Stratigraphic Models and Exploration Plays of Slope and Basin-Floor Carbonates*

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Abstract

Exploration for carbonate-slope and basin-floor reservoirs involves an underdeveloped play type. Significant risks include reservoir quality prediction and top and lateral seal development, but risk can be reduced by improving conceptual models developed using detailed outcrop studies and careful examination of core, log, and, 3D seismic data within a sequence framework. New conceptual models for carbonate-slope and basinal-deposit stratigraphic architecture and several exploration plays have been developed using extensive literature review and several detailed outcrop studies. Six stratigraphic play types can be defined for toe-of-slope and basinal carbonate sediments: (1) Reefal upper slope; (2) toe-of-slope apron; (3) channelized fan; (4) basin-floor fan; (5) drift, contourite; and (6) collapse/olistostrome. These plays will be documented using outcrop and subsurface examples ranging from the Carboniferous to modern-day carbonate depositional systems. Hydrocarbon production comes from the first three types of play and possibly also from true carbonate basin-floor fans. Contourites and margin-collapse plays remain hypothetical. In addition to these pure stratigraphic-trap plays, tectonic deformation, fracturations, and, late diagenesis can greatly enhance the potential for accumulation of hydrocarbon in the toe of slope and basin adjacent to shallow-water carbonate platforms.

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Outline

- **Motivations**
- **General Slope Models**
- **Potential Stratigraphic Trap in Slope/Basin Setting**
  - **Reefal Slope**
  - **Toe-of-Slope Apron**
  - **Channelized Fan**
  - **Basin Floor Fan**
  - **Slump**
  - **Drift**
- **Conclusions**

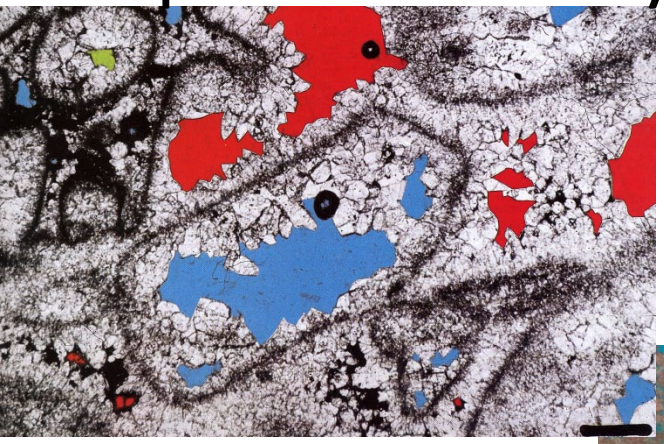
Motivations

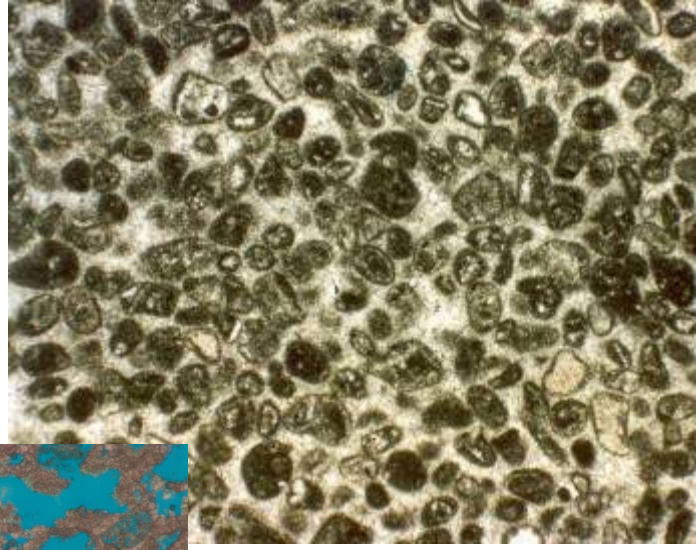
- Slope and basin reservoirs are common in clastic systems.
- There is few existing reservoirs of this type in carbonate system: Cretaceous (Mexico and Italy), Permian (USA), Tertiary (Indonesia).
- The potential for accumulation of hydrocarbon is real and have been talked about for several decades.
- Slope and basin plays are viable because:

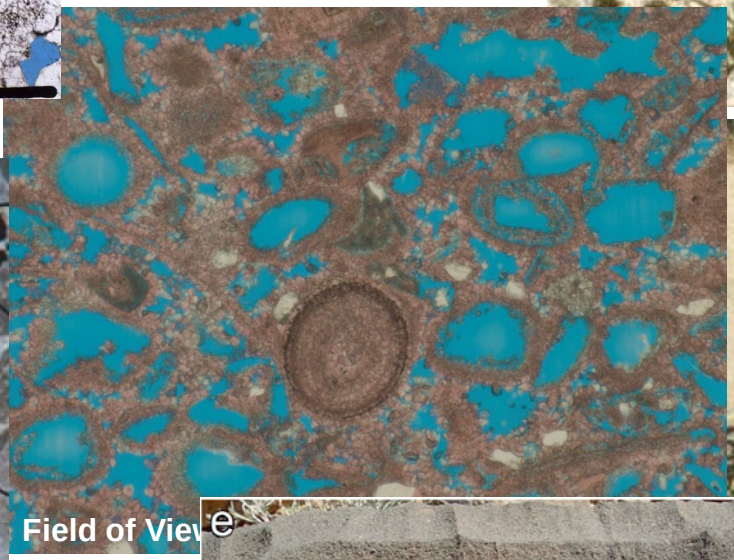
1. Grainy porous carbonate rocks exist on the slope, at the toe-of-slope and in the basin => **Reservoir**
2. Stratigraphic architecture allows for stratigraphic **Traps** that can be enhanced by structure
3. Nearby basinal deposits can be both **Source** and **top Seal**

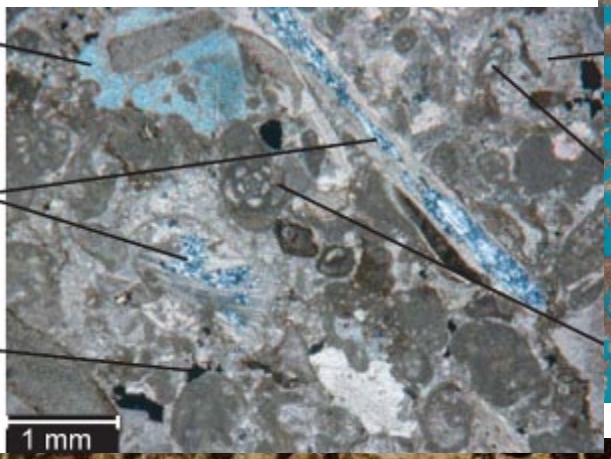
lateral seal and upslope leaking are the biggest issues

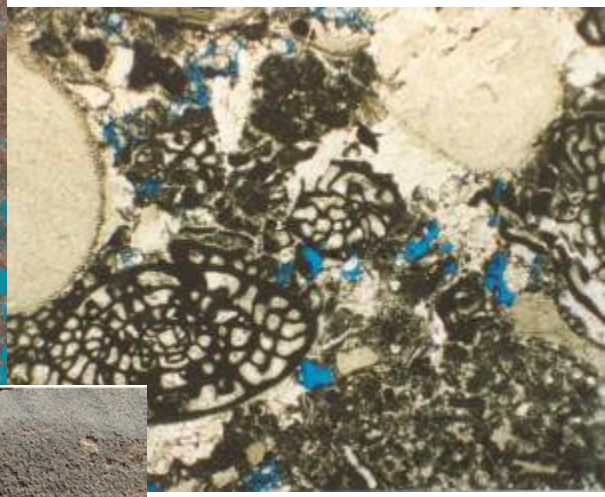
Deep Water Grainy Rocks

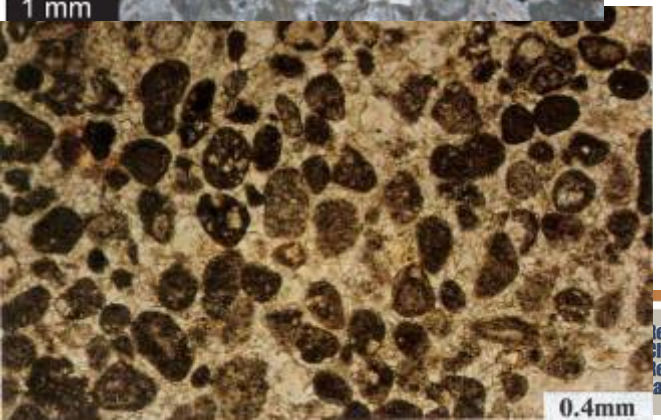




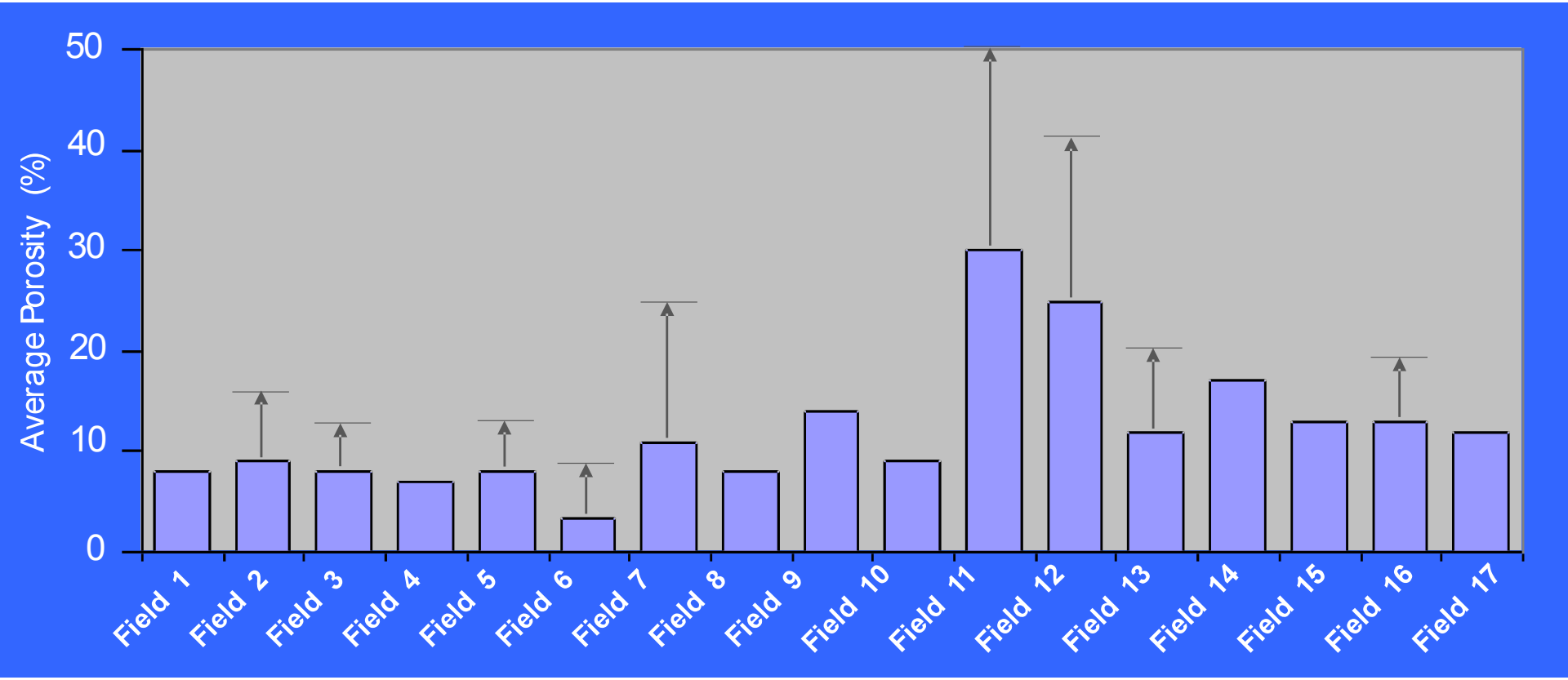








Reservoir Quality

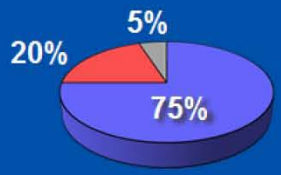


Winefield et al, 2010

Playton et al – this session-

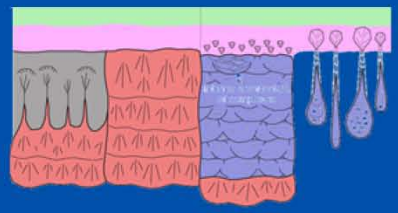
Classification for Carbonate Slopes With Associated Reefal Margins

Deposit Type Classification



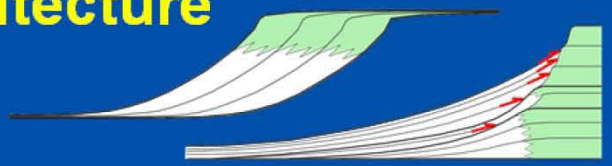
Debris deposits
Grain-dominated deposits
Mud-dominated deposits

Spatial Architecture



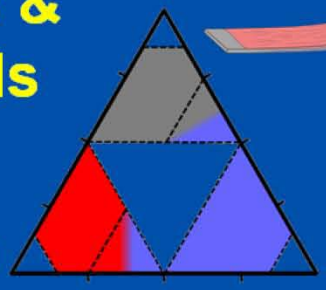
Strike extensive aprons
Discontinuous geobodies

Dip-view Stratal Architecture



Accretionary vs escarpment margins

End-Member Slopes & Spectrum of Controls



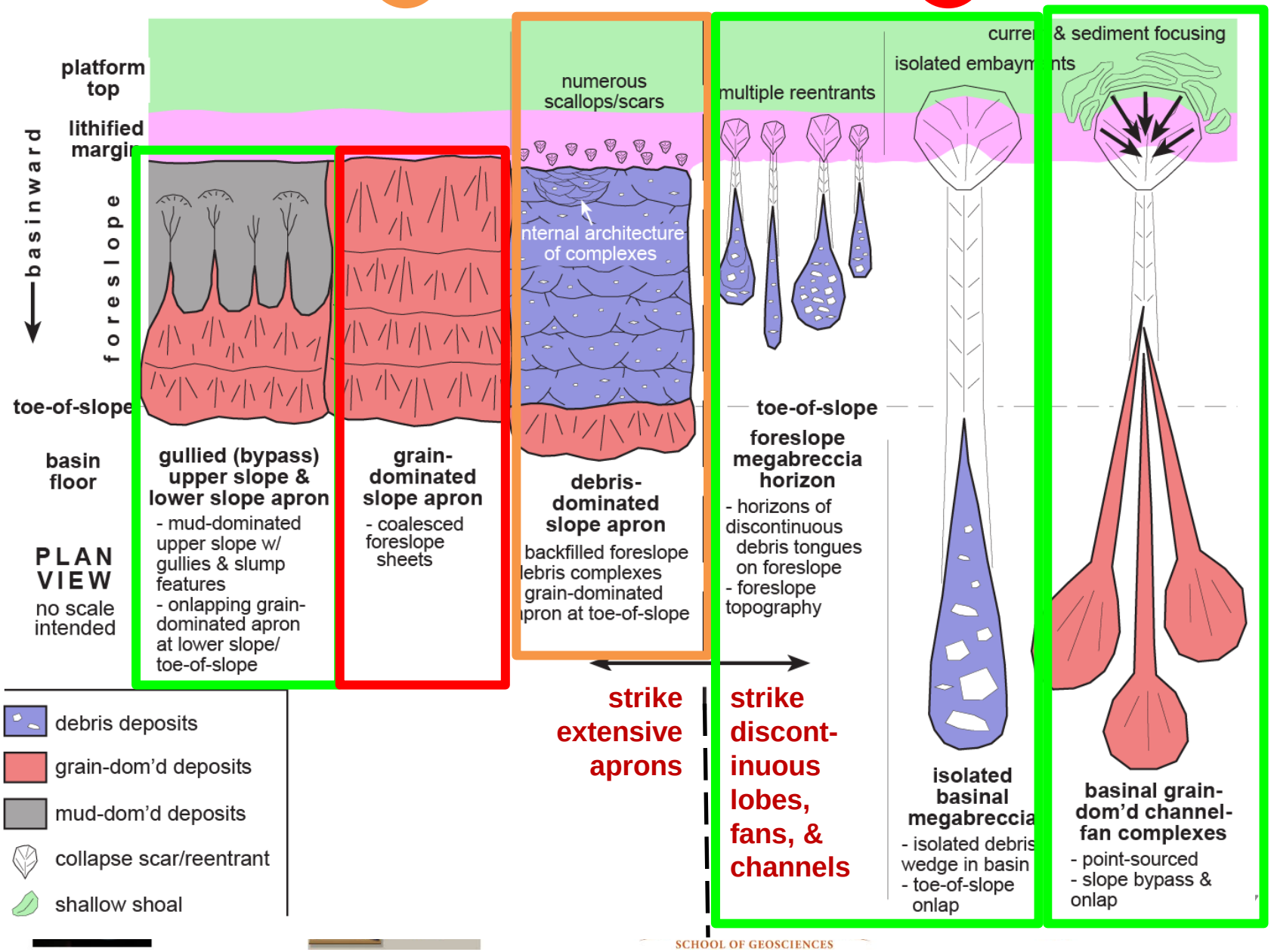
Mud-dom'd slopes → pelagics & broad platforms

Grain-dom'd slopes → shallow skeletal reefs

Debris-dom'd slopes → deep microbial boundstones

Playton et al – this session-

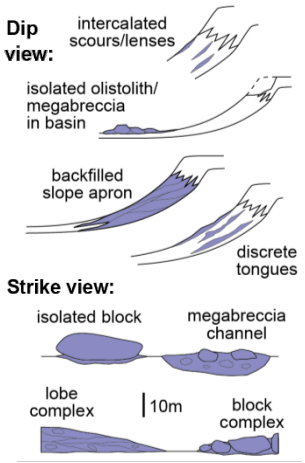
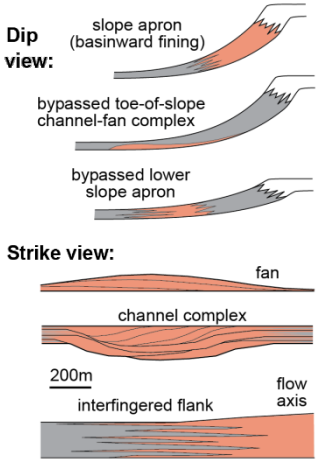
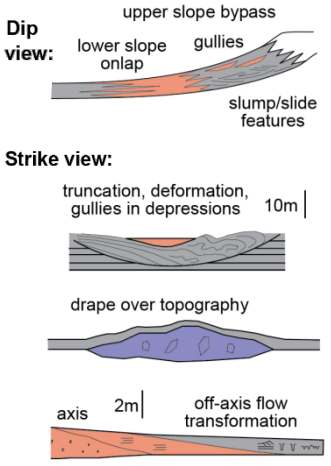
: good trap potential : moderate trap potential : low trap potential



CO_3 Slope/Basin Deposit Type Classification

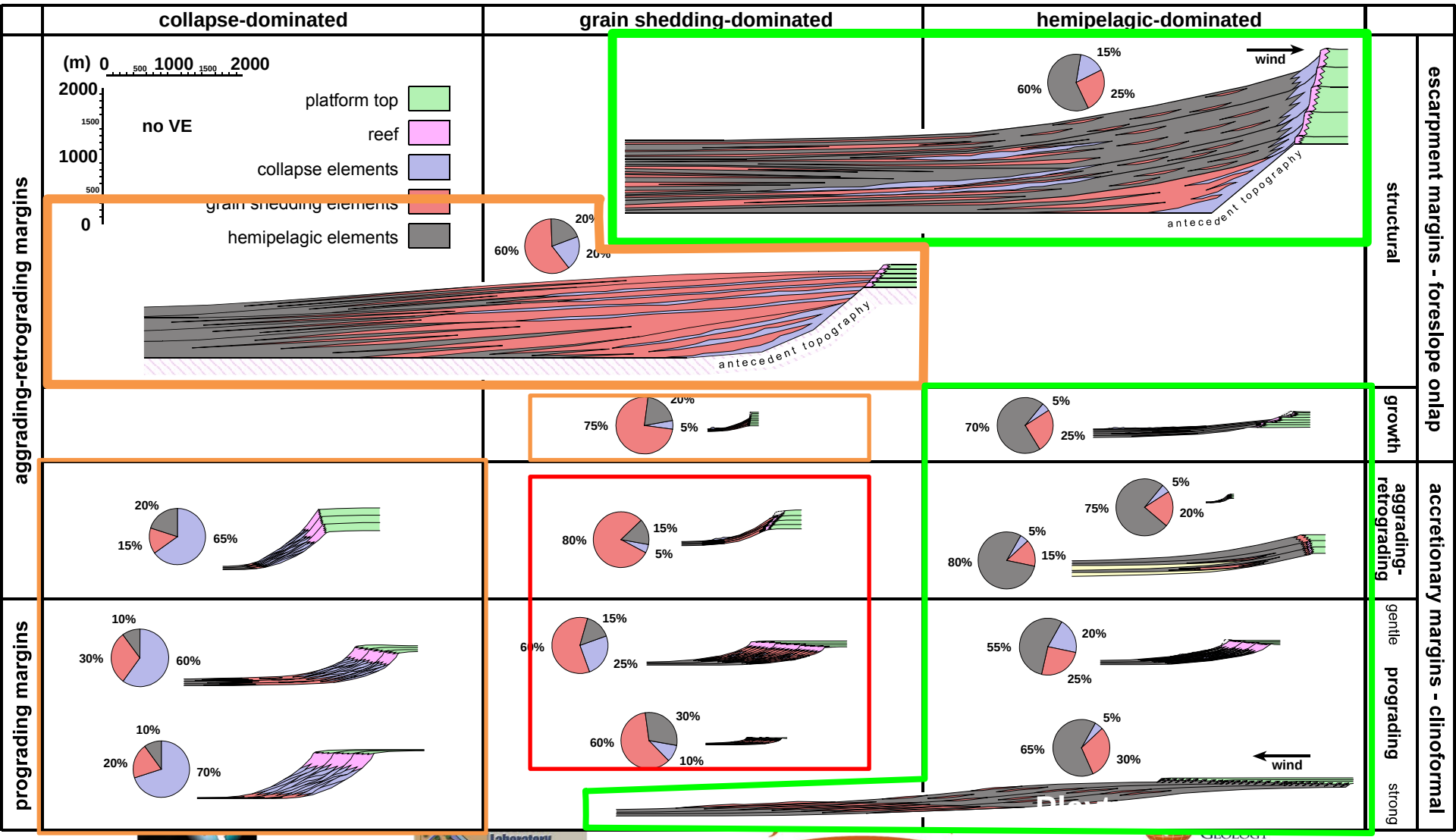
Playton et al – this session-

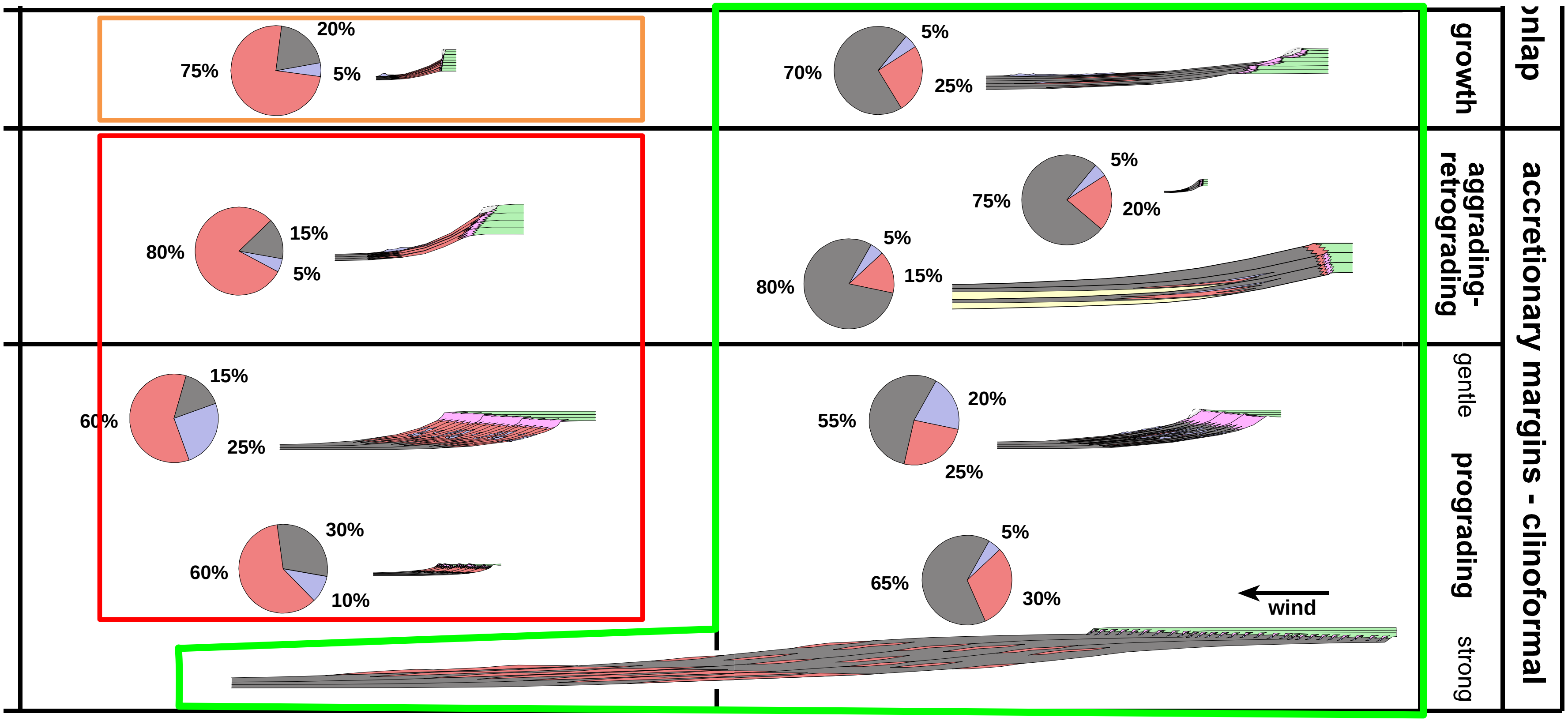
: good ϕ potential : moderate ϕ potential : low ϕ potential

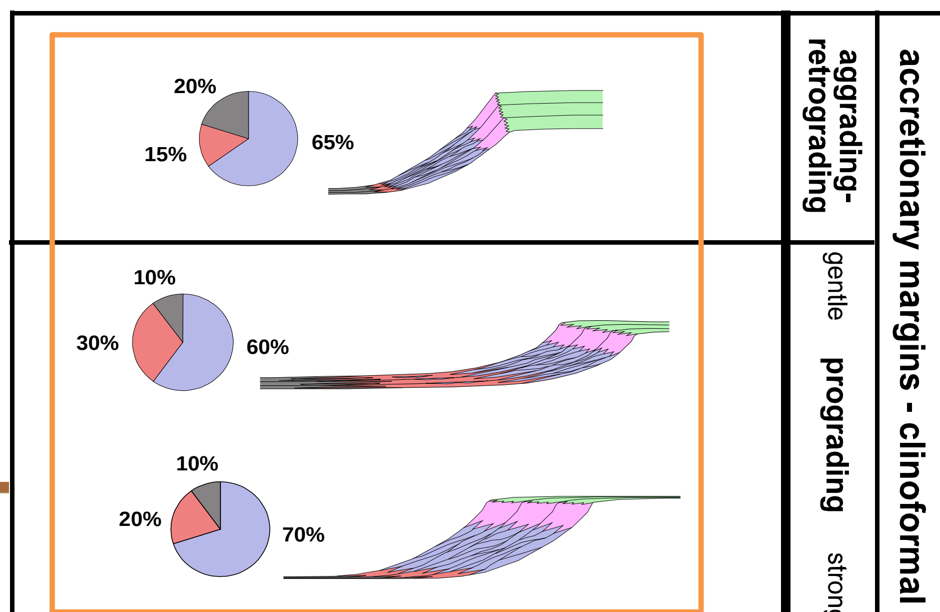
Char-acteristics \ Deposit Type	Debris Deposits	Grain-Dom'd Deposits	Mud-Dom'd Deposits
Texture & Grain Size	megabreccia & blocks; cobbles & boulders	pkstn, gnstn, & fine rudstn; sand & pebbles	mudstn, siltstn, & wkstn; clay & silt
Common Structures & Bedding	unorganized; thick lenticular beds; low length:height (L: H)	graded & stratified; medium tabular beds; moderate L: H	burrowed or rippled & finely laminated; thin bedded; high L: H
Architecture & Associations debris deposits grain-dom deposits mud-dom deposits			
Transport & Flow Support*	rockfall, hyper-concentrated & debris flow; buoyancy & matrix strength	(hyper)concentrated flow; dispersive pressure	turbulent flow & suspension; fluid turbulence
Source CO3 Factory	lithified marginal or upper slope EODs	high energy platform-top & marginal EODs	low energy platform interior EODs or water column
Resedimentation Process	brittle failure & gravitational collapse	offbank shedding from currents	off bank shedding from currents or pelagic fallout

Spectrum of Carbonate Foreslopes (Playton et al, 2010)

: good trap potential : moderate trap potential : low trap potential







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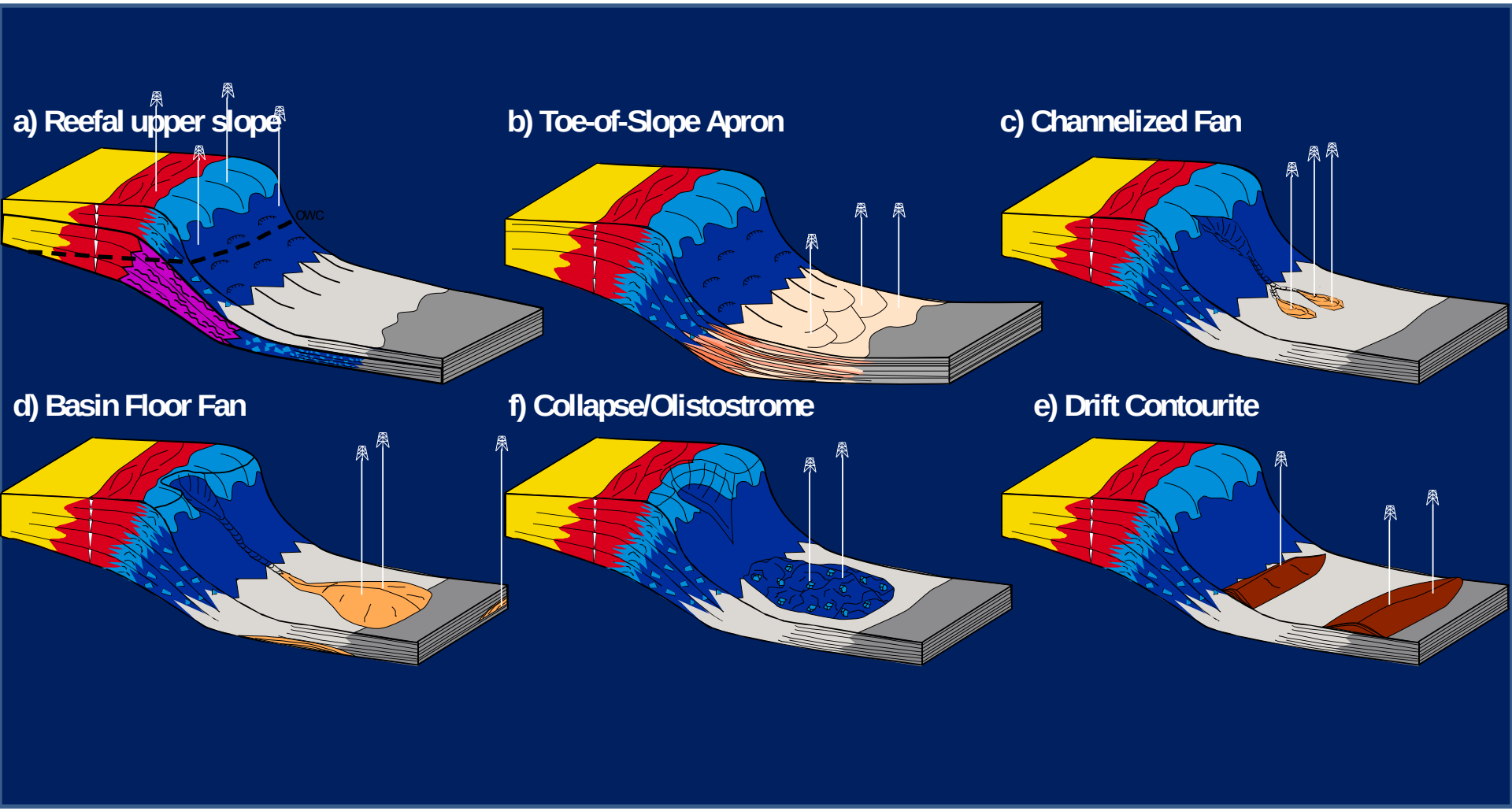
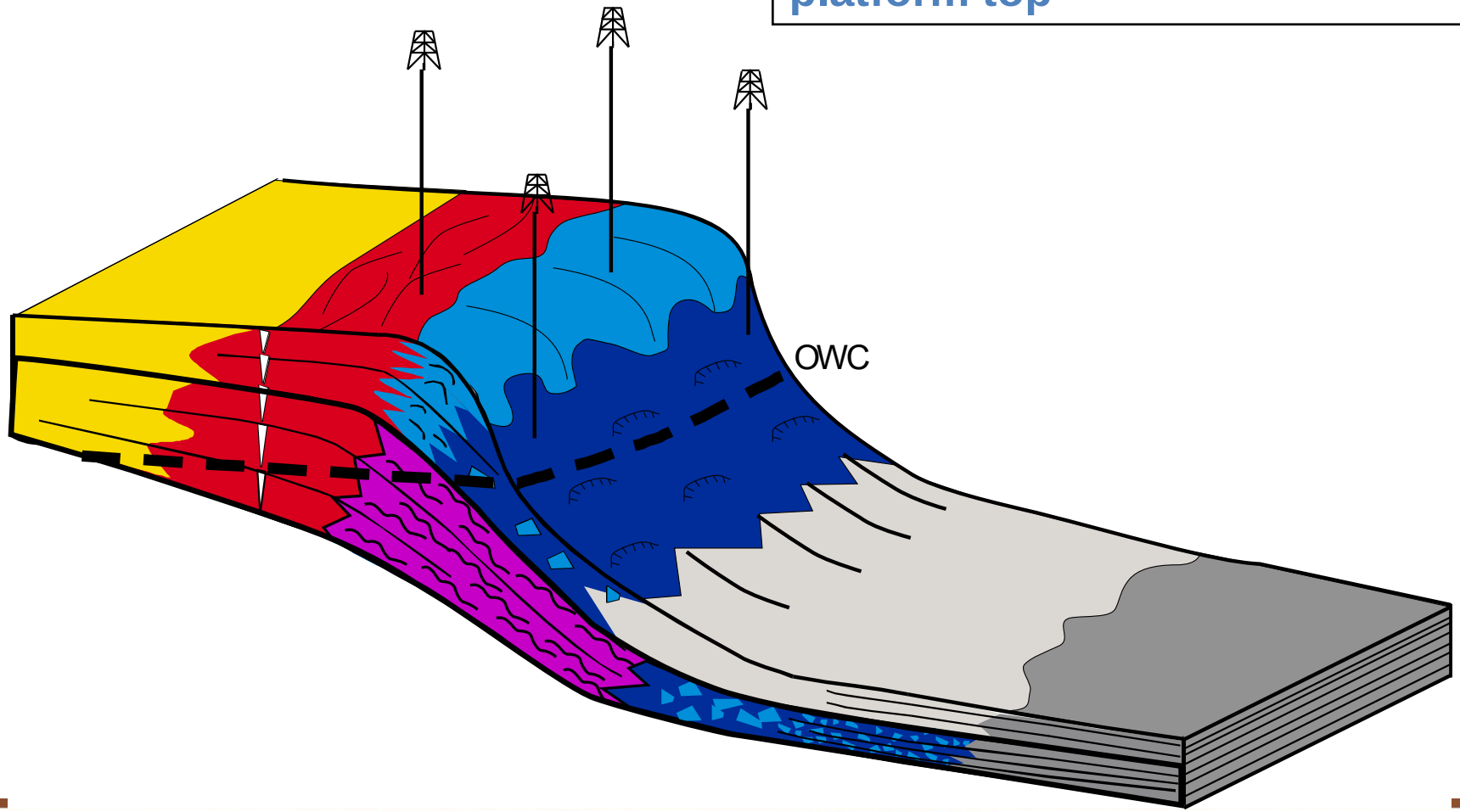
Potential Stratigraphic Traps



Reefal Upper Slope

Requires large oil column,

not real slope reservoir because it's connected to the margin and platform top



TOS/basin-centered debris at embayments during progradation (large collapse)

slope-centered debris at promontories during progradation

no collapse

large collapse

VE = 4X

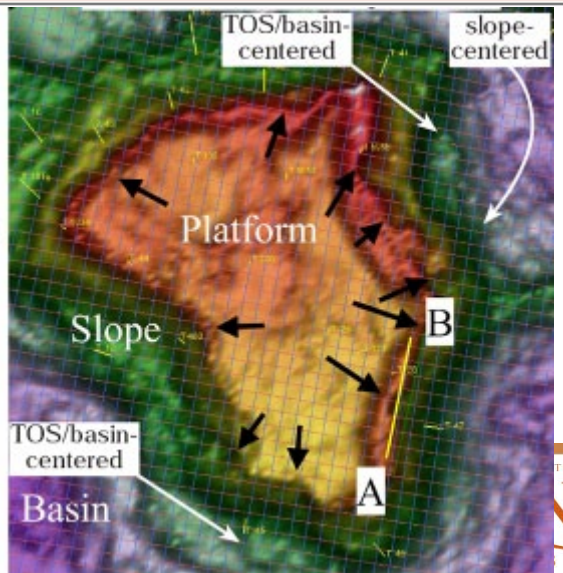
TOS/basin-centered deposits during aggradation

Weber et al, 2003

Brown = Artinskian
Yellow = Bashkirian
Blue = Serpukhovian
Orange = L. Visean
Gray = E. Vis - L. Vis
Green = E. Visean
Brown = Tournaisian
Pink = Devonian

5 kilometers

VE = 1X



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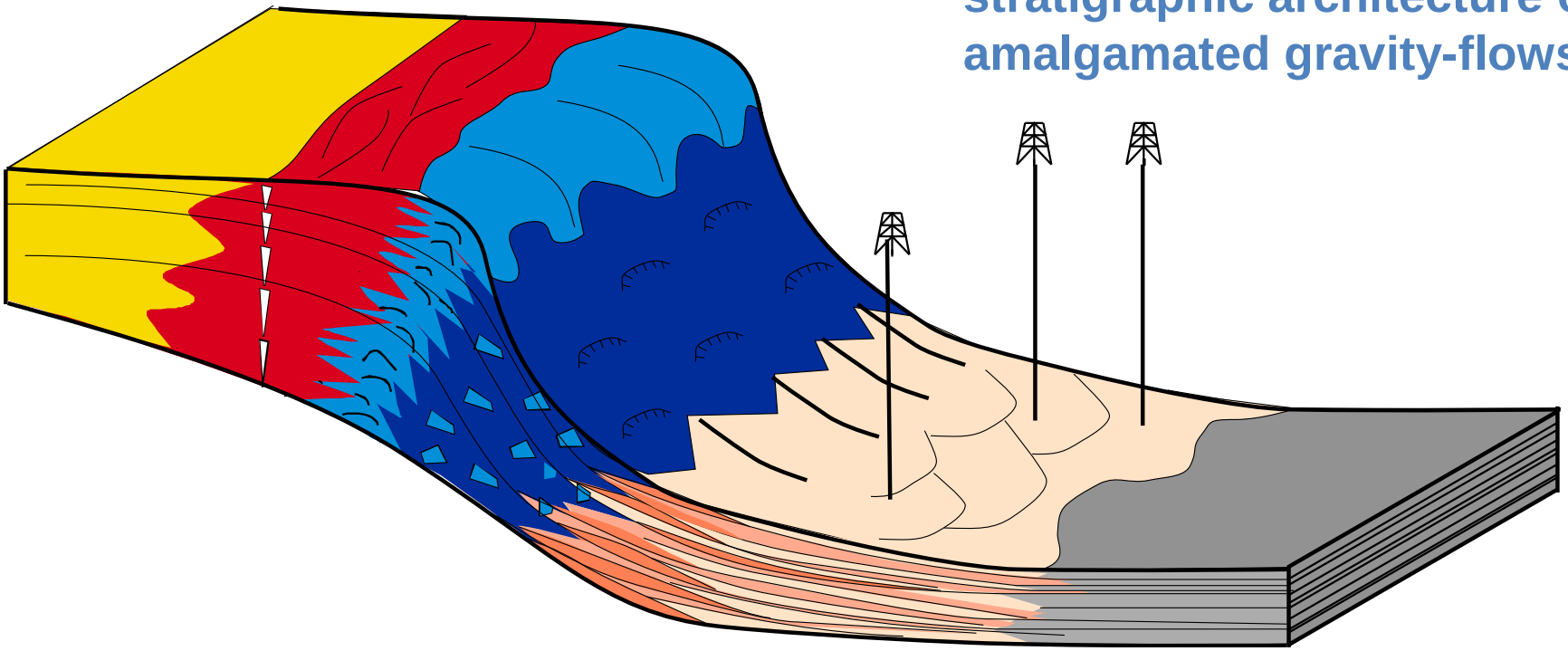
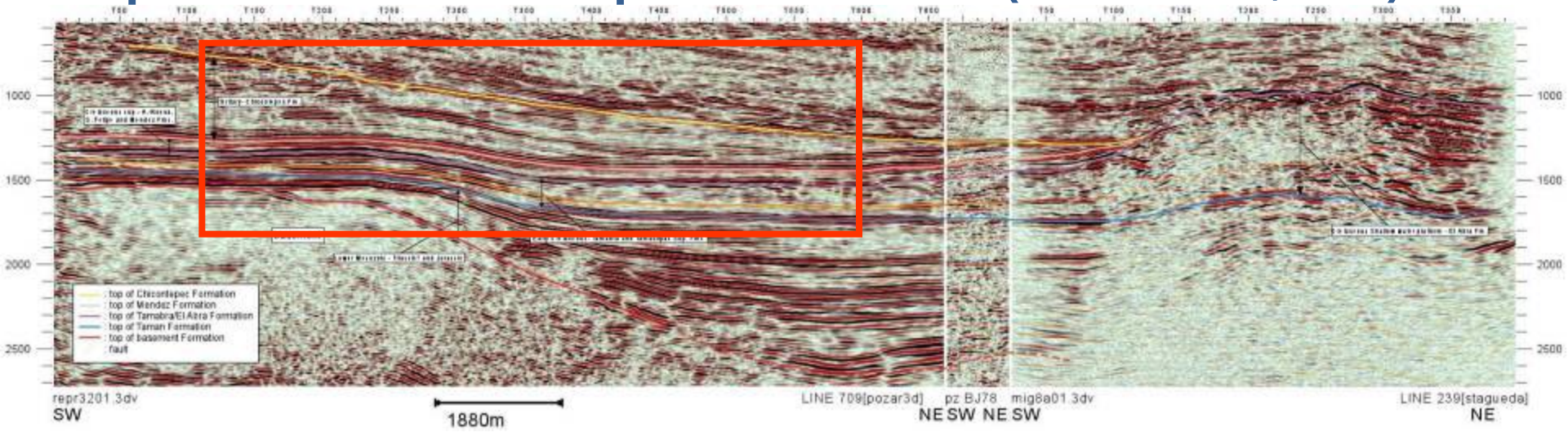
Toe-of-Slope Apron

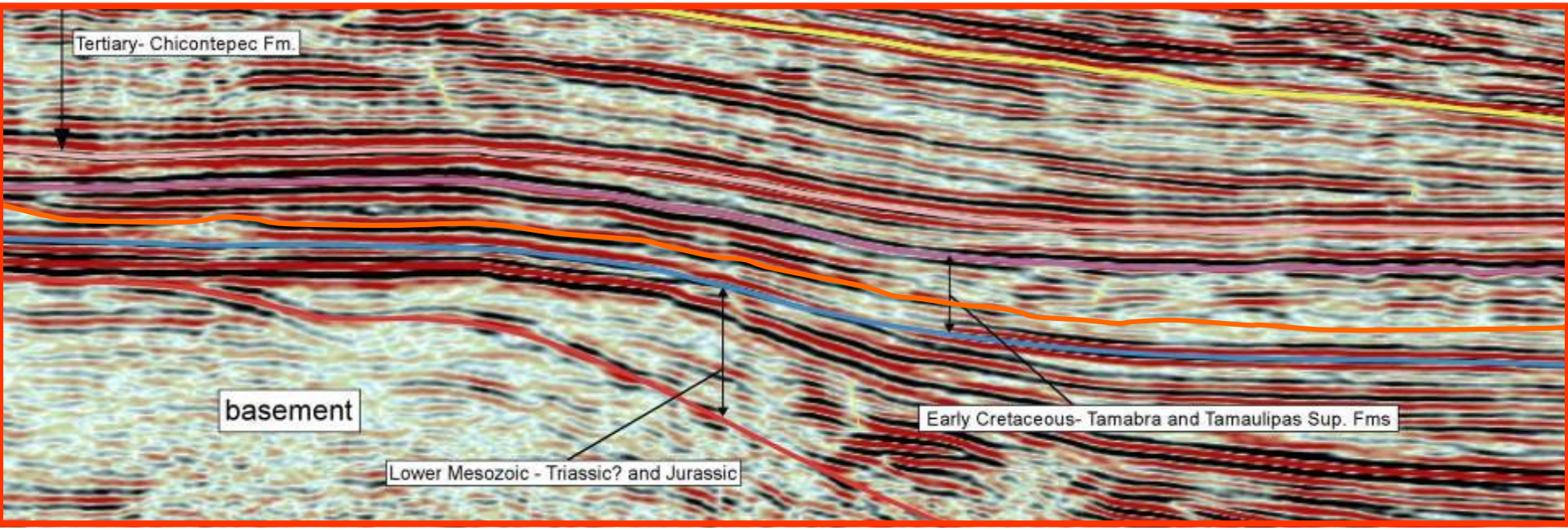
Need to be disconnected from the margin and platform top

Apron has complex stratigraphic architecture of amalgamated gravity-flows



Steep Cretaceous Escarpment Mexico (Janson et al, 2011)





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Reservoir Characterization Research Laboratory

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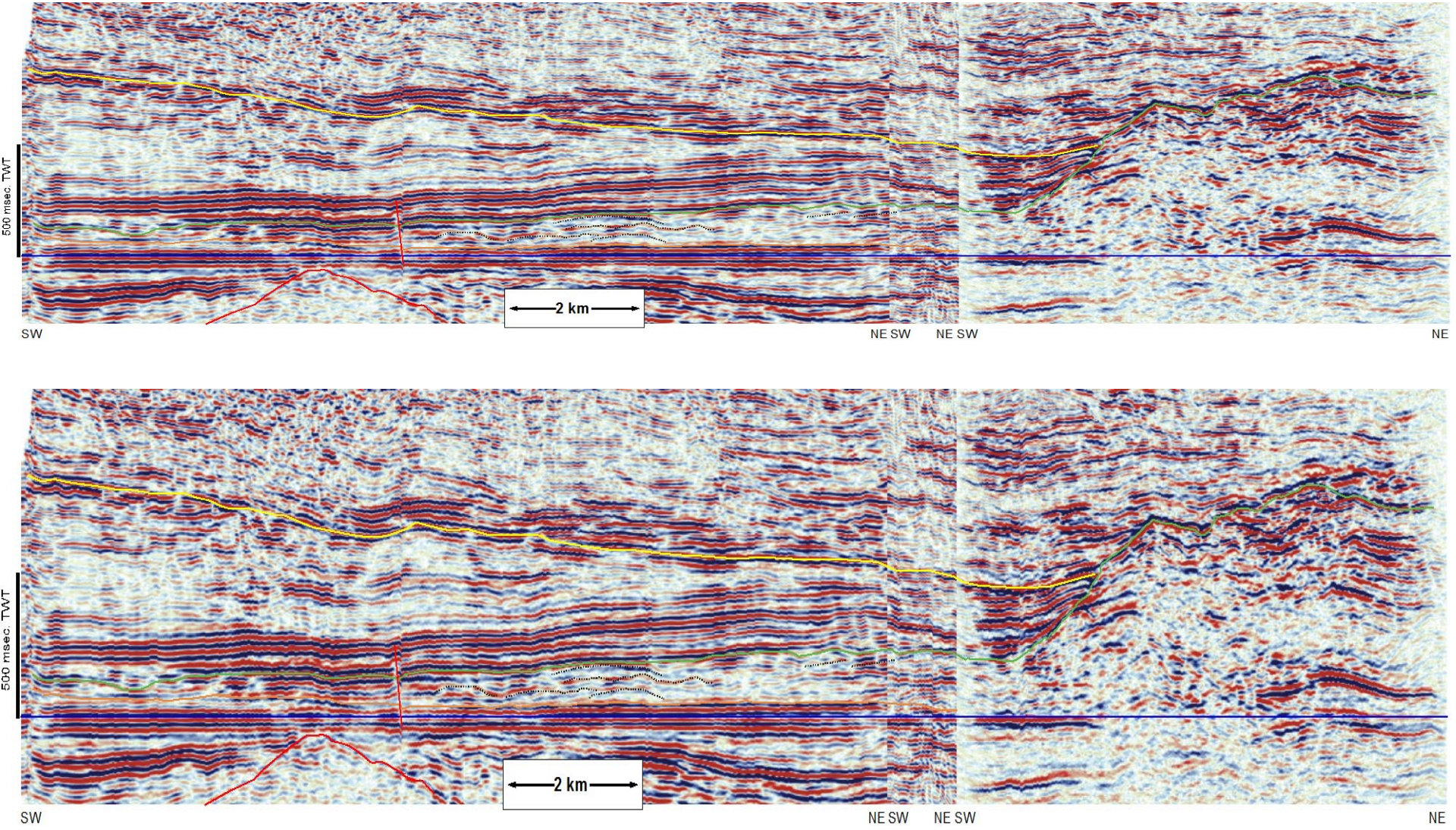
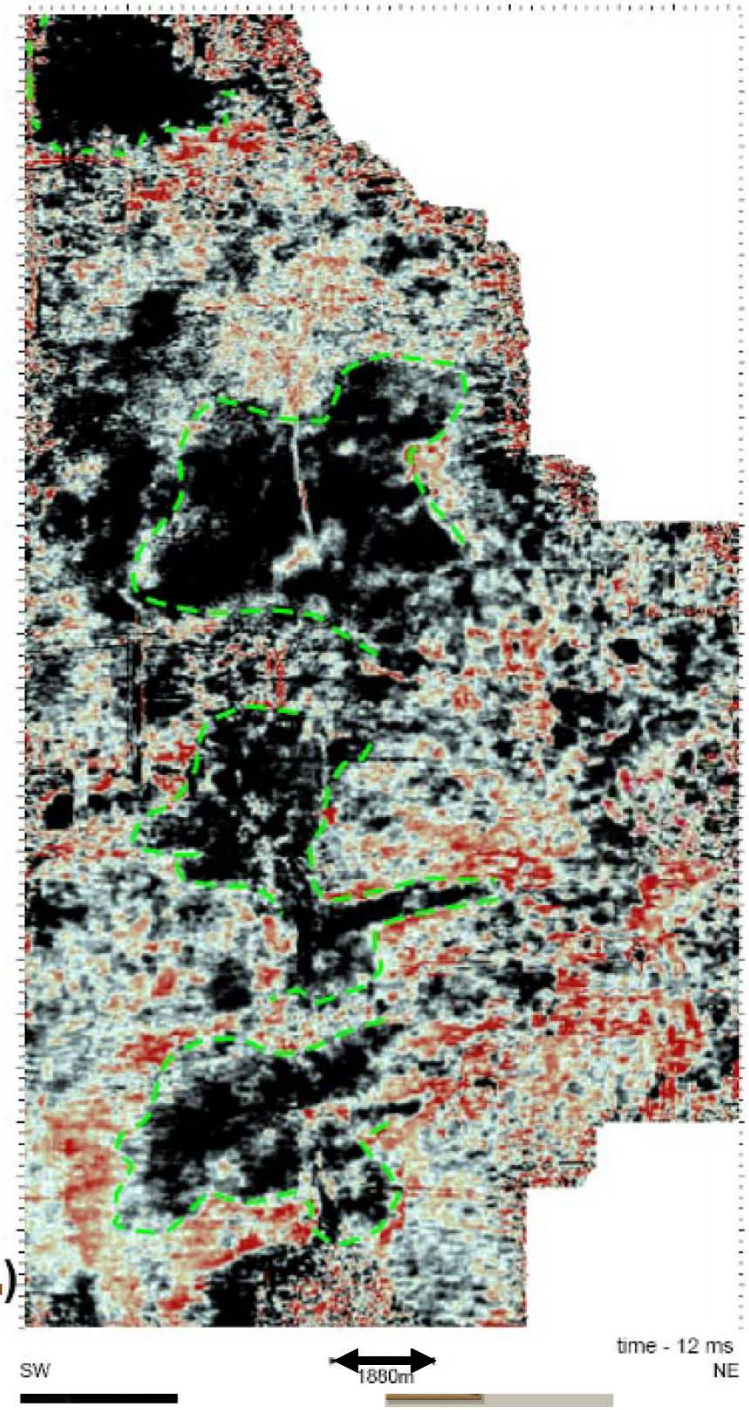
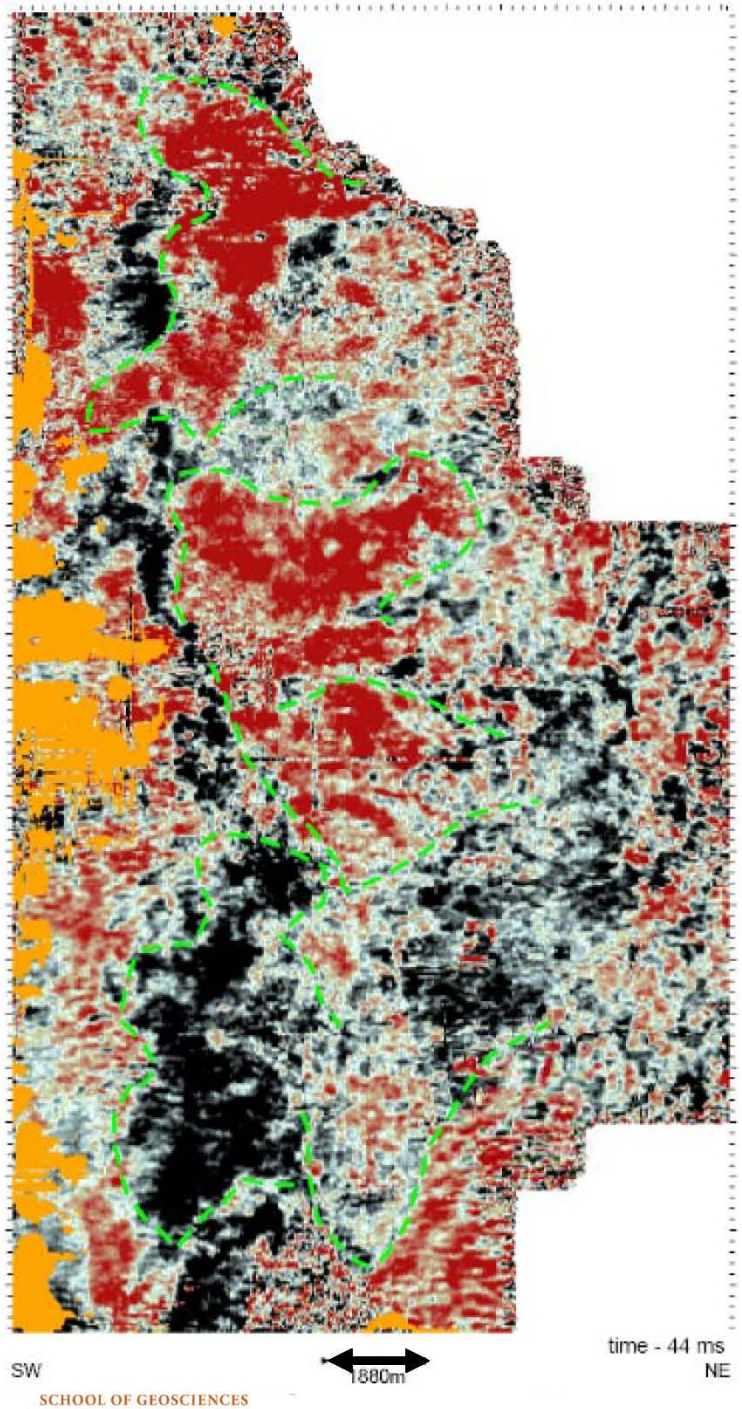
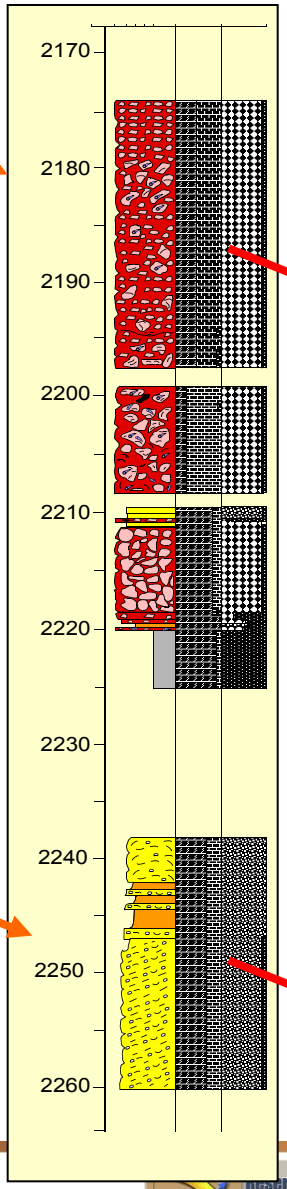
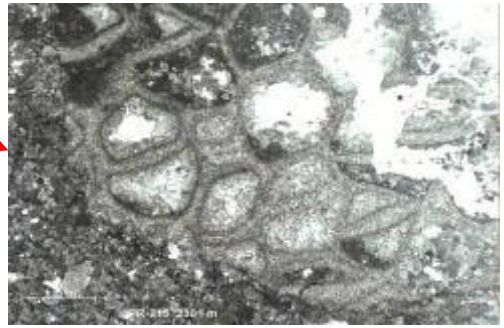
Flattened Regional Dip Section

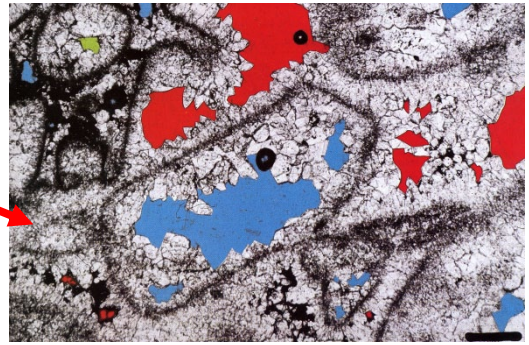


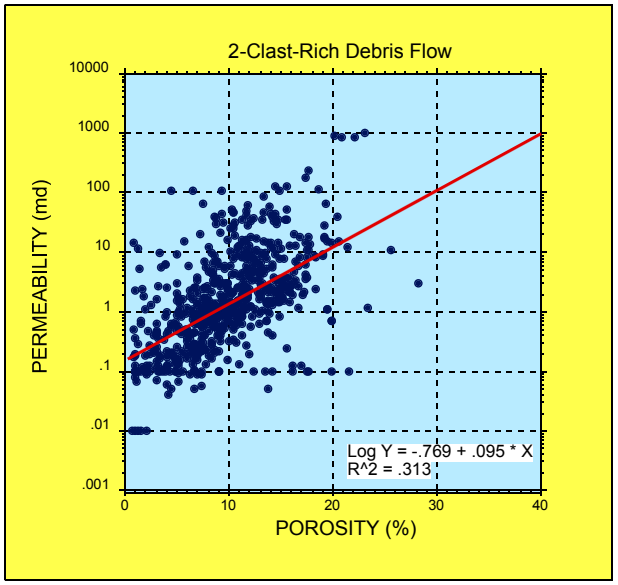

time - 12 ms
SW
1880m
NE

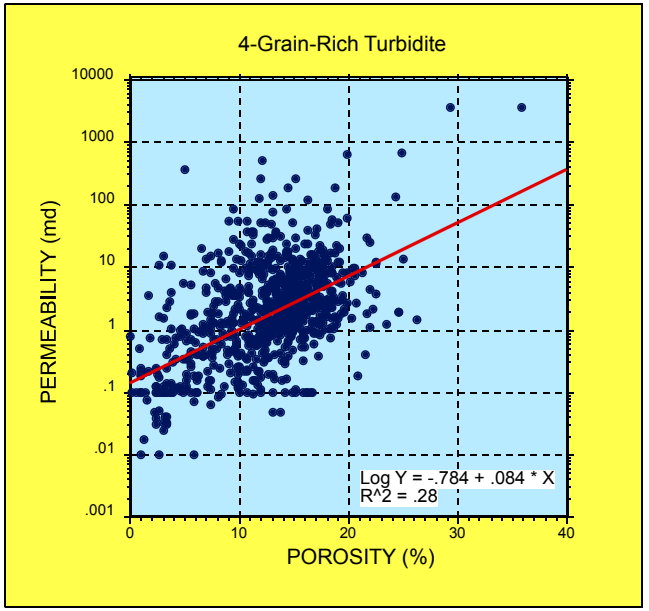

time - 44 ms
SW
1880m
NE


2170
2180
2190
2200
2210
2220
2230
2240
2250
2260






2-Clast-Rich Debris Flow
PERMEABILITY (md)
10000
1000
100
10
1
.1
.01
.001
0
10
20
30
40
POROSITY (%)
Log Y = -.769 + .095 * X
R^2 = .313


4-Grain-Rich Turbidite
PERMEABILITY (md)
10000
1000
100
10
1
.1
.01
.001
0
10
20
30
40
POROSITY (%)
Log Y = -.784 + .084 * X
R^2 = .28

Permian Apron Zechstein Dolomite (Trela et al, 2003)

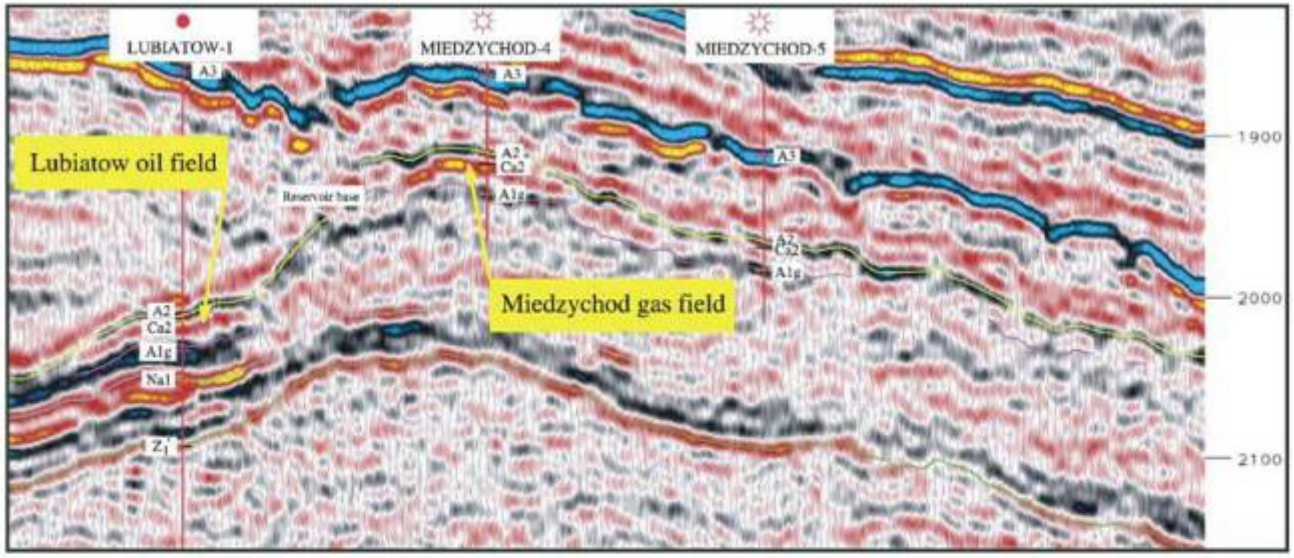
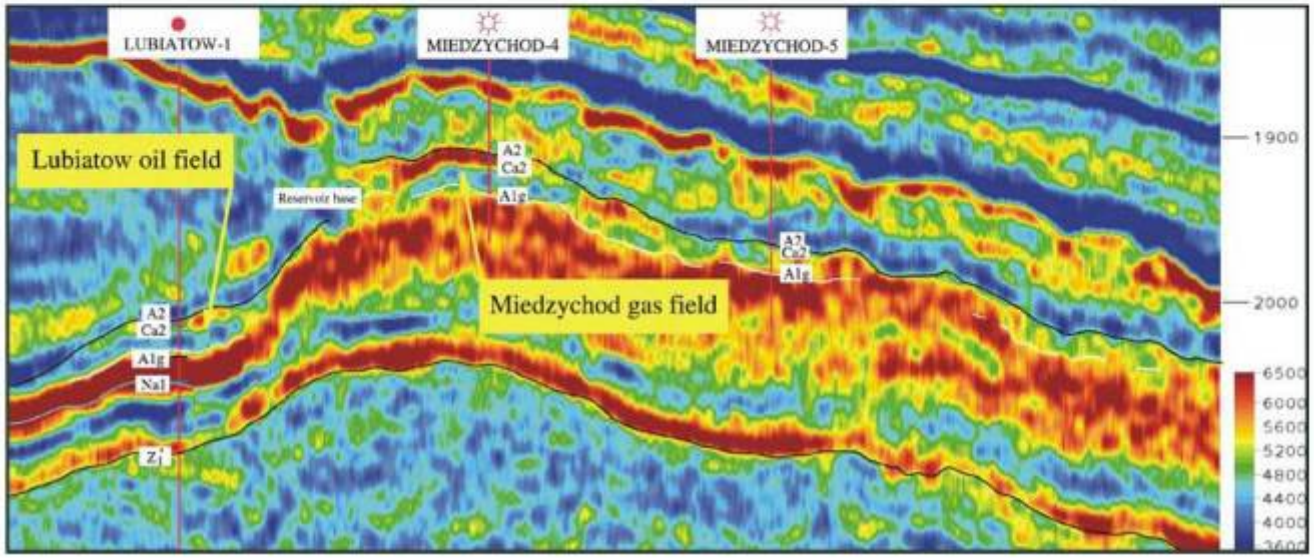


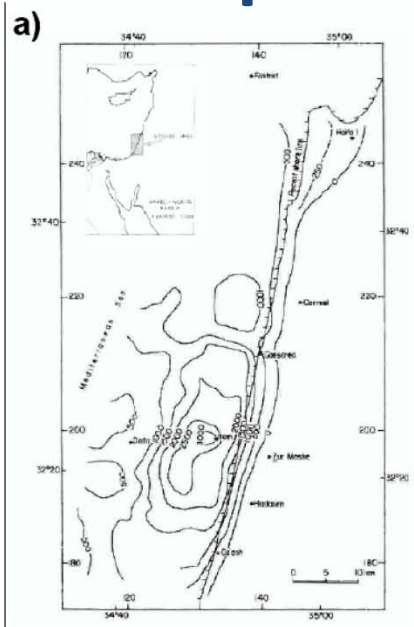
Fig. 11 Amplitude seismic section crossing Lubiatow oil field and Miedzychod gas field.



The discovery well penetrated 56m of the Main Dolomite formation with average porosity 18% (2% - 33%).

The deposit has an area of about 6 km^2 and the crude oil geological reserves of 10 MMT of oil.

Structurally Modified Apron



After Bein and Weiler, 1976

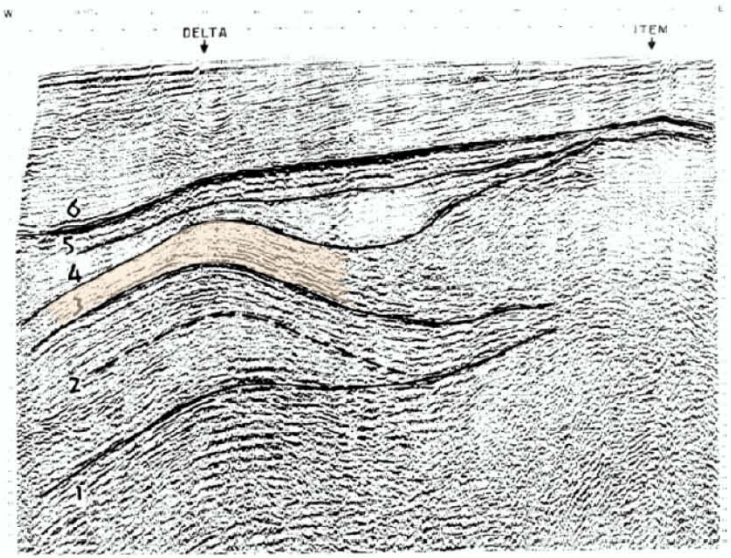
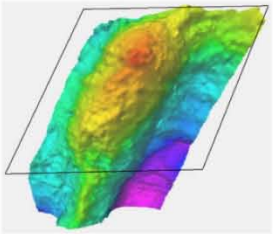


Fig. 13. East–west seismic profile running through the Israeli continental shelf; shows stratigraphic relationships. Note pronounced thickness changes in the Talme Yafe and the Gevar'am formations (1) Jurassic sediments; (2) The Gevar'am Formation; (3) The Talme Yafe Formation; (4) The Shephela Group (Upper Cretaceous-Paleogene); (5) The Saqie Group—lower part (Neogene); (6) The Saqie Group—upper part (Neogene-Holocene).

TSX.V: ADL

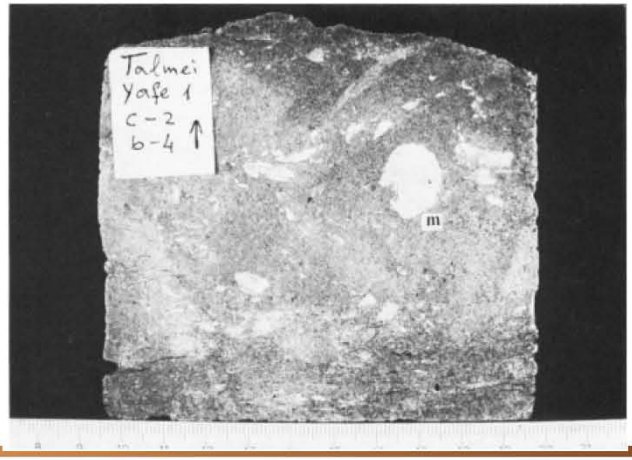
Yitzhak License (31,689 Acres)



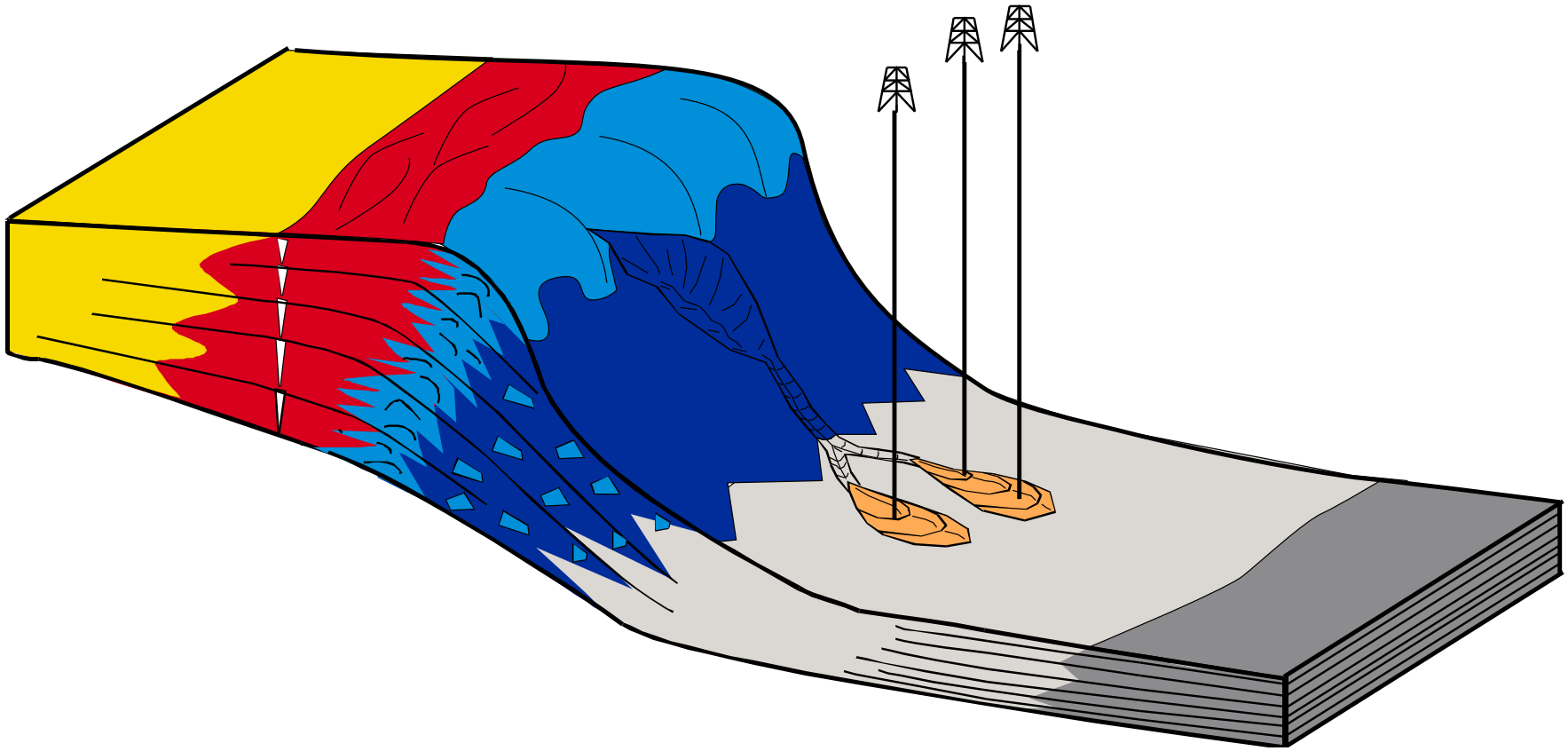
Yitzhak Structure- Depth

p50 (Best Estimate) Prospective Oil (Jurassic): 79.1 MMBO

Target: Oil	Mid Jurassic , Zohar- Fractured Carbonates
Target: Gas	Cretaceous Talme Yafe carbonates and sands
Target: Condensate	Cretaceous Talme Yafe carbonates and sands
Exploration:	129 Km 3D completed by Adira (WesternGeco), processing completed by CGG Veritas
Prior Drilling:	Delta-1 Well drilled (off structure) in 1970's to 4,423m,TD in Upper Jurassic. Oil encountered in Mid Jurassic (Yam Yaffo1 and Yam 2- Gabriella/Shemen) Zohar formation tested for oil in Yam Yafo-1 (4,890m – 4,995m) and Yam-2 Well (5,315m) interesting & significant structural high
Drilling:	Shallow water 140 to 200 meters. Floater
Co-Operator:	Adira 60% WI, up to 4.5% ORRI from AGR & Ellomay
Partners:	Brownstone Energy 15%, AGR 5%, Ellomay 20%



Channelized Fan

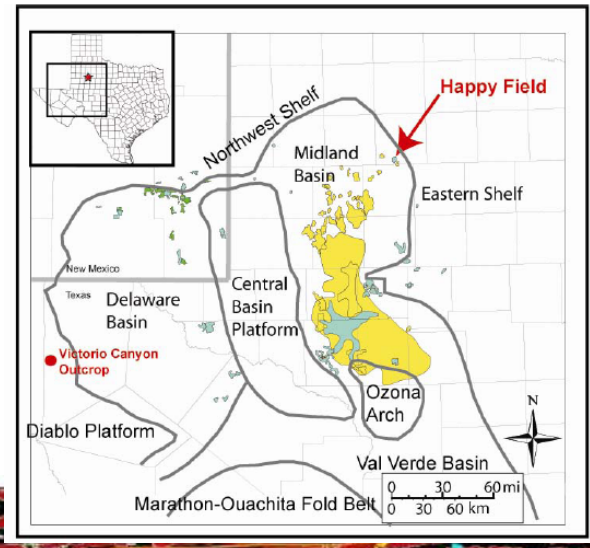


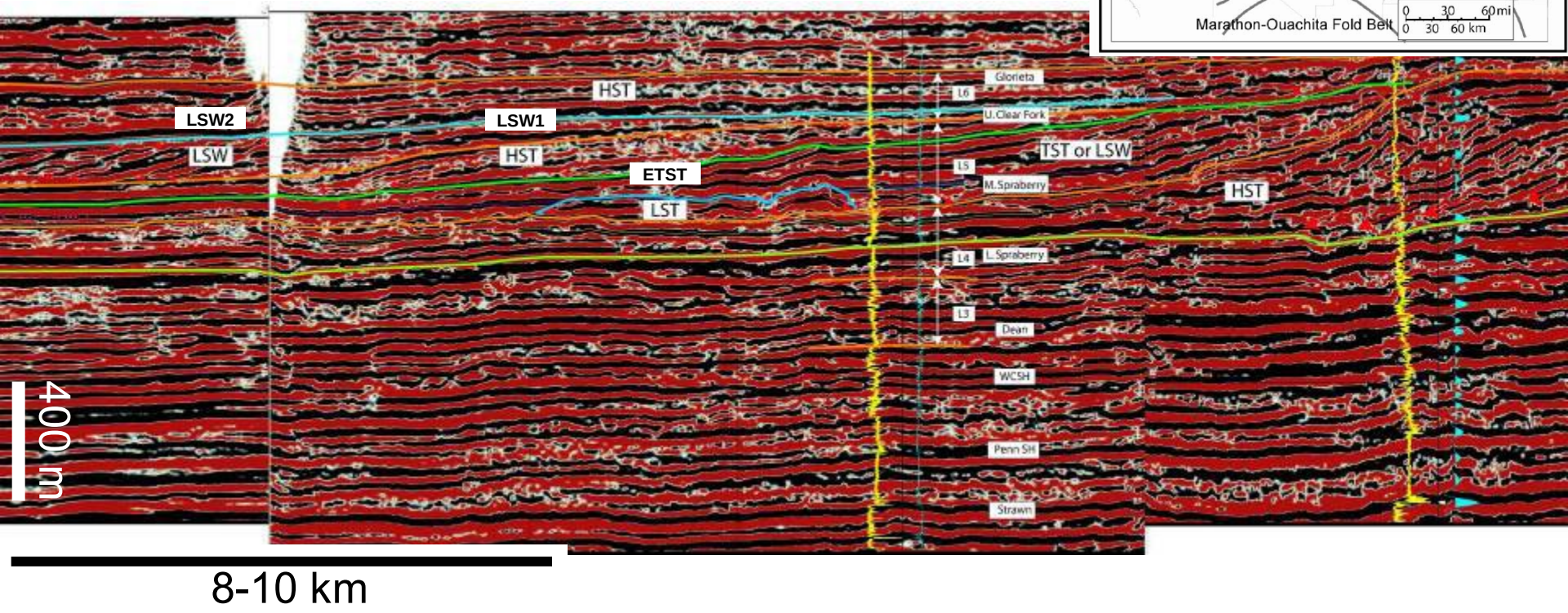
Happy Field Permian West Texas

Maximum Flooding Surface

Transgressive Surface

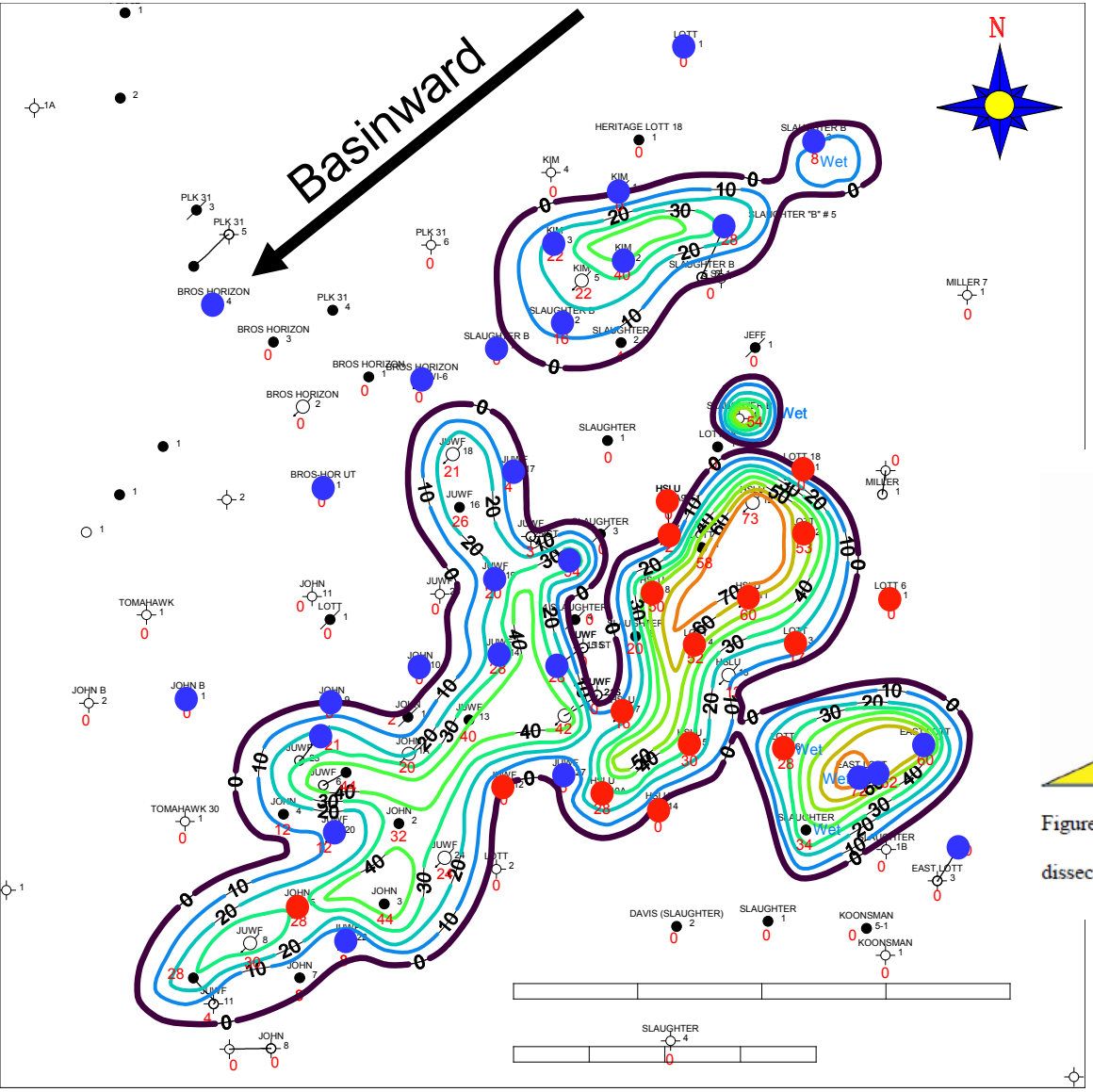
Sequence Boundary

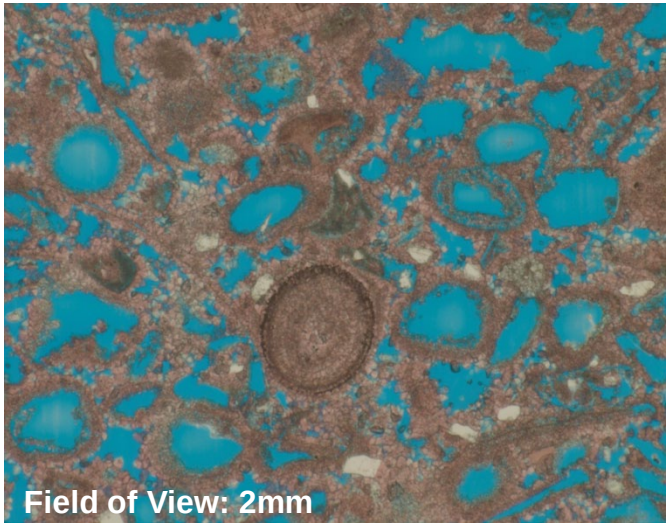




Clayton MSC, 2011

Isopach Map Ooid Grainstone





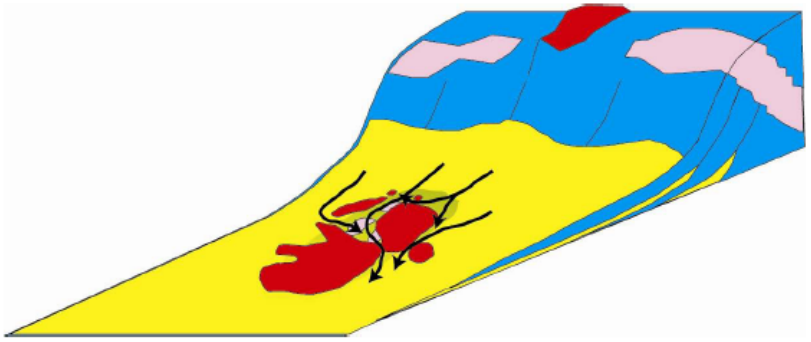
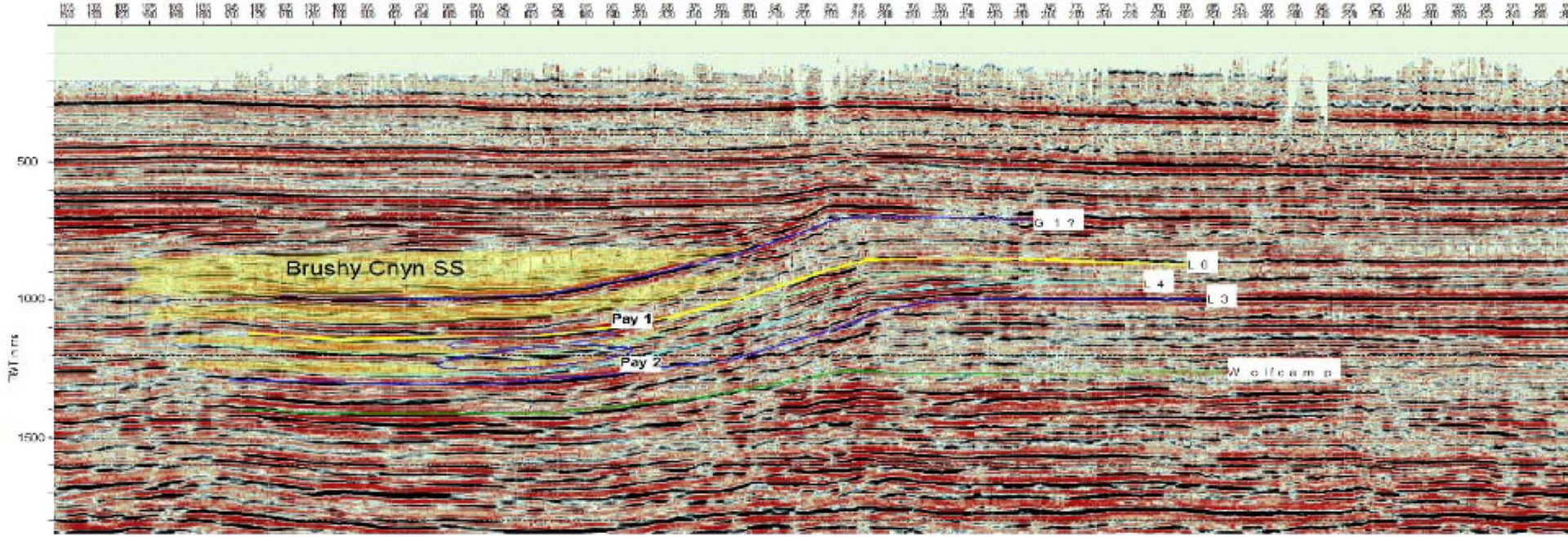
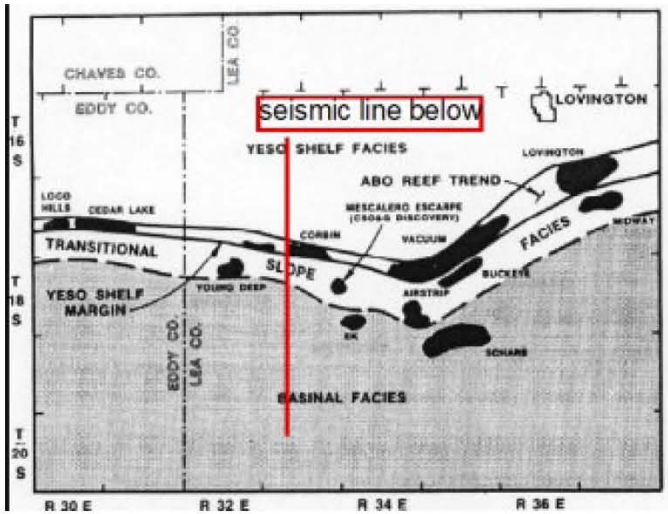
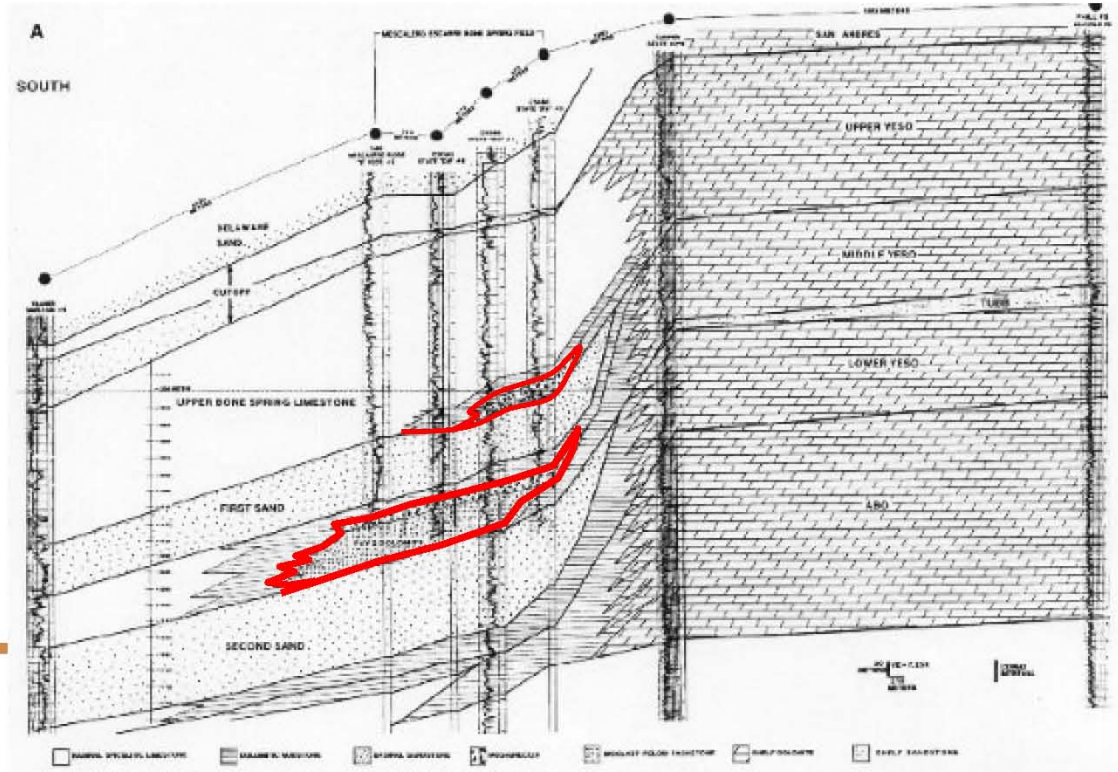


Figure 4.18 L5 Transgressive Systems Tract – Ooid fan formed at the toe-of-slope is dissected by younger debris and turbidity flows.

Clayton MSC, 2011







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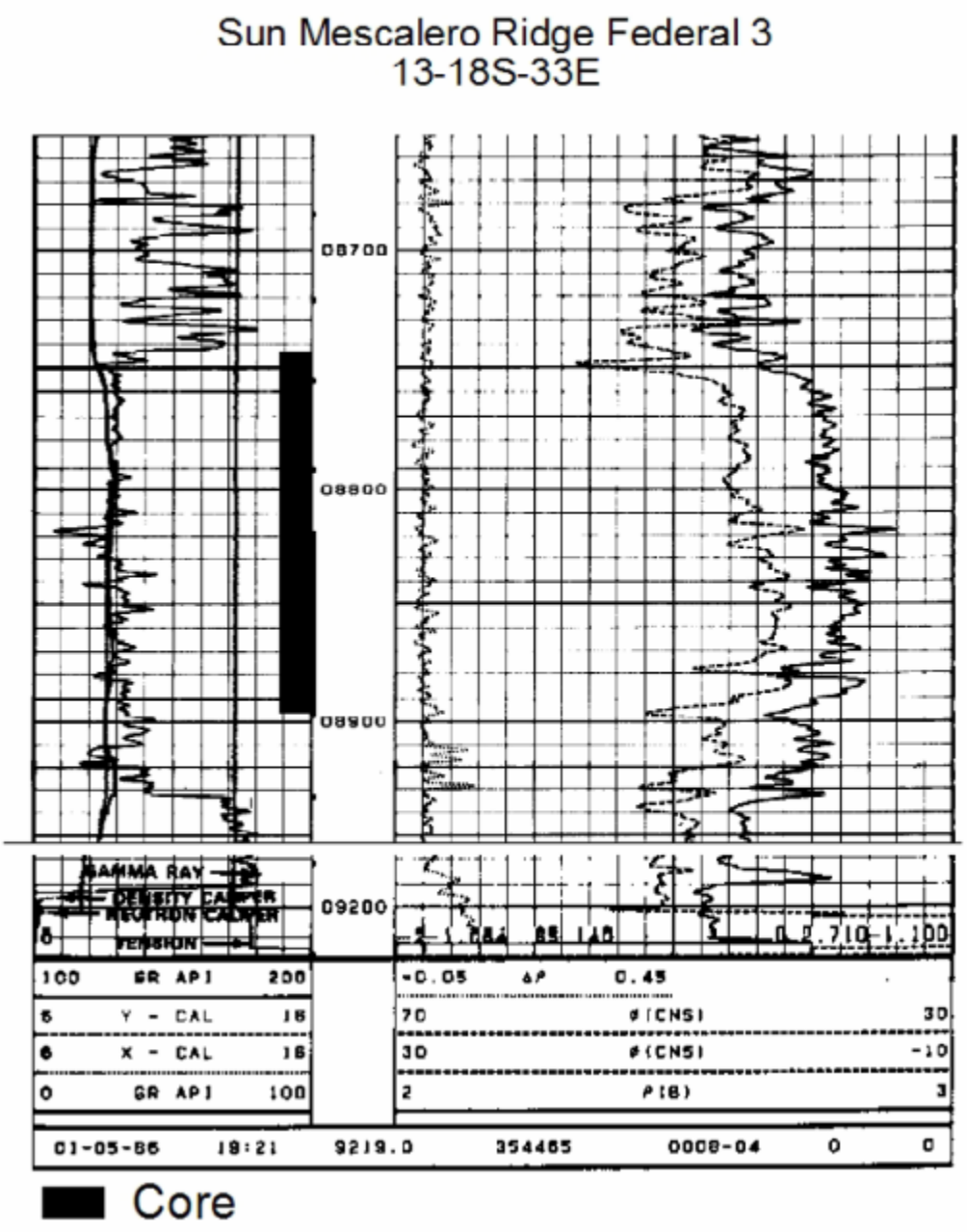
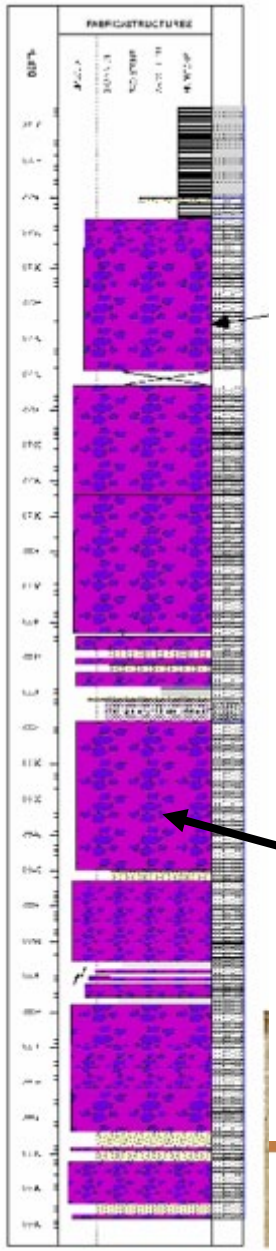
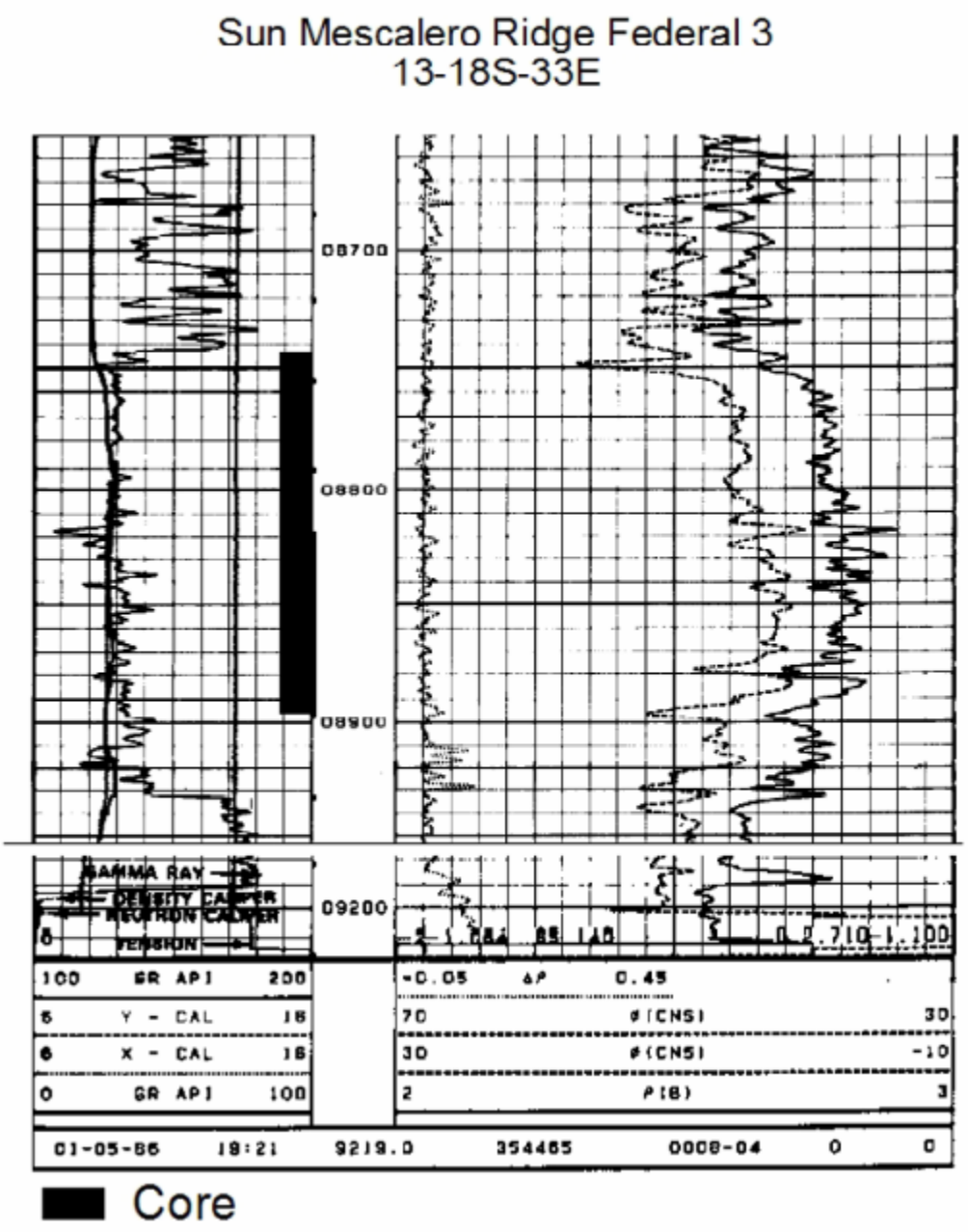
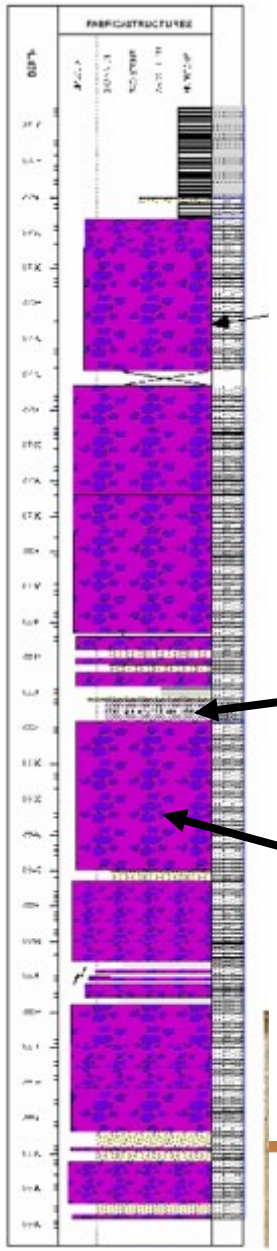
Improving factor

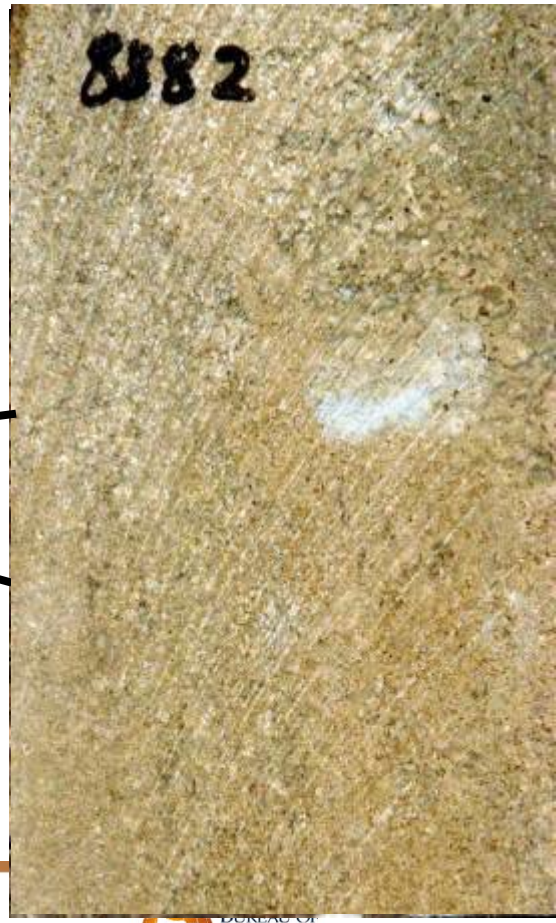




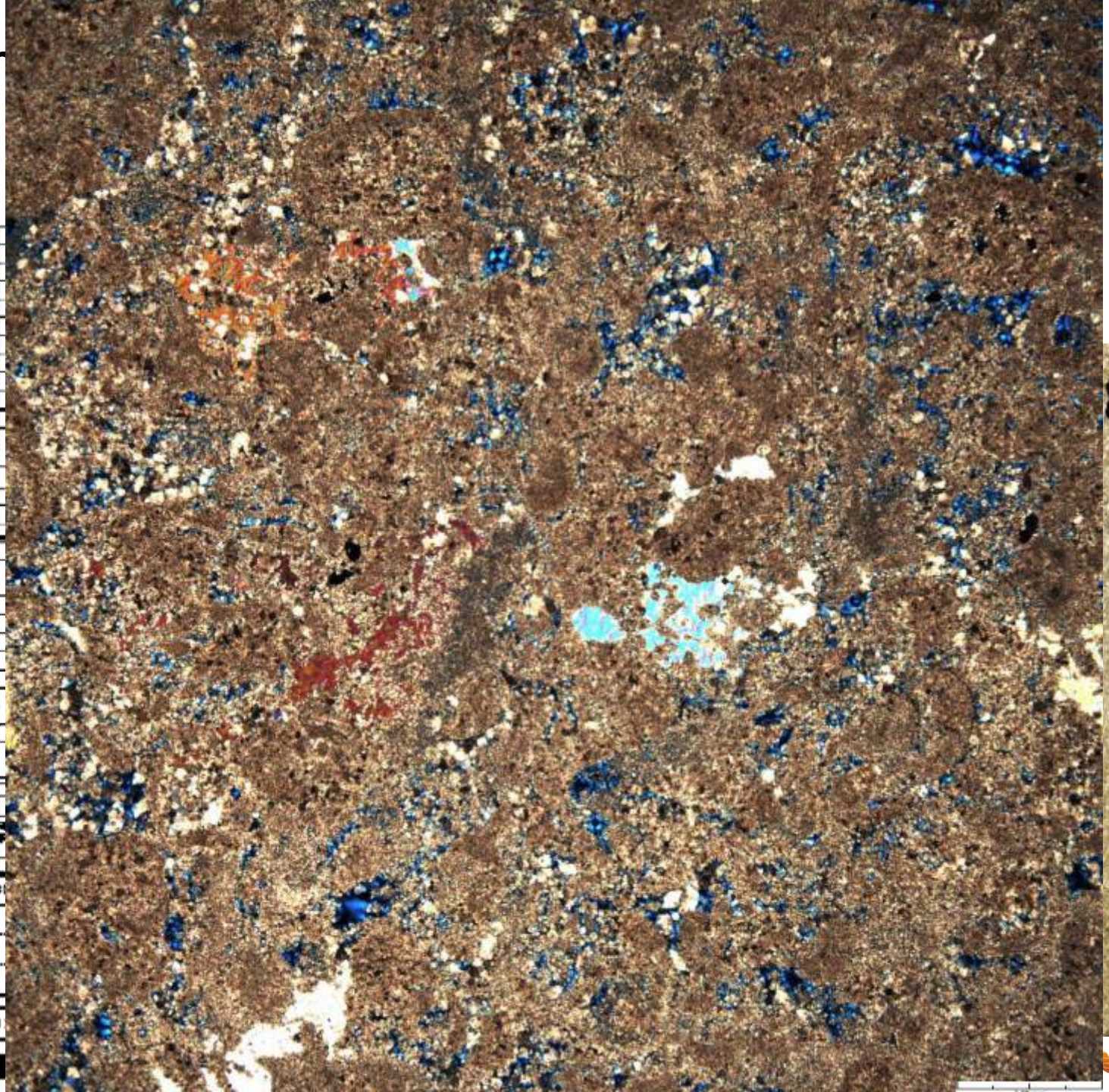
Improving factor



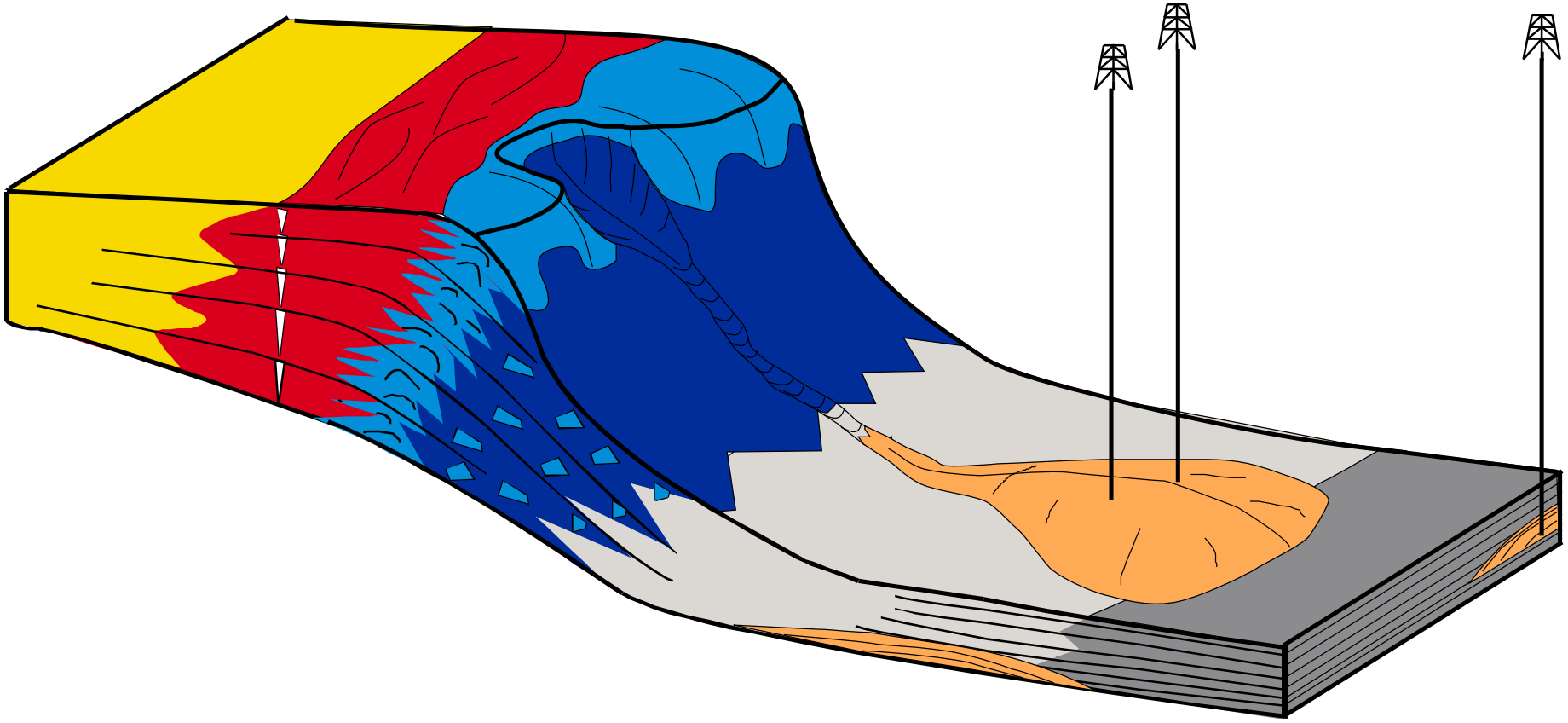




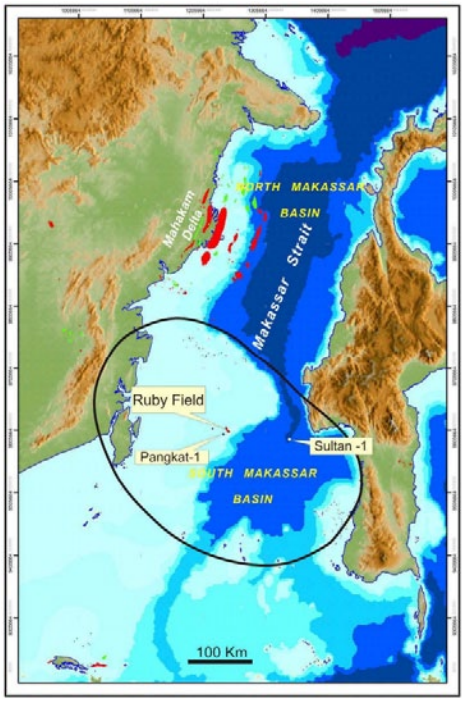
Ir

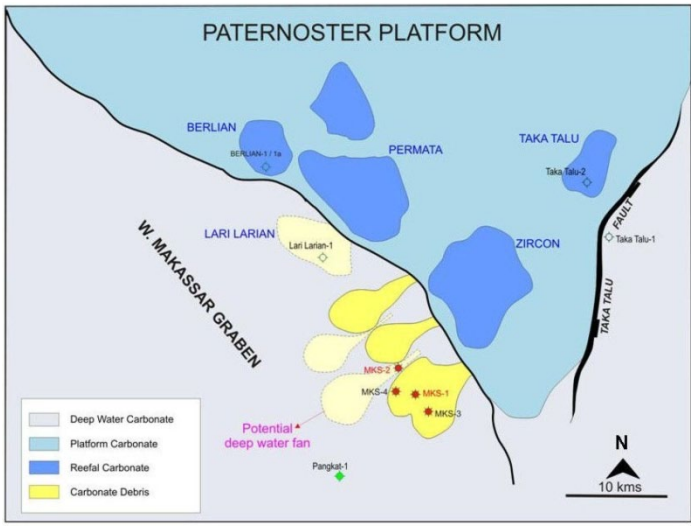


Basin Floor Fan

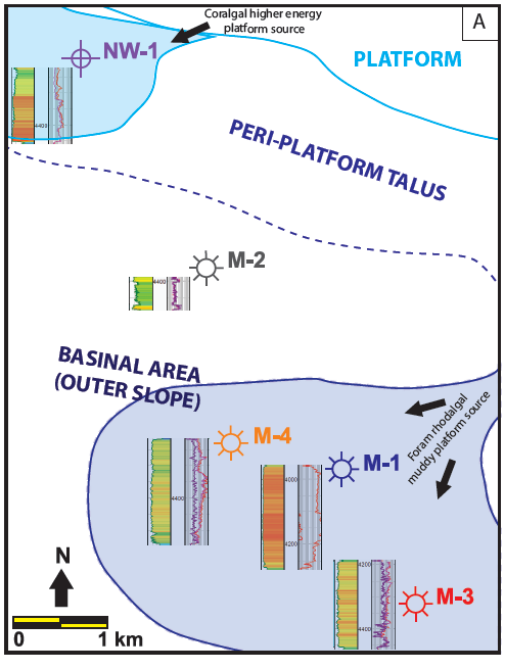


Tertiary Basin Floor Fan

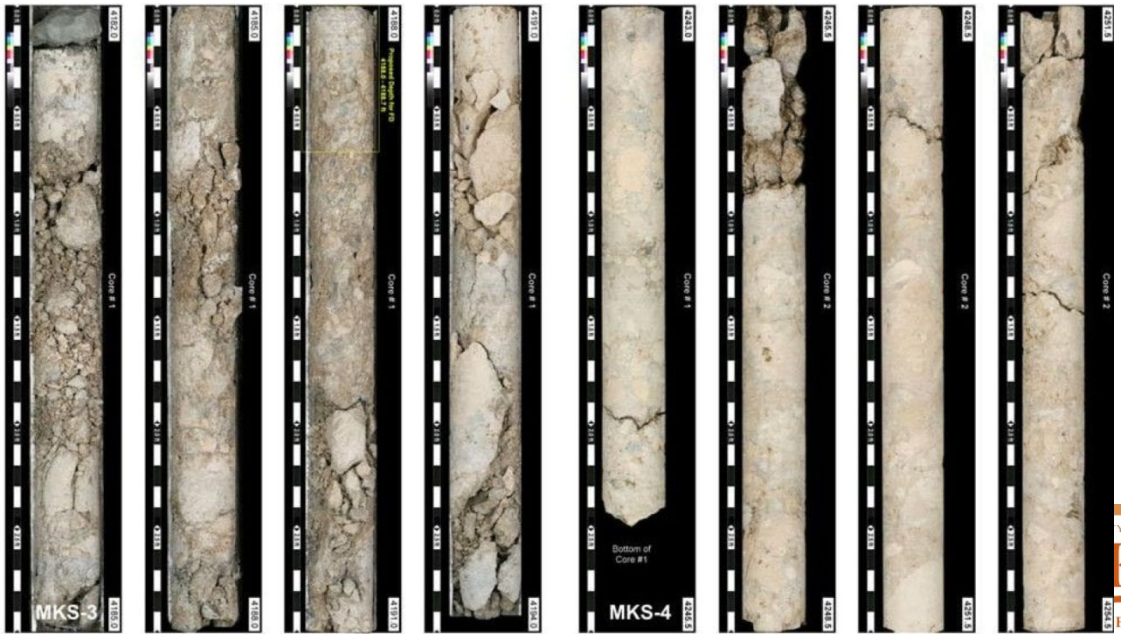




Pireno et al, IPA, 2009



Tanos, MSc, 2011



WELL	MKS-1	MKS-2	MKS-3	MKS-4
DEPTH (ft)	3955 - 4275	4386 - 4510	4185 – 4492	4222 - 4540
GROSS CARBONATE THICKNESS (ft)	330	68	288	318
NET PAY	269	7	123	279
AV. Ø PAY	17.1	15.2	14.6	16.7
Av. Sw	29.6	54.2	29.5	22.2
N/G	0.82	0.10	0.43	0.88

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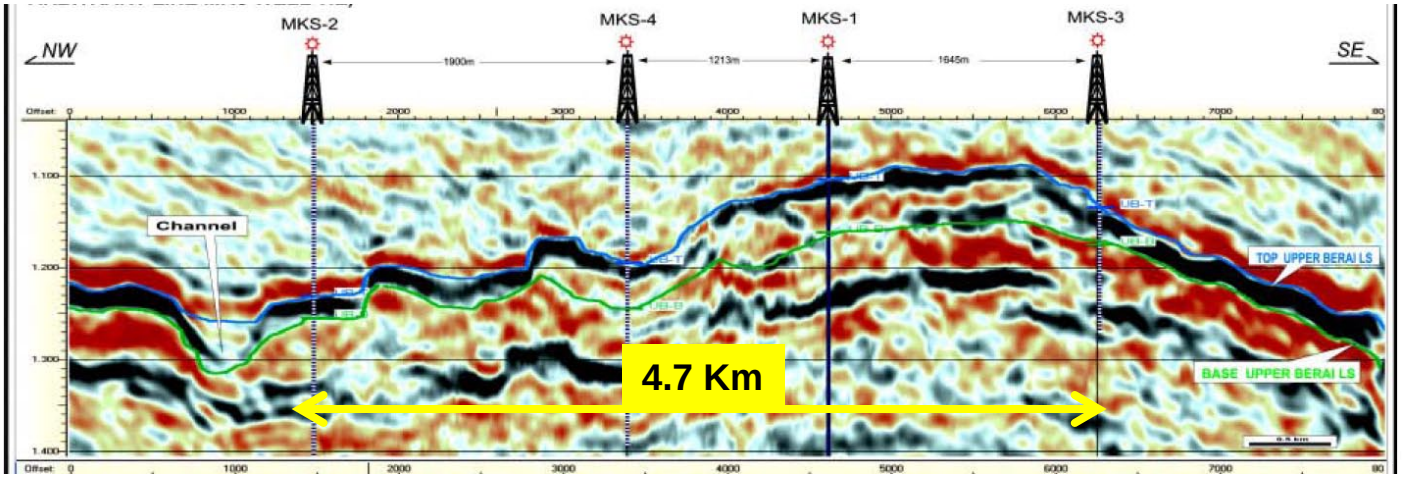
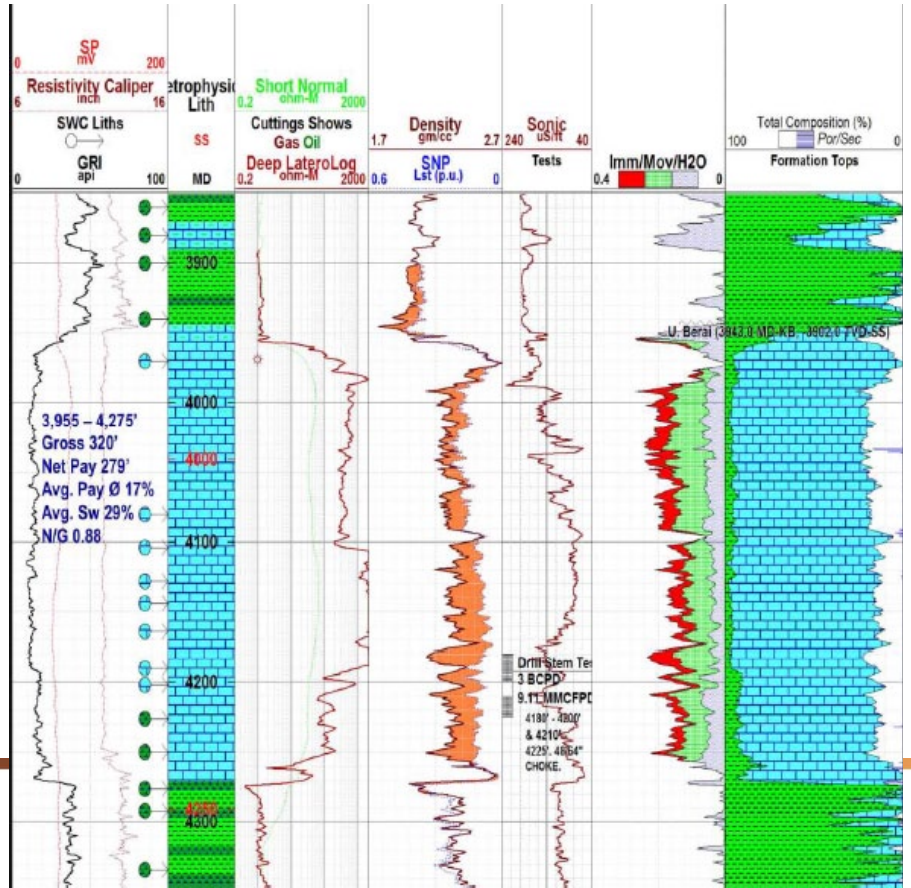
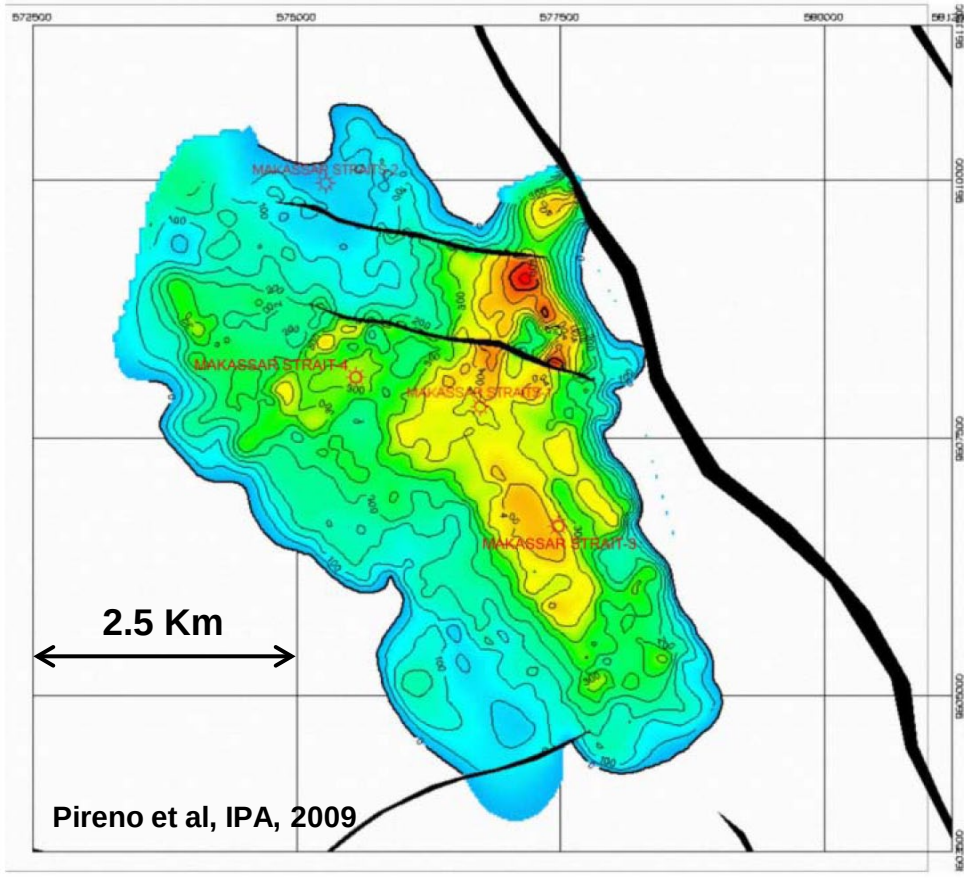
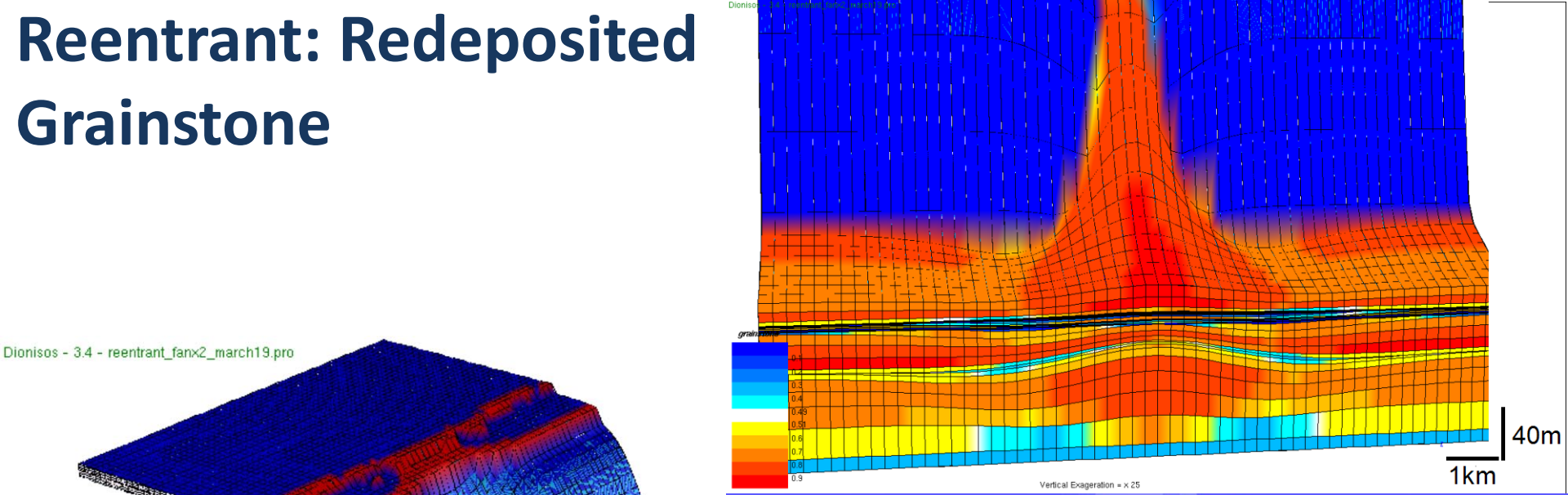
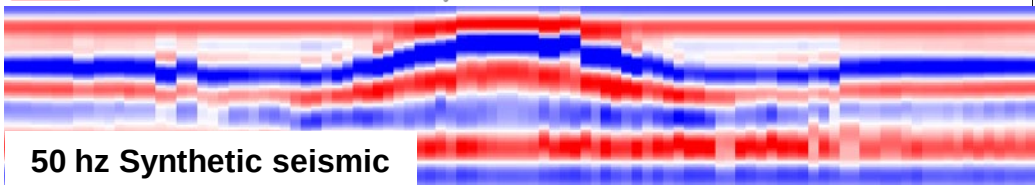

MKS-2
MKS-4
MKS-1
MKS-3
NW
SE
1900m
1213m
1645m
Channel
TOP UPPER BERAI LS
BASE UPPER BERAI LS
4.7 Km

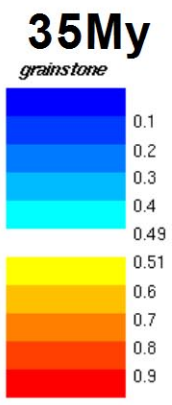

SP
Resistivity Caliper
SWC Liths
GRI
Lith
Short Normal
Cuttings Shows
Gas Oil
Deep LateroLog
Density
SNP
Sonic
Tests
Imm/Mov/H2O
Total Composition (%)
Por/Sec
Formation Tops
MD
3900
4000
4100
4200
4300
3,955 – 4,275'
Gross 320'
Net Pay 279'
Avg. Pay Ø 17%
Avg. Sw 29%
N/G 0.88
U. Berai (3843.0 MD-KB, -3802.0 TVD-SS)


572500
575000
577500
580000
MAKASSAR STRAIT-2
MAKASSAR STRAIT-4
MAKASSAR STRAIT-1
MAKASSAR STRAIT-3
2.5 Km
Pireno et al, IPA, 2009

Reentrant: Redeposited Grainstone







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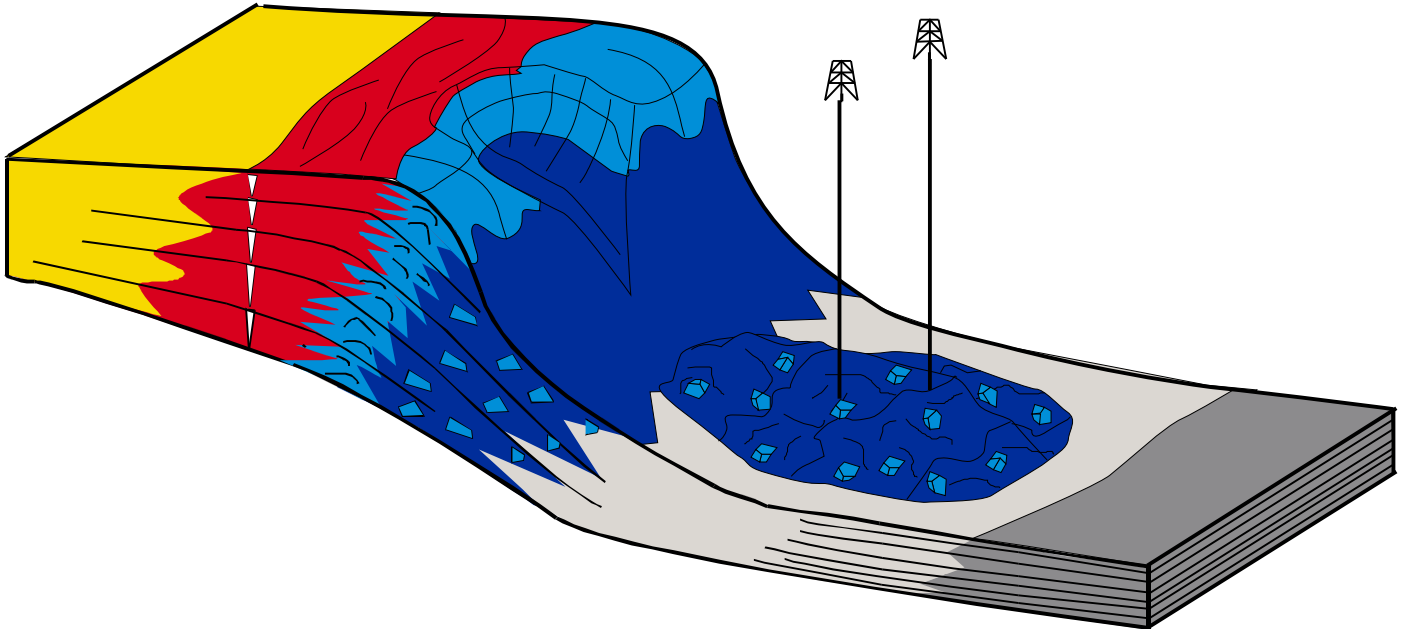
Margin Collapse

Potential export of large amount of porous margin material

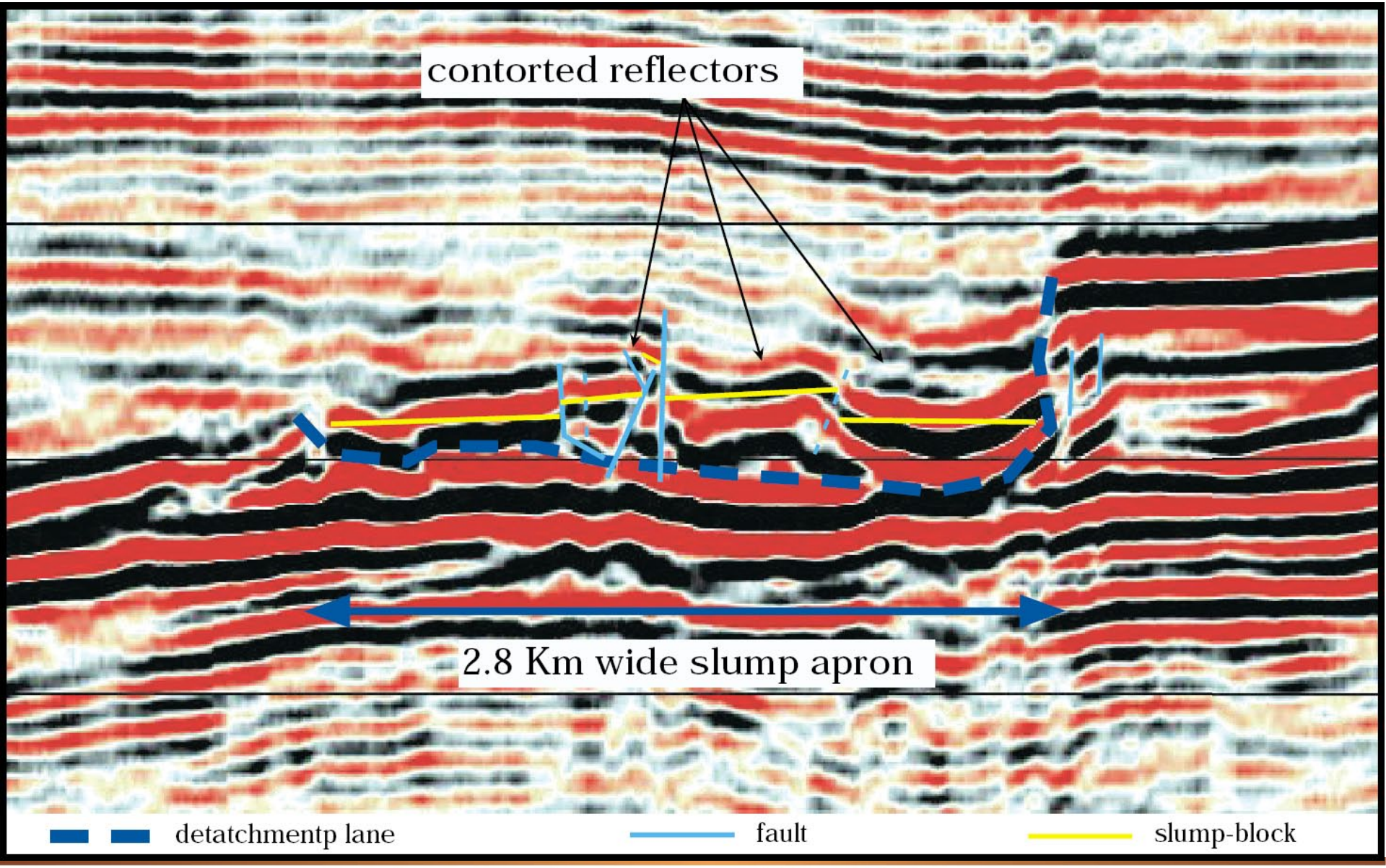
High potential to incorporate muddy slope deposits

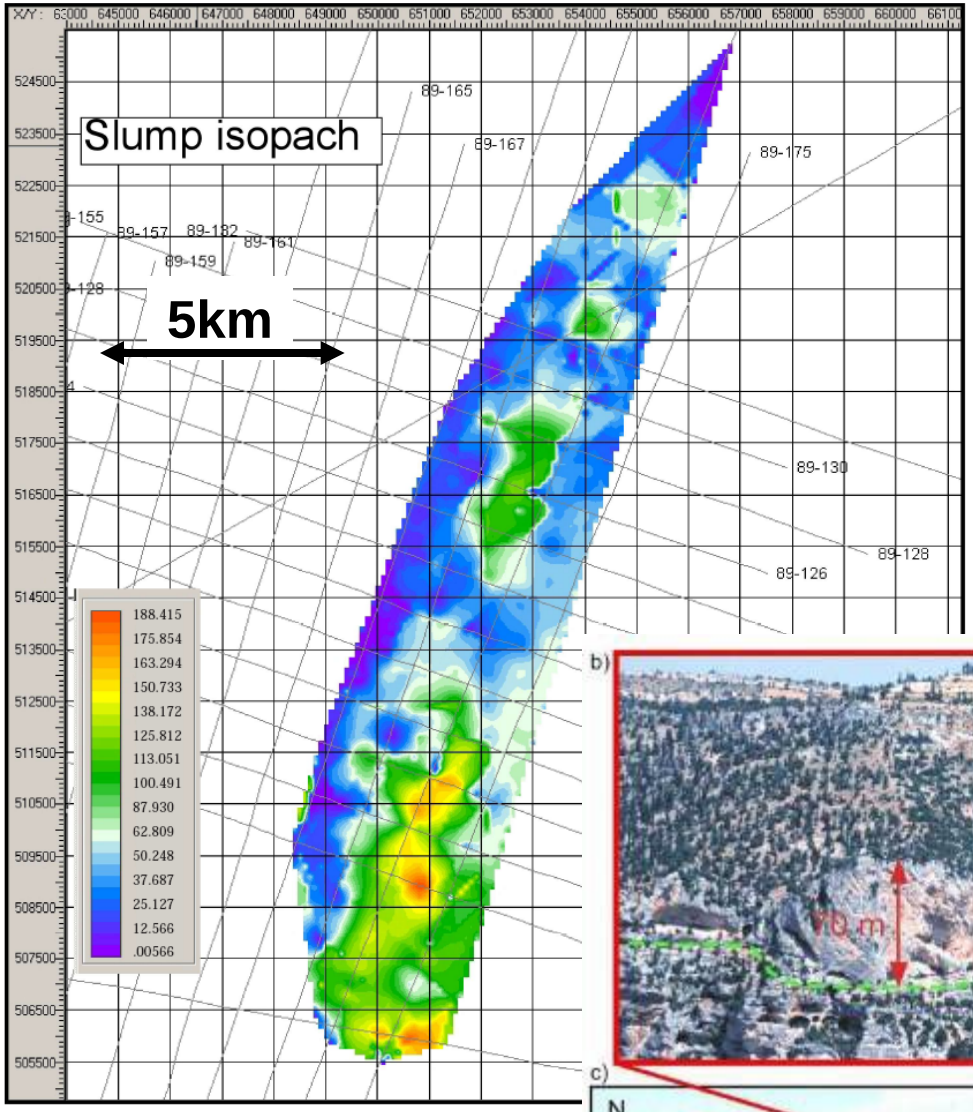
Probably highly compartmentalized reservoir

Seal issue



Miocene slumps (Janson et al, 2011)



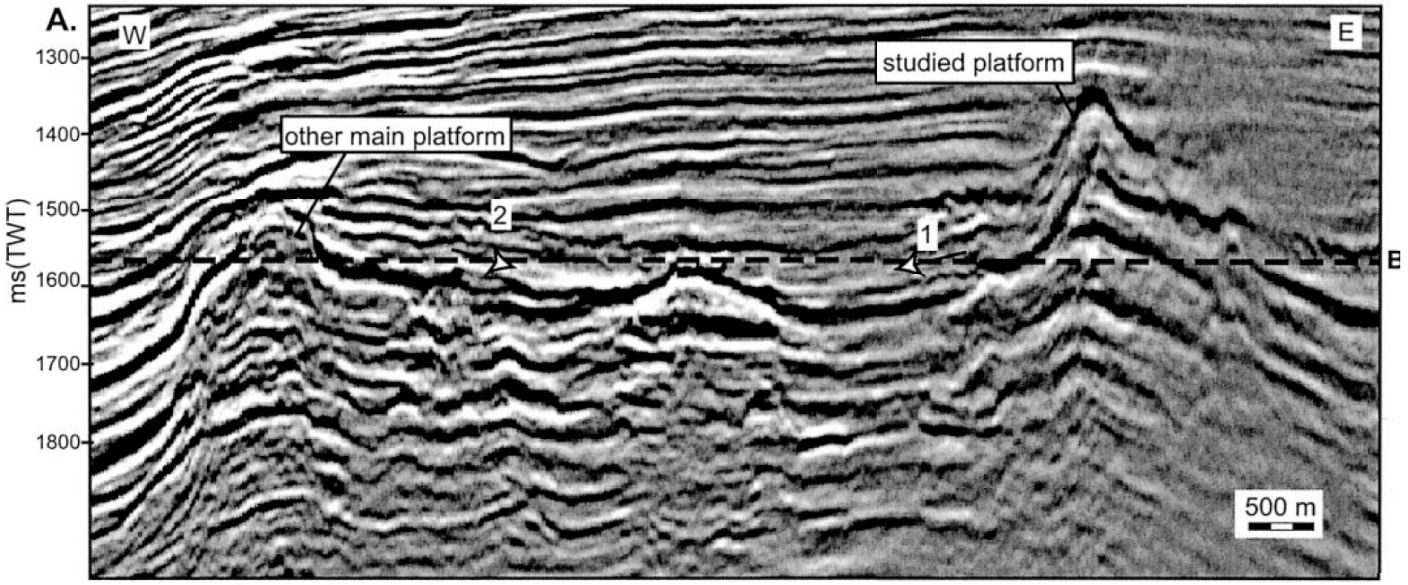

Slump isopach
5km
89-165
89-167
89-175
89-155
89-157
89-182
89-161
89-159
89-128
89-130
89-128
89-126
188.415
175.854
163.294
150.733
138.172
125.812
113.051
100.491
87.930
62.809
50.248
37.687
25.127
12.566
.00566

b)
70 m

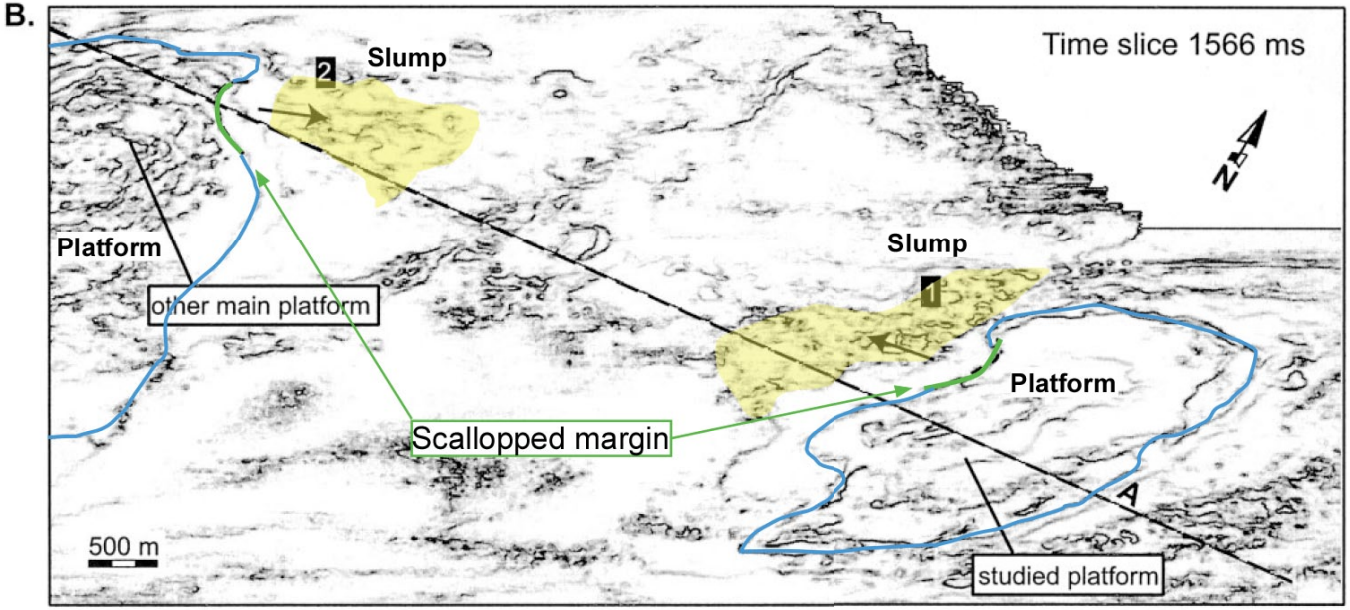

a)
30 m


c)
N
S
slump scar
~250 m
5km

Tertiary, Central Luconian, Malaysia



Zampetti et al, 2004



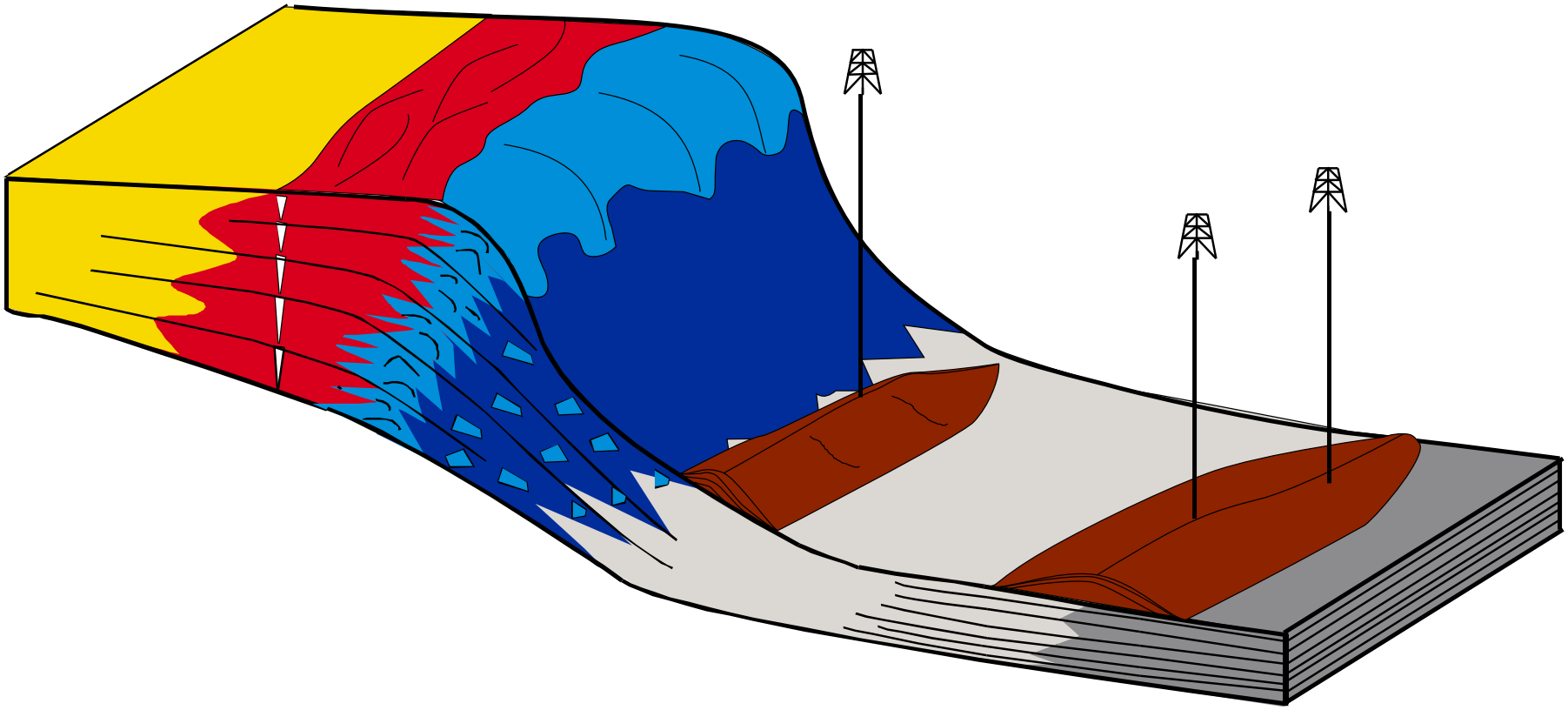
Drift / Contourites

Potential for large accumulation of grainy sediment

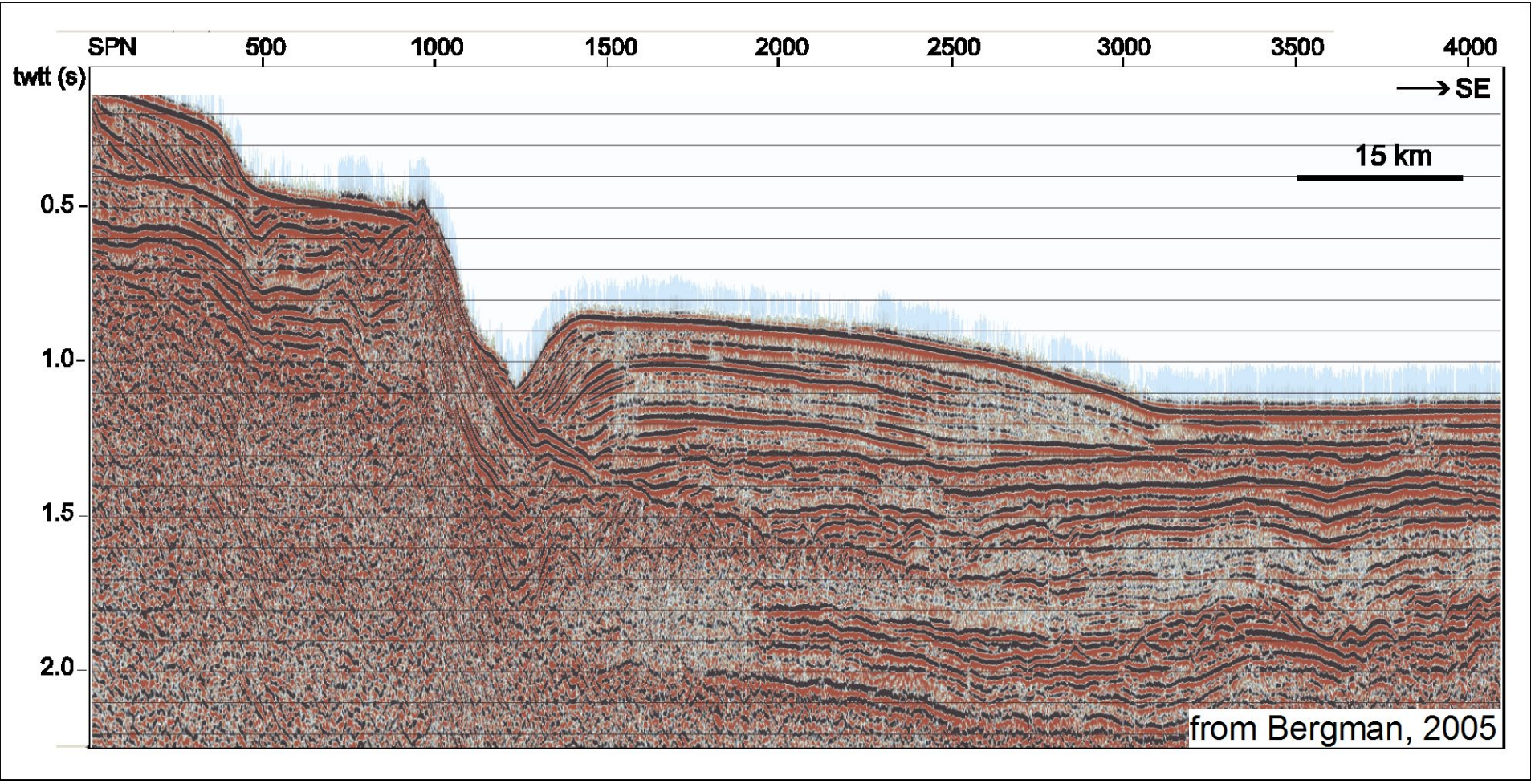
Ideal Stratigraphic trap

Φ up to 35%, Perm. > 1 Darcy

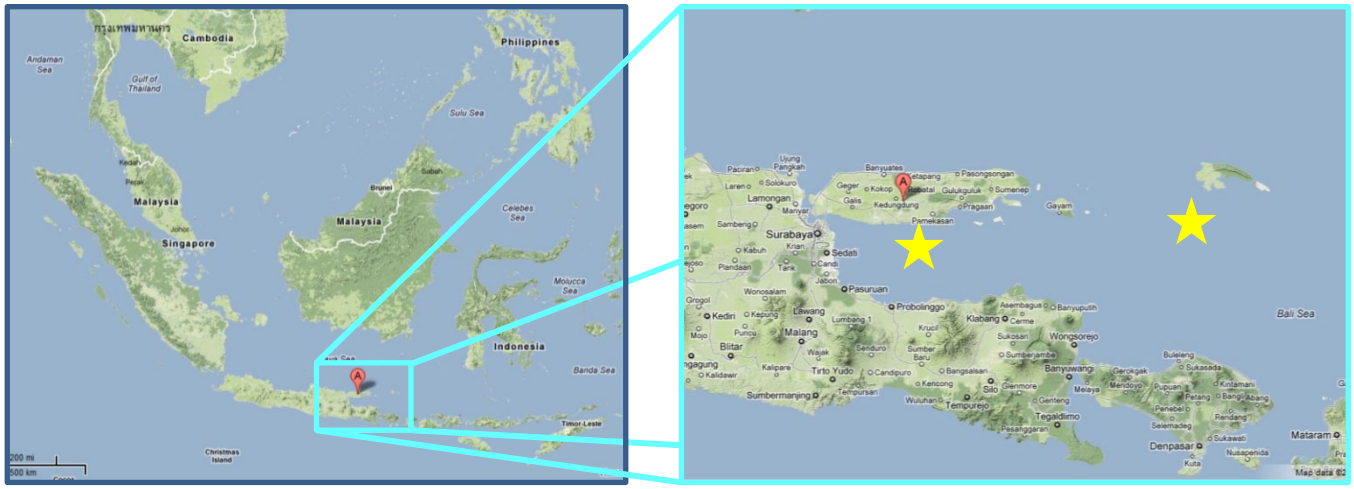
Few ancient examples, interpretation bias?



Drift: stratigraphic trap

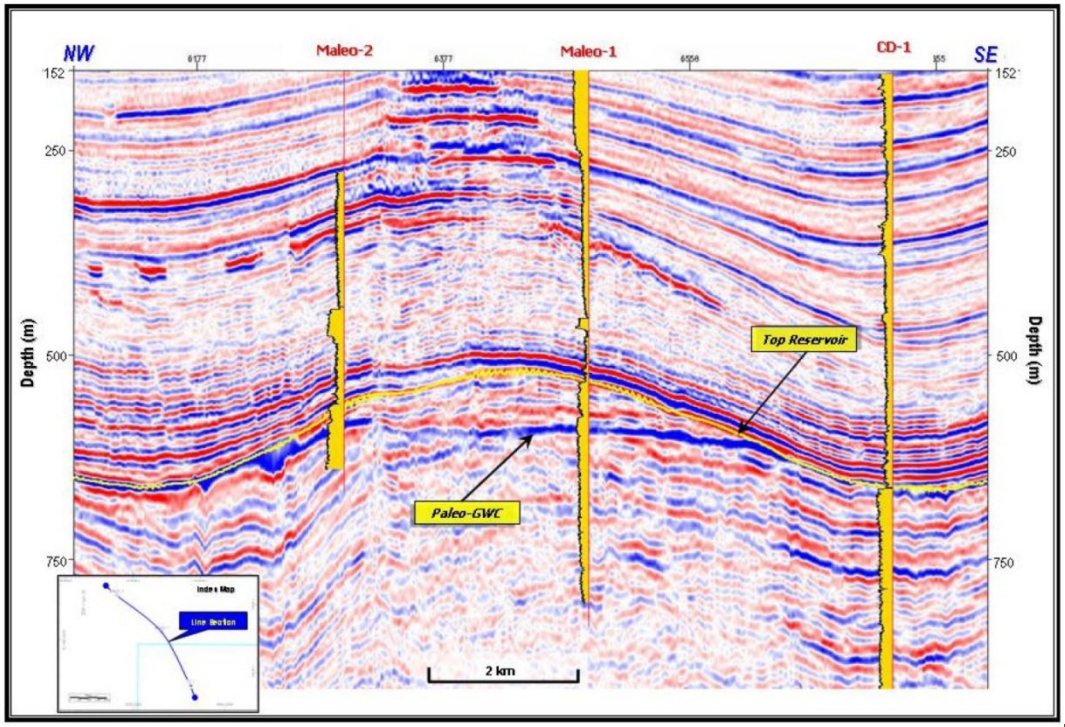


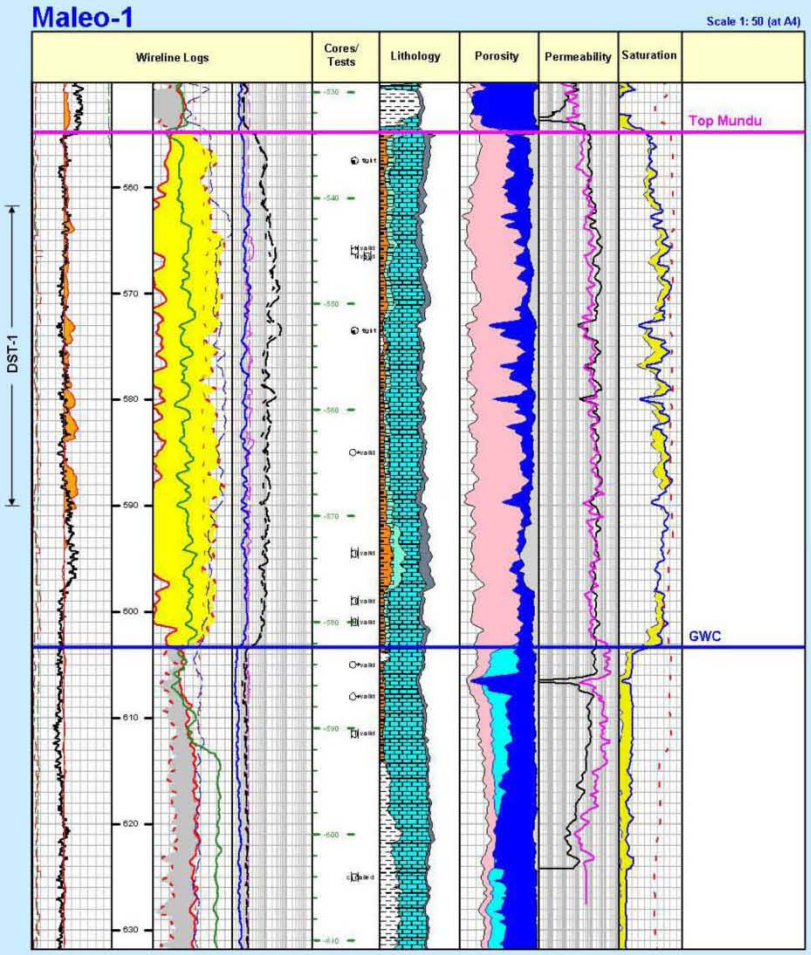
Paciran and Mundu Fm. - Pliocene - Indonesia



Paciran and Mundu Fm were deposits as drift/contourite in basinal setting. The traps are structural with a minor amount of stratigraphic closures (pinch out)

Tryana et al, IPA 2007 and Nur et al, IPA 2010

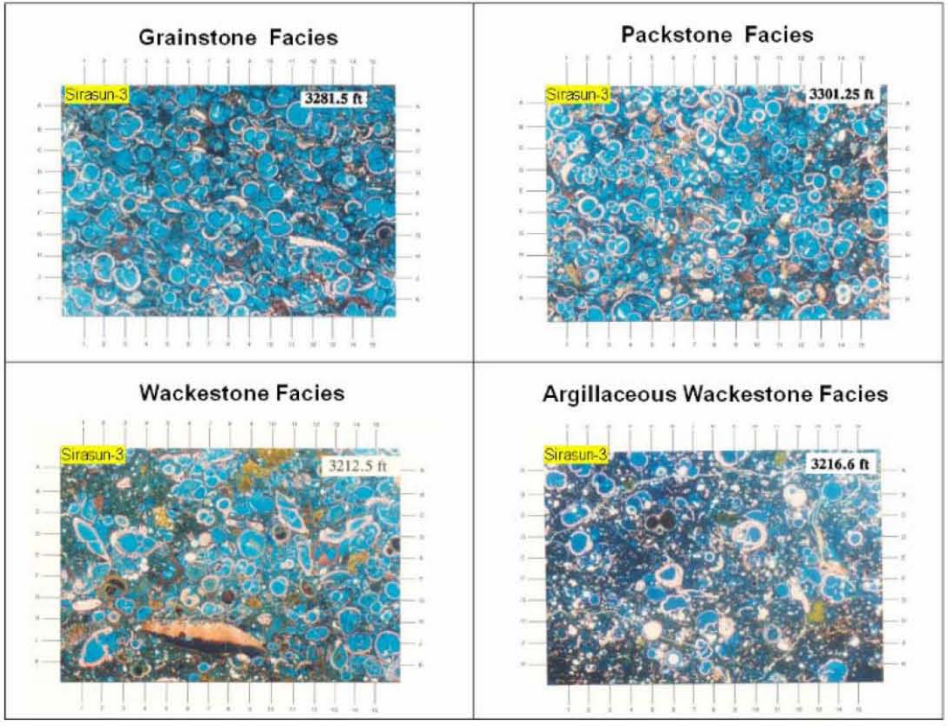


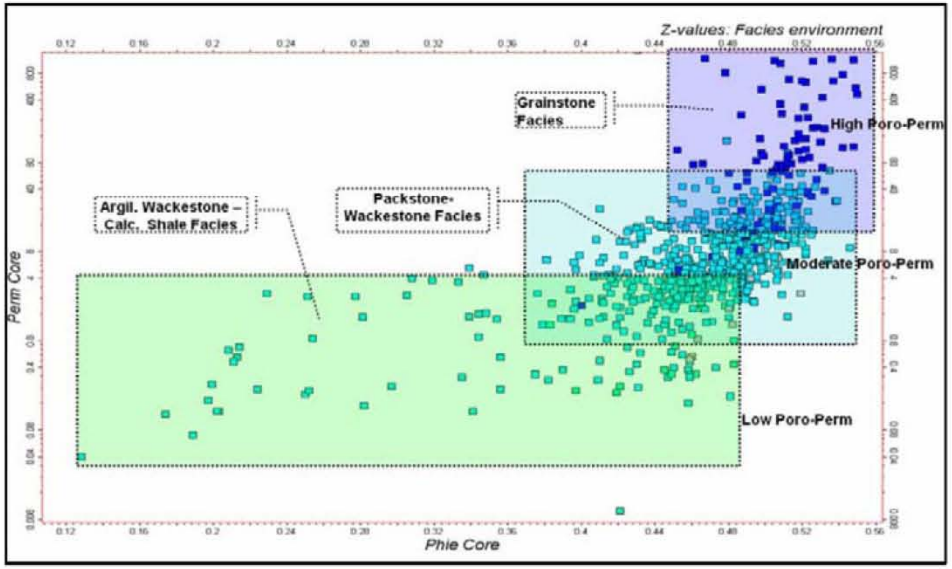


Gross HC interval: 49m
Net Gas Pay: 49m

DST-1:> 99% C1
13.5 MMSCF/D
@410psi THP

Reservoir consists of Globigerina Limestone
Porosities range from 39-50%
Permeabilities range from < 1mD to 400mD





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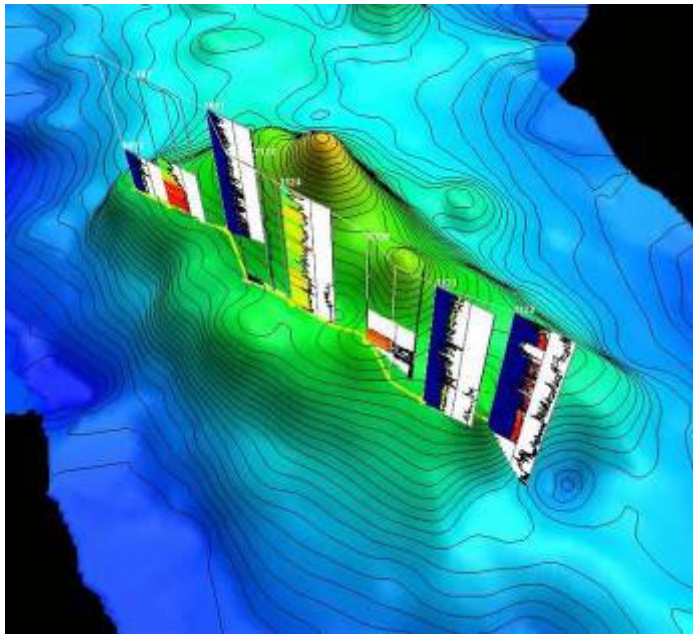
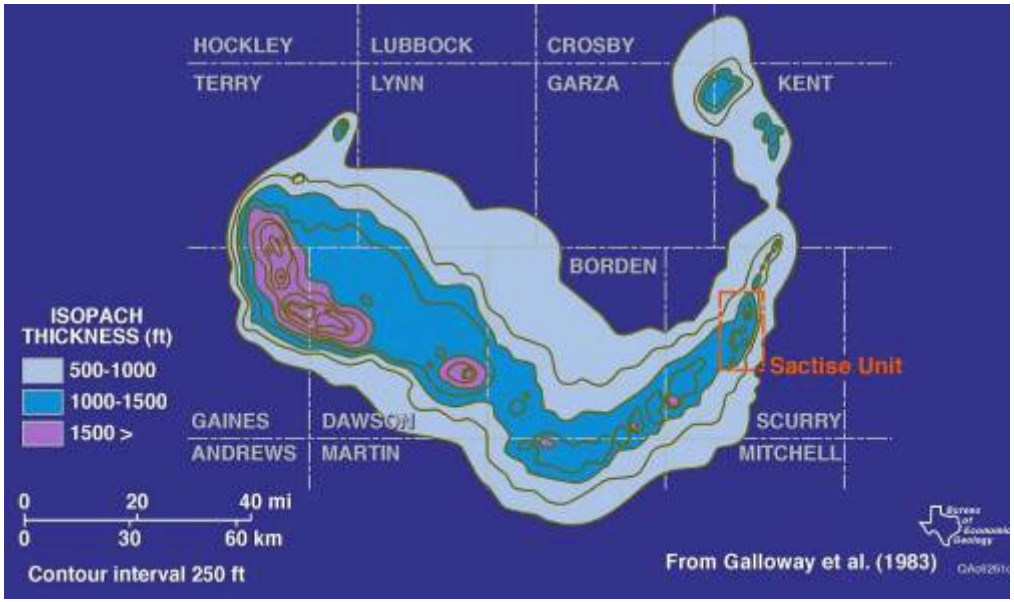
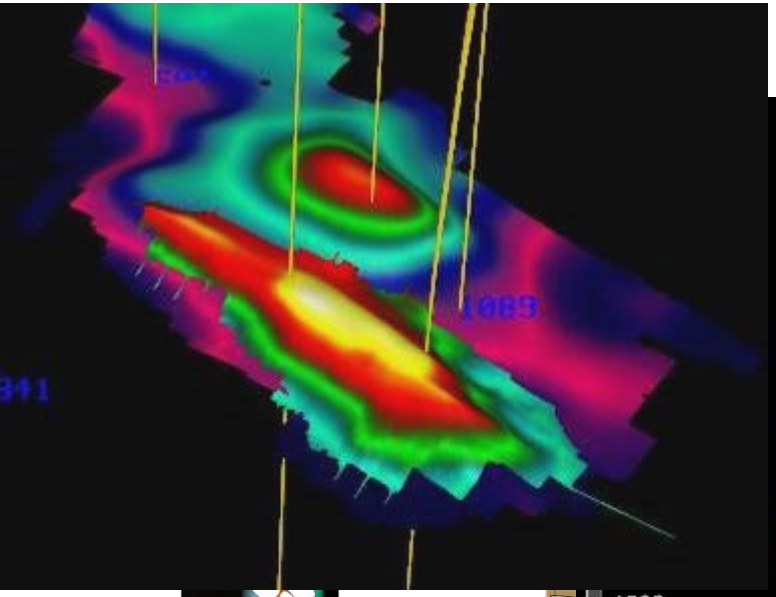
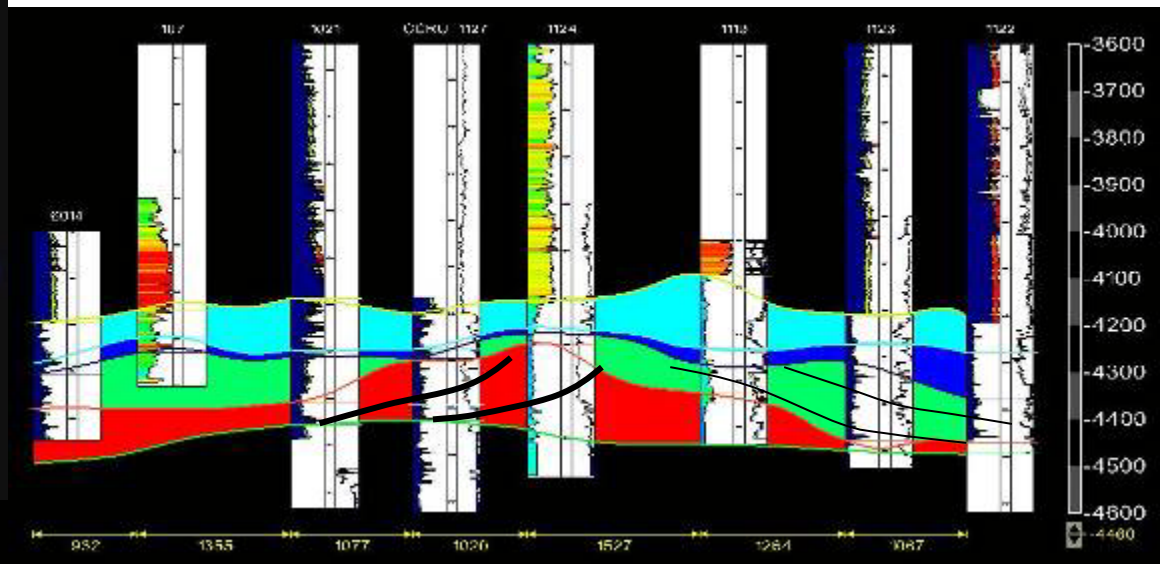
Deepwater Grainstones Cogdell North Platform (Kerans 2004)

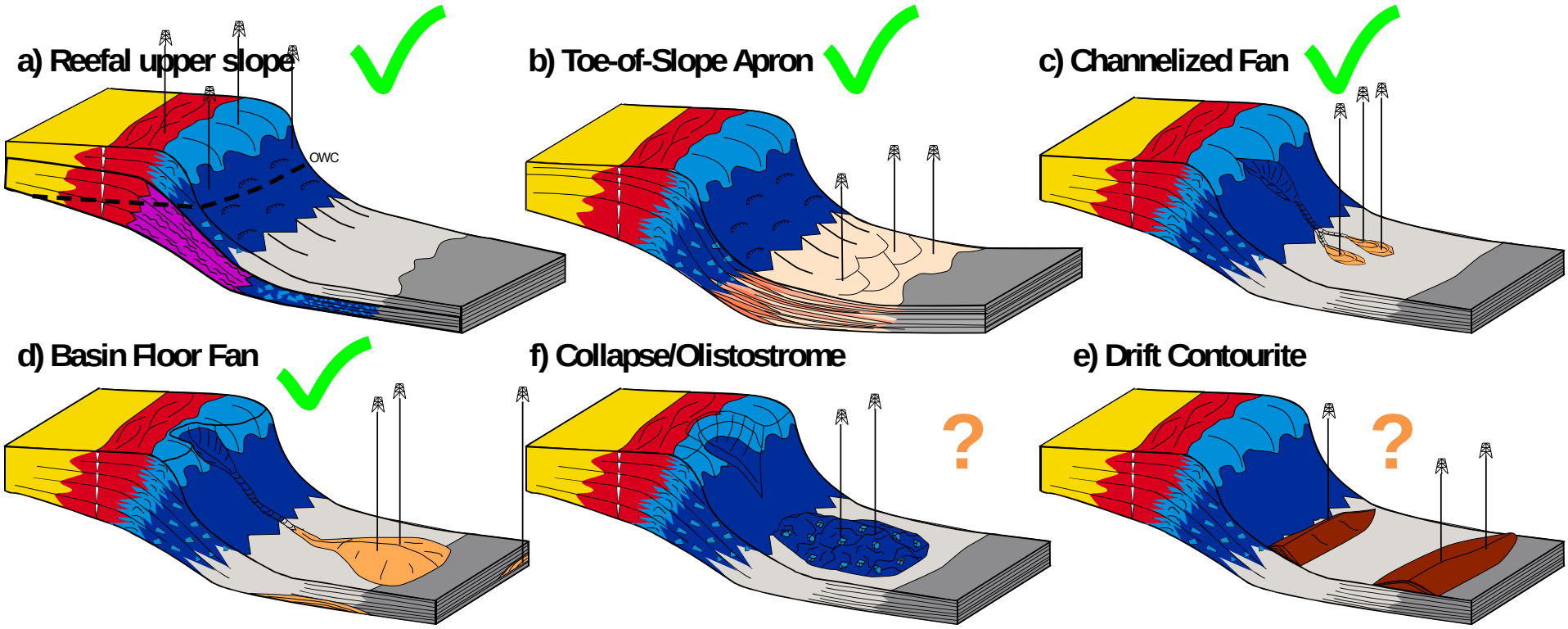






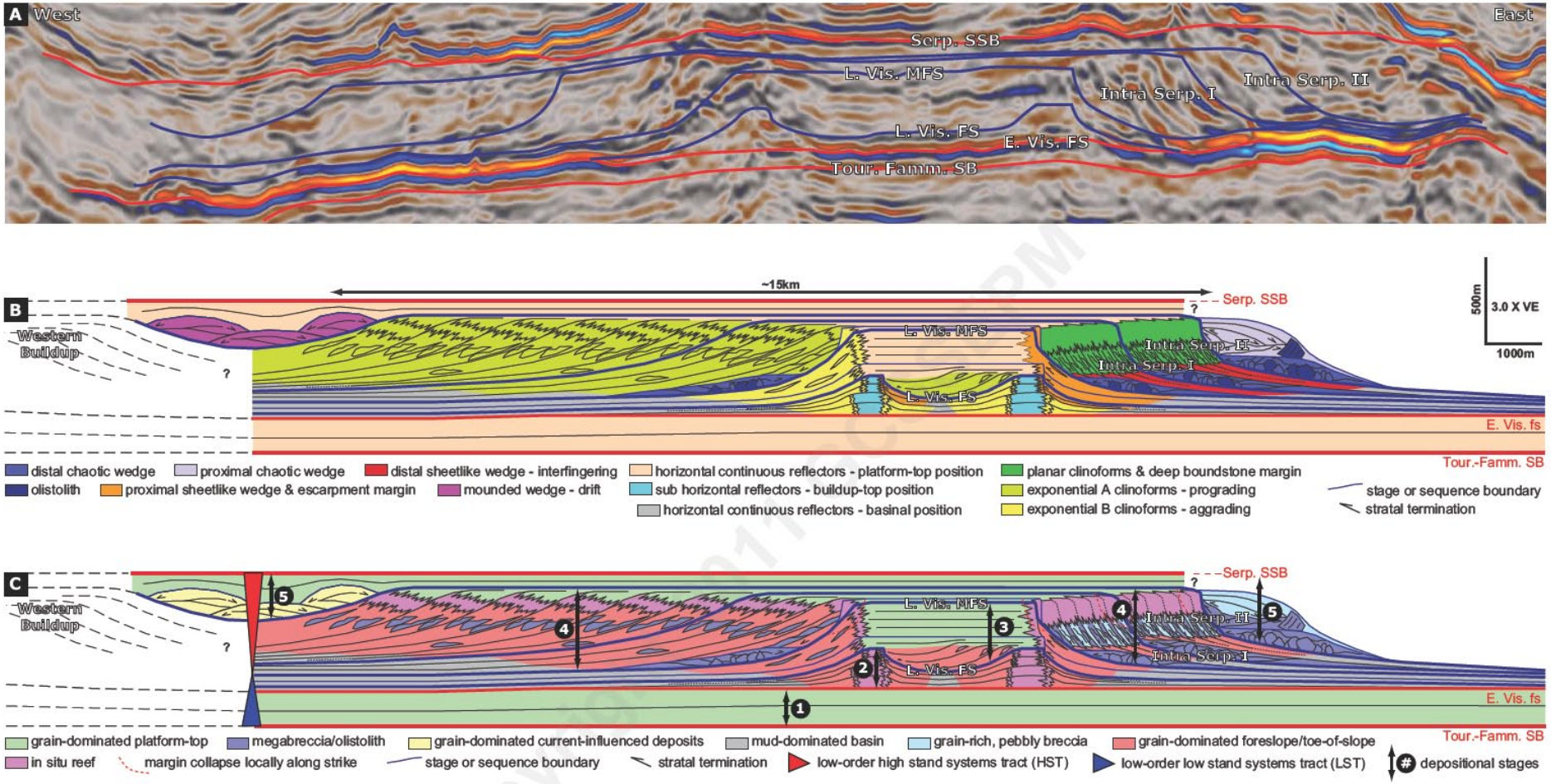


Potential Stratigraphic Traps



One platform different style of slopes and traps

(Katz et al GCSEPM 2010)



Key points

- High relief margin like structural escarpment favors detachment of grainy deposits on slope and basin.
- A muddy slope with grainy facies is better than an entirely grainy slope (up dip leak).
- Debris dominated facies can be good reservoir if the matrix is grainy.
- Focused flows (reentrant/collapse/channel) lead to detached bodies and better traps.
- Aragonitic grain favor early burial porosity development.
- Historically post-depositional deformation play a major role in making those play convincing.