Thinly Bedded Pay in Clastic Reservoirs, Recognition, Geological Occurrence, Understanding, and Quantification*

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Abstract

Thin bedded pay (TBP) refers to oil and gas in porous and permeable beds less than about 30 centimeters (1 ft) thick interbedded with impermeable beds (shales) of similar thicknesses all of which are below standard log resolution. Recognition and quantification of hydrocarbon pore thickness requires better resolution data; cores, image logs, special logs (Rv:Rh, NMR, etc) combined with standard logs and mud logs.

Thin bedded pays are known to be associated with conventional reservoirs, but also occur associated with unconventional reservoirs. This study focused upon TBP associated with clastic conventional reservoirs but TBP probably occurs in carbonate and unconventional shale reservoirs as well. Thin bedded pay may also exist in various fluid scenarios; heavy, viscous, and light oils as well as gas and condensates reservoirs. Gas/condensate and lighter oils will be most easily recoverable but vast resources most likely exist with heavy and viscous oils.

Turbidite, Paralic (Note: Paralic includes lacustrine deltaics here in.), and Fluvial reservoirs have all been shown to have TBP associated with the conventional pay (beds > 1 ft thick), but TBP probably occurs in Aeolian and some other clastic environments as well in lesser amounts.

It is the job of the Petrophysicist to calculate hydrocarbon pore thickness (HPT) in these TBP intervals so that oil and gas in-place estimates can be made. The Geologist and Reservoir Engineer then must evaluate the likelihood of them being recoverable and what performance can be expected.

Historically, outcrop analogue studies have focused upon the object size of sand and shale bodies and rightfully so, to facilitate 3D modelling of different depositional environments/sub-environments. The sub-environments (i.e. Crevasse Splay, Distal Lower Shoreface, Overbank Levee, etc.) making up TBP and the understanding of their net-to-gross (NTG), and connectedness is critical to determining if they can be exploited (i.e. reserves). This study undertook a review of literature and examples to determine what percentages of these TBP sub-environments are to be expected associated with the conventional (thicker) pays since sizes of rock bodies and not percentages have been the focus of studies over the past several decades. No published global studies have been found summarizing these important data for estimating even in-place volume of TBP.

There is much written on the petrophysics of TBP (also historically called Low Resistivity Low Contrast pay, or Hard to Recover Resources) and petrophysical evaluation was reviewed but not the focus of this work. That said, detailed petrophysical evaluation with integration and collection of proper data to appraise TBP is critical to quantifying it. Additionally, testing, and dynamic data acquisition is critical to determining if and how it will perform and whether it is an economically viable resource.

Turbidites will have the most TBP (~30% ave), with Paralic (~20%), and Fluvial (~10%) the least (overall ~20% ave) based upon industry and published data reviewed by the author.

Selected References

Baillie, K., and J. James-Romano, 2010, Identifying and Quantifying Thin-Bedded Pay (Part B): The Use of Dynamic Data to Evaluate Productivity Potential in Gas Reservoirs: Society of Petroleum Engineers, Trinidad and Tobago Energy Resources Conference, 27-30 June, Port of Spain, Trinidad, SPE-133535-MS, 10 p.

Henderson, K., H.J. Rose, and R. Winter, 2010, Identifying and Quantifying Thin-Bedded Pay (Part A): Log Characteristics and Reservoir Quality: Society of Petroleum Engineers, Trinidad and Tobago Energy Resources Conference, 27-30 June, Port of Spain, Trinidad, SPE 133534-MS, 10 p.

Moore, D., 1993, Productive Low Resistivity Well Logs of the Offshore Gulf of Mexico: New Orleans Geological Society, NOCS 03, 206 p.

Passey, Q.R., K.E. Dahlberg, K.B. Sullivan, H. Yin, R.A. Brackett, Y.H. Xiao, and A.G. Guzmán-Garcia, 2006, Petrophysical Evaluation of Hydrocarbon Pore-Thickness in Thinly Bedded Clastic Reservoirs: AAPG Archie Series #1, p. 133-153.

Explorers From New Zealand

Thinly Bedded Pay In Clastic Reservoirs, Recognition, Geological Occurrence, Understanding, And Quantification

Dirk Bodnar,

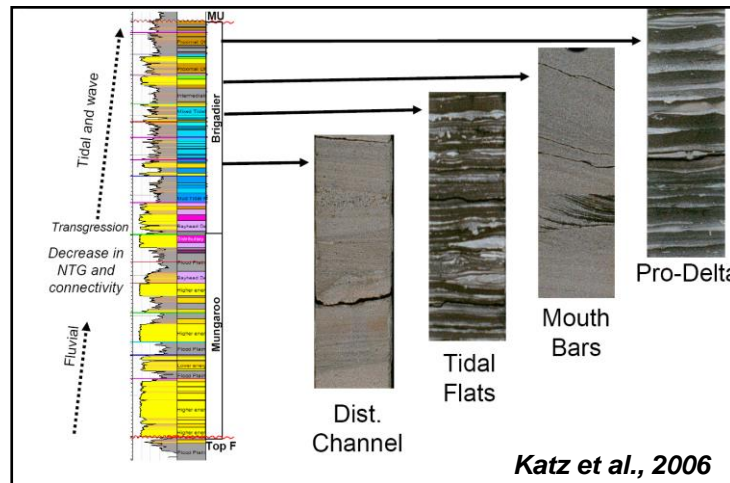El Pilar Petrotechnical Consulting LLC, USA

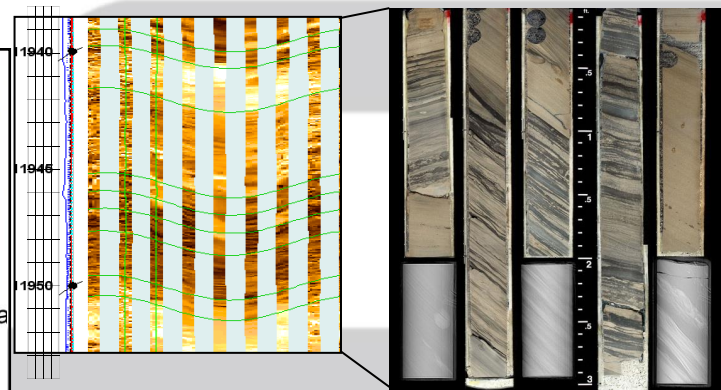April 22, 2015

Objectives of Talk:

- What is Thin Bedded Pay(TBP) and where does it occur.

- Brief Tour of some TBP examples & ideas on development.

- Show my study and estimate of how much TBP you may have by Environment Of Deposition (EOD).

Outcrop Turbidite thin beds

Katz et al., 2006

Goodwyn Brigadier, Distributary Channels & Tidal Flats TBP

Trinidad Distal Lower Shoreface/OTZ TBP FMI image and whole core

Thin Bedded Pay:

- Outline:
  - Background & What is Thin Bedded Pay (TBP)?
  - Habitat of TBP (GDEs & Sub-environments)
  - Identification, and quantification of TBP (HCPV?): data?
  - Examples of TBP
    - Paralic (near the shoreline): Mahakam, Kuparuk, Trinidad
    - Turbidite; Magnus LKCF, Mt. Messenger
    - Fluvial: NWS, Kupe, Endicott
  - Study:summary of % TBP by Environment of Deposition(EOD)
  - Wrap up
    - Some references….
  - Discussion

Thin Bedded Pay: Definition (HCPV)

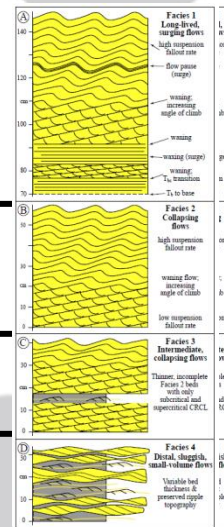Petrophysical Definition: (tool resolutions)

- Standard Logs, Special Logs (Rh/Rv, NMR, etc), Image, Core

Massive Sands (>6 ft)

Layered Sands (1 ft – 6 ft)

TBP {

**Thinly Bedded Sands (1 inch to 1 ft)**

Very Thin Sands (<1 inch)

- Petrophysicist responsible for TBP at well, but away from wells Geologist (Geophysicist) take over with RE and dynamic data for sub-environment size & connectivity.

- Petrophysics has a defined methodology to evaluate it in wells

- NOTE: Most often there are thicker beds (small channels, bars, lobes) mixed in with this definition of TBP (this helps connectivity in general).

Thin Bedded Pay: Definition Vs Conventional Pay
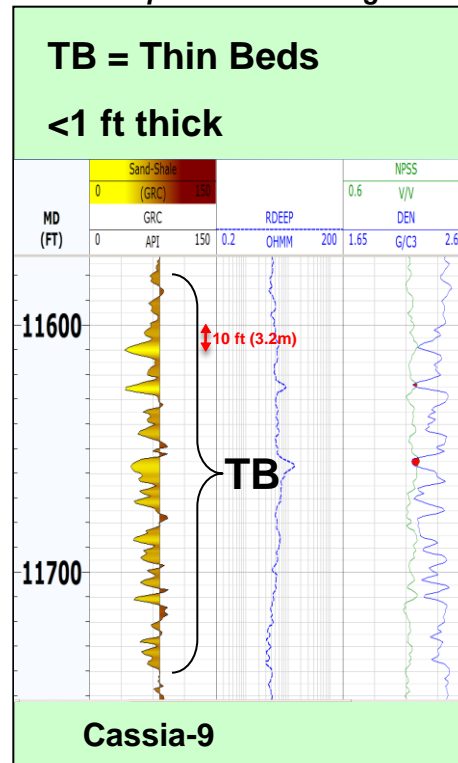
1. Massive / Interbedded Sand *
- *Typical current targets*
- *Easy to quantify volumes*
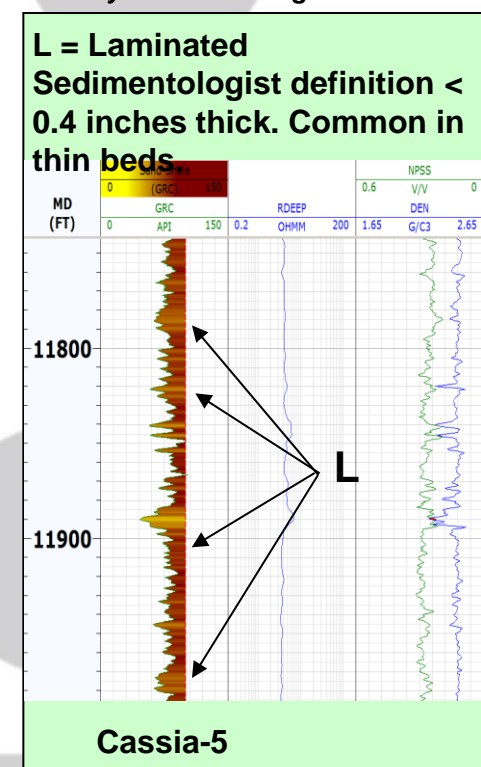- *Lots of Analog data*
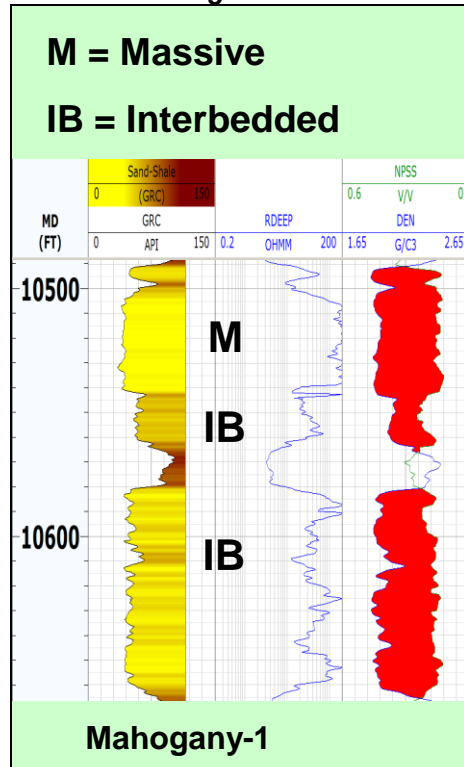
2. Thin Bed Sand / Low Resistivity Pay
- *Able to see on logs*
- *Difficult to quantify volumes*
- *Limited production analogs*

3. Laminated Sand / Low Resistivity Pay
- *Looks like shale on logs*
- *Unable to quantify volumes*
- *Very limited analog data*

Mahogany-1 — M = Massive, IB = Interbedded

Cassia-9 — TB = Thin Beds <1 ft thick, 10 ft (3.2m)

Cassia-5 — L = Laminated, Sedimentologist definition < 0.4 inches thick. Common in thin beds

Pay resolved

Pay unresolved - how much is here?

* K. Baillie and J. James-Romano (BPTT) – SPE 133535 – Identifying and Quantifying Thin-Bedded Pay (Part B): The Use of Dynamic Data to Evaluate Productivity Potential in Gas Reservoirs.

** Trinidad calls TBP "secondary pay", Russia calls TBP "Hard To Recover Resources" HTRR which includes tight oil and gas as well. I took the Pay out of the term as it implies it is economic where ever it is found. In the past people have referred to it as Low Resistiviy Low Contrast Pay (LRLC)

Thin Bedded Pay Talk: Habitat

Fluivial Crevasse Splays

▶ Other

▶ Non-Marine

Lacustrine Delta
Crevasse Splays
River Mouth Bars

Delta Plain Crevasse Splays

Distal Deltaic-Offshore

▶ Marginal-Marine

Levee/Overbank & Slope Channels

▶ Deep-Marine

Tidal Flats & Deltaics

Distal Turbidite Fans

MTCs?

Tidal-Estuary
In incised valleys?

▶ Carbonates

?Contourites?

Thin Bedded Resources
Filling all types
Of Abandoned Channels?

★ Major TBP Occurances

★ Moderate TBP Occurances

★ Minor TBP Occurances

Thin Bedded Pay Habitat: Sub Environments

Source "Kitchen" (Unconventional Resource)

Conventional HC Accumulations

Shoreline   Shelf   Slope   Basin

Thin Bedded Pay Types (Sub-Environments)

Fluvial:
    Crevasse Splays
    Abandoned Channels

Lacustrine (Deltas):
    Crevasse Splays
    Distal Mouthbars
    Abandoned Channels

Paralic:
    Distal Delta Front
    Tidal Flats, Channels & Estuaries
    Delta Plain Crevasse Splays
    Abandoned Channels

Turbidite:
    Levee Overbank
    Terminal Lobes
    Overbank Spay
    Channel Fill
    Distal Basin Fan Lobes

FLUVIAL Crevasse Splays

Delta Plain Crevasse Splays

INCISED VALLEY Estuary & Tidal

OWC

GWC

OWC

INCISED VALLEY Estuary & Tidal +/- Fluvial

DELTA Distal Delta Front

GWC

GWC

SLOPE TURBIDITE Levee Overbank

SLOPE TURBIDTE Levee Overbank

SLOPE TURBIDITE Overbank Splays

GWC

BASIN FAN TURBIDTE Levee Overbank

"Kitchen"

SLOPE TURBIDITE Terminal Lobes

GWC

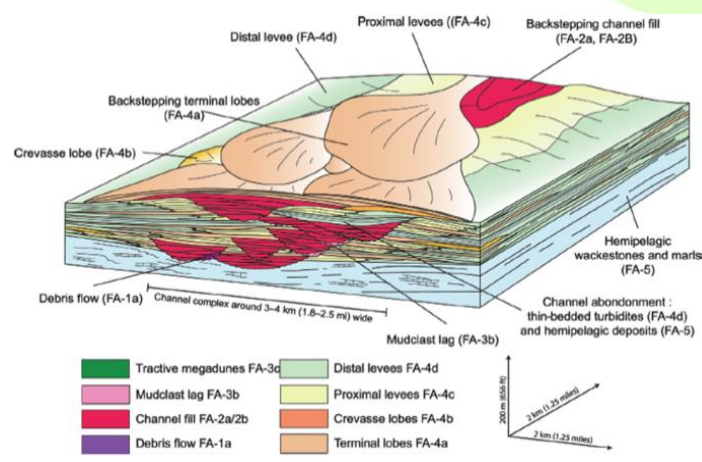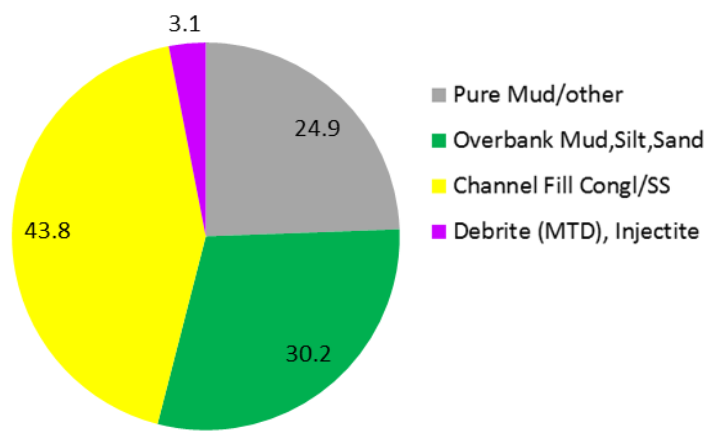TURBIDITE Distal Basin Fan Lobes

Schematic GR-Logs

Note:

Lacustrine Deltas not shown but similar setting to Mariginal Marine Deltas but basin is Lake. Production in Paralic Graph.

Source Rocks in "Kitchen" realm or Unconventional Resources

Turbidite Ave Percent n=12 TBP: min 16% max 58%

- 3.1
- 24.9
- 43.8
- 30.2

- ■ Pure Mud/other
- ■ Overbank Mud,Silt,Sand
- □ Channel Fill Congl/SS
- ■ Debrite (MTD), Injectite

Distal levee (FA-4d)   Proximal levees ((FA-4c)   Backstepping channel fill (FA-2a, FA-2B)

Backstepping terminal lobes (FA-4a)

Crevasse lobe (FA-4b)

Hemipelagic wackestones and marls (FA-5)

Debris flow (FA-1a)   Channel complex around 3–4 km (1.8–2.5 mi) wide   Mudclast lag (FA-3b)

Channel abondonment : thin-bedded turbidites (FA-4d) and hemipelagic deposits (FA-5)

- ■ Tractive megadunes FA-3d
- ■ Mudclast lag FA-3b
- ■ Channel fill FA-2a/2b
- ■ Debris flow FA-1a
- □ Distal levees FA-4d
- □ Proximal levees FA-4c
- ■ Crevasse lobes FA-4b
- □ Terminal lobes FA-4a

200 m (656 ft)   2 km (1.25 miles)   2 km (1.25 miles)

PRODUCTIVE LOW RESISTIVITY WELL LOGS OF THE OFFSHORE GULF OF MEXICO

Examples from 1993 Atlas 150 LRLC completions
Ave completion: 550 Mbo, 6 BcF Cum when documented (240 mmboe)

Dwight "Clint" Moore: Editor-in-Chief

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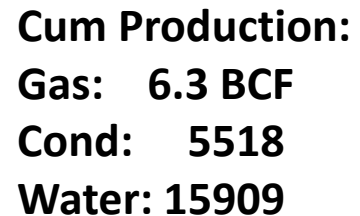
Bill Blair

Bob Douglass

Carl Cannizzaro

Bob Sneider

Harold Darling

Richard Beriltz

New Orleans, Louisiana & Houston, Texas

Copyright 1993

Thin Bedded Pay Talk: Examples References.

Initial Production:
MCFD: 8200
BCPD: 18.5

Cum Production:
Gas: 6.3 BCF
Cond: 5518
Water: 15909

Thin Bedded Pay: ID & Quantification (HCPV)

- Mudlog Shows, then side wall cores (SWCs), whole core.
- Thin bed detection using difference between compressional and shear sonic (normalize in clean wet sands)
- NTG, PHIT, Sw using high resolution logs (FMI SRES, CMR)
- NTG, Sand Porosity, Sw using Thomas Stieber approach
- TBP Permeability Transform
- Saturation Height Function using TBP Permeability Transform as input
- Advanced Logging
- NTG from Image logs, Nuclear Magnetic Resonance (NMR)
- PHIT from NMR
- Sw from multi-component resistivity, NMR
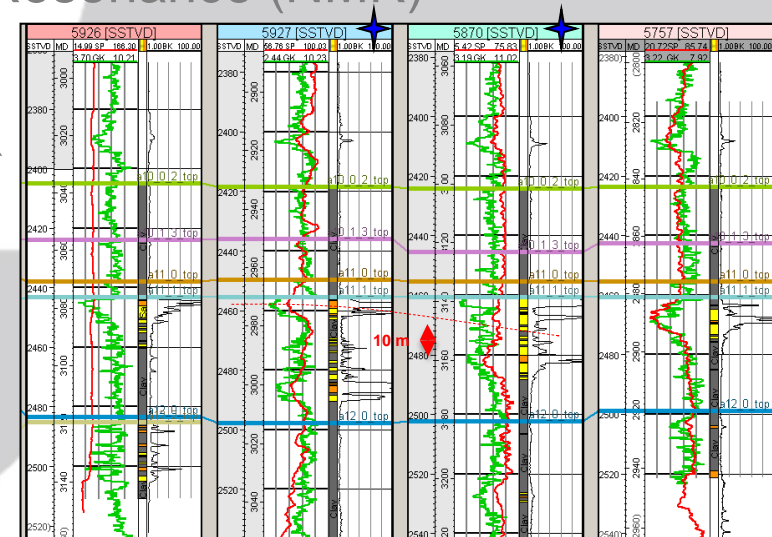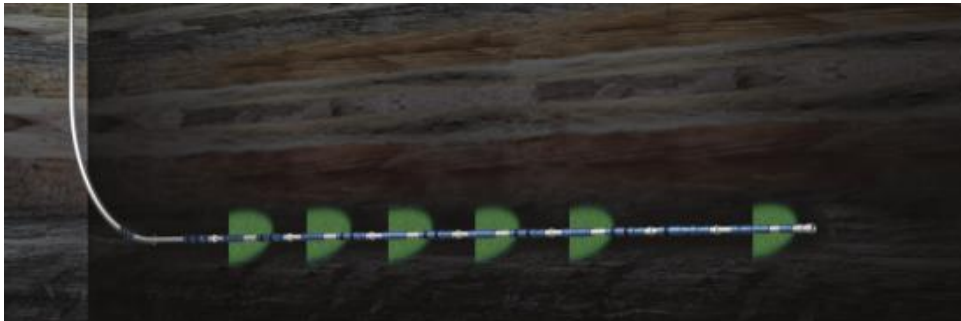
Thin Bedded Pay Talk: Some of Examples found...

In Major

In Literature

Trinidad (SP)
TBP Petrophysics
18-50% more NTG

Egypt Nile Delta
Large 50% TBP
good eval (MDTs)

GOM 1993 Atlas (LRLC Pay)
150 producers: 6 BCF & 550
Mbo Cum./completion

DWGOM Reservoir
RT/VpVsSonic/Images
1% to 40% NTG

DWGOM
TBP production NaKika
Mars/Ursa

Azerbaijan
Core/Image ~10?%TBP
No quantification

Kuparuk A Sands
Core/Image 23% more NTG
20% more STOIIP

UK(LKCF)
Proved Production WF
Magnus Turbidite TBP

Russia (HTRR)
2000+ reservoirs, 20% TBP
Doing TBP stacked fracs

AK Kup SS
Milne/Satellites
13-60% more HPT

SPWLA DW E. Africa
Core/Image 10-20%
More NTG

Malaysia Blk A18 fields
0.8 to 3.0 TCF GIIP increase
Core/Images

Angola
Core 4% more NTG
Facies 3 (TBP)

India Large Vol TBP
Variable connectedness
- performance

Sabah SF30 Field
Core/Images 18% more
STOIIP

Iraq
Core/Image more NTG
And STOIIP

VICO TBP
recompletions

North America Onshore
Powder River, S. Texas
Using stacked fracs TBP

Turbidites
Paralic
Fluvial

Advanced Logging- Image Logs, Core, NMR, Rh:Rv
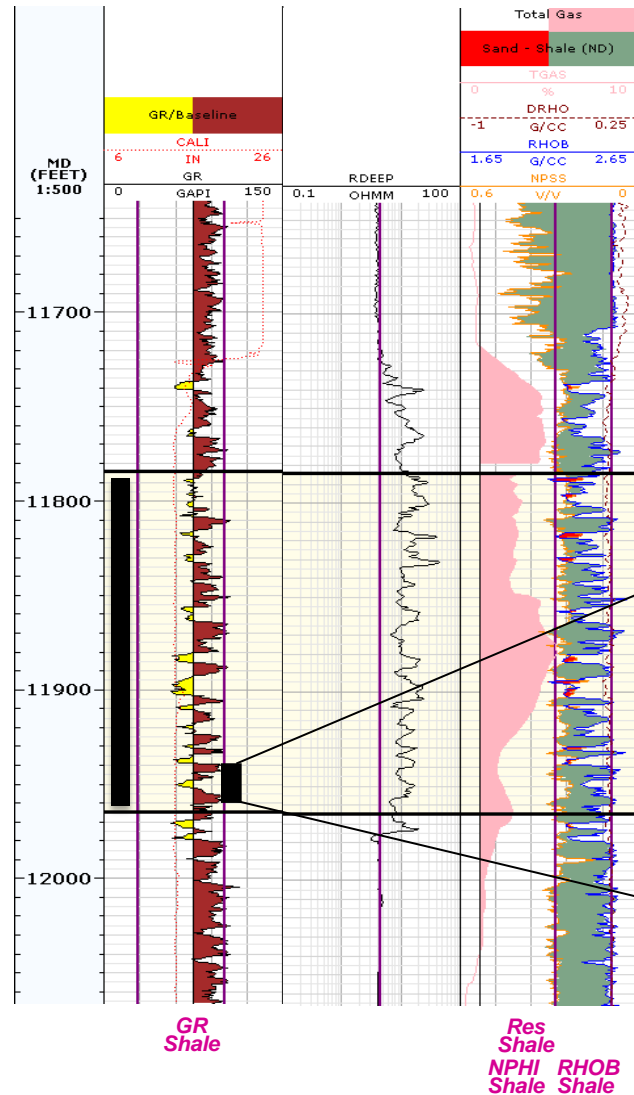
- whole core
- Full RCA, SCAL
- Advanced wireline suites including NMR, Image log, Multi-Component Resistivity and Sonic
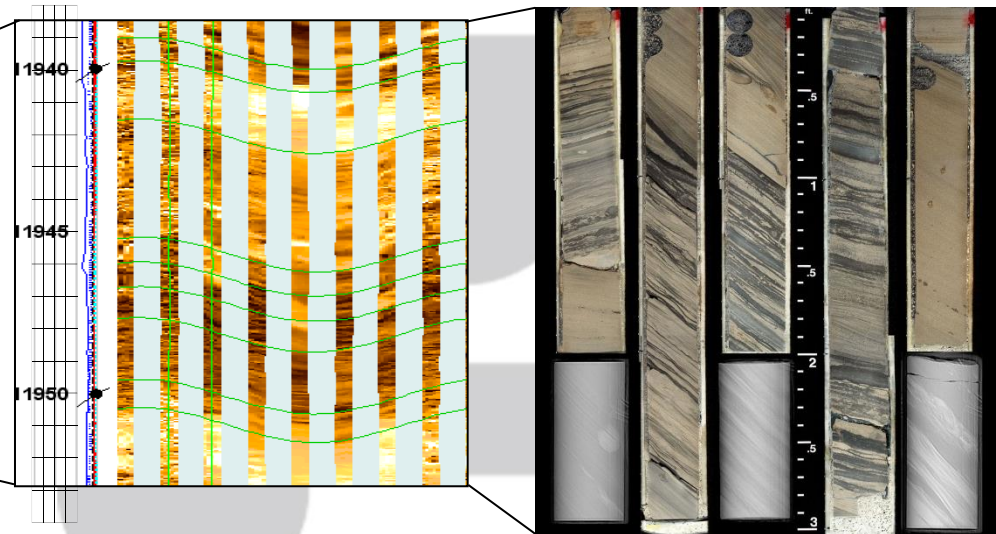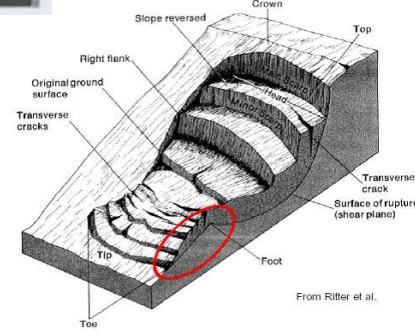
Thin Bedded Pay: Paralic Tidal Indonesia Mahakam

Modern Mahakam Delta, Analog for Semberah field

Channel reservoir

Bar reservoir
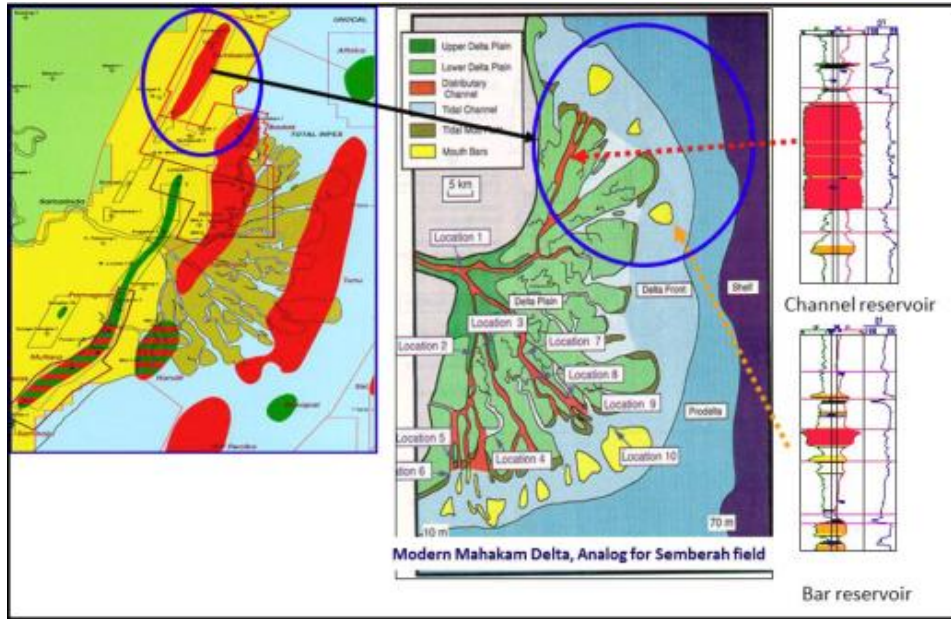
TBP Recomplete Candidates

- E interval: 20%
- F Interval: 26%
- G Interval: 28%
- I Interval: 24%
- J Interval: 2%

1 ft

TBP Zone
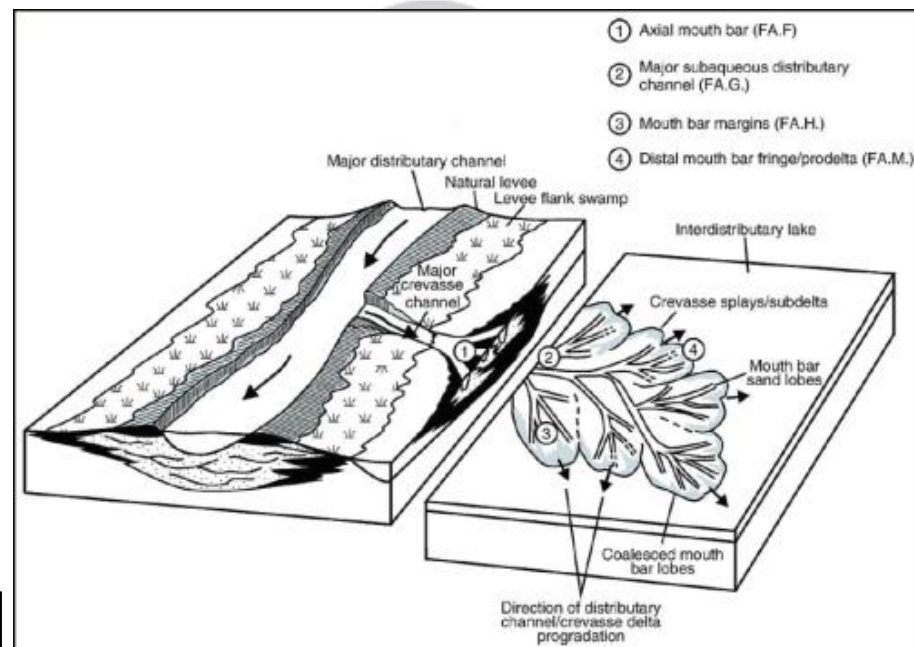
20 ft

Semberah-36

1ft
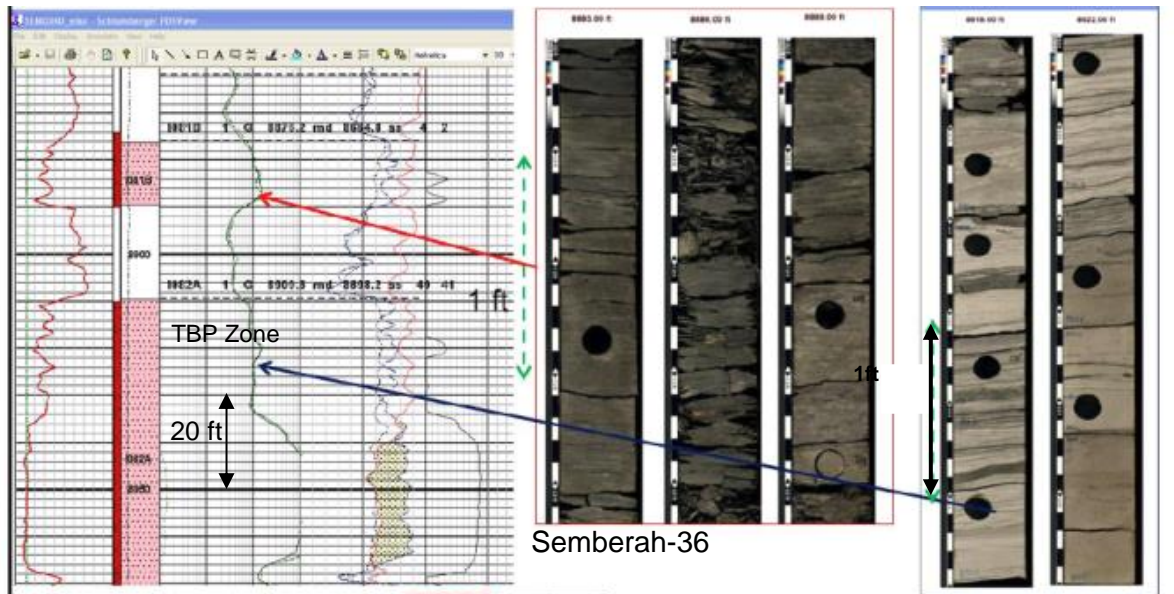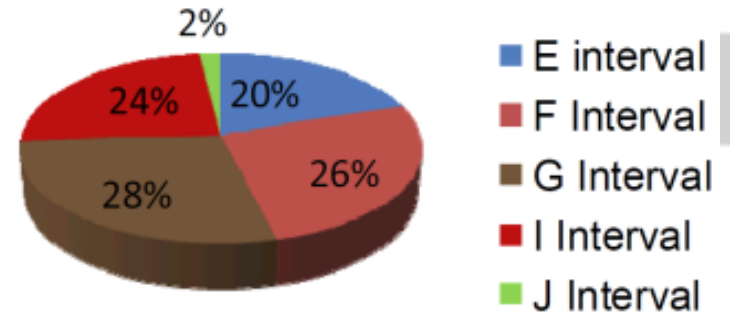
Thin Bedded Pay: Turbidite Magnus LKCF
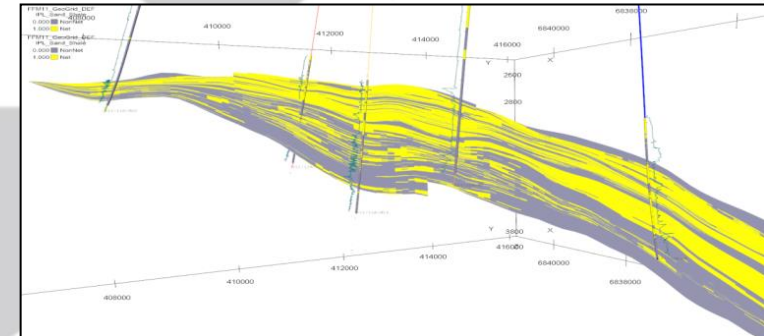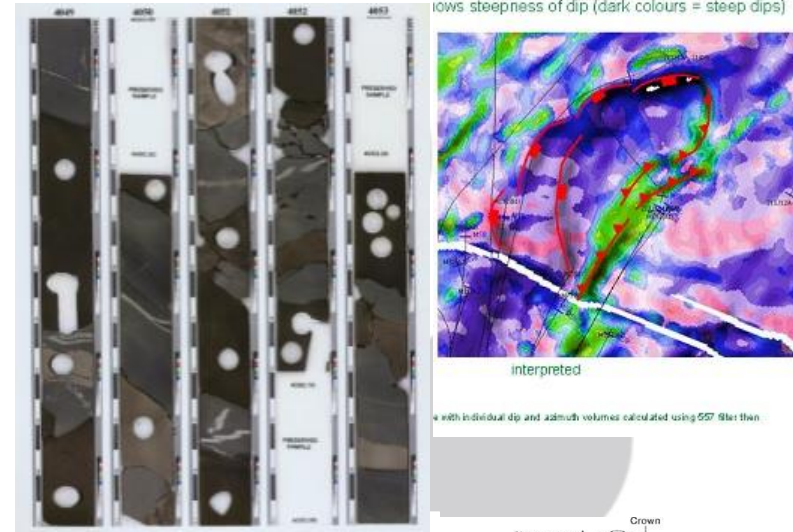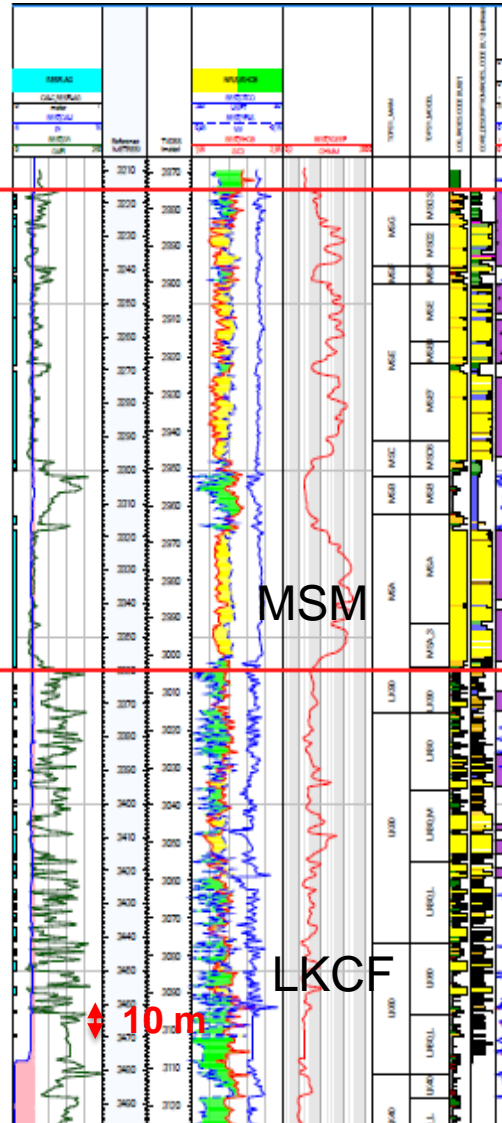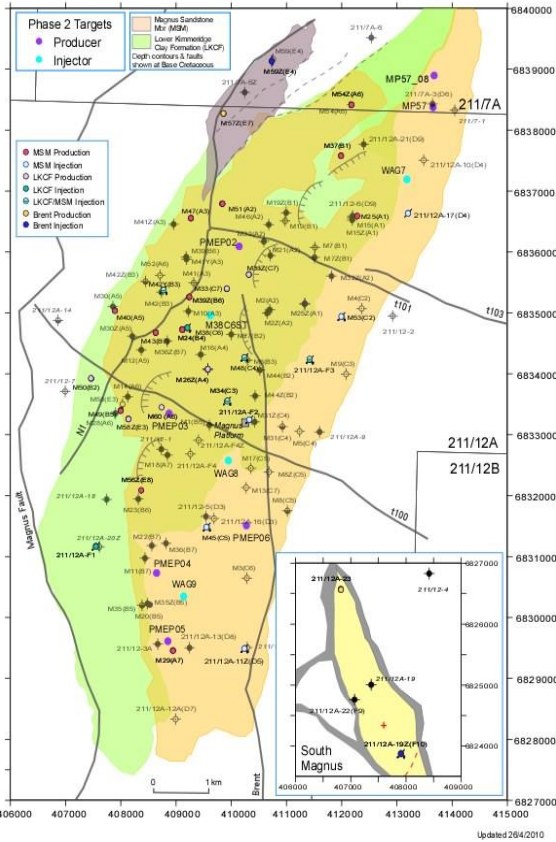
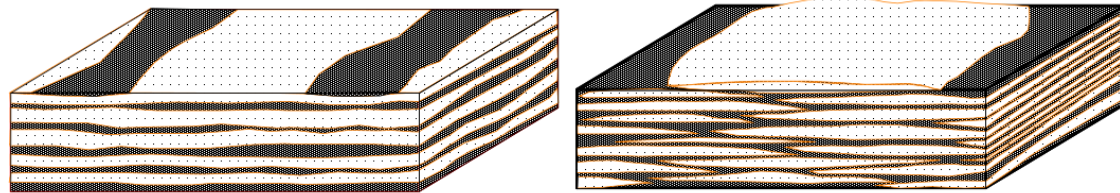# Thin Bedded Pay: Fluvial Goodwin, N. Rankin

Mungaroo Fluvial Facies Percent
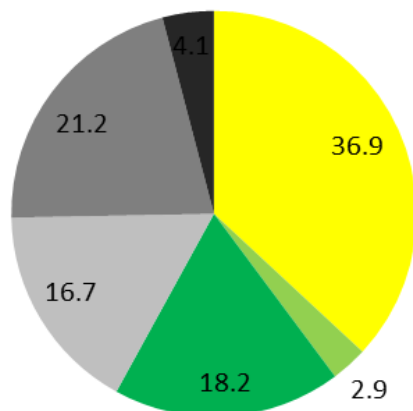
Legend:
- Channel Fill
- Crevasse Splay
- Crevasse Splay Delta
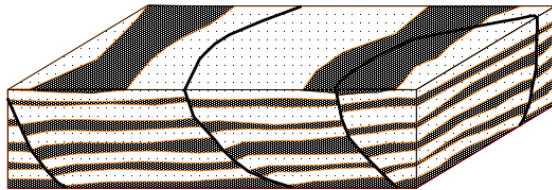- Floodplain(some TBP)
- Floodplain Lake
- Swamp (Coal)

① Axial mouth bar (FA.F)
② Major subaqueous distributary channel (FA.G.)
③ Mouth bar margins (FA.H.)
④ Distal mouth bar fringe/prodelta (FA.M.)
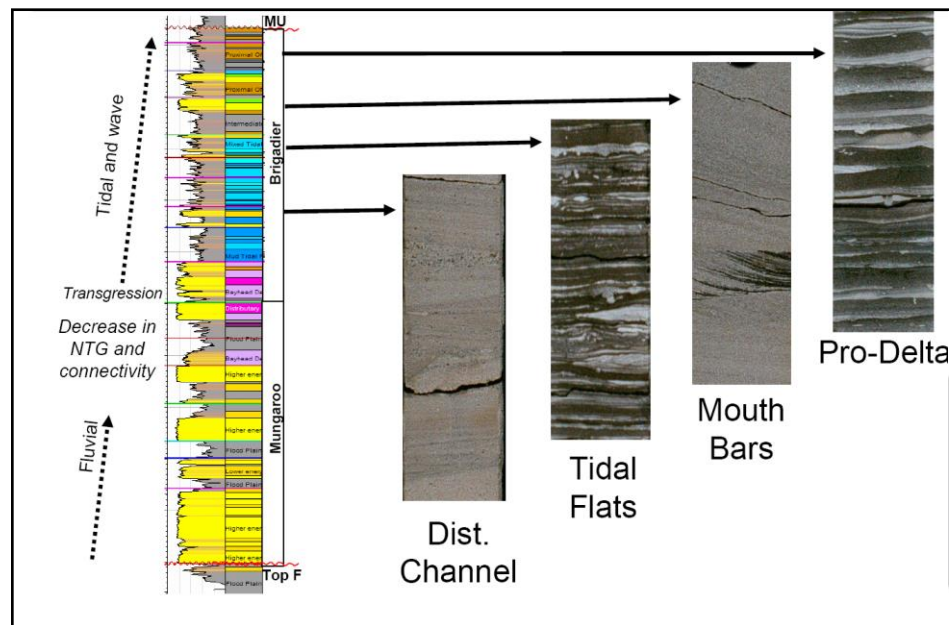
What Modifies Quality of TBP:

Bioturbation

Net To Gross (NTG)

Layering and Deformation – Lateral Connectivity

Bioturbation Index: 5-6 **HIGH**

Bioturbation Index: 3-4 **MED**

Bioturbation Index: 1-2 **LOW**

Soft Sediment Deformation)

Levee Crest

Levee Crest
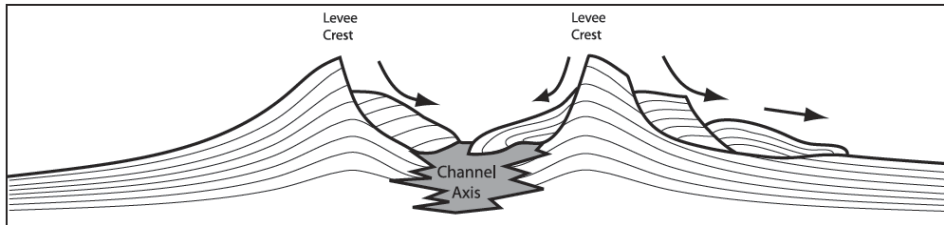
Channel Axis

Figure 11. Diagram of levee collapses, showing collapse both toward and away from the channel axis.

Crown
Slope reversed
Top
Right flank
Main Scarp
Head
Minor Scarp
Original ground surface
Transverse cracks
Transverse crack
Surface of rupture (shear plane)
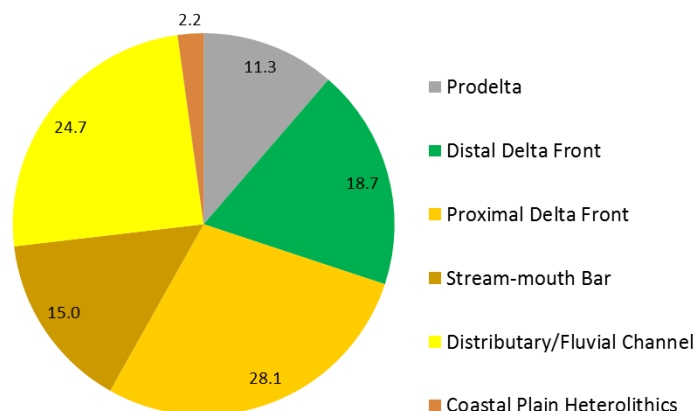Tip
Foot
Toe

Diagenesis & cementation (tight !)
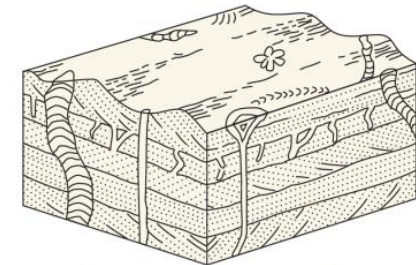
From Ritter et al.

TBP Statistical % from literature examples: Sub Environments

Paralic Ave Percent n=8 TBP: min 6% max 43%
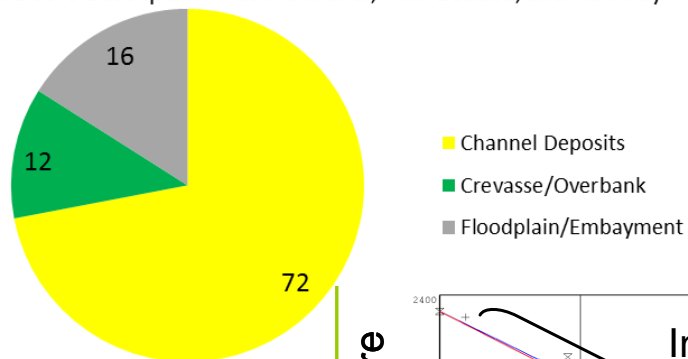
Pie chart values:
- Prodelta: 11.3
- Distal Delta Front: 18.7
- Proximal Delta Front: 28.1
- Stream-mouth Bar: 15.0
- Distributary/Fluvial Channel: 24.7
- Coastal Plain Heterolithics: 2.2

Legend:
- Prodelta
- Distal Delta Front
- Proximal Delta Front
- Stream-mouth Bar
- Distributary/Fluvial Channel
- Coastal Plain Heterolithics

Turbidite Ave Percent n=12 TBP: min 16% max 58%

Pie chart values:
- Pure Mud/other: 24.9
- Overbank Mud,Silt,Sand: 30.2
- Channel Fill Congl/SS: 43.8
- Debrite (MTD), Injectite: 3.1

Legend:
- Pure Mud/other
- Overbank Mud,Silt,Sand
- Channel Fill Congl/SS
- Debrite (MTD), Injectite

Fluvial Ave Percent n=4 TBP: min 5% max 21%

Pie chart values:
- Channel Fill: 49.1
- Crevasse Splay (TBP): 13.0
- Floodplain: 35.8
- Abandoned Channel: 1.1
- Swamp (Coal): 1.0

Legend:
- Channel Fill
- Crevasse Splay (TBP)
- Floodplain
- Abandoned Channel
- Swamp (Coal)
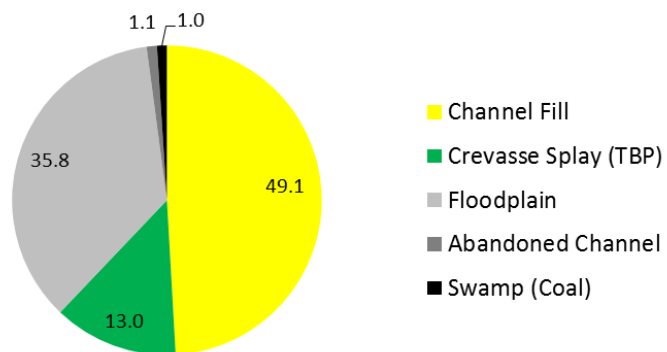
KUPE Core Description % Conventional, Thin Bedded, and Non-Pay

Pie chart values:
- Channel Deposits: 72
- Crevasse/Overbank: 12
- Floodplain/Embayment: 16

Legend:
- Channel Deposits
- Crevasse/Overbank
- Floodplain/Embayment

MATBAL

Plot: Tank Pressure (psig) vs Cum. Gas (bcf)
- Initial volumetric depletion
- Pressure maintenance

EVERYTHING SHALLOWER IS NET SAND/NET PAY FROM LOG MODEL

EVERYTHING DEEPER IS NON-NET SAND/NET PAY FROM LOG MODEL

LKO Current Log Model

LKO Thin Bed Model
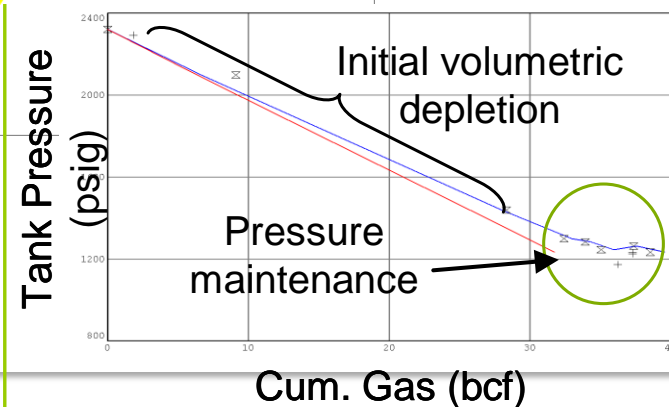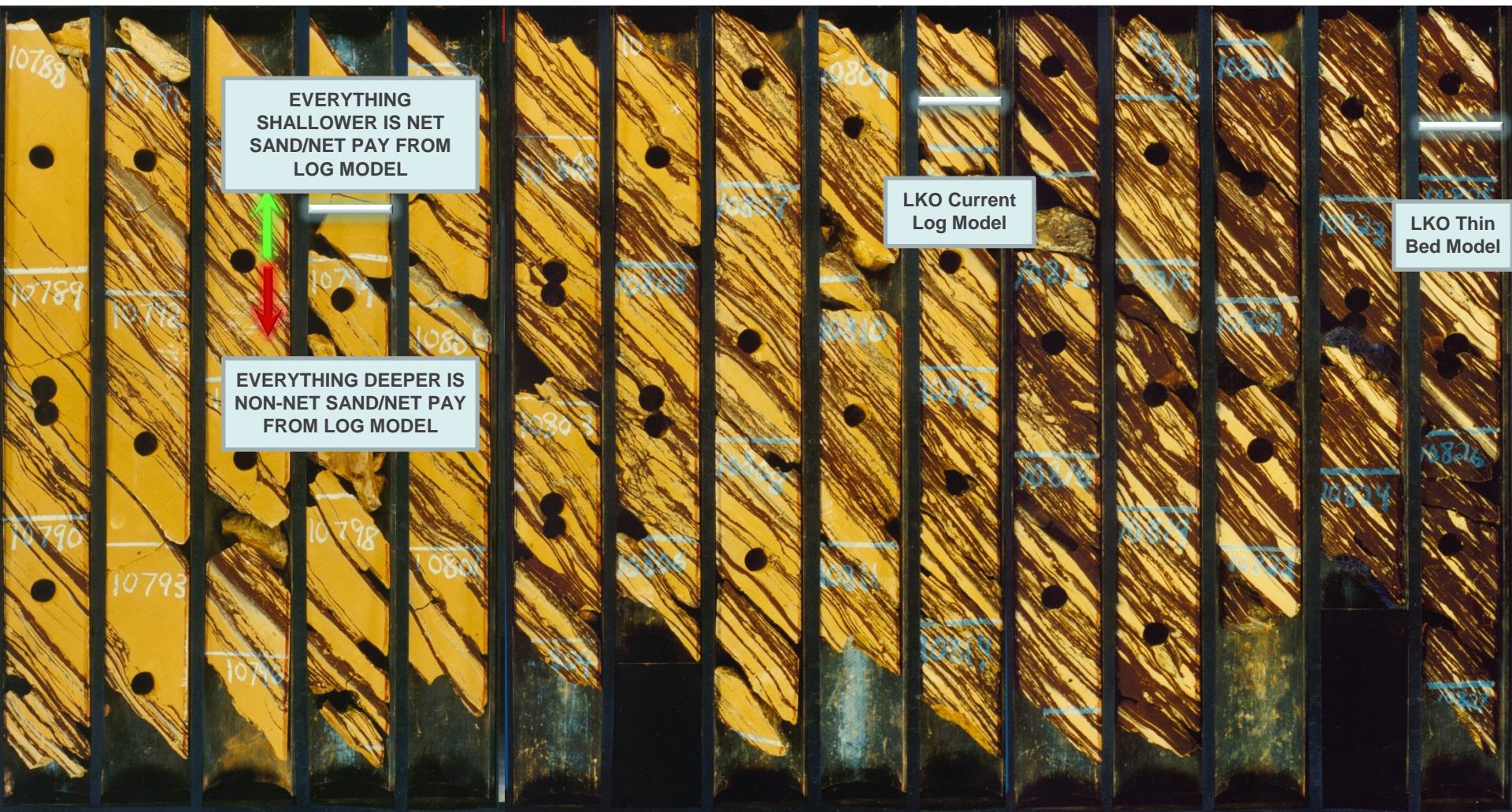
Fluvial Floodplain Example outcrop Salt Wash Utah:

Floodplain + crevasses

Amalgamated Braided Fluvial Channels

~ 1000 ft
(300 m)

~ 50 ft
(15 m)

Channel belt sandstones and floodplain mudstones, Jurassic Morrison Fm., Utah
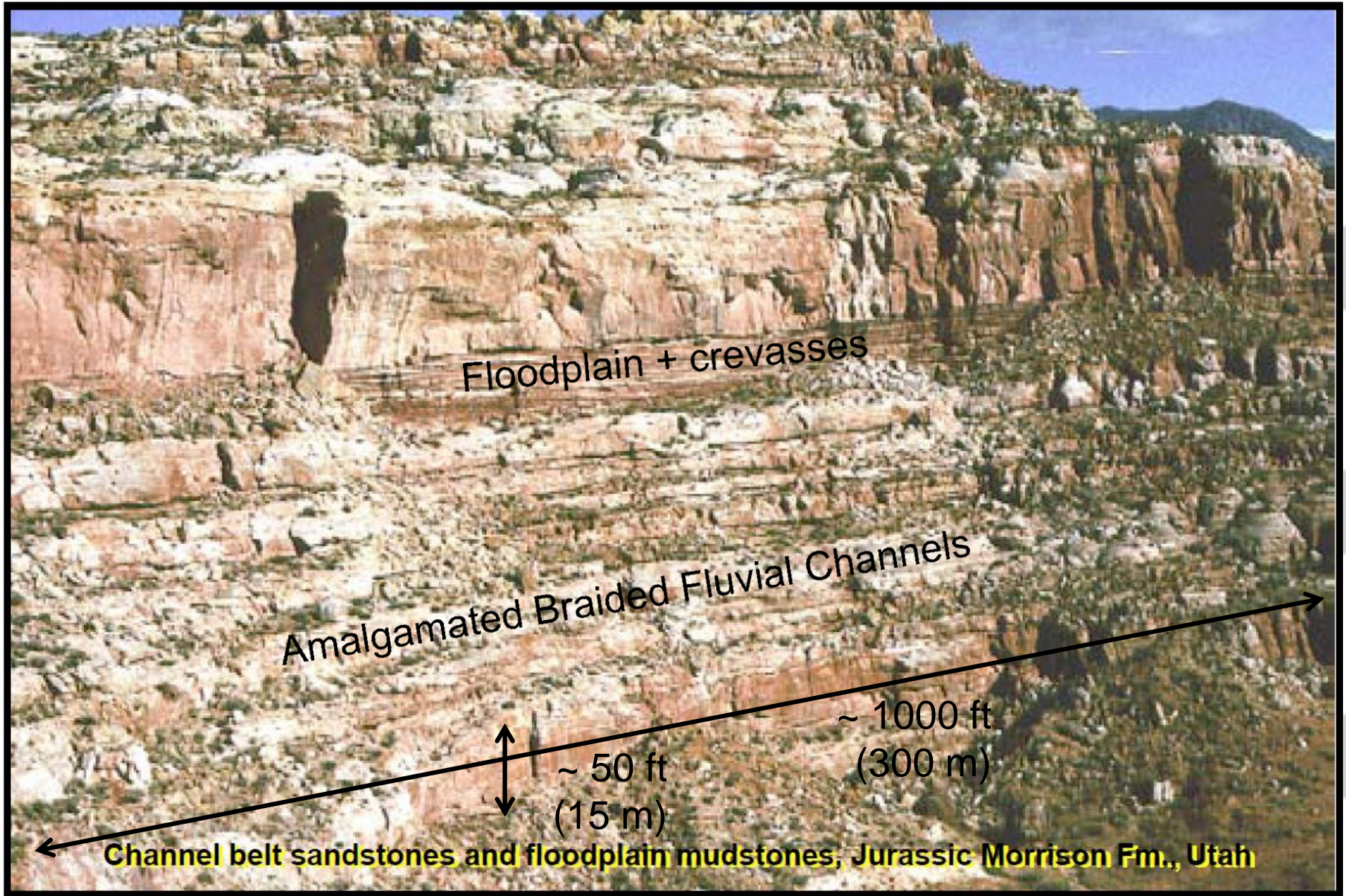
Use vertical fish bone laterals to connect the beds?

Thin Bedded Reservoir with Oil or Gas

50 ft
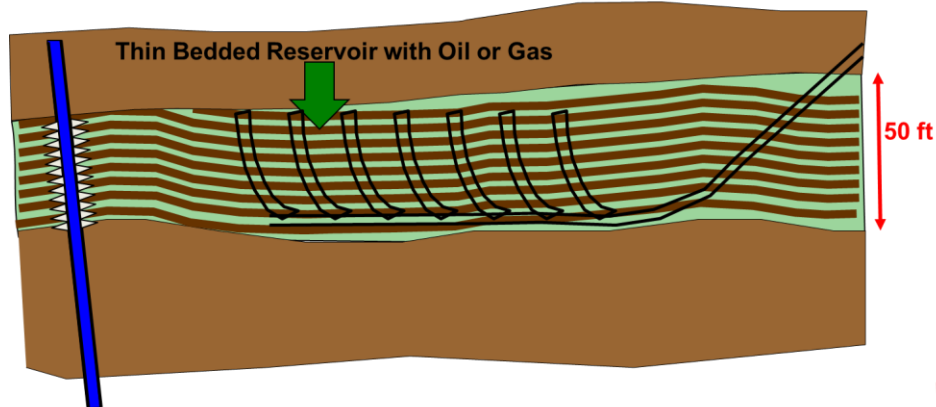
Traditional Deviated
Well with high density
Perfs (CH or OHGP)

Shale (non-net)

Oil/Gas Sand TBP

Use staged fracs like Non-Conventionals to connect the beds?

Thin Bedded Reservoir with Oil or Gas

50 ft

Use undulating or porpising wells to connect to pay?

Thin Bedded Reservoir with Oil or Gas

50 ft
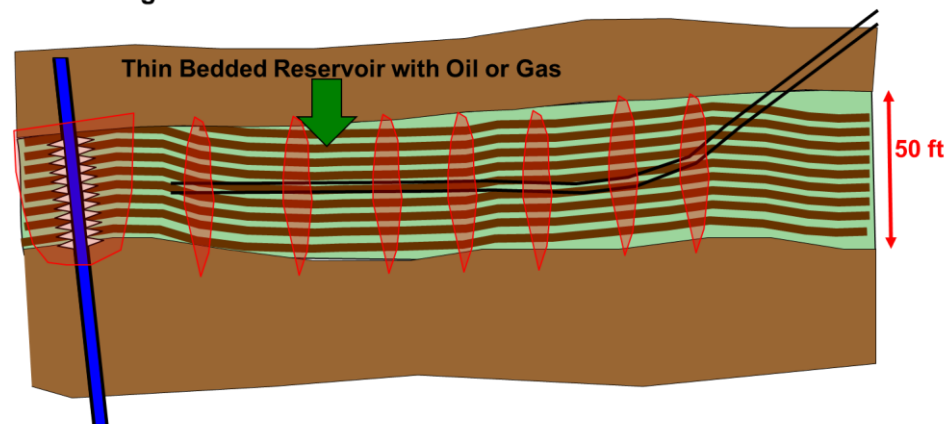
Traditional Deviated
Well with high density
Perfs (CH or OHGP or Frac)

What other ideas are out there????
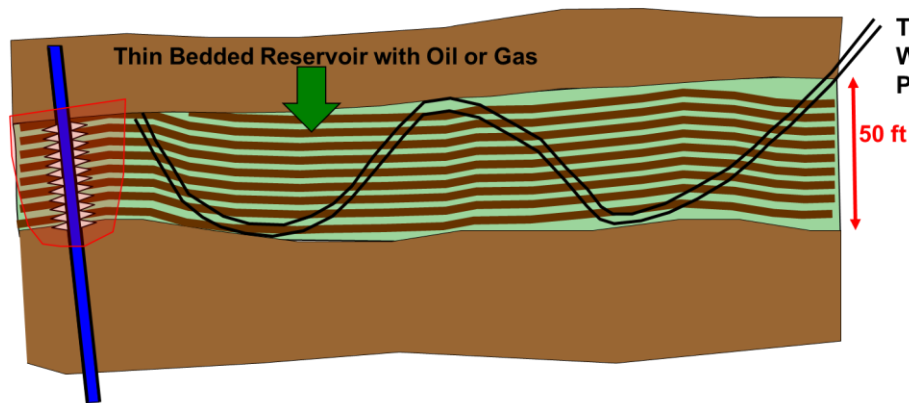
Traditional Deviated
Well with high density
Perfs (CH or OHGP or Frac)

Thin Bedded Pay Talk: References

- Sneider, 1993, HGS-NGS Atlas of Low Resitivity Low Contrast Pays of GOM (Shelf).

- Passey, Q., et.al., 2006. AAPG Archie Series #1. Petrophysical Evaluation of Hydrocarbon Pre-Thickness in Thinly Bedded Clastic Reservoirs.

- K. Baillie and J. James-Romano (BPTT) – SPE 133535 – Identifying and Quantifying Thin-Bedded Pay (Part B): The Use of Dynamic Data to Evaluate Productivity Potential in Gas Reservoirs.

- K. Henderson, H. Rose, R. Winter (BPTT) – SPE 133534 – Identifying and Quantifying Thin-Bedded Pay (Part A): Log Characteristics and Reservoir Quality

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Milne Pt, Schrader Distal LSF OTZ, 3 ft.