PS Slope to Basin-Floor Evolution of Channels to Lobes, Jurassic Los Molles Formation, Neuquén Basin, Argentina*

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Search and Discovery Article #10615 (2014)**
Posted July 28, 2014

*Adapted from poster presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

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Abstract

Approximately 400m high clinoformal, shelf-slope-basin-floor deposits of Jurassic Los Molles Formation outcrops are evaluated for reservoir scale definition of facies and architectures in the La Jardinera field area, Neuquén Basin. Slope deposits represent the accretionary front of the prograding shelf margin that was fed by a coarse-grained shelf (Lajas Fm.). Mapping of a high-resolution satellite image draped on a digital elevation model resolved a sub-meter stratigraphic framework. An analysis of outcrops exposed along a 5km transect reveals the down-dip evolution of sand body architectures from shelf edge incisions filled with conglomerates, to confined channels in mid to upper slope reaches, to weakly confined channels on the lower slope and sheet-like lobes on the basin floor that also drape up onto the lower slope. Along the slope to basin floor profile, the depositional architecture changes by overall decrease in bed thickness, grain size and degree of erosion. Confined slope channels are up to 25m deep, isolated within muddy slope deposits and have complex multistory fills marked by basal and internal erosion surfaces with mud-clast and/or pebble conglomerates. Channel axes contain amalgamated, medium to coarse sandstones that taper and fine towards channel margins over 200m. Down-dip, lower slope channels are up to 400m wide and less than 10 m deep. A downslope decrease in flow energy is indicated by marked reduction in mud clasts and conglomeratic material at basal erosional surfaces in weakly confined channels. However, distinct, meter scale erosion surfaces are recognizable where thin, ripple laminated sands are truncated on channel margins by amalgamated, structureless sands. Erosional surfaces are absent in laterally extensive (>10km), sheet-like lobes of basin-floor fans that are generally finer grained than lower or upper slope channel fills. However, there are lenticular debrites and thin micro-conglomerates associated with basin-floor fans. This relatively steep and narrow Neuquén Basin margin provides an excellent laboratory for monitoring down slope changes in sediment gravity flow bed thickness, grain size and facies, as well as channel to lobe transitions.

I: Slope to Basin-floor Evolution of Channels to Lobes, Jurassic Los Molles Formation, Neuquén Basin, Argentina

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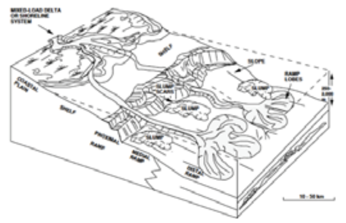
Abstract

The relatively steep and short-headed Neuquén Basin margin provides an excellent natural laboratory for documenting down slope changes in sediment gravity flow bed thickness, grain size and sedimentary facies, including channel to lobe transitions. Approximately 400m high clinoformal, shelf-slope-basin-floor deposits of Jurassic Los Molles Formation outcrops are evaluated for reservoir scale definition of facies and architectures in the La Jardinera field area, Neuquén Basin. Slope deposits represent the accretionary front of the prograding shelf margin that were fed by a coarse grained shelf (Lajas Formation). Mapping of high-resolution satellite images draped on digital elevation model resolved a sub-meter stratigraphic framework. Thirty-three measured sections from outcrops exposed alon a 5km transect characterize the evolution of sand body architectures from the shelf edge to the basin floor. The Neuquén Basin margin is typified by four main depositional environments that transition from shelf edge incisions filled with conglomerates, to confined channels in upper- to middle-slope reaches, to weakly confined channels on the lower slope to sheet-like lobes and distributary channel complexes that drape onto both the lower slope and basin floor. Along the slope to basin floor profile the depositional architecture changes by overall decrease in grain size, amalgamation of beds and degree of erosion.

Confined slope channels are up to 25m deep, isolated within muddy slope deposits and have complex multistory fills marked by basal and internal erosive contacts lined with mud-clast and/or pebble conglomerates. Channel axes contain amalgamated, medium to coarse sandstones that thin and fine towards channel margins over 100m. Down dip, lower slope channels are up to 400m wide and less than 10m thick. A marked reduction in mud clasts and conglomeratic material at basal erosional surfaces in weakly confined channels represent a downslope decrease in flow energy. However, distinct meter scale erosion surfaces continue to be recognizable where thin ripple laminated sands are truncated on channel margins by amalgamated structureless sands. Erosional surfaces are absent in laterally extensive (>5km), sheet-like lobes of basin-floor fans that are generally finer grained than lower or upper slope channel fills. There are lenticular debrites and thin micro-conglomerates associated with basin-floor fans.

Project Scope

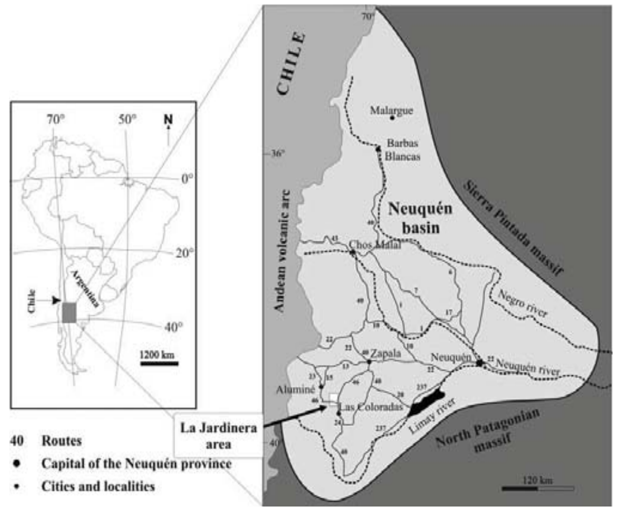


Define architectural elements and their paleo-physiographic position in the La Jardinera field area

Quantify sand body dimensions by aspect ratio

Quantify vertical and lateral variability of parameters that affect reservoir properties and volumes
- Grain Size
- Bed Thickness
- Facies Proportions
- Degree of Erosion
- Degree of Amalgamation

Background Information

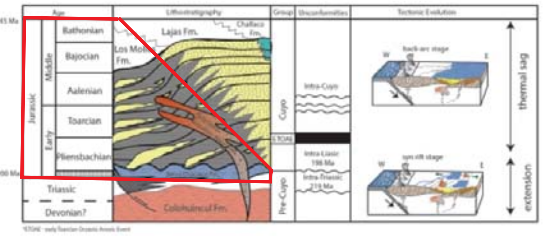


-West-central Argentina

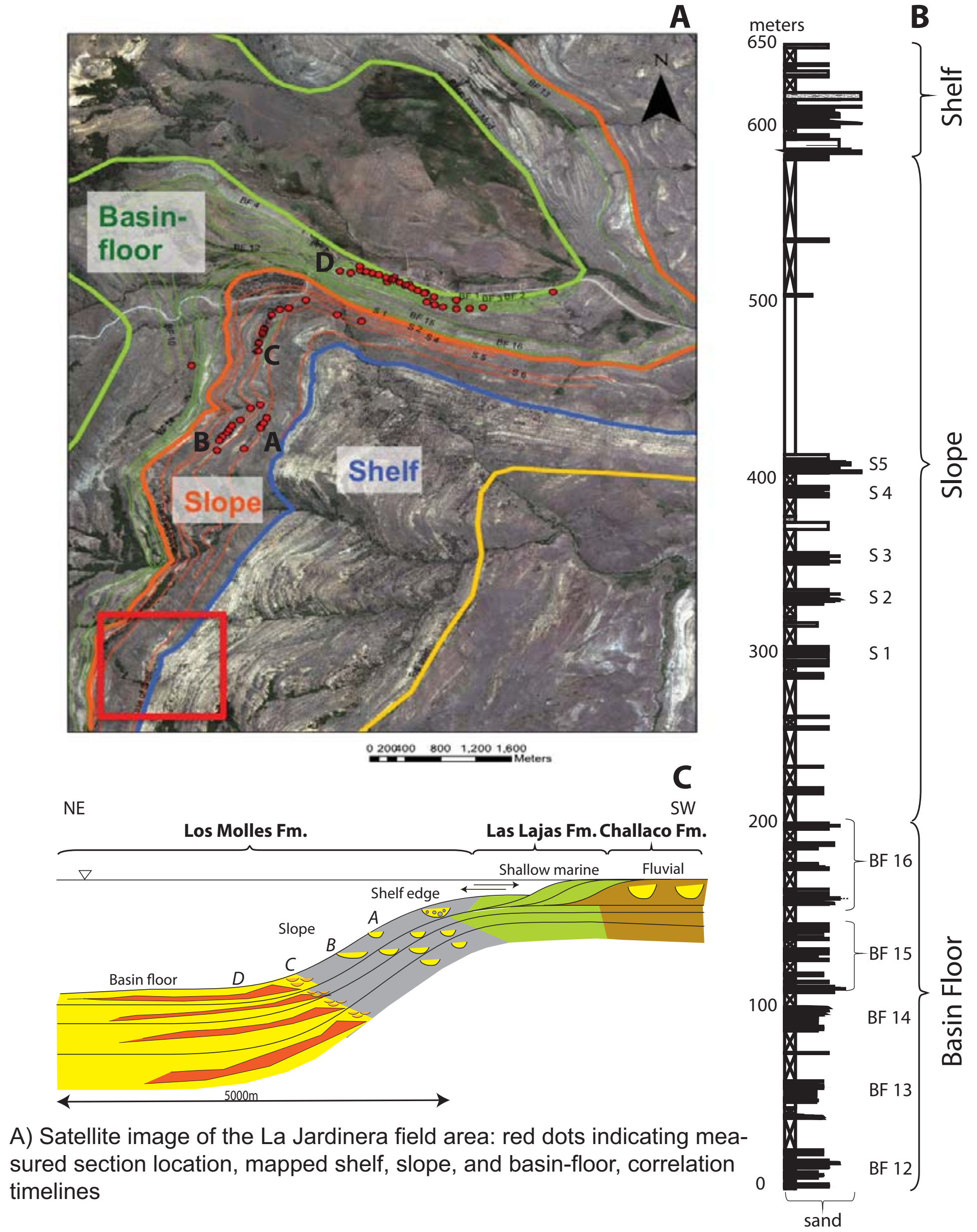
-Jurassic Los Molles Formation- Deep-water slope and basin floor

-Contemporaneous Lajas Fm.-Shallow-water and Challaco Fm.-Fluvial

-Rift to back-arc basin



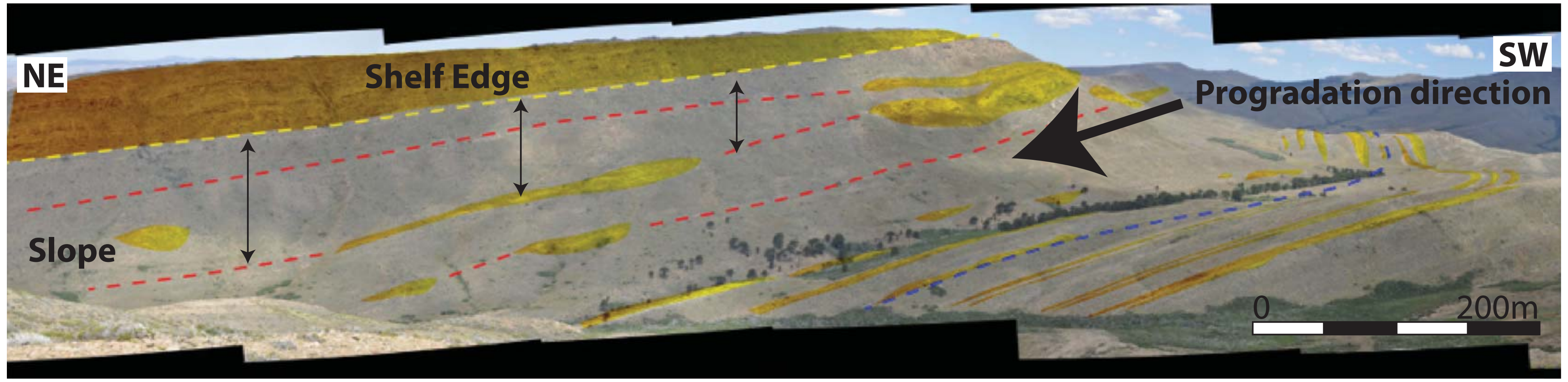
Field Area Mapping & Paleophysiography



A) Satellite image of the La Jardinera field area: red dots indicating measured section location, mapped shelf, slope, and basin-floor, correlation timelines

B) Composite measured section through entire vertical section from the shelf to basin floor

C) Cartoon indicating hypothesized outcrop exposure location and stratigraphy along a clinoformal margin



Clinoformal Geometry

-NE prograding clinoformal margin

-Exposure of the clinoformal margin is key in establishing depositional setting of architectural elements within the field area outcrops

Lithofacies Subdivisions

Facies	Description	Interpretation	Depositional Environment	Photo
Mud rip-up conglomerate	Clean sand to poorly sorted muddy matrix, 10-50 cm thick, erosive/irregular contact, Lense-like within beds	Deposition from basal scouring turbidity current (Grundveg), clean sand debris flow (Talling,) high energy, erosive	Upper and lower slope channel lag, high energy channel axis	
Pebble conglomerate a)muddy/ poorly sorted b)sandy/graded	Gravel to pebble conglomerate a) muddy matrix, cobbles and rafted blocks, 10cm-2m thick b) sandy matrix, 10-50 cm thick, lenticular	a)cohesive debris flow b)high density turbidity current, suggestive of bypass	a) slope and basin floor fan b)channel lag deposit, basin floor lobe	
Amalgamated to Non-amalgamated Structureless Sandstone	Ranging from well to poorly sorted, very coarse to fine sand, structureless, flute casts and tool marks on sharp, loaded base, sharp top, amalgamation surfaces defined by mud clast or grain size break, containing organic matter	Sustained flow, sand-rich, depletive turbidity currents, liquefied debris flow	Basin floor lobes and slope channels, increasing amalgamation indicating flow axis and degree of proximity to confinement	
Normally graded sandstone	Graded from very coarse sand, sometimes pebble to medium/fine sand, ranging in thickness from 20 cm to 2 meters, sharp base with tool marks and flute casts common, variable thickness laterally up to 50 cm	Waning, decelerating sand-rich or poor turbidity currents	Axial, proximal, Basin floor lobe, upper and lower slope channel (less well defined)	
Plane, parallel, low angle parallel, cross bedded sandstone	Coarse to fine sand, often faint plane parallel to cross beds, Wedge shaped, discontinuous along a single bed, 10-50 cm thick, commonly overlying structureless or normally graded bed	Waning, dilute, turbidity current, high to low concentration flows, dilute turbidity current forms coarser grained upper plane bed regime, sandier flows form by en masse freezing or traction carpets	Basin floor lobe deposits, lower slope channel deposits, spaced laminations indicate proximity	
Ripple laminated sandstone	Coarse to fine sand, sharp base and top, finely laminated ripples with some mud drapes, 5-20 cm thick, lenticular	Dilute and fully turbulent suspension, low fallout rates	Distal/off-axis basin floor lobe	
Heterolithic, interbedded, sandstone and mudstone	5-50 cm, mud to silt interbedded with 1-10 cm, fine to coarse sand, up to 10 m thick packages, commonly sharp bases and drag marks on sand, sharp to fining up top, lenticular sand bodies, slump features common	Alternating suspension fallout deposits and dilute turbidity current	Distal/off-axis basin floor lobe	
Silty mudstone	Dark, organic rich mud with faint parallel laminations to structureless, slump features, commonly occurring in thick packages between sand layers, 1 cm to 5 m thick	Suspension fallout, background sedimentation, hemipelagic mud	Distal/off-axis basin floor lobe, sedimentation during avulsion, slope	

II: Slope to Basin-floor Evolution of Channels to Lobes, Jurassic Los Molles Formation, Neuquén Basin, Argentina

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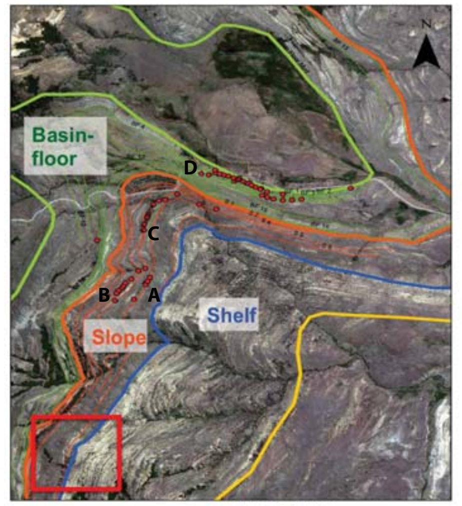
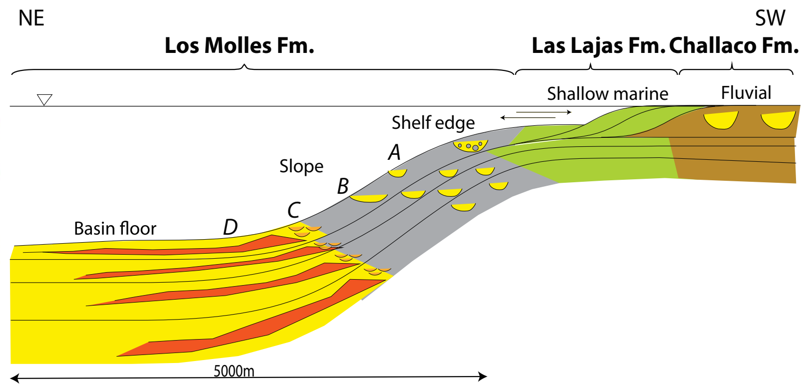
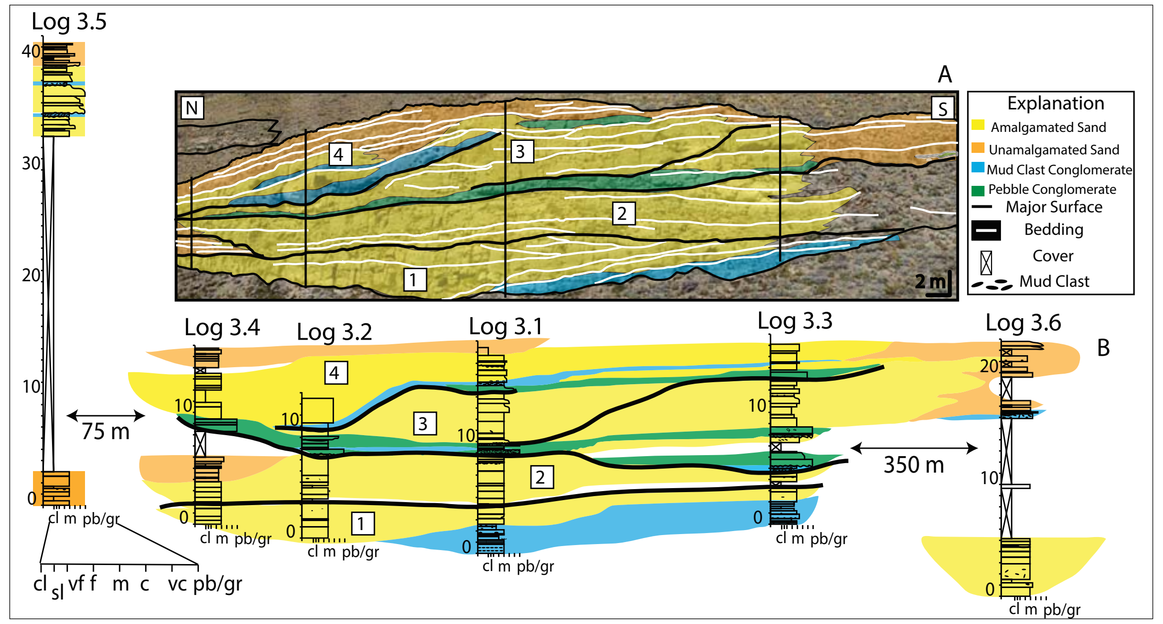




A) Upper/Middle Slope Confined Channels



Features:
- -steep erosional surfaces defined by mud clast and pebble conglomerates
- -highly amalgamated, thick, structureless sand
- -no tractional sedimentary structures

Grain Size:
-Avg. Medium Upper sandstone, overall increase in coarse fraction and decrease in fines

Bed Thickness:
-Avg. 60cm, highest in axial position, thinning towards margins and top

Net to Gross Ratio:
-up to 98% within channels, 25-40% marginal

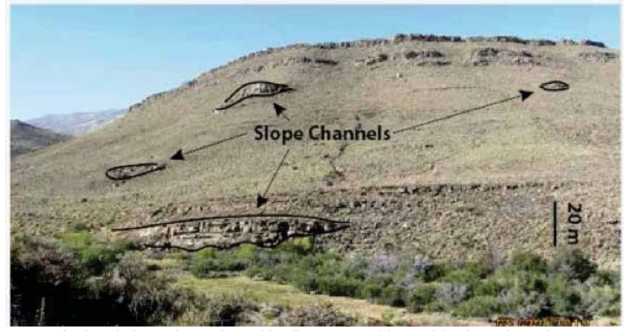
Sand Body Dimension:
- -Aspect Ratio: ~7
- -Width: 100m
- -Depth: 15m


Amalgamated beds in channel axis


Pebble conglomerate erosional surface

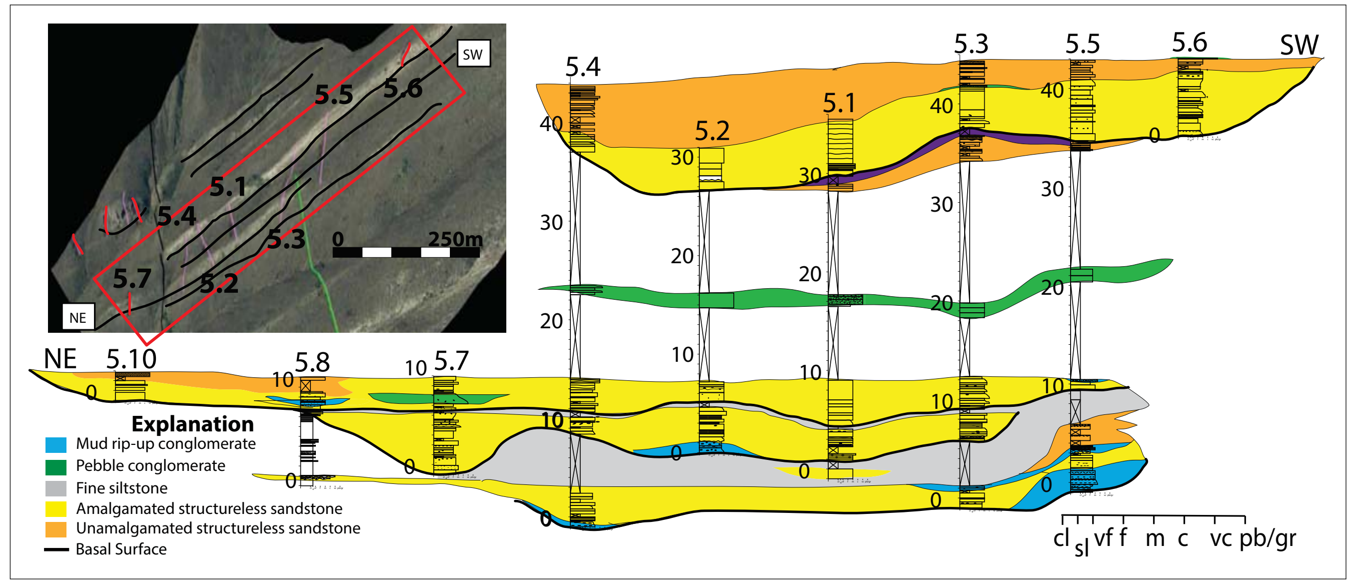

Leaf imprint in clean channel sand


Mud rip-up clast lense



Isolated slope channel sand bodies encased in muddy slope deposits

B) Mid-lower Slope Weakly Confined Channels




Outcrop exposure of continuous sand bodies positioned in the mid-lower slope.

Features:
- -Broad sheet-like fill
- -Abrupt lateral termination of sand bodies
- -Thick (5-8m) amalgamated structureless sand
- -Mud clast and pebble conglomerate lenses
- -Channels separated by fine intervals

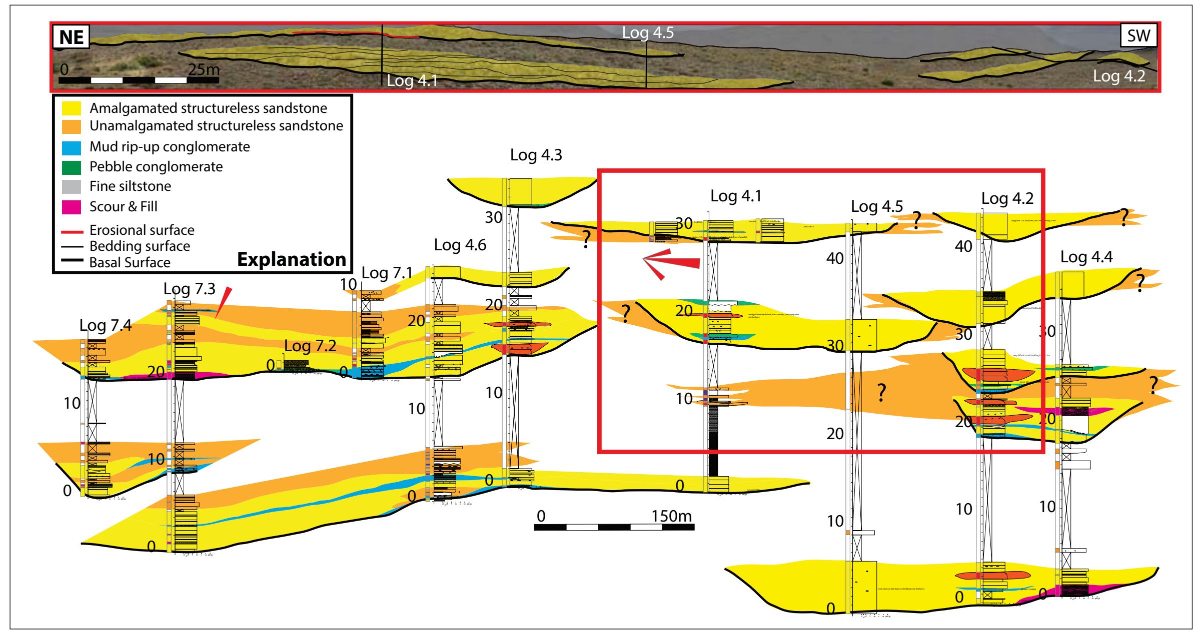
Net to Gross Ratio:
-70-98% within channels, 35-40% marginal

Grain Size:
-Avg. Medium lower sandstone, decrease in coarse fraction

Bed Thickness:
-Avg. 15-40cm, highest in axial position, thinning towards margins and top

Sand Body Dimension:
- -Aspect Ratio: ~17
- -Width: 175m
- -Depth: 10m

C) Base of Slope Distributary Channel Complex




Scour and fill structure


Erosion, truncation of thinly bedded sands by thick amalgamated sand


Ripples and planar laminated thinly bedded sandstone


Rare, large organic debris, petrified wood

Features:
- -2-7m amalgamated sand bodies separated by cover/fines
- -ripples and planar laminations truncated by 0.5m erosion in axial channel position
- -scour and fill structures
- -lateral discontinuity and marginal thinning of sheet-like sands
- -few mud clast or conglomerates
- -no tractional sedimentary structures

Net to Gross Ratio:
-up to 60% within and marginal combined

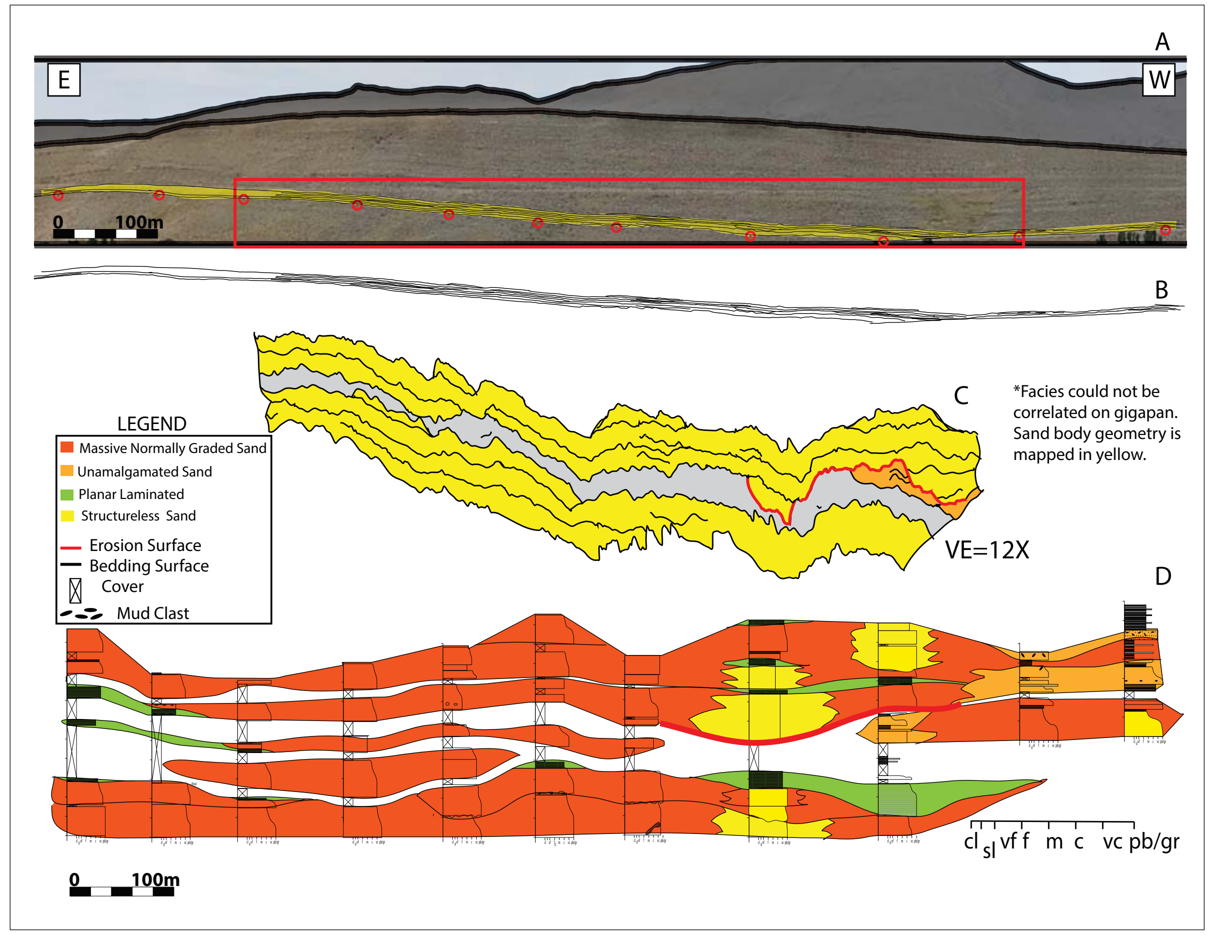
Grain Size:
-Avg. Medium-lower sandstone, decrease in coarse fraction

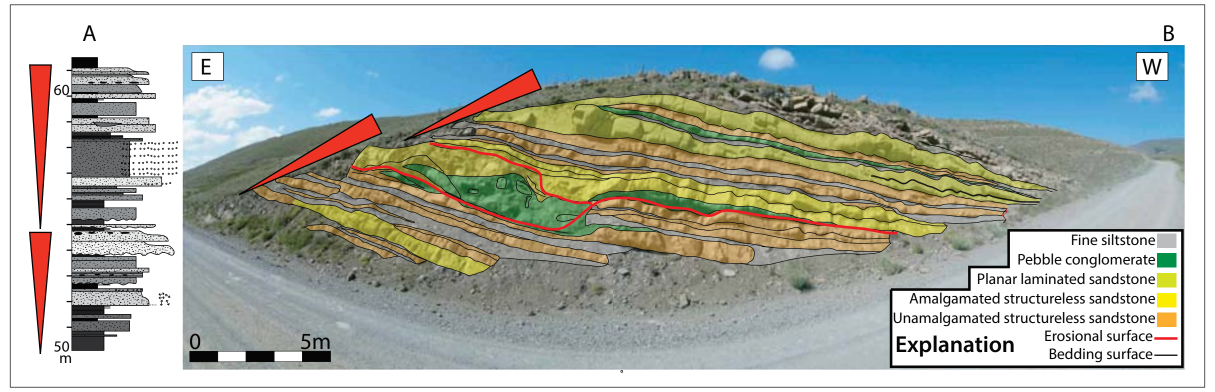
Bed Thickness:
-Avg. 20-30cm, highest in axial position, thinning towards margins and top

Channel Complex Dimension:
- -Aspect Ratio: ~50
- -Width: 1500m
- -Depth: 30m

Individual Channel Dimension:
- -Aspect Ratio: 20-30
- -Width:100-150m
- -Depth: 5-7m

D) Basin Floor Lobe Complex






Normally graded bed with erosional contact on mud


Massive amalgamated beds and un-amalgamated beds in lobe complex


Heterolithic interval deposition from abandoment or avulsion


Ripple laminations within heterolithic interval

Features:
- -Thickening upward intervals
- -Rare, small erosional features
- -Common normal grading and planar laminations
- -Ripple laminations within heterolithic intervals
- -Laterally continuous (several km) sands separated by fines
- -thin conglomerate lenes at base of normally graded sands
- -Down-dip and lateral fining, thinning, decreasing amalgamation

Net to Gross Ratio:
-37% composite

Grain Size:
-Avg. medium lower sandstone

Bed Thickness:
-Avg. 40 cm

Sand Body Dimension:
- -Aspect Ratio: ~1000
- -Width: 5000 m
- -Depth: 5m

III: Slope to Basin-floor Evolution of Channels to Lobes, Jurassic Los Molles Formation, Neuquén Basin, Argentina

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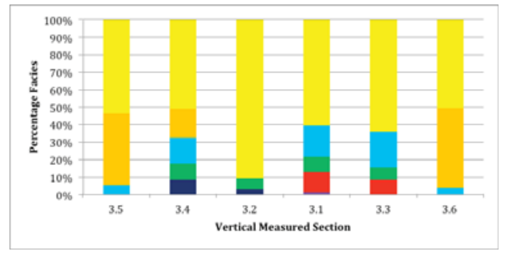
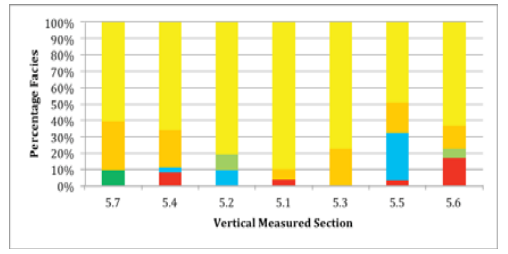
Lithofacies Trends

A) Upper/Middle Slope Confined Channels



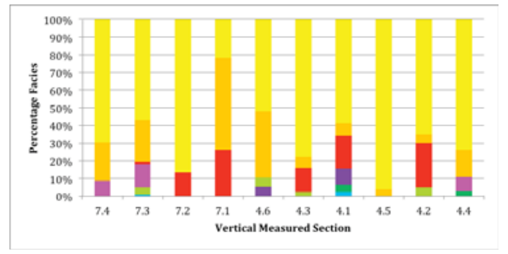
Upper slope confined channel depositional environment is primarily composed of amalgmated structureless sandstone beds. Secondary components that are prominent are pebble conglomerate and mud-rip up clast conglomerate lenses. Very rare normal grading is observed in confined slope channel setting. Degree of amalgamation decreases away from channel axis.

B) Mid-lower slope weakly confined channels

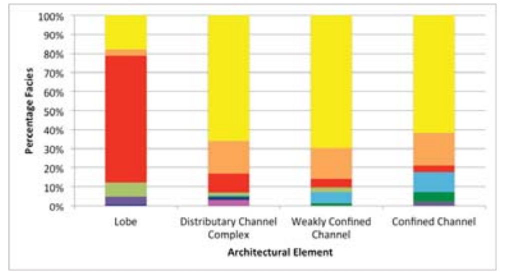


Weakly confined mid-lower slope channels show little variation from upper/middle slope channels. Decrease in presence of pebble conglomerate and presence of low angle crossbeds.

C) Base of Slope Distributary Channel Complex

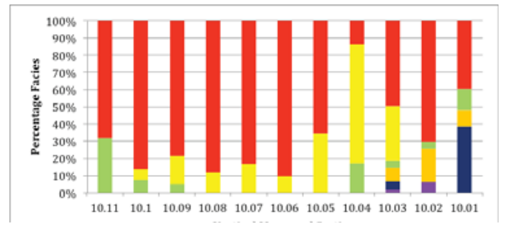


Structureless sandstone is dominant across the channel complex. Note scour and fill structures are only present at the channel complex margin, while normally graded sandstone is confined to the central part of the channel complex.



Overall lithofacies comparison between depositional environments showing marked change in lithofacies between lobe and channel deposits. Note the change in dominant facies from amalgamated sandstone (yellow) in channel elements to normally graded sandstone in lobe elements. Also, pebble and mud rip-up conglomerate proportions decrease down-slope within channels and disappear completely in lobes.

D) Basin Floor Lobe Complex



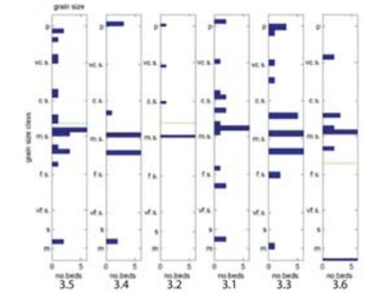
Dramatic increase in normally graded sands. Presence of planar laminated sands towards flow margins where flow energy decreases. Increase in amalgamated sandstone (yellow) is indicative of flow axis where unamalgamated (orange) sands are cut out by erosional surface.

- normally graded
- pebble conglomerate
- scour-fill
- mud rip up conglomerate
- plane parallel/low angle crossbeds
- unamalgamated structureless
- amalgamated structureless

Legend

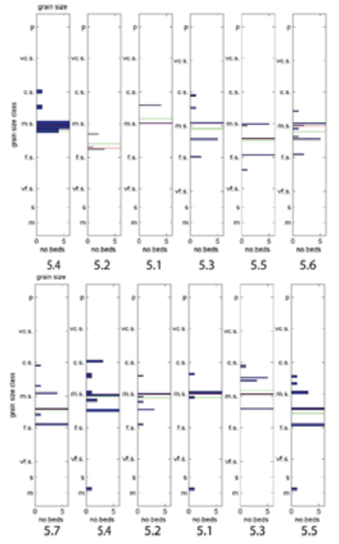
Grain Size Analysis

A) Upper/Middle Slope Confined Channels



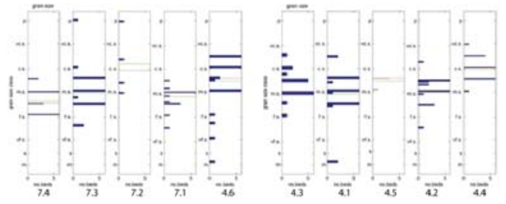
Contains coarsest fraction of grains. Average grain size varies little around medium grain sandstone. However, not that section 3.2 (central channel) has no fine beds.

B) Mid-lower Slope Weakly Confined Channels



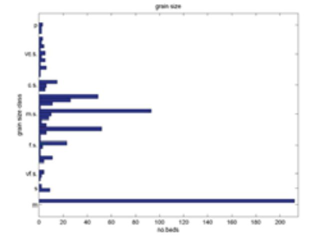
Average grain size does not vary much from lower/upper medium sand. However, central channels have an increase in overall grain size with some having up to very coarse sand.

C) Base of Slope Distributary Channel Complex



Grain size varies from medium to coarse sand. An increase in grain size is possibly an indication of flow deposition due to decreasing confinement.

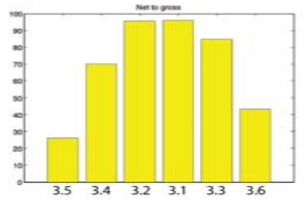
D) Basin Floor Lobe Complex



Average grain size from vertical measured section through several basin floor lobes shows a normal distribution of sand around medium sand with an increase in silty mud.

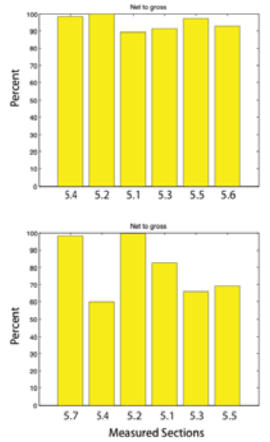
Net to Gross Ratio

A) Upper/Middle Slope Confined Channels



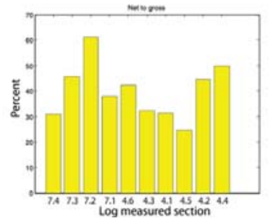
Highest net to gross ratios within channel axis position as high as 95%. Channel margin net to gross ratios decrease to 27 and 40%..

B) Mid-lower Slope Weakly Confined Channels



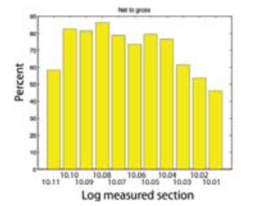
Decrease in net to gross ratio, from 98% to 60% in measured sections that include slope fines.

C) Base of Slope Distributary Channel Complex



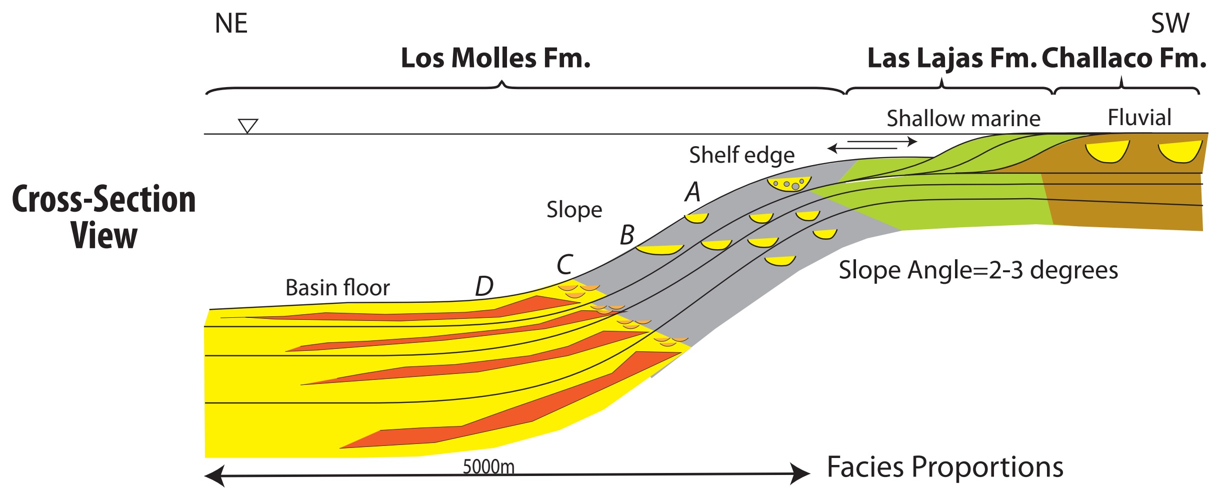
Net to gross ranges from 27 to 60 % depending on log location, whether through channel axis or channel margin position.

D) Basin Floor Lobe Complex



Within sandy lobe body net to gross ratios range from 58 to 88%. Note lower net to gross ratios distal to flow axis.

Conclusions

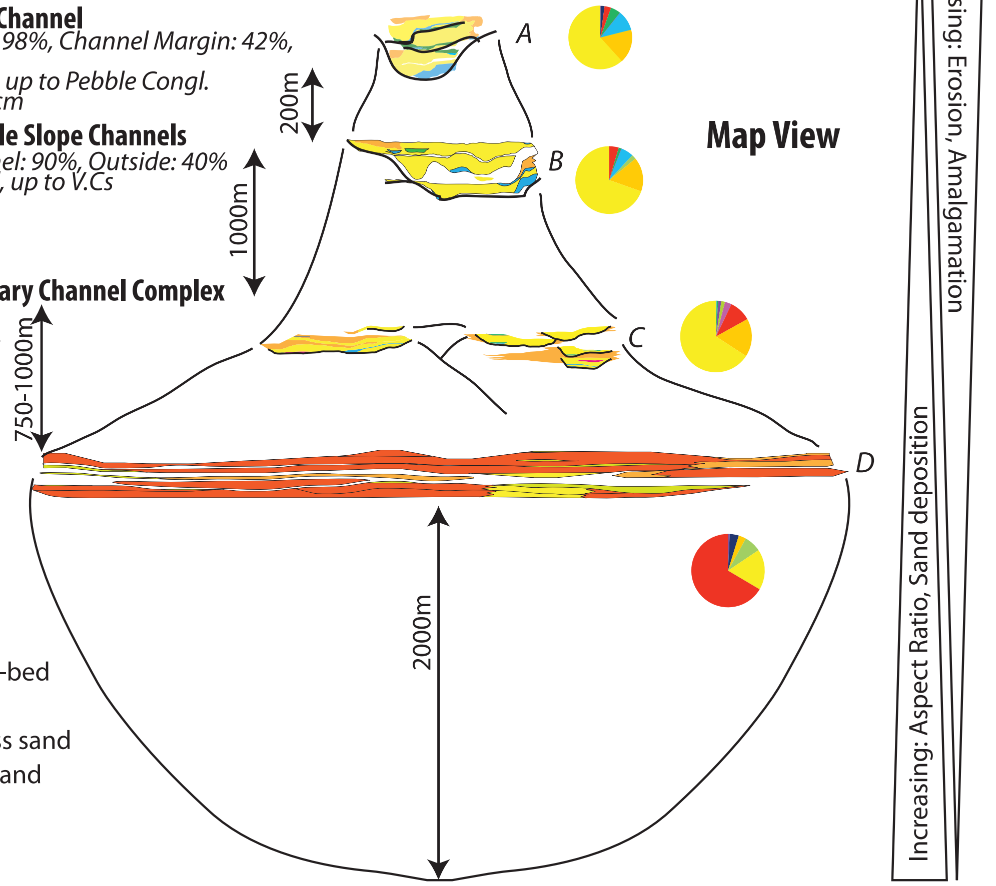


Outcrop A: Confined Upper Slope Channel
Net to gross: Channel axis: 98%, Channel Margin: 42%, outside, 20%
Grain Size: Avg-Med. Sand, up to Pebble Congl.
Bed Thickness: Avg.-25-65cm

Outcrop B: Weakly Confined Middle Slope Channels
Net to gross: Within Channel: 90%, Outside: 40%
Grain Size: Avg.-Med. Sand, up to V.Cs
Bed Thickness: 18-45cm

Outcrop C: Base of slope Distributary Channel Complex
Net to gross: 25-60%
Grain Size: Avg. Med. Sand, up to Pebble Congl
Bed Thickness: Avg. 20-45cm

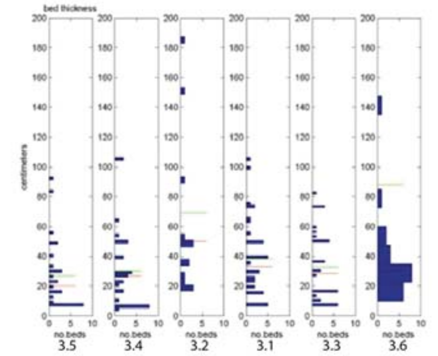
Outcrop D: Basin-floor Lobe
Net to gross: 50%
Grain Size: Avg.-Med Sand
Bed Thickness: Avg. 20cm, up to 100 cm in flow axis



Facies Explanation
- muddy silt
- heterolithic mud/sand
- plane-parallel to low angle X-bed
- normally graded sand
- unamalgamated structureless sand
- amalgamated structureless sand
- scour-fill structure
- pebble conglomerate
- Mud rip-up conglomerate

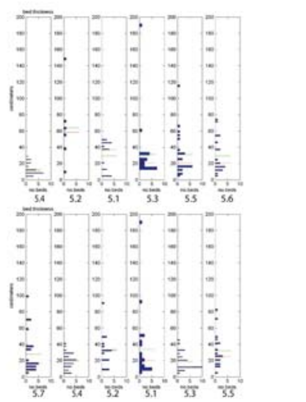
Bed Thickness Analysis

A) Upper/Middle Slope Confined Channels



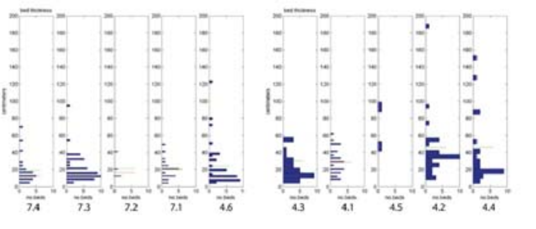
Bed thickness ranges from 5cm to 1.8m. Average bed thickness ranges from 20-90cm. Thickest beds are deposited in central channel location (Log 3.2).

B) Mid-lower Slope Weakly Confined Channels



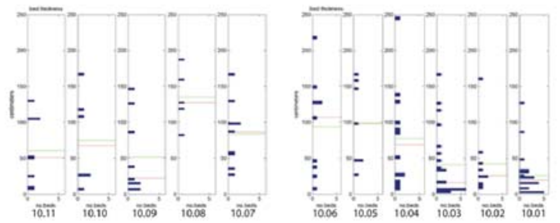
Note decreasing average bed thickness away from the center of the channels from 45cm to 25cm. Central measured sections also have the thickest bed up to 190cm.

C) Base of Slope Distributary Channel Complex

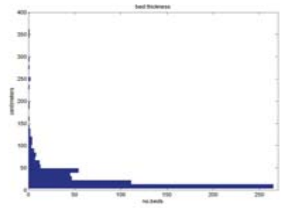


Average bed thickness ranges from 20 to 45cm and is thickest in measured sections containing channel axis facies.

D) Basin Floor Lobe Complex

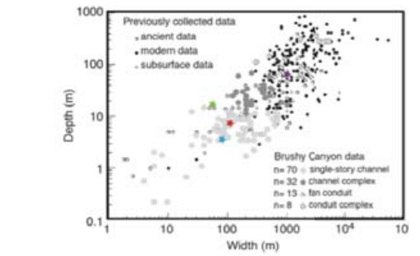


Average bed thickness ranges from 20-125cm depending on depositioinal position. Increases in bed thickness in channel axis position up to 140cm.



Average bed thickness from a vertical measured section through several lobes is ~20cm, while beds range from <5cm to 3.5m.

Channel Width to Depth Ratio



Graph showing width versus depth of channels from ancient, modern and subsurface datasets. Data from this study are plotted. Red star indicates upper-slope confined channel, green star indicates mid-slope weakly confined channel, light blue star indicates individual base of slope distributary channels and purple star indicates the entire distributary channel complex. From this graph we see that upper slope multi-story confined channels correspond to data that indicates single-story channels from Brushy Canyon outcrops. Weakly confined channels are vertically and laterally offset and dimensions are consistent with single-story channels from the Brushy Canyon study. Lastly, distributary channel complex dimensions are consistent with channel complex dimensions from the Brushy Canyon study and composed of smaller single-story channels marked in dark blue. Modified from Gardner & Borer (2000).

Reservoir Implications

-Basin floor lobe sand intervals have high volumetric potential, good lateral connectivity and high overall net to gross sand ratio, however mud and less amalgamated sands between can serve as baffles to productivity.

-Upper slope confined-weakly confined channels have high net to gross sand ratio and good reservoir quality inside channels. However, isolation on the slope causes poor vertical and lateral connectivity.

Acknowledgements
Support from Statoil Research Grant & Mason Dykstra, Ron Steel, Cornel Olariu , David Mohrig, Nick Perez, Meredith Bush, Eugen Tudor, Rene Winter, Steel Research Group, Friends of Sediment Laden Gravity Flows, ConocoPhillips SPIRIT scholarship, Belisle & Cordero Estancias, town of Alumine, Argentina, Nestor Angelino and Family