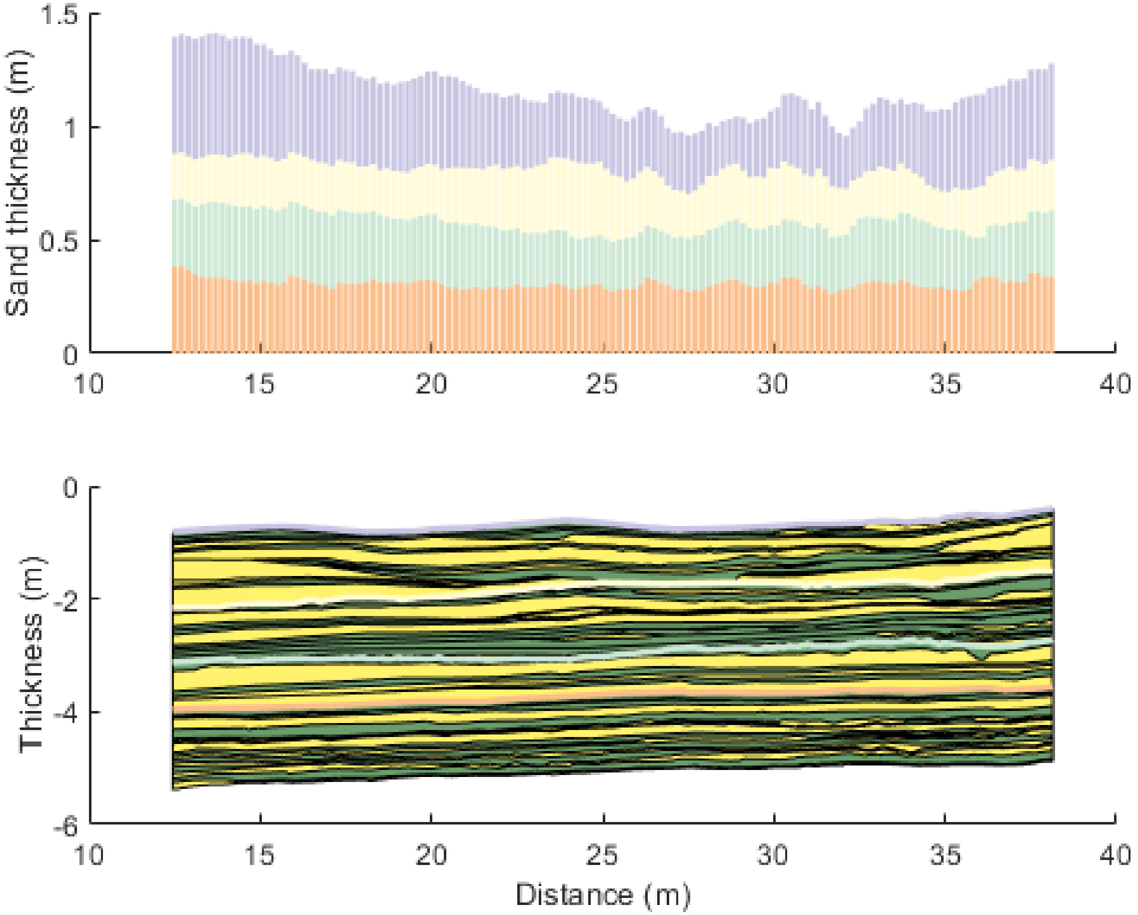


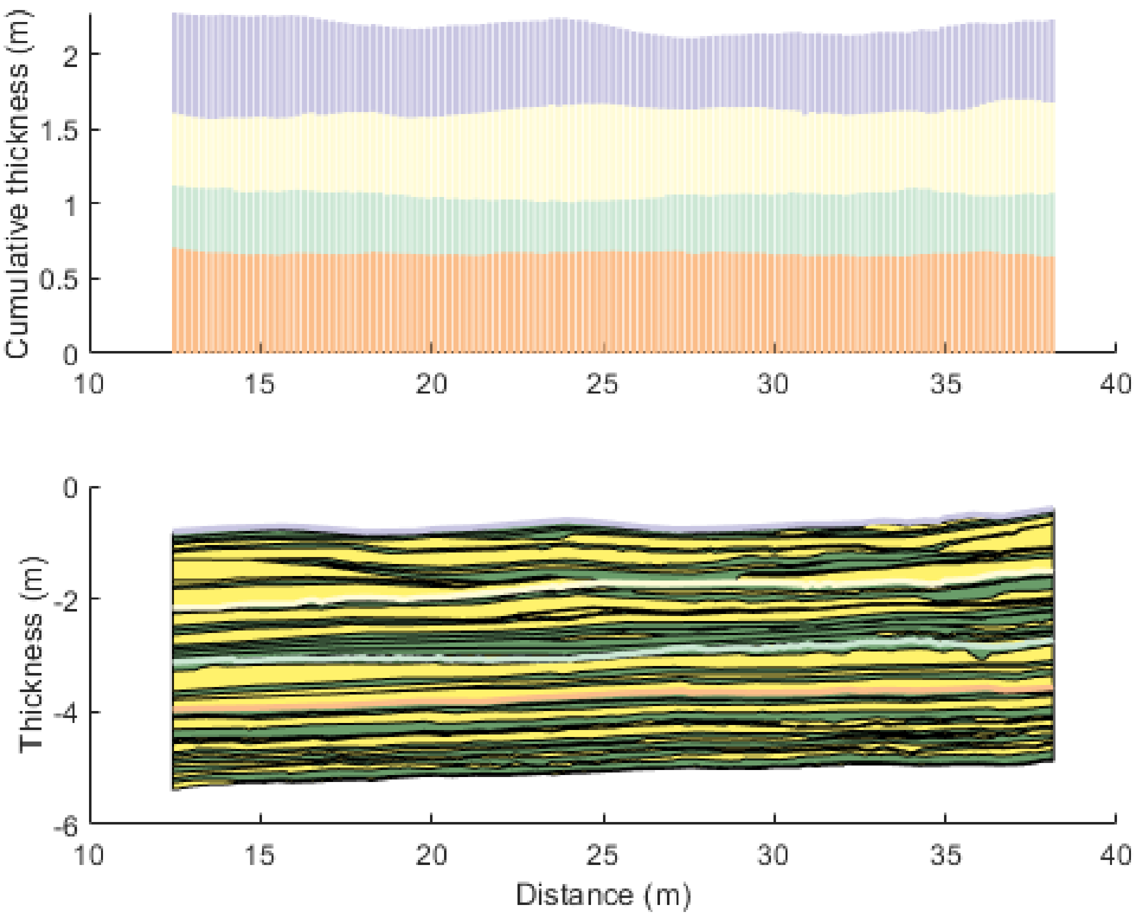
Photopanel detail shot



Arc Map tracing





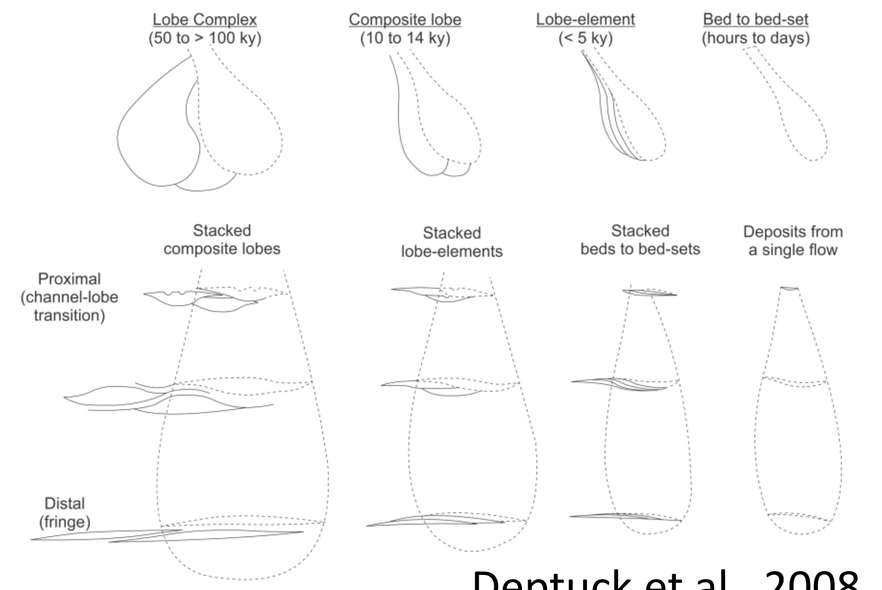


Cumulative sand thickness plotted by element
Colored lines on bottom plot are the tops of elements

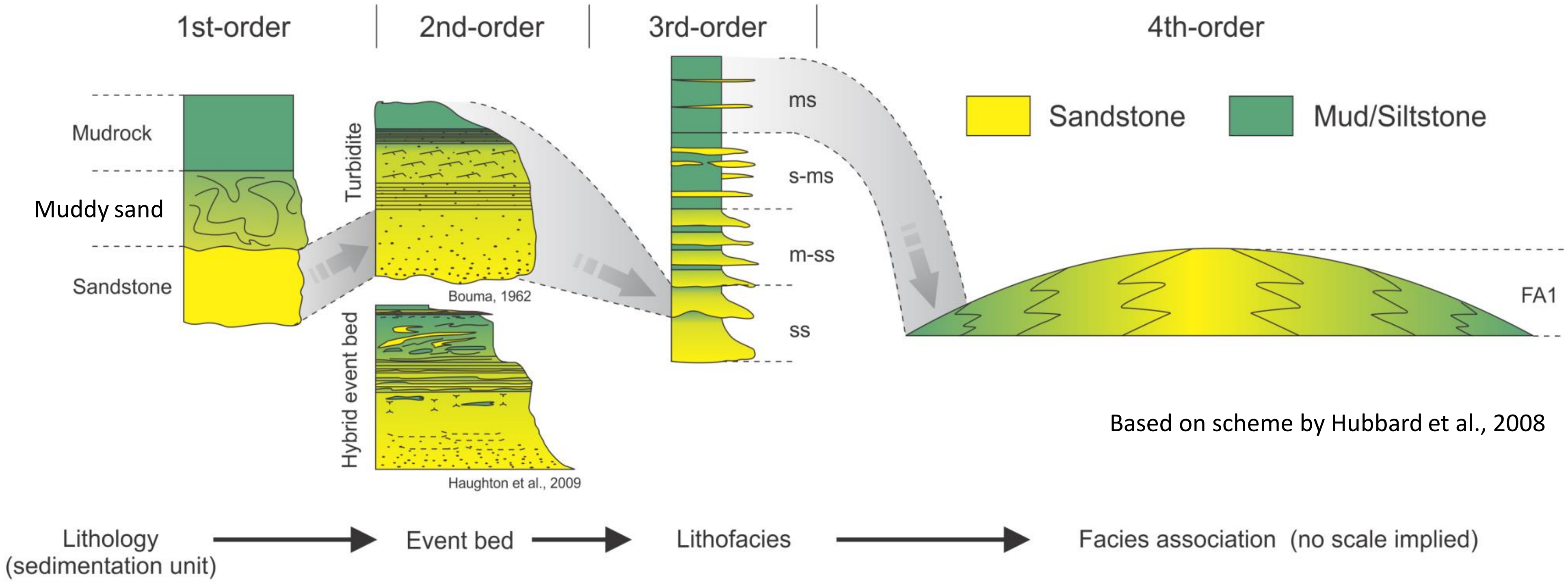
Cumulative thickness plotted by element
Colored lines on bottom plot are the tops of elements

Facies hierarchy

- Both turbidite event beds and hybrid event beds are second order
- Elements are distinguished based on a general tapering of a set of beds, often accompanied by a vertical shift in lithofacies.
  - A single element is roughly equivalent to the facies association scale, as a lobe element contains the lateral transitions between lithofacies



Deptuck et al., 2008

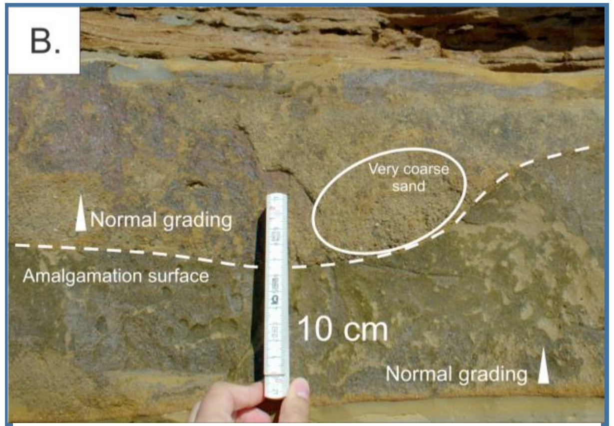


Based on scheme by Hubbard et al., 2008

Defining lithofacies

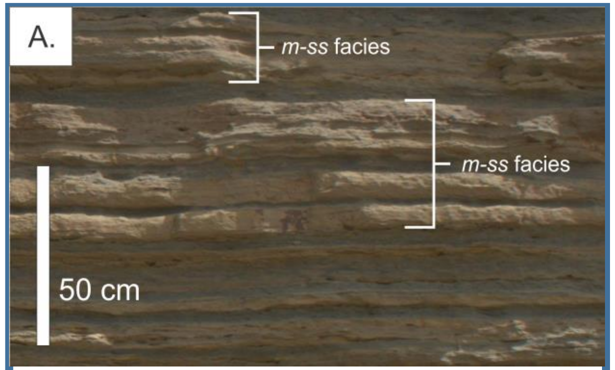
- The smallest unit universally identifiable in both the photopanel and measured sections
  - While individual beds can often be traced in the photopanel, there are also many instances where poor resolution makes it impossible to identify every beds ubiquitously
- Lithofacies are determined based on N:G and bed thickness.
- Lithofacies identification in the cross-section was automated using k-means clustering in Matlab

Amalgamated sandstone (ss)



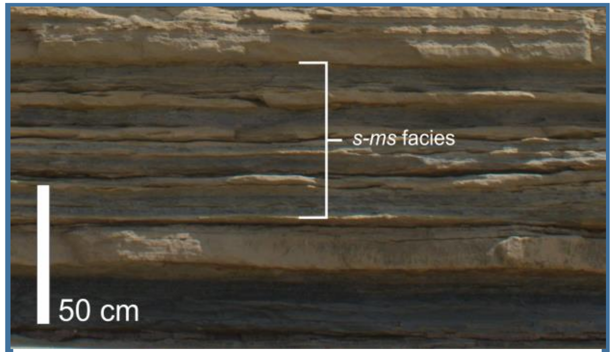
- NG = 0.81
- Mean sand bed thickness = 6.1 cm
- Mean mudstone bed thickness = 3.1 cm

Sandstone with minor mudstone (m-ss)



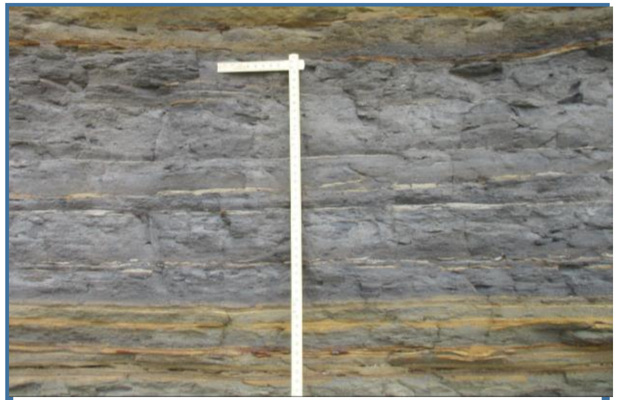
- NG = 0.62
- Mean sand bed thickness = 4.6 cm
- Mean mudstone bed thickness = 3.9 cm

Thin-bedded sandstone and mudstone (s-ms)



- NG = 0.40
- Mean sand bed thickness = 3.8 cm
- Mean mudstone bed thickness = 5.0 cm

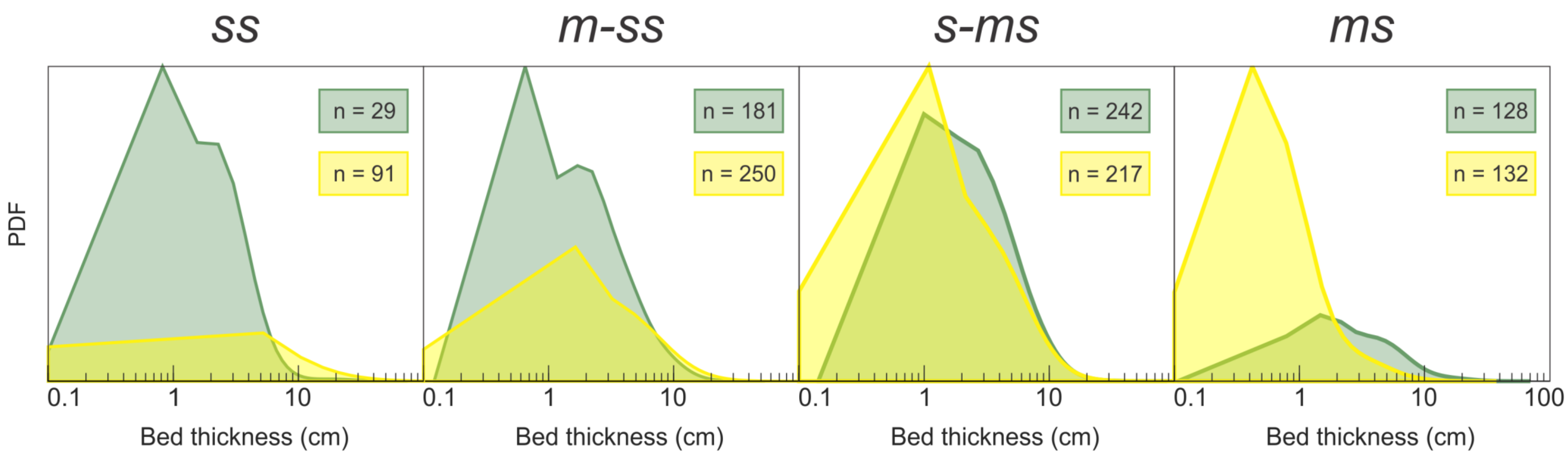
Mudstone with minor sandstone (ms)



- NG = 0.23
- Mean sand bed thickness = 1.8 cm
- Mean mudstone bed thickness = 6.1 cm

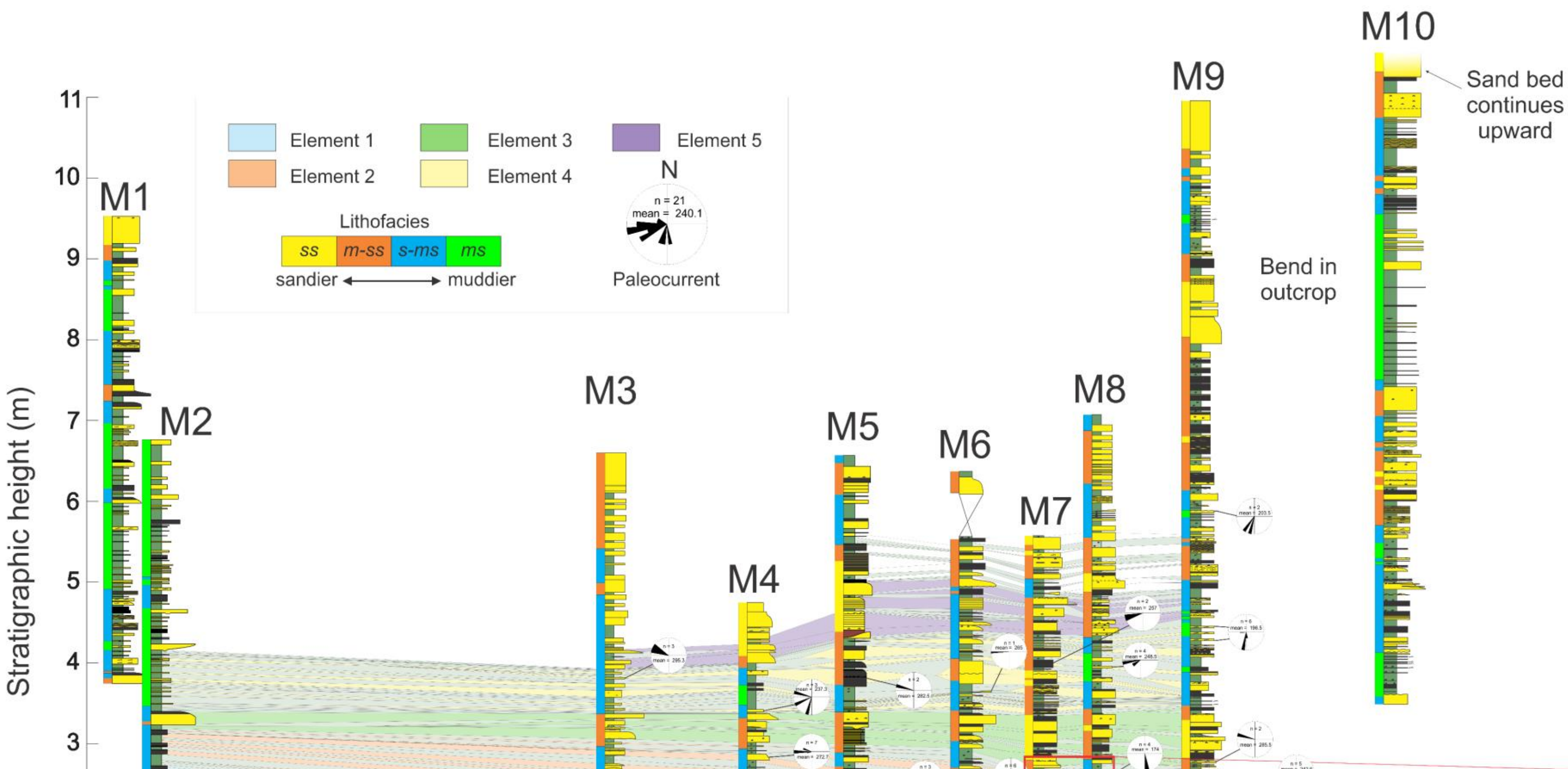
Probability density functions of lithofacies

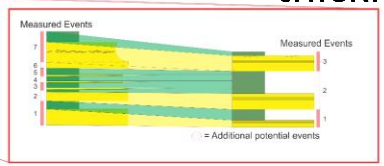
- Green = mudstone beds, yellow = sandstone beds
- Data from automated lithofacies detection based on measured section bed thickness and grain-size data



- ss lithofacies has widest range of sandstone bed thicknesses, mean sand bed thickness of 6.5 cm
- ms lithofacies has a mean sand thickness of 1.8 cm
- Similar mudstone distributions, although the ms lithofacies tends to have slightly thicker mudstones

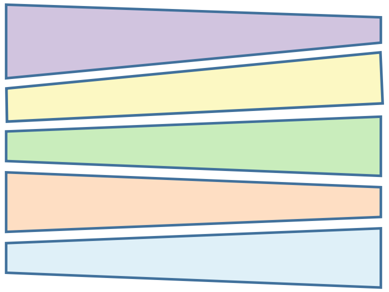
Cross-section and correlations



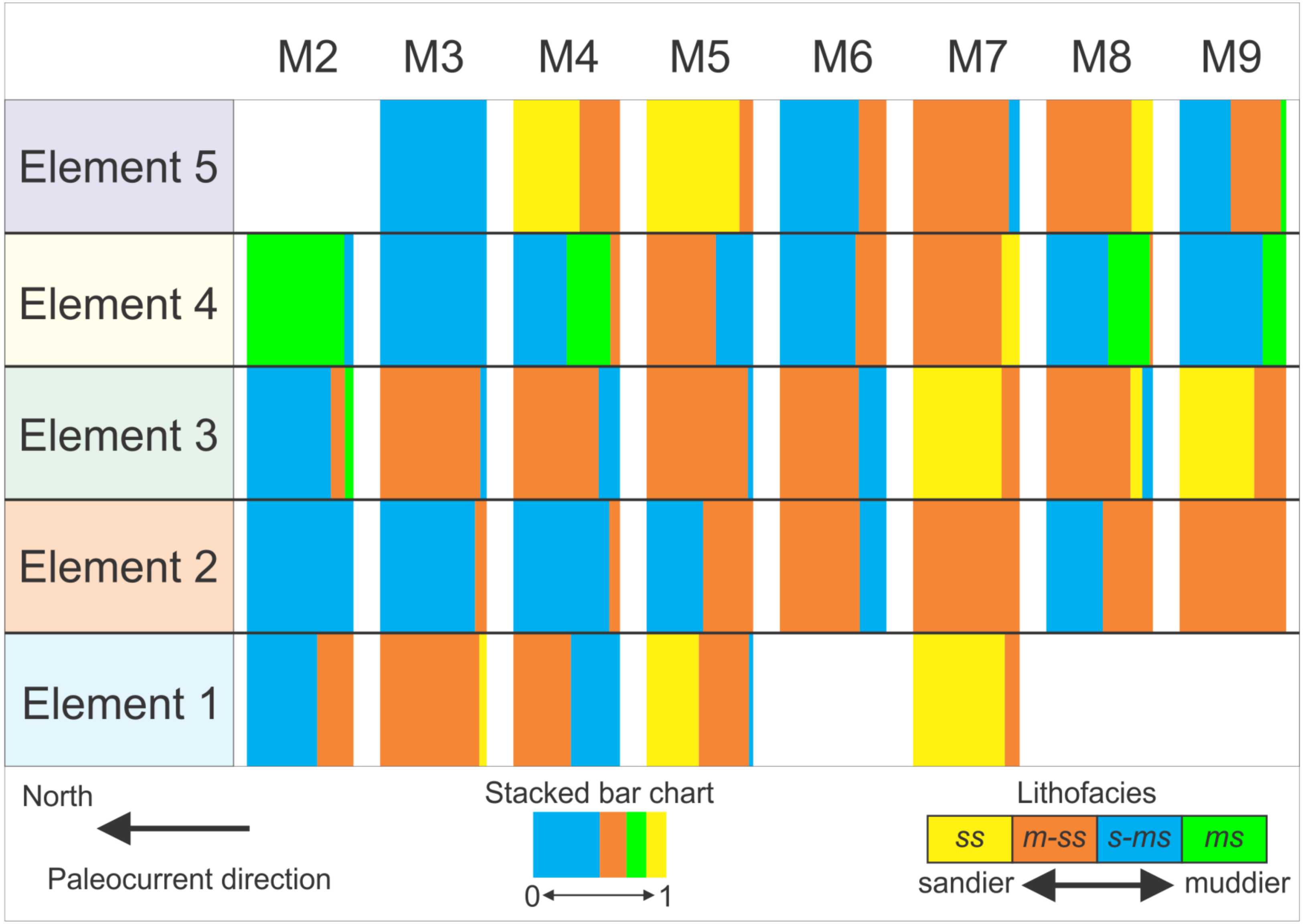


- Elements identified based on outcrop geometries when there appeared to be a general tapering of a package in one direction and/or shift in bed character (N:G, thicknesses, etc).
- Major changes in lithofacies tends to correspond (although not always) with a change in element.
- Elements share a max thickness of ~1m

Mini schematic of how elements are stacked

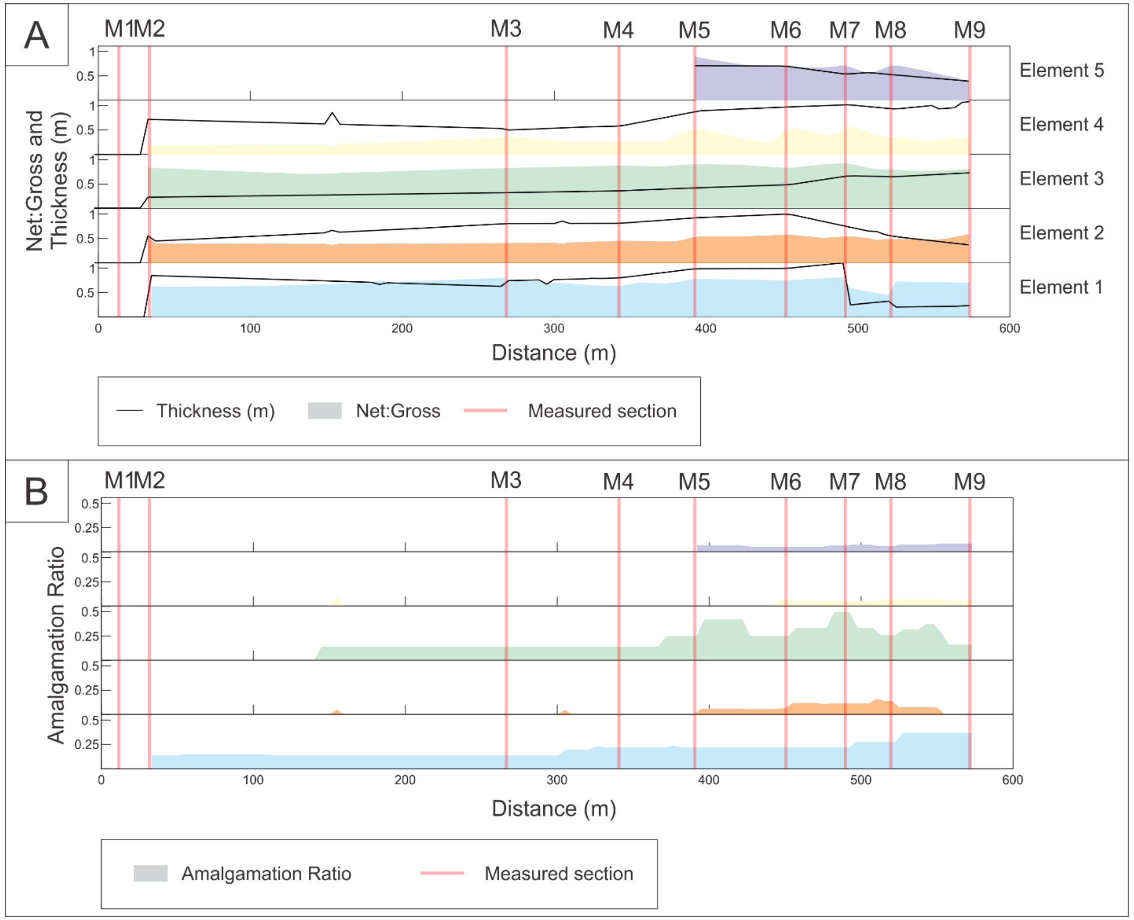


Lithofacies proportion by element



- **Vertically** a change in element is almost always accompanied by **major change in lithofacies proportions**
- There are **lateral changes** in lithofacies proportion **within elements**, but they are less pronounced and occur over 100's of meters.
- Alternating sandier-to-muddier-to-sandier stacked pattern could be evidence of **compensational stacking** of lobe elements

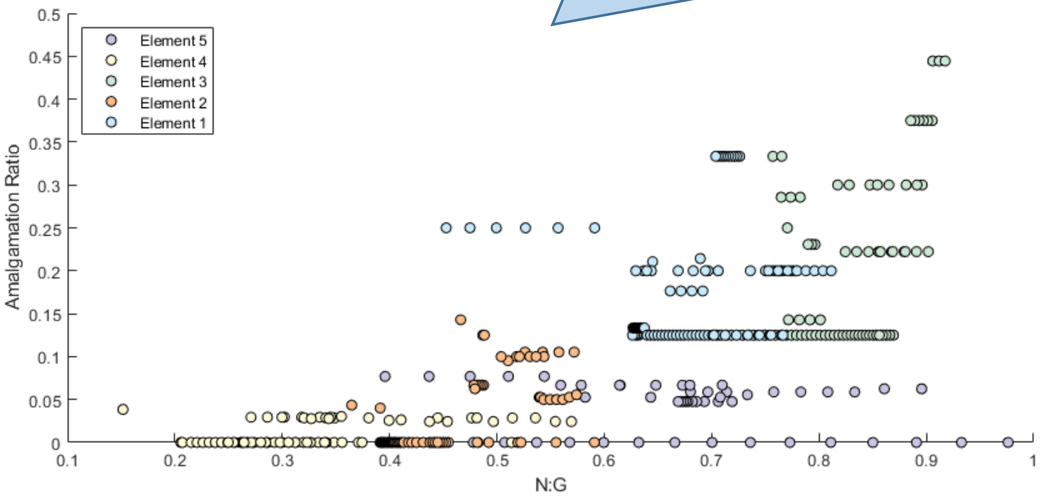
N:G and Amalgamation ratio (AR)



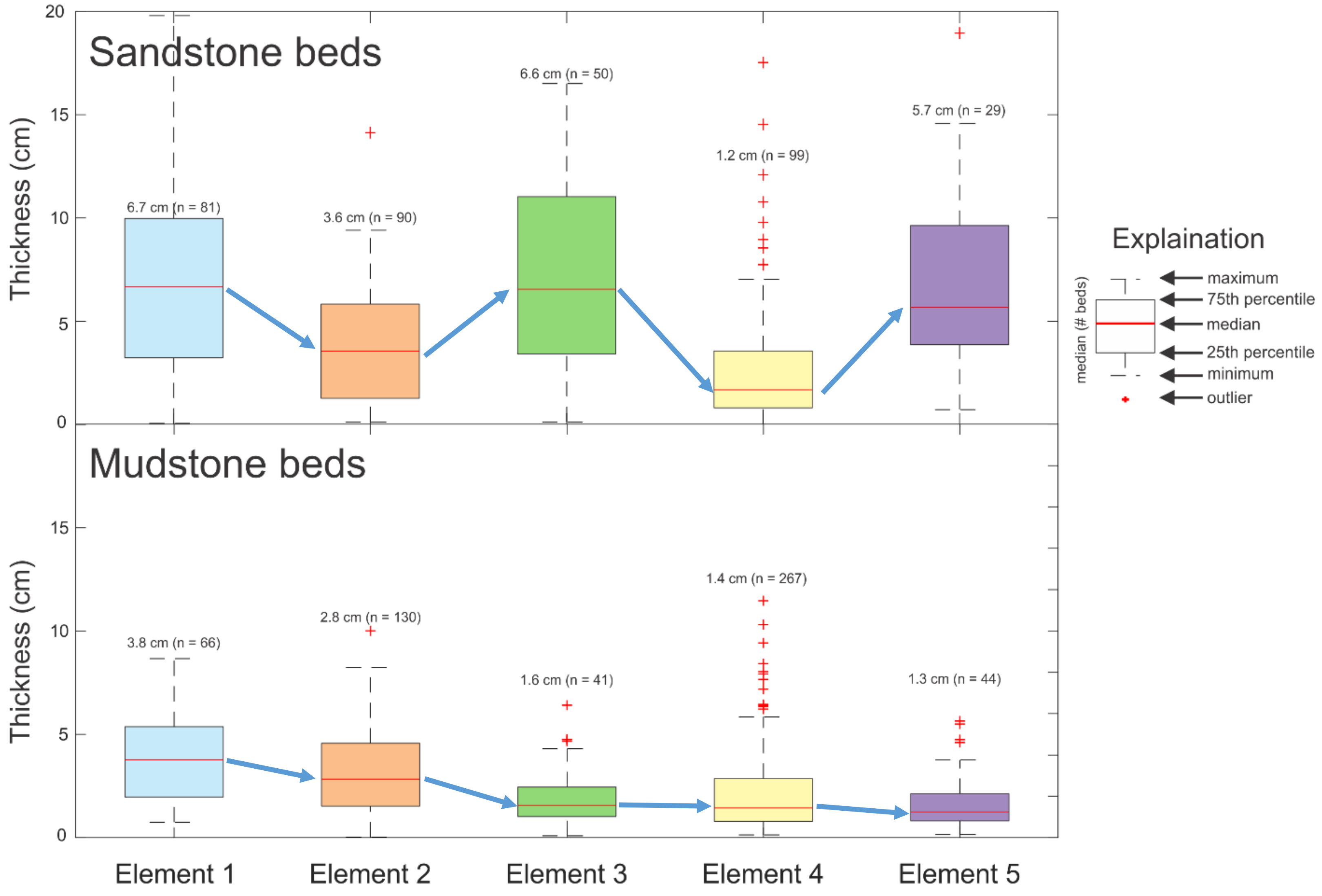
(A) Net-to-gross variability by lobe element (filled in). The cumulative thickness of each element is displayed as a black line (same scale as N:G). (B) Amalgamation ratio by lobe element (filled in).

- Element thickness is plotted as a black line in (A)
- Within a single element there is no correlation between N:G and AR, but when all elements are plotted together there is a moderate positive correlation (r = 0.63)

- In other words: AR within an element stays within a limited range, but elements with higher ARs tend to have higher N:G



Thickness distributions

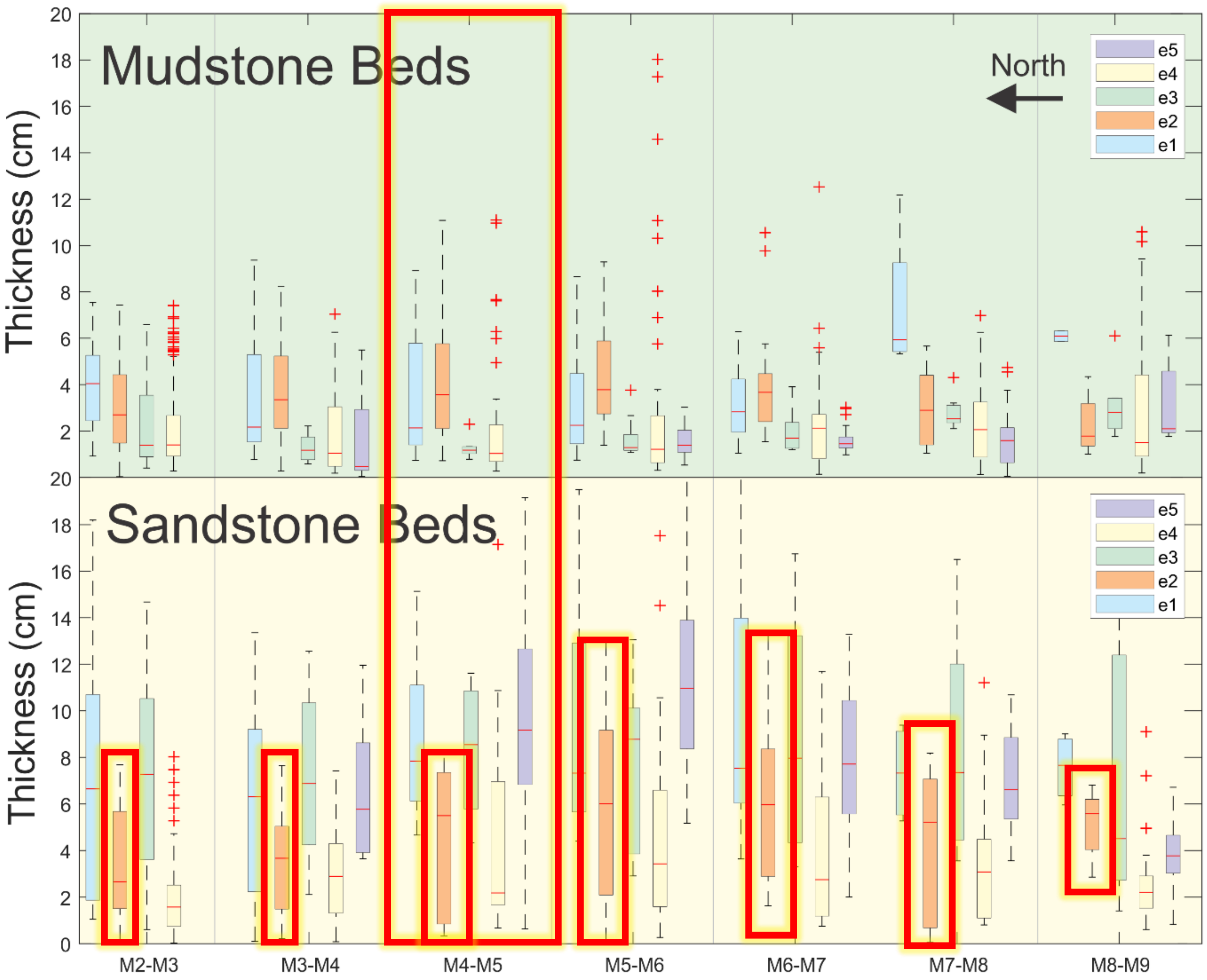


- Sand beds shift in thickness from element to element in a predictable way
- Mudstone also shift from element to element but in a less discernable/predictable way
- If you were to combine sandstone and mudstone beds and compare them that way, you would find even less difference from element to element

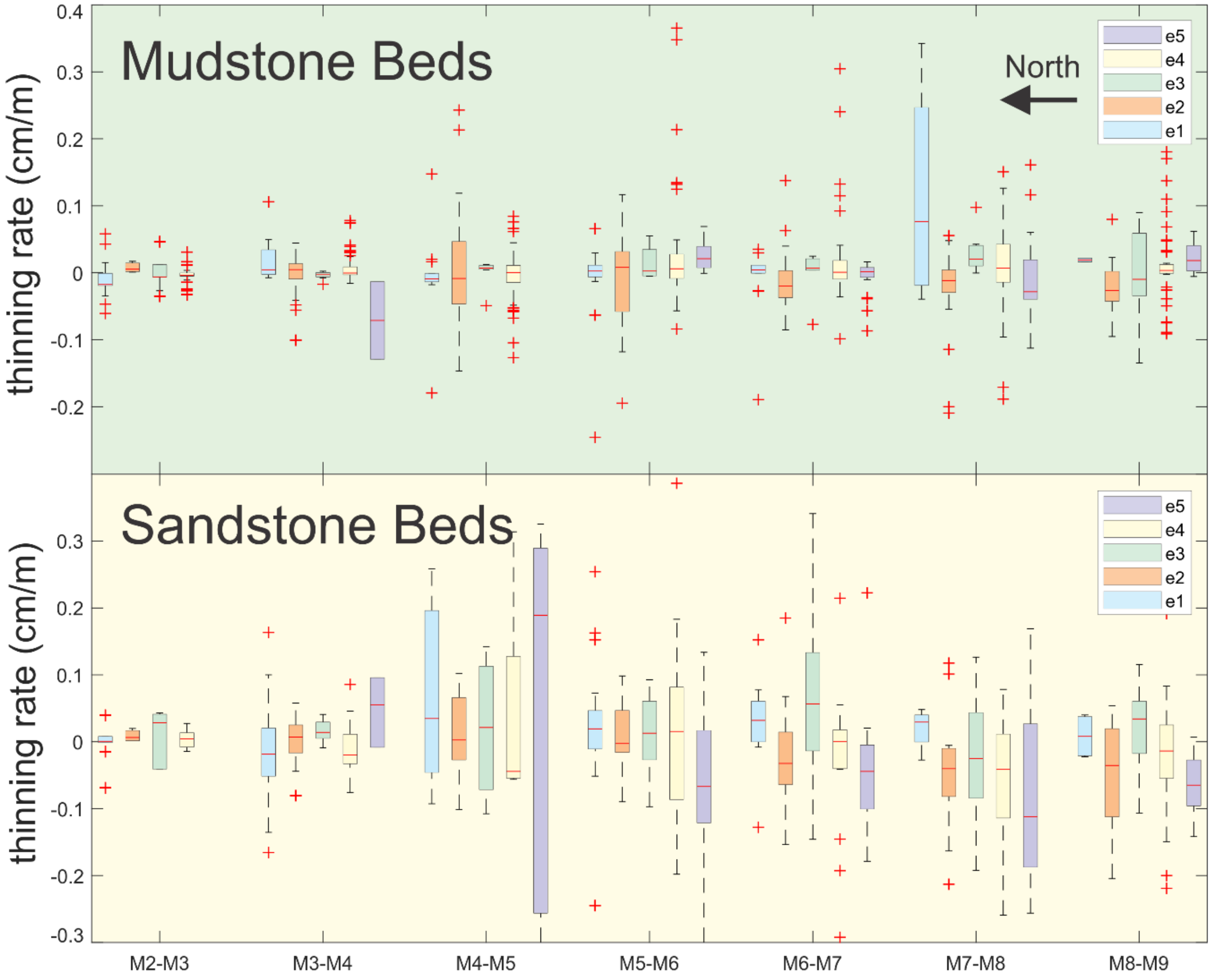
Thickness distributions

- When a second (lateral) dimension is added, you can see that not only do thickness distributions change from element to element, but they change laterally as well

- For this reason, you cannot simply average all data from across an element and say that all elements are indistinguishable from one another because through averaging you lose the lateral variability

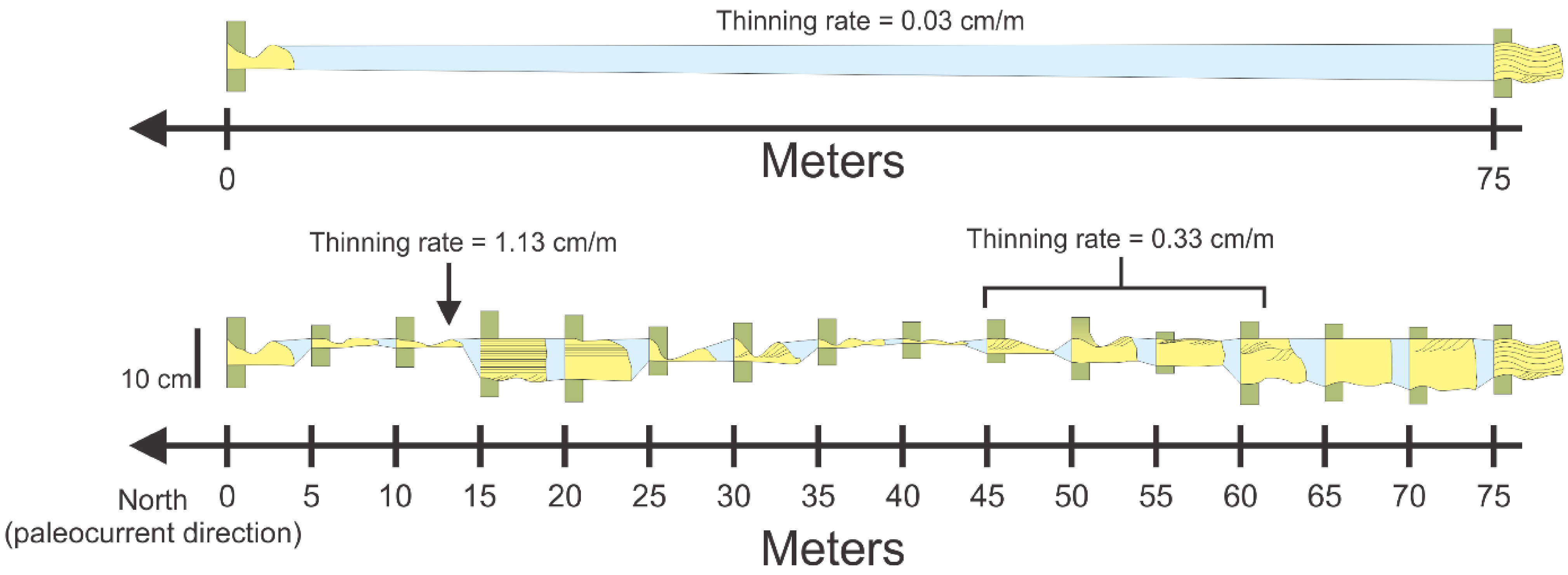


Thinning rates



- With thinning rate again, sand beds show greater variation from element-to-element, but especially laterally

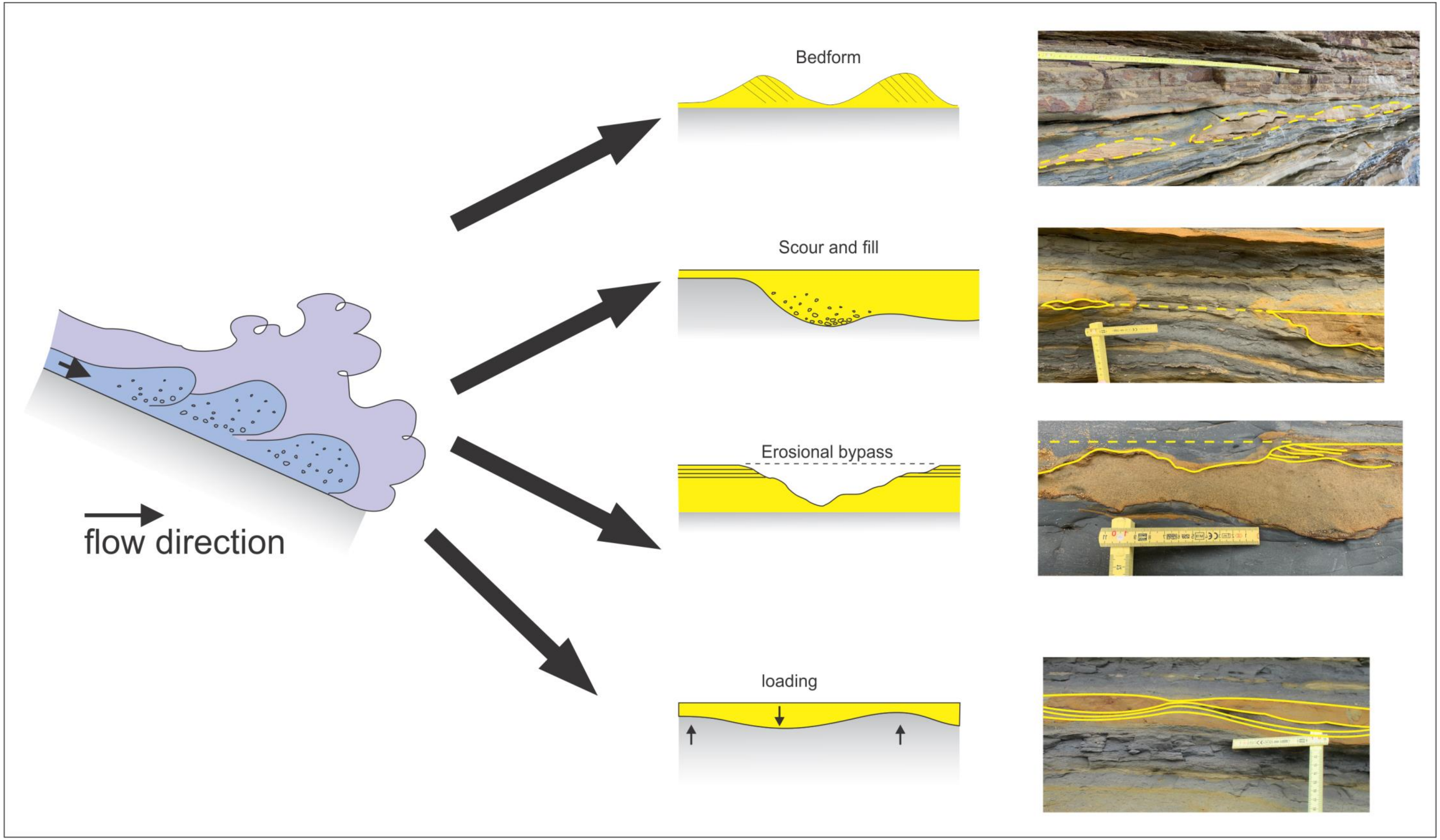
High-resolution lateral bed measurements



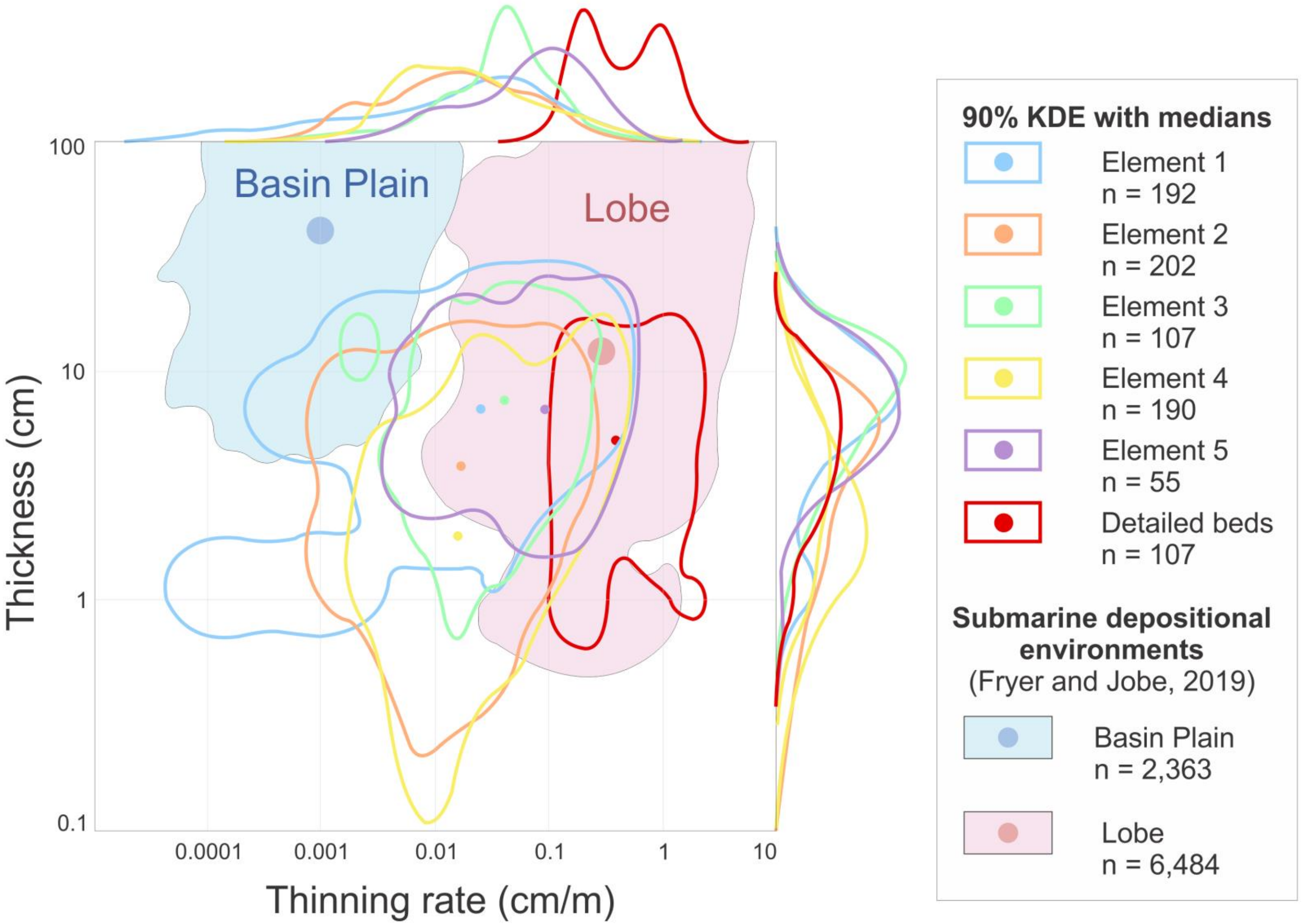
- Seven sandstone beds (chosen for their high variability) measured at 5 m intervals with each bed being traced 55-125 m
- Potentially bedforms?

- **How does the lateral resolution of the data affect the thinning rate variability and interpretation?**

Processes for pinch outs?

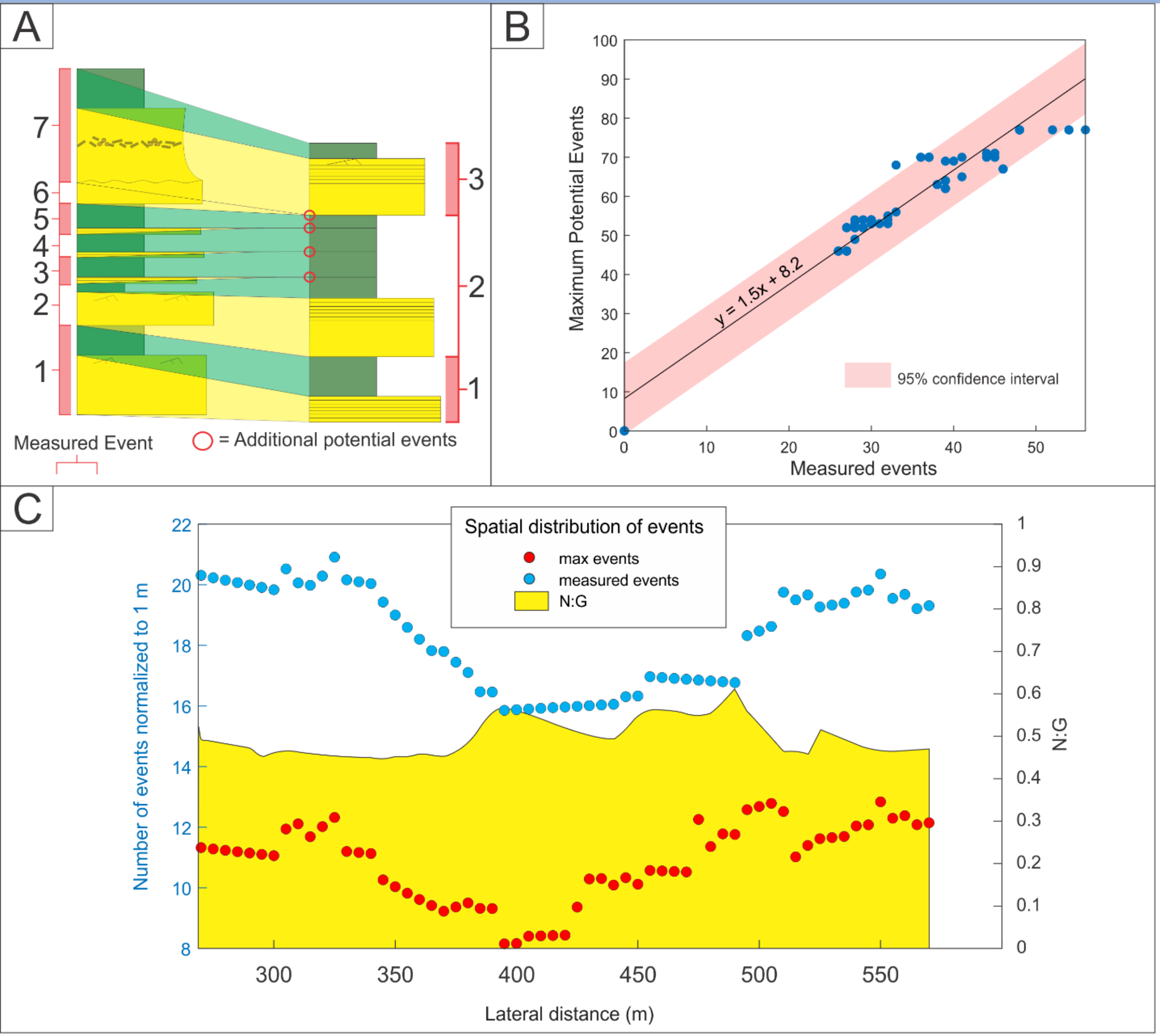


90% KDE of Thickness vs Thinning rate



- All elements' thicknesses and thinning rates plot similarly, overlapping in the "lobe" environment (based on Fryer and Jobe, 2019).
- The detailed beds (5 m measurements) plot with distinctly higher in thinning rate, but with the same thickness as elements (which is to be expected).
- This is simply to highlight how **averaging over 10's to hundreds of meters can greatly skew the perception of how highly variable thin-bedded turbidites can be**.

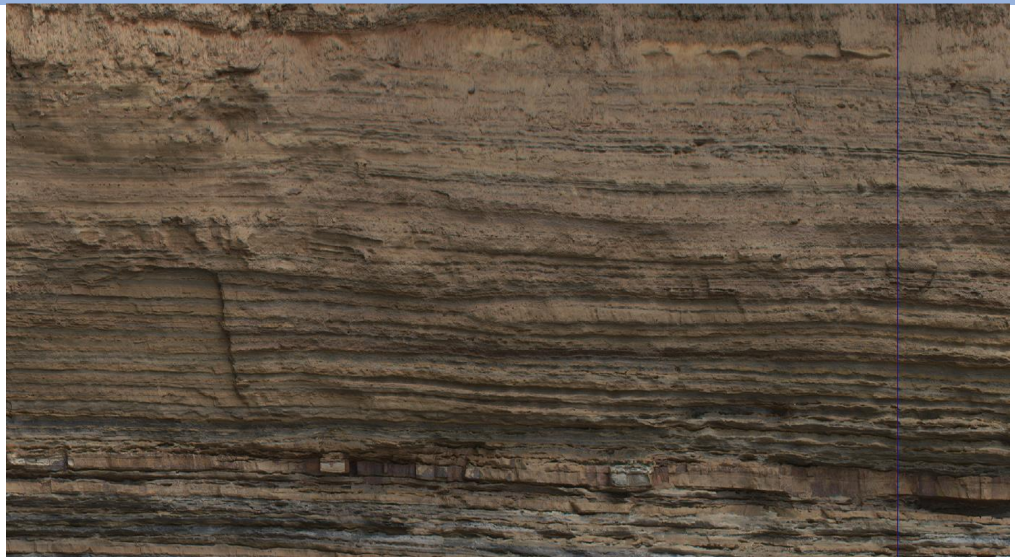
Event Potential



- Assumption: All flows whether they deposit sand or not will leave an aerially wide “tail” (mud cap)
- For every measured event bed there is a 66% chance that there was a subsequent flow that did not deposit sediment at that location
- When N:G increases, number or events decreases

Normalized to 1 meter because the vertical thickness of data collected at any given point varies across the outcrop

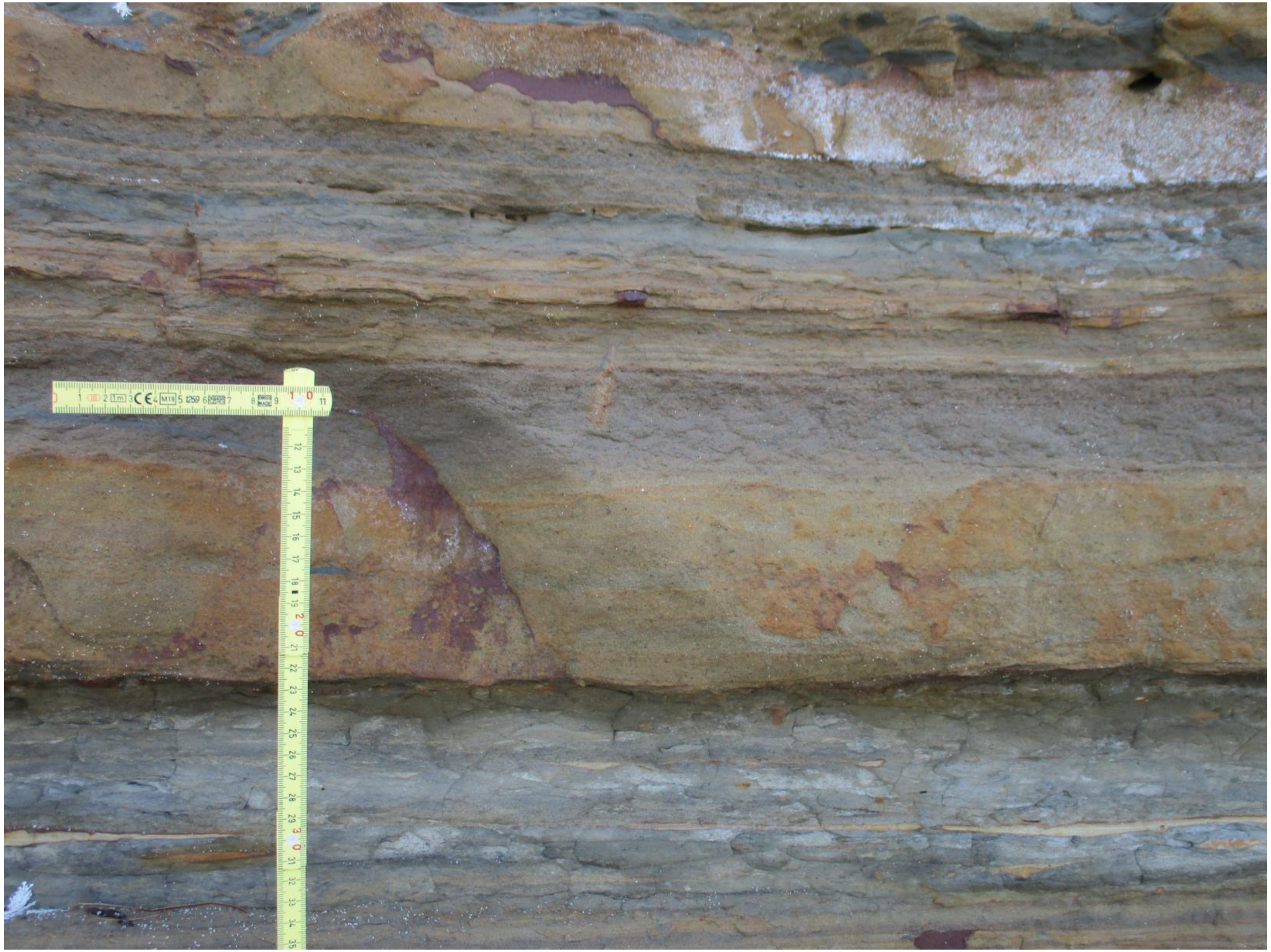
Tracing lithofacies in ArcMap



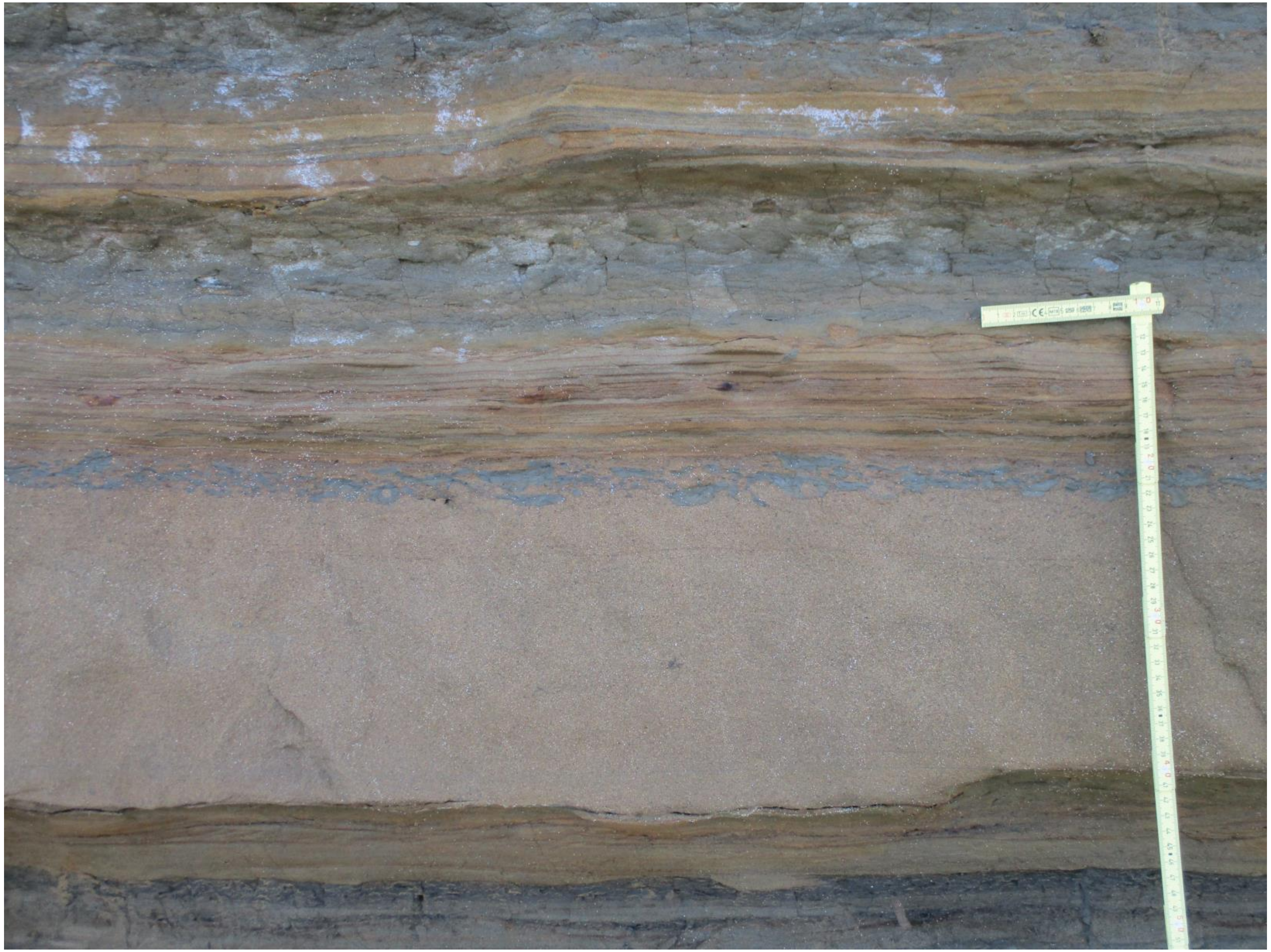
- Lithofacies tracing in arcmap isn't able to capture every bed individually, but helps to show a little more detail as to how things are pinching/amalgamating in interesting areas of the outcrop
- Will be used to compare cross-section correlations to outcrop scale heterogeneity to give better idea of how the character of the outcrop

Backup

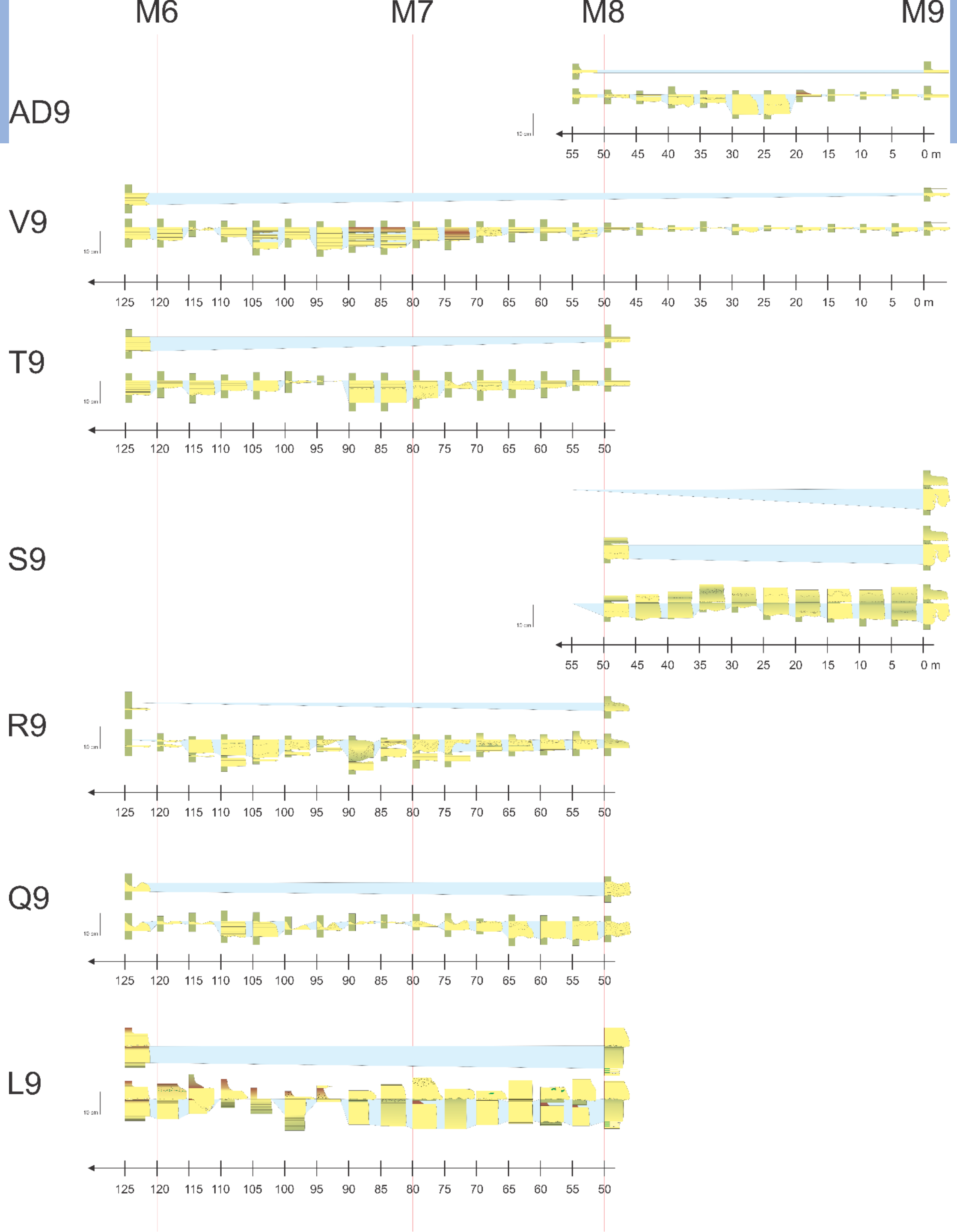
Hybrid-y looking reddish muddy section

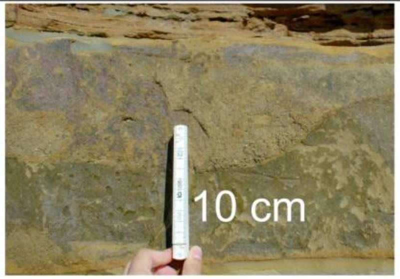
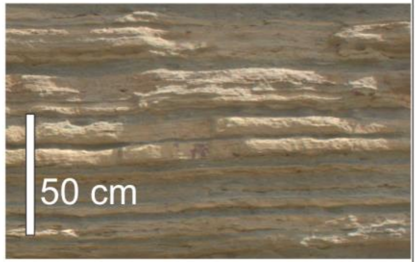
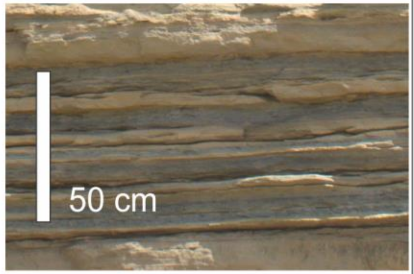
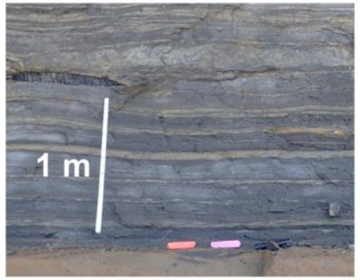


HEB with mud clast layer



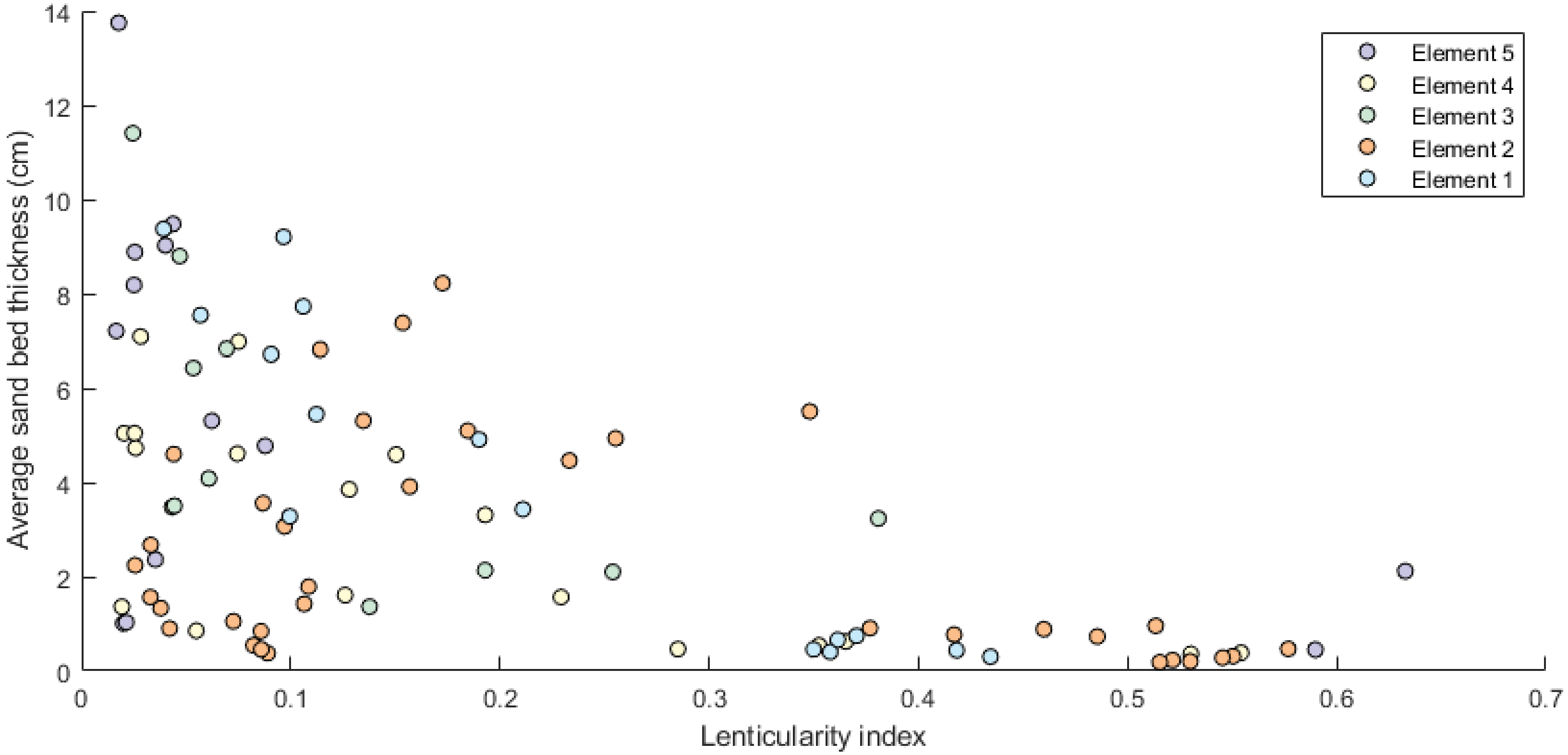
Scour and fill with little sand injection


M6
M7
M8
M9
AD9
V9
T9
S9
R9
Q9
L9
125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 m

	Abbrev.	Lithofacies	Grain-size and mean N:G	Bed thickness (cm)	Sedimentary structures/equivalent divisions from Bouma (1962)	Flow types (Mulder and Alexander, 2001)	Photo example
Facies 1	ss	Amalgamated sandstone	Very coarse sands to very fine sands. Mud/silt. N:G μ = 0.81	sandstone μ = 6.1 mudstone μ = 3.1	Structureless and often amalgamated (Ta). Scours are often filled with coarser grains with normal grading.	Turbulent flow experiences rapid suspension fallout.	
Facies 2	m-ss	sandstone with minor mudstone	Very coarse sands to very fine sands. Mud/silt. N:G μ = 0.62	sandstone μ = 4.6 mudstone μ = 3.9	Structureless and planar-laminated (Tb) to ripple-laminated (Tc). Erosive bases are common. Distribution of structures within bed was highly variable.	Concentrated to turbulent flow.	
Facies 3	s-ms	thin-bedded sandstone and mudstone	Fine to very fine sands. Mud/silt. N:G μ = 0.40	sandstone μ = 3.8 mudstone μ = 5.0	Structureless and planar-laminated (Tb) to ripple-laminated (Tc). Erosive bases are common. Distribution of structures within bed was highly variable.	Turbulent flow - surge or surge-like.	
Facies 4	ms	mudstone with minor sandstone	Fine to very fine sands. Mud/silt. N:G μ = 0.23	sandstone μ = 1.8 mudstone μ = 6.1	Pseudonodular and/or massive mud (Te). Sands are often cross-laminated with common starved ripples (Tc and Td).	Turbulent flow - surge.	

Lenticularity

- change in bed thickness taken between equally spaced nodes, divided by the average thickness of the bed



- All > 0.1, making them most similar to semi-amalgamated wedge body type described by Romans et al. (2009).
  - Wedge shape over lateral scale of tens to hundreds of meters
- Elements 4 and 5 have lenticularity indices > 0.2, making them fit the description of non-amalgamated wedges (Romans et al., 2009)