# The Influence of Tectonic Evolution on Deep-Water Stratigraphic Architecture: Upper Cretaceous, Magallanes Basin, Chile*

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## Abstract

The impact of tectonic processes on the evolution of sedimentary basins and their stratigraphic architecture is significant. Patterns of uplift and subsidence in space and time influence fundamental boundary conditions of depositional systems, such as basin-margin relief, sediment supply, and dispersal. The fills of sedimentary basins contain robust records of such tectonic processes. The objective of this study is to combine an integrated analysis of provenance (e.g., detrital-zircon ages, sandstone composition, etc.) with high-resolution stratigraphy in order to assess the evolution of deep-water architecture within the context of mountain-building episodes and unroofing during basin development.

This analysis of the Cretaceous Magallanes Basin, Chile, provides constraints on depositional age, basin configuration, and source area, as well as insights into the evolution of ~4000 m of stratigraphic architecture during ~20 m.y. of basin filling. A robust provenance database, integrated with well-studied stratigraphic architecture, provides the first comprehensive record of the northern Magallanes foreland basin succession. The stratigraphic succession consists of three deep-water formations capped by a deltaic/shallow-marine unit, reflecting distinct phases of deposition, each with a distinct stratigraphic architecture (i.e., lobes, leveed channels, progradational slope systems). The transition from unconfined slurry-bed prone deposits of the Punta Barrosa Formation to erosional and levee-confined conglomerate-filled channel complexes of the Cerro Toro Formation is marked by the appearance of pre-foreland Jurassic igneous rocks in the detrital zircon record. This unroofing signal indicates the general timing of thrust-sheet emplacement and, thus, corresponding changes to the basin, which include

narrowing of the foredeep and introduction of abundant conglomeratic detritus. A subsequent transition from basin-axial channel-belt sedimentation to sandstone- and mass-transport-dominated prograding slope systems of the Tres Pasos Formation is characterized by additional input of pre-foreland material suggesting continued denudation of existing thrust sheets. The integrative approach of this study bridges the gap between provenance analysis and purely high-resolution stratigraphy in order to build a robust model of basin-filling stratigraphic architecture for prediction in frontier sedimentary basins.

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# The Influence of Tectonic Evolution on Deep-Water Stratigraphic Architecture

## Upper Cretaceous Magallanes Basin, Chile


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# Evolution of deep-water stratigraphic architecture

- Tectonically controlled **basin configuration** and geometry → stratigraphic change from relatively unconfined (Punta Barrosa) to focused/confined (Cerro Toro)

- Tectonically influenced **sediment supply** and **staging area characteristics** controlled availability and caliber of sediment (e.g., presence/absence of gravel)

- Variability in architectural style as a function of **basin-filling evolution** → stratigraphic change from axial channel-belt (Cerro Toro) to prograding slope systems (Tres Pasos)

- High-resolution stratigraphic characterization integrated with **robust provenance database** → improved understanding of basin fill at multiple scales and controls on evolution of architecture

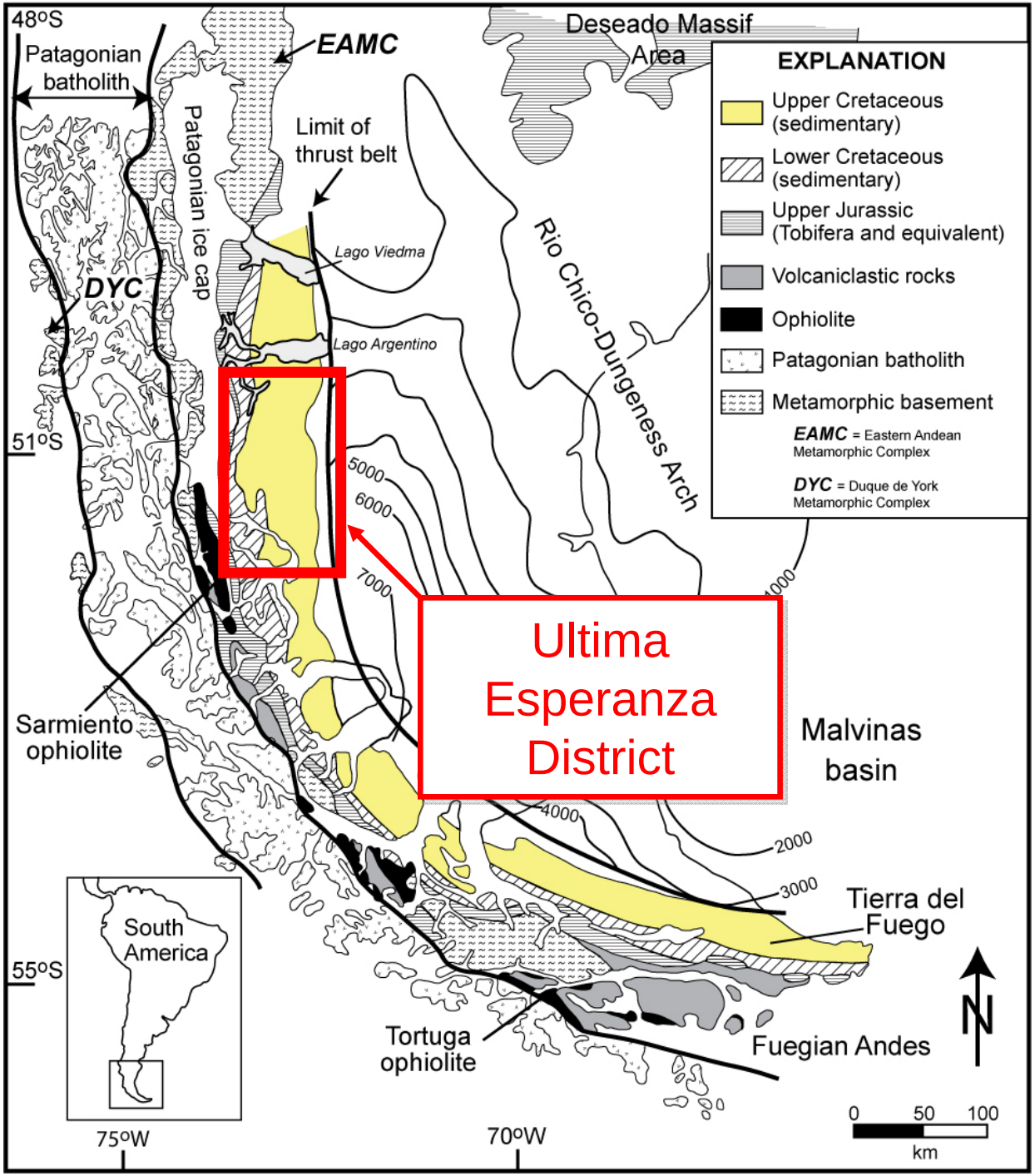
# Integrated stratigraphic and provenance database

- Synthesis of decades of sedimentologic and tectonic studies
  - Dott and students (University of Wisconsin-Madison; 1970s)
  - Wilson (Columbia University; 1970s-80s)
  - Eleven PhD dissertations (Stanford University; 1999-present)
  - Recent collaborative research between University of Calgary and Chevron (e.g., SEPM 2009 research conference and field guide)
- Stratigraphic database
  - 10s of thousands of meters of cm-scale measured sections
  - High-resolution geologic mapping covering 3000 $km^2$
  - Bed-tracing and photomosaic mapping of cliff-face architecture
  - 10s of thousands of paleocurrent measurements
- Provenance and structural data
  - Structural restoration and evolution of fold-thrust belt (see Fosdick et al., 2009)
  - 650 detrital-zircon ages from 13 samples
  - Sandstone composition (QFL) from >40 samples
  - Shale geochemisrty (REE) from >30 samples

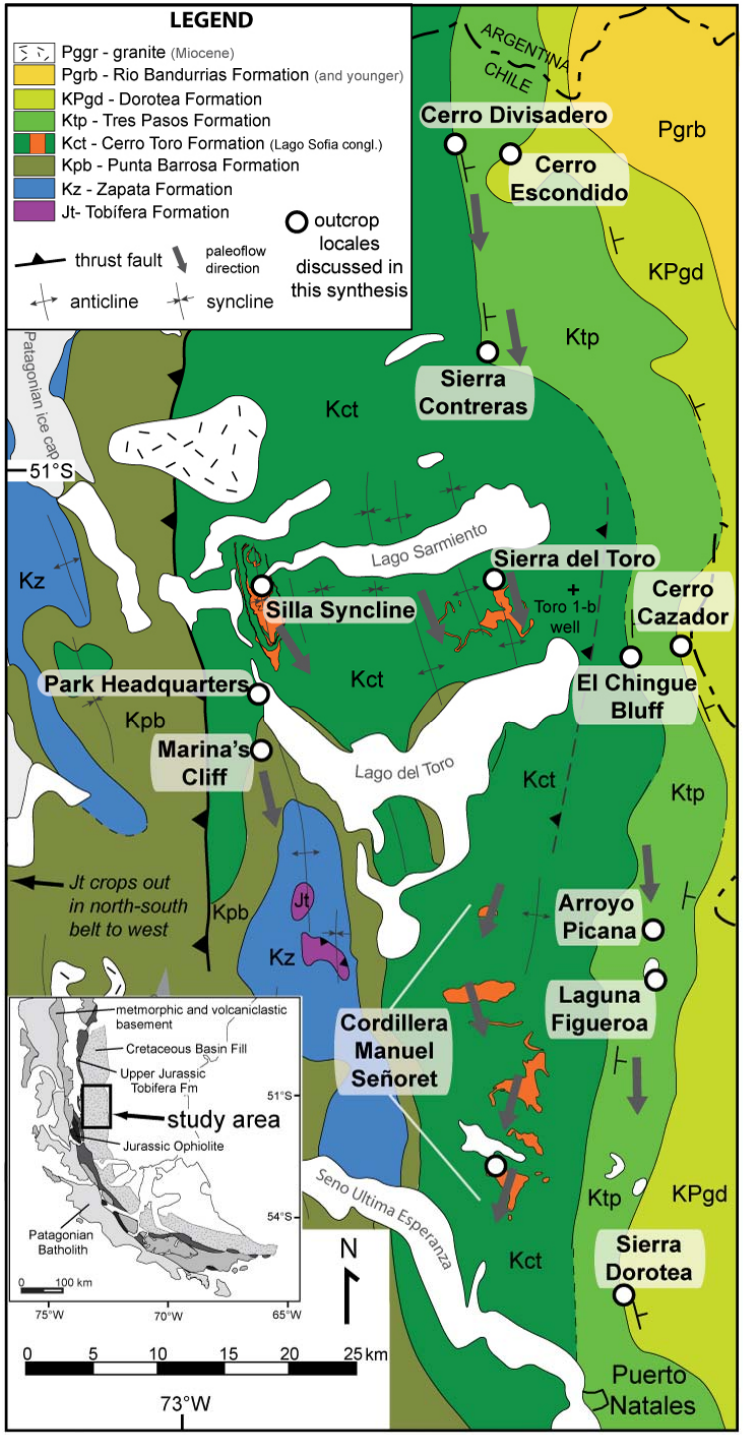
# Magallanes retro-arc foreland basin – southern South America (50-52°S)

Mesozoic-Cenozoic convergent margin orogenic system at southern end of 7000 km-long Andean Cordillera

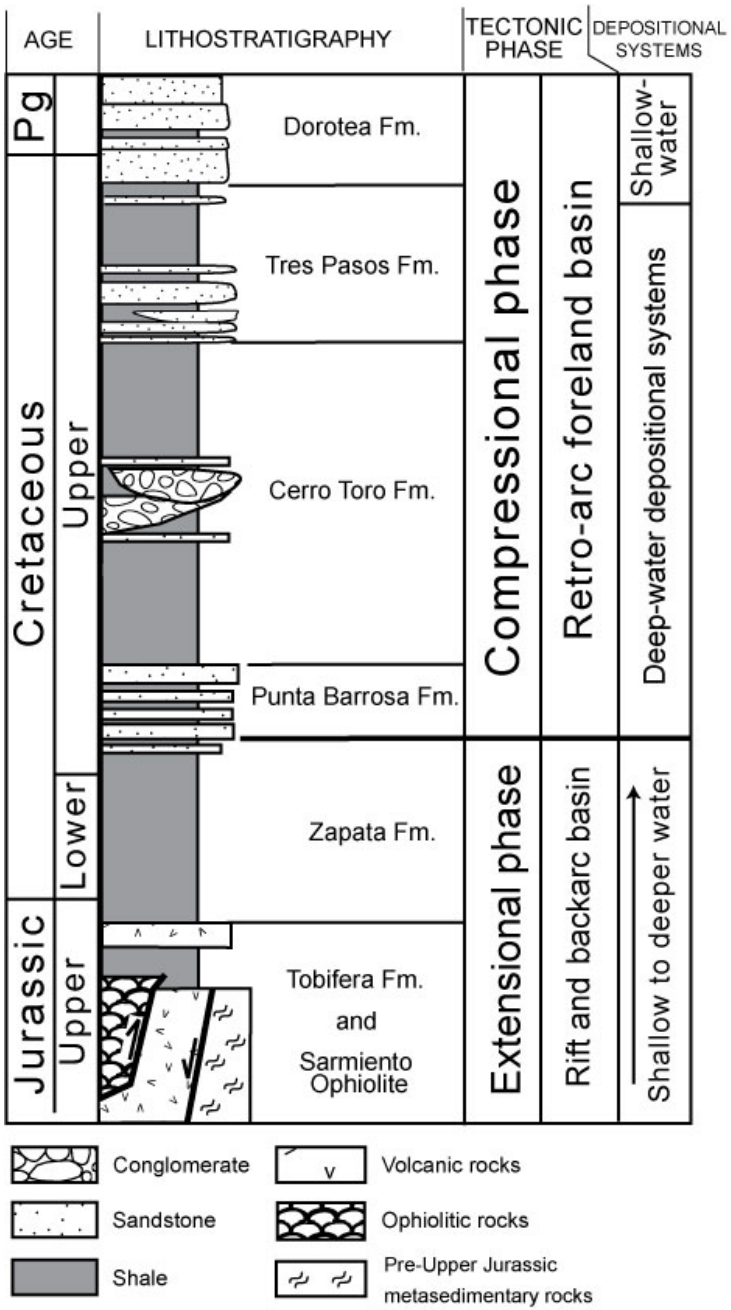




# Outcrops of Cretaceous foreland basin system

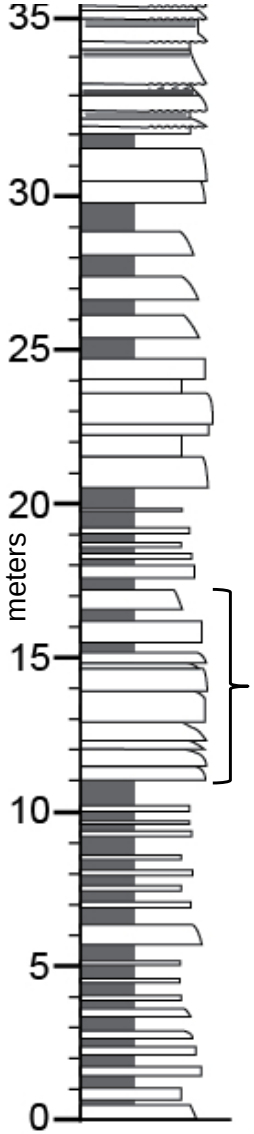


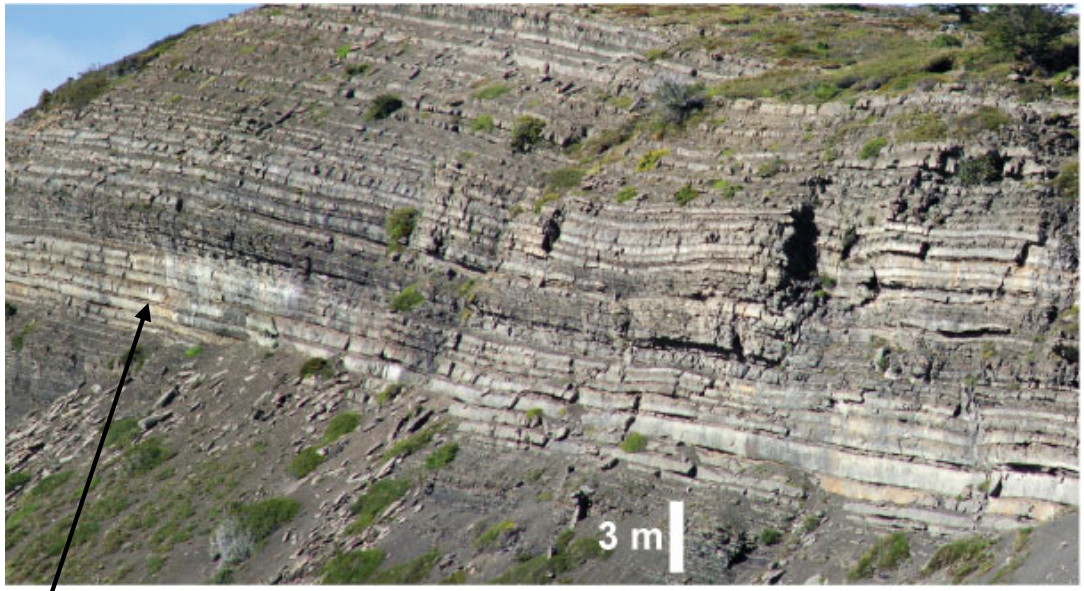

- Exceptional exposures of entire Mesozoic orogenic cycle
- Late Jurassic-Early Cretaceous extensional phase → **Rocas Verdes Basin**
- Late Cretaceous contractile phase → **Magallanes Basin**
- Foreland basin phase recorded by **>4000 m of predominantly deep-marine strata** in Ultima Esperanza District



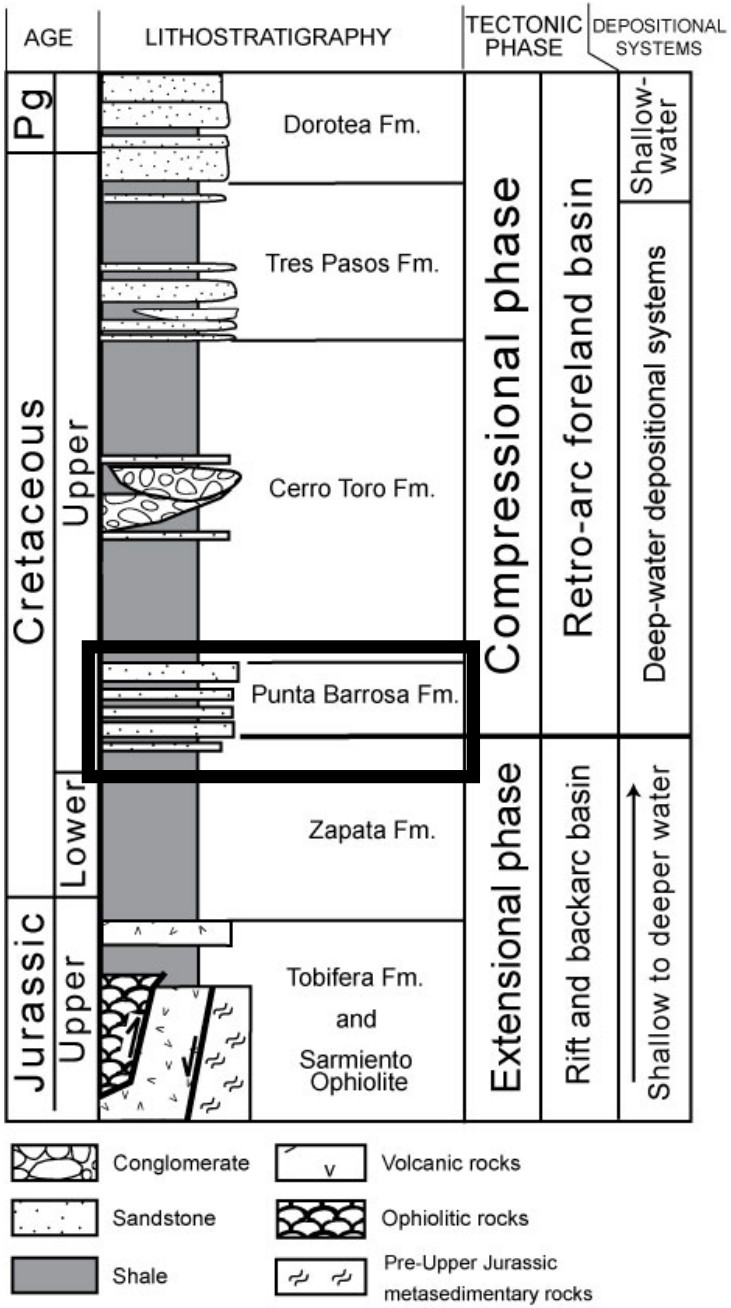
# Magallanes basin sedimentary fill – **Punta Barrosa Formation**

Punta Barrosa Fm is characterized by thin- to medium-bedded 'sheet'-like turbidite deposits → interpreted to represent **unconfined basin plain** depositional environment



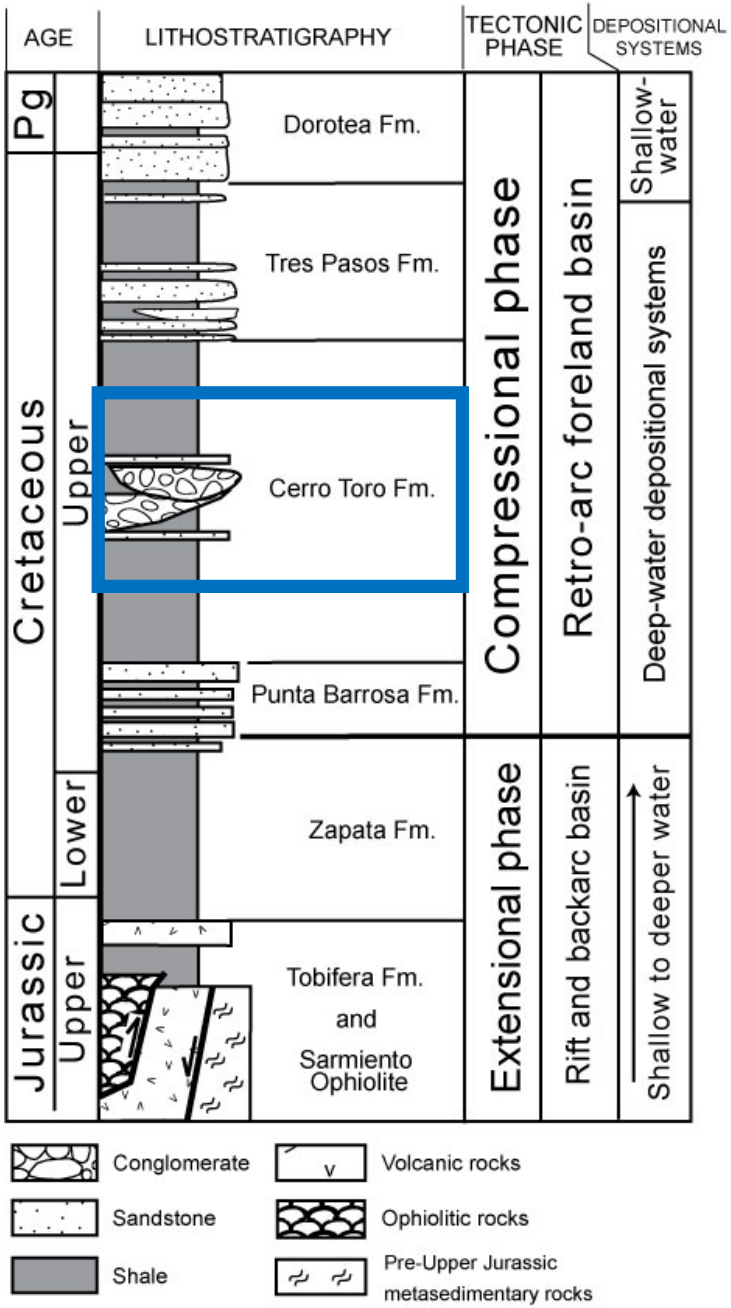

Romans et al. (submitted); *Marine and Petroleum Geology*



# Magallanes basin sedimentary fill – Cerro Toro Formation

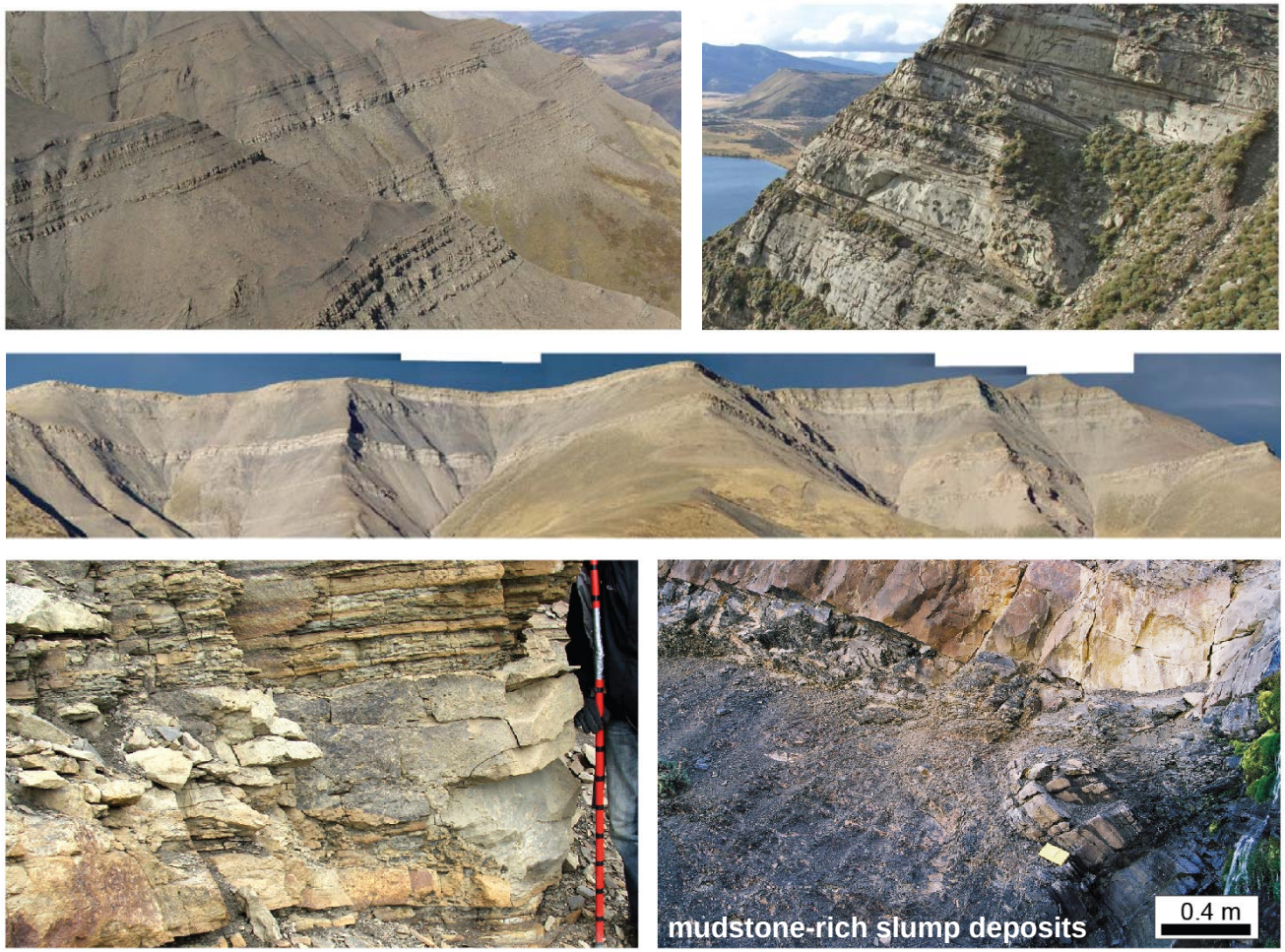
Cerro Toro Fm is dominated by shale with thick (>300 m) turbiditic conglomerate and sandstone member → interpreted to represent **axial submarine channel-belt** deposits (~8-10 km wide; parallel to strike of orogenic belt)


Jobe et al. (2009) and Fildani et al. (2009); *SEPM Guidebook #10*

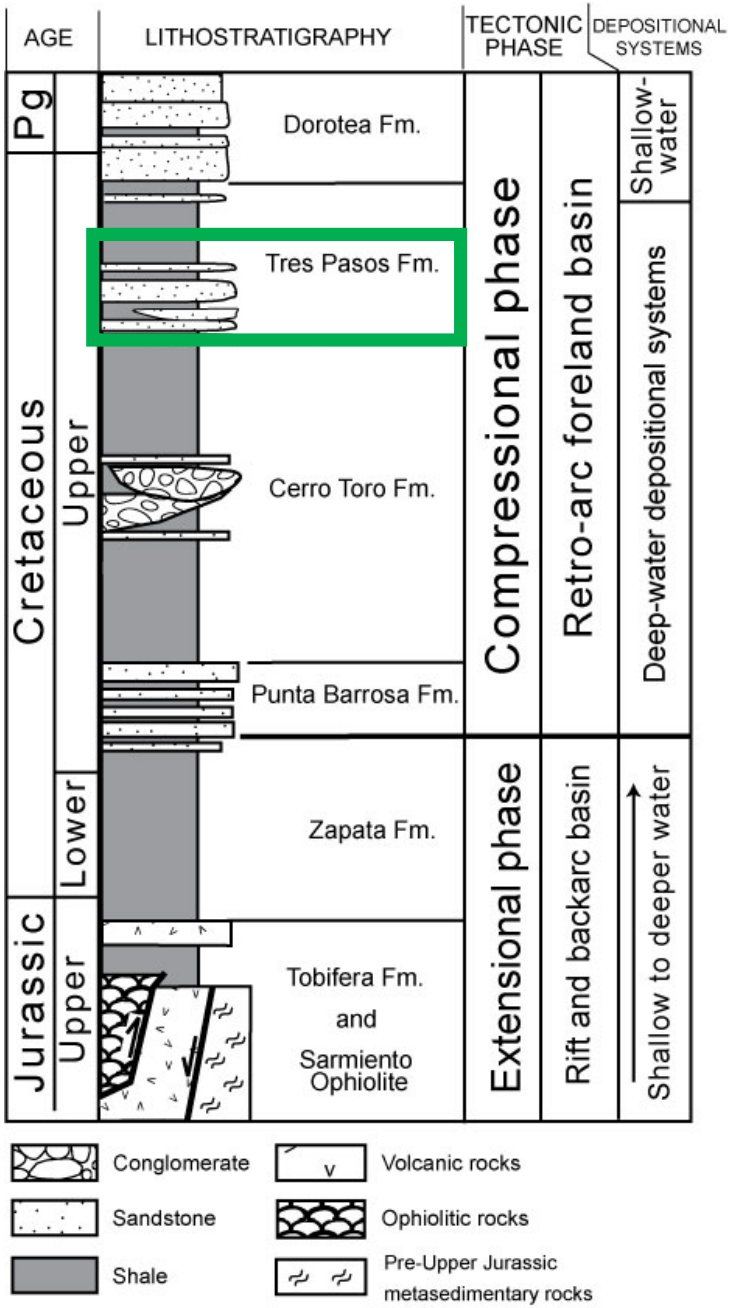


# Magallanes basin sedimentary fill – **Tres Pasos Formation**

Tres Pasos Fm is characterized by mudstone-rich mass-failure deposits interbedded with sandstone-rich turbidite packages → interpreted to represent deposits of **prograding, delta-fed slope systems** that filled in deep-marine basin from north-to-south

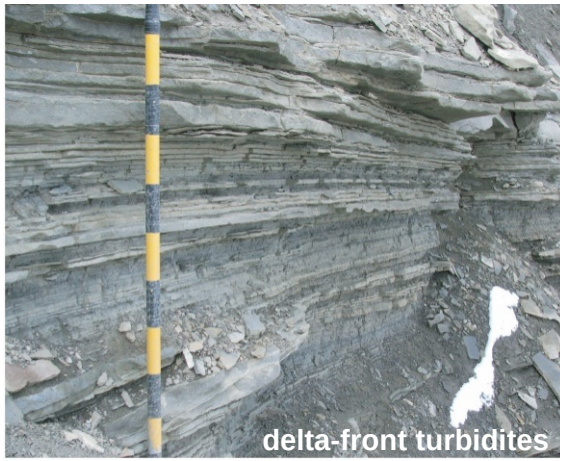



Romans et al. (2009) and Armitage et al. (2009); *SEPM Guidebook #10*



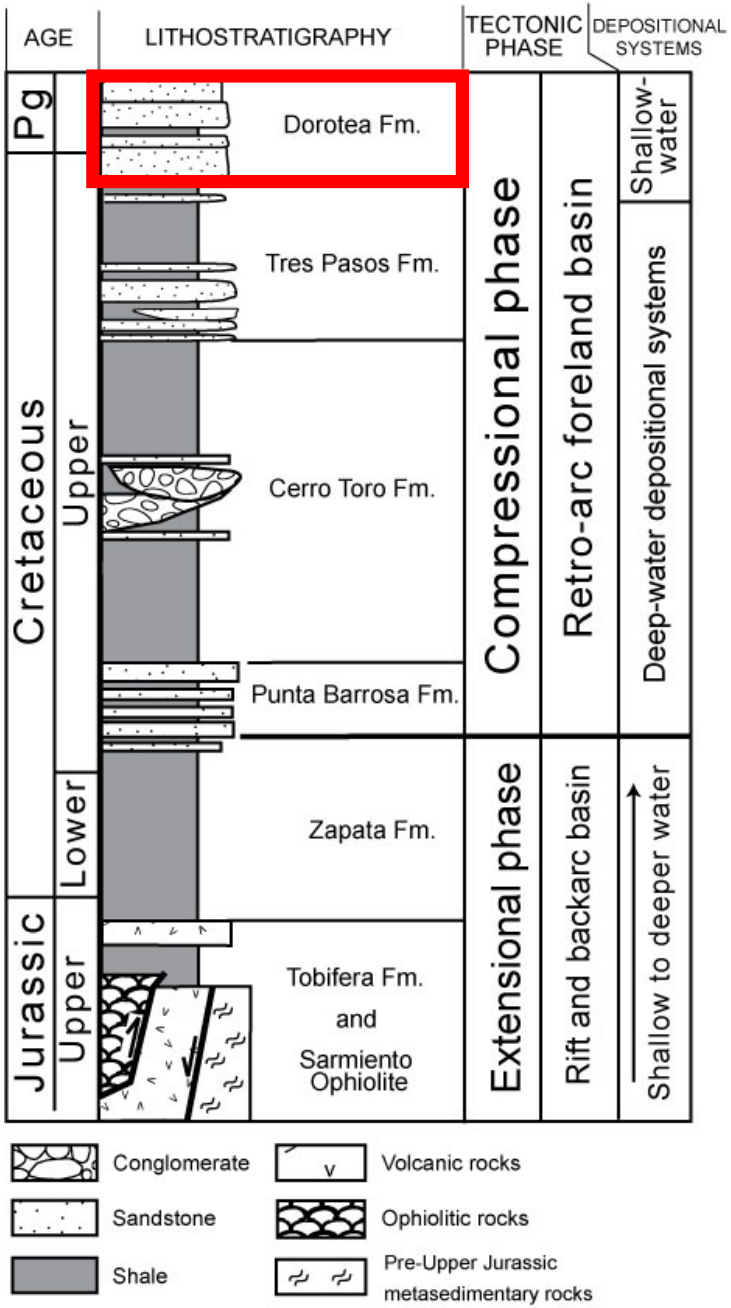
# Magallanes basin sedimentary fill – **Dorotea Formation**

Dorotea Fm is characterized by shallow-water deposits (e.g., hummocky cross-stratification) and prograding deltaic successions → interpreted to represent **shallow-marine/shelf and deltaic** depositional environments

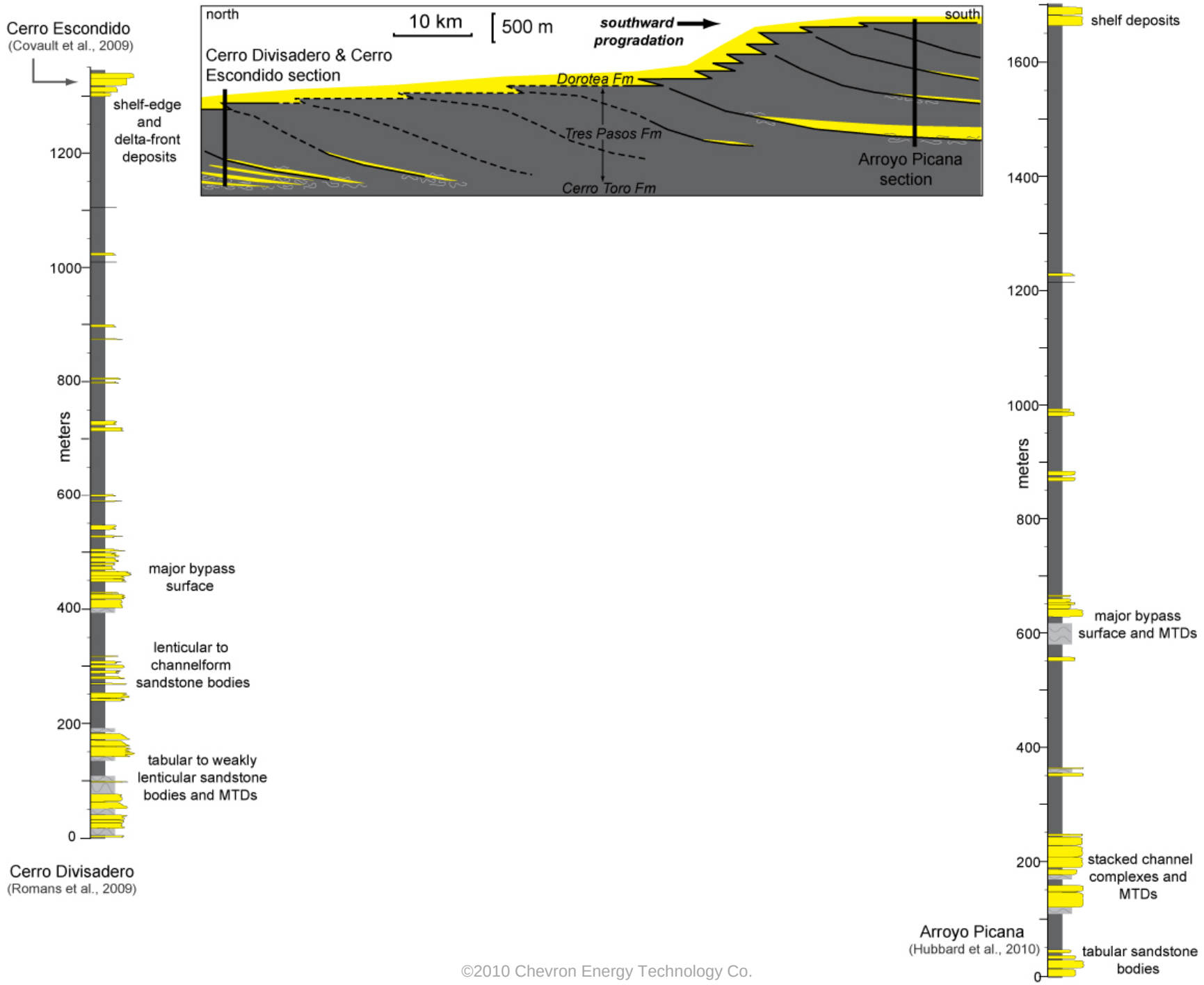





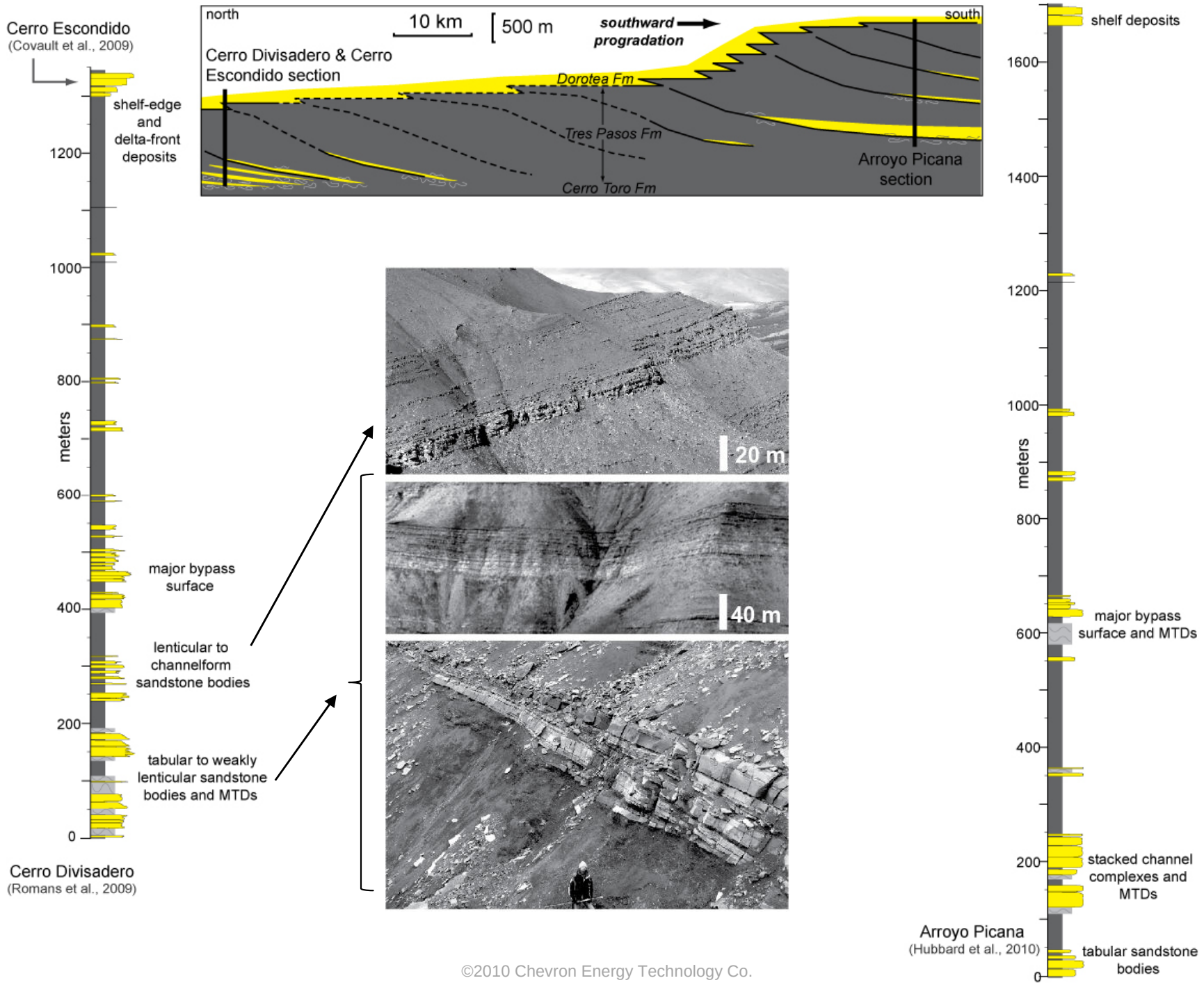

Covault et al. (2009); *SEPM Guidebook #10*



# Prograding slope systems – Tres Pasos Formation and Dorotea Formation



# Highly variable slope sand body architecture – **Tres Pasos Formation**



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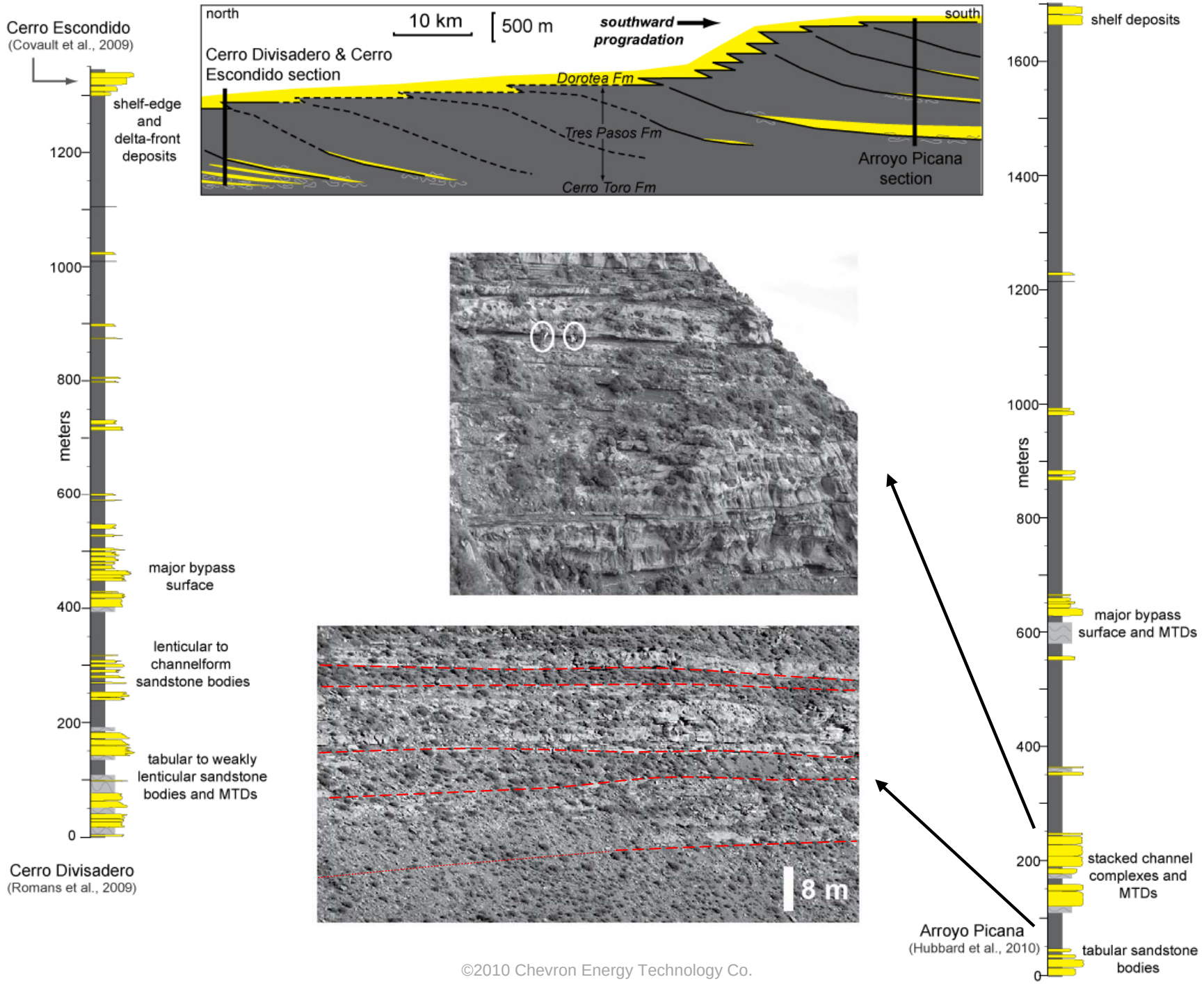
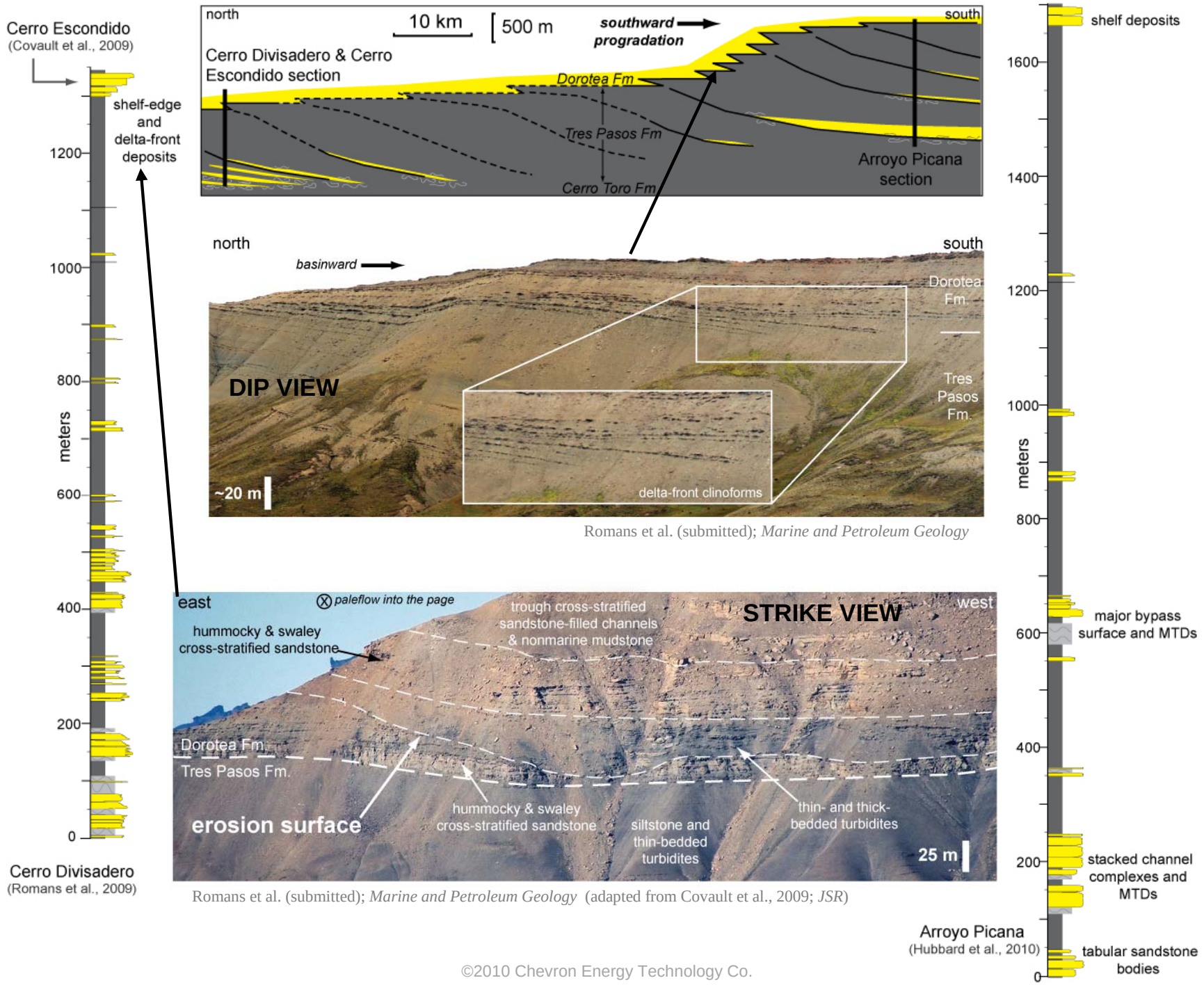
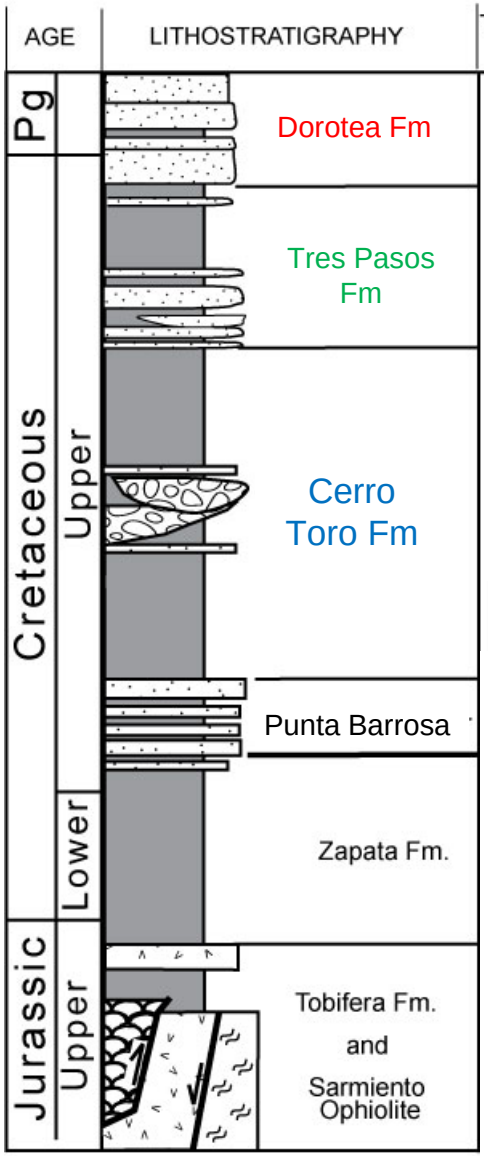
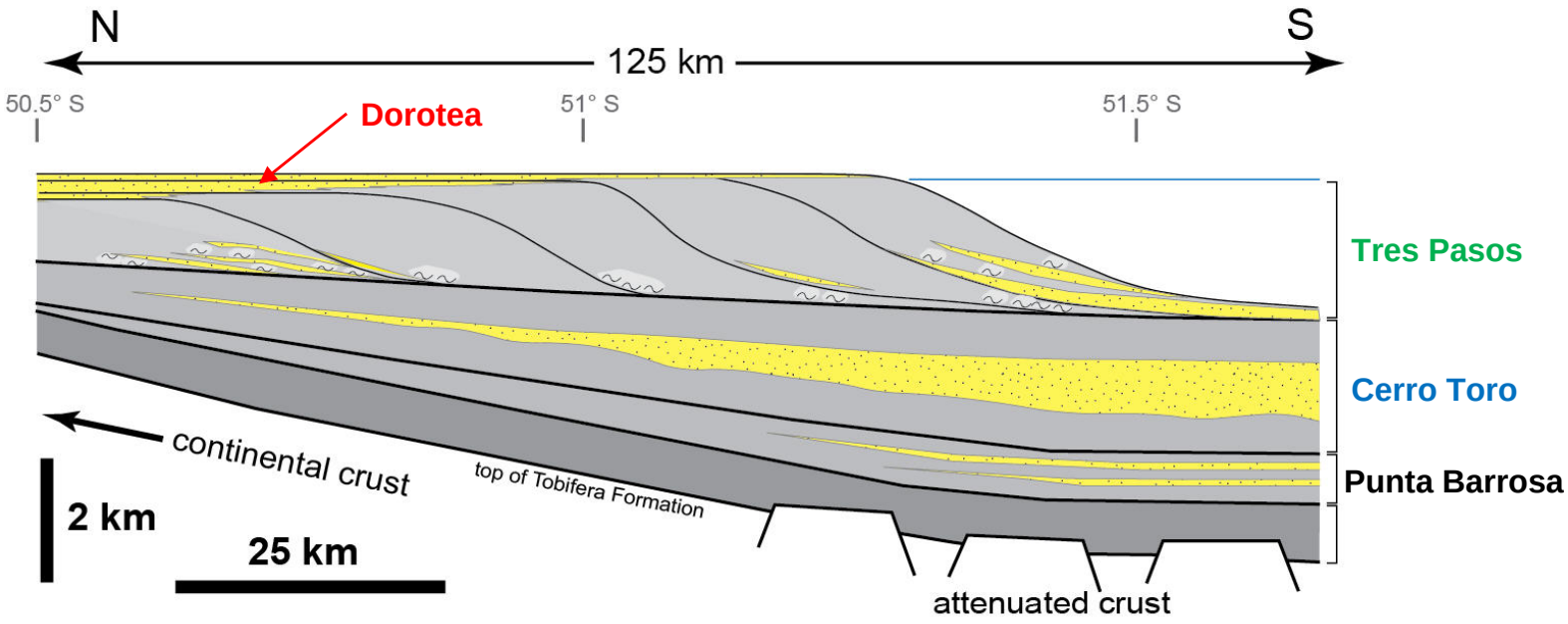


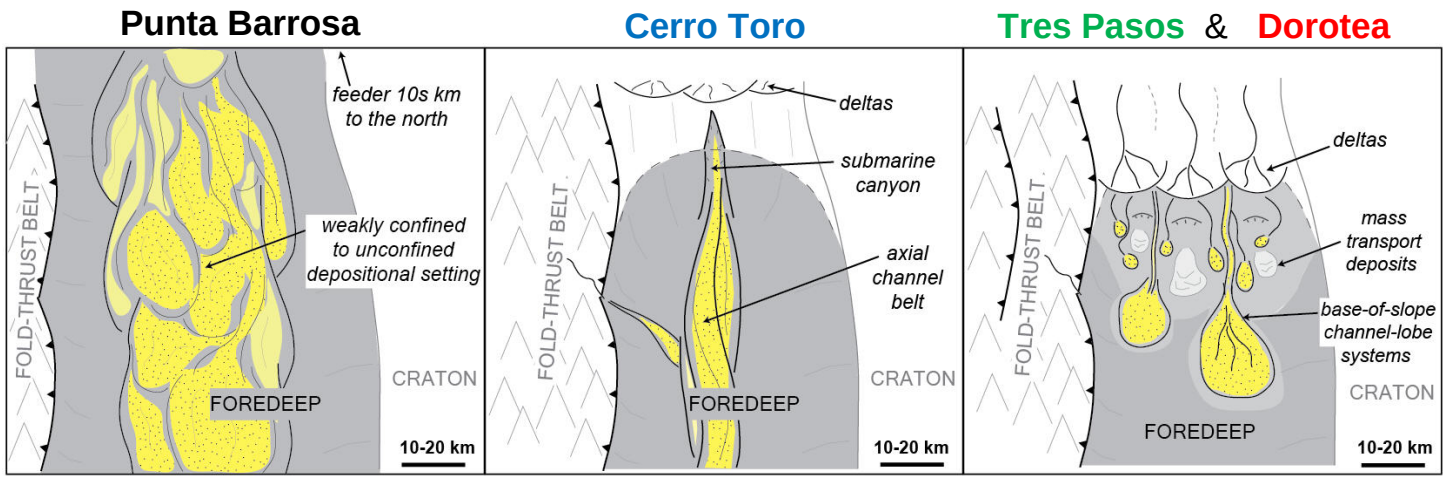
# Shelf, shelf-edge, and deltaic systems – **Dorotea Formation**



# Depositional systems and basin evolution



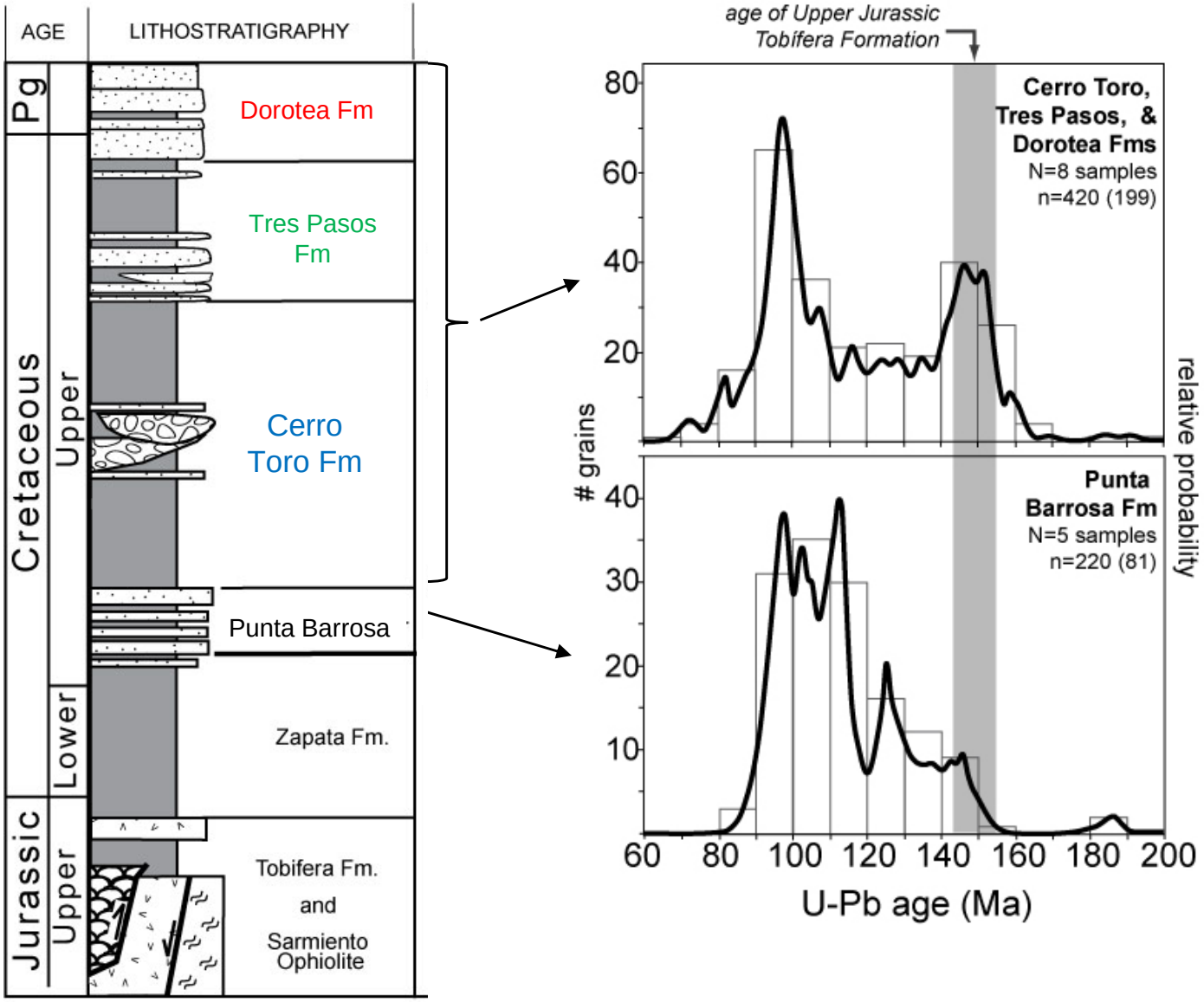




*basin evolution through time* →

Fildani, Hubbard, & Romans (2009); *SEPM Guidebook #10*

# Detrital-zircon ages constrain timing of thrust sheet emplacement




Introduction of Upper Jurassic age zircons from Cerro Toro Fm and younger formations → emplacement of Tobifera Fm thrust sheets in source area

Data from Romans et al. (2010); *Basin Research* and Fildani et al. (2003); *Geology*
Figures from Romans et al. (submitted); *Marine and Petroleum Geology*

# Sandstone composition and sediment dispersal patterns

Cerro Toro Fm sandstone composition at Silla Syncline (Crane, 2004) compared to Cordillera Manuel Senoret (Valenzuela, 2006) → tributary vs. axial channel belt

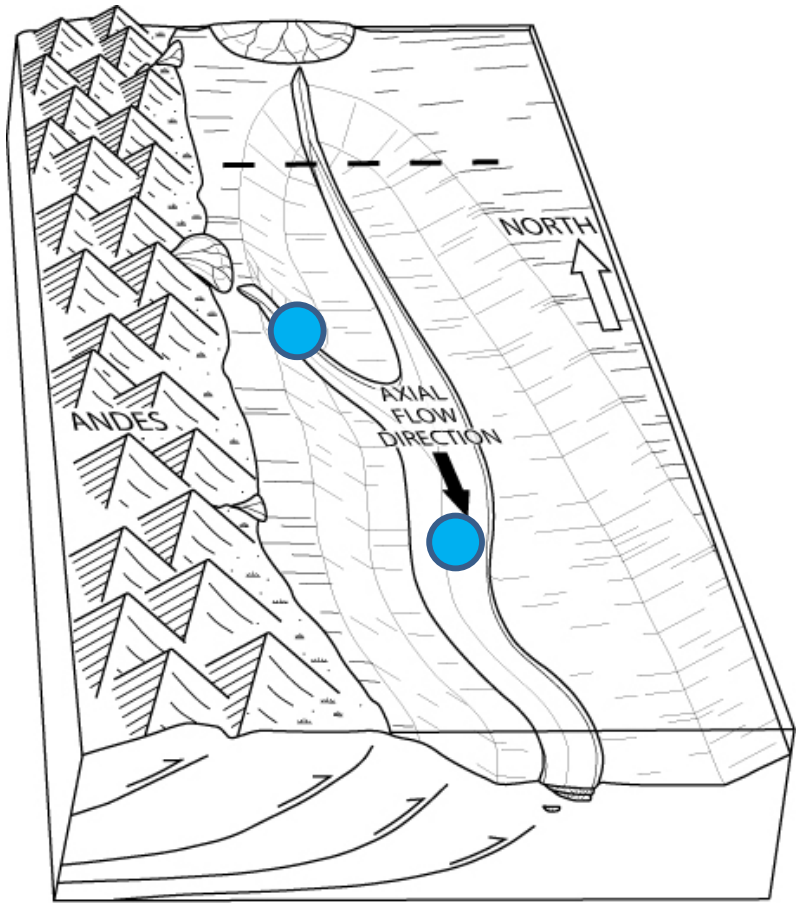
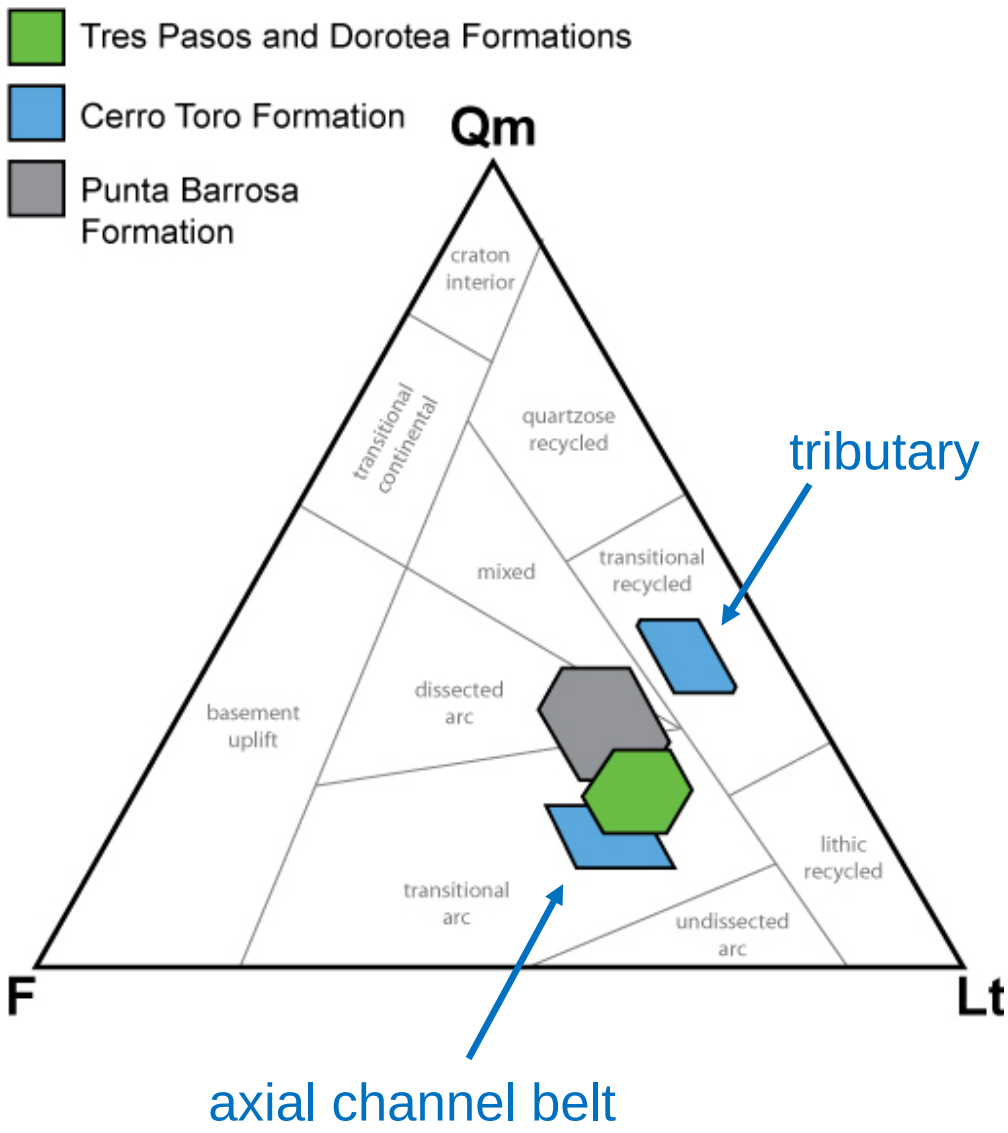
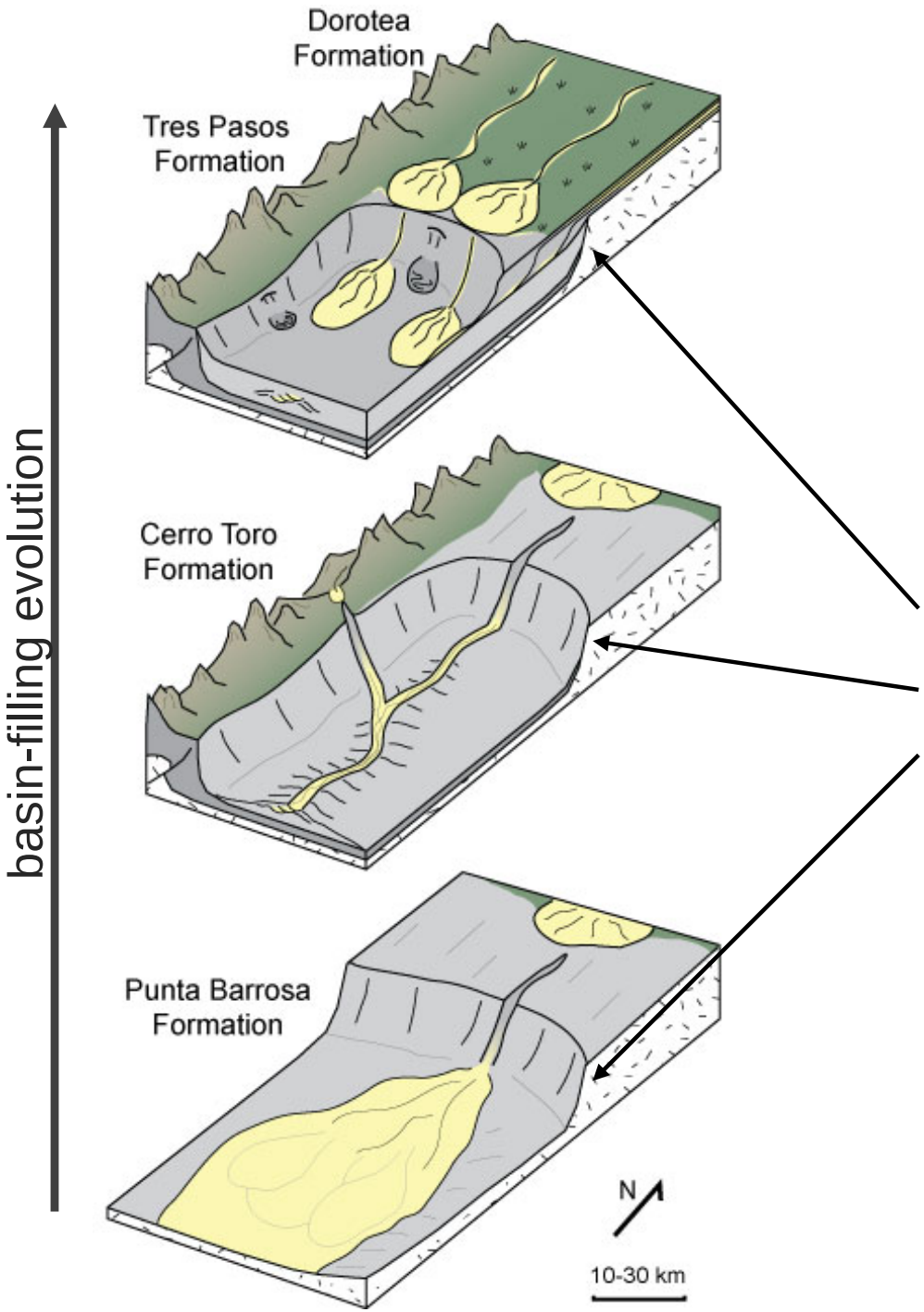



diagram from Hubbard et al. (2008); *Sedimentology*

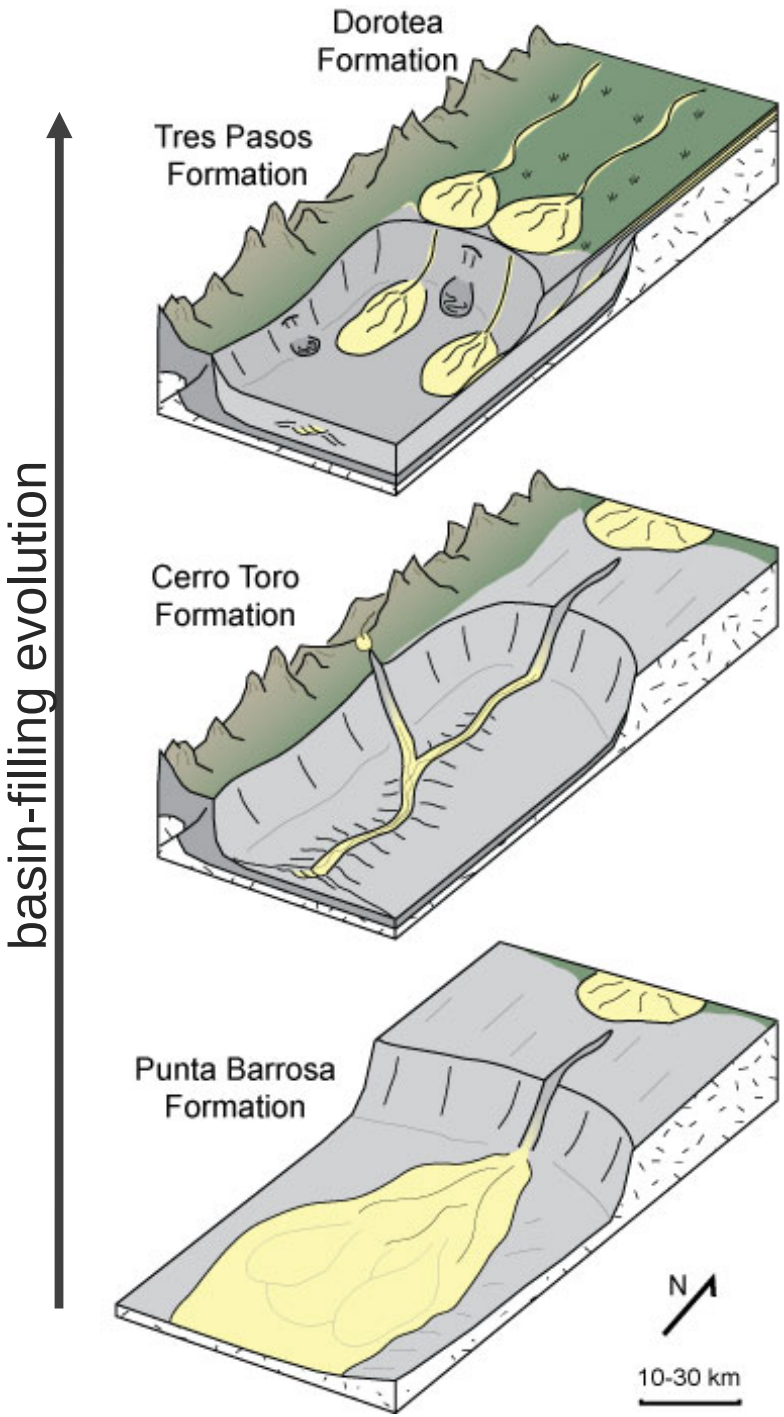


# Evolution of deep-water architecture in the Magallanes Basin




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

# Evolution of deep-water architecture in the Magallanes Basin



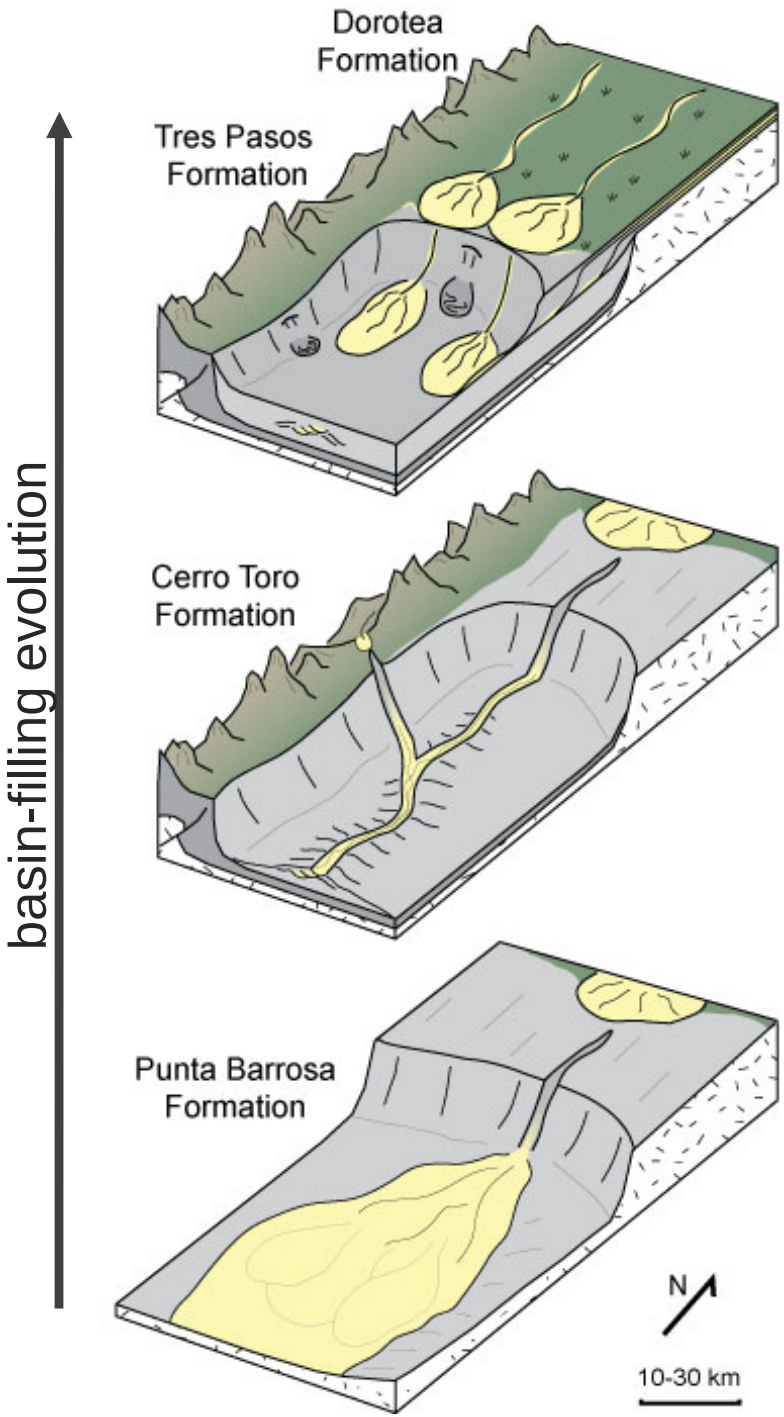

## Basin Configuration

Continued southward progradation of feeder systems into relatively narrow basin

Uplift in fold-thrust belt → deepening / narrowing of foredeep and development of axial dispersal pattern

Unconfined (to partially ponded?) in relatively wide foreland basin

# Evolution of deep-water architecture in the Magallanes Basin

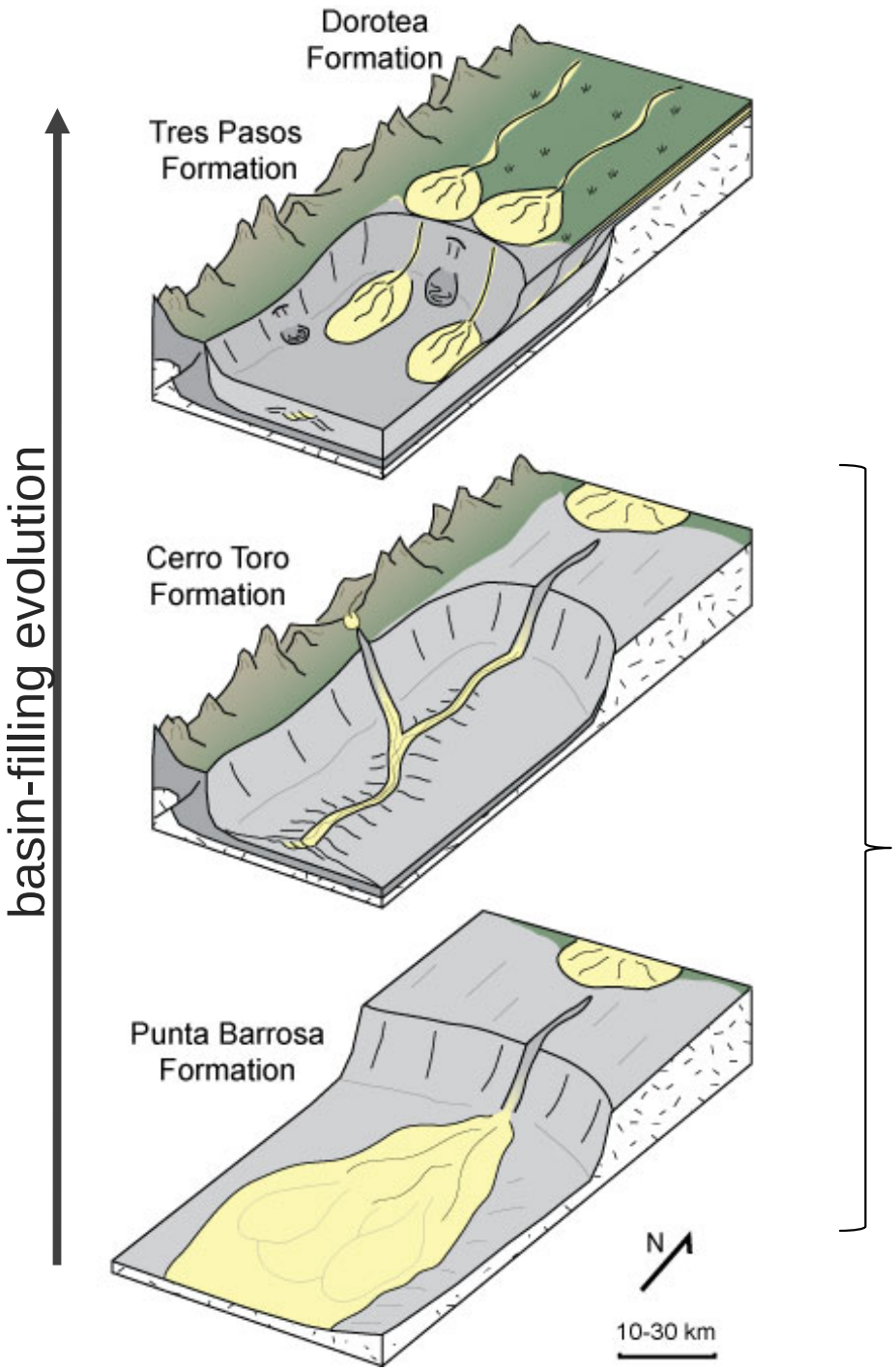



## Sediment Supply & Staging Area

Sequestering much of gravel in fluvial / coastal plain → sand making it to delta-fed slope systems

Uplift in fold-thrust belt → introduction of gravel-caliber sediment to basin via bypass-dominated slopes

# Evolution of deep-water architecture in the Magallanes Basin




## Evolution as function of filling

Deep-water accommodation diminished during filling → progradation and development of 'in grade' slope systems

Bypass-dominated northern margin → or, 'out of grade' deep-water systems

# Evolution of deep-water stratigraphic architecture

- Tectonically controlled **basin configuration** and geometry → stratigraphic change from relatively unconfined (Punta Barrosa) to focused/confined (Cerro Toro)

- Tectonically influenced **sediment supply** and **staging area characteristics** controlled availability and caliber of sediment (e.g., presence/absence of gravel)

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# Acknowledgements

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Stanford Project on Deep-Water Depositional Systems (SPODDS)
- industry-sponsored consortium since 1995 co-directed by Steve Graham and Don Lowe
- former and current students whose work that contributed to this synthesis
  - Andrea Fildani (Chevron)
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  - Will Crane (Chevron)
  - Steve Hubbard (Univ of Calgary)
  - Brian Romans (Chevron)
  - Jake Covault (Chevron)
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