Variability in Slope Sandstone Bodies: Linkage to Slope Morphology and Evolution*

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Abstract

Prediction and characterization of sandstone reservoirs deposited in deep-water slope environments has significantly improved over the past two decades, largely as a result of 3-D seismic data acquisition for appraisal and development. However, consistently accurate prediction of sub-seismic reservoir heterogeneity remains elusive. High-relief slope systems are particularly challenging because of local gradient changes caused by mass wasting and/or syn-depositional substrate deformation, in addition to turbidity-current processes. Comparison of sandstone bodies from two outcropping slope systems in the Magallanes Basin, Chile, provide insights into patterns of sandstone-body geometry and facies distribution, as well as linkages between sub-seismic- and seismic-scale stratigraphic packaging. The slope systems analyzed are both from the Tres Pasos Formation; high-relief slopes prograded axially along the foredeep. The northern Tres Pasos (NTP) slope system is dominated by evidence for frequent mass wasting, and the southern Tres Pasos (STP) consists of mapped clinoforms with > 1 km of relief. The older NTP is ~50 km north of the STP.

Sandstone bodies of the NTP are attributed to intraslope fans and channelized lobes. Thick (20-100 m) mudstone-dominated intervals interpreted as mass transport deposits (MTD) in between the sandstone bodies have a noticeable effect on overall sand body architecture. The sandstone bodies of the STP represent channel-fills with systematic internal facies distributions, including sandstone-rich axes transitioning to sandstone-poor facies in off-axis and margin positions. High-resolution 3-D mapping demonstrates that STP channel-fill bodies of similar size and geometry cluster to form larger-scale channel complexes with dimensions similar to those imaged in seismic data. Although many of the NTP sandstone bodies have favorable reservoir characteristics internally, their overall geometry is more variable and their stacking less systematic compared to the channelized STP architecture. We interpret these fundamental differences to be a function of the overall slope gradient and aggradation history. In the north, slope readjustment occurred frequently enough to significantly influence the substrate topography over which sand-laden turbidity currents traversed. In contrast, the systematic channel-fill deposition and stacking of the STP system suggests a long-lived phase of turbidity current delivery to the base of slope.

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Variability in Slope Sandstone Bodies

Linkage to Slope Morphology and Evolution

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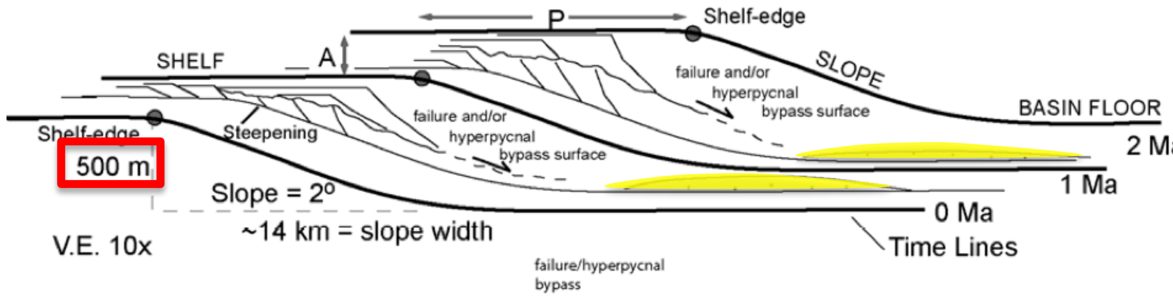
CHILE SLOPE SYSTEMS

Size Matters

- Smaller basin margins (≤500 m) tend toward “smoother” profiles and, thus, more efficient bypass of sand to base-of-slope and basin floor

Low-relief clinoform systems



Carvajal et al. (2009); *Earth-Science Reviews*

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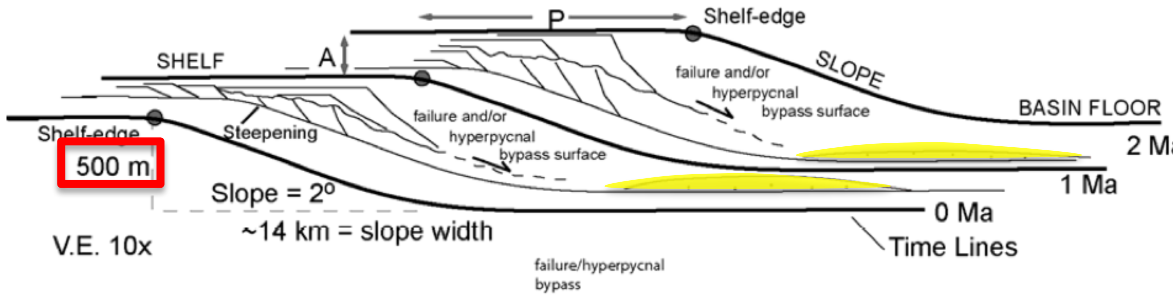
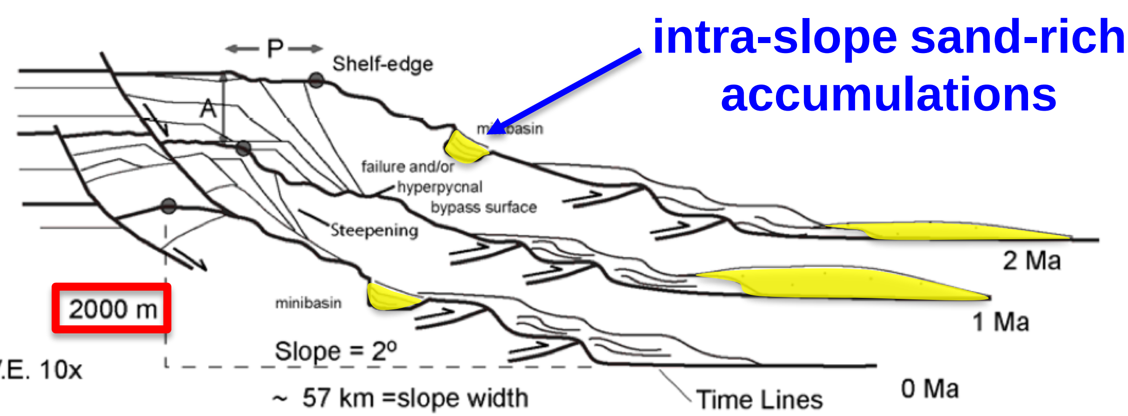
Low-relief clinoform systems



- Generally, larger basin margins (≥2000 m) have more rugose slope profiles and, thus, potential for significant sand accumulations in intra-slope accommodation (e.g., slope minibasins)

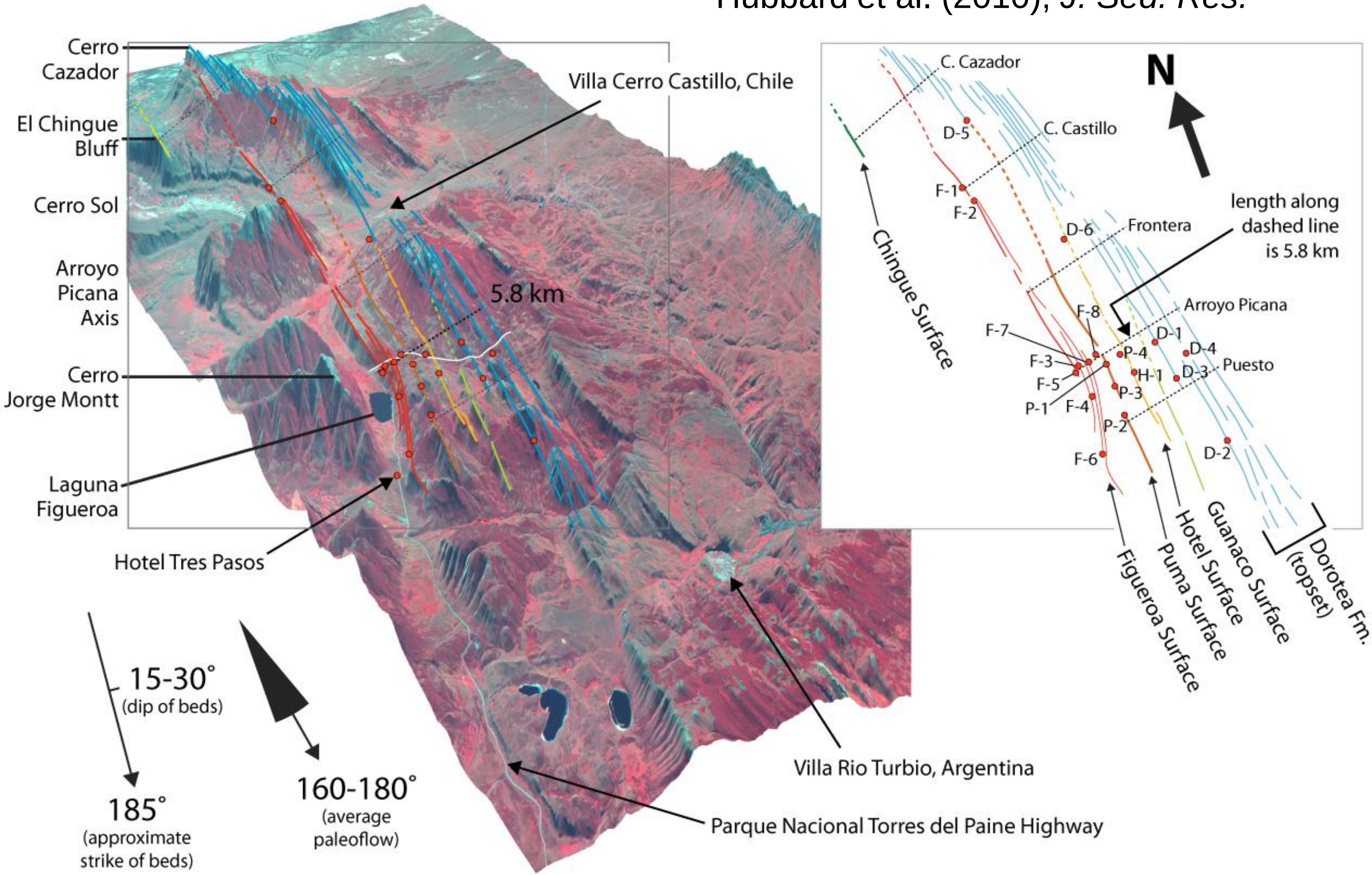
High-relief clinoform systems



Carvajal et al. (2009); *Earth-Science Reviews*

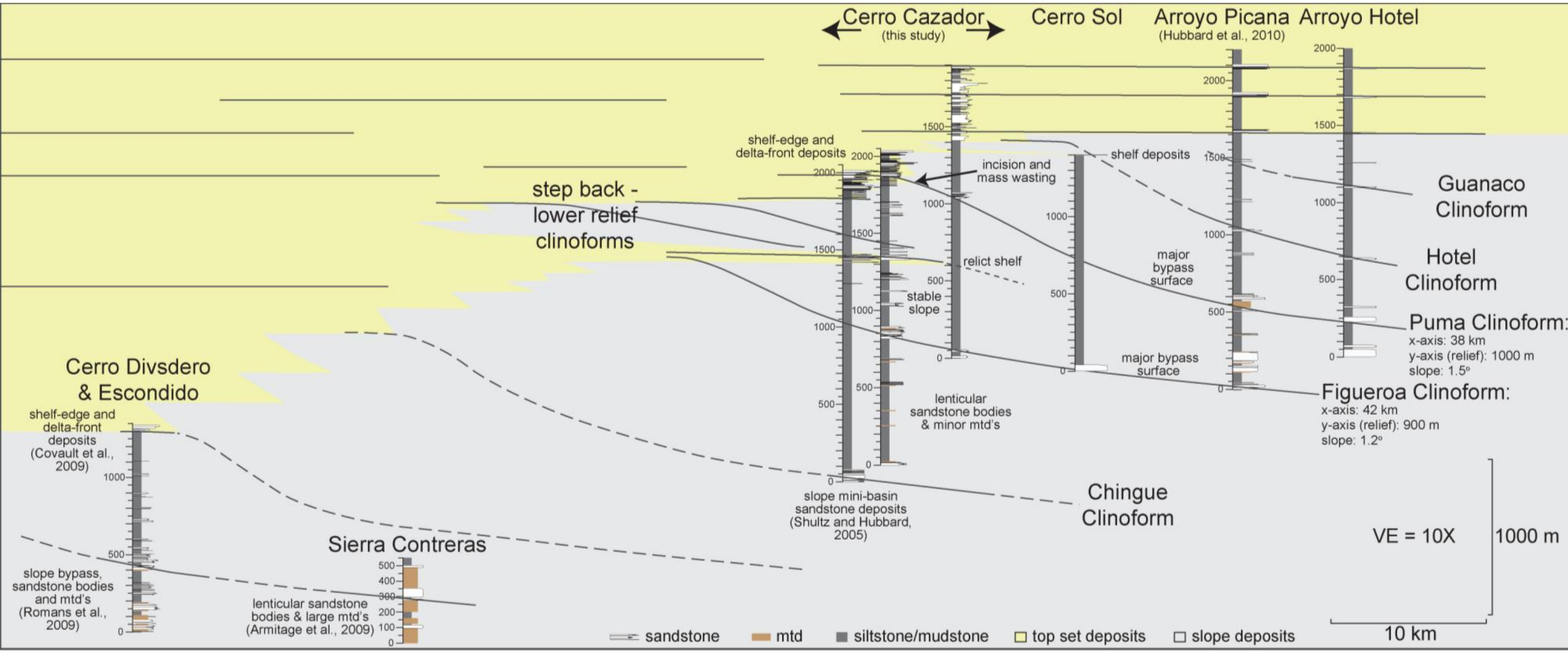
Magallanes Basin slope systems

Hubbard et al. (2010); *J. Sed. Res.*



Magallanes Basin slope systems

Numerous detailed outcrop studies (1999 – present) integrated with basin-scale/tectonic context provide exceptional dataset to examine slope processes and evolution

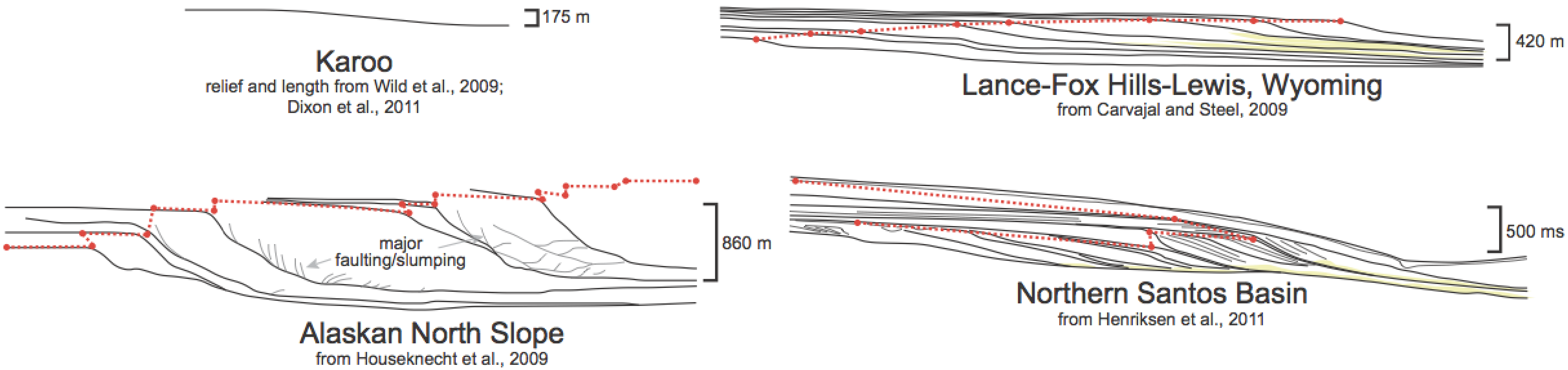


1000 m

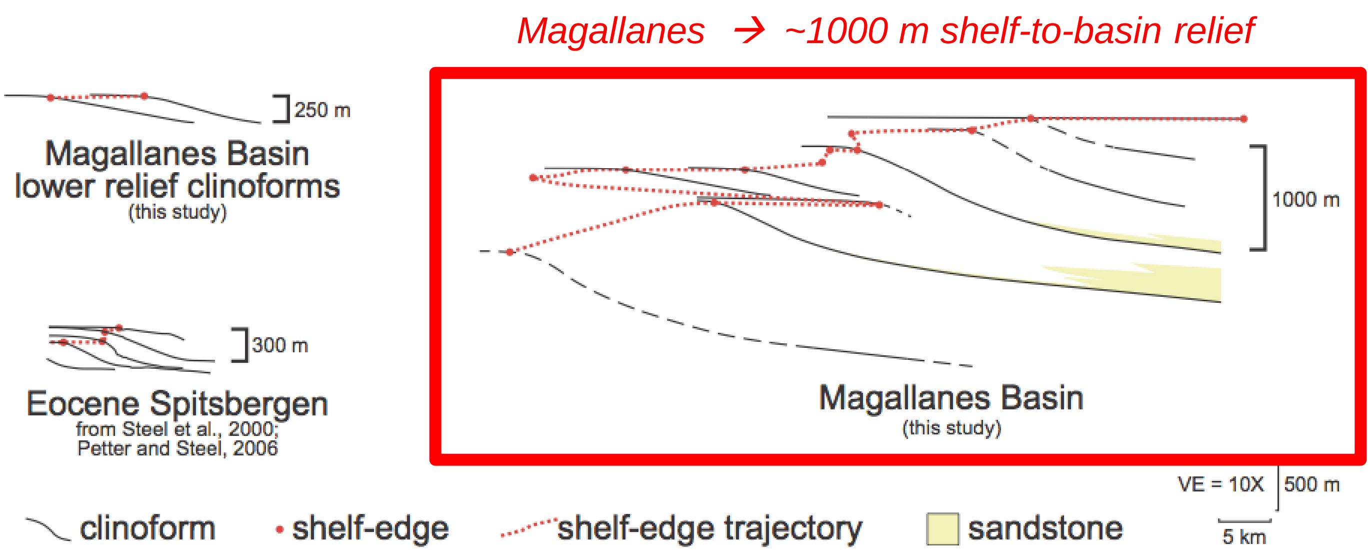
25 km

Bauer and Hubbard (in prep)

Intermediate relief provides examples along continuum



Magallanes Basin slope systems (~1000 m relief) provide opportunity to examine patterns between end members



Bauer and Hubbard (in prep)

Improving prediction of slope stratigraphic architecture

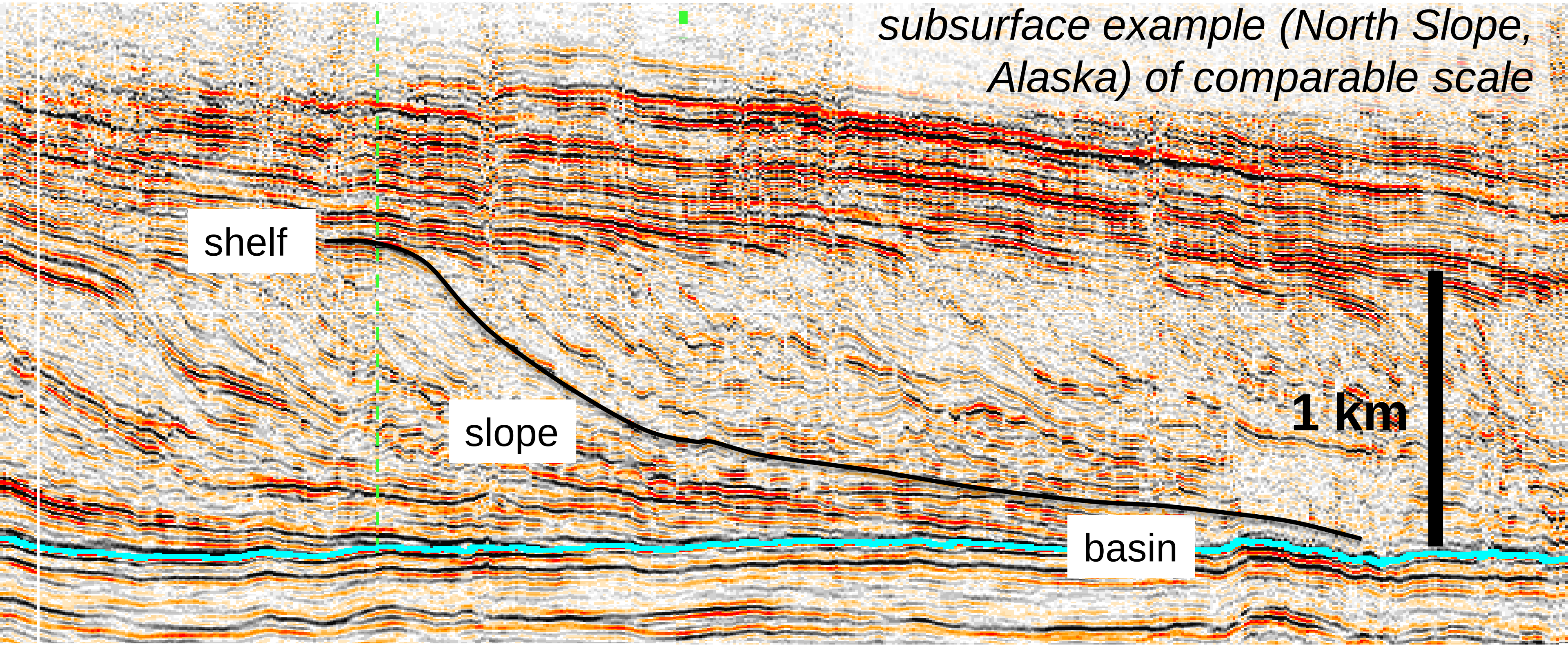
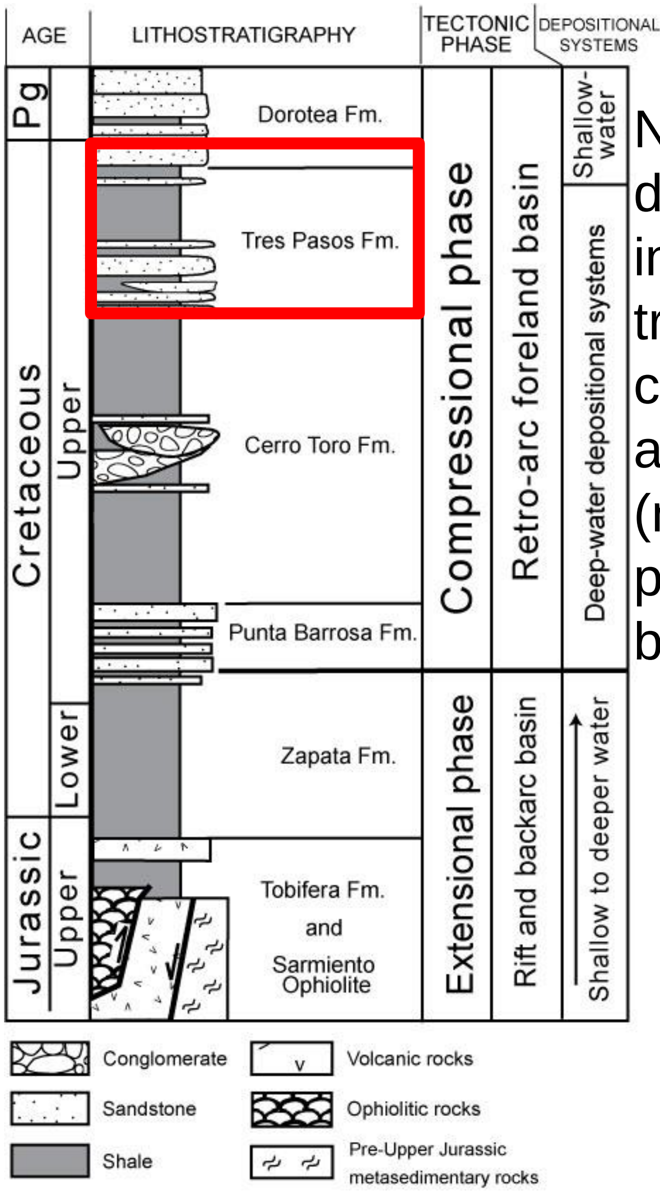


image courtesy of Henry Posamentier; see Houseknecht et al. (2009) for interpretations

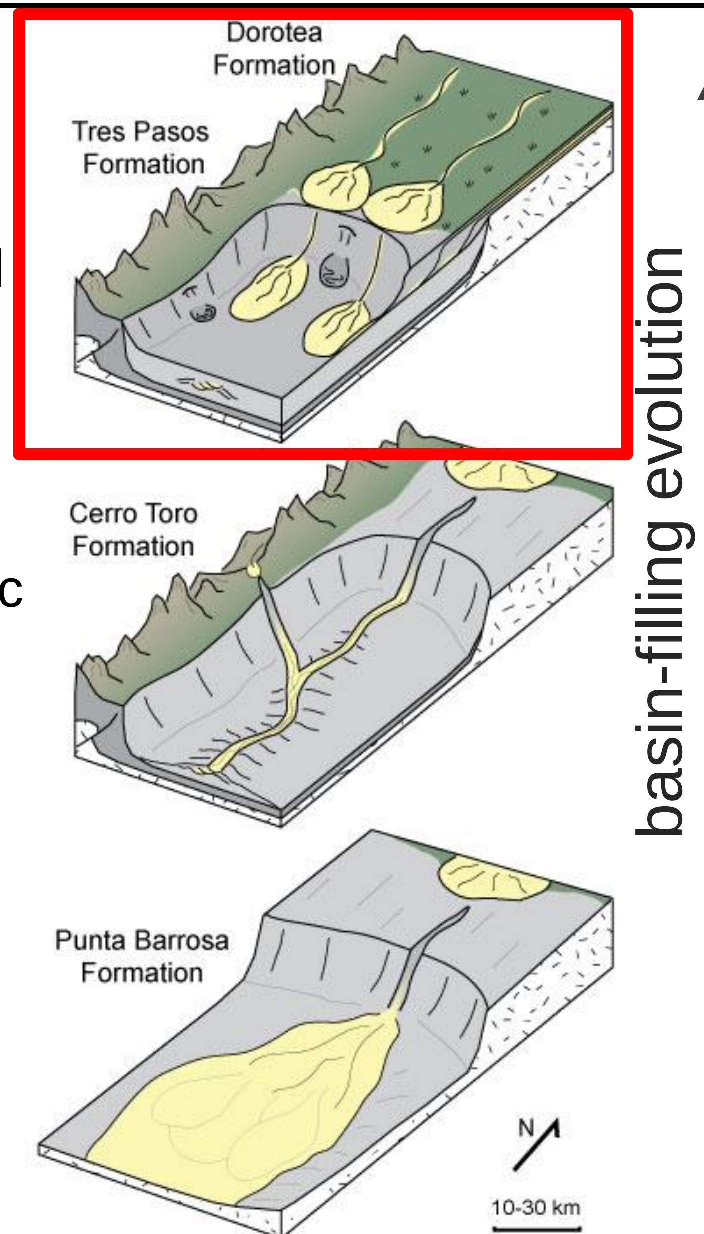
How do slope sand bodies vary as a function of slope morphology and evolution?

A unique retroarc foreland basin



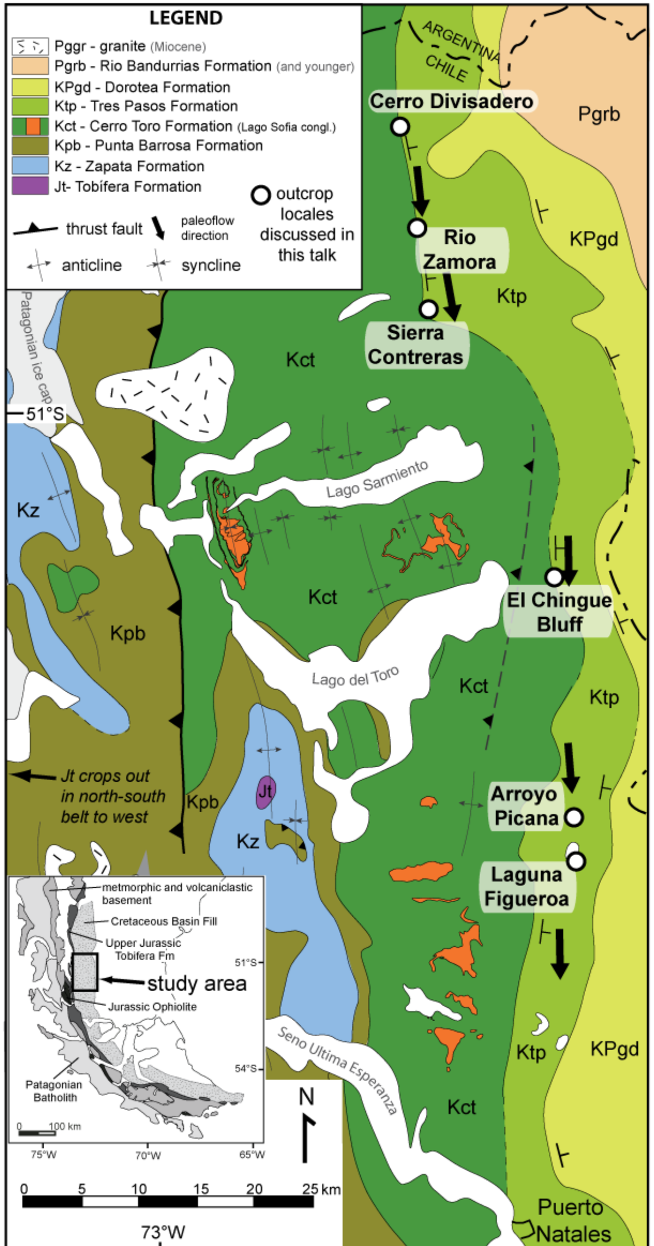
Northern margin of deep-water basin inherited from spatial transition from fully continental to attenuated crust (northern limit of predecessor back-arc basin).

Tres Pasos Formation → progradational, delta-fed slope systems

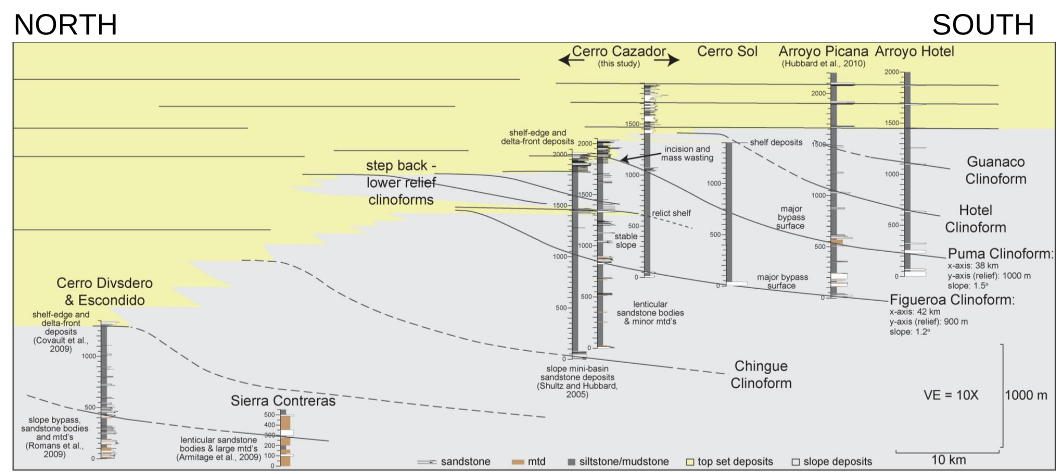


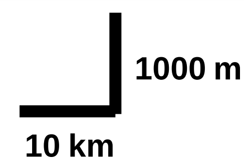
Romans et al. (2011); *Mar. & Petrl. Geology*

Regional context for outcropping slope systems



Regionally consistent southward-directed paleoflow (parallel to outcrop belt trend) provides >80 km depositional-dip transect of this basin fill.

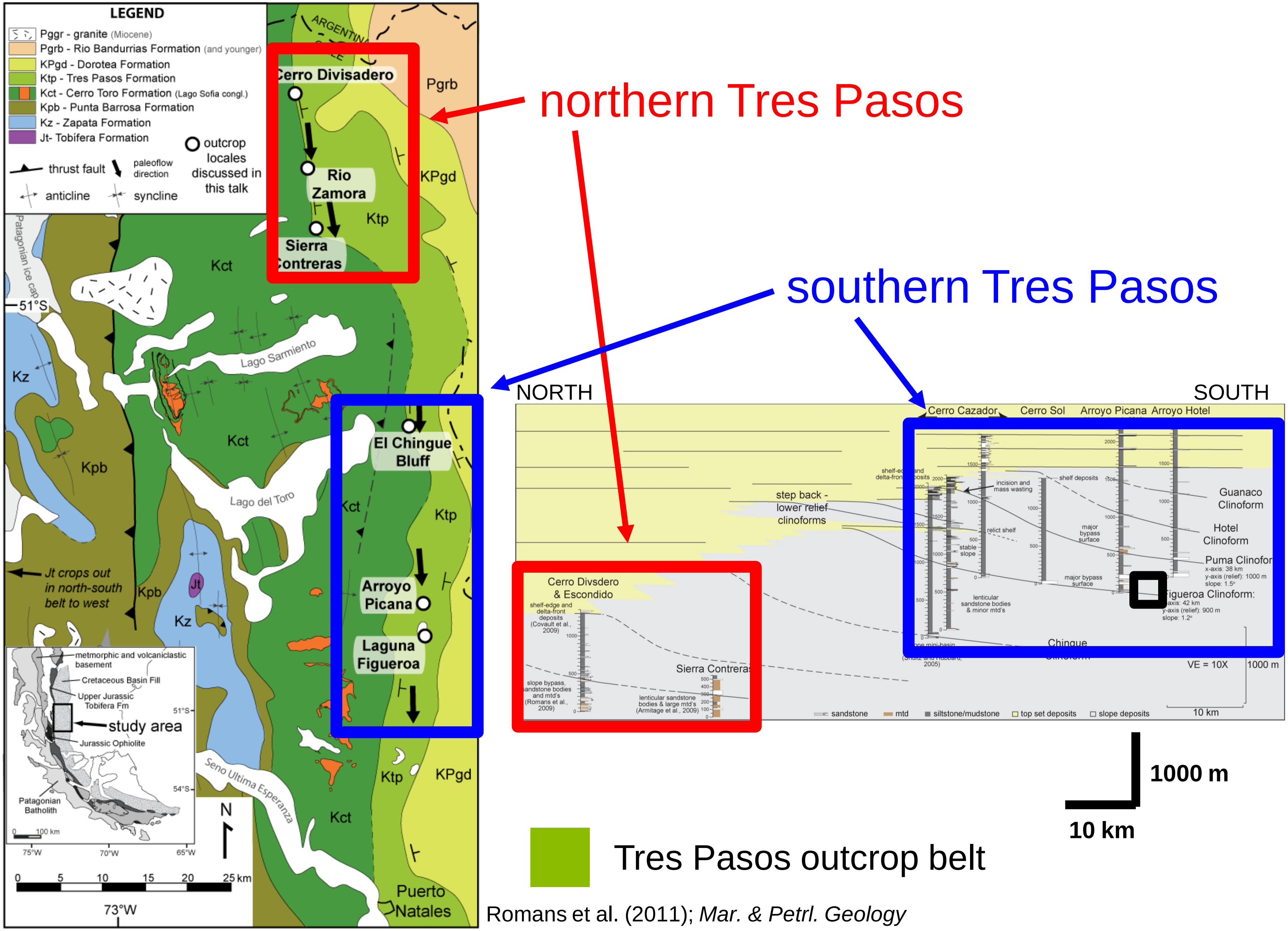




Tres Pasos outcrop belt

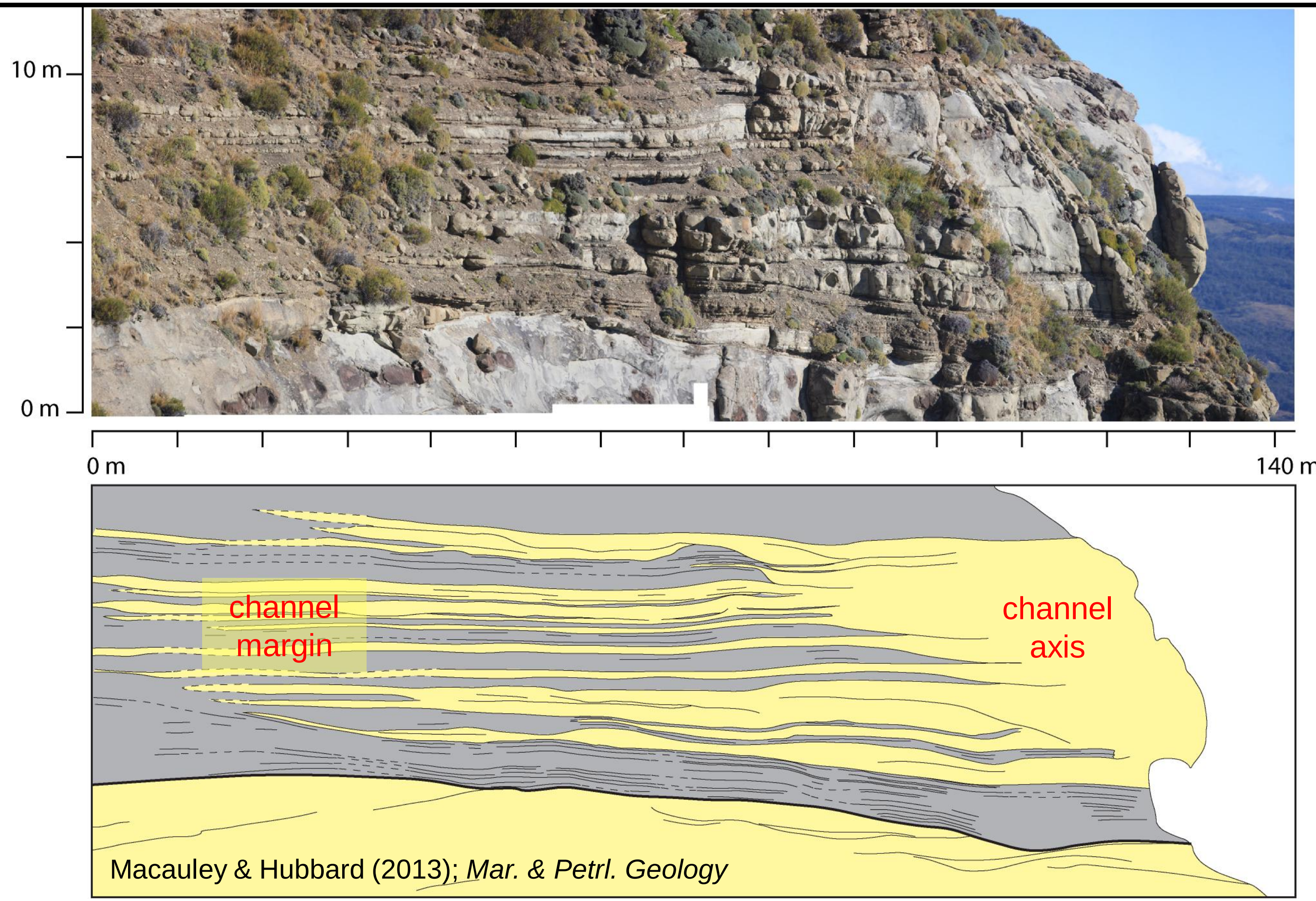
Romans et al. (2011); *Mar. & Petrl. Geology*

Regional context for outcropping slope systems



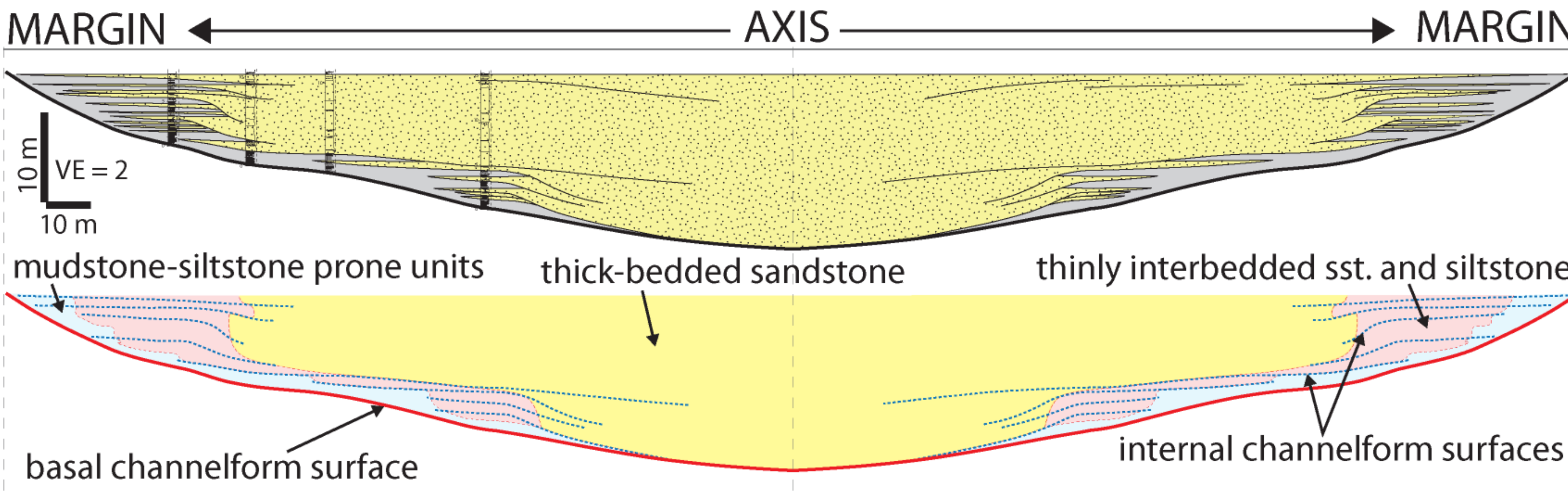
Romans et al. (2011); *Mar. & Petrl. Geology*

Channel axis-to-margin relationships

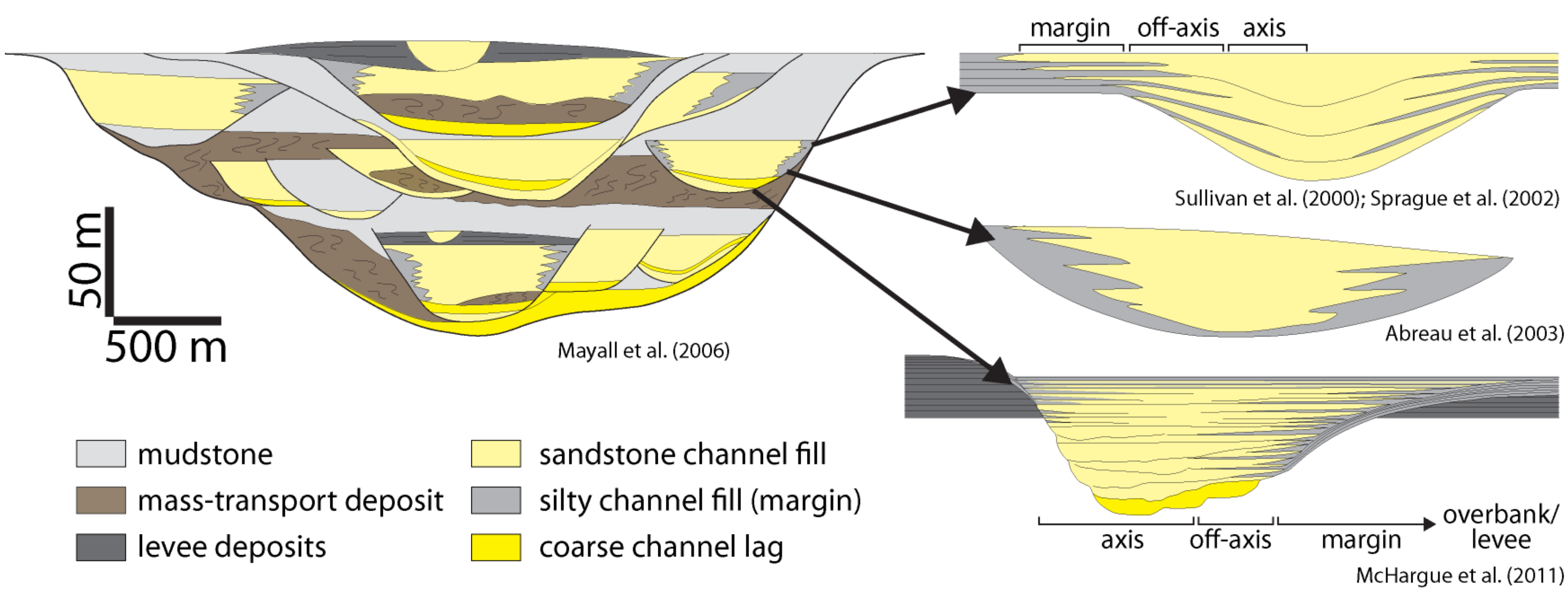


Base-of-slope to lower slope sandstone bodies in southern TP systems show systematic lateral facies changes interpreted as axis to margin positions in submarine channel fills

Channel axis-to-margin relationships

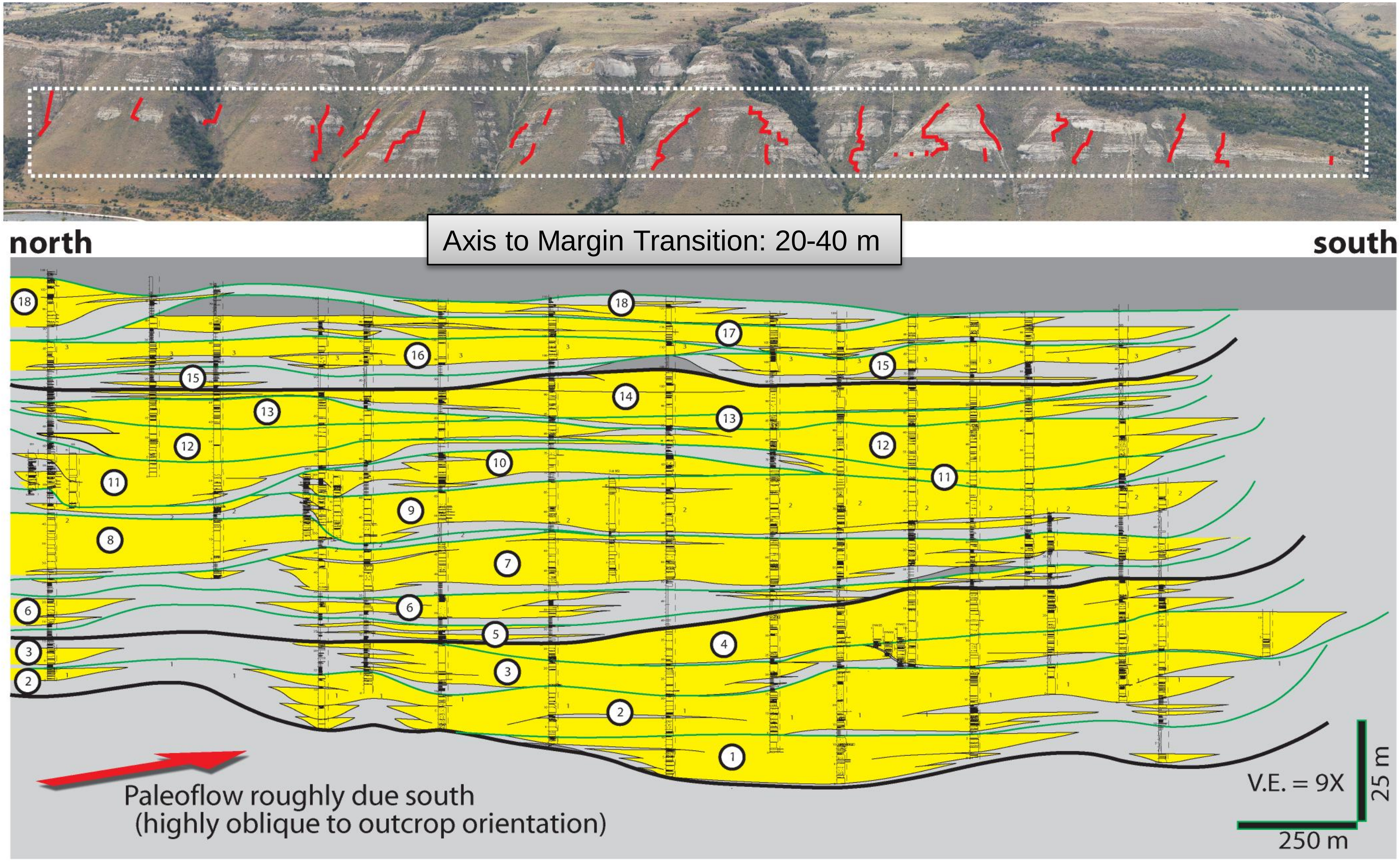


Hubbard et al. (in prep)



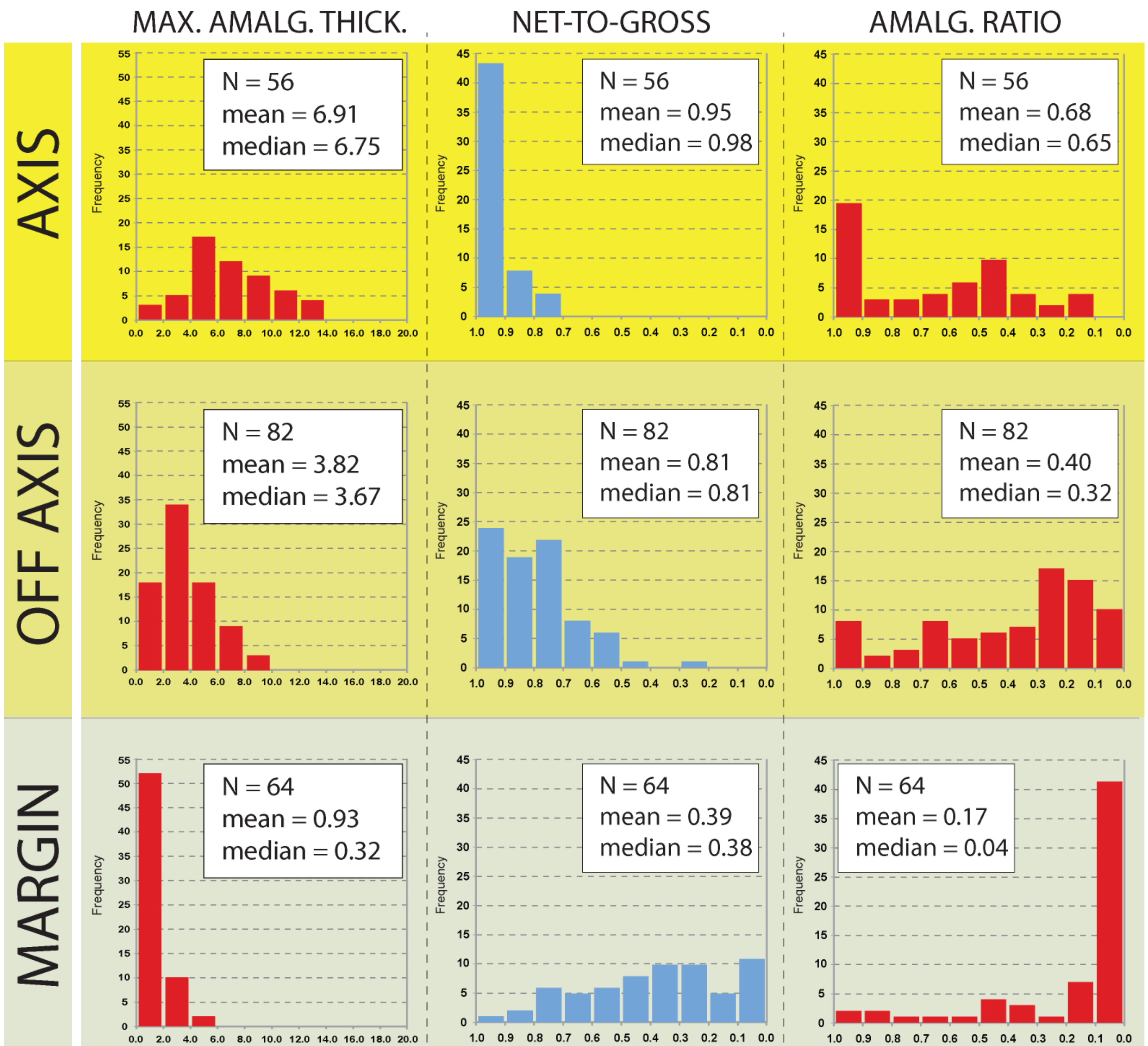
Intra-channel facies relationships are systematic

18 channel-fill elements identified and correlated across outcrop



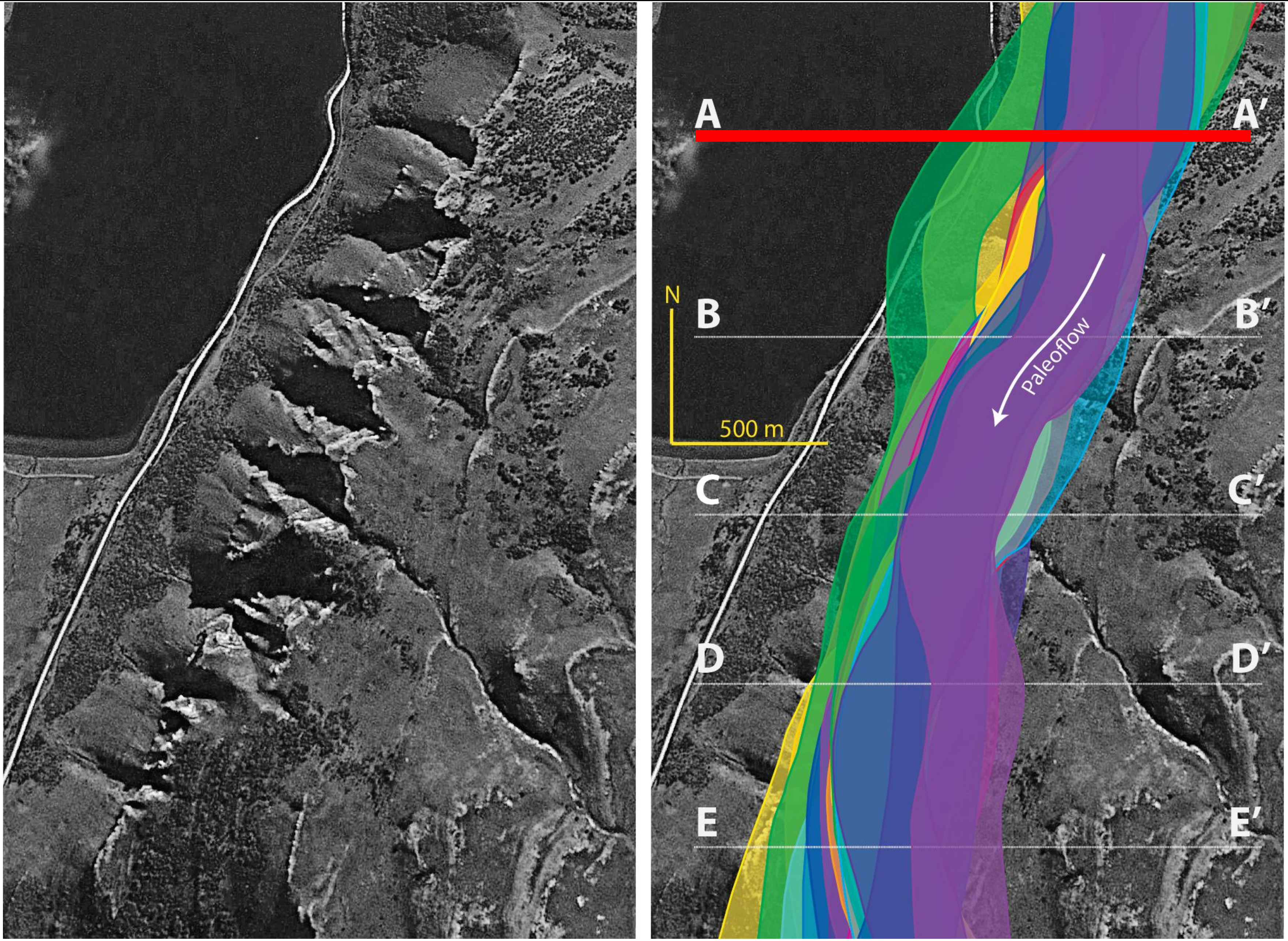
Macauley & Hubbard (2013); *Mar. & Petrl. Geology*

Intra-channel facies relationships are systematic



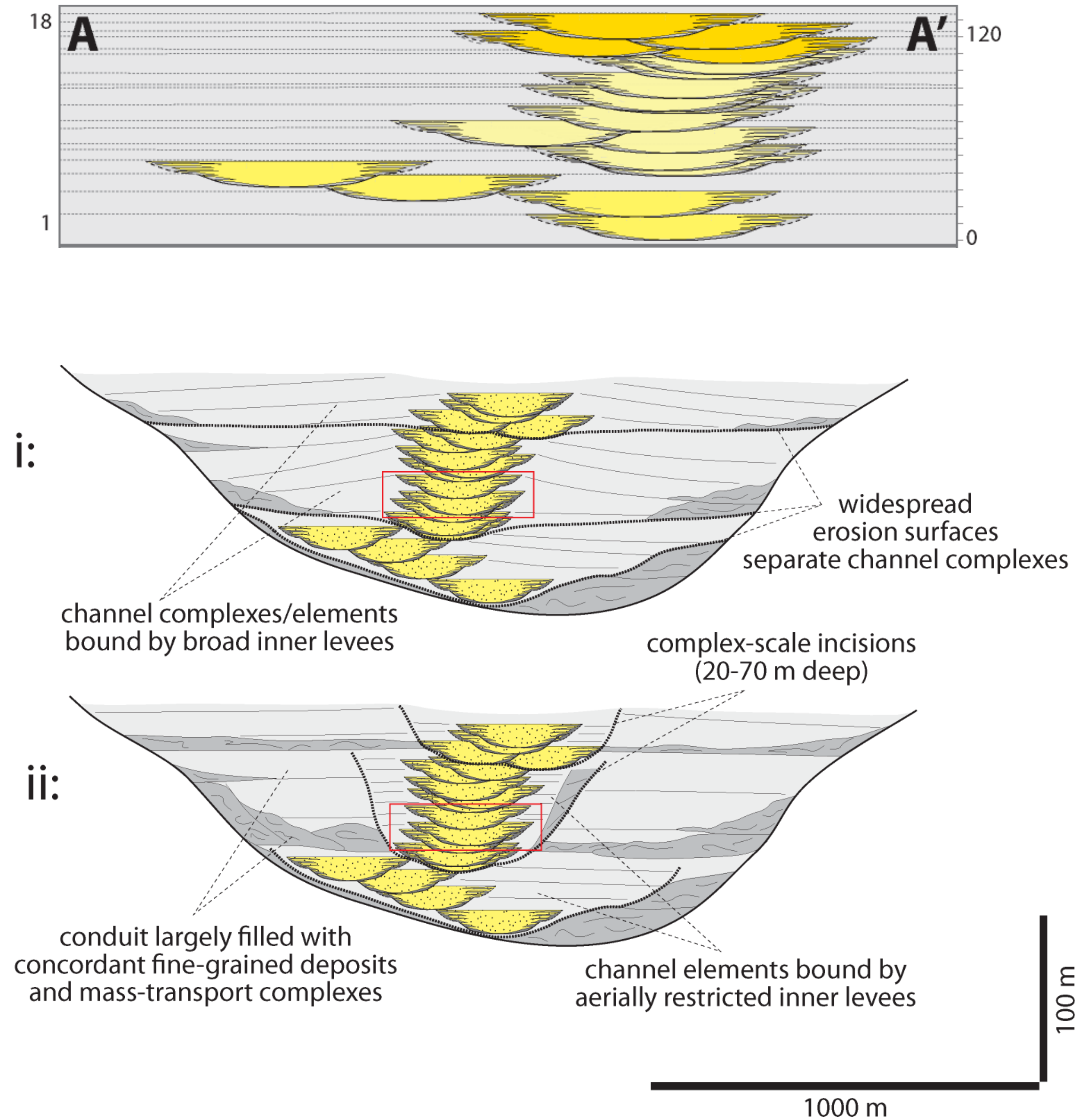
Macauley & Hubbard (2013); *Mar. & Petrl. Geology*

Planform context → channel stacking patterns



Channel stacking patterns

Systematic channel-fill styles allow identification and mapping of multiple elements → investigation of their stratigraphic stacking

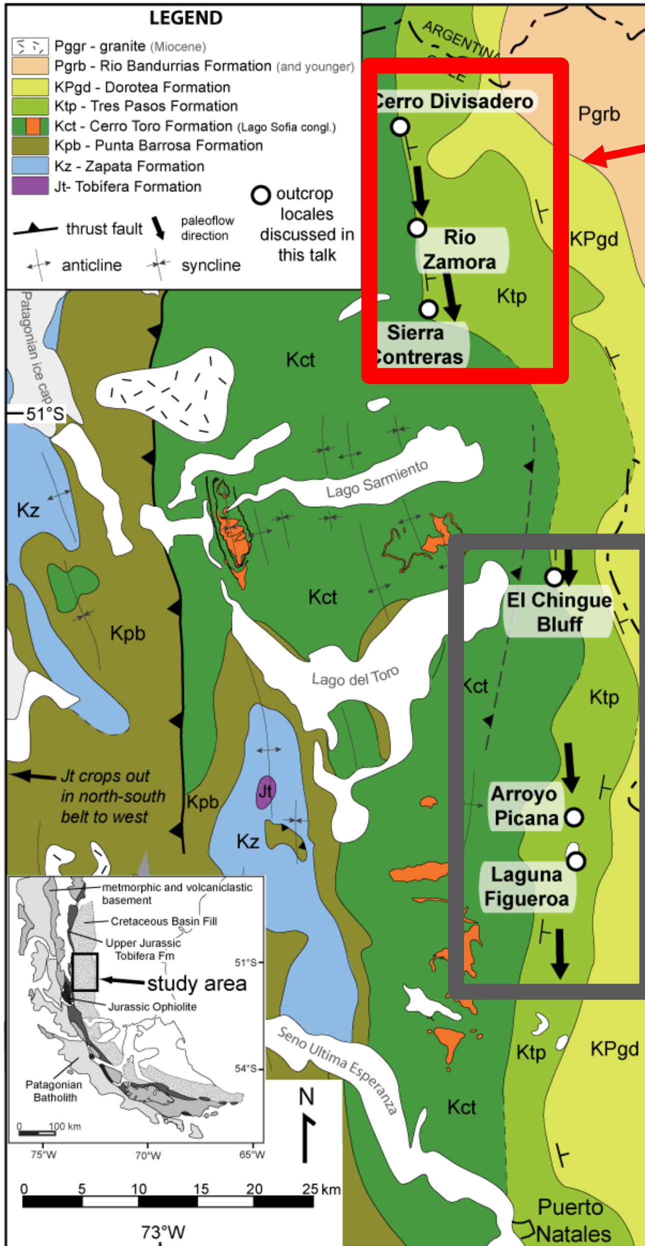


Yes, uncertainty remains!

But, a conceptual model (constrained by metrics) can reduce uncertainty and improve prediction.

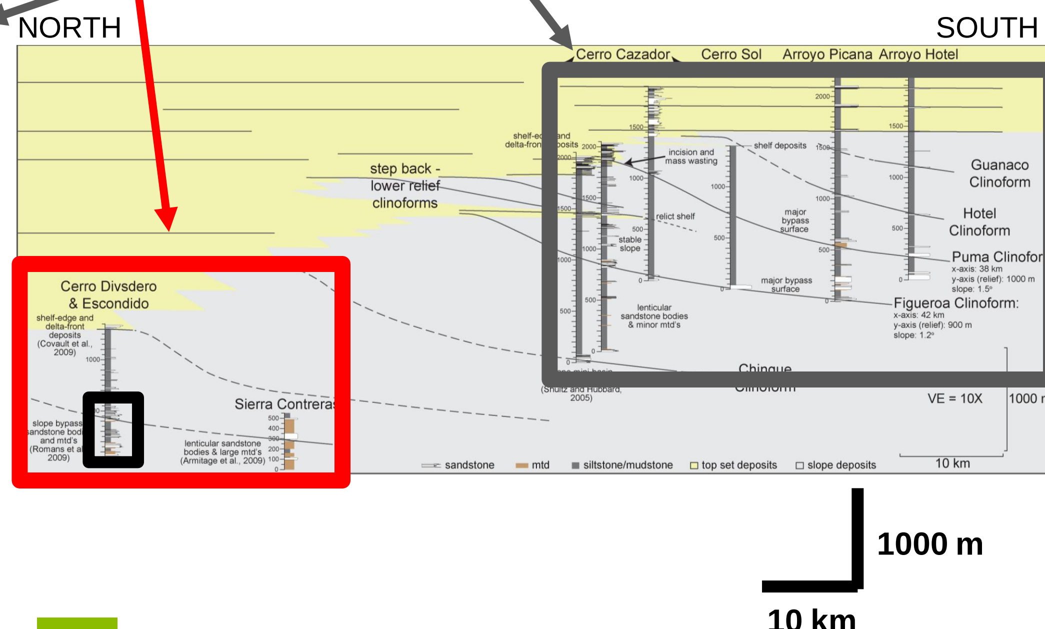
Macauley & Hubbard (2013); *Mar. & Petrl. Geology*

Regional context for outcropping slope systems



northern Tres Pasos

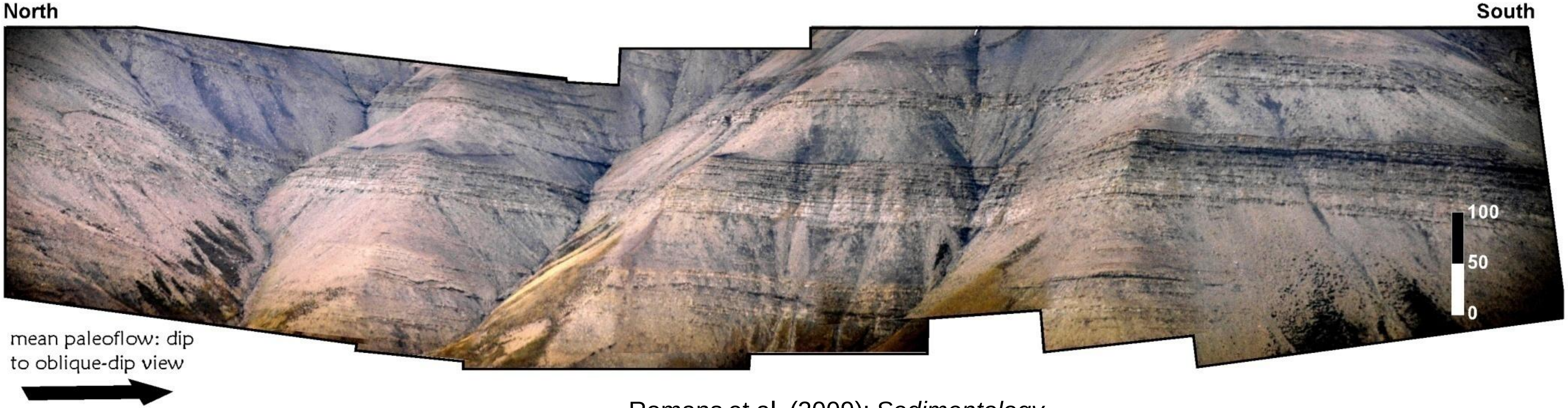
southern Tres Pasos



Tres Pasos outcrop belt

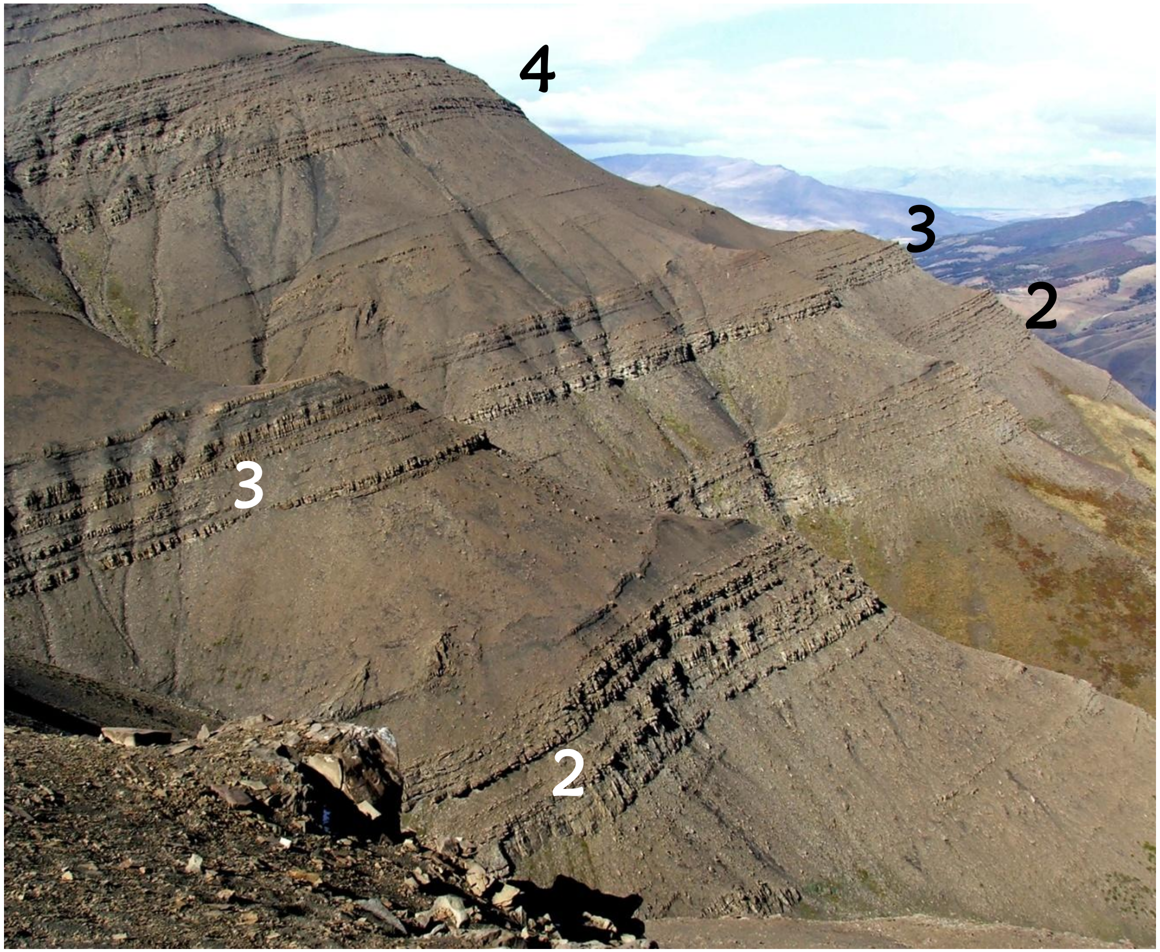
Romans et al. (2011); *Mar. & Petrl. Geology*

Northern Tres Pasos – Cerro Divisadero

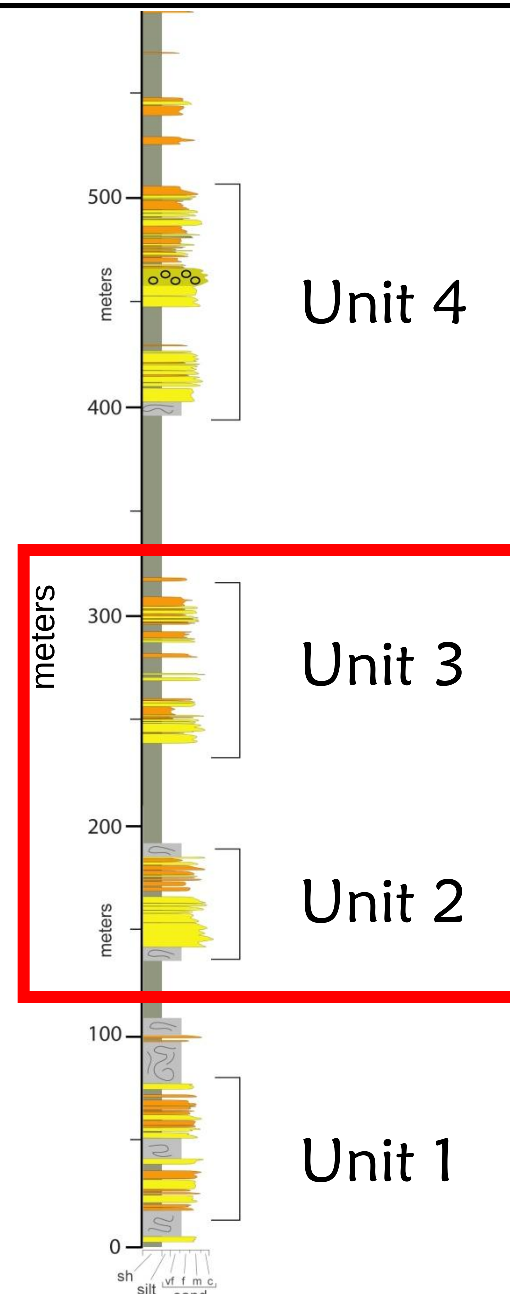


Romans et al. (2009); *Sedimentology*

Northern Tres Pasos – Cerro Divisadero

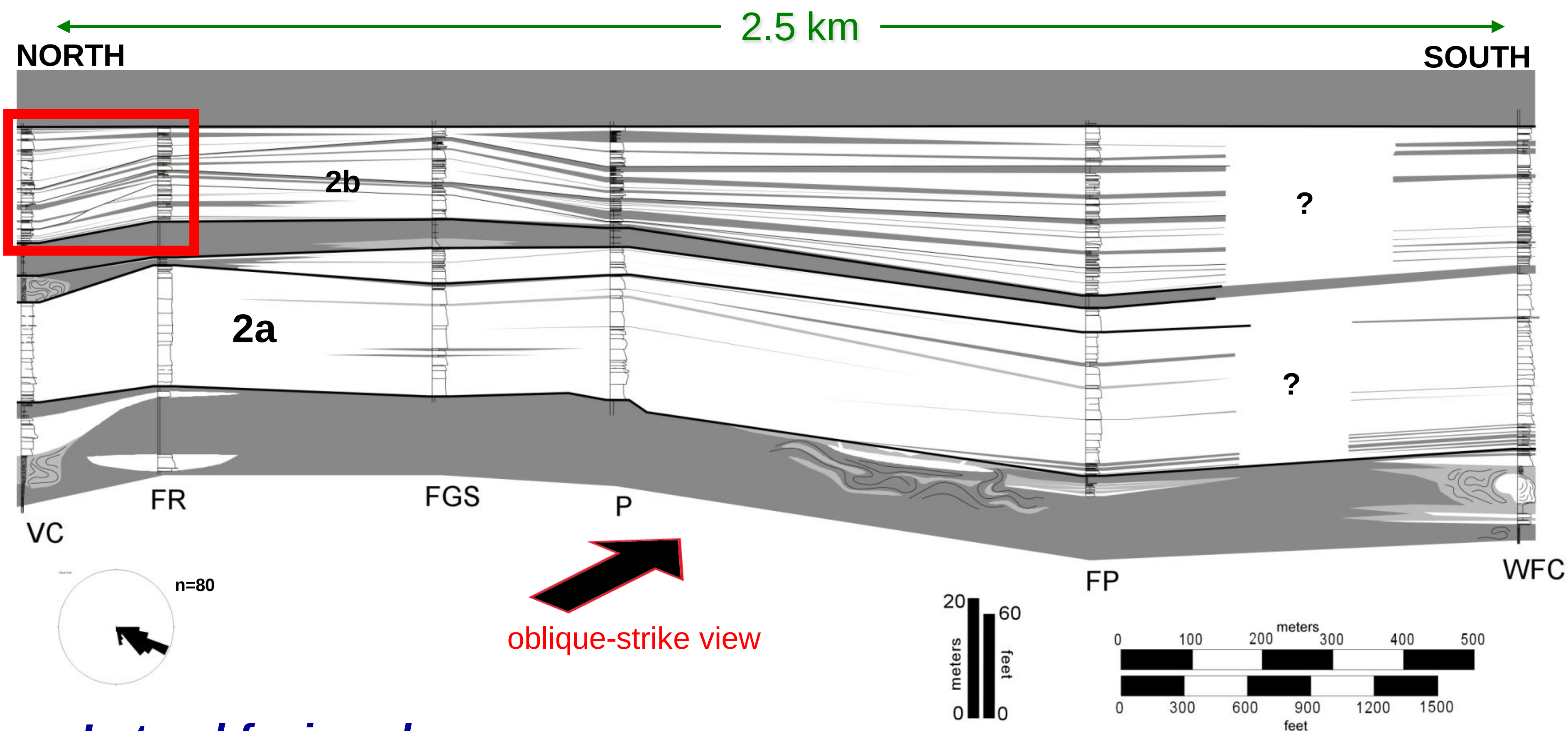


Greater than 600 m (2,000 ft) of slope strata exposed on west face of Cerro Divisadero



Romans et al. (2009); *Sedimentology*

Intra-sand body facies relationships?

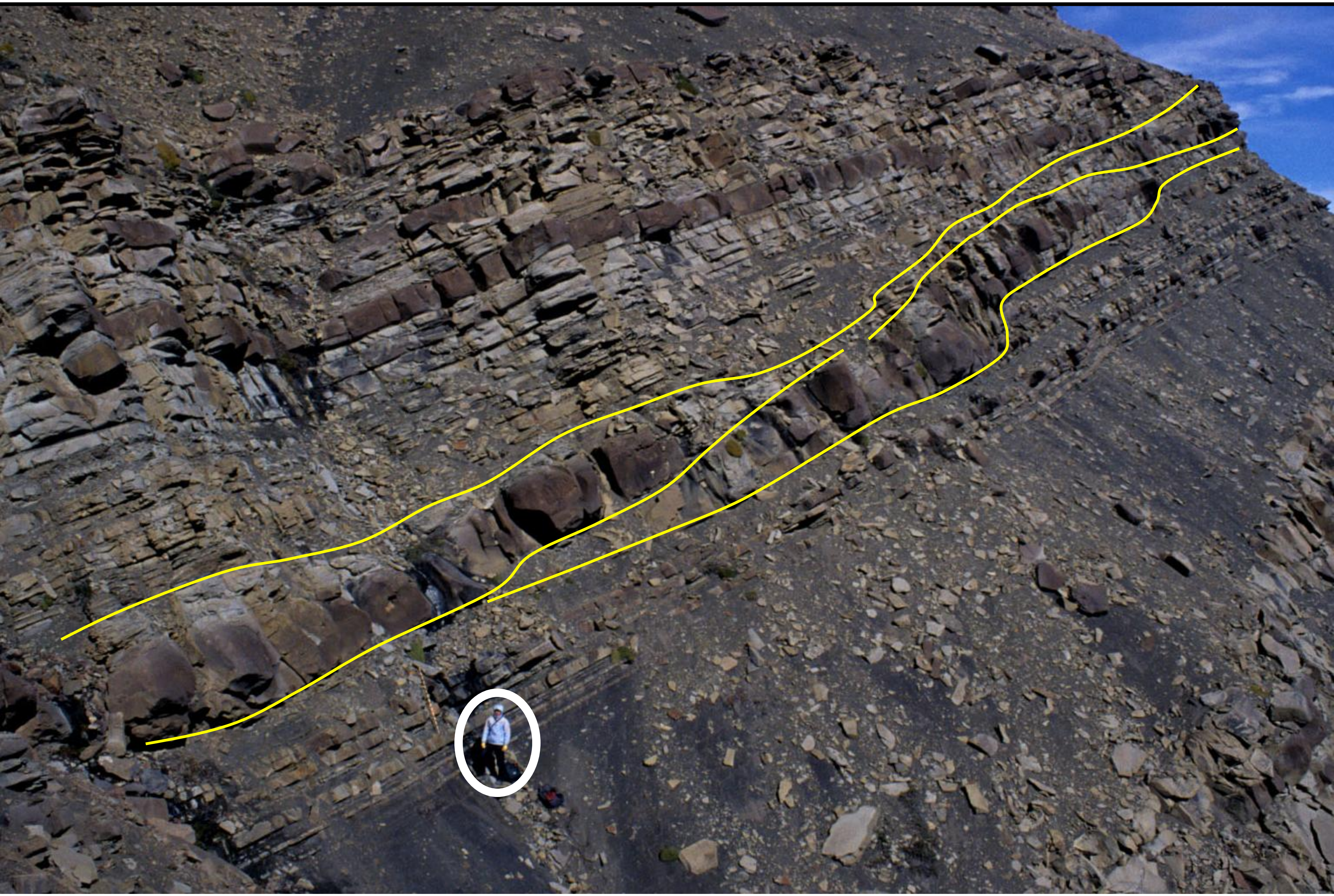


Lateral facies changes:

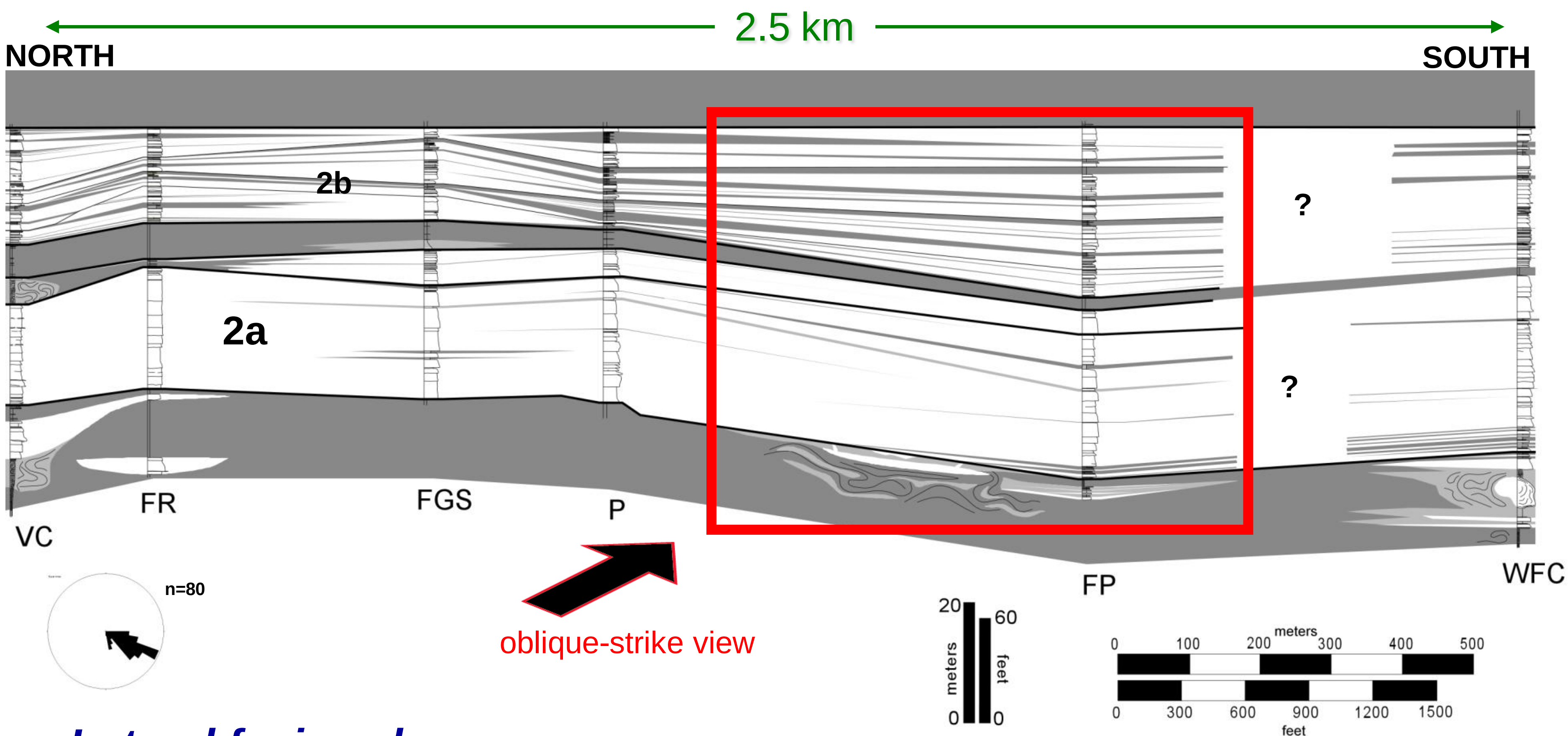
- *more amalgamated to lesser amalgamated (2a)*
- *Scour surfaces with truncation, bed-scale pinch-outs (2b)*

Romans et al. (2009); *Sedimentology*

Intra-sand body facies relationships?



Intra-sand body facies relationships?



***Lateral facies changes**:*

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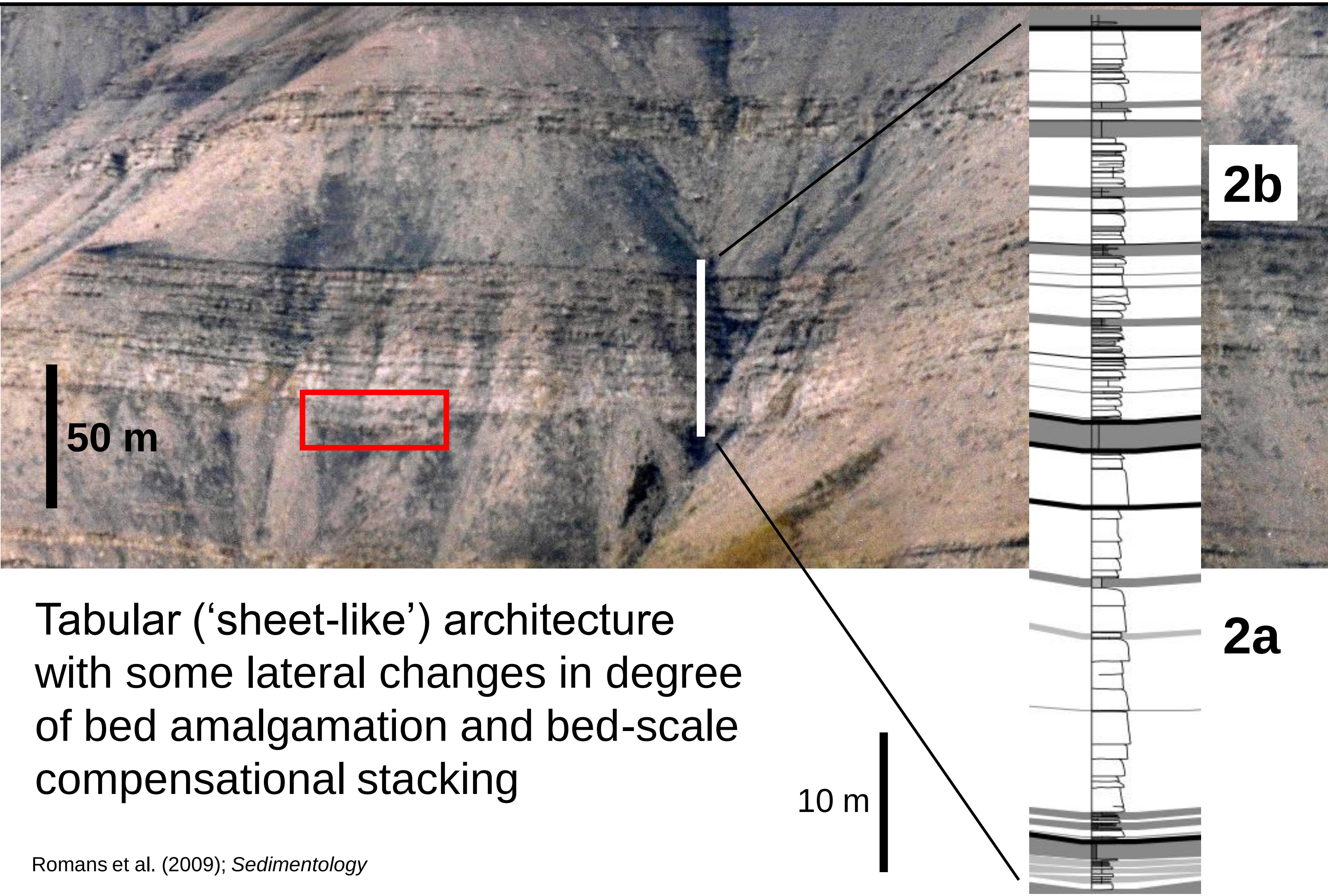
- *Scour surfaces with truncation, bed-scale pinch-outs (2b)*

Romans et al. (2009); *Sedimentology*

Intra-sand body facies relationships?



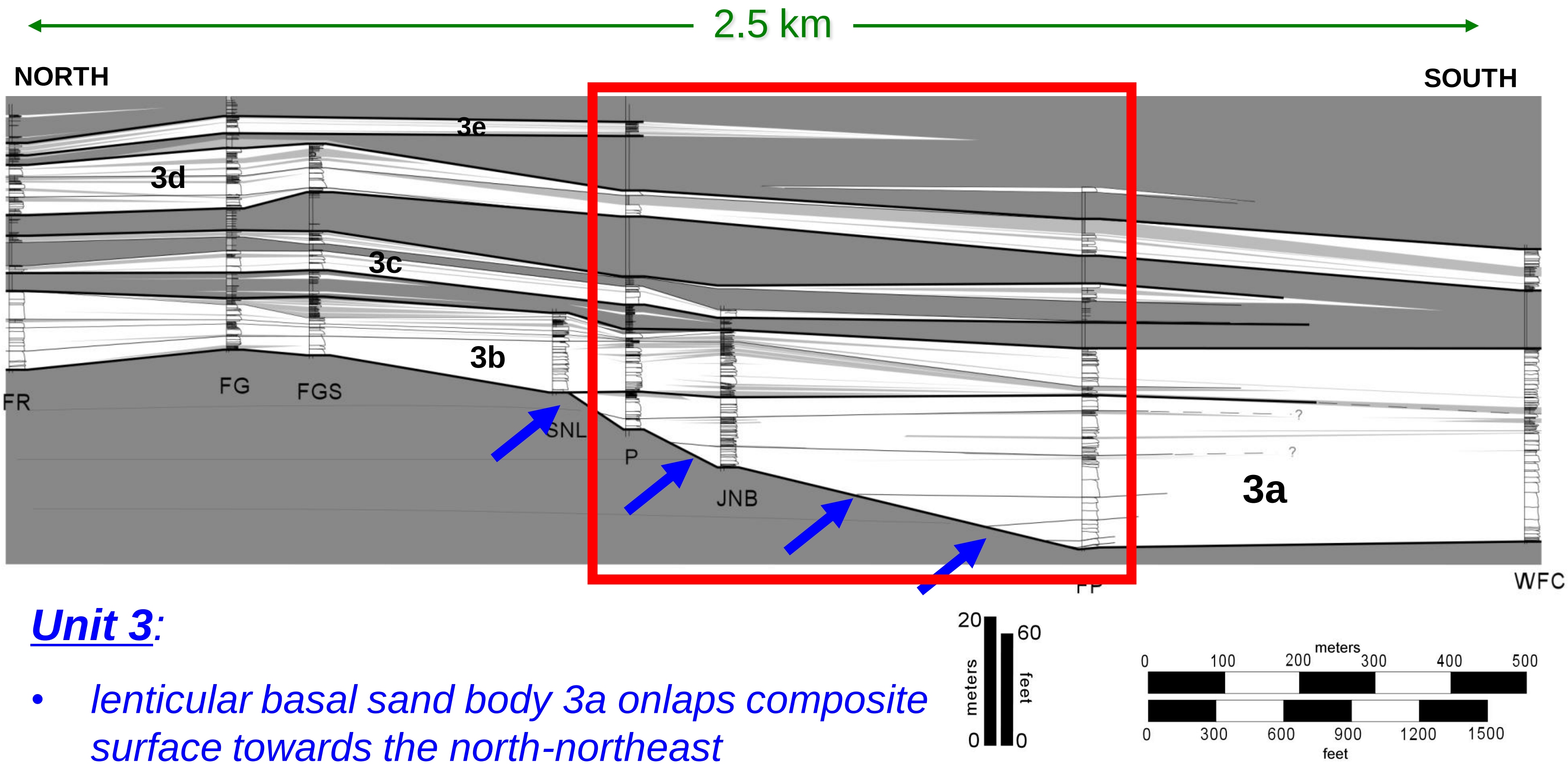
Tabular ('sheet-like') architecture with some lateral changes in degree of bed amalgamation and bed-scale compensational stacking

Romans et al. (2009); *Sedimentology*

Sand bodies overlie chaotic/discordant mudstone

Romans et al. (2009); *Sedimentology*

Facies architecture of overlying package (Unit 3)



Unit 3:

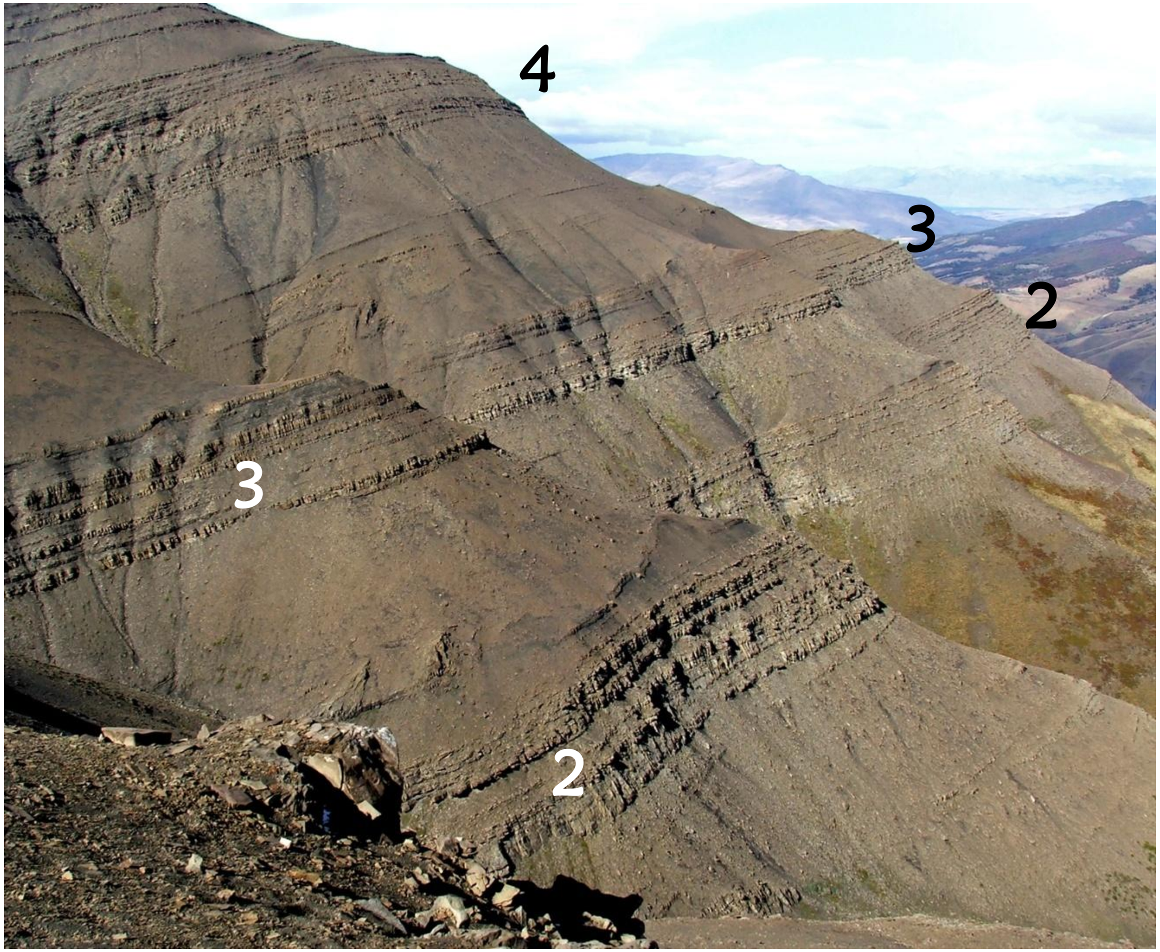
- *lenticular basal sand body 3a onlaps composite surface towards the north-northeast*
- *overlying subunits exhibit small-scale scouring and general southward thinning and/or pinching out*

Romans et al. (2009); *Sedimentology*

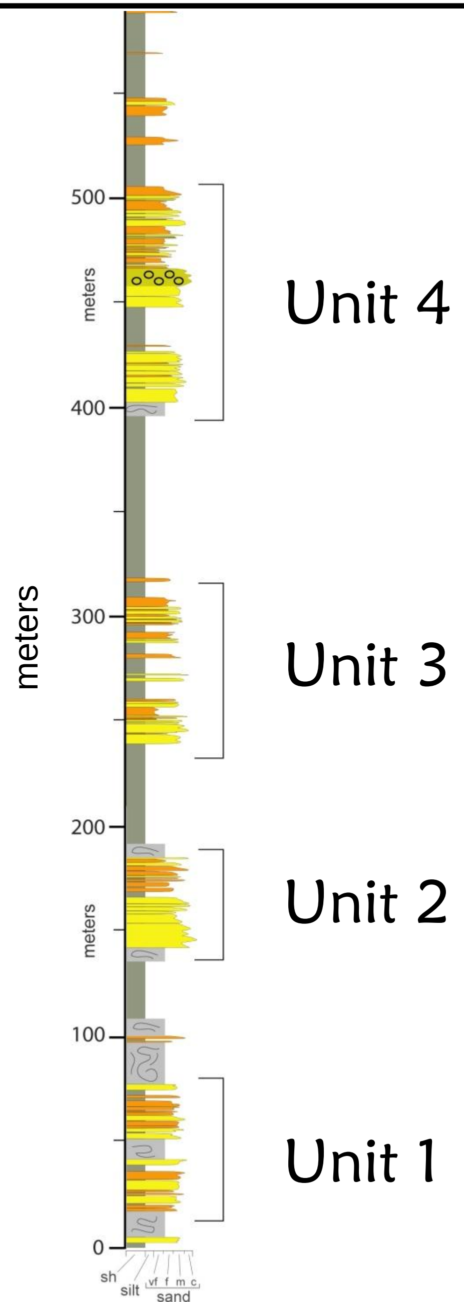
Internal facies changes exist, but are less systematic

Northern Tres Pasos: Different style of slope architecture?

Generally comparable internal architecture throughout >500 m thick succession → i.e., not function of more distal settings in lower strata



Romans et al. (2009); *Sedimentology*



Sierra Contreras (~20 km downdip of Divisadero)

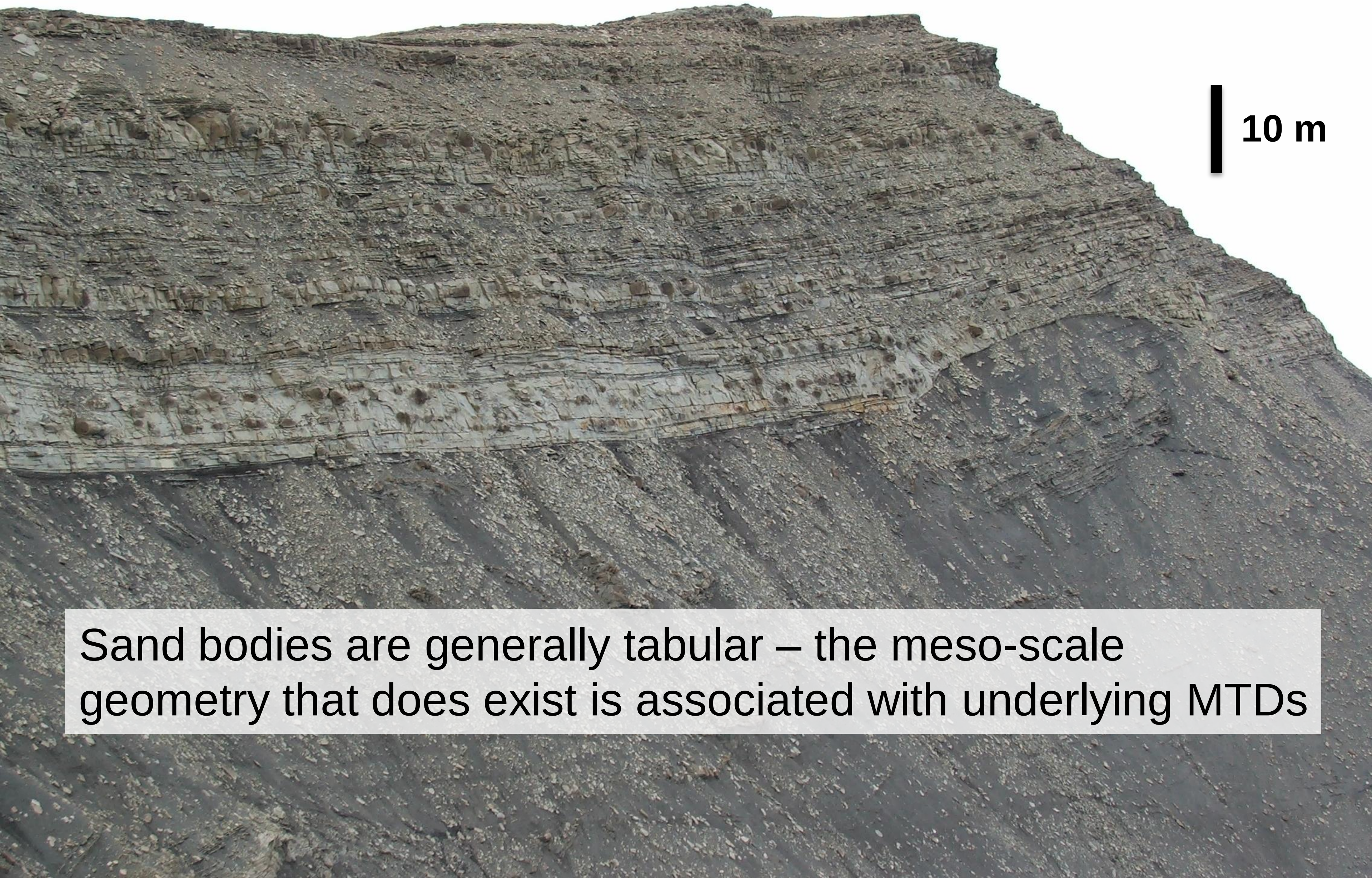
Armitage et al. (2009); *J. Sed. Res.*

Sierra Contreras (~20 km downdip of Divisadero)

Lenticular architecture associated with MTDs

Lenticular architecture associated with MTDs

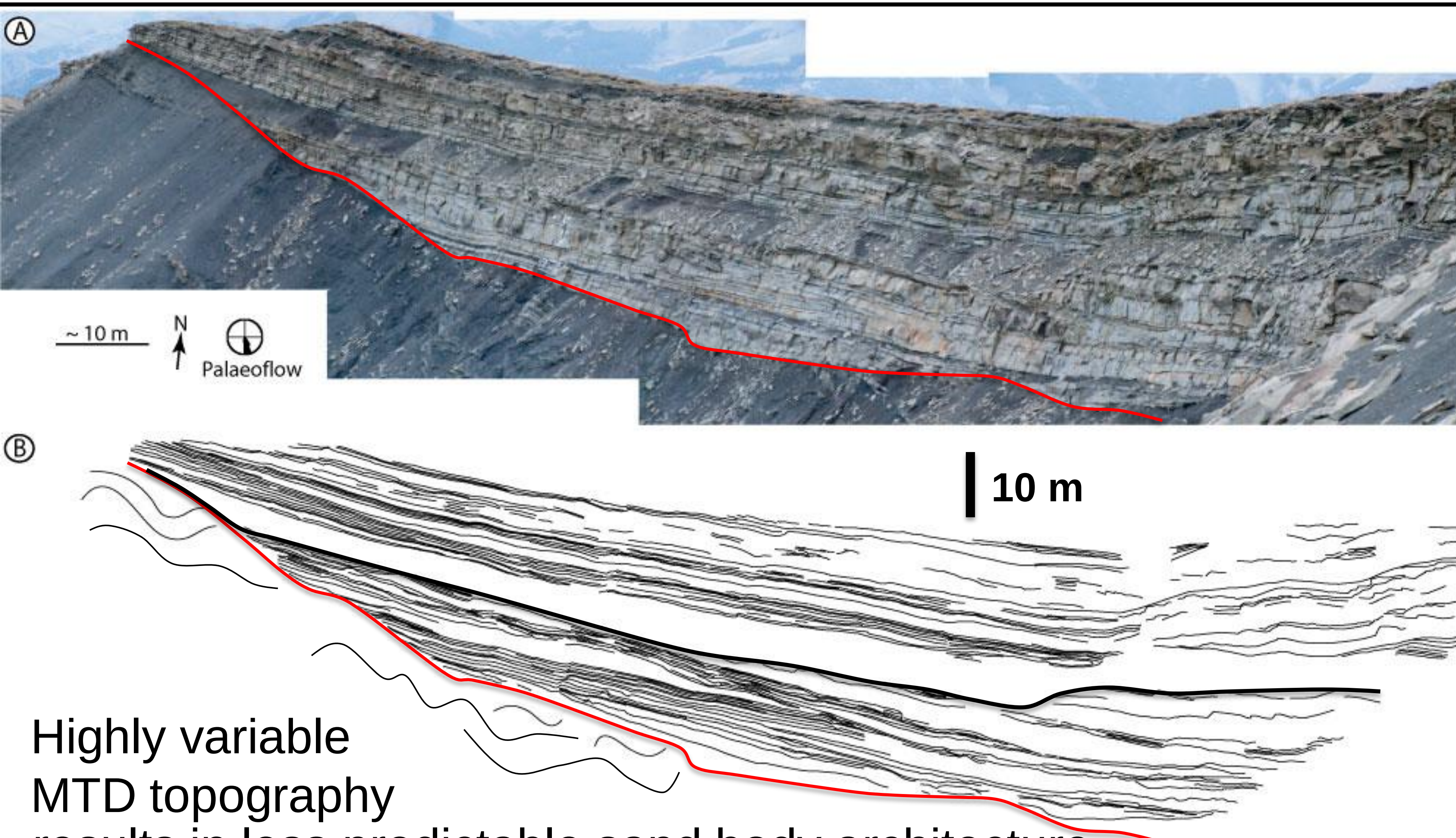
CHILE SLOPE SYSTEMS



Sand bodies are generally tabular – the meso-scale geometry that does exist is associated with underlying MTDs

Influence of MTD topography

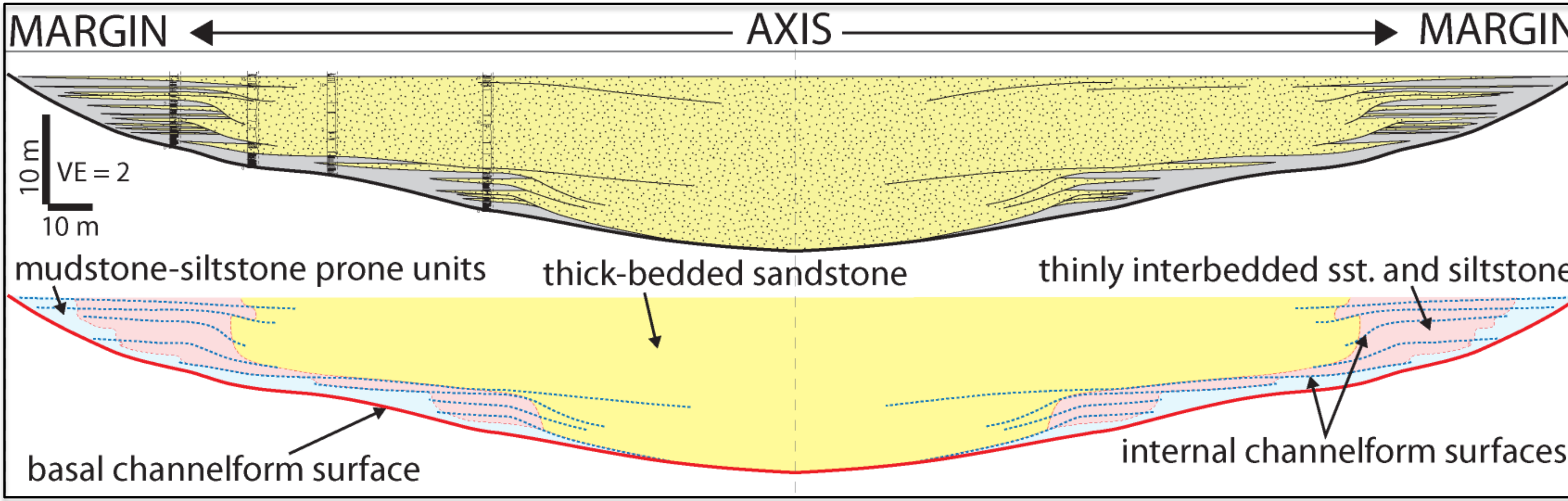
CHILE SLOPE SYSTEMS

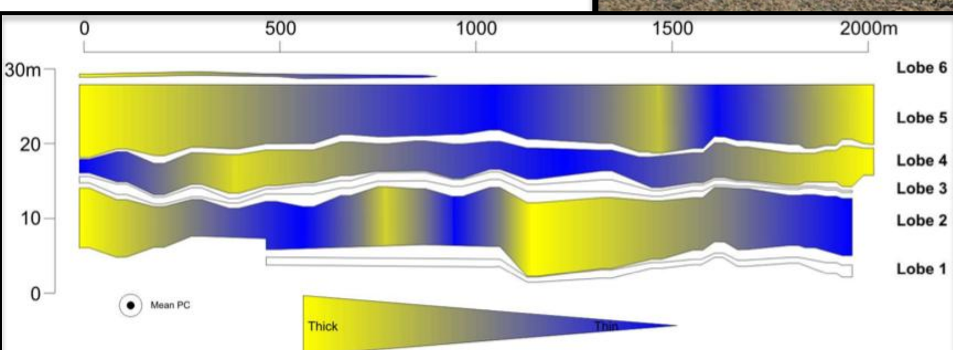


Highly variable
MTD topography
results in less predictable sand body architecture
(compared to more systematic channels)

Armitage et al. (2009); *J. Sed. Research*

Lateral facies prediction in deep-water sand bodies

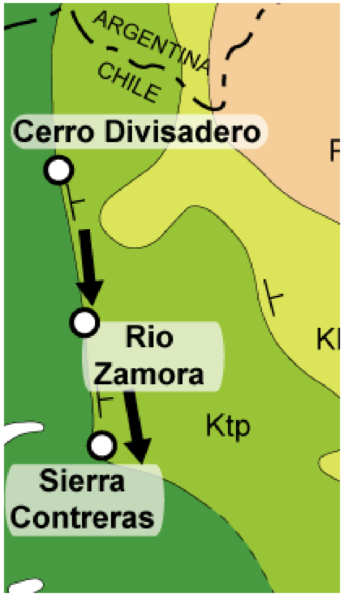




Prelat et al. (2010)

Dave Hodgson explaining lobe architecture, Tanqua Karoo

Ongoing work → Rio Zamora transect



New project in well exposed region between Divisadero and Contreras aims to:

(1)correlate sand bodies at km-scale
(2)examine internal facies patterns w/in context of topography

Northern Tres Pasos sand body architecture

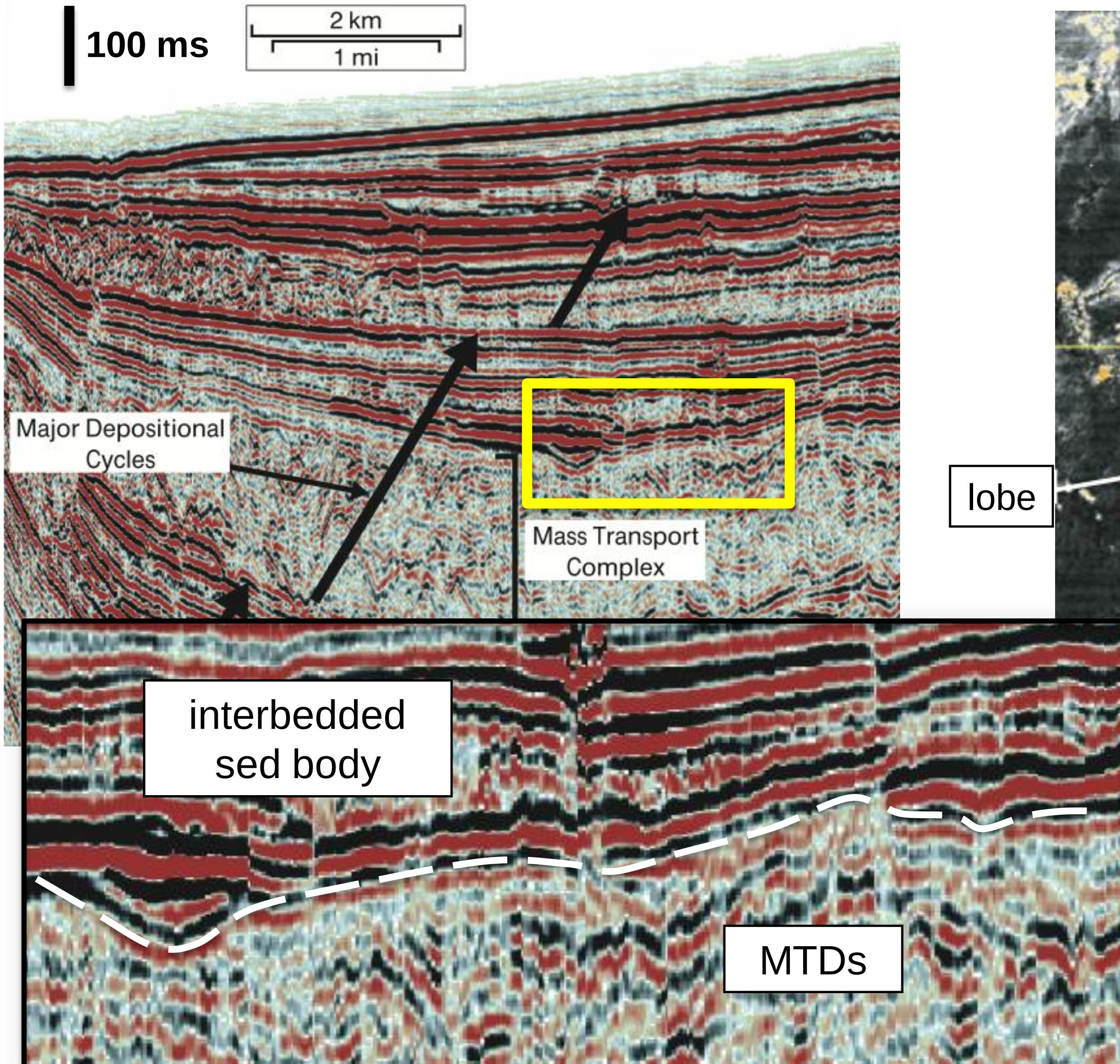
- We *do* observe lateral facies changes at the element scale (5-20 m thick mappable sedimentary bodies) … but, relationships are not as systematic* compared to channel-fills of the southern TP

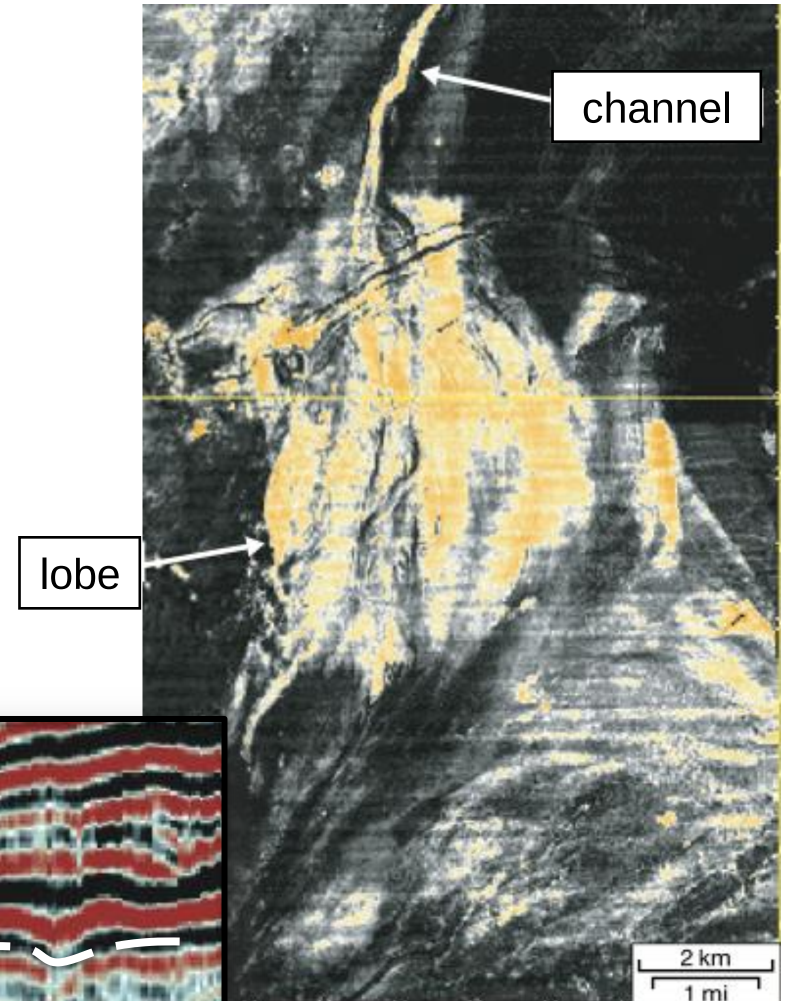
- Variable topography (as a result of mass wasting, slope creep, etc.) imparts a significant influence on sand-laden turbidity-current processes

- These sand bodies have some internal characteristics of lobes (e.g., Tanqua Karoo of Prelat et al., 2010); however, their overall geometry is lenticular

* consider this a hypothesis … we need to collect more data and compile the statistics

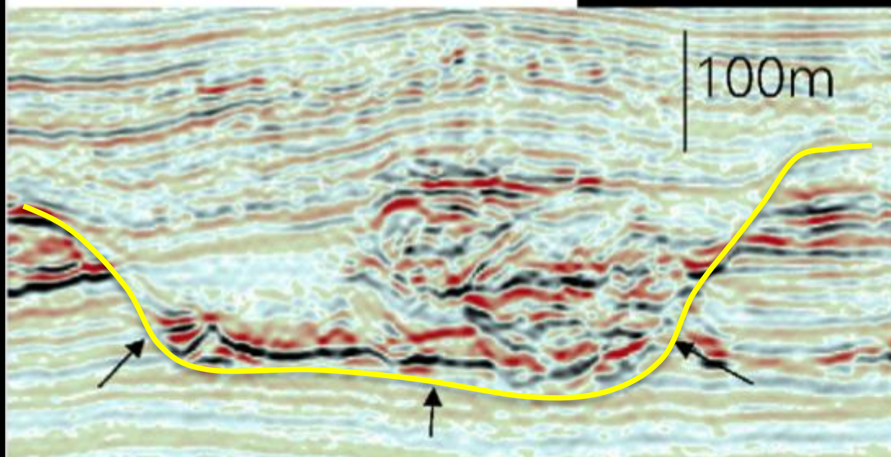
Short-lived accumulation vs. long-lived conduit?



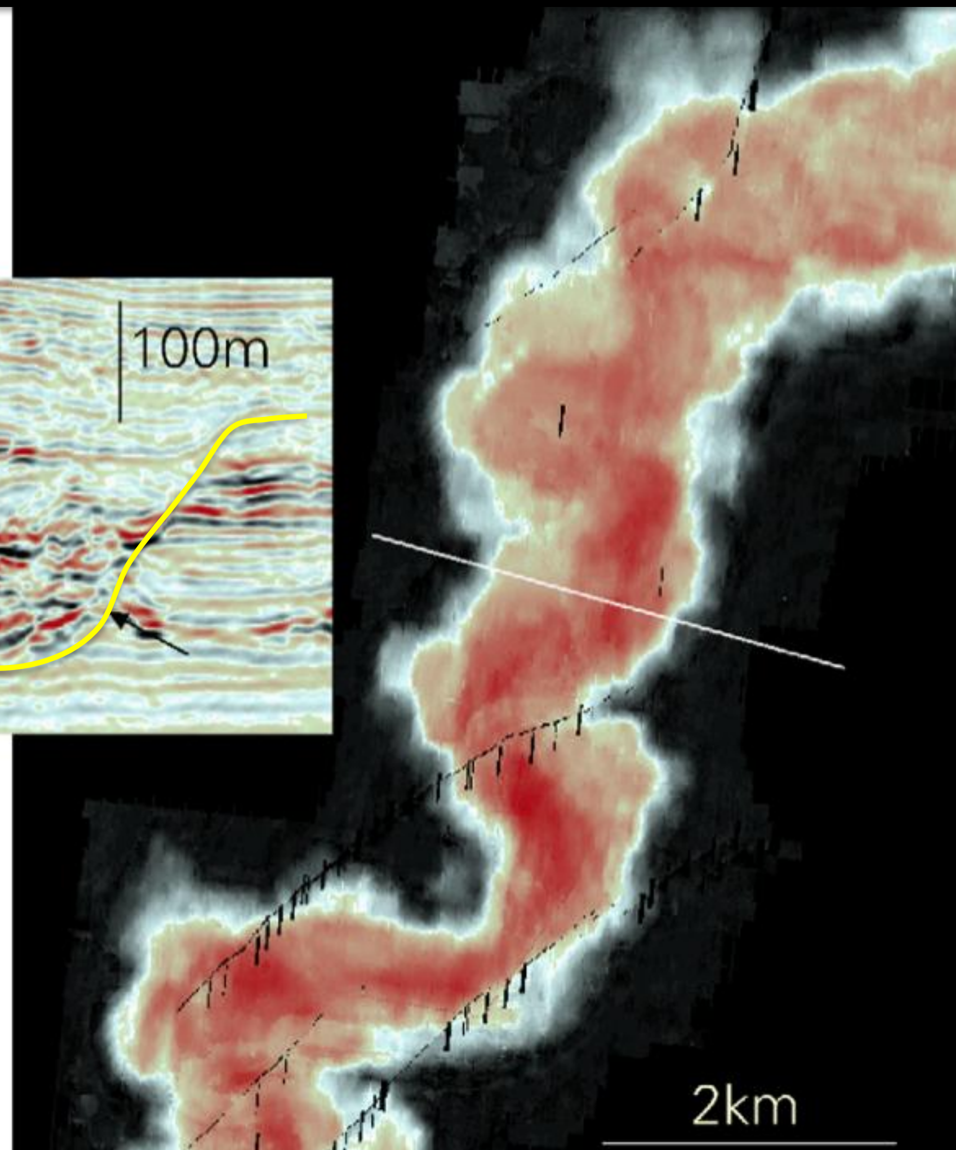


Adedayo et al. (2005); *AAPG Bulletin*

Short-lived accumulation vs. long-lived conduit?

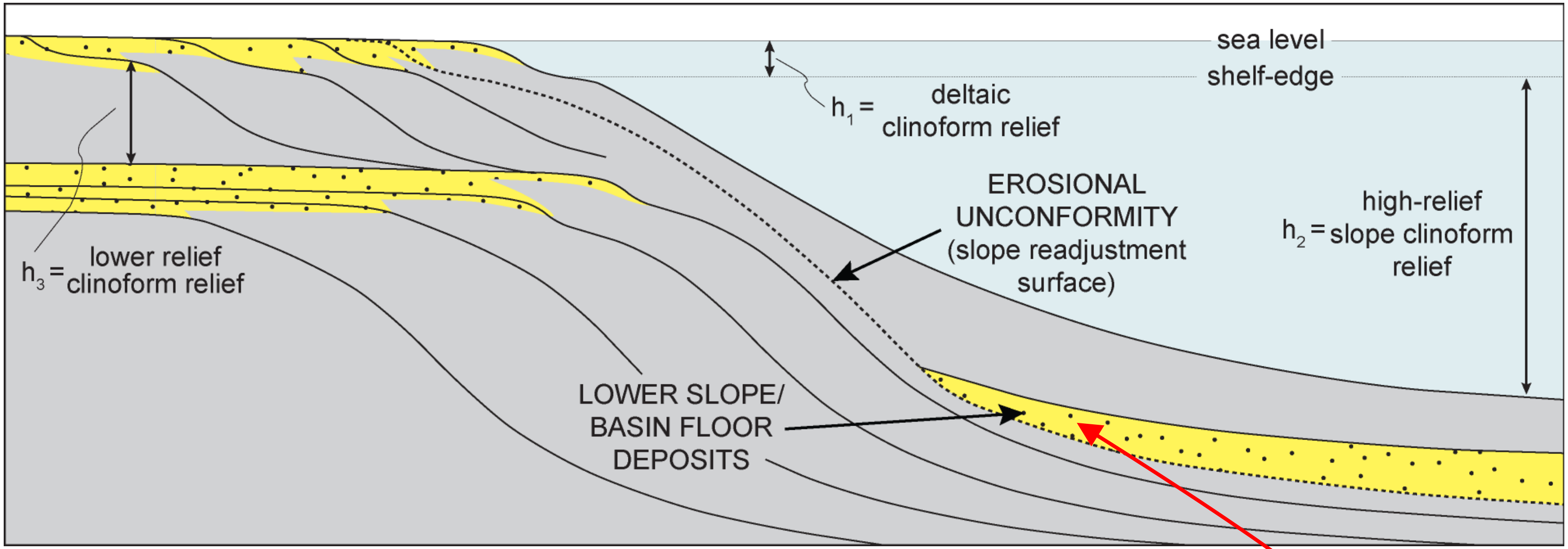


Mayall et al. (2006); *Mar. & Petrl. Geol.*



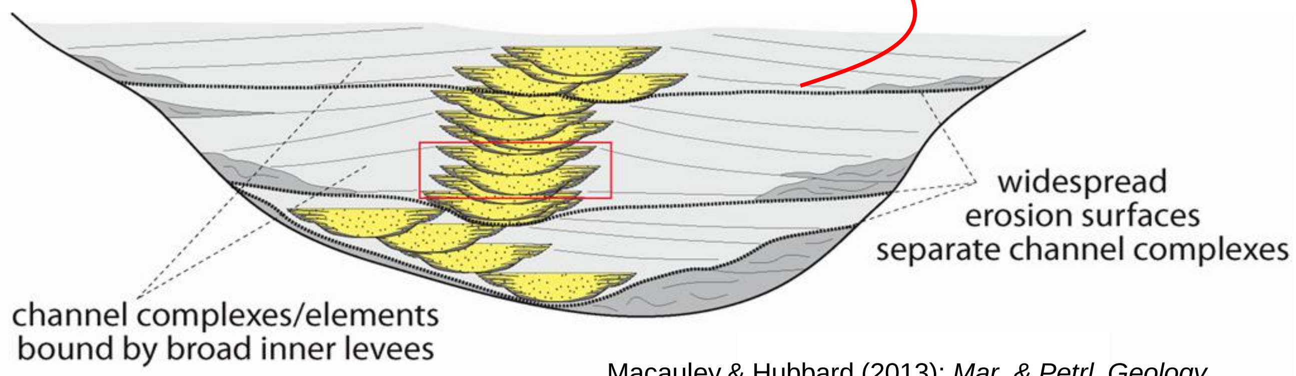
Adeogba et al. (2005); *AAPG Bulletin*

Who Cares? So What?



Bauer and Hubbard (in prep)

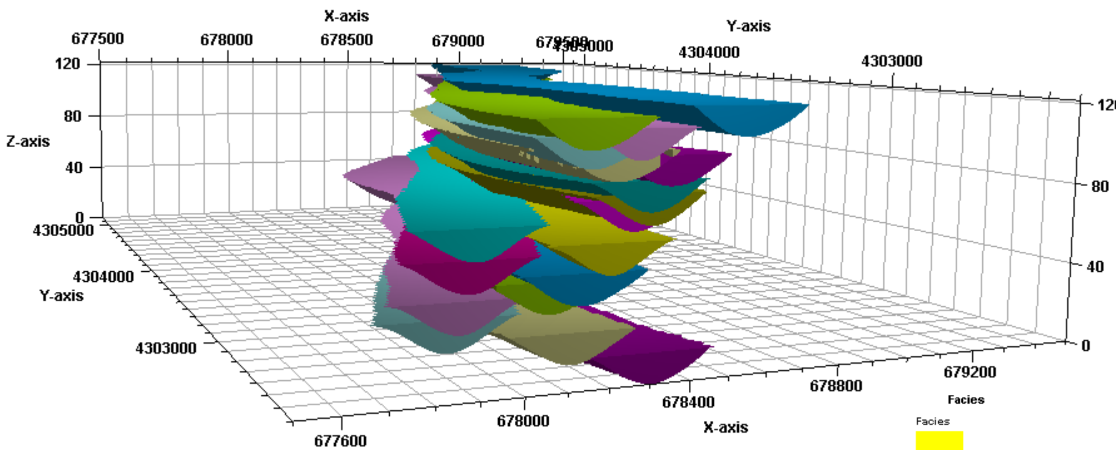
Improved prediction of reservoir-scale patterns from larger-scale stratigraphic context



Macauley & Hubbard (2013); *Mar. & Petrl. Geology*

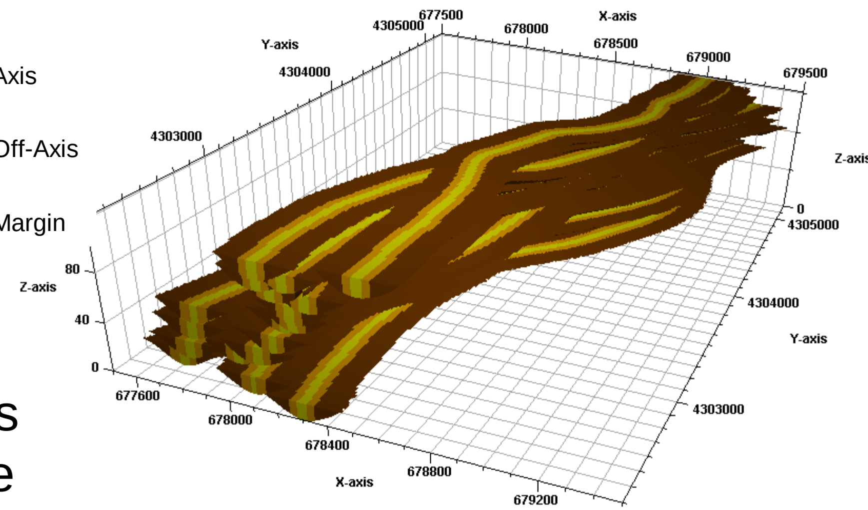
Who Cares? So What?

CHILE SLOPE SYSTEMS



ongoing work by Lisa Stright and students

For example, these outcrop-constrained architectural models being used to examine reservoir connectivity.



Depicted intra-channel facies relationships constrained by southern Tres Pasos outcrops (and comparable to other outcrop/subsurface examples).

We can't build reservoir models capturing facies relationship for lenticular slope sand bodies until we develop a comparable conceptual model

CHILE SLOPE SYSTEMS

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Collaborators and Magallanes Basin gurus: Andrea Fildani, Jake Covault, Julie Fosdick, Zane Jobe, Anne Bernhardt, Zoltan Sylvester, Dominic Armitage, and many more!

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