Sequence Stratigraphy, Depositional Environments and Reservoir Geology of Wave-Influenced Deltaic Systems in the Lower and Middle Frio Formation, Redfish Bay, Corpus Christi, Texas*

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Abstract

Over 1,800 feet of continuous core, combined with log and 3-D seismic data, illustrate a stratigraphic succession of high-frequency progradational episodes composed of wave-modified deltaic and shoreface deposits within an overall second-order lowstand systems tract in the lower and middle Frio Formation in Redfish Bay, Texas.

This second-order succession is divided into 11 higher order (4th or 5th) sequences. Upward-coarsening parasequences display a transition of depositional environments from offshore to lower and middle shoreface. The typical facies succession within a parasequence consists of gray, massive mudstone interbedded with thin (0.1- to 0.2-ft), very fine grained, wavy rippled sandstone with *Zoophycus* at the base followed by alternating fair-weather and storm-dominated deposits. The fair-weather suite is characterized by highly bioturbated, very fine to fine grained sandstone, with *Cruziana* ichnofacies including *Planolites*, *Thalassinoides*, *Asterosoma*, *Paleophycus*, *Chondrites* and *Rosselia*. Remnant wavy laminations or ripples are also preserved. The coarser and cleaner sandstones of storm origin are massive and weakly bioturbated with *Ophiomorpha*. Parallel and low-angle laminations with possible hummocky cross-stratification and ripples are present. The lower part of the ARCO #470-4 core (10,335 to 11,460 ft), parasequences 1st - 7th is composed predominantly of low-energy deposits in a distal setting, indicated by the dominance of the deposit-feeding infauna over the suspension-feeding infauna. Soft-sediment deformation occurs below shoreface sandstones, implying an unstable substrate and rapid deposition in middle- to outer-shelf environments. The upper part of the cored interval (9,651 to 10,335 ft), parasequences 8th - 11th, has more opportunistic trace fossils with vertical to subvertical structures (mostly *Ophiomorpha* and possible *Diplocraterion*) and records proximal shoreface successions. The uppermost 285 feet core consists of fine- to medium-grained, sparsely bioturbated sandstone with *Skolithos* Ichnofacies including *Ophiomorpha*, *Diplocraterion* and *Paleophycus*. The coarser grain size, the sparsely bioturbation with *Skolithos* ichnofacies, integrated with the presence of shell layers and mud chips indicate a proximal-shoreline setting. In any single parasequence, cleaner storm beds with coarser grain size and less bioturbation have better reservoir quality (porosity and permeability) than highly bioturbated fair-weather beds.

Selected References

Bann, K.L., S.C. Tye, J.A. MacEachern, C. Fielding, and B.G. Jones, 2008, Ichnological and sedimentologic signatures of mixed wave- and storm-dominate deltaic deposits; examples from the Early Permian Sydney Basin, Australia, *in* G.J. Hampson, R.J. Steel, P.M. Burgess, and R.W. Dalrymple, eds., Recent advances in models of siliciclastic shallow-marine stratigraphy: Special Publication Society for Sedimentary Geology, v. 90, p. 293-332.

Bhattacharya, J.P., and L. Giosan, 2003, Wave-influenced deltas; geomorphological implications for facies reconstruction: Sedimentology, v. 50/1, p. 187-210.

Brown, L.F., Jr., R.G. Loucks, R.H. Trevino, and U. Hammes, 2004, Understanding growth-faulted, intraslope sub-basins by applying sequence stratigraphic principles: Examples from the South Texas Oligocene Frio Formation: AAPG Bulletin, v. 88/11, p. 1501-1522.

Hampson, G.J., 2000, Discontinuity surfaces, clinoforms, and facies architecture in a wave-dominated, shoreface-shelf parasequence: JSR, v. 70/2, p. 325-340.

Helland-Hansen, W., and G.J. Hampson, 2009, Trajectory analysis; concepts and applications: Basin Research, v. 21/5, p. 454-483.

Sixsmith, P.J., G.J. Hampson, S. Gupta, H.D. Johnson, and J.F. Fofana, 2008, Facies architecture of a net transgressive sandstone reservoir analog; the Cretaceous Hosta Tongue, New Mexico: AAPG Bulletin, v. 92/4, p. 513-547.

Taylor, A.M., and R. Goldring, 1993, Description and analysis of bioturbation and ichnofabric, *in* R. Goldring and J.E. Pollard, eds., Organisms and sediments; relationships and applications: Journal of the Geological Society of London, v. 150/1, p. 141-148.

Tonkin, N.S., D. McIlroy, R. Meyer, and A. Moore-Turpin, 2010, Bioturbation influence on reservoir quality; a case study from the Cretaceous Ben Nevis Formation, Jeanne d'Arc Basin, offshore Newfoundland, Canada: AAPG Bulletin, v. 94/7, p. 1059-1078.

Trevino, R.H., and B.C. Vendeville, 2008, Origin of coast-perpendicular extensional faults, western Gulf of Mexico; the relationship between an early-stage ridge and a late-stage fault: AAPG Bulletin, v. 92/7, p. 951-964.

Sequence stratigraphy, depositional environments and reservoir geology of wave-influenced deltaic systems in the lower and middle Frio Formation, Redfish Bay, Corpus Christi, Texas

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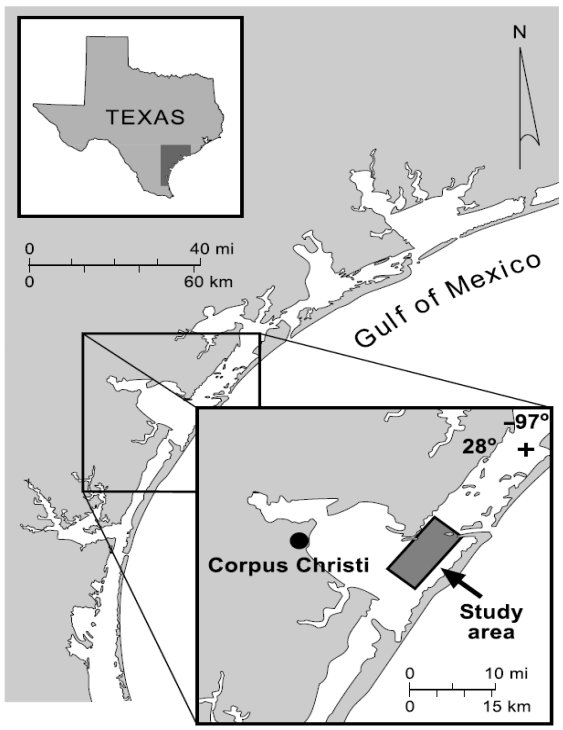
Outline

- Research objectives
- Geologic setting and data base
- Sequence stratigraphic framework
- Depositional environments: core descriptions, gross sandstone maps, and seismic stratal slice maps
- Reservoir geology: sandstone continuity and reservoir quality

Research objectives

- Establish high-resolution sequence stratigraphic framework and define related depositional environments
- Describe sandstone-body distribution, continuity and architecture
- Describe controls on reservoir quality at different scales

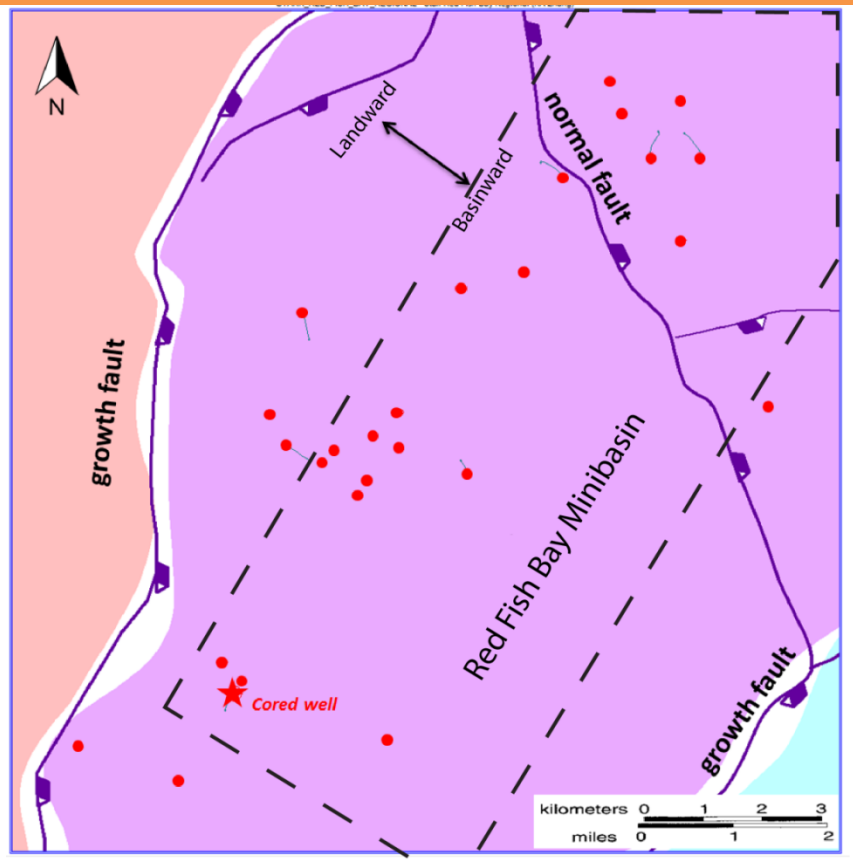
Geologic background and data base



Location of study area (Trevino and Vendeville, 2008)

Study interval

Age (Ma)	Chronostratigraphic Units				Lithostratigraphic Units	
	Erathem	System	Series	Stage	Group	Formation
23.0	Cenozoic	Paleogene	Oligocene	Late Chattian	Catahoula	Anahuac
28.4						Frio
33.4				Early Rupelian	Vicksburg	Vicksburg

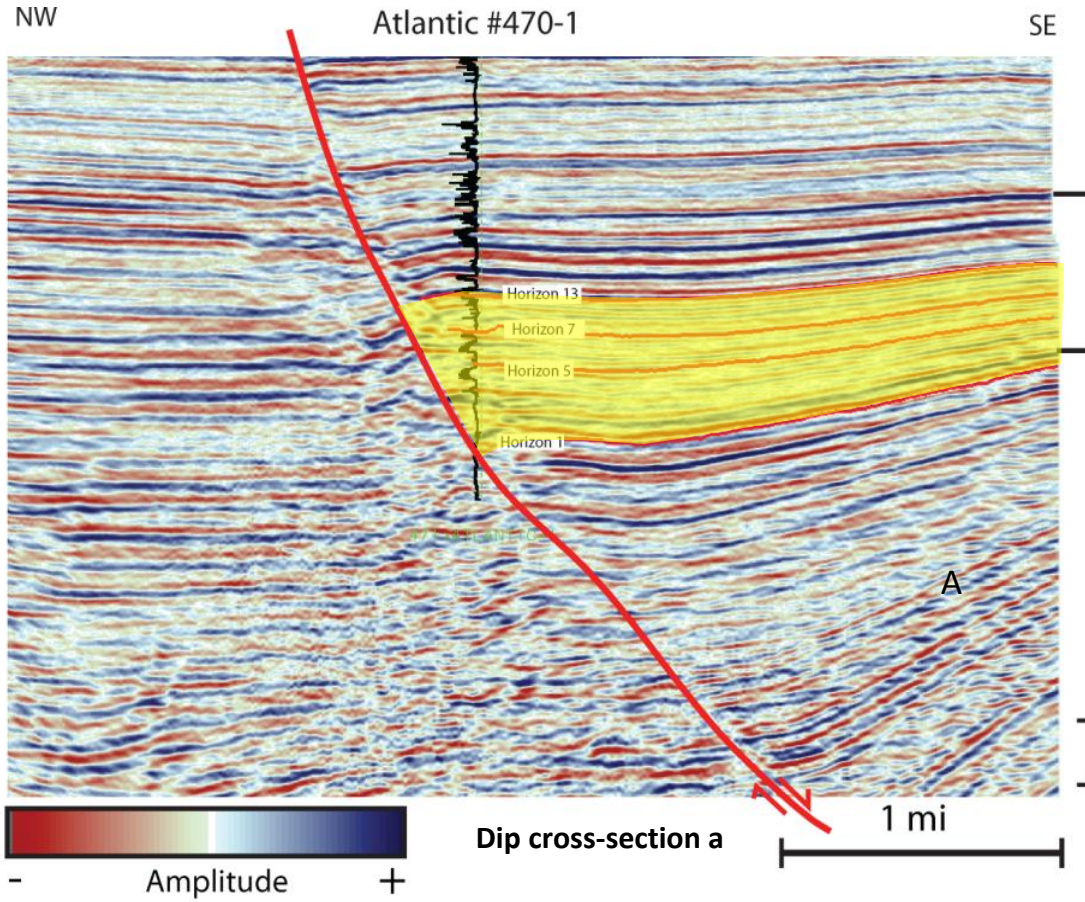


Seismic data | Cored well | Wire-line log

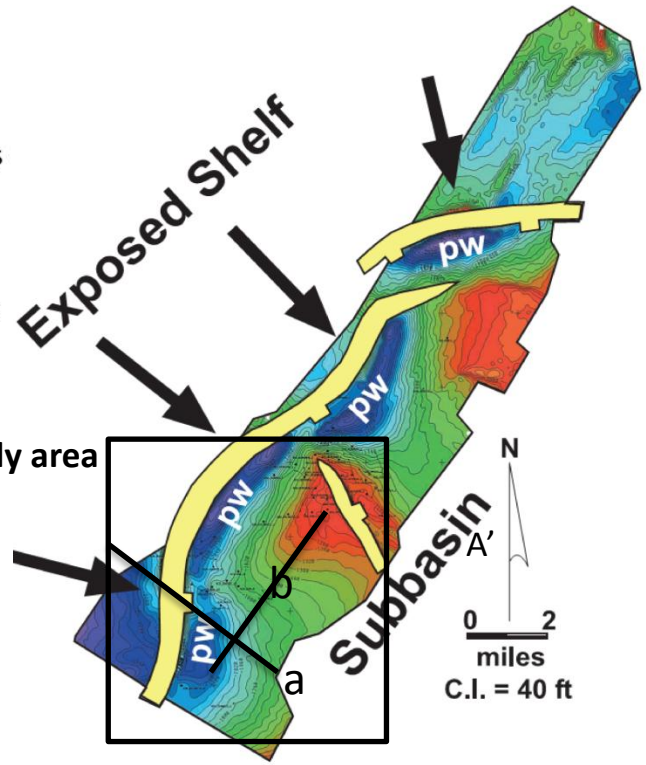
Base map showing:

- 28 well logs
- One cored well, continuous 1,800 feet cores with reservoir quality data
- Seismic data cover most of study areas

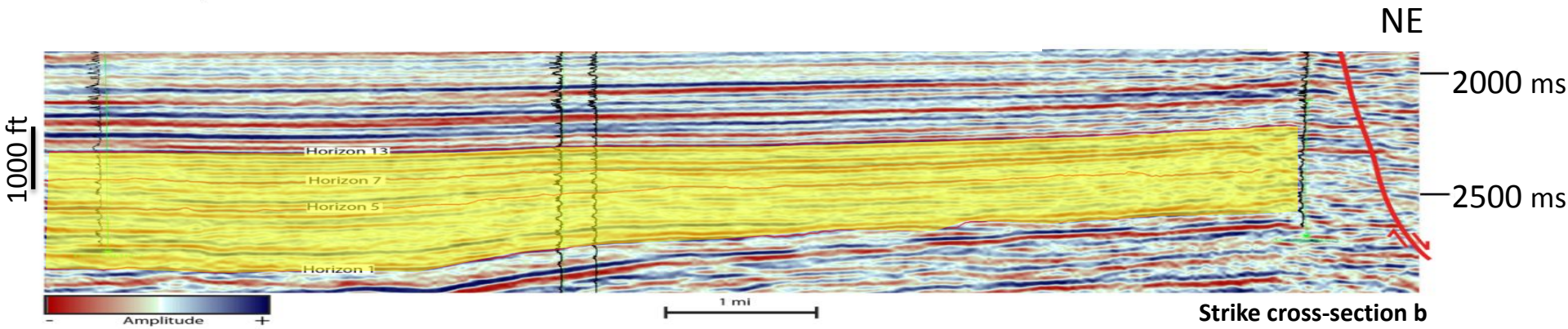
Geological setting



Dip cross-section a

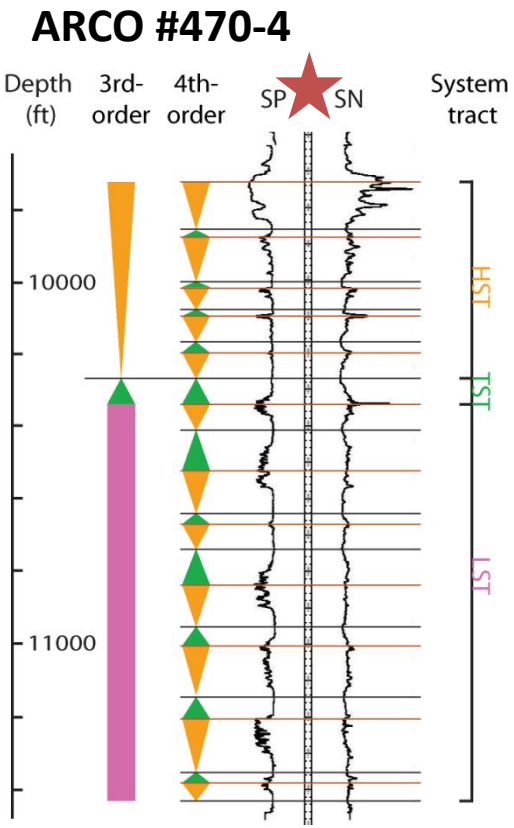


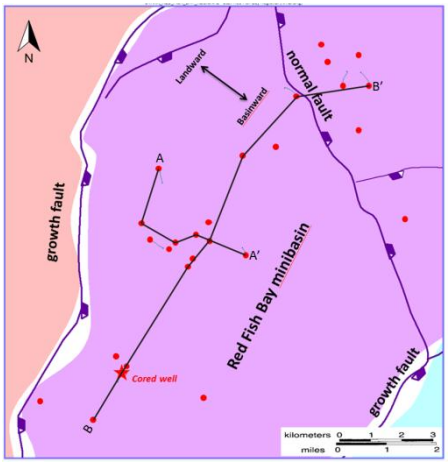
Isopach map of Frio (Brown et al., 2004)

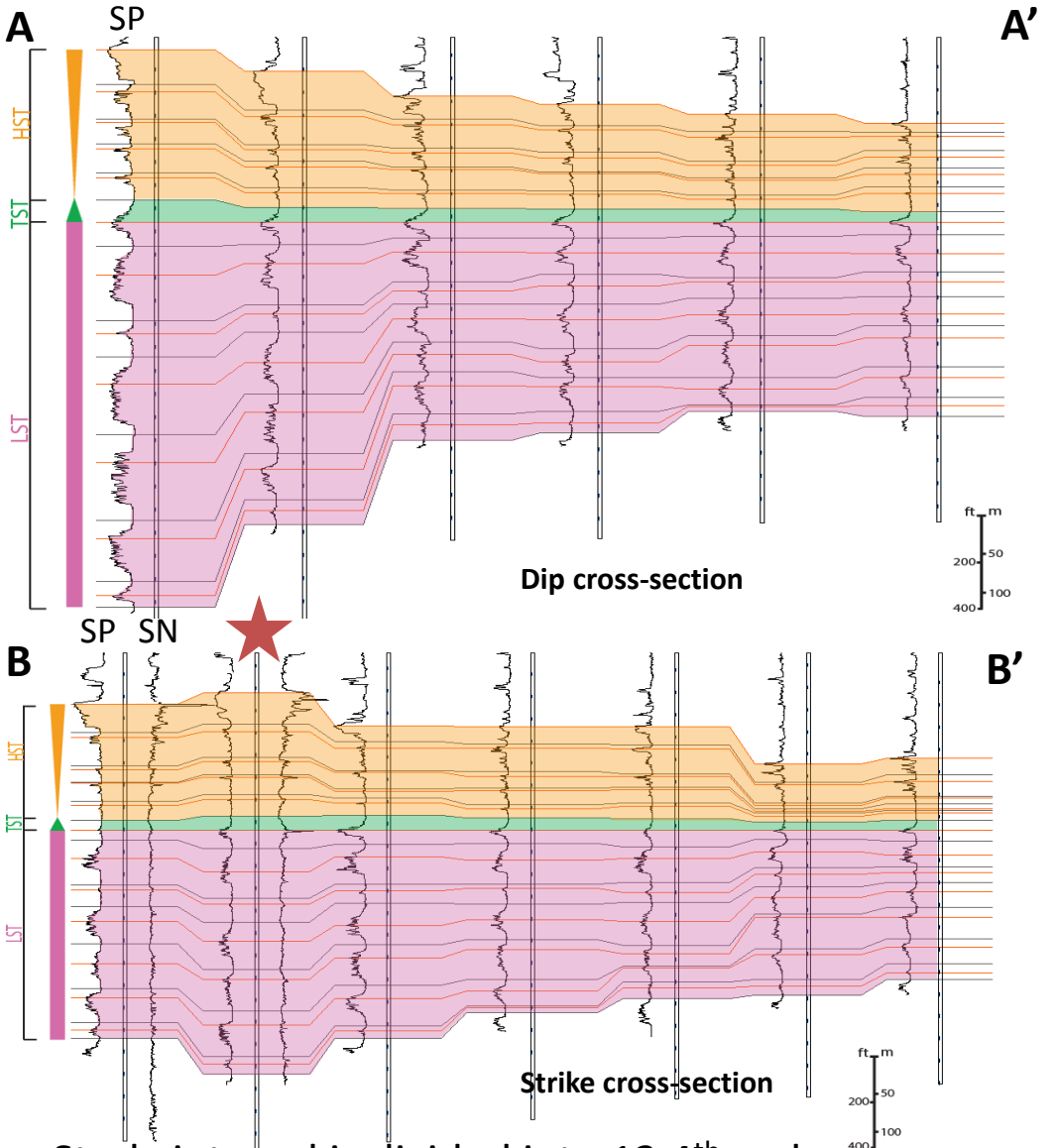


Strike cross-section b

Sequence stratigraphic framework



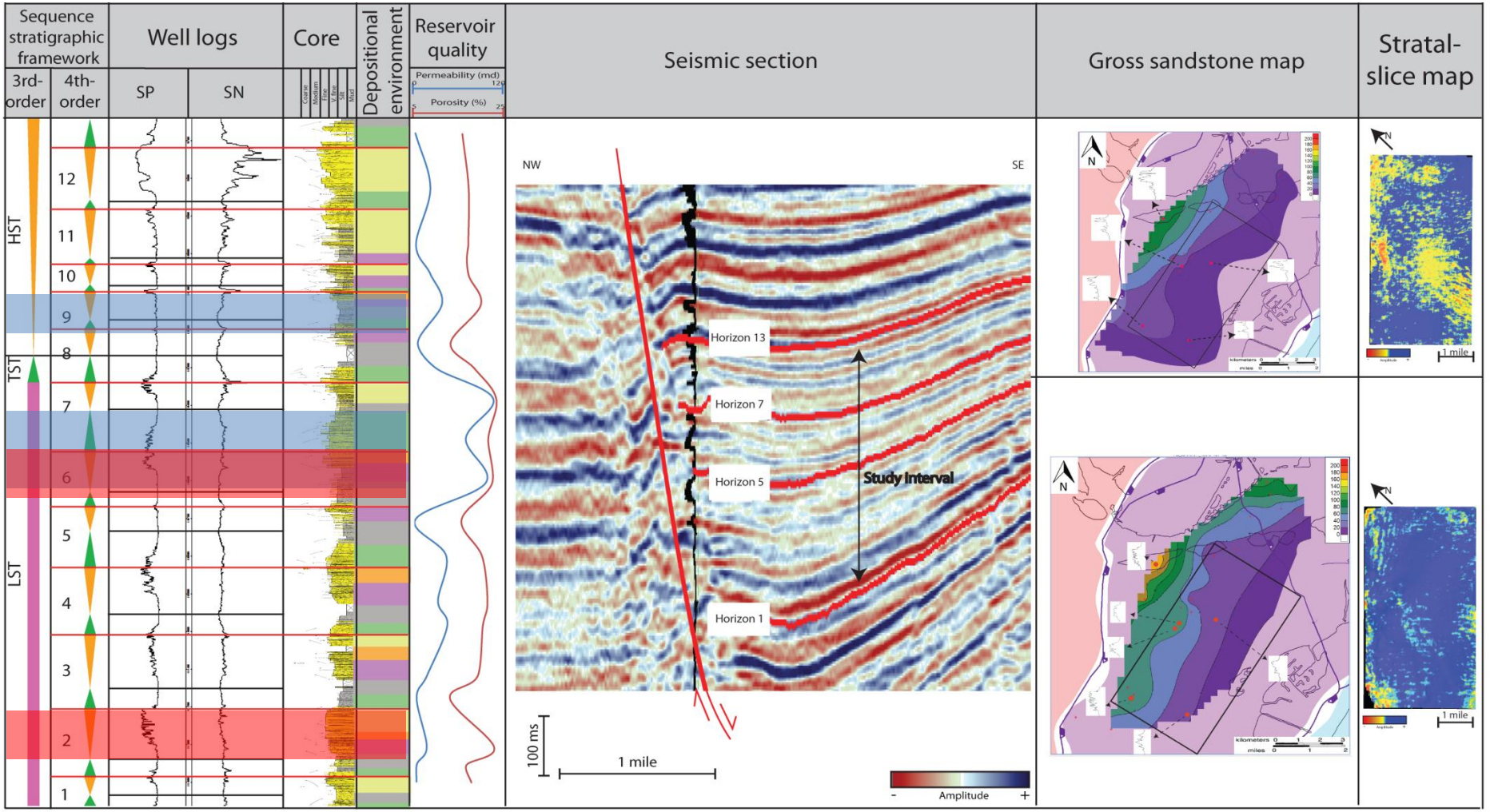




- Study interval is divided into 12 4th-order sequences, which compose an incomplete 3rd-order sequence.

Depositional environments

- core descriptions
- sandstone maps
- stratal slice maps



Upper shoreface or delta front

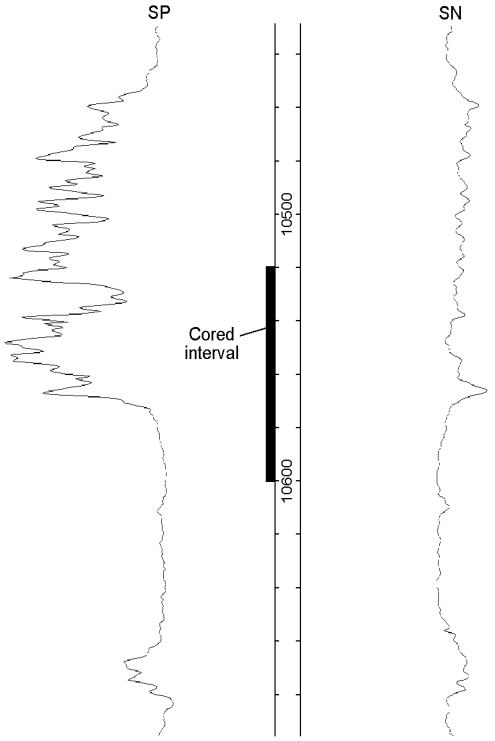
Middle shoreface

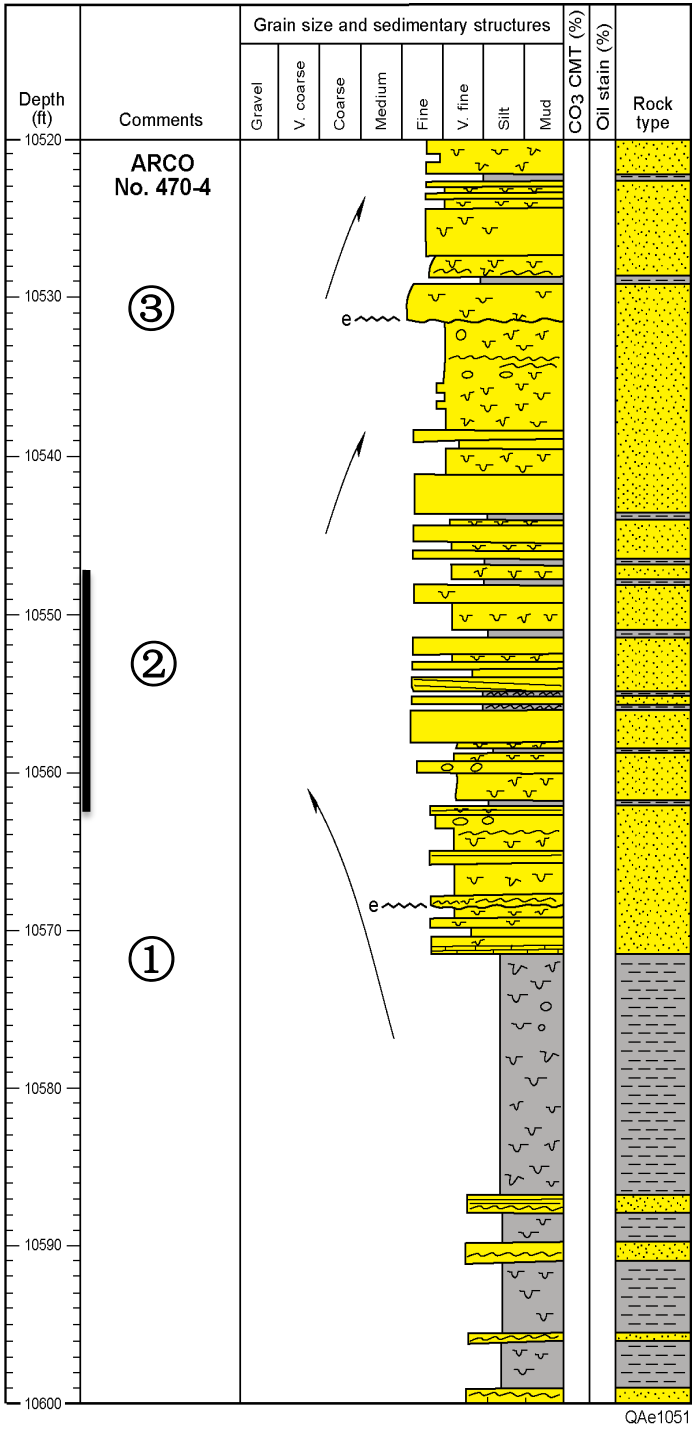
Lower shoreface or prodelta

Offshore to inner shelf

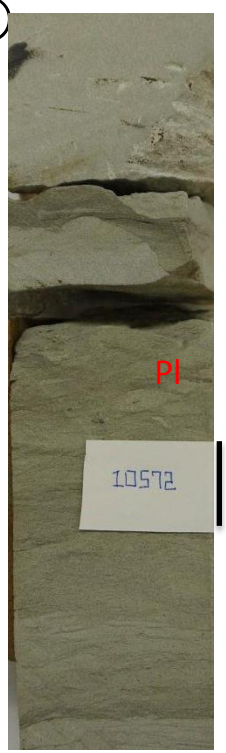
backstepping shoreface or washover fans

Regressive cycle of 4th-order sequence 6

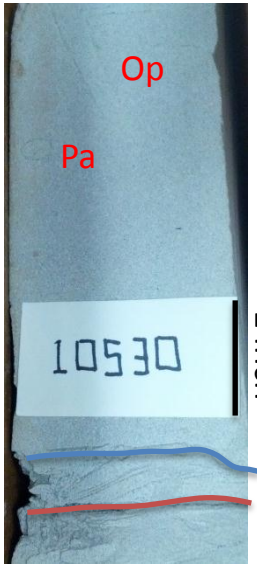




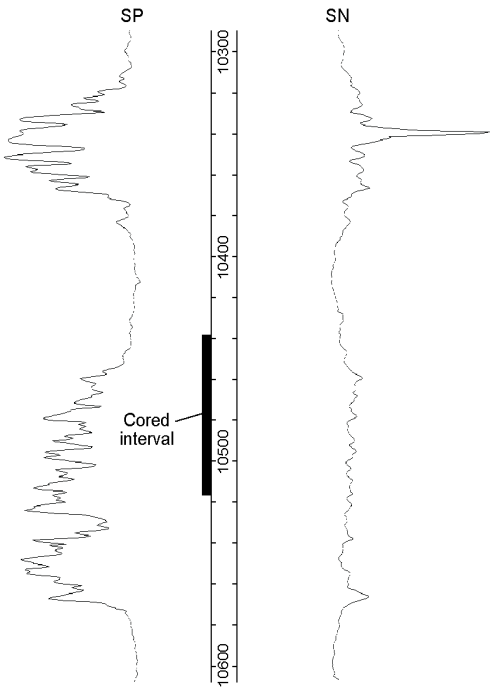
Top 10547 ft

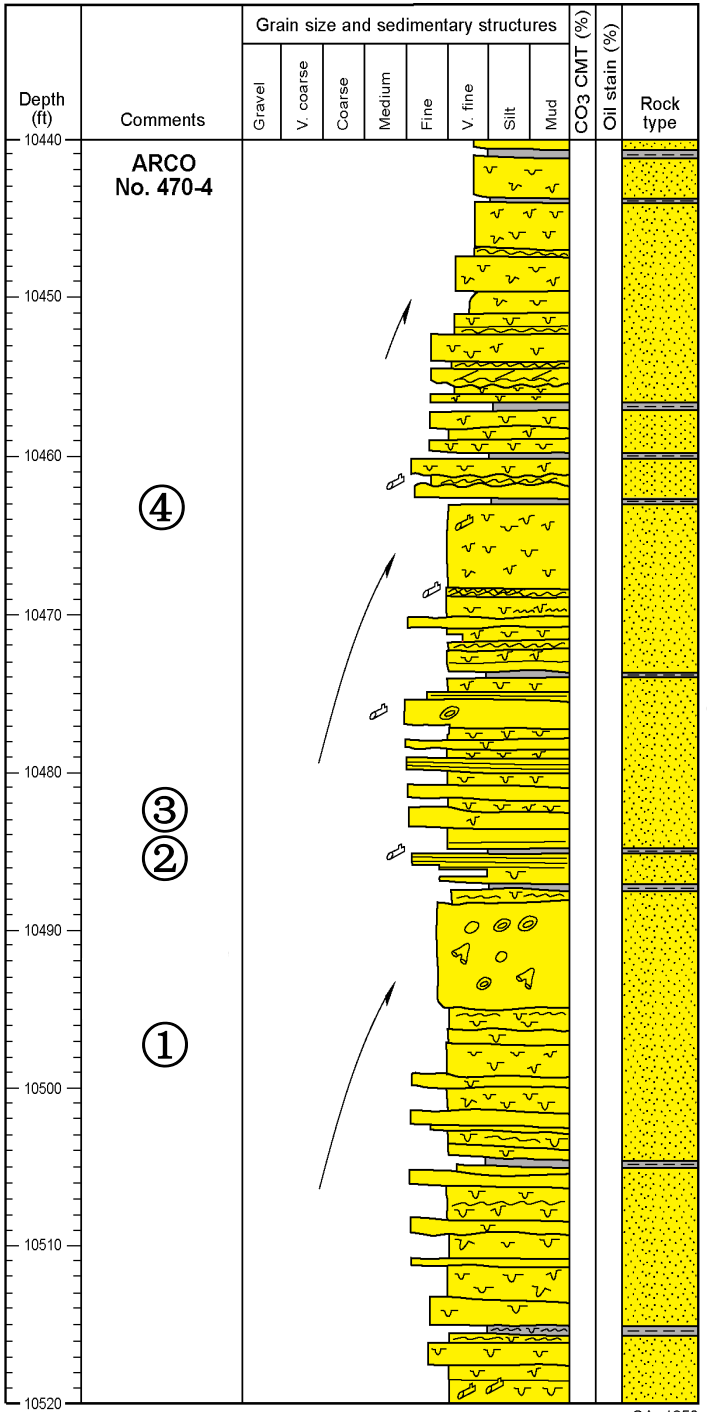


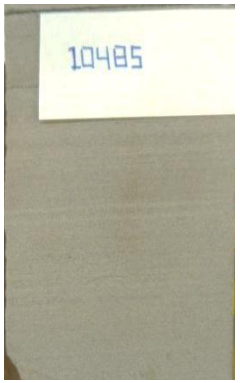
Bottom 10562 ft

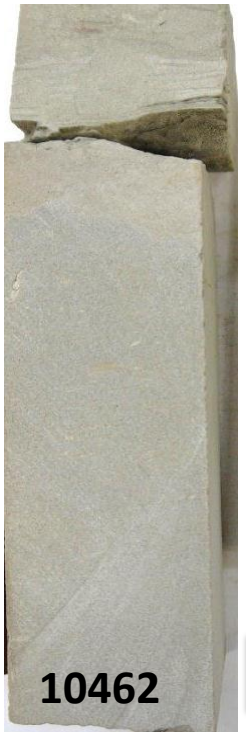


Transgressive cycle of 4th-order sequence 6

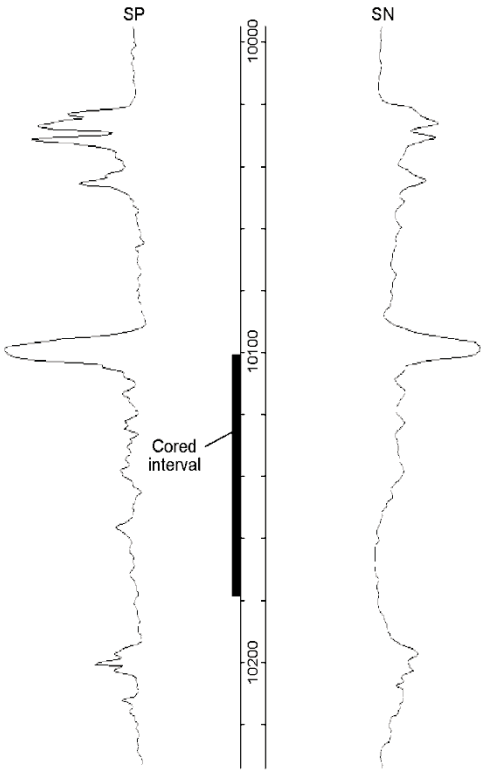


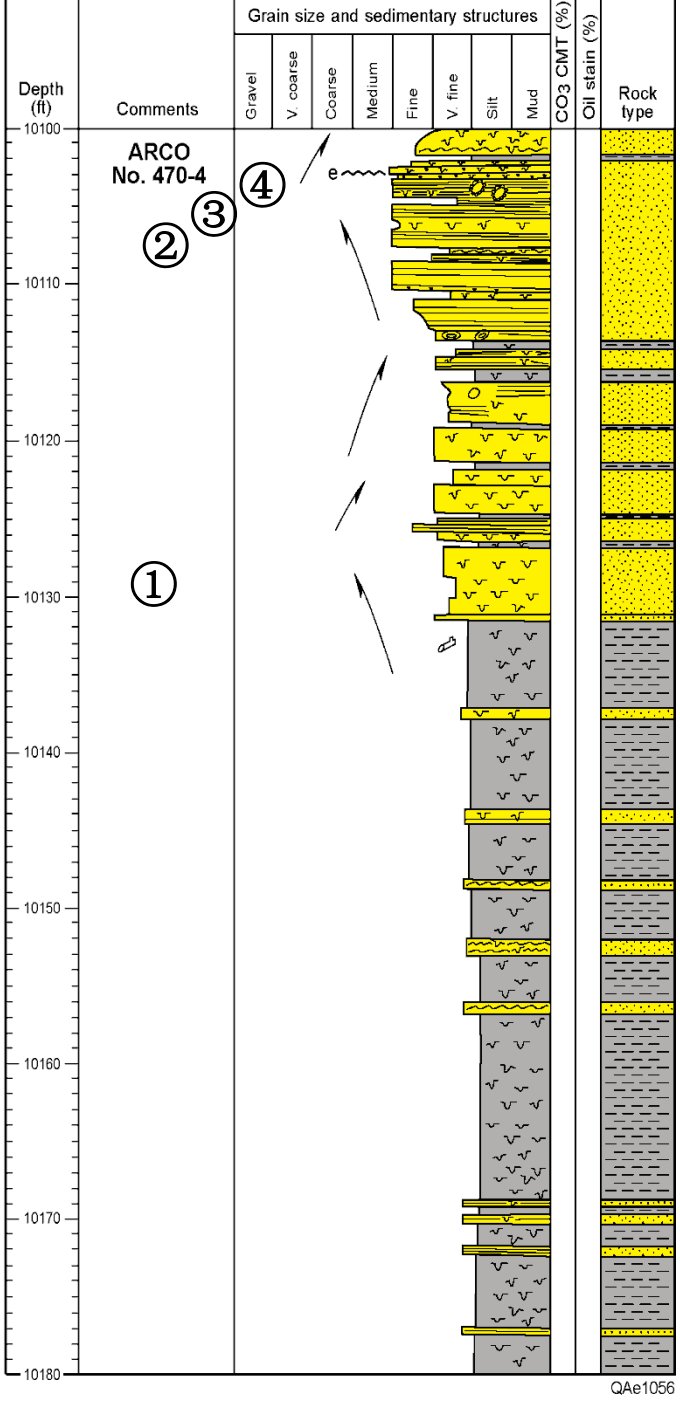




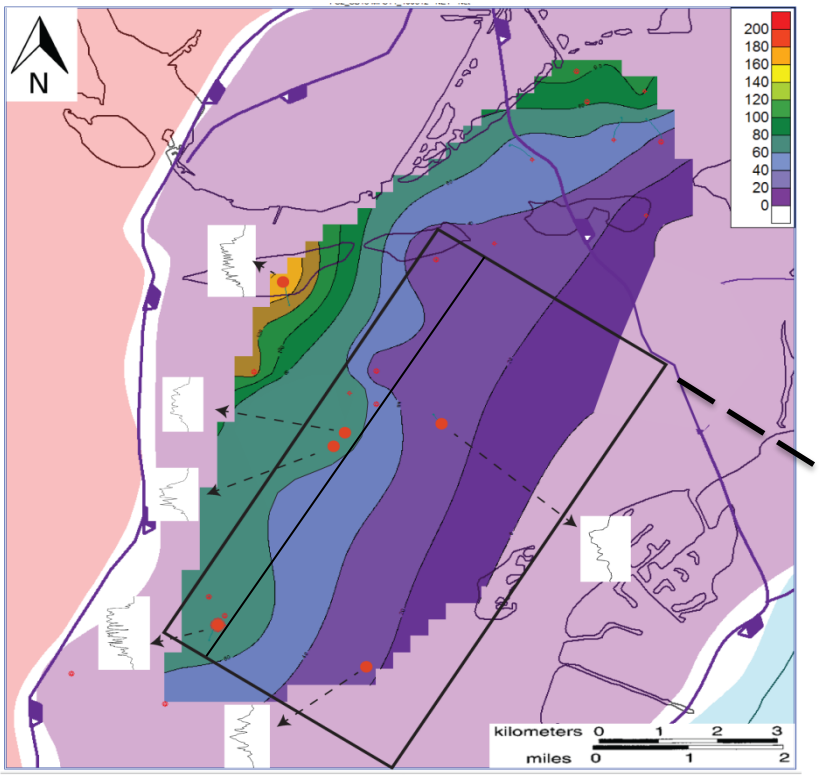


4th-order sequence 9

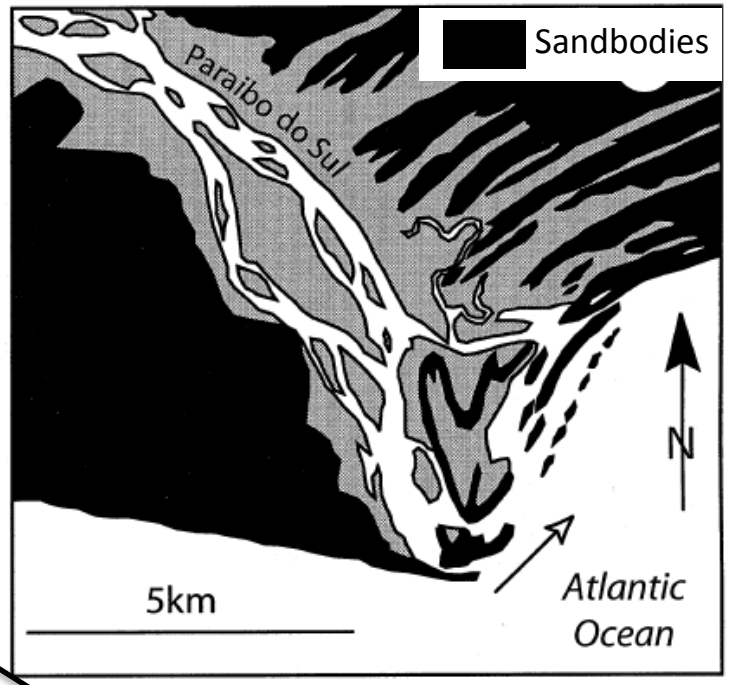


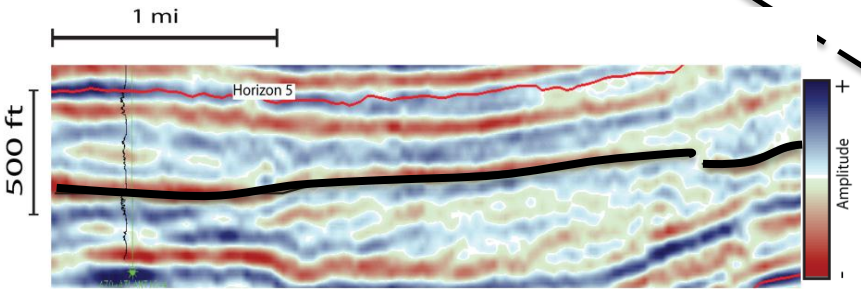


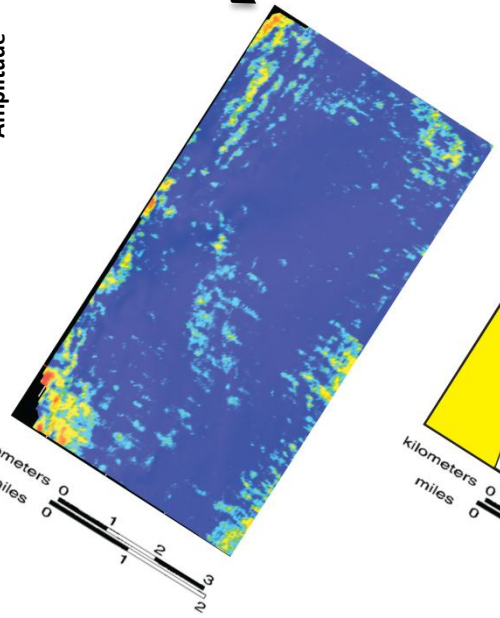
Regressive cycle of 4th-order sequence 2

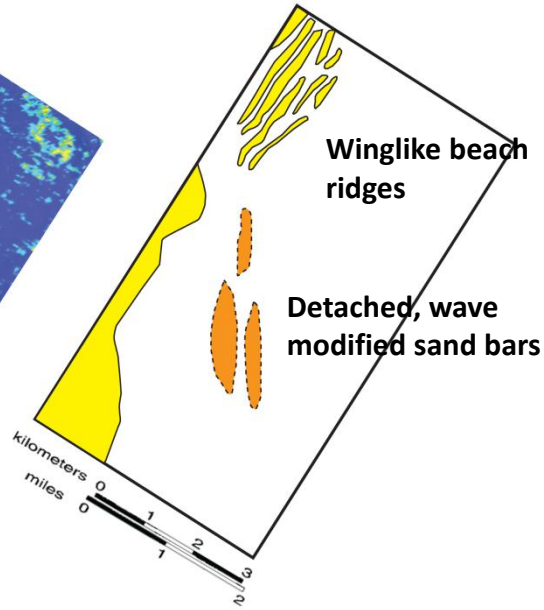


Paraibo do Sul delta, Brazil (Bhattacharya and Giosan, 2003)

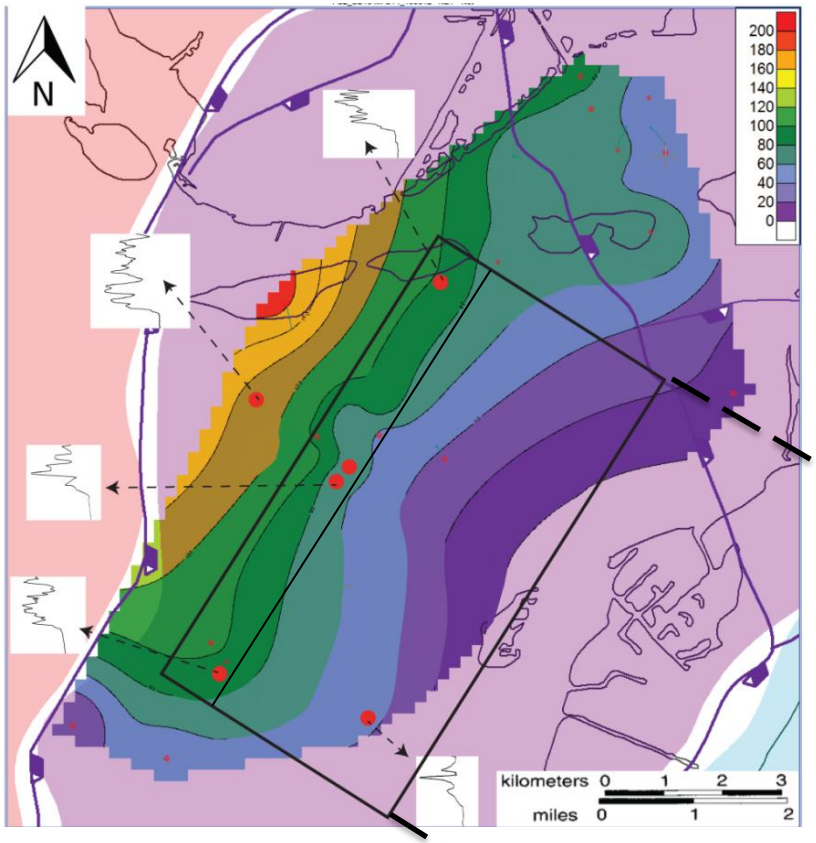




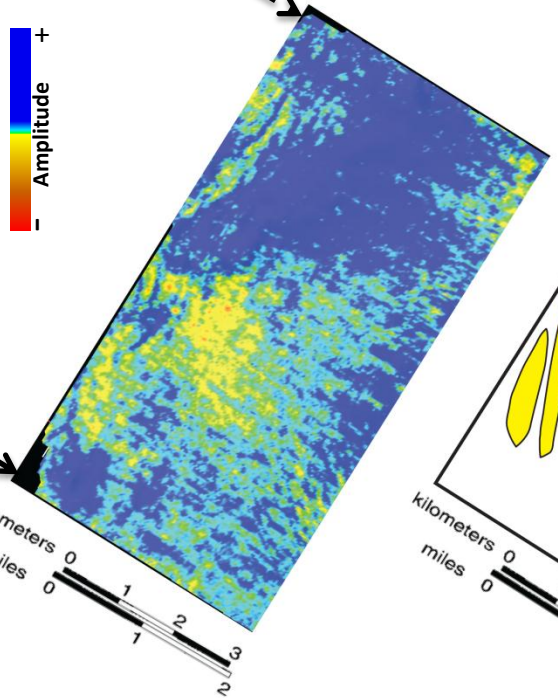


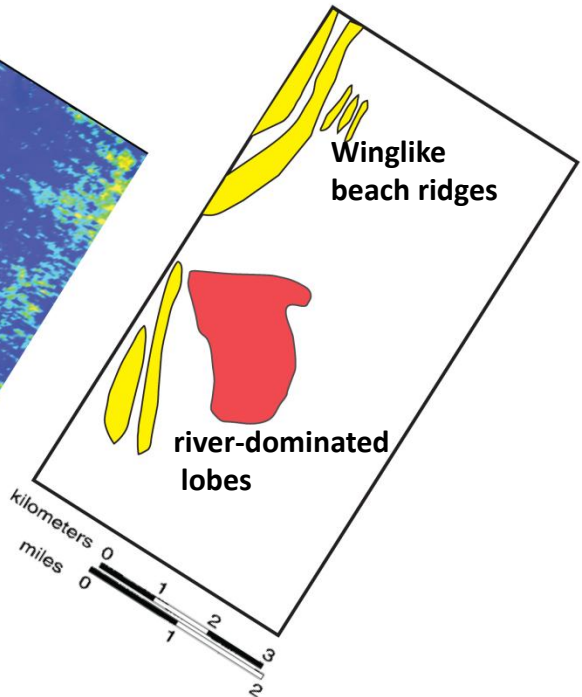


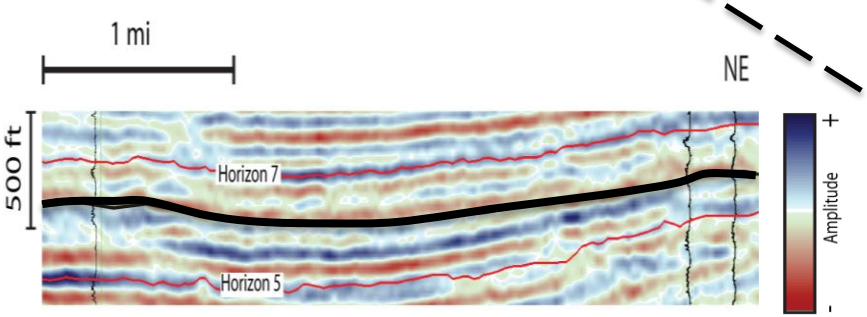
Regressive cycle of 4th-order sequence 4



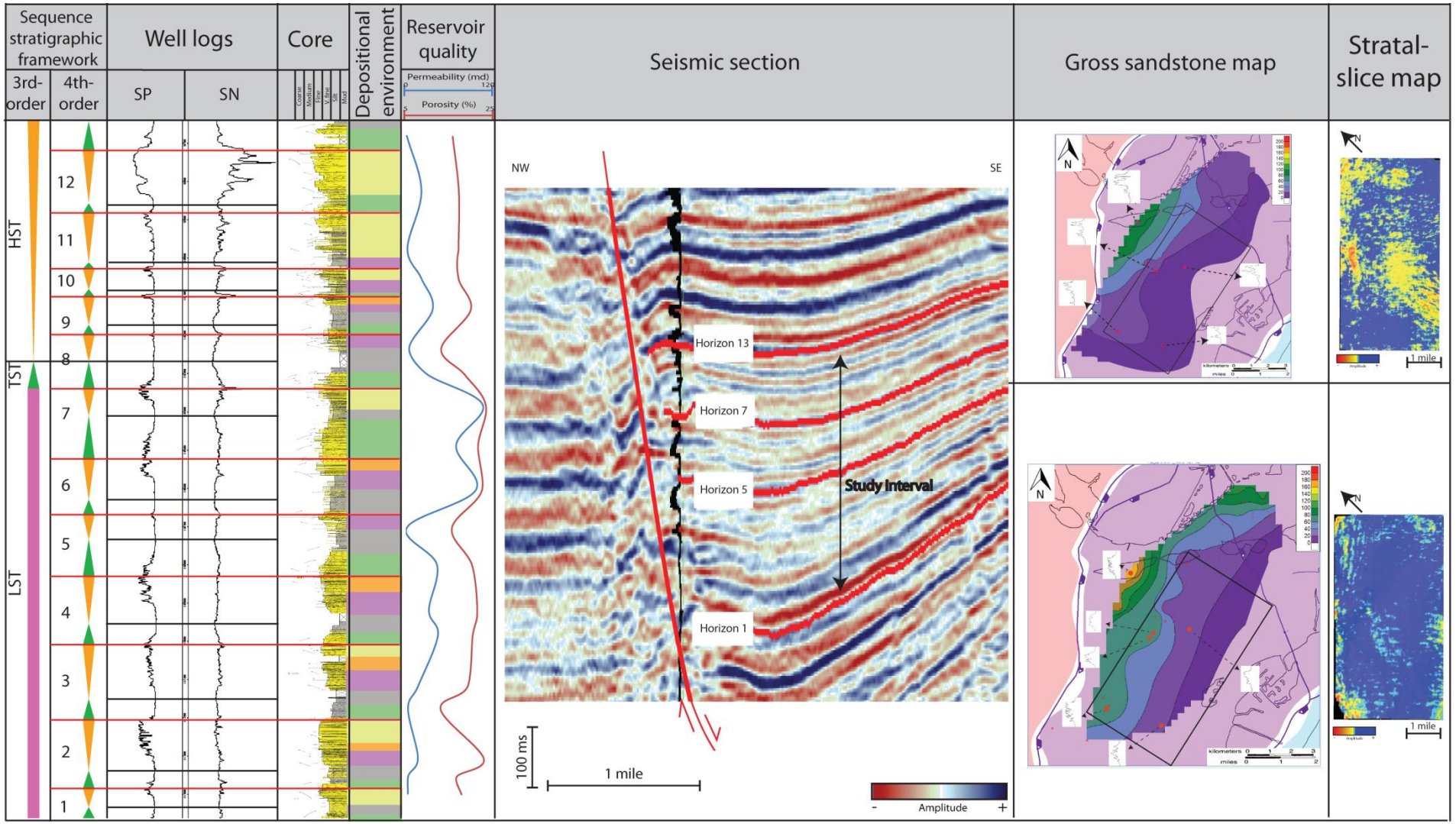
Danube delta, Romania
(Google Earth)







Summary



Upper shoreface or delta front

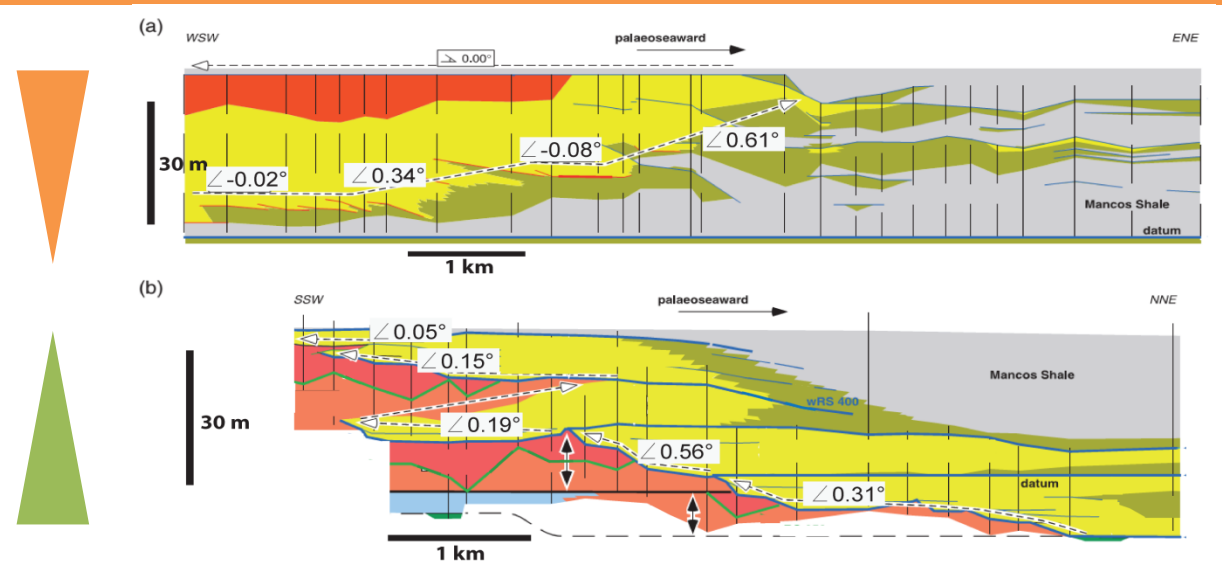
Middle shoreface

Lower shoreface or prodelta

Offshore to inner shelf

backstepping shoreface or washover fans

Depositional model and architecture

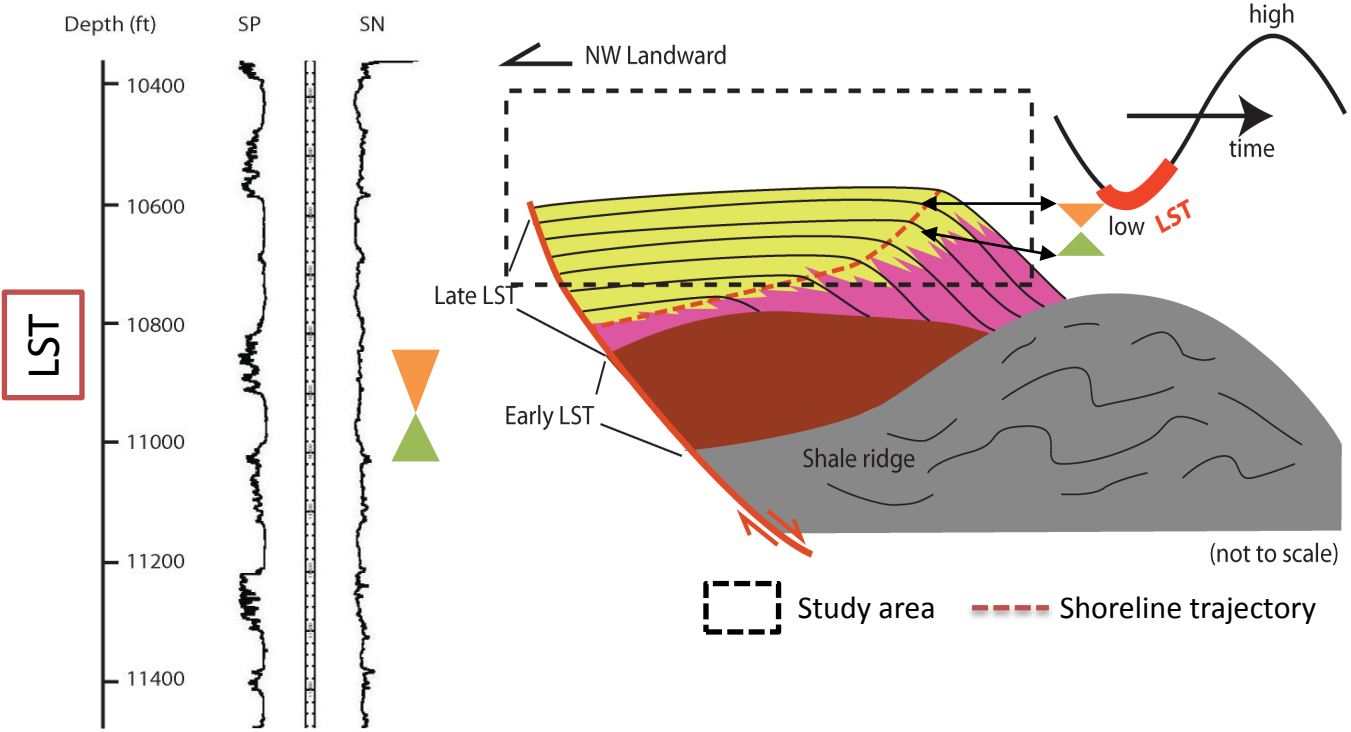


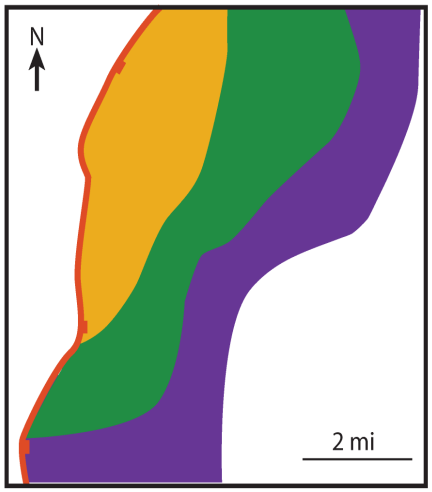
Wave-dominated shoreface-shelf deposits

- Foreshore and upper shoreface facies belt
- Proximal lower shoreface facies belt
- Distal lower shoreface and inner shelf facies belt
- Offshore transition / offshore facies belt

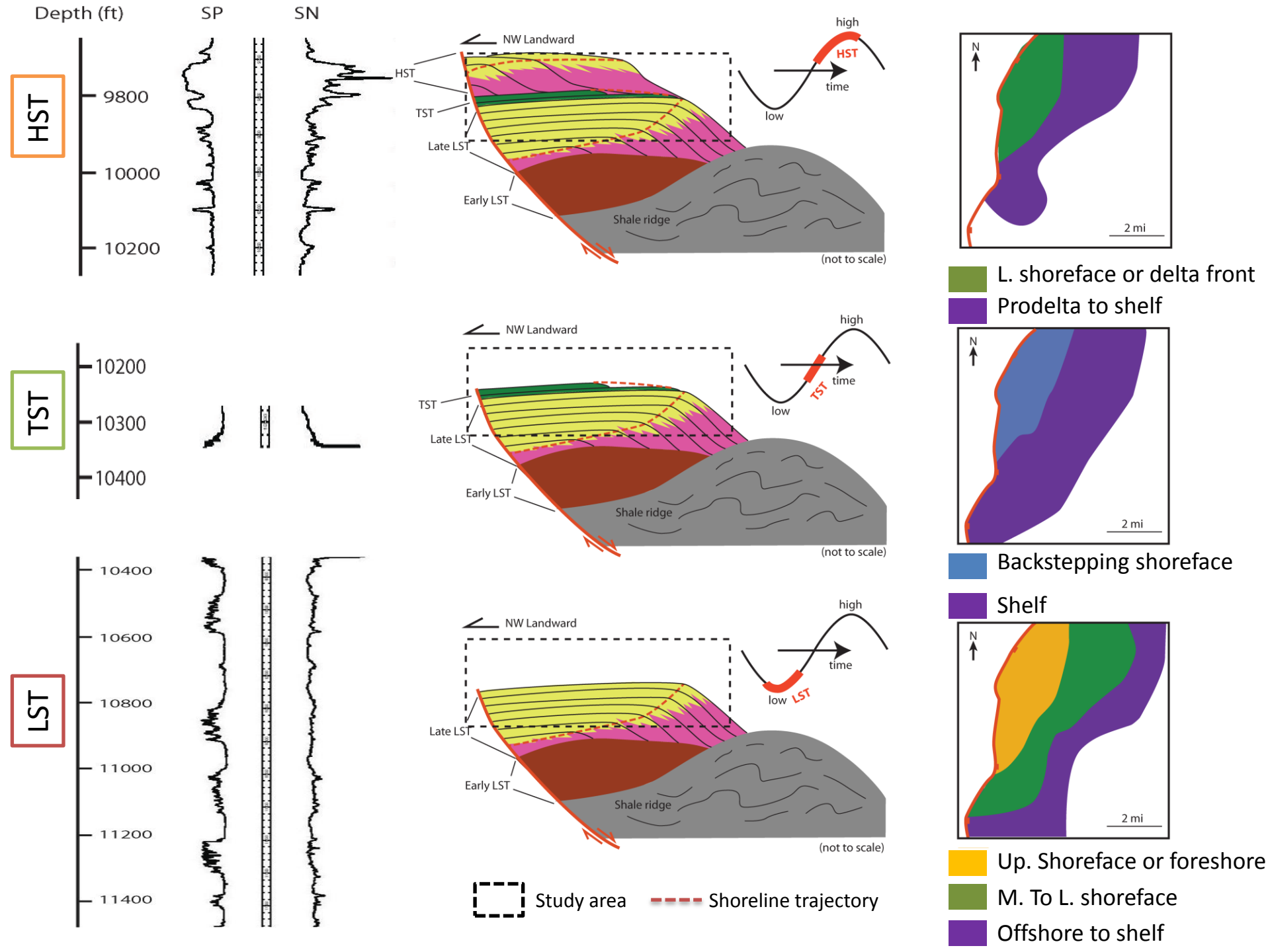
0.07° Shoreline trajectory (trend and angle)

(Helland-Hansen and Hampson, 2009, after Hampson, 2000; Sixsmith et al., 2008)

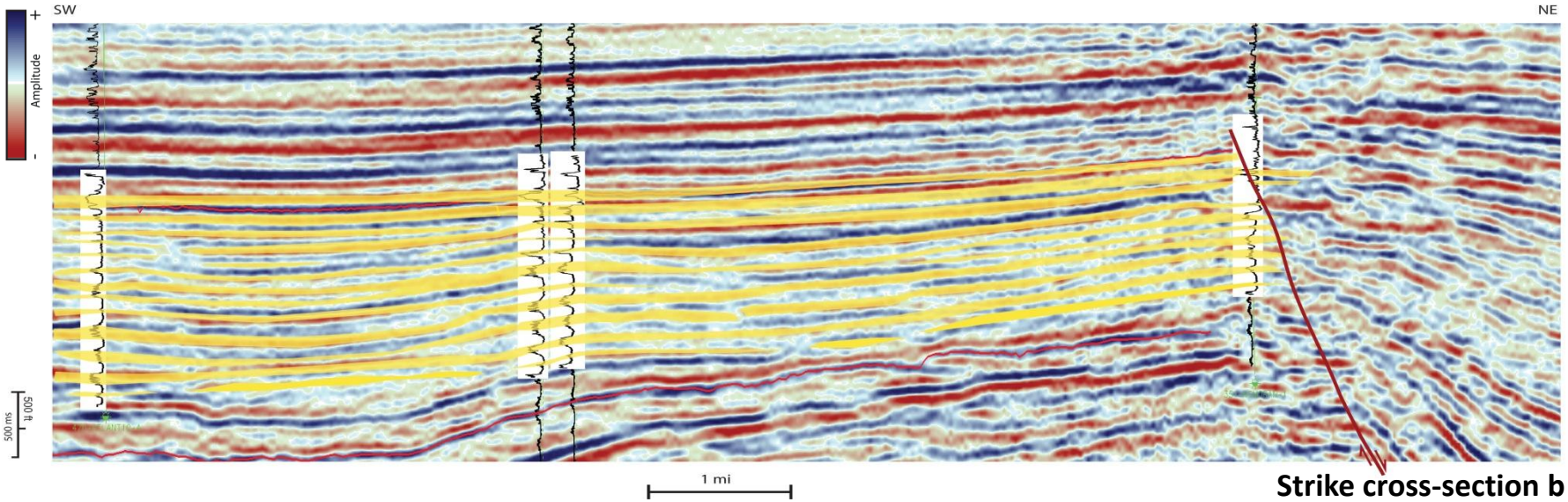




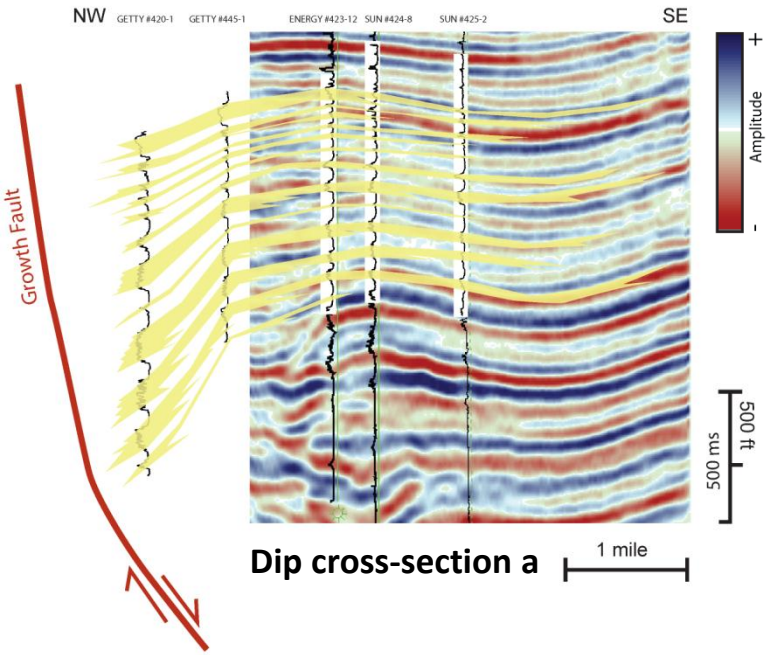
- Up. Shoreface or foreshore
- M. To L. shoreface
- Offshore to shelf


Depth (ft)
SP
SN
HST
9800
10000
10200
TST
10200
10300
10400
LST
10400
10600
10800
11000
11200
11400
NW Landward
HST
TST
Late LST
Early LST
Shale ridge
(not to scale)
high
low
time
HST
TST
LST
N
2 mi
L. shoreface or delta front
Prodelta to shelf
Backstepping shoreface
Shelf
Up. Shoreface or foreshore
M. To L. shoreface
Offshore to shelf
Study area
Shoreline trajectory

Sandstone continuity

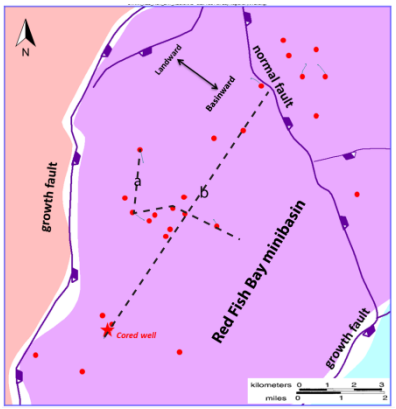


Strike cross-section b



Dip cross-section a

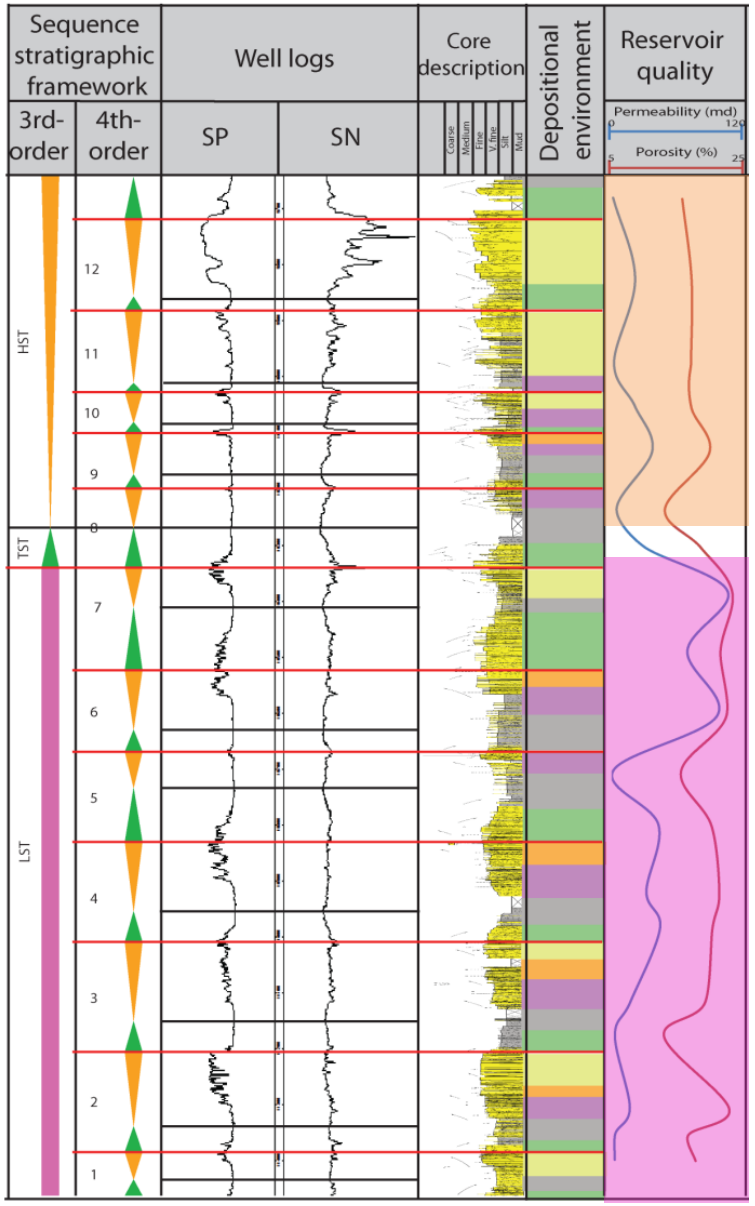
- Sandstone body has very good lateral continuity along depositional strike and dip and very low heterogeneity



Reservoir quality

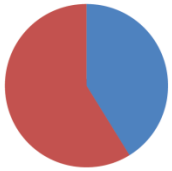
	Porosity (%)
Count	843
Mean	19.4
Std. dev.	5.6
Minimum	0.024
Maximum	34.3
	Permeability(md)
Count	837
Mean	33.6
Std. dev.	85.2
Minimum	0.01
Maximum	650

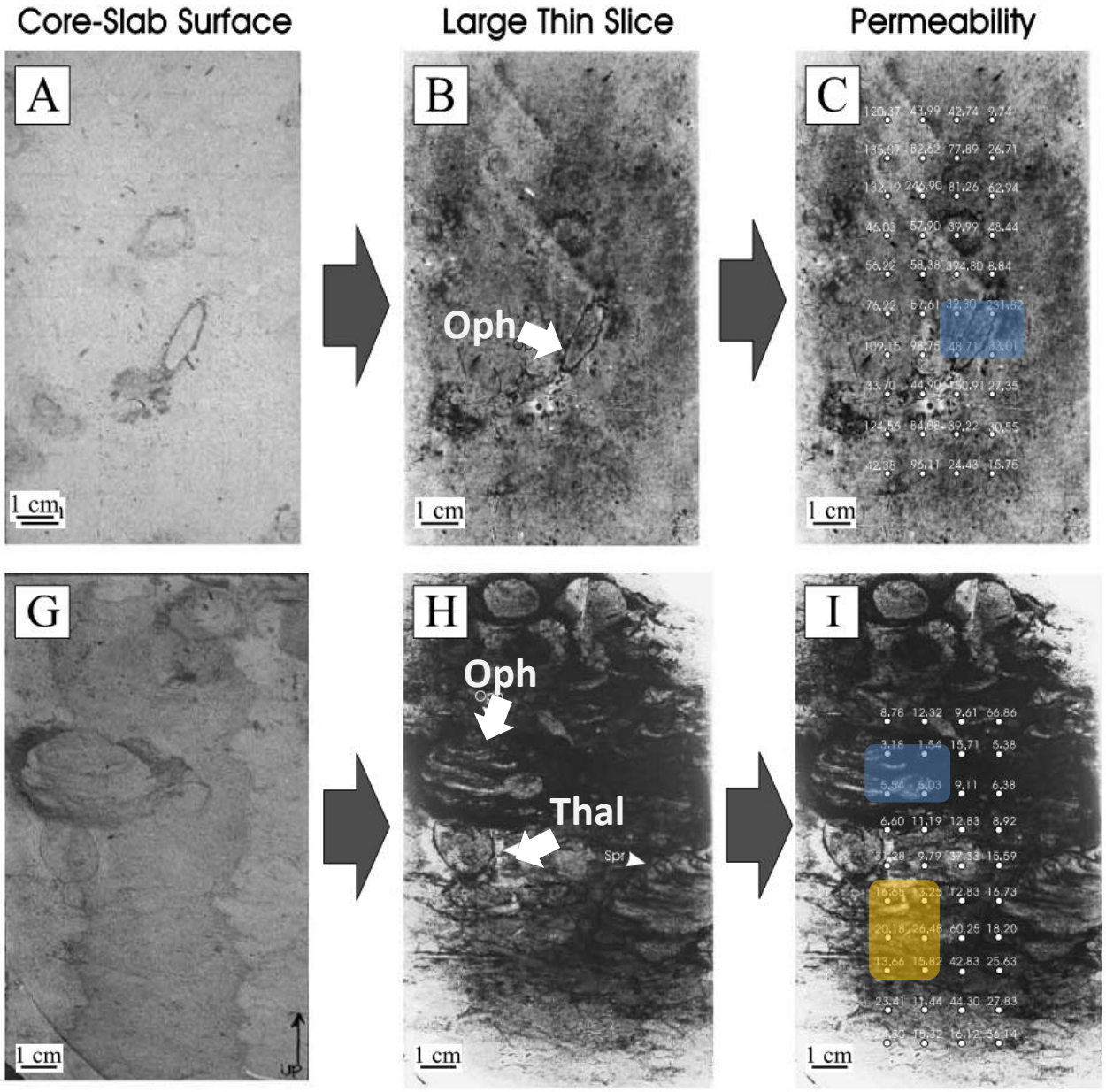
Reservoir quality data



- Reservoir quality in LST is higher because a proximal position of deltaic systems.

Shoreface variability

Depostional environments	Example	Thickness ratio between sandstone and siltstone and mudstone Sandstone Siltstone and mudstone	Thickness ratio between stratified beds and bioturbated beds Stratified beds Bioturbated beds	Reservoir quality Porosity (%) Permeability (md)	Ichnological Assemblages
Upper shoreface or delta front	4th-order sequence 2	 95 : 5	N/A	 24.4 24.7	Skolithos Ichnofacies
Middle shoreface	4th-order sequence 2	 87 : 13	 59 : 41	 21.1 7.4	
Lower shoreface or prodelta	4th-order sequence 3	 85 : 15	 26 : 74	 17.7 8.9	Cruziana Ichnofacies



- Mudstone-filled and/or lined burrows (e.g., *Ophiomorpha*, *Palaeophycus*, and clusters of *Chondrites*) can decrease permeability.
- Sand-filled burrows (e.g., *Thalassinoides*) can increase permeability.

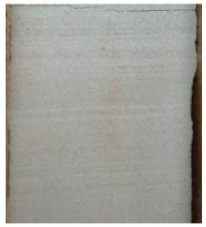
(Tonkin et al., 2010)

❑ Burrows are important controls on reservoir quality in individual shoreface intervals.

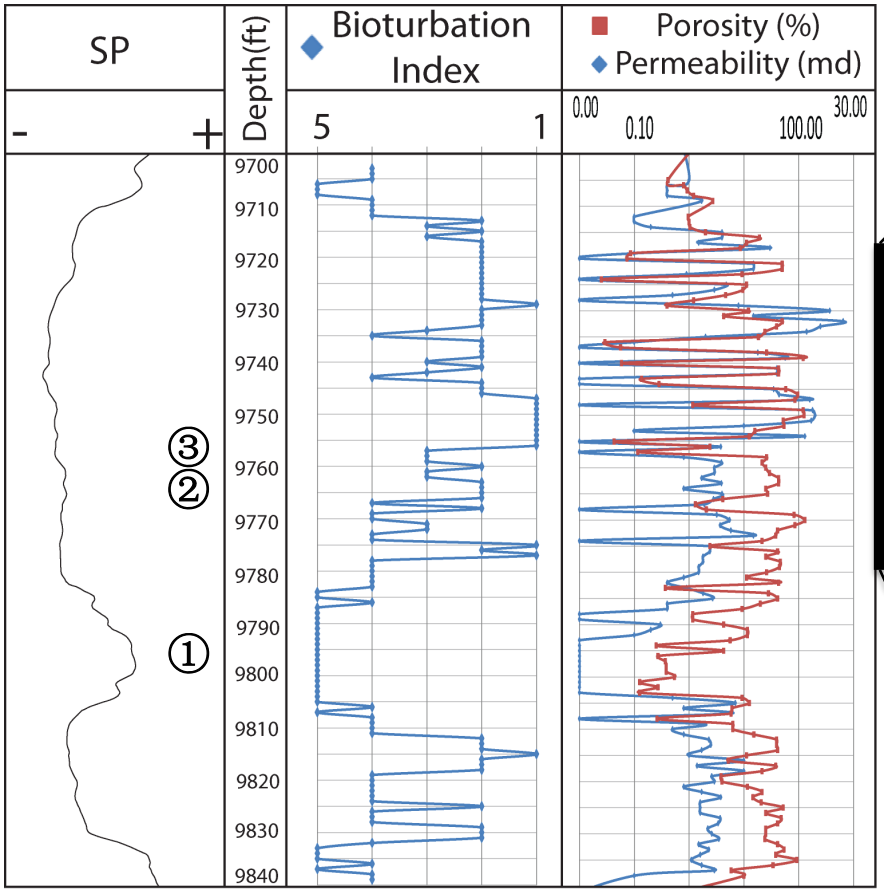
Relatively low permeability area

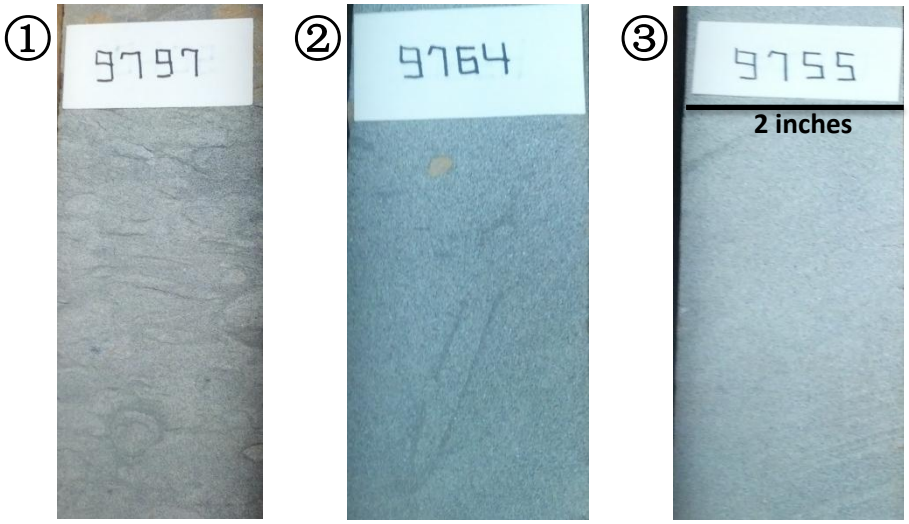
Relatively high permeability area

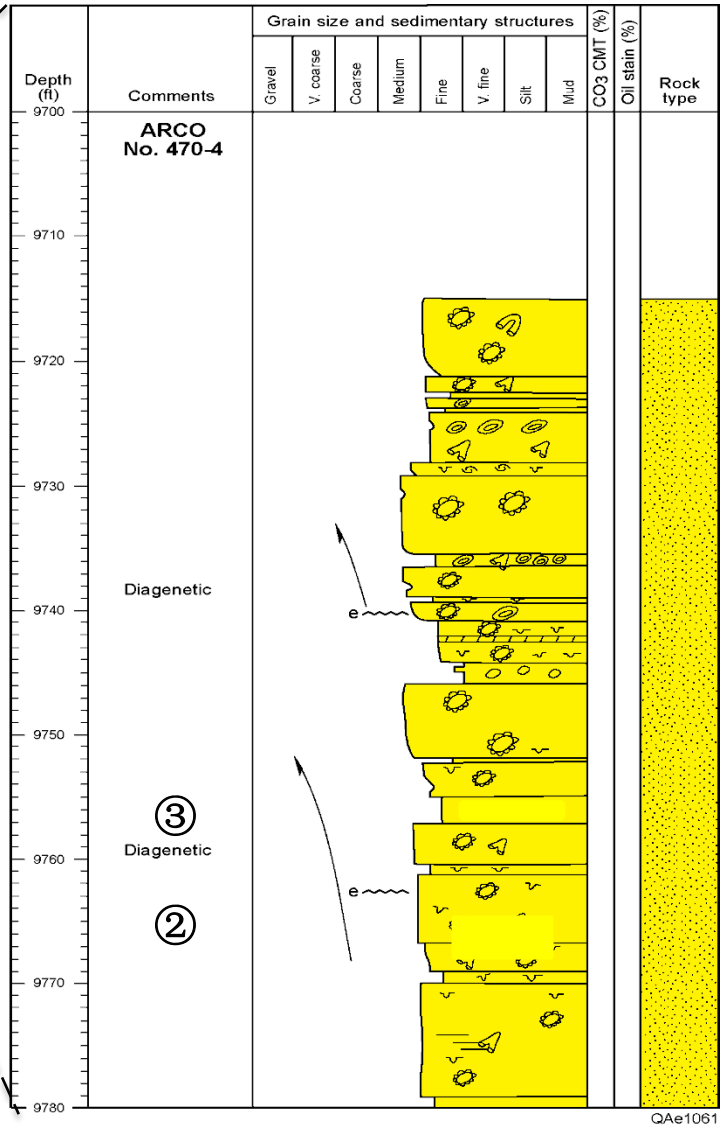
Relation between bioturbation intensity and reservoir quality

BI	Mudstone Facies	Sandstone Facies	ARCO #470-4	Characteristics
1				Bioturbation absent
2				Sparse bioturbation, bedding distinct
3				Rare bioturbation bedding broken
4				Common bioturbation, bedding just visible
5				Complete bioturbation, homogenization of sediment

Bioturbation Index scheme (Table modified from Bann et al., 2008, after the original concepts of Taylor and Goldring, 1993, and Bann, 1998).







- Reservoir quality within each 4th-order sequence is also controlled by degree of burrowing

Conclusions

- The study interval is an incomplete 3rd-order sequence, composed of LST, TST and HST sequences from bottom to top;
- Wave-dominated deltaic systems are recognized from core descriptions, sandstone maps, and stratal-slice maps. The systems are also influenced by fluvial processes;
- The sandstone-body continuity is very good along both depositional strike and dip;
- Reservoir quality is controlled by sequence-stratigraphic framework at large scales; In high-frequency sequences, it is controlled by type and intensity of burrows.

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