

# **PS Stratigraphic Evolution of High Relief Slope Clinoforms from Shelf-Edge to Basin Floor, Magallanes Basin, Chile\***

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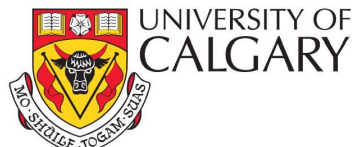
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## **Abstract**

Few examples of high-relief clinoforms have been studied in outcrop due to the inability to recognize seismic-scale geometries in limited exposures. The Tres Pasos and Dorotea formations of the Magallanes Basin, southern Chile, representing shelf and slope to basin floor deposits respectively, provide an opportunity to analyze the understudied bed-scale details of these extensive slope systems. The Upper Cretaceous-Paleogene sediments record construction and evolution of high relief (>800 m) slope clinoform depositional systems, from shelf-edge to basin floor. The objective of this study is to demonstrate the high-resolution architectural and sedimentological evaluation of the clinoforms in the Magallanes Basin, providing unprecedented insight into analogous, hydrocarbon-bearing strata from high relief graded slopes on the margins of numerous ancient basins (e.g., Alaskan Brookian succession).

Parts of at least four clinothem are documented over a ~100 km<sup>2</sup> area along a depositional-dip oriented outcrop belt characterized by ~3500 m of continuously exposed strata. The dataset consists of satellite imagery, photo mosaics and ~2200 m of detailed measured sections from over 50 outcrop locations. Slope strata is dominated by fine-grained units, including extensive mass-transport deposits. Aggradational through to flat shelf-edge trajectories are readily defined in the outcrop belt; this shelf-edge architecture is closely linked with the abundance of coarse-grained facies mapped in the deep basin. A major period of transgression is associated with shelf-edge retreat; a subsequent lowstand delta built on the relic shelf until accommodation was limited, enhancing delivery of coarse-grained detritus to the deep-sea. Generally, mapped flat shelf edge trajectories are associated with shelf-edge progradation and increased sediment delivery to the basin, recorded by bypass conduits with gravel lags, and stacked turbidite channels at a lower to base-of-slope position.





# Stratigraphic Evolution of High-Relief Slope Clinoforms from Shelf-Edge to Basin Floor, Magallanes Basin, Chile

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## Study Objectives:

A. Characterize the high-resolution architectural and sedimentological evolution of a high-relief (>800 m) clinoform system in the Magallanes Basin, Chile

B. Document middle to upper slope depositional characteristics in the outcrop belt; relate evidence for sediment bypass to position on mapped paleo-slope profiles

C. Define clinoform surfaces linked to major slope readjustments; the generally graded slope system is punctuated by at least two major out-of-grade periods (ie, Figueroa and Puma Clinoforms)

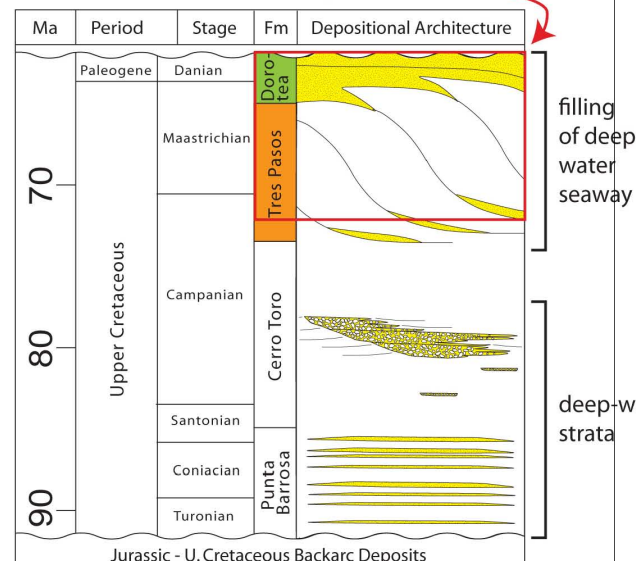
D. Construct a high-resolution outcrop-based slope evolution model that can provide insight into analogous hydrocarbon-bearing strata from around the world

## Geological Setting and Cerro Cazador Study Area

Upper Cretaceous-Paleogene sediments record the filling of the Magallanes retro-arc foreland basin, which formed in response to the Andean Orogeny

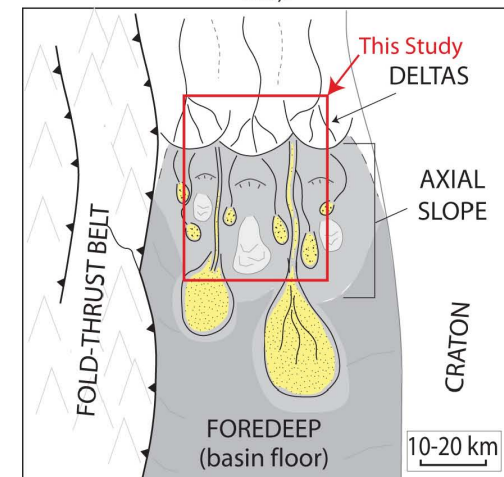
### Magallanes Basin Stratigraphy

The focus of this study is to examine middle to upper slope and shelf deposits of the Tres Pasos and Dorotea formations (outlined by red box).



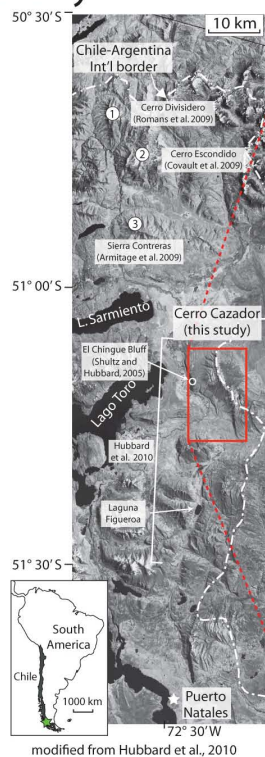
### Cretaceous Paleogeographic Reconstruction

The Magallanes Basin was ultimately filled by a southward (basin axial) progradational high-relief slope clinoform system. This study focuses on the lower to upper slope and shelf deposits (outlined in red).

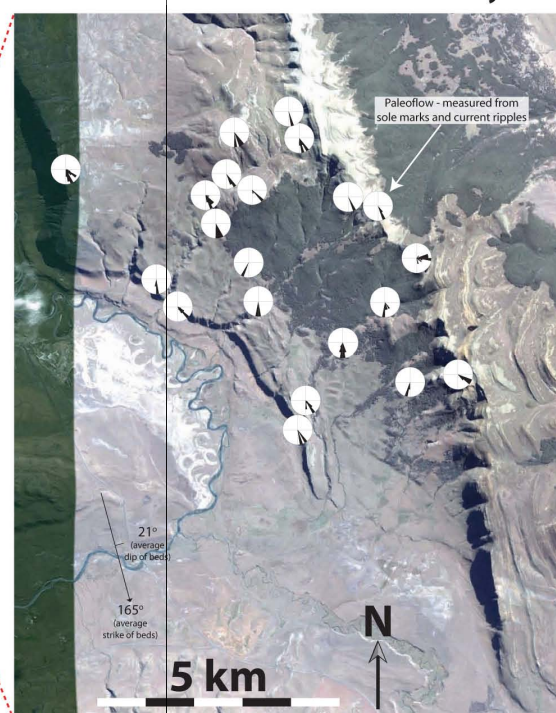


### Regional Context of Study Area

The study area location (red rectangle) and adjacent outcrops of the Tres Pasos and Dorotea formations are shown in the satellite image at right. Inset shows the study area location at the southern tip of South America (green star).



### Cerro Cazador Study Area

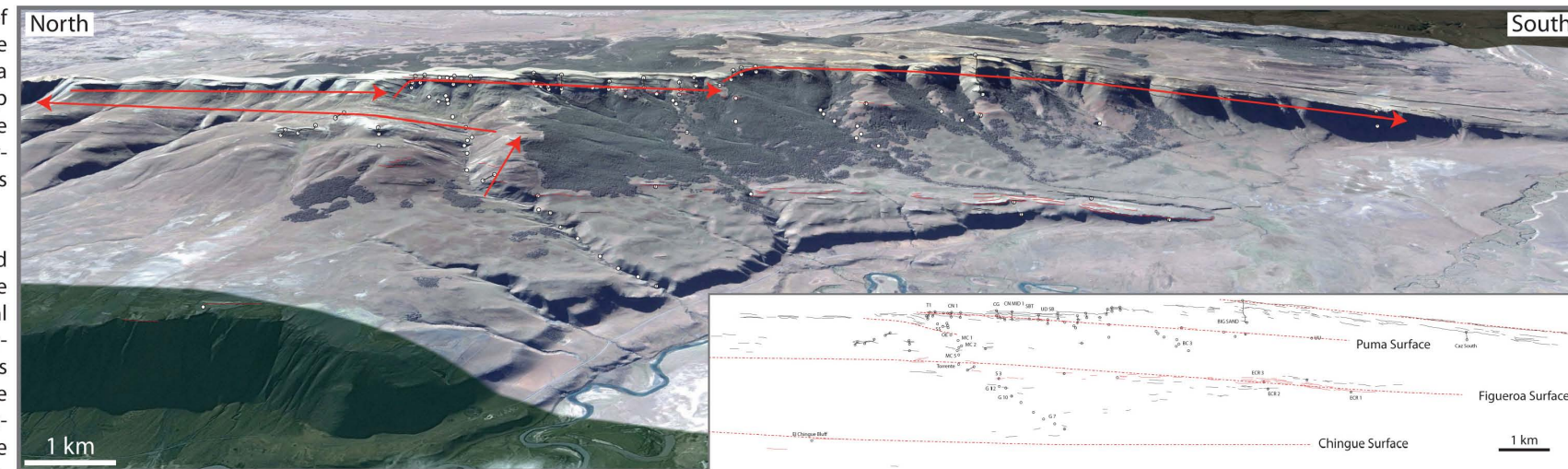


Satellite image of the north-south trending Cerro Cazador; the area of interest for this study includes ~200 km<sup>2</sup>. It is outlined in red on the regional satellite image (to the left). Paleoflow measurements are shown in rose diagrams, showing an overall south-southeast trend. The average strike and dip of the outcrop belt is 165°/21°E.

## Nature of Outcrop: Depositional Dip Profile of High-Relief Slope Clinoform System

Recognition of high-relief (>800 m) clinoforms in the outcrop belt is possible as a near ideal depositional dip section is exposed. Average paleoflow is 165°-175°, parallel to the strike of beds (165°/21°E).

At right is a dip oriented cross-section based on the satellite image (no vertical exaggeration) of Cerro Cazador. The outcrop locations visited in the study (white circles) and relative trajectory of the shelf edge (topset deposition) is identified (red arrows).

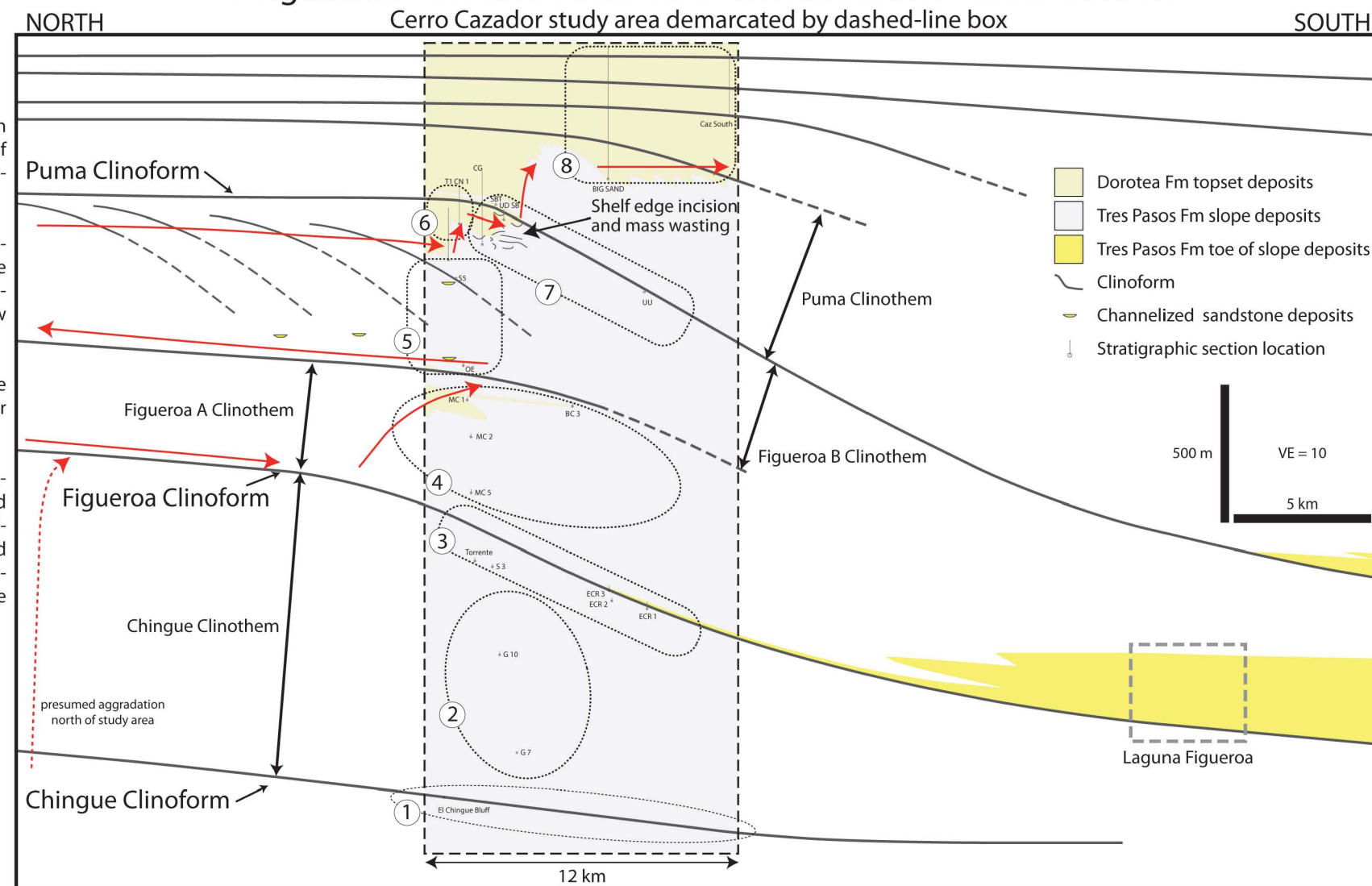


Stratigraphic evolution of high-relief clinoforms can be observed through shelf margin propagation (red arrows).

Bed-set traces coupled with detailed outcrop observations form the basis for clinoform evolution interpretation.

## Magallanes Foreland Basin Clinoform Evolution - Cross Section

Cerro Cazador study area demarcated by dashed-line box



The stratigraphic evolution of the exposed slope strata is described through 8 stages, as shown in the overview cross-section on the left and outlined in detail on posters 2 and 3:

- 1) Chingue Clinoform - graded surface with ponded slope mini basin fill
- 2) Chingue Clinothem - unstable slope dominated by MTD deposits associated with presumed shelf-edge aggradation north of the study area and limited sand delivery to the basin floor
- 3) Figueroa Clinoform - significant sediment bypass surface along extensive mappable horizon in outcrop belt; represents slope readjustment and increased sediment delivery to basin floor
- 4) Figueroa A Clinothem - in-grade slope system characterized by rising trajectory, lesser MTDs and reduced sediment delivery to the basin floor
- 5) Figueroa B Clinothem - significant back-stepping of the shelf edge followed by progradation of relatively lower relief clinoforms
- 6) Puma Clinoform - Transition phase as smaller clinothems build to relict high-relief shelf edge; recorded by progradational shelf-edge delta deposits
- 7) Puma Clinoform - Major out-of-grade slope readjustment surface characterized by abundant incision and mass-wasting, and ultimately delivery of coarse-grained detritus to the basin floor
- 8) Puma Clinothem - progradation of shelf-edge delta sediments (both fluvial and wave influence important)





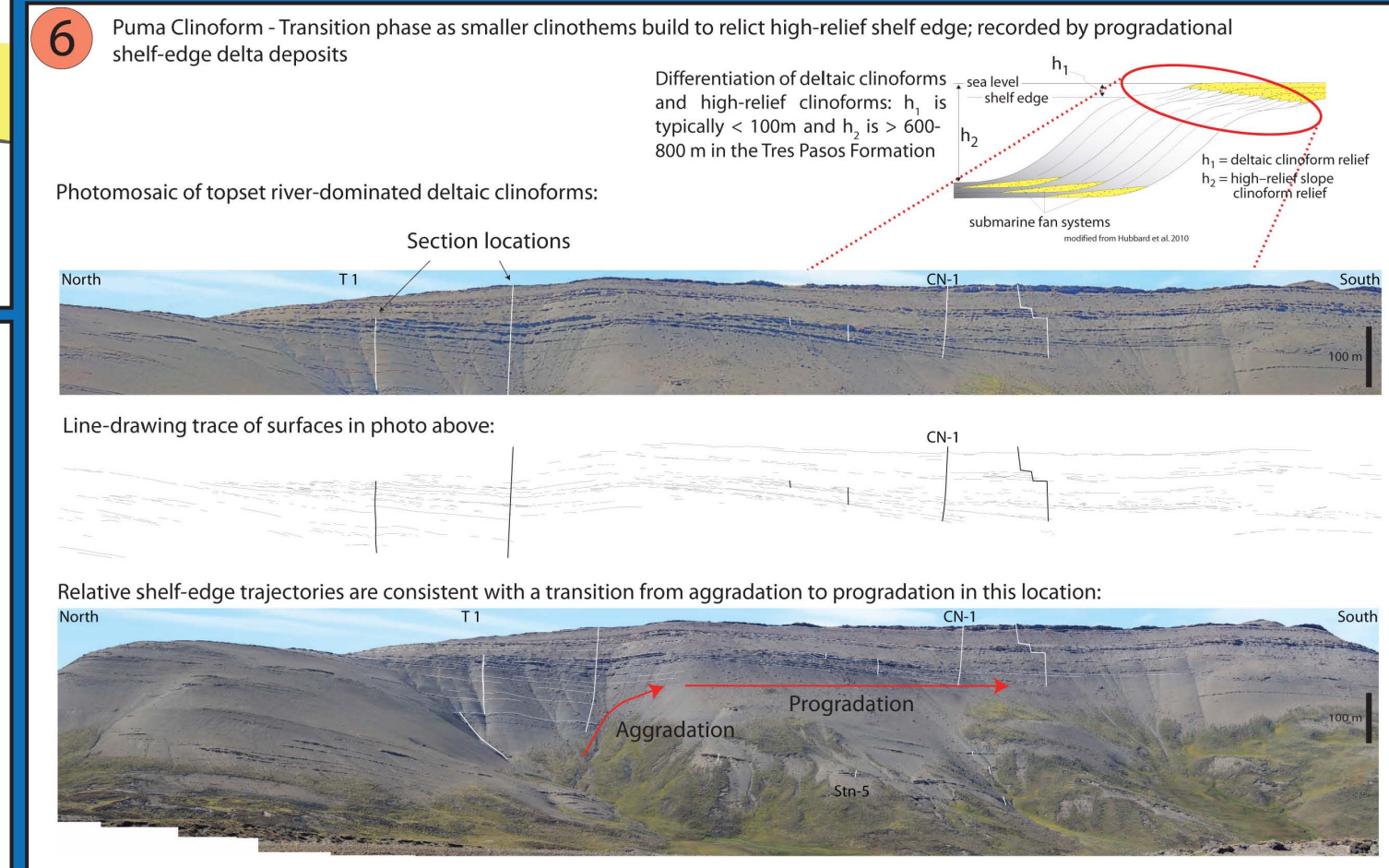
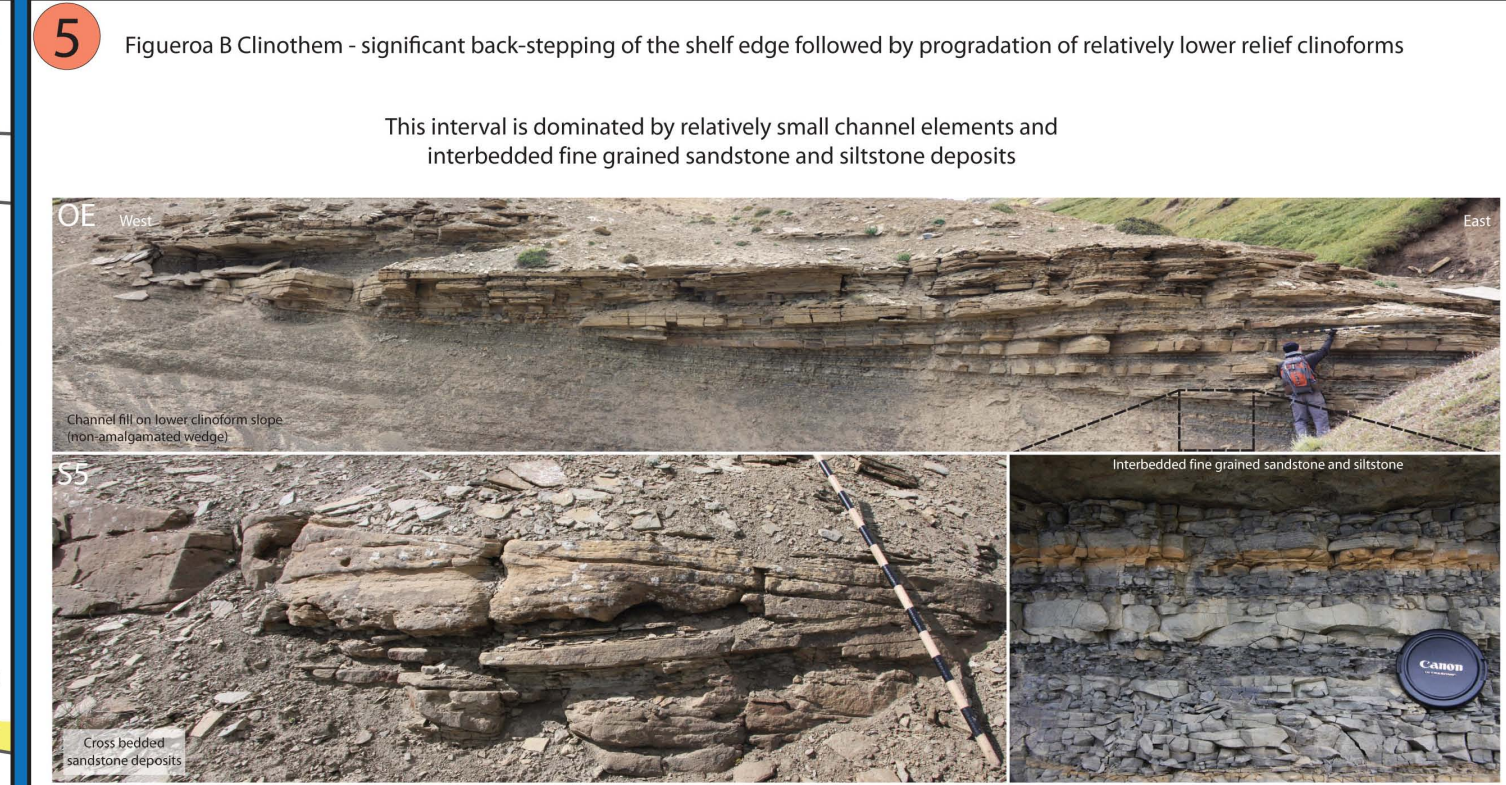
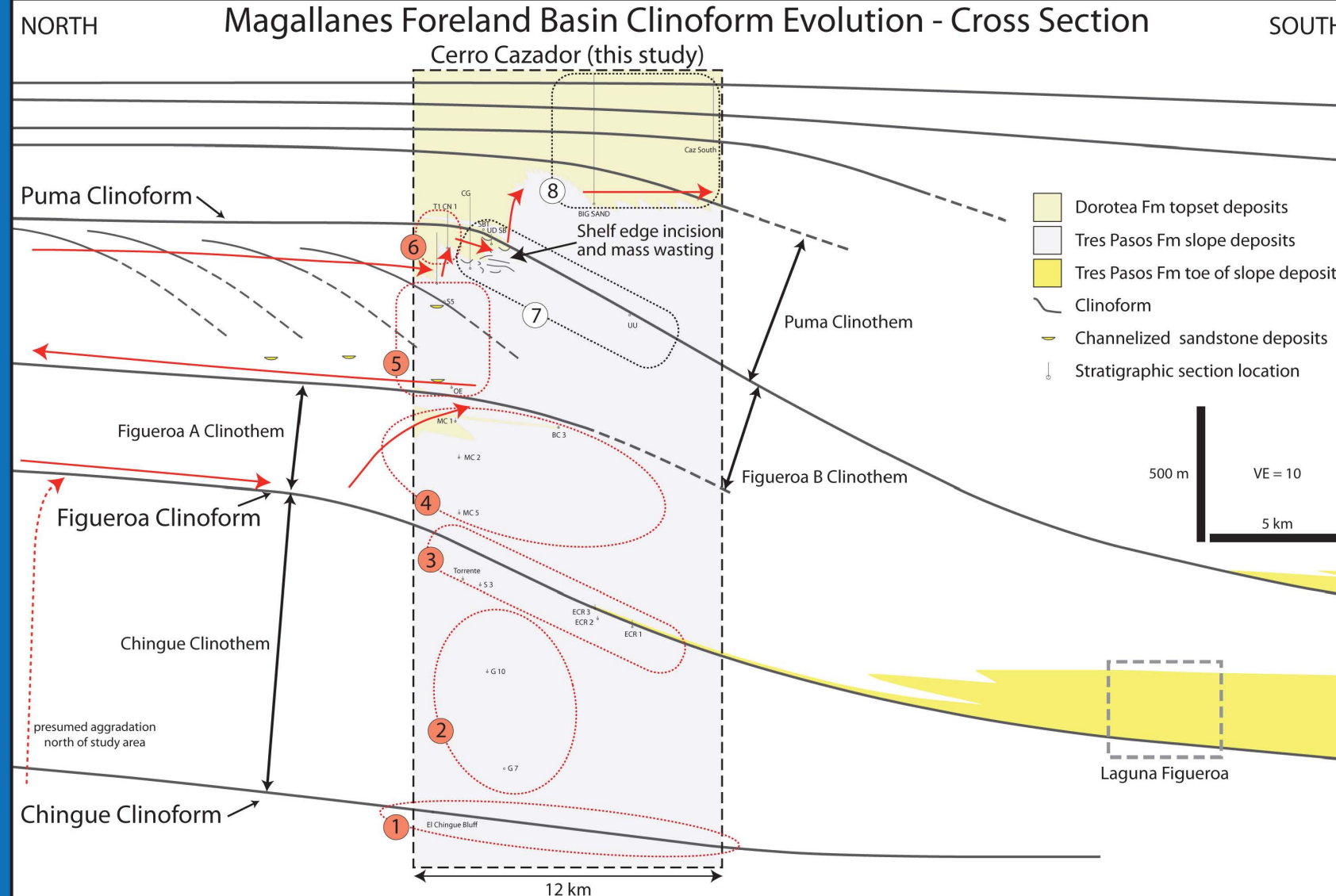
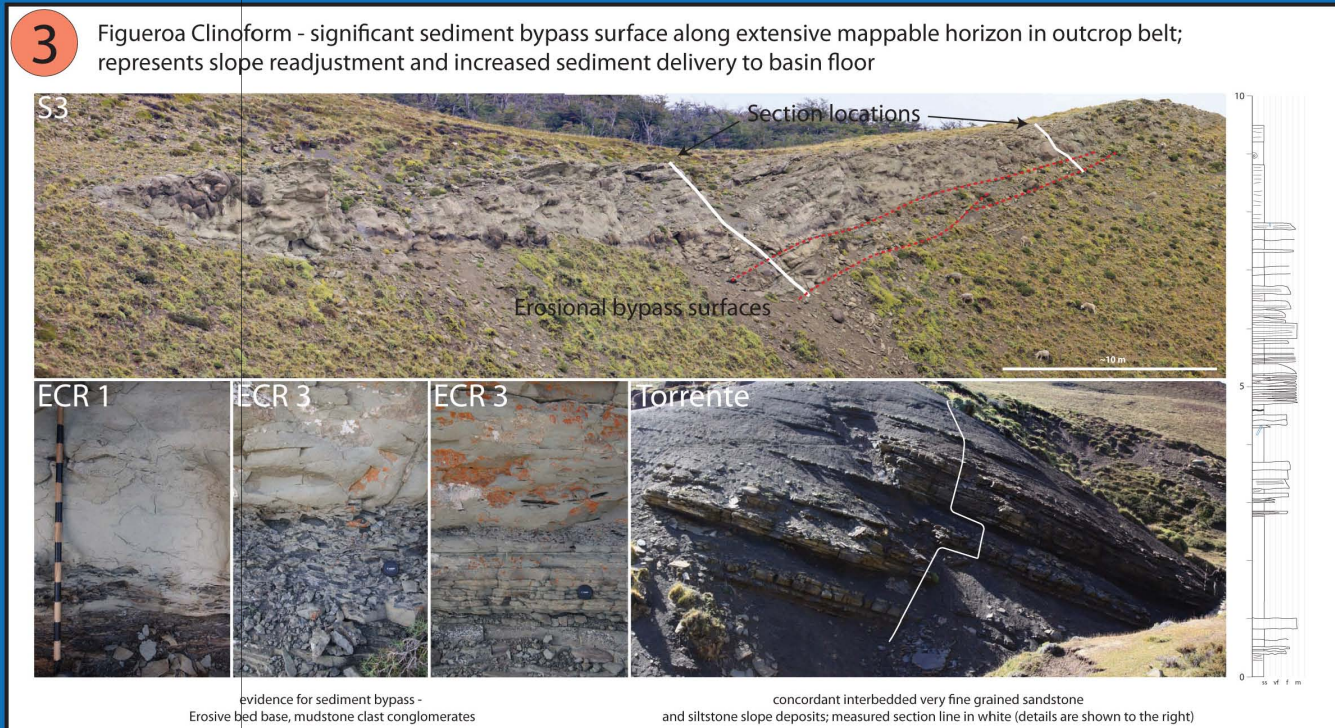
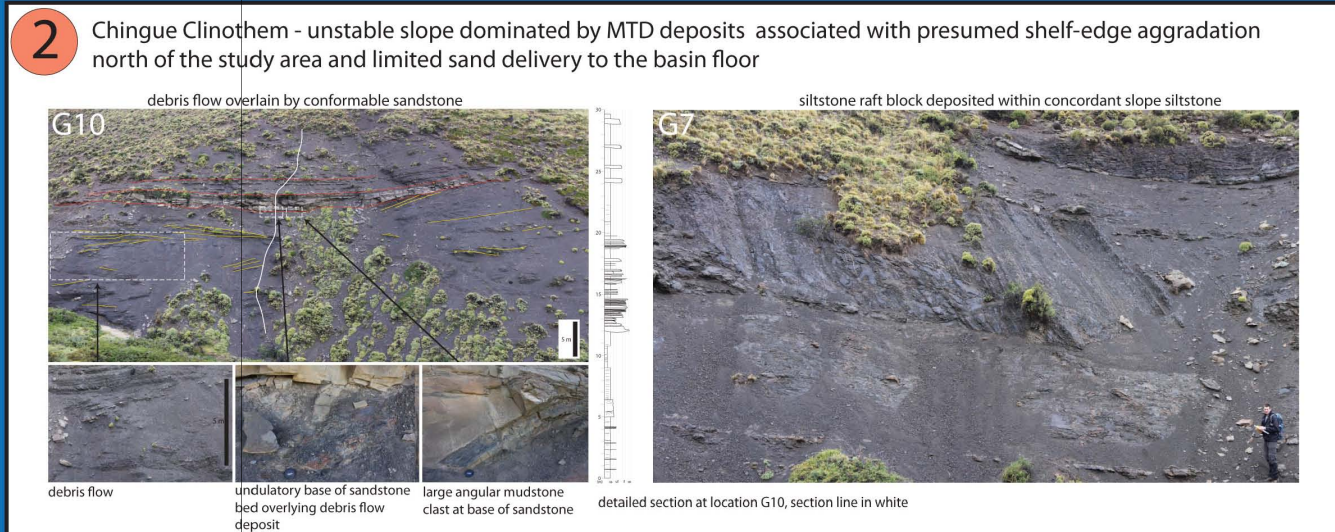
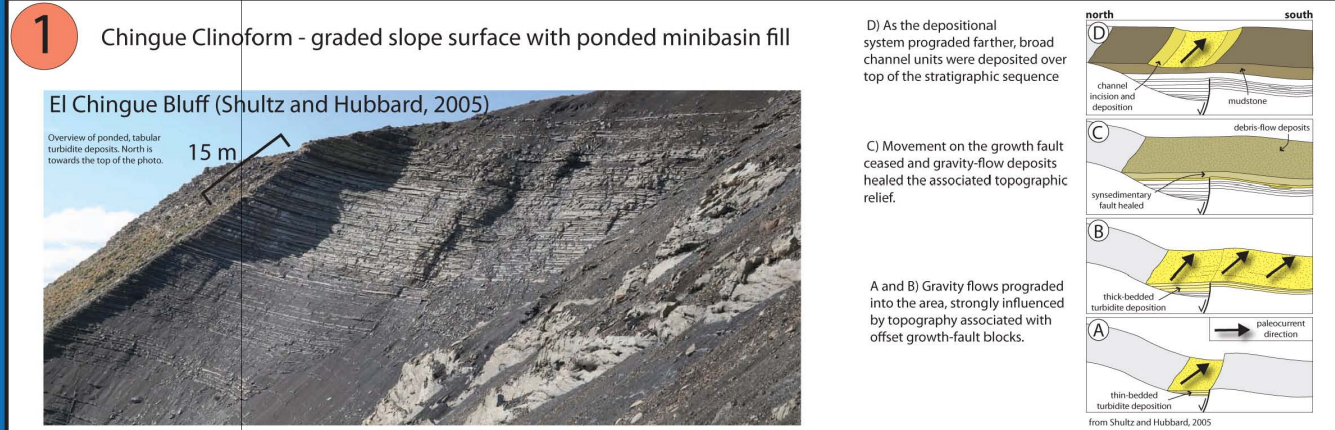
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Poster 2 of 3  
Directions

Follow the poster numerically through the stratigraphic evolution stages to gain a full appreciation of the stratigraphic architecture and bed-scale features of high-relief slope clinoforms

Climoform evolution overview is in the center of the poster and the details are systematically represented through numbered outcrop photo panels.

Refer to overview cross section for outcrop locations, which are labelled on photos





Outcrop photos along Puma Surface are characterized by extensive incision and mass wasting at the shelf edge and on the upper slope

CG

Cazador Pequena

truncated sandstone beds

SBT

incision

mass wasting

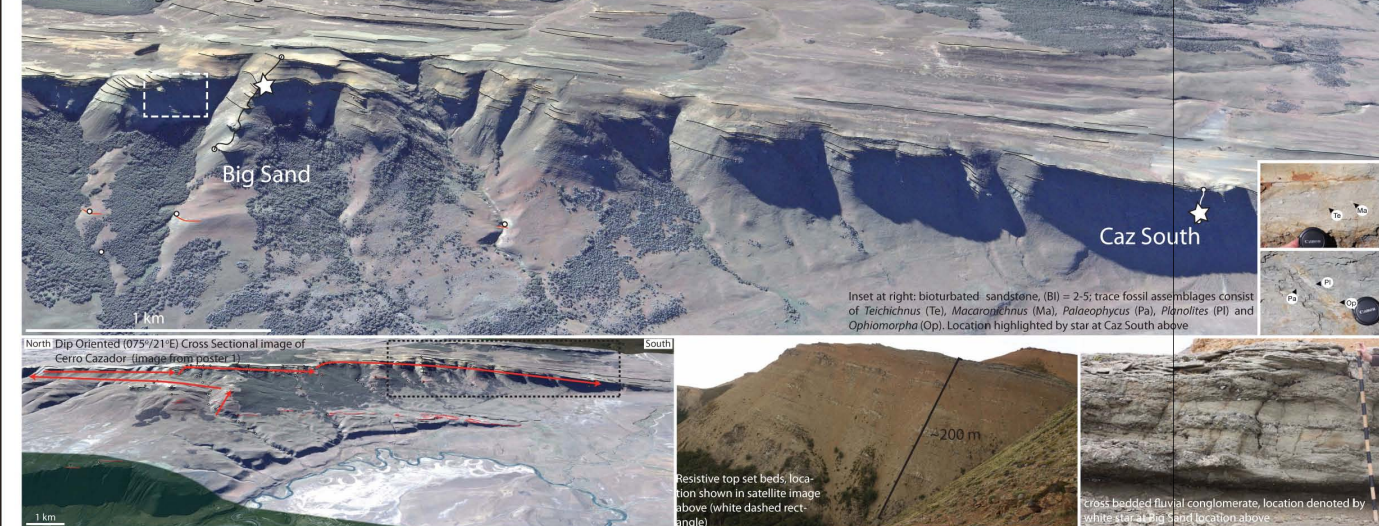
UD SB

incision

incision

Topset beds of the Dorotea Formation at the south end of the outcrop belt studied have a flat trajectory and consist of wave-influenced sandstone and siltstone overlain by fluvial conglomerate and sandstone deposits

Cross Sectional satellite image of flat trajectory topset strata of Cerro Cazador, location shown as dashed black rectangle in image at lower left



**Magallanes Foreland Basin Clineform Evolution - Cross Section**

**Cerro Cazador (this study)**

**Legend:**

- Dorotea Fm topset deposits
- Tres Pasos Fm slope deposits
- Tres Pasos Fm toe of slope deposits
- Clineform
- Channelized sandstone deposits
- Stratigraphic section location

**Map Labels:**

- Puma Clineform
- Figueroa A Clineform
- Figueroa B Clineform
- Chingue Clineform
- Shelf edge incision and mass wasting
- Channelized sandstone deposits
- Stratigraphic section location
- Laguna Figueroa

**Scale:** 500 m, 5 km, VE = 10

**Dimensions:** 12 km

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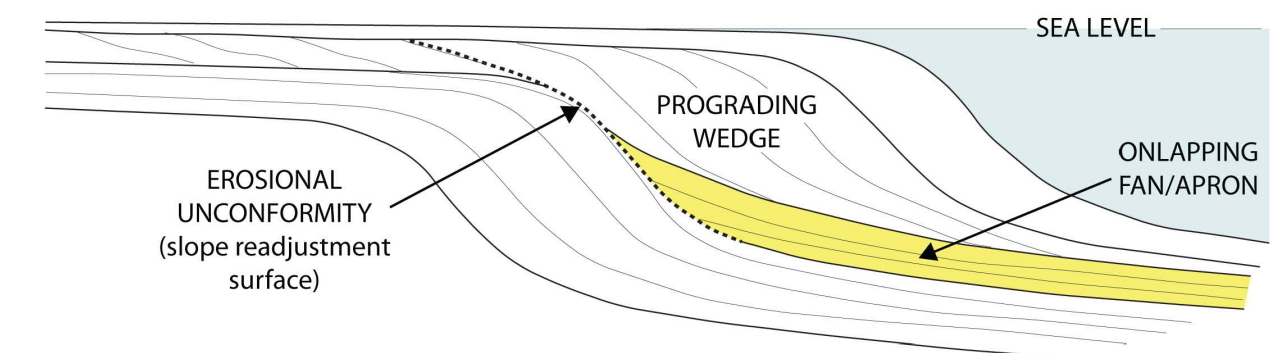
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Romans, B.W., Hubbard, S.M., and Graham, S.A., 2009, Stratigraphic evolution of an outcropping continental slope system, Tres Pisos Formation at Cerro Divisadero, Chile: *Sedimentology*, v. 56, p. 737–764.

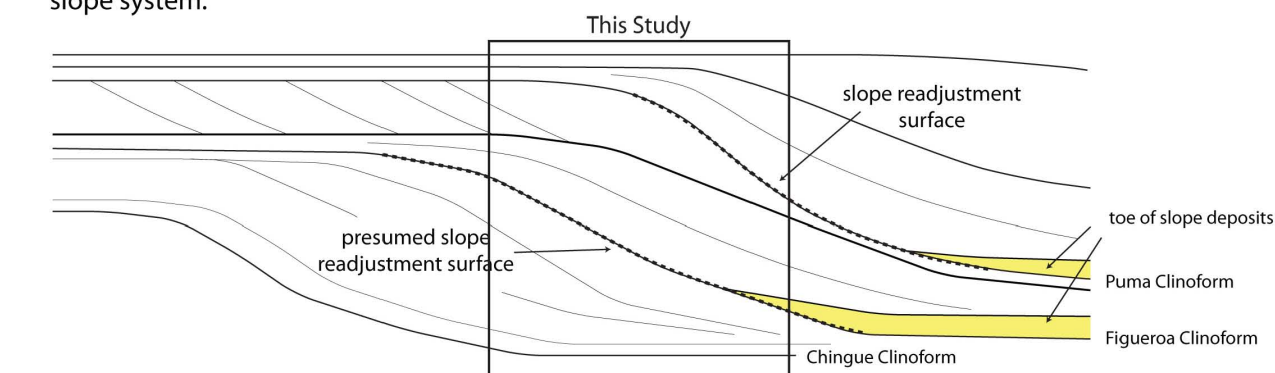
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Shultz, M.R., and Hubbard, S.M., 2005, Sedimentology, stratigraphic architecture and ichnology of gravity-flow deposits partially ponded in a growth-fault-controlled slope minibasin, Tres Pisos Formation (Cretaceous), southern Chile: *Journal of Sedimentary Research*, v. 75, p. 440–453.

Ross et al. (1994) provided an eloquent model for slope clinoform evolution. Graded slope clinoforms are associated with progradational and aggradational evolution of a margin. During punctuated periods, a margin becomes over-steepened and bypass of sediment to the basin floor is dominant ("out-of-grade").



In the Magallanes Basin, two major slope bypass surfaces are present (Figueroa and Puma). These surfaces record slope readjustment and out-of-grade periods during the evolution of an otherwise graded slope system.



Thus far, this study has focused on data collection and compilation; conclusions to date include:

1. The Tres Pasos and Dorotea formations of the Magallanes Basin, southern Chile, represent shelf and slope to basin floor deposits respectively.
2. Multiple scales of clinoforms are present in the outcrop belt, preserving < 100 m to > 800 m of paleo margin relief.
3. Parts of at least four clinothems are documented over a ~100 km<sup>2</sup> area along a depositional-dip oriented outcrop belt characterized by ~3500 m of continuously exposed strata.
4. Clinothems are generally dominated by fine-grained units, including extensive mass-transport deposits. Aggradational through to flat shelf-edge trajectories are readily defined in the outcrop belt; this shelf-edge architecture is closely linked with the abundance of coarse-grained facies mapped in the deep basin.
5. Two major slope bypass surfaces are present in the outcrop belt (ie, Figueroa and Puma). These surfaces record slope readjustment and out-of-grade periods during the evolution of an otherwise graded slope system.
6. The outcrop in Chile offers the opportunity to consider fine-scale detail needed to characterize reservoirs within a seismic exploration-scale framework. Future analysis will emphasize the linkage between stratigraphic architecture and basin-scale sediment distribution, as well as comparison of the outcropping slope clinoform system to analogous hydrocarbon-bearing intervals (e.g., Brookian succession, Alaska).