Evaluation of the Multiple Origins of Thin-Bedded Deep-Water Slope Sandstones: El Rosario Formation (Upper Cretaceous - Paleocene) Baja California, Mexico*

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Abstract

One dilemma in sedimentology is that multiple depositional processes can produce similar features while one formative process can generate multiple patterns. A comparison of (1) depositional energy trends from grain size and primary structures, (2) placement within a stratigraphic hierarchy, (3) ichnofacies type, and diversity, and (4) sedimentary body type and associated architectural changes are used to assess the causal mechanism. Variations of these attributes reflect flow initiation processes (flood vs. failure), flow evolution (velocity, run-out length), preservation (bypass, erosion), and reworking (biological, physical).

Cretaceous and Tertiary outcrops in the Mesa San Carlos area expose four different thin-bedded sandstone types (TBS). This study presents a matrix of the most important attributes used to recognize them: (1) hyperpycnite successions (4-15m thick) are interbedded with slope mudstone deposits that together form tabular (85m thick; >1km wide) successions, with sandstone channels and scours common at the base and mass transport deposits present at the top, (2) Wedge-shaped TBS turbidites that flank and confine multistory channelbelts up to 90m thick that thin and pinch out within 500m of interdigitated but stacked conglomerate channels, (3) TBS turbidites separating channel bodies form 25m-thick and 230m-wide preserved remnants, and (4) TBS contourites comprising <3m wide sandstone lenses amalgamated laterally to form tabular bedsets. Paleocurrent indicators change from unidirectional offshore during hyperpycnal flow to slope parallel flow during waning energy conditions of this mudstone-rich cycle.

Turbidite and hyperpycnite deposition respond to external controls, whereas contourites are reflecting internal controls in the slope system. Failure-initiated flows dominate the deposition in the third-order growth phase and flood-initiated flows dominate in the third-order initiation and retreat phases. Bottom current rework is the main internal process that affects deposits in the initiation and retreat phases. In the growth phase, the internal processes are more variable. They are controlled by overspilling and superelevation of the flows. Channel and scour bodies deposited by hyperpycnal flows show downstream and vertical changes in grain size, primary sedimentary structures, bed thickness, and sedimentation units that allow recognition of an energy matrix recording variations of the flow magnitude.

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- Outline

  Study Area
  Methodology
  Sedimentology
  Conclusions

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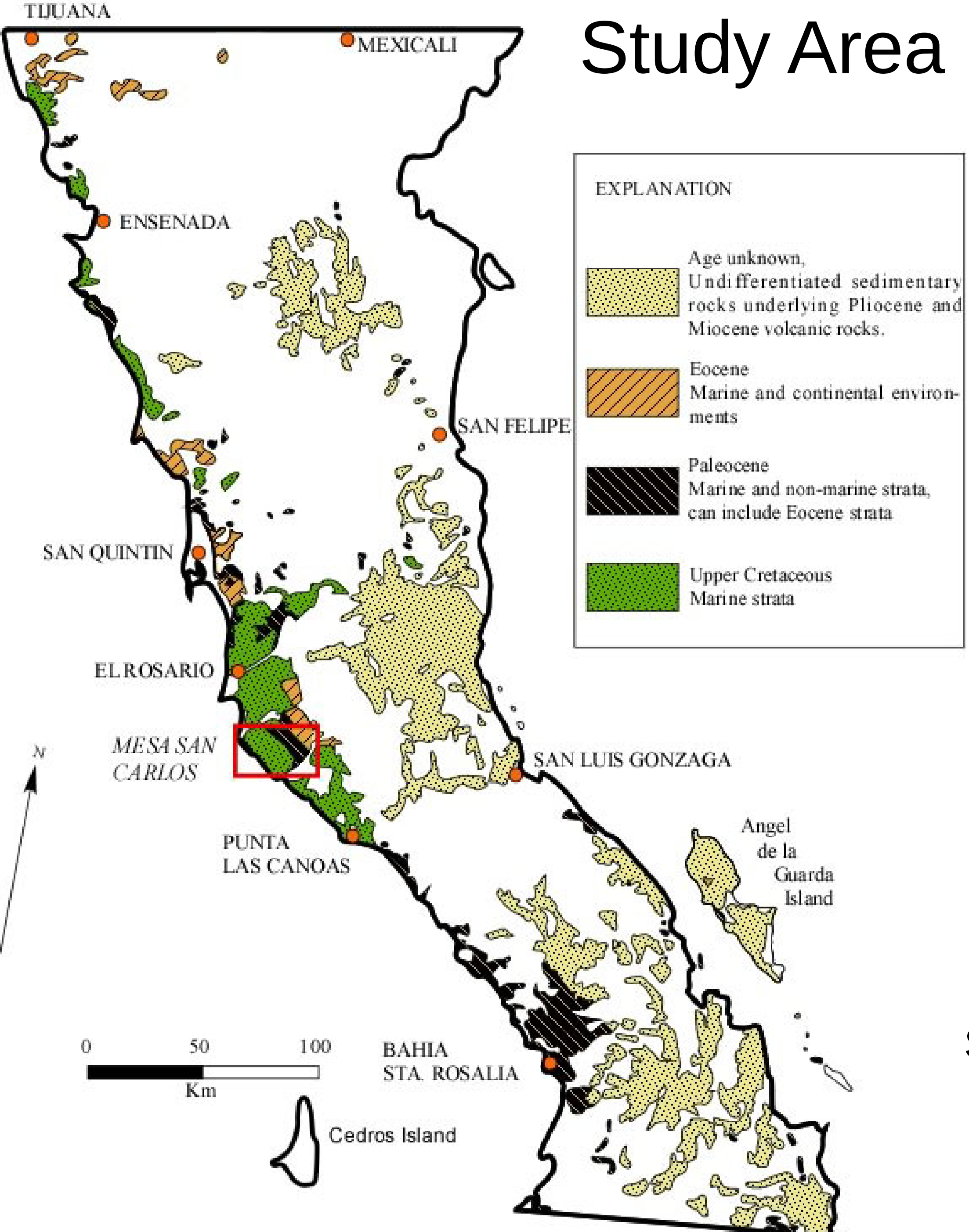
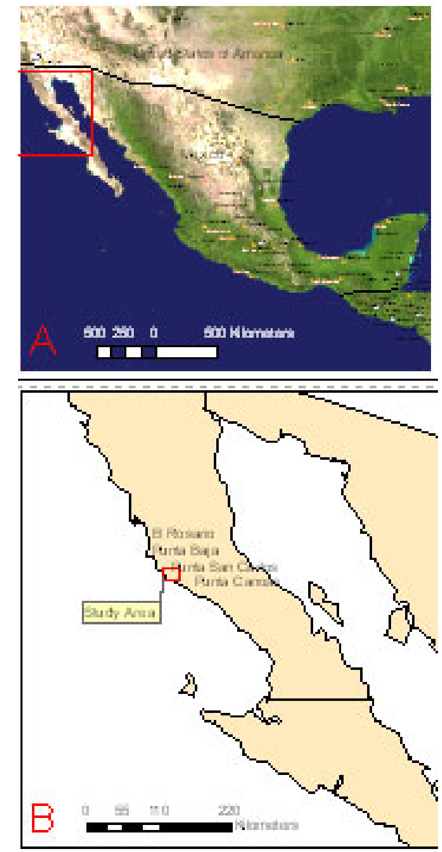
Dr Michael Gardner.

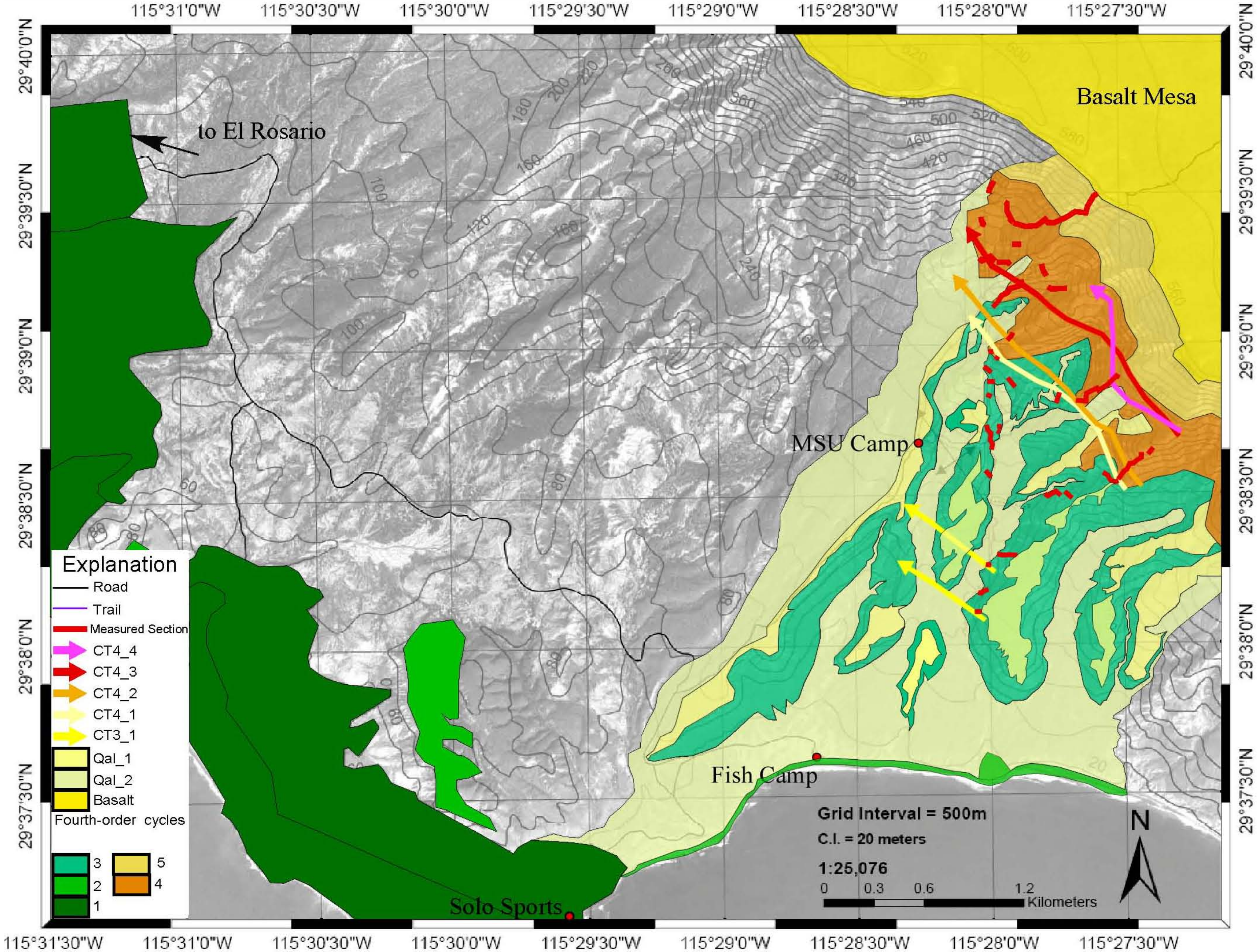
June, 9 - 2009

Study Area



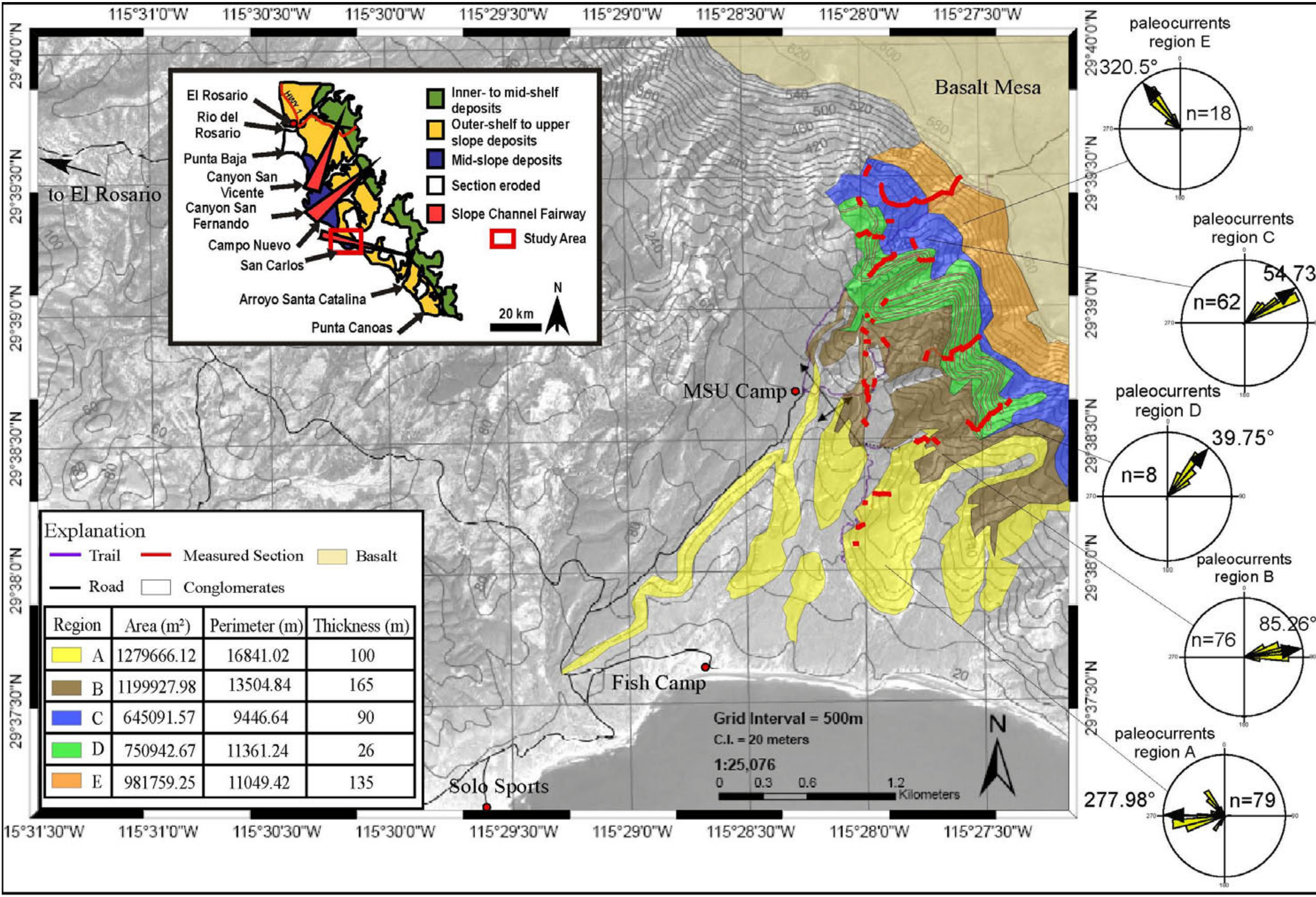


Distribution of Sedimentary Rocks in Baja California (Modified from Santillan and Barrera, 1930, Gastil et al., 1975, and Yeo, 1984). Red box outlines Mesa San Carlos study area.



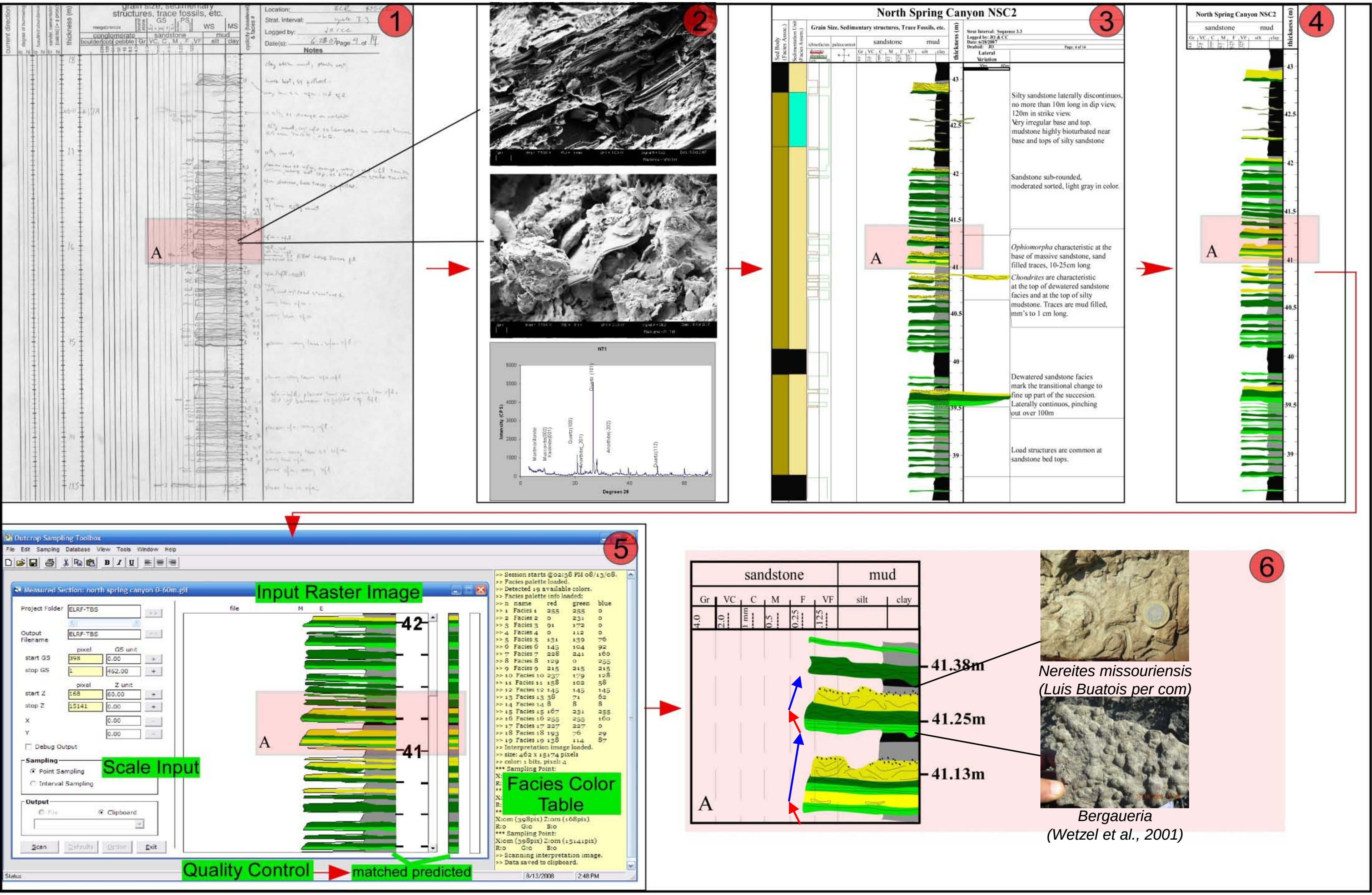
115°31'30"W
115°31'0"W
115°30'30"W
115°30'0"W
115°29'30"W
115°29'0"W
115°28'30"W
115°28'0"W
115°27'30"W
29°40'0"N
29°39'30"N
29°39'0"N
29°38'30"N
29°38'0"N
29°37'30"N
Basalt Mesa
to El Rosario
MSU Camp
Fish Camp
Solo Sports
Explanation
Road
Trail
Measured Section
CT4_4
CT4_3
CT4_2
CT4_1
CT3_1
Qal_1
Qal_2
Basalt
Fourth-order cycles
3
2
1
5
4
Grid Interval = 500m
C.I. = 20 meters
1:25,076
0 0.3 0.6 1.2
Kilometers
N

How do we evaluate the origin TBS deposits?

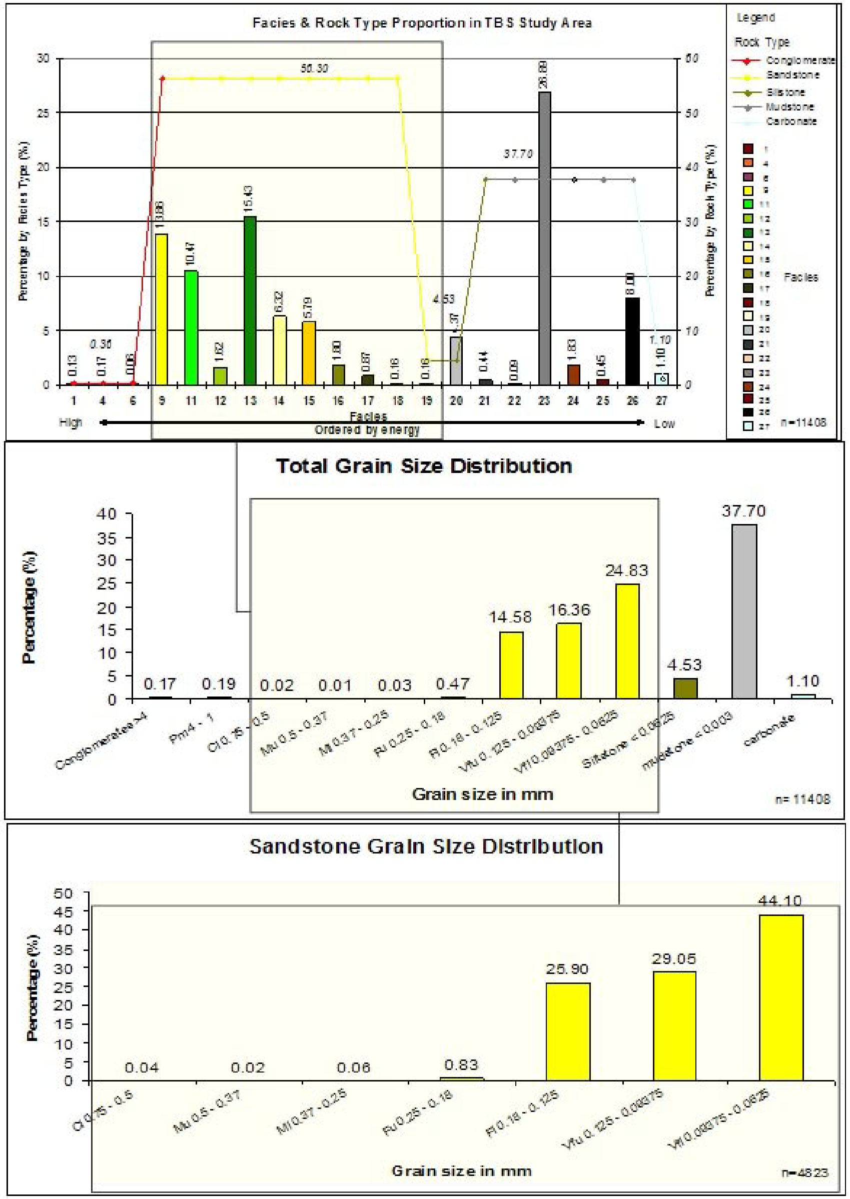


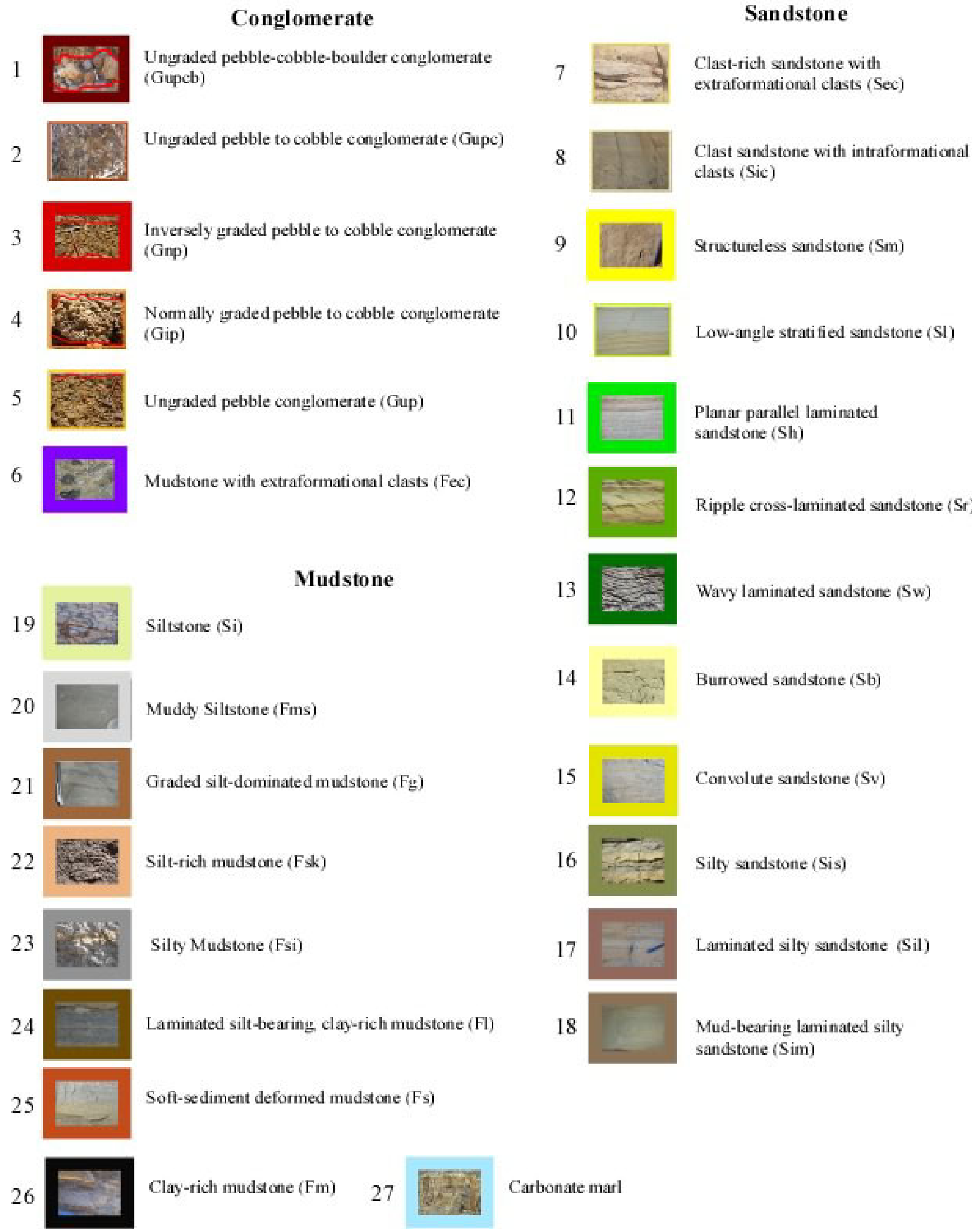
Region	Area (m²)	Perimeter (m)	Thickness (m)
A	1279666.12	16841.02	100
B	1199927.98	13504.84	165
C	645091.57	9446.64	90
D	750942.67	11361.24	26
E	981759.25	11049.42	135

Diagram showing the methodology to measure the vertical thickness for facies and sedimentation units of TBS



Sedimentology

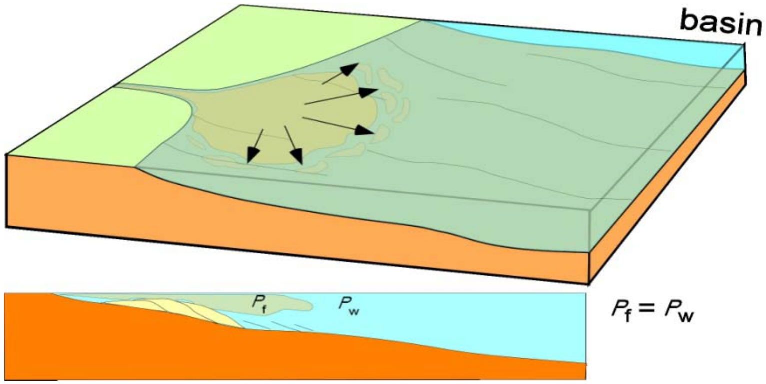




Hypothesis

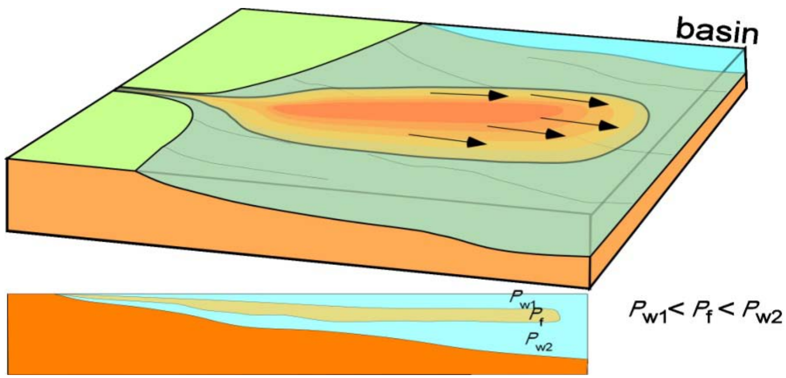
Dominant Flow Process	1 Flow Response Sedimentology	2 Possible Sedimentary Bodies	1+2= Sedimentation Regions
I. Flow Behavior and Evolution. A. Velocity B. Run-out length	I. Turbidites (Overbank) A. Proximal B. Distal	Levee-Overbank Lobe Scour Channel	E. Mudstone-rich thin-bedded sandstones overlying conglomerates D. Thin-bedded sandstone separating conglomeratic channels
II. Flow Initiation. A. Failure B. Flood	II. Turbidites (Levee). A. Proximal B. Distal	Levee Lobe Scour Channel	C. Thin-bedded sandstone flanking and confining con-glomeratic channels
III. Reworking. A. Biological B. Physical	III. Contourites. A. Sandstone-rich, high bioturbated B. Mudstone-rich, low bioturbated	Channel Levee Lobe Scour	B. Mudstone-rich thin-bedded sandstone underlying conglomerates
IV. Preservation. A. Bypass B. Erosion	IV. Hyperpycnites. A. High-magnitude flood B. Medium-magnitude flood C. Low-magnitude flood	Channel Levee Lobe Scour	A. Sandstone-rich thin-bedded sandstone underlying conglomerates

Flood-Initiated Subaqueous Flows



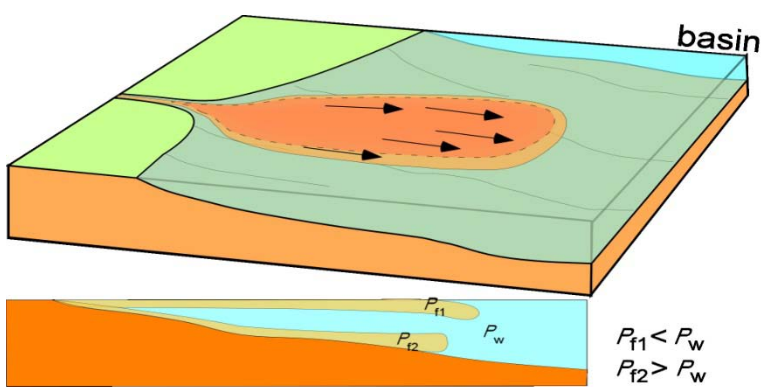
1) Homopycnal flow

- Inflow rapidly loses competence and deposits coarse sediment fraction
- Creates Gilbert type delta



2) Hypopycnal flow

- Buoyant Inflow “floats” over basin water
- Mud flocculation promotes deposition by suspension settling

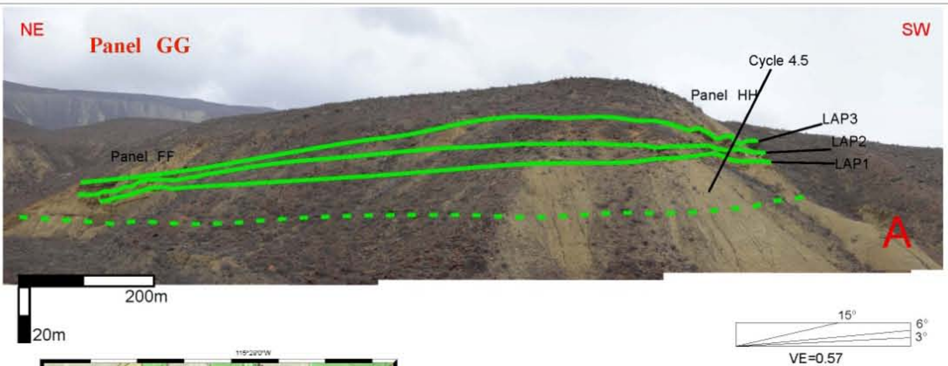


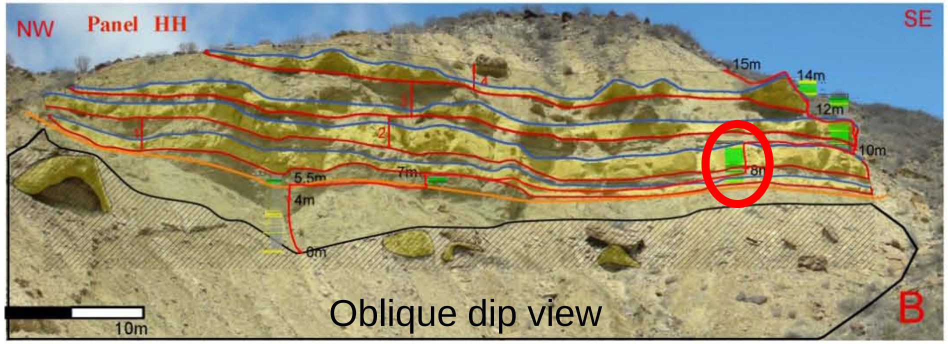
Modified from Bates, 1953

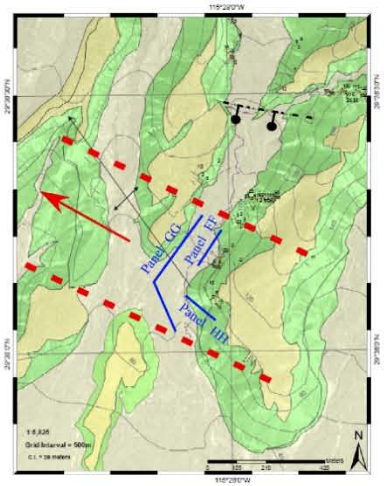
3) Hyperpycnal flow

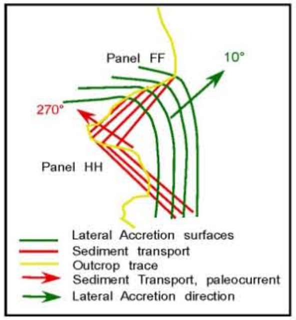
- Gravity driven gradient current descends below basin water as density underflow
- Turbulence scours seafloor w/ suspension plus tractive transport and deposition

Sedimentary Bodies – Region A

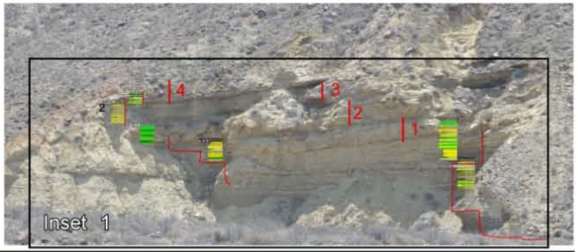


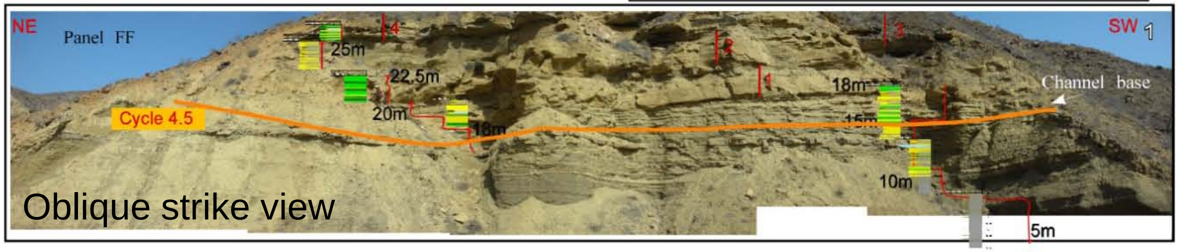


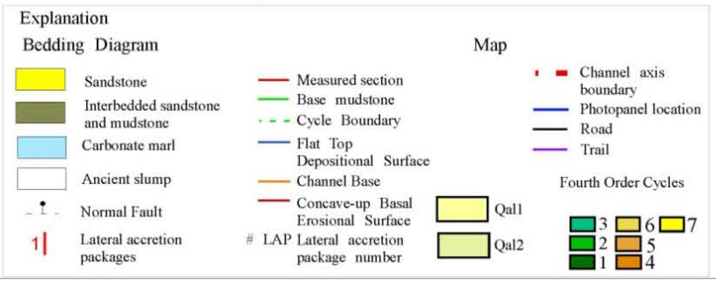


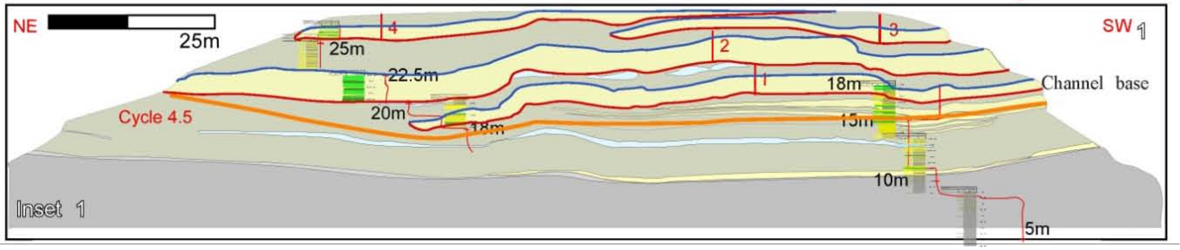


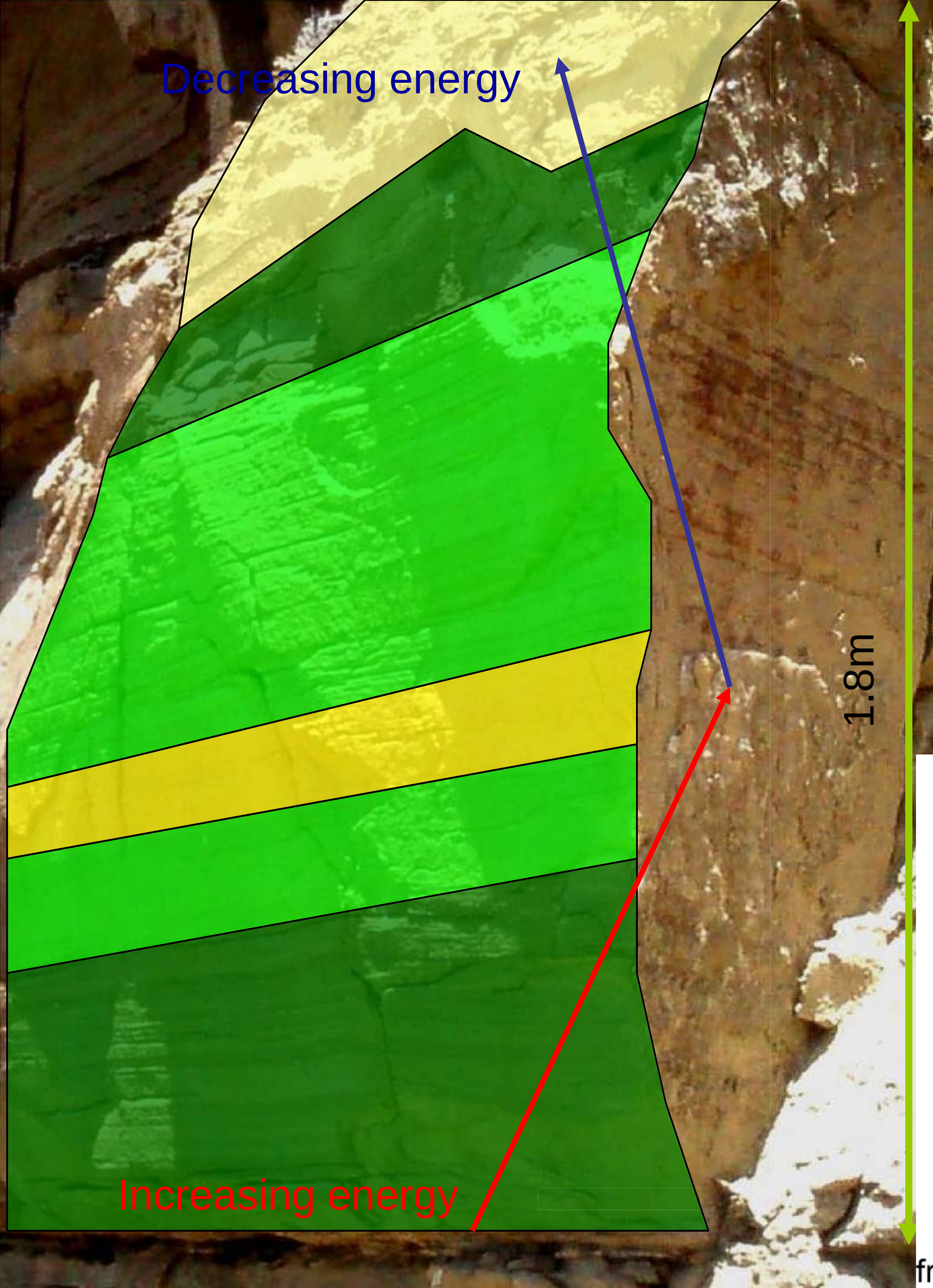
Channel Recognition
1. Bar form, Lateral Accretion Packages (LAP). organized flow in an open channel
2. Unidirectional sediment transport
3. Mappable bodies through multiple facies, length longer than width
4. Flanked by thin-bedded deposits

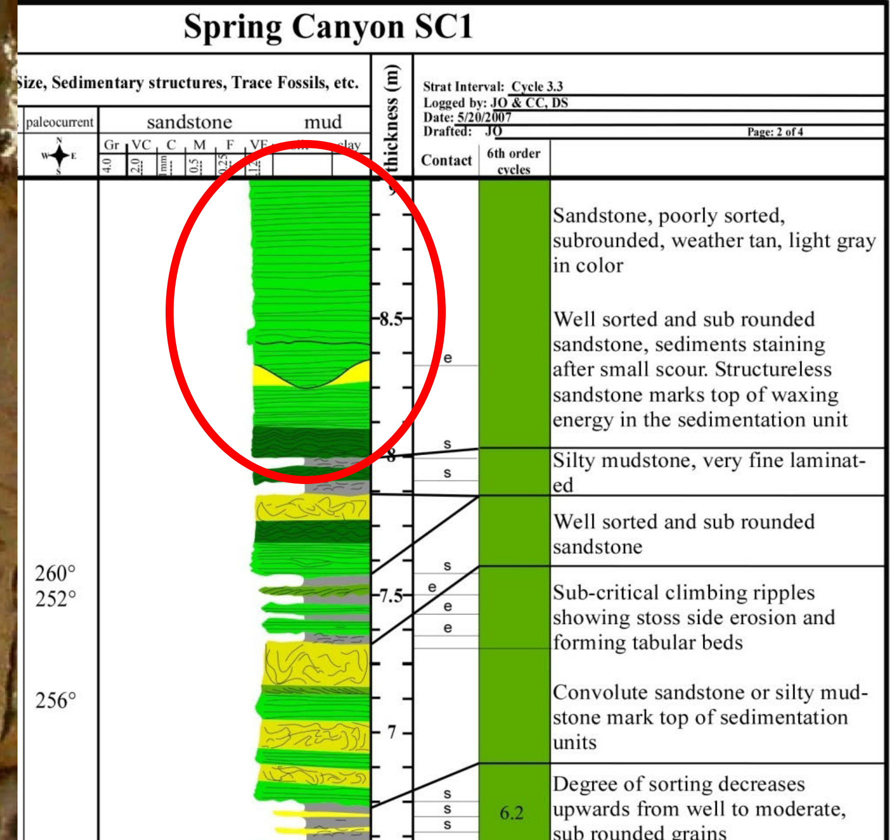


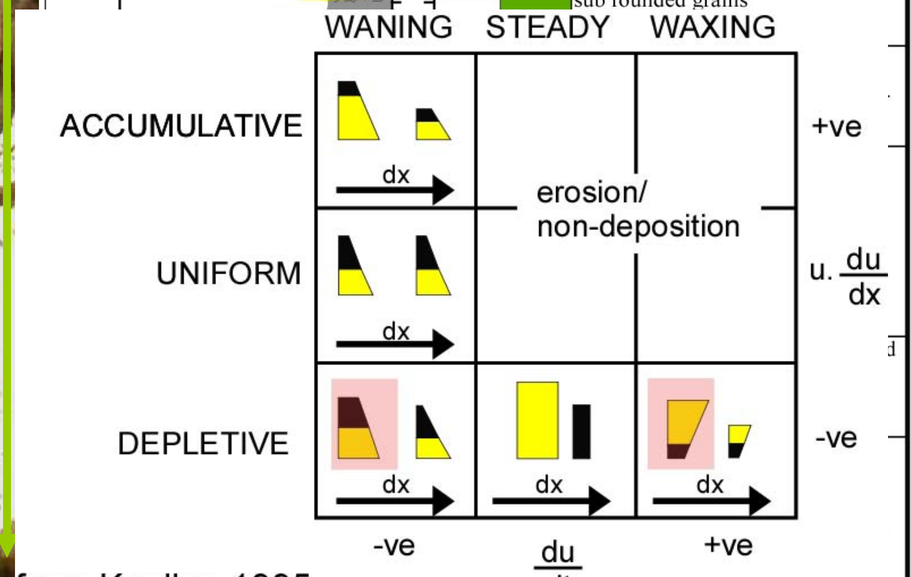








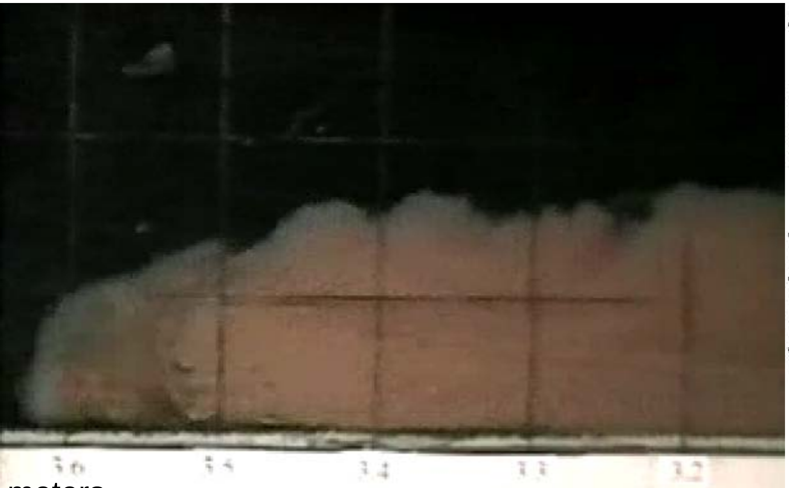




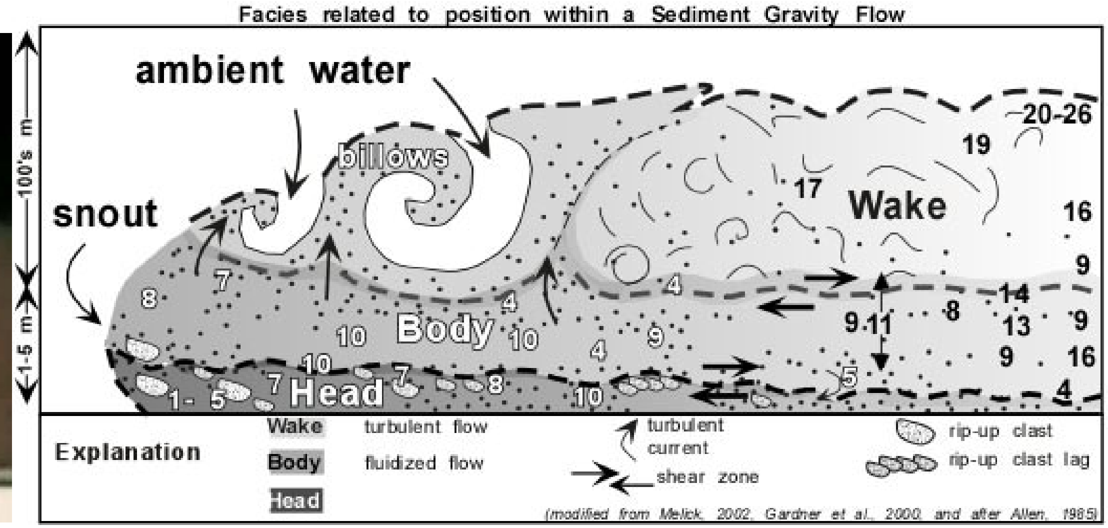
from Kneller, 1995

Attribute variations reflect processes

High-density turbiditic flows

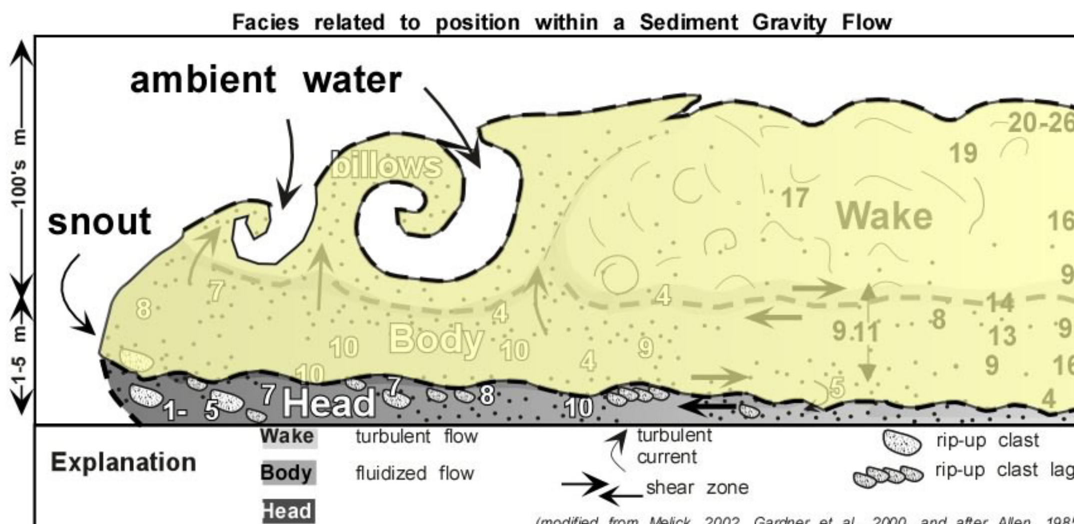


meters



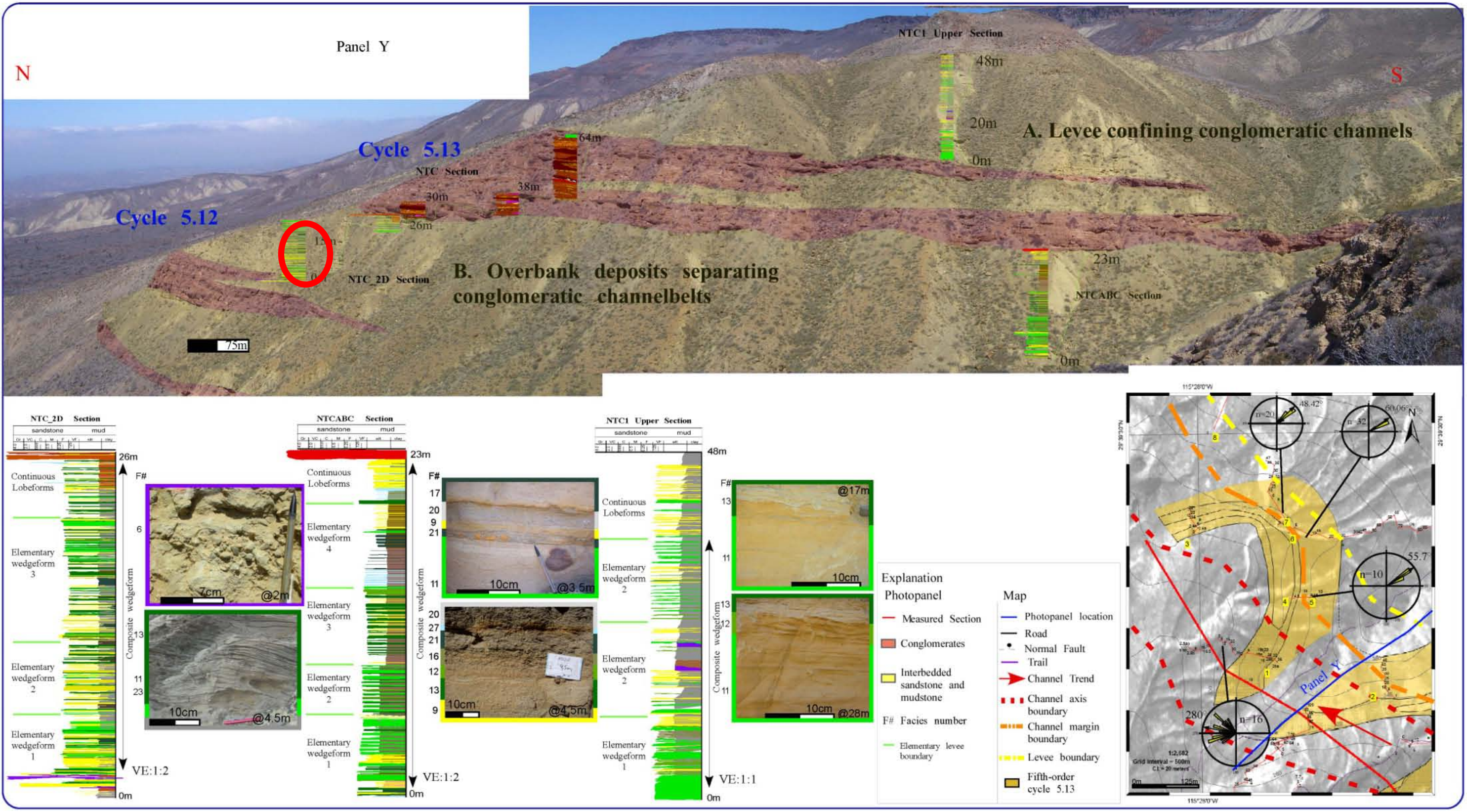
Low-density turbiditic flows

meters

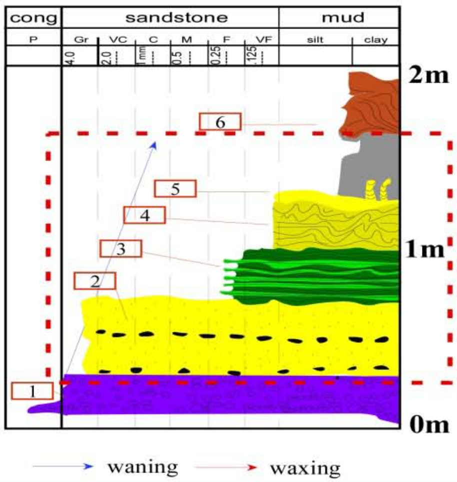


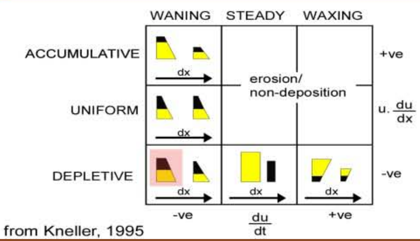
Parker, G. St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

Sedimentary Bodies – Regions D & C



Sedimentation unit near channel margin





from Kneller, 1995

Pebbly mudstone

Granule to lower medium sandstone with mud rip-up clasts

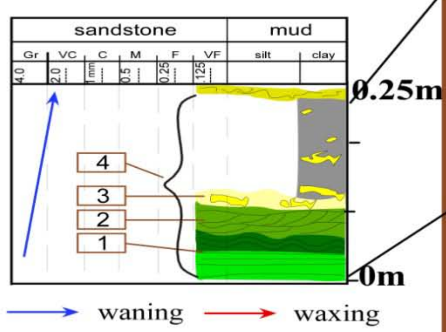
Plane parallel to wavy laminated lower fine sandstone

Wavy laminated lower fine to convolute very fine sandstone

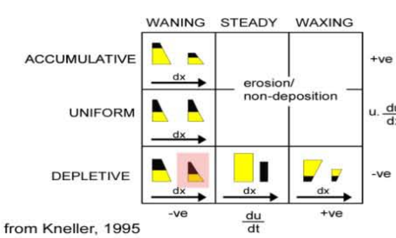
Silty mudstone with vertical sand filled traces

Convolute mudstone

Sedimentation unit far away from channel margin



Wavy laminated sandstone



from Kneller, 1995

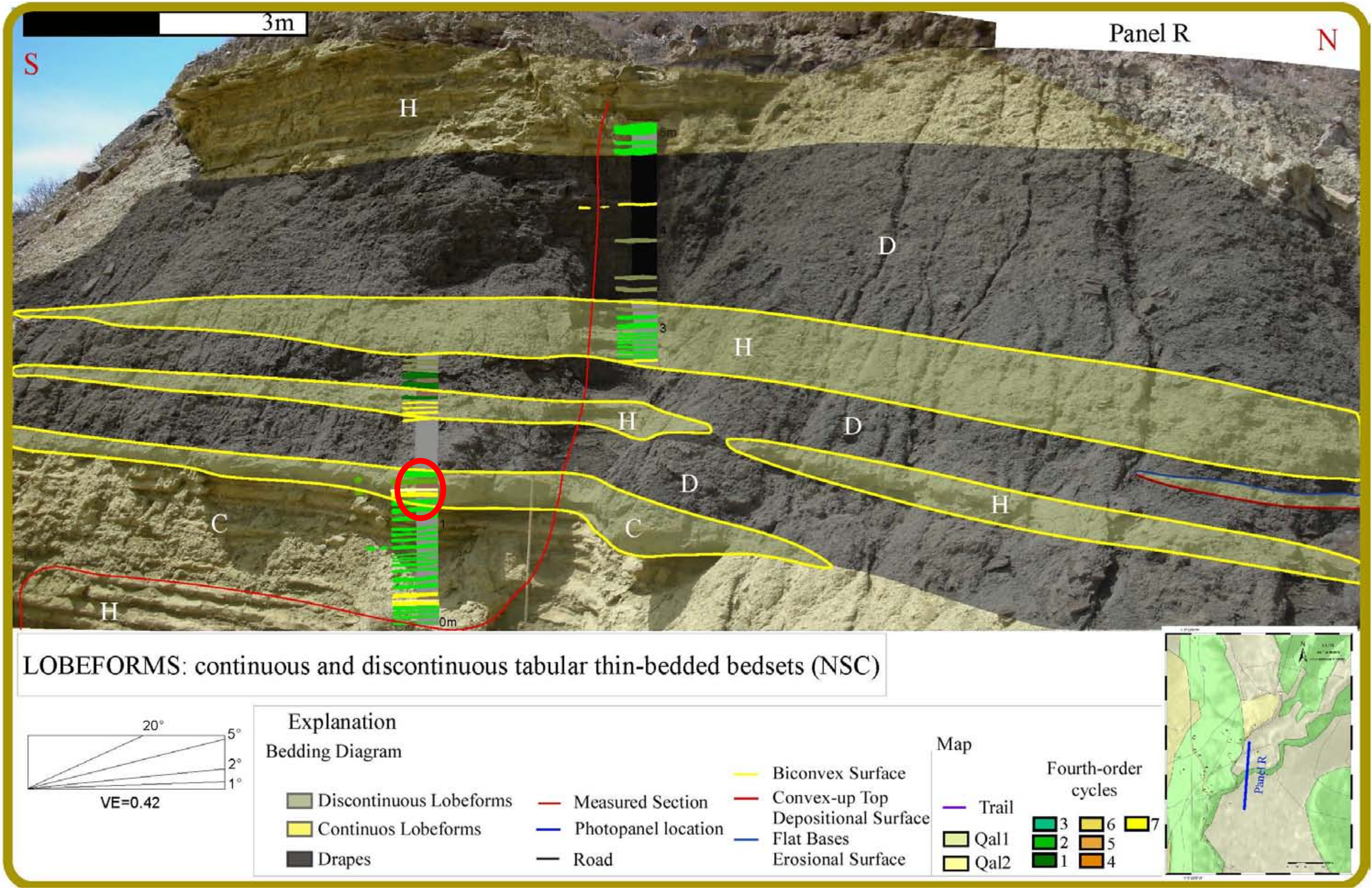
Highly bioturbated sandstone and silty mudstone with sand-filled horizontal traces

TC2D

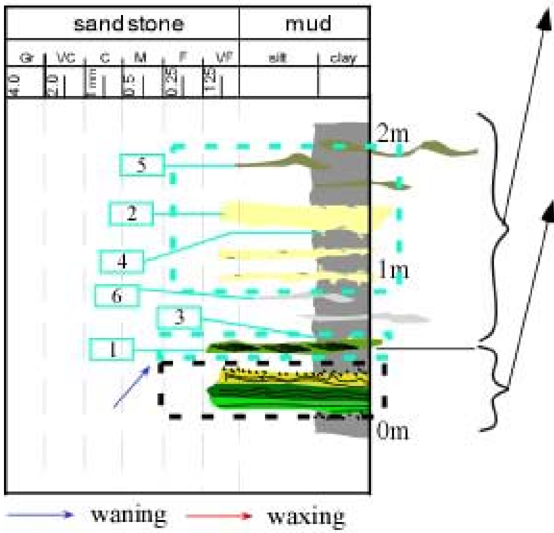
rval: Cycle 3.5
y: JO & CC, DS, SA
0/2007
JO/K
Page: 1 of 6

6th-order cycles	Hydrodynamic Facies
	Thinly interbedded sandstone and mudstone. Sandstone with erosive tops and base, concretions
	Sandstone poorly sorted, sub-angular, tan in color
	Sandstone bioturbated by horizontal sand filled traces Sandstone beds laterally continuos by 50m
5.28.2	Interbedded massive sandstone and very fine laminated silty mudstone, not bioturbated
	Sandstone lenses highly bioturbated by horizontal and vertical traces, sand filled, less than 5cm long
	Fining up sandstone beds, angular to sub-angular grains, poorly sorted, at base granule sandstone with mud rip up clasts, beds laterally discontinuos pinching out over 40m
	Pebbly mudstone forming laterally discontinuos beds. Mudstone bioturbated at the base by vertical sand filled traces, 4-5cm of diameter and 10-14cm long
	Poorly sorted, angular, tan in color
	Poorly sorted, sub-angular, tan in color
	Structureless granule sandstone, mud rip up clasts at bed base
	Pebbly mudstone, granule matrix, biotite and quartz grains very abundant
	Convolute mudstone, high abundance of sandstone layers at the base
	Silty mudstone, light gray in color, wheather medium gray, concoidal fracture, with laterally discontinuos sandstone layers. Vertical traces at the base, sandstone filled, 4-5cm of diameter, 12 cm long

Sedimentary Bodies – Regions B & E

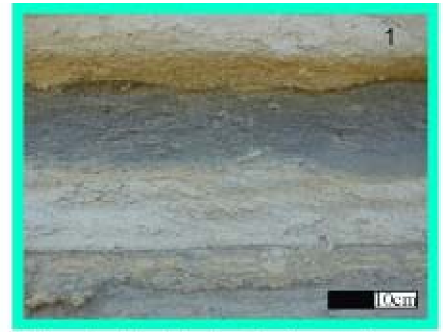


Facies for contourites



Waning phase is dominated by the action of bottom currents. Ripple laminated sandstone with paleocurrents parallel to slope parallel flow.
Highly bioturbated sandstone and silty mudstone.

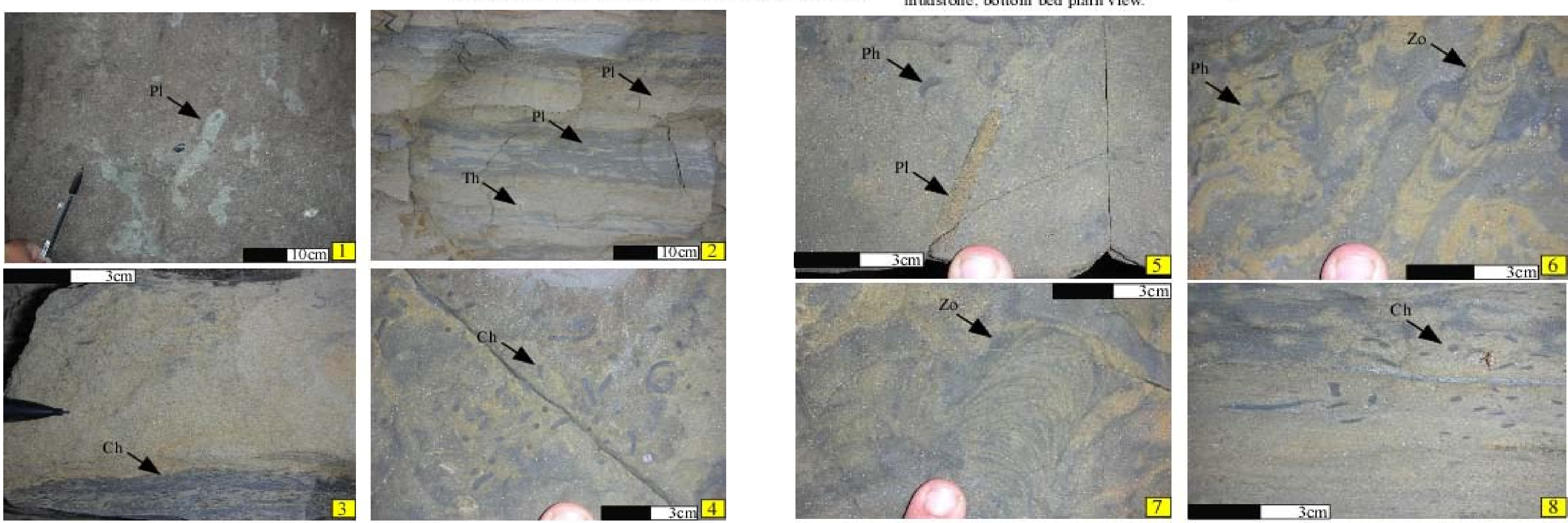
Waxing phase is dominated by medium-magnitude flood hyperpycnites. Action of bottom currents is not appreciable. Change in grain size from lower very fine to upper very fine.



Unidirectional ripple laminated sandstone with paleocurrent directions indicating slope parallel flow

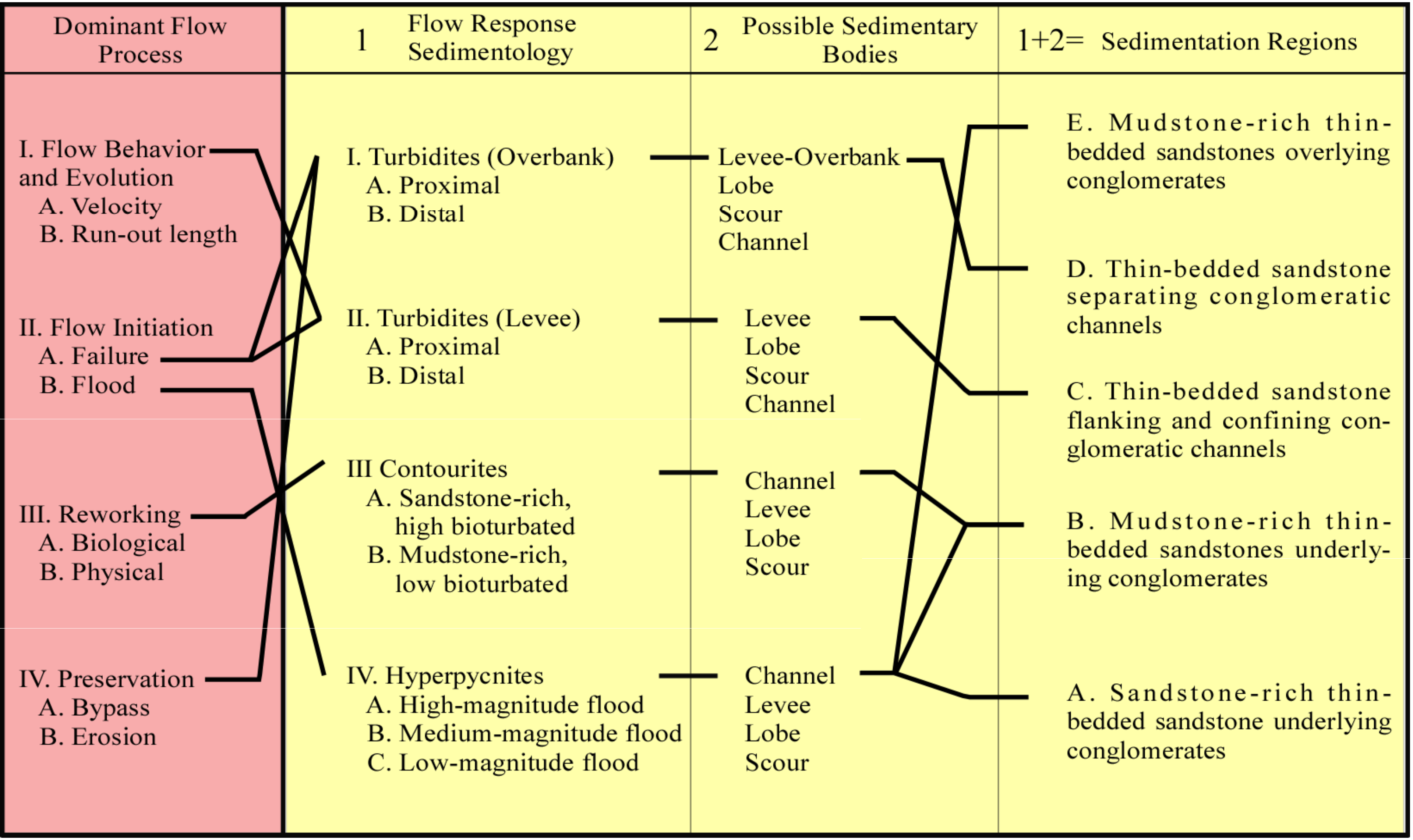
Silty sandstone lenses from 1 to 7m long on dip view.

Detail of mud filled horizontal traces in clay rich mudstone; bottom bed plain view.



1-2 *Planolites*, 3-4 *Chondrites*, 5 *Phycosiphon* and *Planolites*, 6. *Zoophycos* and *Phycosiphon*, 7 *Zoophycos*, 8 *Chondrites*

Conclusions



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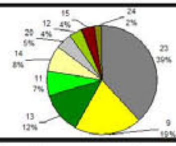
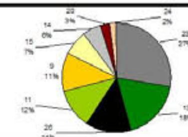
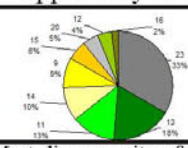
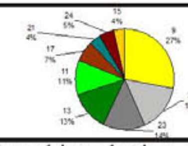
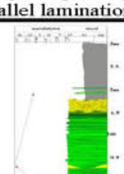
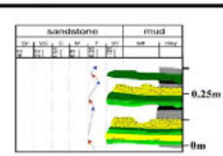
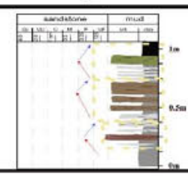
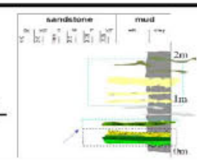
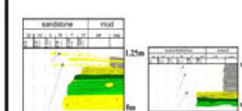
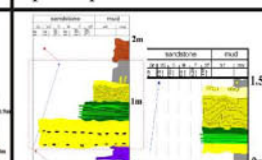
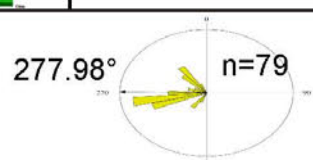
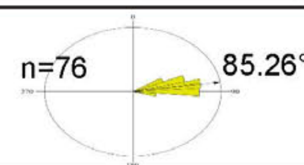
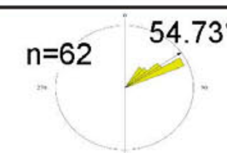
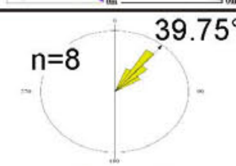
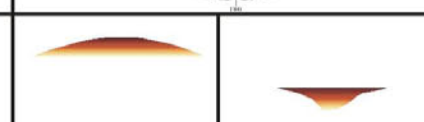
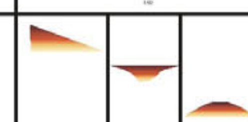
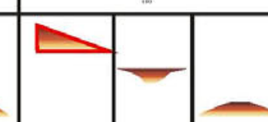
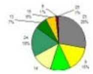
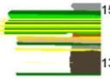
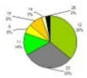
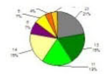
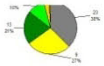
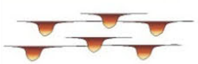
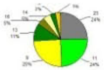
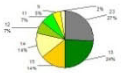
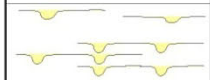
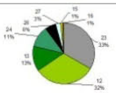
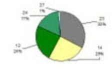
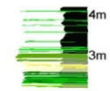
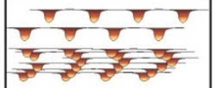
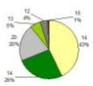
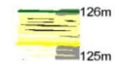
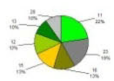
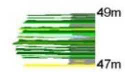
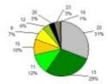
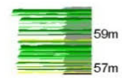
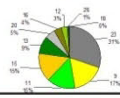
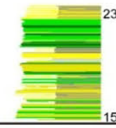
Jeannette Wolak, Logan Hansen, Eric Williams, Bryan Anderson, Kelsey McNamara, Christina Carr, Syverine Abrahmson, Annemali Abrahmson, Tom Beers, Daniel Shepard, Elizabeth Helkme, Bob Cruz, Cecil Roy, Dan Shepard, Carin Oberturf, Travis Jester and Corina Sulbarán.


Questions?

Sedimentary and stratigraphic attributes for recognition of the different types of thin-bedded sandstones and their relation to the different sedimentation regions

Sedimentation Region	A. Sandstone-rich thin-bedded sandstone successions.		B &E. Mudstone-rich thin-bedded successions.		C. Thin-bedded sandstone successions flanking and confining conglomeratic channels	D. Thin-bedded sandstone successions separating conglomeratic channels
Dominant Rock Type	Hyperpycnite			Contourite	Turbidite	
Rock SubType	High-magnitude flood Hyperpycnite	Medium-magnitude flood Hyperpycnite	Low-magnitude flood Hyperpycnite			
Grain Size, Texture, Sorting	Uniform grain size, mainly fine sand	Upper very fine to lower fine	Upper very fine to silt	Upper very fine to silt	Lower medium to upper very fine and upper very fine	Granule to lower very fine and lower fine
Common Facies						
Ichnofacies	Icnofacies *Nereites* and *Zoophycos* are characteristic at the top of the convoluted sandstone facies. Traces are horizontal, sandstone-filled, and abundant and have low diversity, indicating substrate and nutrient controls on distribution in a partly muddy seafloor. Preservation of pre- and post-event traces within the sedimentation units indicates longer flow durations and gradual changes in flow behaviour. Common ichnotaxa include: *Nereites*, *Palaeophycos*, *Phycosiphon*, and *Psilonichnus*. Preservation of graphogliptids reflect atypical sedimentation conditions that can be related to waxing and waning flow behaviour.			High abundance of traces, with *Phycosipho Zoophycos*, and *Chondrites* being the mo typical forms. The traces are mainly filled with mudstone, but sandstone-filed traces are also present. Mainly pre-event traces are preserve indicating the presevation of elements from different moments in time, faunal climax at marine depths, and high variability in flow conditions.	Most diverse suite of ichnofacies: *Nereites*, *Skolithos*, *Zoophycos*, and *Cruziana*, and abundance of post-event traces indicating high-energy stages. However, pre-event traces increase at channel-distal positions indicating lower energy conditions.	Low bioturbation, with *Skolithos* and *Cruziana* being characteristic, mainly sand-filled post-event traces, with a high proportion of traces cross-cutting beds thicker than 10cm.
Common Sedimentary Structures	Climbing ripple, wavy and planar parallel lamination	Wavy, convolute and planar parallel lamination	Planar parallel laminated silty sandstone	Ripple and wavy laminated, highly bioturbated sandstone	Planar parallel and wavy lamination	Structureless and plane parallel lamination
Sedimentation Units				Not present, facies in close association with hyerpycnites sedimentation units. 		
Sediment Transport Indicator						
Common Sedimentary Body Type (Increasing Frequency)						

Sedimentary and stratigraphic attributes for recognition of the different types of thin-bedded sandstones and their relation to the different sedimentation regions

Sedimentary Bodiy	Common Facies within sedimentary bodies	Vertical Sandstone Bed Thickness	Vertical Thickness Distributions	Facies Associations		Stratigraphic Position	Sedimentation Region
		▼	Power-law	- Upward thickening and coarsing of sandstone bedsets with silty mudstone nterbeds. These successions are up to 5 meters thick and their top is usually marked by convolute and wavy laminated sandstones that weather red.		Fifth-order cycles 5.11 to 5.14	D. Thin-bedded sandstone successions separating conglomeratic channels
		▼	Log-normal	- Thickening and coarsing up successions. They are mainly filled by ripple cross or plane parallel laminated sandstone and silty mudstone. Sandstone facies dominate. Commonly isolated or multistory scours.			
		◆	Exponential	- Successions thicken and thin upwards. Grain size vary from lower fine to very fine. Shear and traction structures in the sandstone facies are typical, silty mudstone commonly cap the succession.			
		▼	Power-law	- Upward thickening and coarsing of sandstone bedsets with silty mudstone interbeds. These successions are up to 10 meters thick and their tops are usually marked by wavy or ripple laminated sandstones.		Fifth-order cycles 5.13 to 5.15	C. Thin-bedded sandstone successions flanking and confining conglomeratic channels
		▼	Log-normal	- Thickening and coarsing up successions. Mainly filled by plane parallel or structureless sandstone and silty mudstone. Sandstone facies dominate. Commonly isolated or multistory scours.			
		◆	Exponential	- Successions thicken and thin upwards and grain size of the sandstone beds show variations from lower very fine to upper very fine. Traction structures in the sandstone facies dominate, burrowed sandstone are common, and silty mudstone commonly cap the succession.			
		▼	Log-normal	- Thickening and coarsing up successions. They are mainly filled by ripple or wavy laminated sandstone and silty mudstone. Commonly isolated scours.		Fifth-order cycles 5.8 to 5.10 and 5.17 to 5.19	B & E. Mudstone-rich thin-bedded successions.
		▲	Exponential	- Less than 3 meters wide sandstone lenses that do not amalgamate laterally. These sedimentary bodies are characteristic at the top of the continuous lobeform tabular successions. Typically filled by burrowed sandstone, wavy laminated sandstone and silty mudstone.			
		▼	Exponential	- Thickening and coarsing up successions. They are mainly filled by burrowed sandstone, and wavy, ripple cross laminated sandstone and muddy siltstone mudstone. Sedimentation units vary depending on the type of scour and their position in the stratigraphic profile (Fig 46). Multilateral, multistory and isolated types are present.		Fifth-order cycles 5.6 to 5.7	A. Sandstone-rich thin-bedded sandstone successions.
		◆	Log-normal	- These successions thicken and thin upwards. Fine to very fine grain size. Traction structures in the sandstone facies are typical, silty mudstone commonly cap the succession.			
		▼	Power-law	- Upward thickening and coarsing of sandstone bedsets with muddy siltstone or laminated silty mudstone interbeds.			
		◆	Log-normal	- Thin-bedded rippled, wavy and plane parallel laminated sandstones that thin and fine upward and are capped by convolute sandstones and silty mudstone deposits. They interbed to form up to 5m thick successions.			

References

Bates, C.C., 1953, Rational theory of delta formation: AAPG Bulletin v. 37/9, p. 2119-2162.

Gastil, R.G. and D. Krummenacher, 1975, Reconstruction of the Mesozoic plutonic belt of southern California and western Mexico: Abstracts with Programs Geological Society of America, v. 7/3, p. 320.

Kneller, B., 1995, Beyond the turbidite paradigm; physical models for deposition of turbidites and their implications for reservoir prediction: Geological Society Special Publications, v. 94, p. 31-49.

Santillan, M. and T. Barrera, 1930, Las posibilidades petroliferas en la costa occidental de la Baja California, entre los paralelos 30 y 32 de latitud norte: Anales del Instituto Geologico de Mexico, v. 5, p. 1-37.

Yeo, R.K., 1984, Stratigraphic sections of the northern Baja California field area. Annual Meeting Pacific Section AAPG, v. 54, p. 69-88.

Yeo, R.K., 1984, Sedimentology of Upper Cretaceous strata, northern Baja California, Mexico: Annual Meeting Pacific Section AAPG, v. 54, p. 57-68.