CHILE SLOPE SYSTEMS

University of Calgary
Virginia Tech
University of Utah

JOINT INDUSTRY PROJECT

Architectural Analysis and Modeling of Outcropping Slope Deposits, Magallanes Basin, Chile

Project Motivation: The deposits of deep-water systems, despite recent advances, are the most poorly constrained in the clastic sedimentary record. An integrative approach is required to tackle the unique field development and reservoir management challenges posed by channelized slope reservoirs. The application of outcrop analogs is a proven method for reducing uncertainty in subsurface prediction/characterization and reservoir model construction.

Objectives: The JIP is focused on deciphering the processes of sediment transfer (i.e., erosion, bypass and deposition) across slopes, motivated to better constrain hydrocarbon distribution and to optimize recovery:

Objective 1: Predictive sedimentologic models
Document the bed-scale sedimentology of slope channel deposits with an emphasis on development of conceptual models that can be used to improve prediction laterally away from 1-D data (e.g., well logs, cores).

Objective 2: 3-D architectural models of reservoir-scale sedimentology
Characterize the stratigraphic architecture of outcropping slope channel deposits (and related sedimentary bodies). Construct outcrop-constrained three-dimensional architectural models in Petrel. Analysis will include compilation of quantitative data and metrics that describe channel stacking patterns and intra-channel heterogeneity (Fig. 1).

Objective 3: Reservoir analog geomodeling and flow simulation
Leverage data and derived statistics from architectural model analysis to generate reservoir analog geomodeling strategies. Develop innovative methods to capture reservoir architecture and rock properties and test predictive capability of reservoir performance (e.g., static and dynamic connectivity).

Objective 4: Regional stratigraphy and paleogeography
Provide a sequence stratigraphic framework and the basin-scale context for reservoir-scale models developed from the deep-marine Tres Pasos Fm and genetically linked shallow-marine Dorotea Fm.

People: The JIP consists of an integrative collaboration of professors and students with geology and engineering backgrounds from the University of Calgary, Virginia Tech, and the University of Utah. The principal investigators are:

Steve Hubbard
Associate Professor
University of Calgary
(403) 966-0211
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www.ucalgary.ca/shubbard

Experience:
- Professor, 2006-present
- Ph.D., Stanford (2006)
- Chile slope channel JIP head (2007-2012)
- Prof. geologist : 3 yrs

Brian Romans
Assistant Professor
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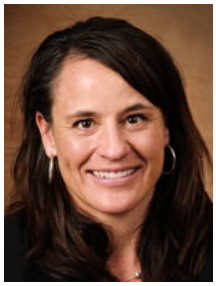
Experience:
- Professor, 2011-present
- Ph.D., Stanford (2008)
- Prof. Geologist: 6 yrs



Lisa Stright
Assistant Professor
University of Utah
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Experience:
- Professor, 2011-present
- Ph.D., Stanford (2011)
- Prof. Geomodeler/ Engineer: 7 yrs

PROJECT HISTORY: The stratigraphy of deep-water outcrops in the Magallanes Basin has been studied for >50 years by researchers from both academia and industry. The 3 principal investigators gained expertise in the region as Ph.D. students with the Stanford Project on Deep-water Depositional Systems. Since 2007, Steve Hubbard has led an industrial consortium focused on slope systems, and in particular channel deposits of the Tres Pasos Formation. The consortium had 3 members in 2010, and 7 members in 2012. The growth in interest in the consortium, and exceptional opportunity for continued research in the area, has inspired expansion of the project into a multi-university JIP.

GEOLOGIC BACKGROUND: The Upper Cretaceous Magallanes Basin of southern Chile contains >4,000 m of deep-marine strata, including several coarse-grained units that record turbidite depositional system evolution. The unique tectonic history of this basin has resulted in a regionally continuous outcrop belt of high-relief slope systems, the deposits of which comprise the Dorotea (topset) and Tres Pasos (slope) formations (Fig. 2). The basin filled axially, from north to south – in the north, rugose slope surfaces persisted due to extensive mass wasting, which had a profound effect on sand deposition. Southward, clinoforms that represent a series of paleoslope profiles that formed as the bathyal Magallanes Basin filled, are on the order of >1 km high (paleobathymetric relief) and 30-40 km long (from

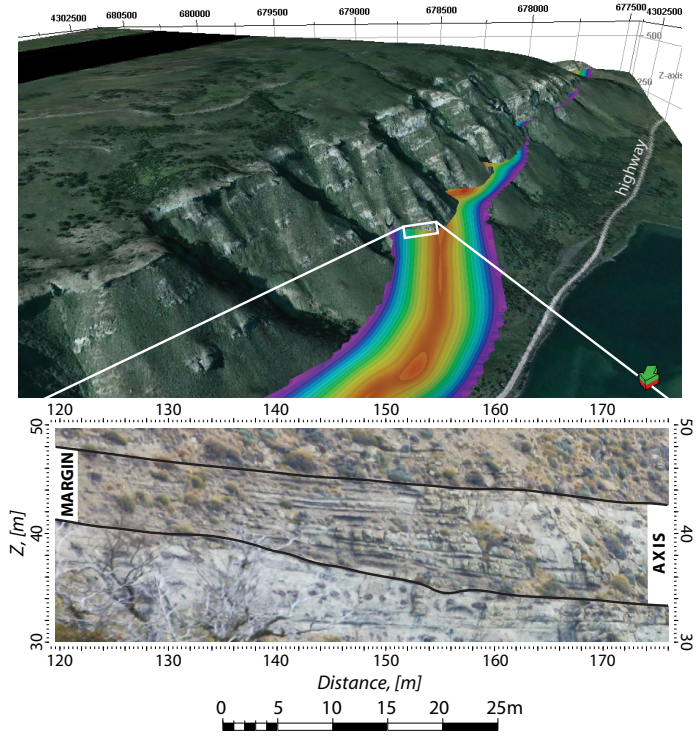

Figure 1. Upper: South-facing perspective of channelized strata exposed at Laguna Figueroa (Tres Pasos Fm) highlighting a single modeled channel element, which is ~250m wide and 14m thick. Hot colors represent sand-rich channel axis facies and cool colors represent sandstone-poor margin facies. Below: Photograph of the axis-to-margin transition revealing the intra-channel architecture. The link between bed scale heterogeneity, channel architecture and channel complex stacking is all captured by detailed measured sections and surveyed stratigraphic surfaces (<10 cm resolution differential GPS). Data is integrated into a detailed 3-D architectural model, which provides the foundation for reservoir analog geomodeling studies.

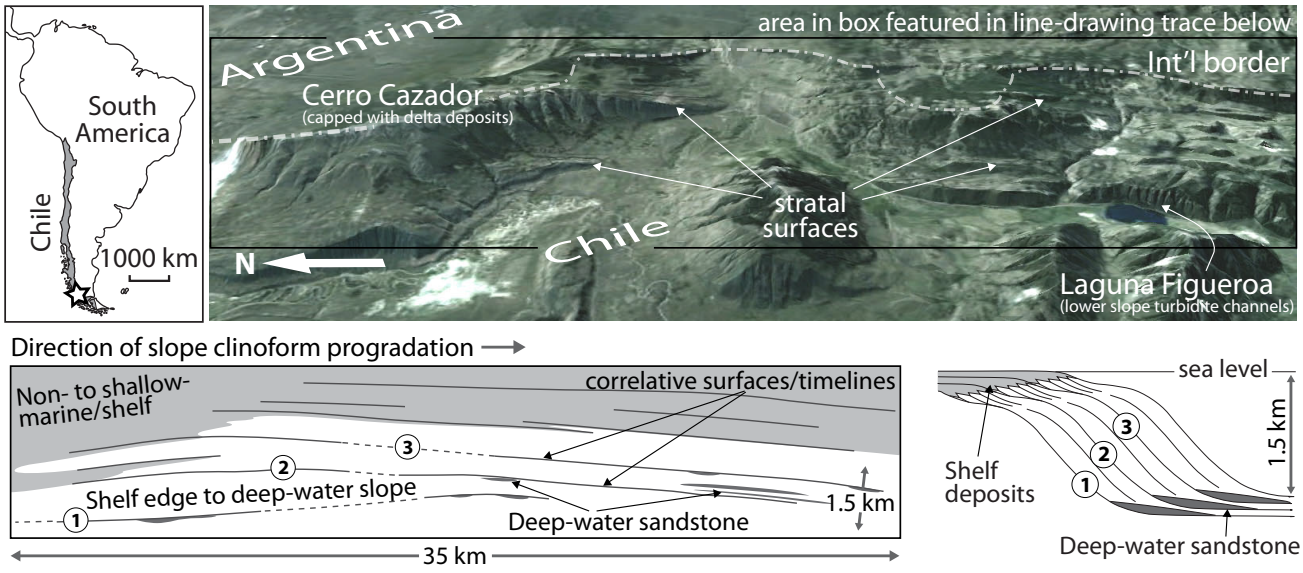

Figure 2. Upper left: map of South America with the location of the Magallanes Basin denoted by star in southern Chile. Upper right: eastward view of the study area in satellite imagery draped on topography, highlighting the Chile-Argentina border. Below right: idealized, highly vertically exaggerated depositional-dip cross-section through clinoform-dominated strata. Below left: line drawing trace of main stratal surfaces in area bound by large box in satellite image above, emphasizing the extent of clinoforms in the near perfect dip-oriented outcrop exposure. Shallow marine/shelf deposits (grey) are prevalent in the east and shelf-edge to deep-water slope deposits (white) are dominant westward. Stratigraphic surfaces considered equivalent to timelines correlate shallow marine deposits to deep marine deposits over tens of kilometers along depositional dip. The proposed research will focus on sandstone-rich deposits within the vast exposure of mudstone-dominated slope strata (white). Numbers 1-3 delineate successive clinoforms, as in cartoon at right.

paleo shelf edge to lower slope). This seismic-scale constraint on basin-filling patterns provides exceptional stratigraphic context within which to investigate detailed, reservoir-scale architecture.

Research Plan: The four project objectives will be achieved through a series of focused activities, framed below in context of potential graduate student theses. In all instances, the studies will be accomplished through the collective effort of students and principal investigators. Note that an expanded project description is included in the appendix of the proposal for those activities with bolded titles in the table below. The appendix also includes a map of the Magallanes Basin with locations of activities indicated.

Activity ↓ / Objective →	1. Sedimentology	2. Arch. Modeling	3. Geomodeling	4. Paleogeography	Year ↓ 2013	2014	2015	2016
1) Upper to lower slope variability of channel architecture along 25 km of the Figueroa Clinoform surface	■	■		■	Ph.D. 1 (a)			
2) Differentiating the record of erosion, bypass and deposition within middle slope channel complexes, Cerro Sol (Figueroa Clinoform)	■	■				Ph.D. 1 (b)		
3) Documenting stacking patterns and internal architecture of asymmetric slope channels, Arroyo Picana (Puma Clinoform)	■	■			M.S. 1			
4) Architectural variability of sandstone bodies in a channel-lobe transition zone, Arroyo Picana (Figueroa Clinoform)	■	■			Ph.D. 2			
5) Architectural variability of sandstone bodies (ponded to channelized) on a topographically complex slope, Rio Zamora	■	■		■	Ph.D. 3 (a)			
6) Investigating slope channel patterns and processes at Cerro Mirador: Punctuated or continuous lateral migration?	■	■				Ph.D. 3 (b)		
7) Characterizing the impact of channel stacking patterns and intra-channel heterogeneity on fluid flow, Laguna Figueroa		■	■		M.S. 2			
8) Characterizing the impact of channel stacking patterns and intra-channel heterogeneity on fluid flow, Arroyo Picana		■	■			M.S. 3		
9) Distribution and characterizion of ponded sandstone on a topographically complex slope, Cerro Sol (Chingue Clinoform)	■	■		■		Ph.D. 4 (1)		
10) Predictive facies characterization in slope channel complexes: Insights into beyond-wellbore predictions	■				integrated ongoing work			
11) Investigating stratigraphic stacking in levee-overbank strata: Relationship to channel evolution, Cerro Toro Formation	■	■				M.S. 4		

Sponsor Benefits:

- Access to data, posters, presentations, and reports/papers via a password-protected website.
- Annual opportunities for interaction with PIs and graduate students:
  - At least two people per company will be invited to attend an excursion to visit the field area.
  - A one-day meeting associated with the timing/location of the annual AAPG Meeting to discuss research results and plans.
- Companies will receive annual progress report of findings, as well as a final summary report highlighting the findings of the JIP.
- Companies will be acknowledged on all disseminated material.

Additional Information:

For an electronic copy of this document and supplemental information, please refer to http://www.ucalgary.ca/shubbard/chileJIPinfo

Joint Industry Project

Consortium Terms

Architectural Analysis and Modeling of Outcropping Slope Deposits

Magallanes Basin, Chile

General Terms

- ☑ *Project Leader:* Steve Hubbard, University of Calgary
  - *Project Co-Leaders:* Brian Romans, Virginia Tech & Lisa Stright, University of Utah

- ☑ *Term of Agreement:* 3 years (2013-2016), option to opt out of the agreement at the conclusion of each project year

- ☑ *Financial Contribution:* $30,000-40,000/year/per sponsor, plus 25% for indirect costs

Cost Per Year/Company is:	Necessary Sponsors
30,000.00	10
35,000.00	9
40,000.00	8

  - Final financial commitment to be determined by total number of sponsors that participate
  - Consortium funds will be paid to and held at the University of Calgary
  - Calgary will distribute project funds accordingly to the Project Co-leaders

- ☑ *Research Results:* IP rights from Project Co-Leaders will be consolidated at Calgary
  - Sponsors will be given a license to research results for internal use

Benefits to Consortium Membership

- ☑ *Research Results:* non-exclusive, world –wide, perpetual, non-exclusive right to use all Research Results internally
  - Access to data, posters, presentations, reports & papers through a password protected website
  - Annual scientific and financial progress report of findings as well as a final summary report

- ☑ *Field Opportunities:* at least two individuals per Sponsor will be invited to attend an excursion to the field areas with the Principal Investigators and students

- ☑ *Annual Consortium Meeting:* A meeting associated with the timing & location of the annual AAPG meeting to discuss research results and plans

- ☑ *Recognition:* Sponsors will be acknowledged on all disseminated material