Quantification of Static Connectivity between Deepwater Channels and Stratigraphically Adjacent Architectural Elements Using Outcrop Analogs*

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Abstract

This research uses data from well-exposed outcrops and published information to document static connectivity in Deepwater channelized systems. Two measures of static reservoir connectivity on outcrop analogs are proposed: margin connectivity and sand-on-sand connectivity. Margin connectivity (Cm) is the length between two stratigraphically adjacent elements not obstructed by a barrier normalized by the total length of the interface. Sand-on-sand connectivity (Cs) is the length of sand-on-sand contacts between two stratigraphically adjacent elements normalized by the total length of the interface.

The data and observations collected from this study include multiple outcrops from California's ancient turbidite systems (Capistrano Formation at San Clemente State Beach and the Scripps Formation in La Jolla). These were compiled with data from additional domestic outcrops from the Brushy Canyon Formation, Cherry Canyon Formation, Jackfork Group, Lewis Shale, and supplementary data from published studies to describe connectivity between channel-fills and their stratigraphically adjacent elements.

Cm and Cs are analyzed with regard to four categories: (1) association of architectural elements, (2) stacking pattern of channel elements, (3) setting on the slope-to-basin profile, and (4) net sand content. Results are as follows. First, connectivity varies by association of architectural elements. Channel-lobe contacts have higher Cm and Cs than channel-channel and channel-levee contacts. Second, connectivity varies by stacking pattern of channel elements. Predominantly vertically stacked channel elements have higher Cm and Cs than predominantly laterally stacked channel elements. Also, disorganized non-

sequentially stacked channel elements have higher Cm than organized systematically stacked channel elements. Third, connectivity varies by setting on the slope-to-basin profile. Channel elements in confined settings have higher Cm than both weakly confined and unconfined-distributive settings. Fourth, connectivity varies by net sand content. Channel elements with a high net sand content have higher Cm than those with a low net sand content.

Knowledge of a reservoir's placement in these categories can be used to aid in the prediction of static connectivity and in the related reservoir heterogeneity. Furthermore, data presented herein can reduce deepwater stratigraphic uncertainty and be used to constrain static connectivity on a 2-D plane in reservoir models.

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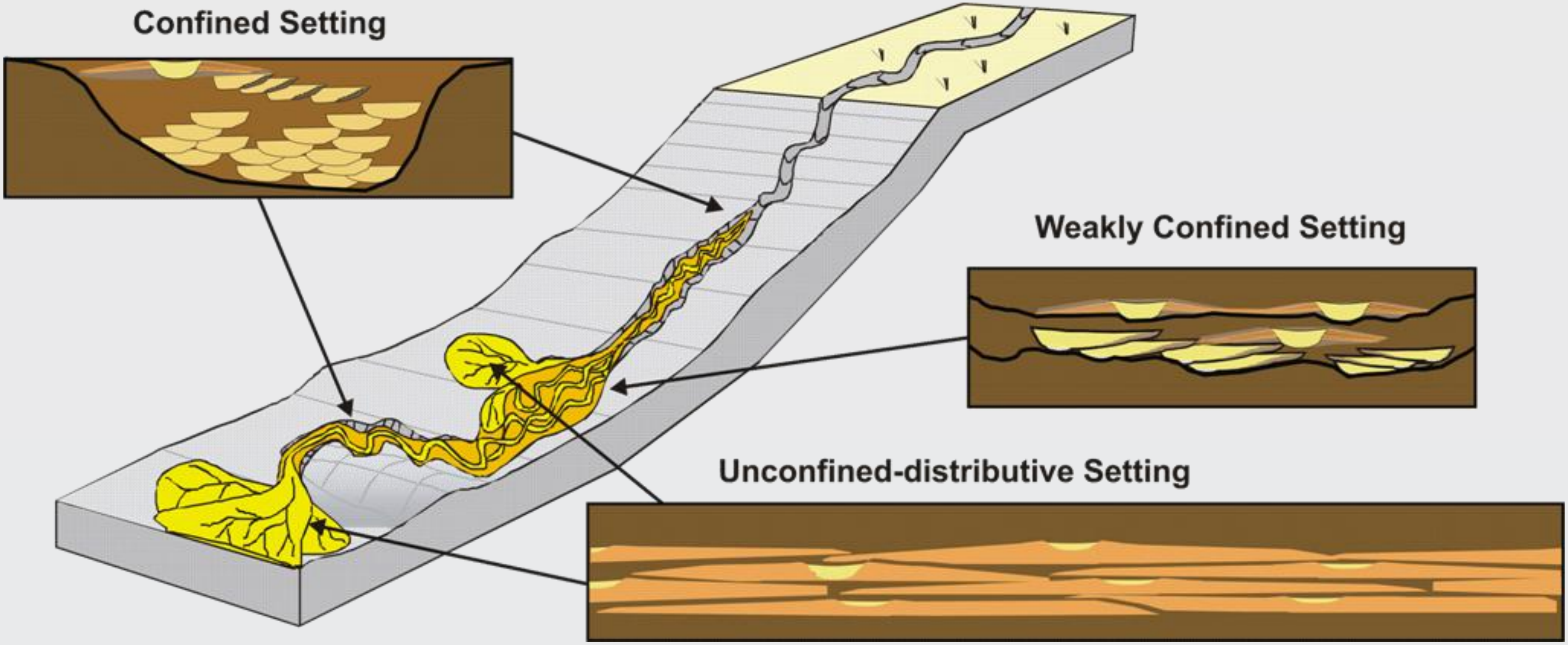
Marathon Oil

Deep-water channelized environments



Modified from Campion et al., 2005

- **Importance**:
  - Play type relatively **immature** yet holds **significant** reserves
  - Variable performance affects development plans and project economics
- **Problem**:
  - Reservoir connectivity **rarely documented** but affected by sub-seismic features (i.e. shale drapes)

What do channel bases look like?

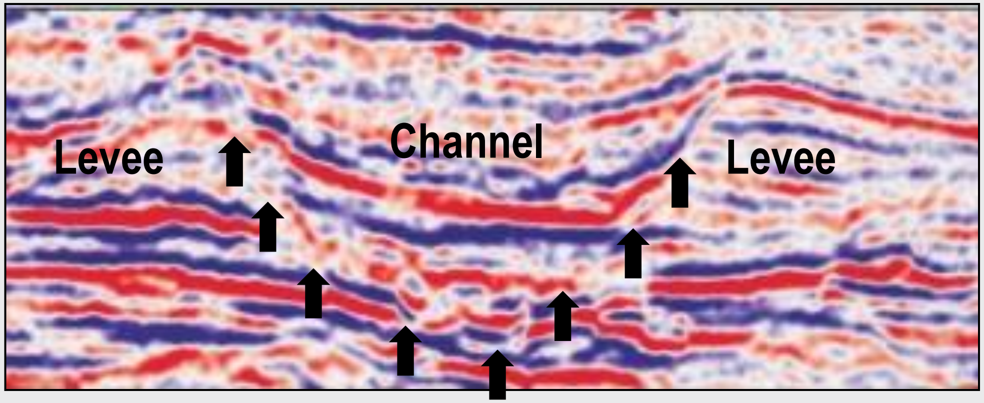


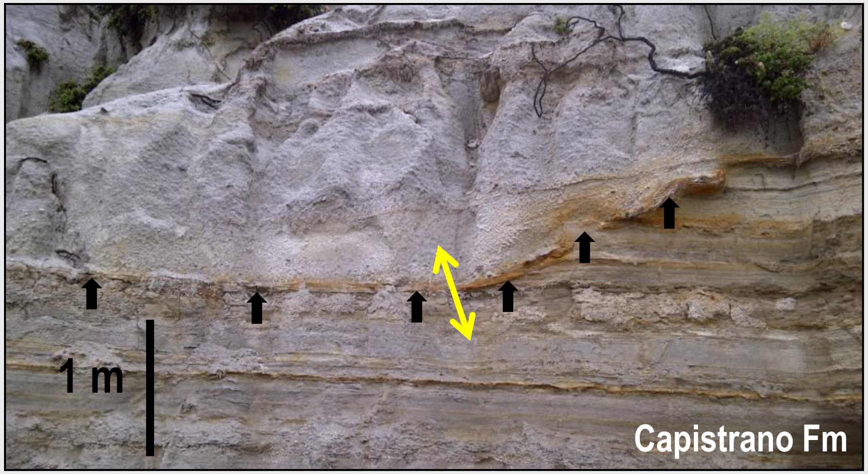
Image provided by Roger Slatt

1) Subsurface data set limitations

2) Study of **outcrops** and core

3) Focus on bounding surfaces between elements

1) Sand-on-sand contact (potential connectivity)



2) Mud-rich facies along base (potential barrier)

3) **Combination** of both (i.e. partial connectivity!)

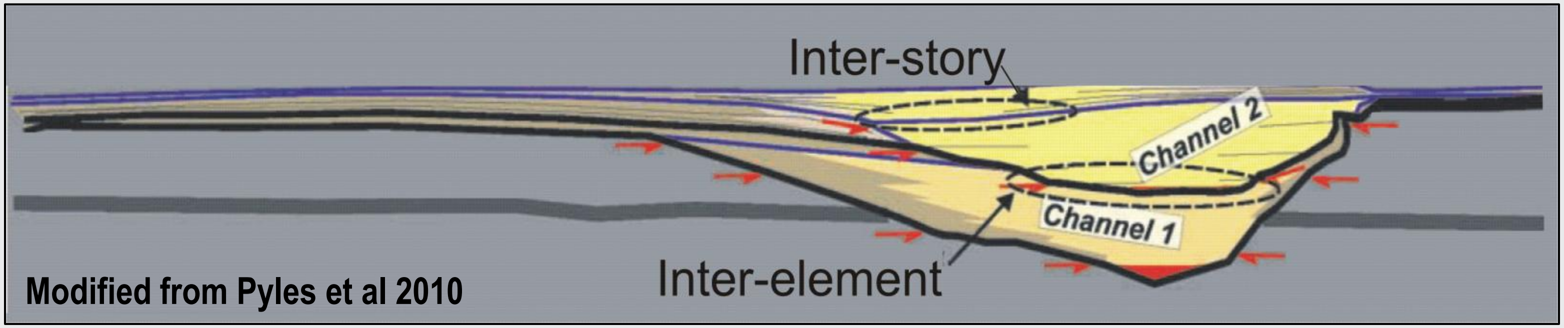
How can we measure connectivity on outcrops?

- Multiple methods have been developed:

Amalgamation percent (Chapin et al 1994)

Channel base shale drape coverage (Nilsen et al., 2007)

Reservoir connectivity (Pyles et al 2010)

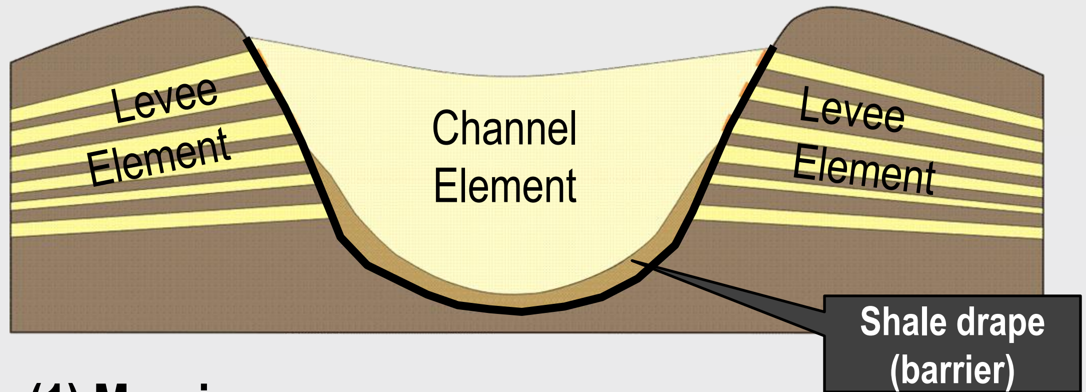


Modified from Pyles et al 2010

Although useful for the goals of their studies, none of these methods adequately capture the continuity of fine-grained barriers between architectural elements

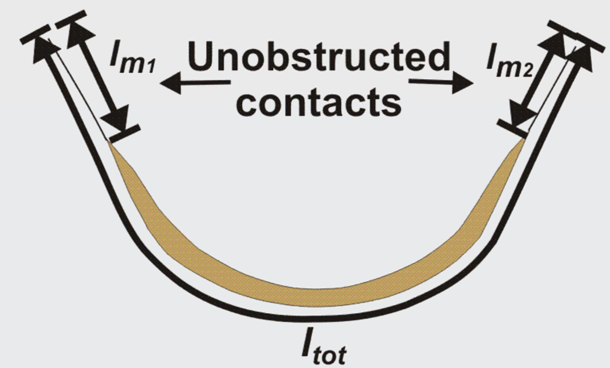
How can we measure connectivity on outcrops?

- **Methods**:
  - **Focus on the boundary between channels & their stratigraphically adjacent element(s)**
    - **Barriers?**
    - **Sand-on-sand?**



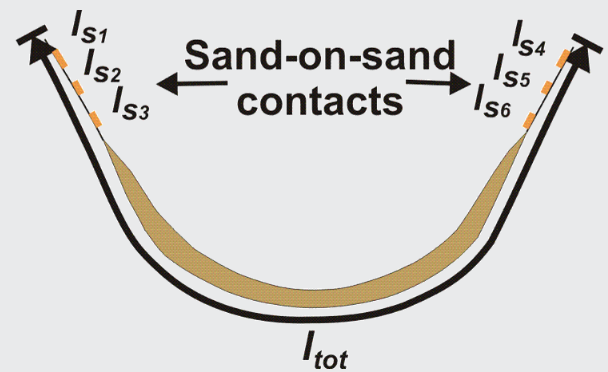
(1) Margin connectivity (C_m)

$$C_m = \left(\sum l_{mi}\right) / l_{tot}$$



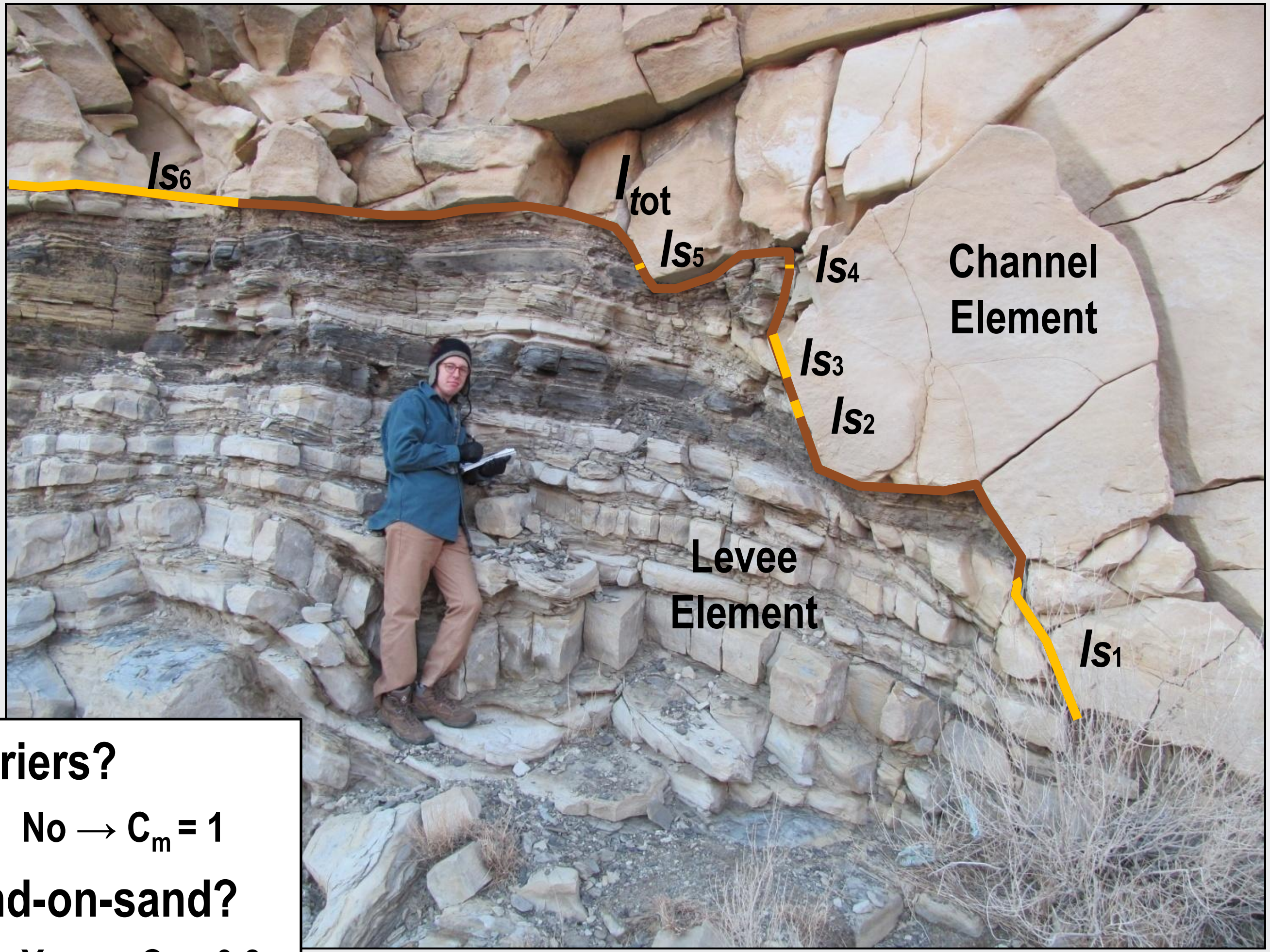
(2) Sand-on-sand connectivity (C_s)

$$C_s = \left(\sum l_{si}\right) / l_{tot}$$



- **Limitations:**
  - Connectivity is a 3D characteristic
  - Outcrop exposure

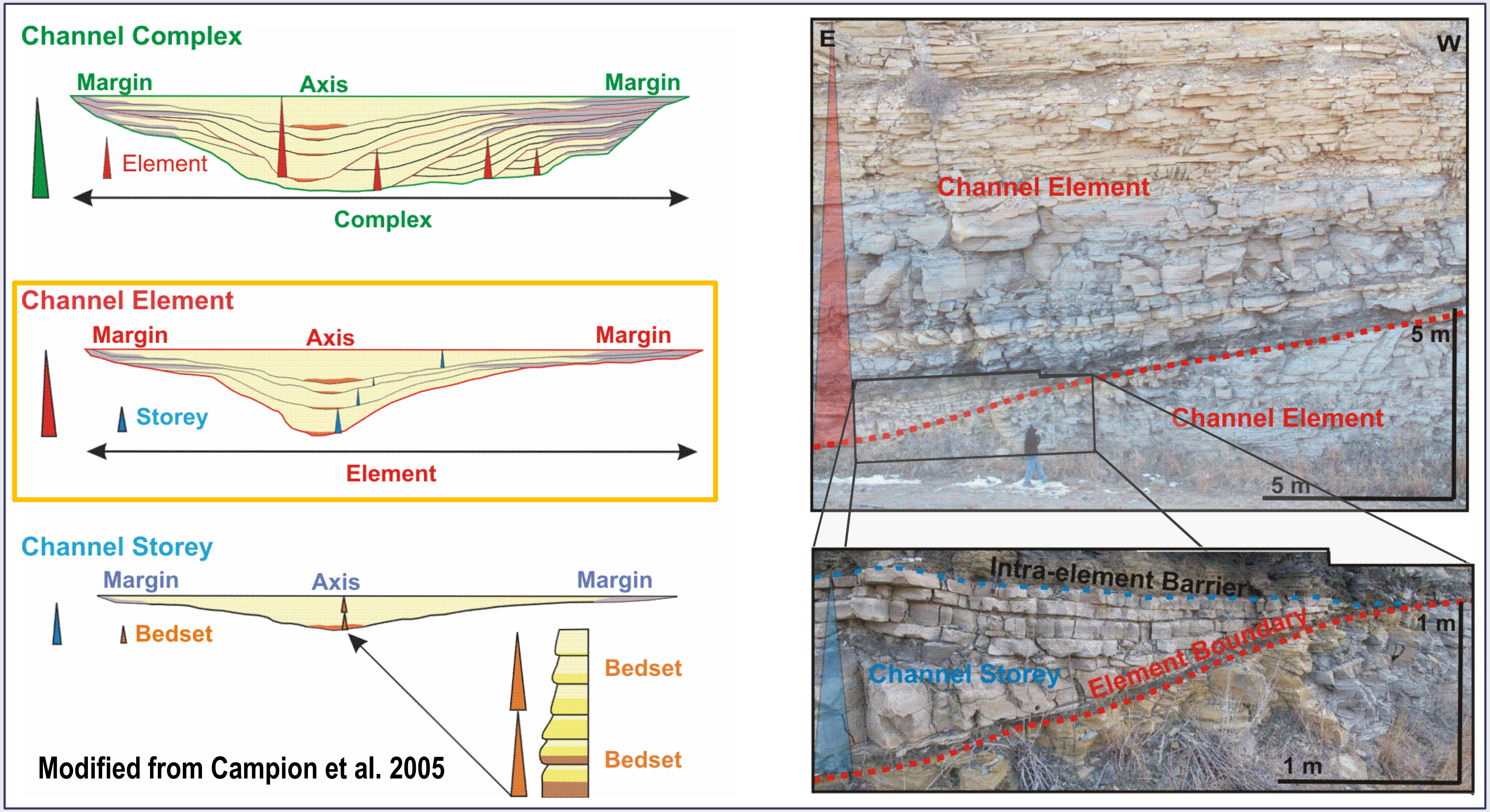
How can we measure connectivity on outcrops?



- **Barriers?**
  - No → $C_m = 1$
- **Sand-on-sand?**
  - Yes → $C_s \approx 0.3$

Illustrative example of field measurements at Brushy Canyon Roadcut, West Texas

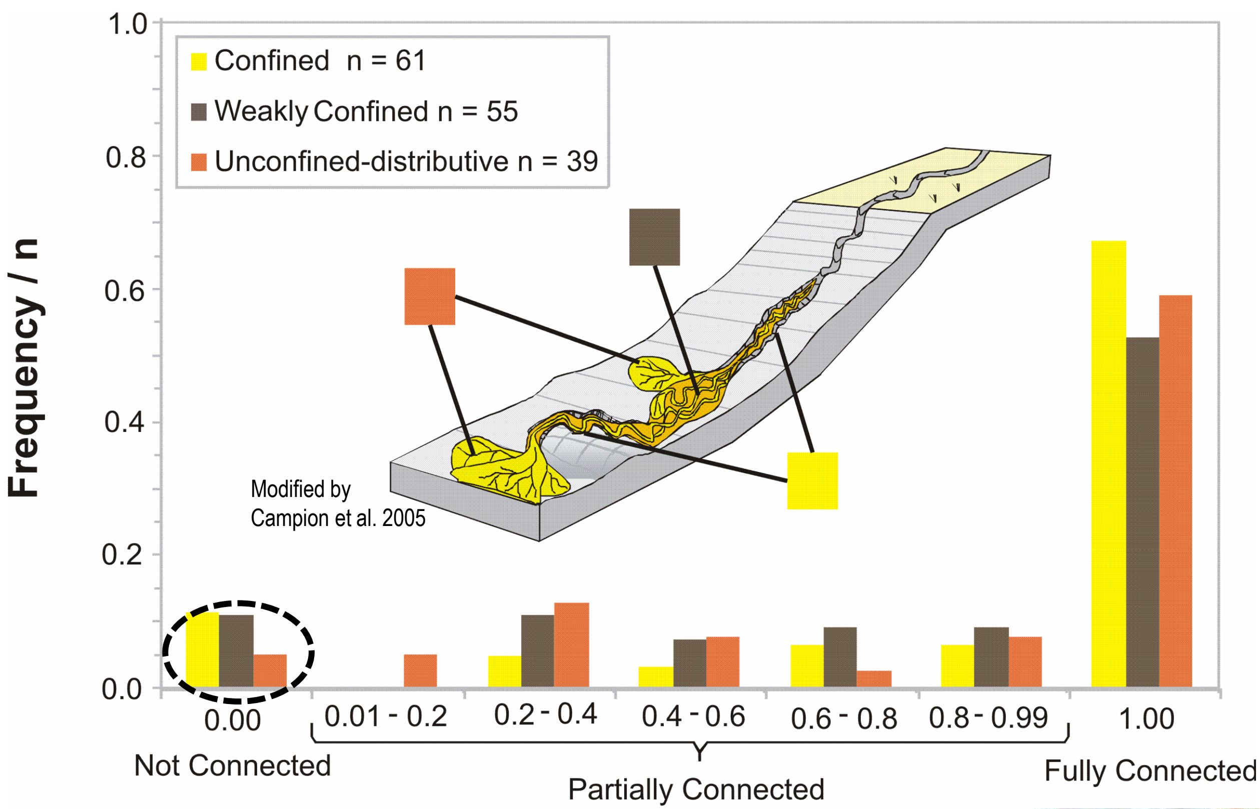
How can we measure connectivity on outcrops?



- Barriers can occur at many scales → Focus on element
- Measurements from the Brushy and Cherry Canyon, Lewis Shale, Jackfork, Scripps, Capistrano, Ross, Skoorsteenberg, Tourelle and Pab as well as supplementary data from the Atlas of Deepwater Outcrops

How does connectivity vary?

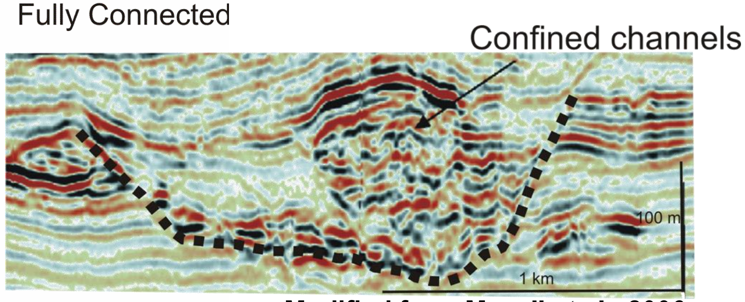
Slope-to-basin profile



- 5-10% of **each** population are not connected (Cm =0)
- Confined channels have the **highest** C_m of all of the settings
- Key is likely the abundance of erosional surfaces (Sprague et al. 2005)

Setting on Profile

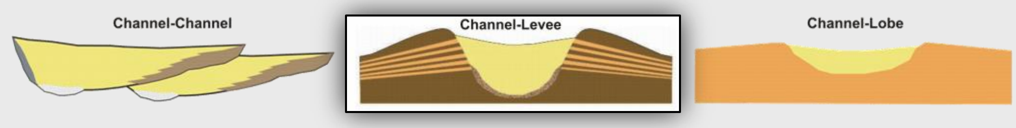
x	0.81	0.75	0.76
Median	1.00	1.00	1.00
Mode	1.00	1.00	1.00
σ	0.35	0.36	0.35

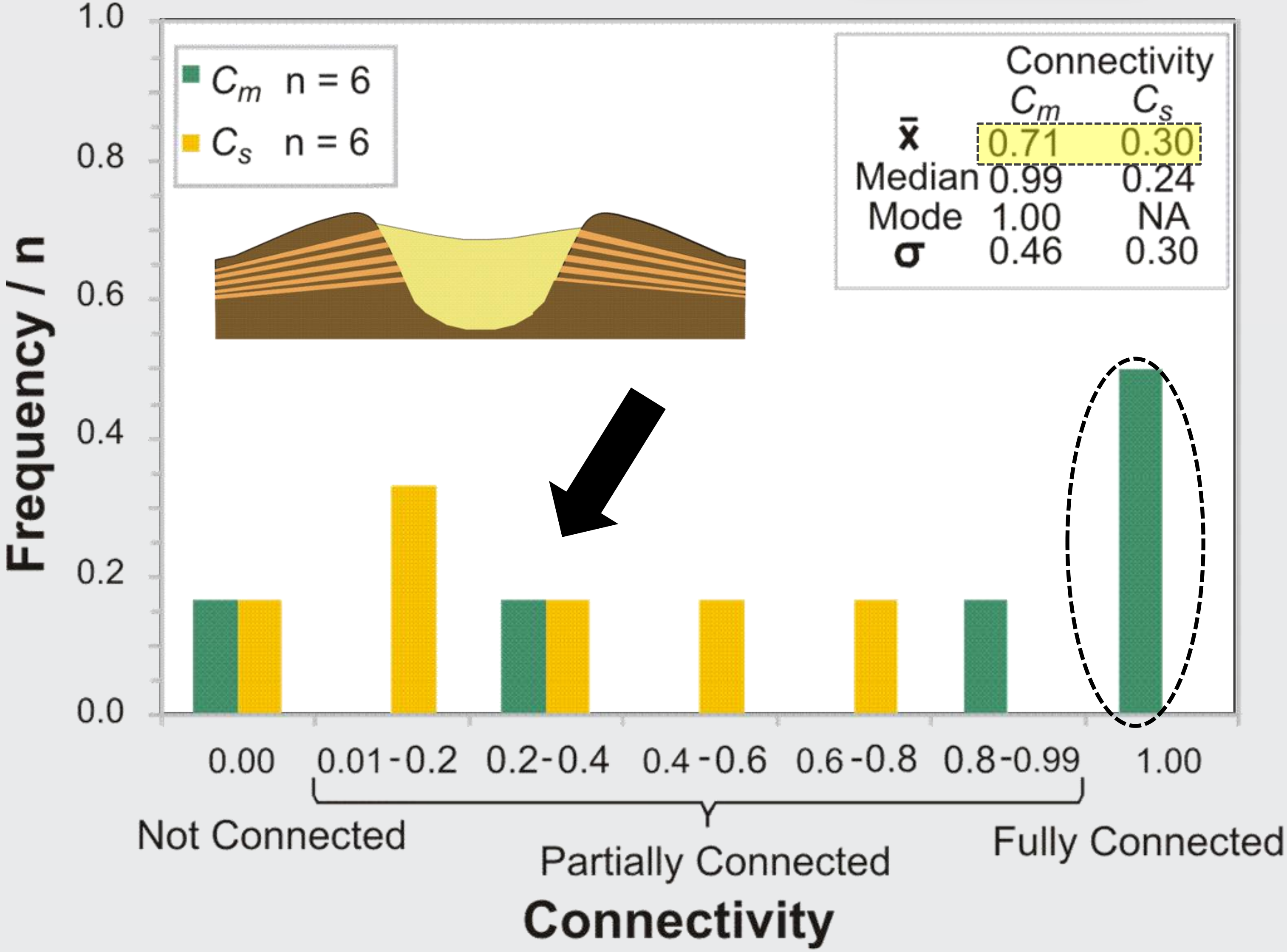


Modified from Mayall et al., 2006

How does connectivity vary?

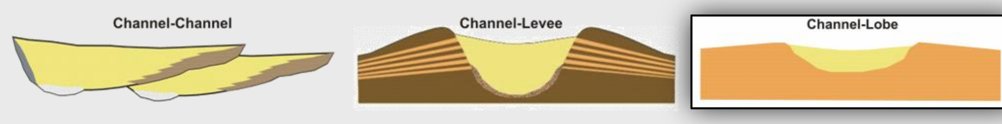
Association of Architectural Elements

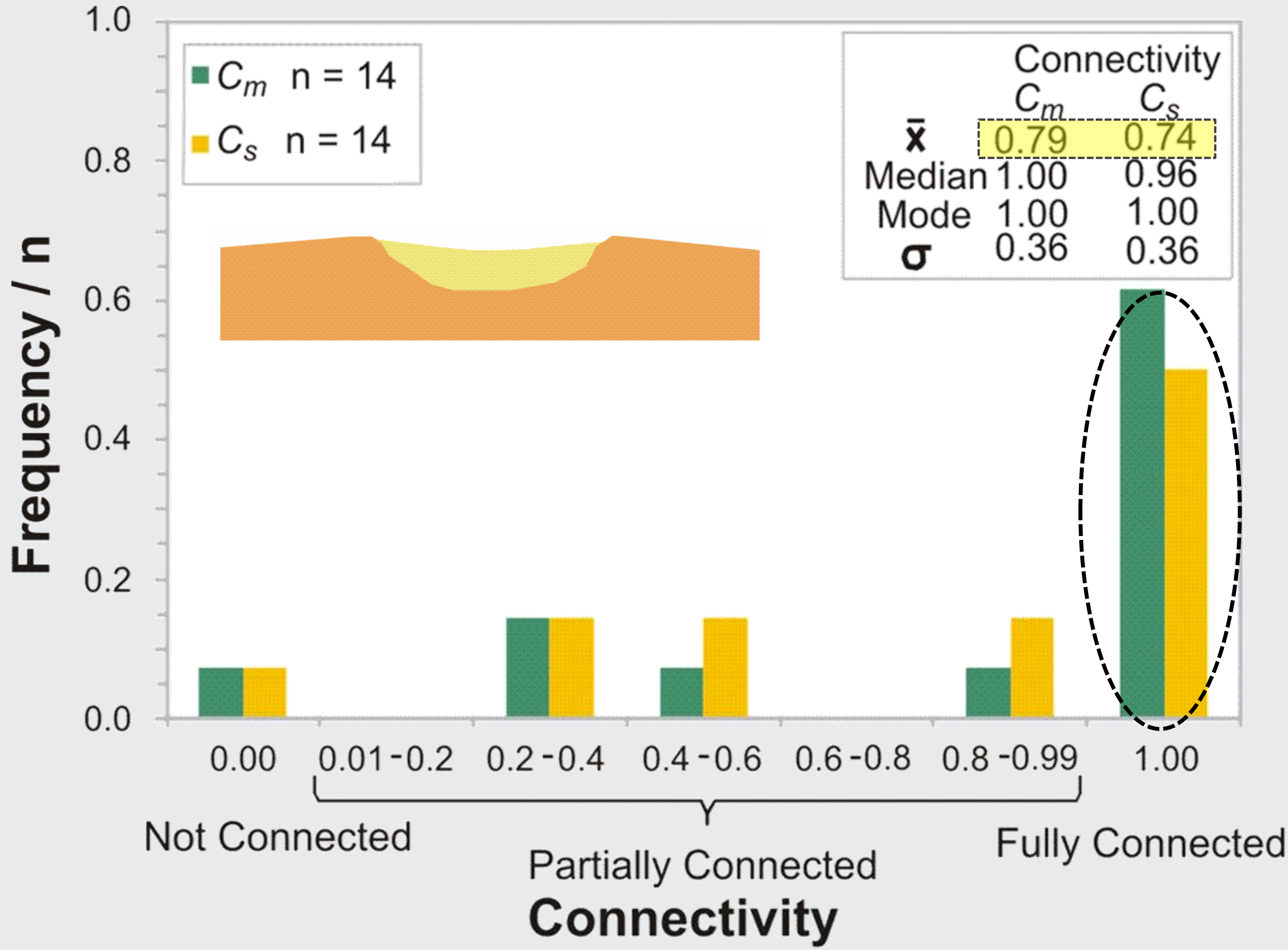




How does connectivity vary?

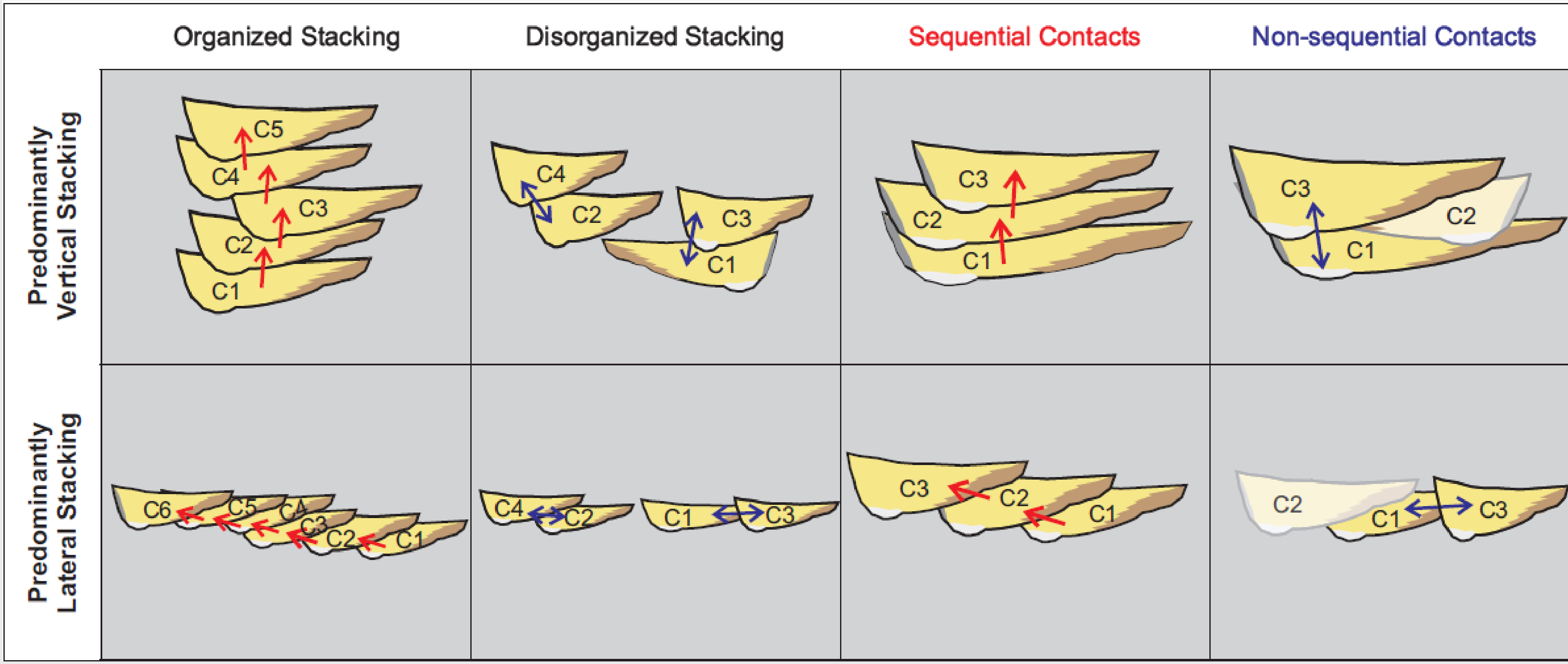
Association of Architectural Elements





How does connectivity vary?

Channel stacking pattern

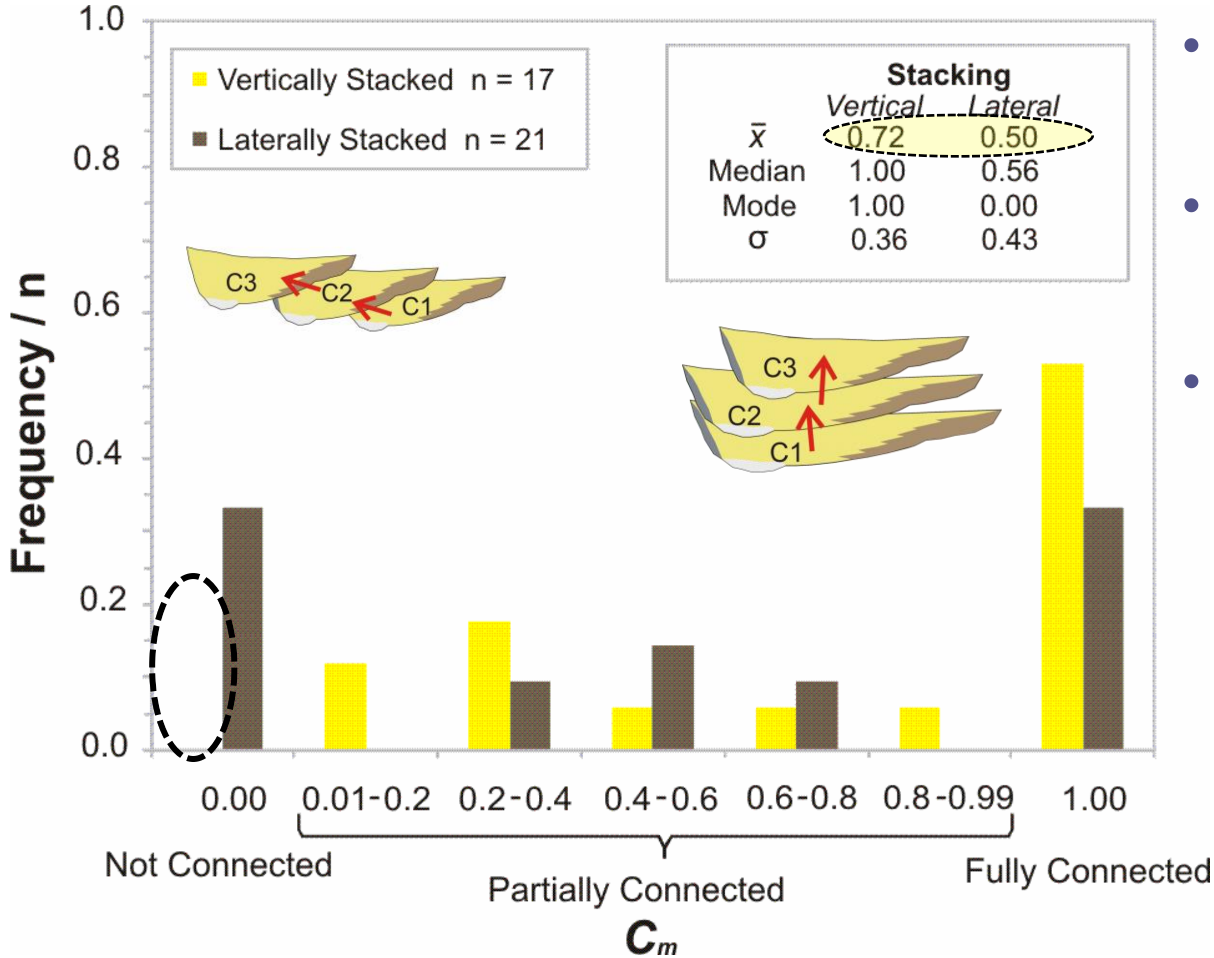


- Many different types of channel stacking that occur at the inter-element scale
- Stacking type can be determined (or at least inferred) from seismic data
- The degree of sandstone connectivity is likely influenced by the channel stacking pattern…..

BUT HOW??

How does connectivity vary?

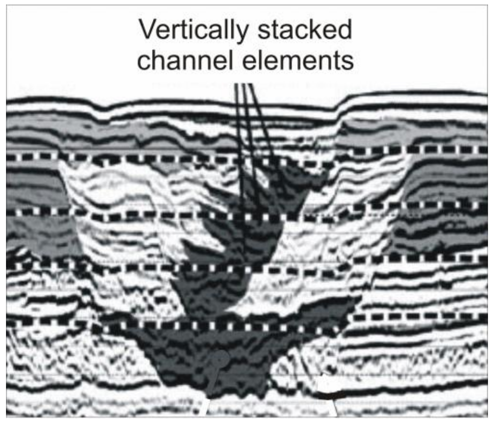
Channel stacking pattern – Vertical vs. Lateral



	Stacking	
	Vertical	*Lateral*
$\bar{x}$	0.72	0.50
Median	1.00	0.56
Mode	1.00	0.00
σ	0.36	0.43

- Significant variability in laterally stacked channels' C_m
- Vertically stacked channels have at least partial connectivity
- Vertical stacking superimposes sand-rich axes of channels and as a consequence have high C_m

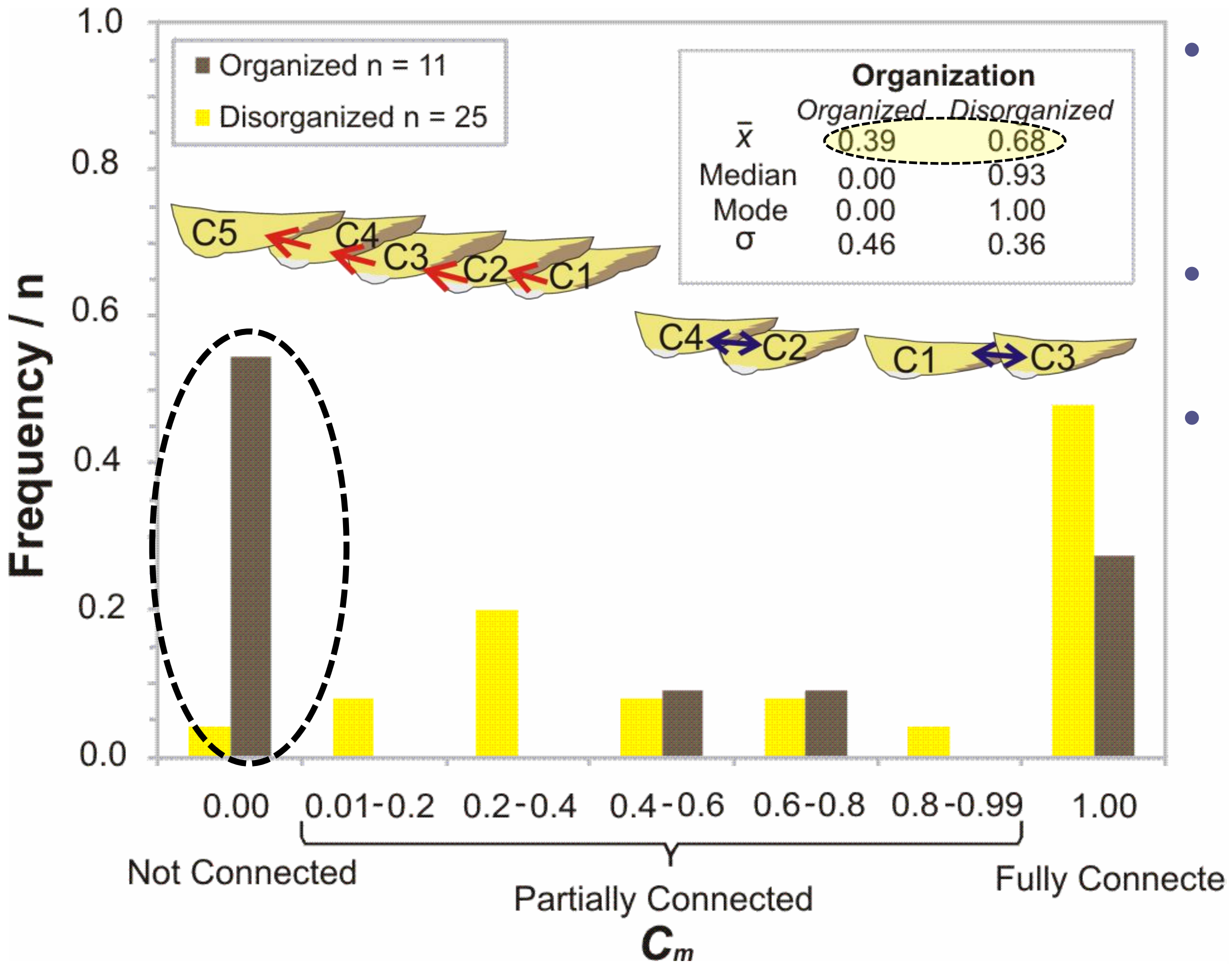
C_m in Laterally stacked << Vertically stacked



Deptuck, 2003

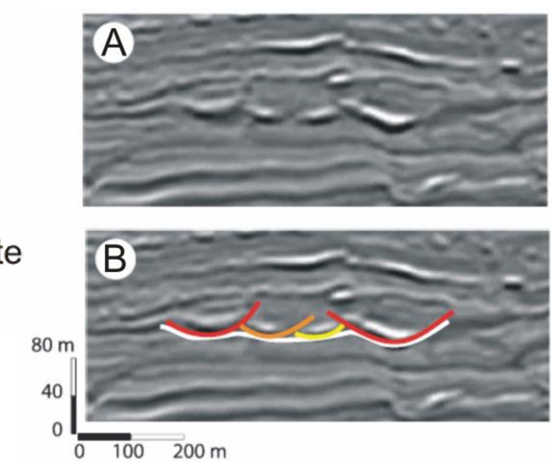
How does connectivity vary?

Channel stacking pattern – Organized vs. Disorganized



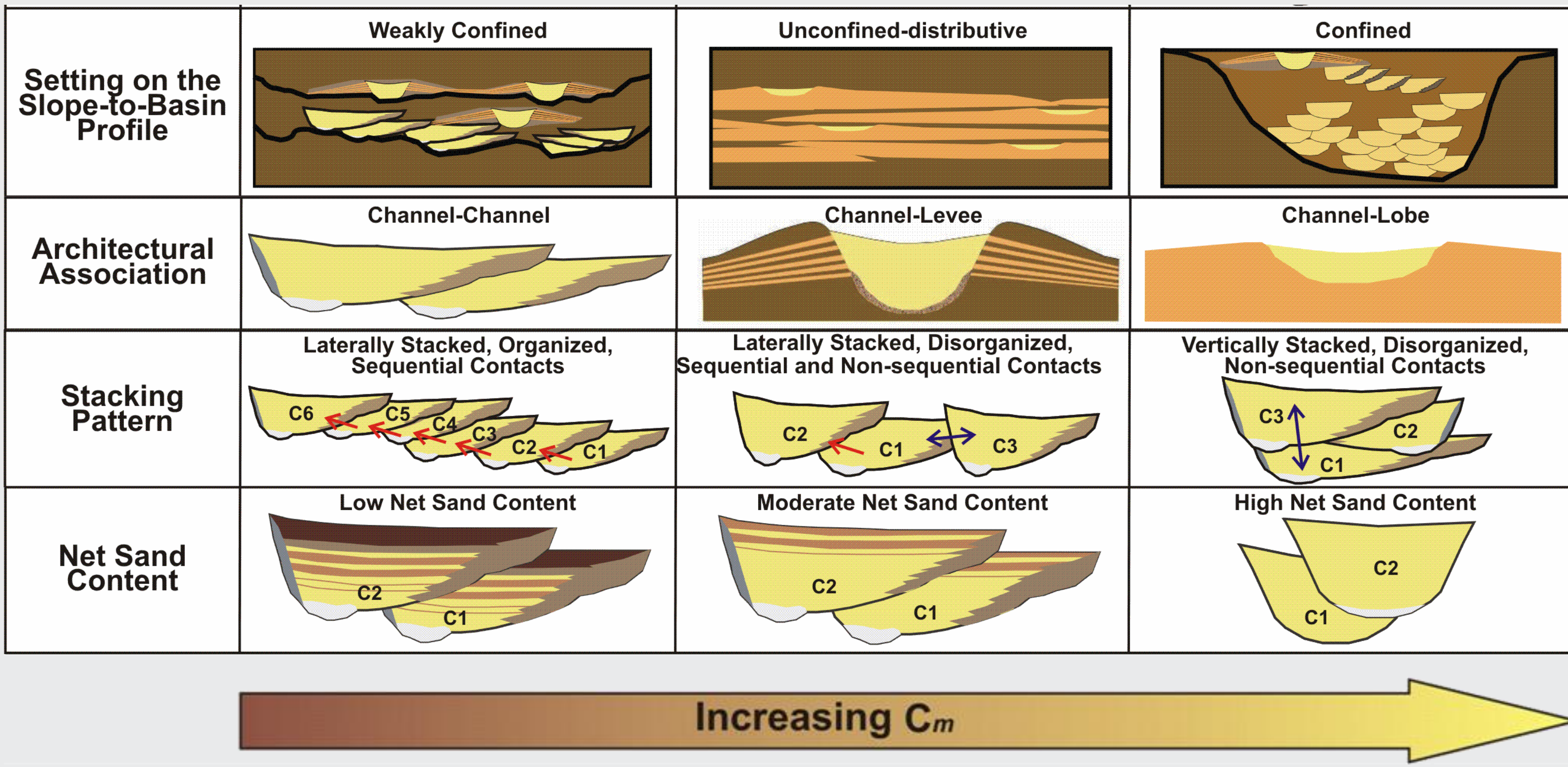
- Organized stacking patterns result as channel elements systematically stack in an upward and/or lateral pattern
- Organized channels tend to be underfilled (McHargue et al. 2008)
- Majority of organized channels are not connected

C_m in Organized << Disorganized



Labourdette and Bez, 2010

Summary



- **Future work:**
  - Focus on anisotropy in the third dimension
  - Application to other depositional environments

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Thanks for your attention!

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ABSTRACT

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