Classifying and Characterizing Sand-Prone Submarine Mass-Transport Deposits*

Trey Meckel[1]

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Key Elements

Basis

- Most mass-transport deposits are muddy.
    - 10% (or less) globally are sandy. *So why should we care?*
- No criteria (currently) exist to characterize and classify sand-prone mass-transport deposits.
    - The depositional setting and sandy nature of most sand-prone mass-transport deposits have been recognized only after extensive drilling.
    - Important implications for exploration, development, and shallow drilling hazard identification.
        1. Pre-drill: It is difficult to differentiate sand-prone mass-transport deposits from shale-prone mass-transport deposits. *Is this feature a shallow drilling hazard? Is it a hydrocarbon prospect?*
        2. Post-drill: It can be difficult to differentiate sand-prone mass-transport deposits from turbidite systems and injected sands. *How extensive is this sand? How continuous is it? How might it perform?*
- The term 'mass-transport deposit' has a disparate, and often confusing, usage.

Discussion Points

- What are **mass-transport deposits**?
- How are **sand-prone mass-transport deposits** different from other, more 'typical' deepwater sands (e.g., turbidites)?
- What are the **exploration, development, and other implications** of these distinctions?

Definition

- Mass-transport deposits are sedimentary, stratigraphic successions that were remobilized after initial deposition but prior to substantial lithification and transported downslope by gravitational processes as non-Newtonian rheological units (Bingham plastics or dilatant fluids).
  - – Mass-transport deposits are not specifically associated with a particular sequence stratigraphic position.
  - – Mass-transport deposits include what are frequently termed *creep, slides*, *slumps*, *mass flows, slope failure complexes*, and similar terms, but **not turbidites**.
  - – Mass-transport deposits also include *cohesive* (shale-prone or sand-prone with detrital clay) and *non-cohesive* (sand-prone) *debrites*, as discussed and defined in Gani (2004).

Conclusions

MTDs vs Turbidites

- Seismic morphology
  - – Cross section
  - – Map view
- Seismic facies
- Dipmeter /image logs
- Core facies and dFacies associations
- Grain sorting (shale content)

Sand vs Shale

- Calibrated seismic phase
- Size
  - – Relative
  - – Absolute
- Well penetrations
- Dewatering features

Significance ($)

- Continuity vs compartmentalization --» performance
- Development concepts
  - - Well count
  - - Completion strategy
  - - Ability to workover/recomplete
- Shallow drilling risks

Selected References

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14 April 2010

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$$$

Gulf of Mexico

- Joliett
- Neptune
- K2
- Shenzi
- Mad Dog
- Gunnison
- Thunder Horse “Pink” sands (?)
- Diana(?)

- *Shallow Water Flow* (Ursa, Atlantis, ...)

North Sea

- Sele Formation
- Agat Formation
- Maureen
- Moira
- Gannet
- Guillemot
- South Brae-Miller-Kingfisher
- Magnus
- Everest-Lomond-Pierce
- Schiehallion(?)
- Britannia(?)

West Africa

- Ubit (Nigeria)
- Tiof (Mauritania)

Australia

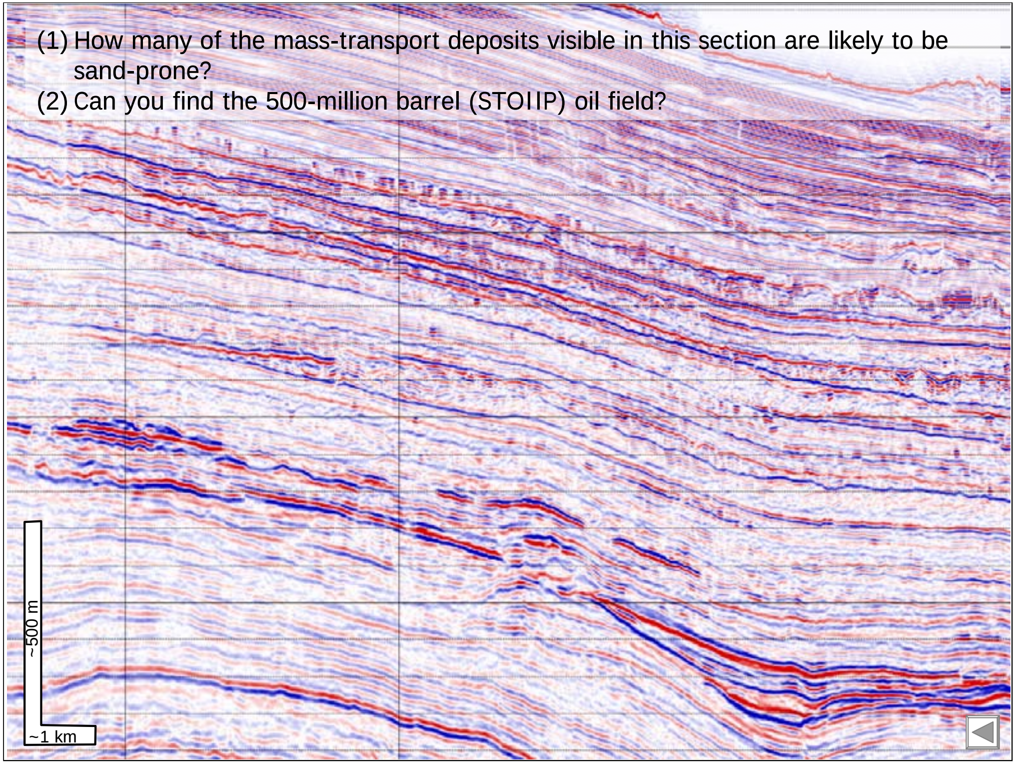
- Enfield
- Stybarrow(?)
- Otway(?)

Russia

- Middle Ob’ region, Siberia

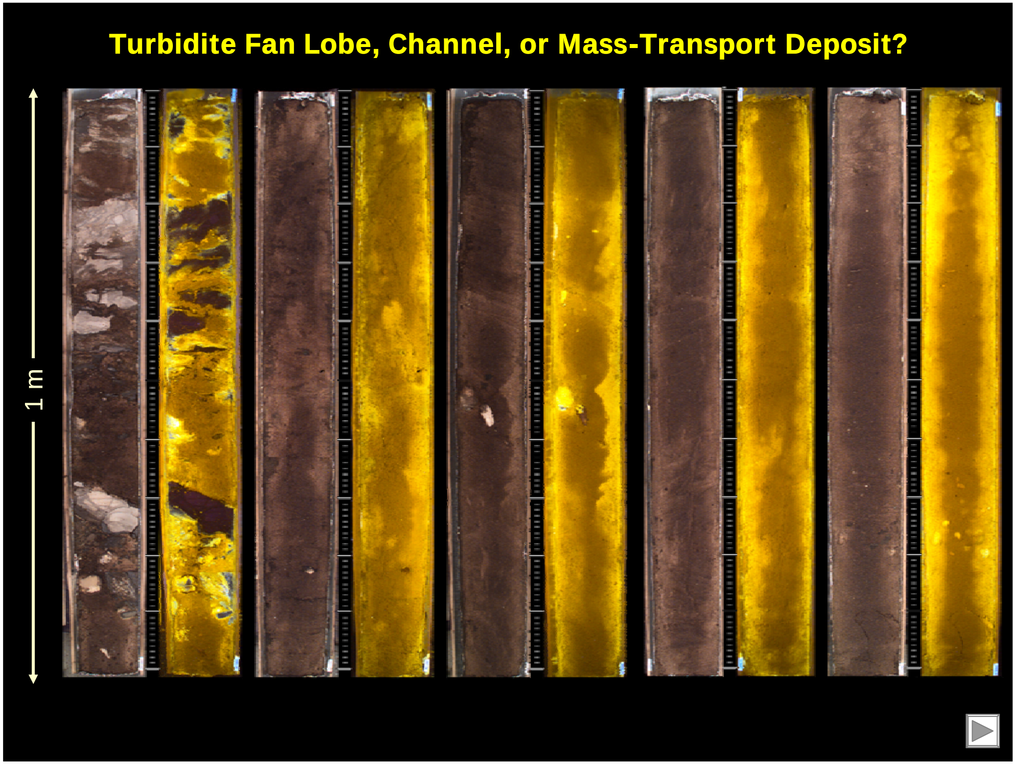
Presenter’s Notes:

Sand-prone mass-transport deposits (or resedimented sands) are major reservoirs in all of the fields listed. Many of the world’s major hydrocarbon basins are represented. The list is not exhaustive, however, and additional study, review, and documentation can help to identify other fields that have reservoirs in mass-transport deposits.



Presenter's Notes:

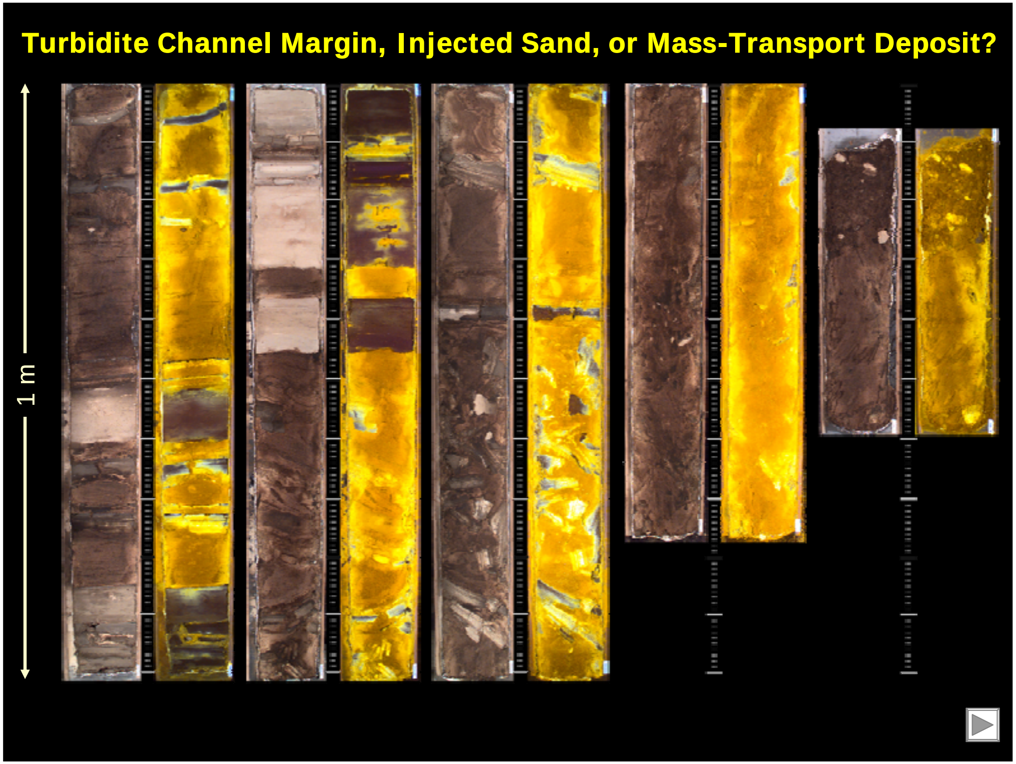
Thought-provoking questions to highlight that MTDs are common, and fields (even large fields) can be very subtle. See Meckel et al. (2010) for more details on this area.



Presenter's Notes:

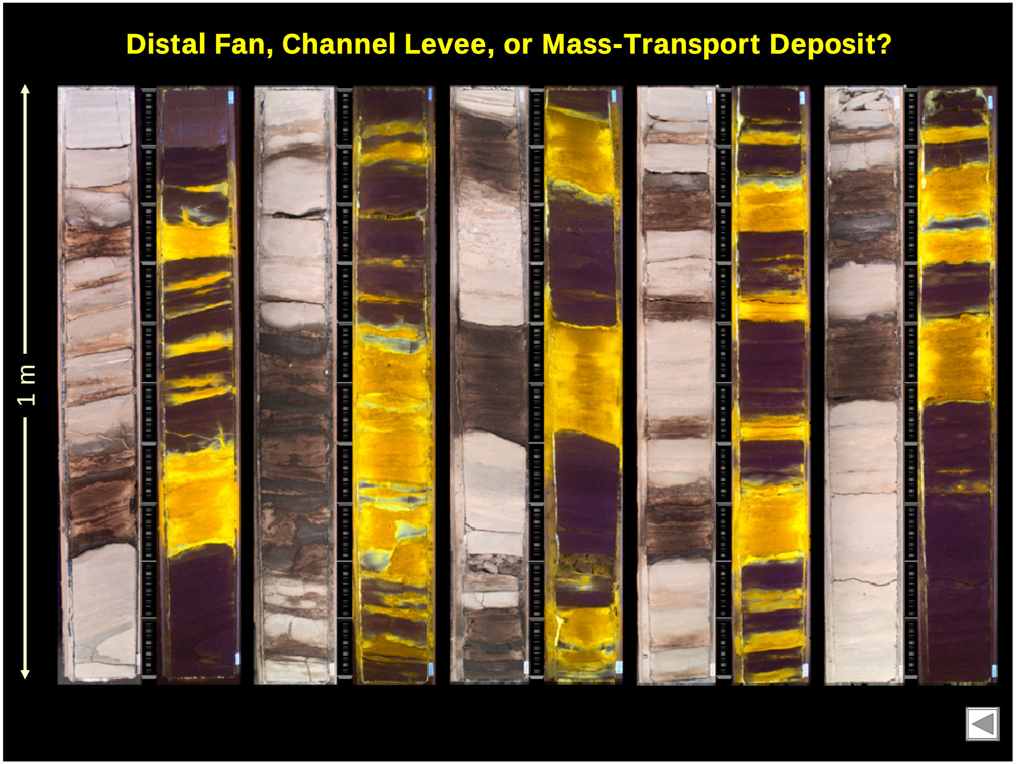
5 m of continuous paired core barrels (plane light on left; UV light on right of each pair). Very different possible interpretations in terms of reservoir continuity, connectivity, and performance, with impact on exploration risk, reserves and economics, and field development planning. What are the key elements that would help to discriminate between depositional environments? Note floating clasts, broken shale beds, highly variable dips in shales.

Also note excellent oil saturations. Compare and contrast with next two slides – all three occur in vertical association. This suite of core is deepest in the 3-slide succession.



Presenter's Notes:

4+ m of continuous paired core barrels (plane light on left; UV light on right of each pair). Very different possible interpretations in terms of reservoir continuity, connectivity, and performance, with impact on exploration risk, reserves and economics, and field development planning. What are the key elements that would help to discriminate between depositional environments? Note chaotic intervals, floating clasts, broken shale beds, highly variable dips in shales, and 'wispy' saturations at top of second core pair from left. Also note excellent oil saturations. Compare and contrast with previous and following slides – all three occur in vertical association. This suite of core is in the middle of the 3-slide succession.



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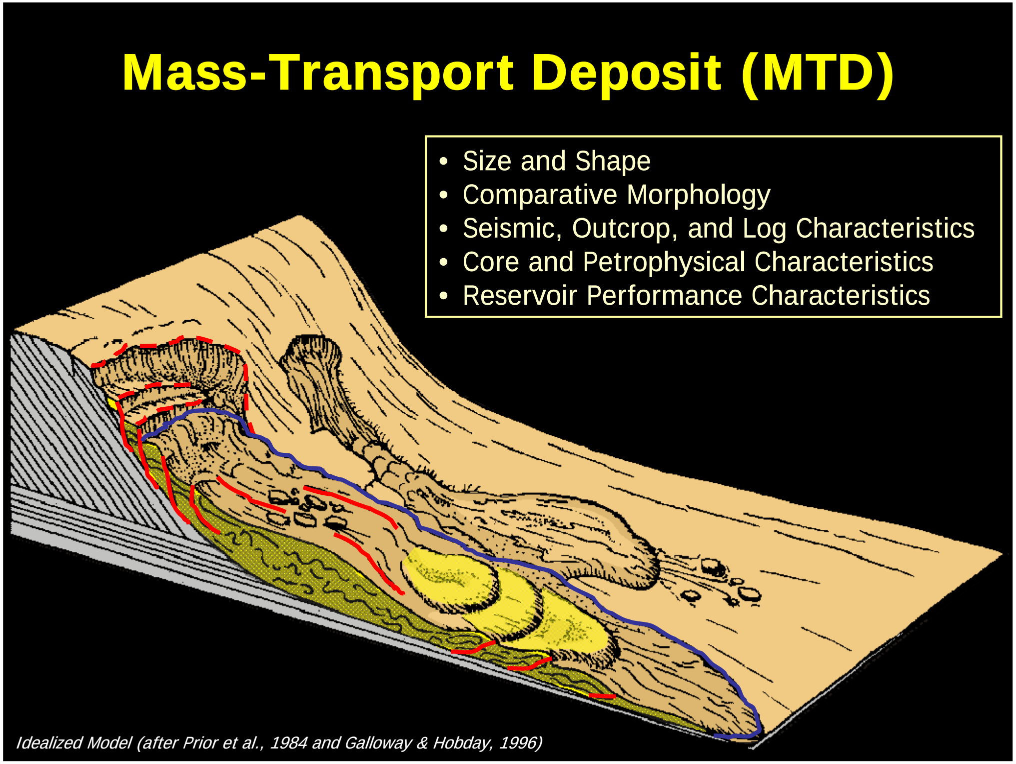


Presenter's Notes:

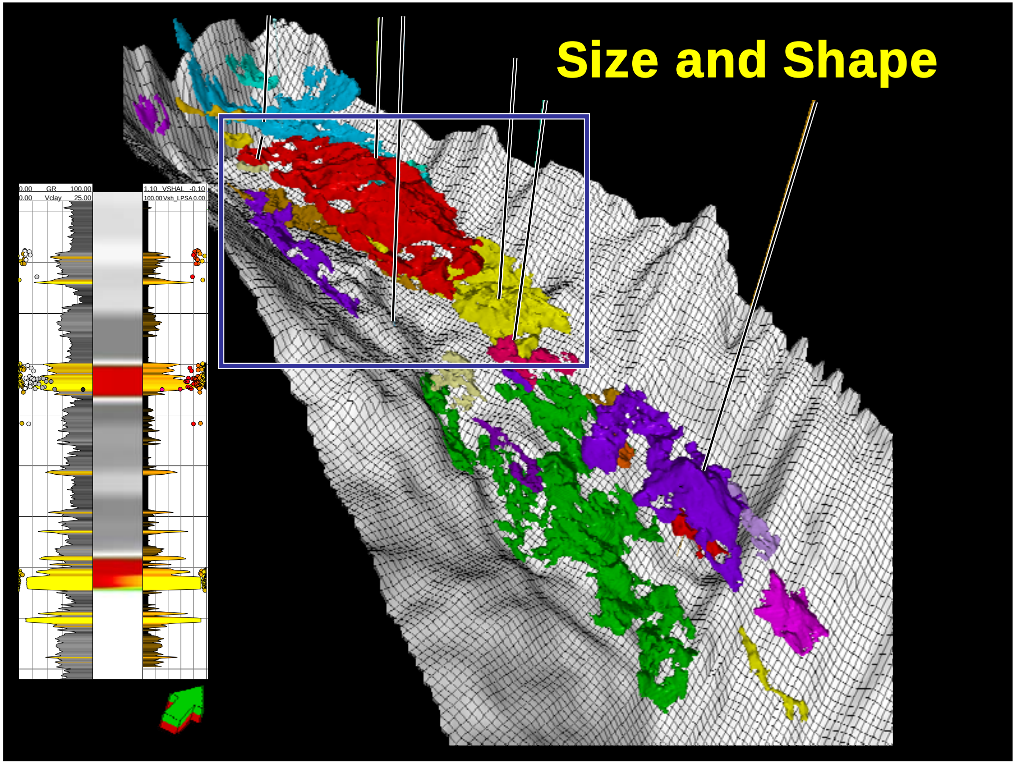
What model does illustrate:

1. Updip head scarp with coherent rotated blocks
2. Middip internally chaotic slumps
3. Downdip thrusting
4. Terminal apron

What model does not imply:

1. May or may not be change in slope from updip to downdip
2. Detachment and slide on glide plane(s)
3. Height, width, and length relationship

Following 2 slides are subsurface examples that illustrate the generic concepts shown here.



Presenter's Notes:

Subsurface example (perspective view) of sand-prone mass-transport deposits. Compare the morphologies of the seismic bodies (from impedance volumes) with preceding slide. Log is from one of the wells shown, and illustrates the gamma ray and Vshale log response of three stacked sandy MTDs. Actual seismic impedance response at the well bore is shown in middle panel. Of note, the log curves in the middle sand display inverse relative values to core-derived measurements of comparable properties (Vclay and Vsh; colored points overlying logs). This relationship occurs because the lower part of the unit has a high degree of non-radioactive matrix clay, whereas the upper part of the unit is thin-bedded, and the sands are much cleaner.

Comparative Morphology

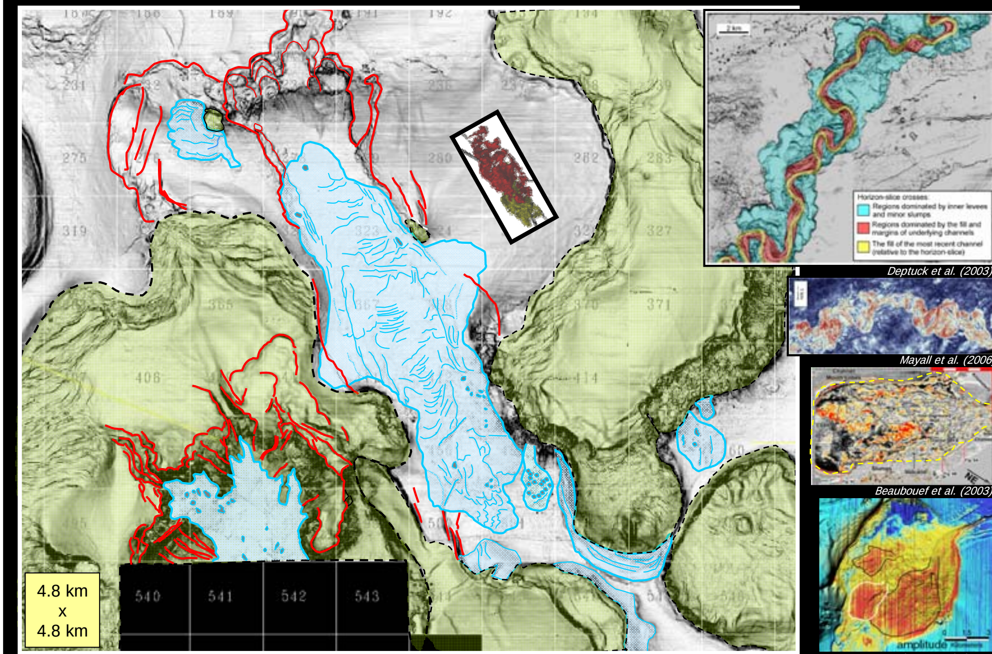
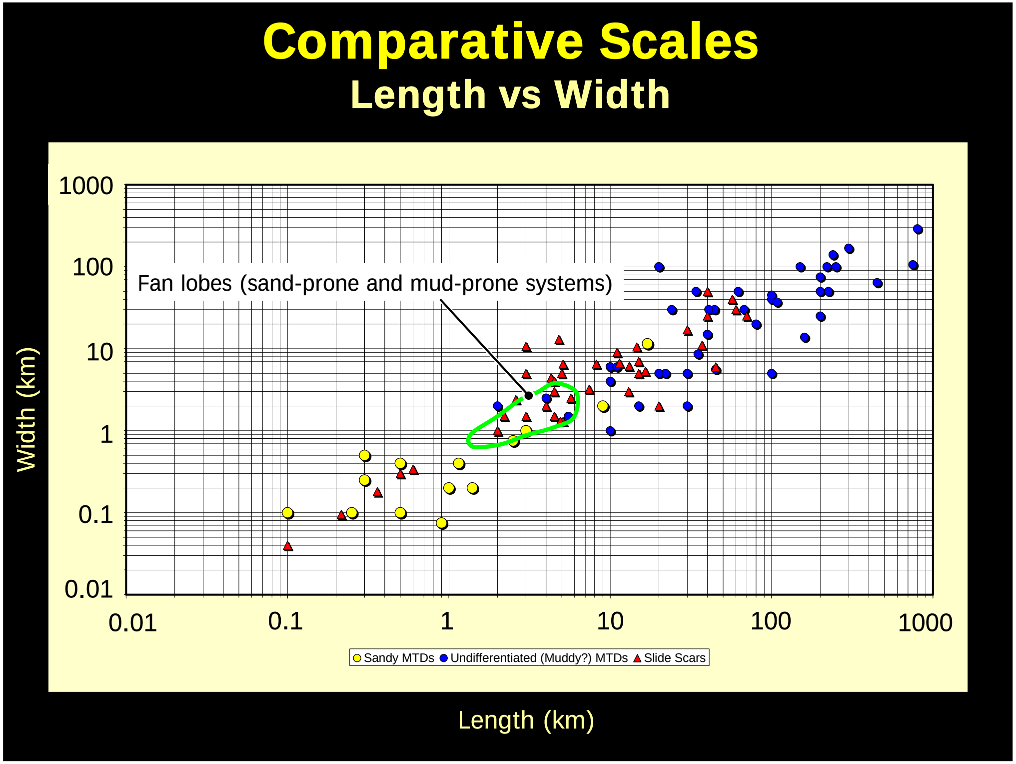


Image courtesy P. Ventris

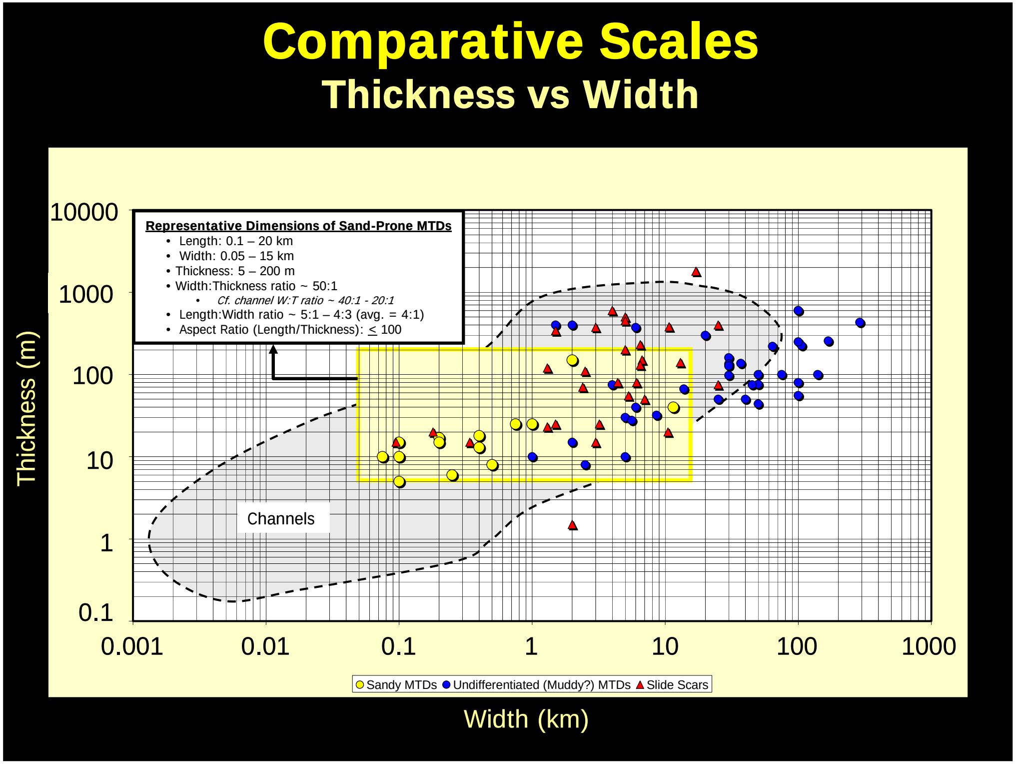
Presenter's Notes:

All images shown at identical scales. Compare and contrast 'typical' morphologies of the three major reservoir-prone deepwater facies types.



Presenter's Notes:

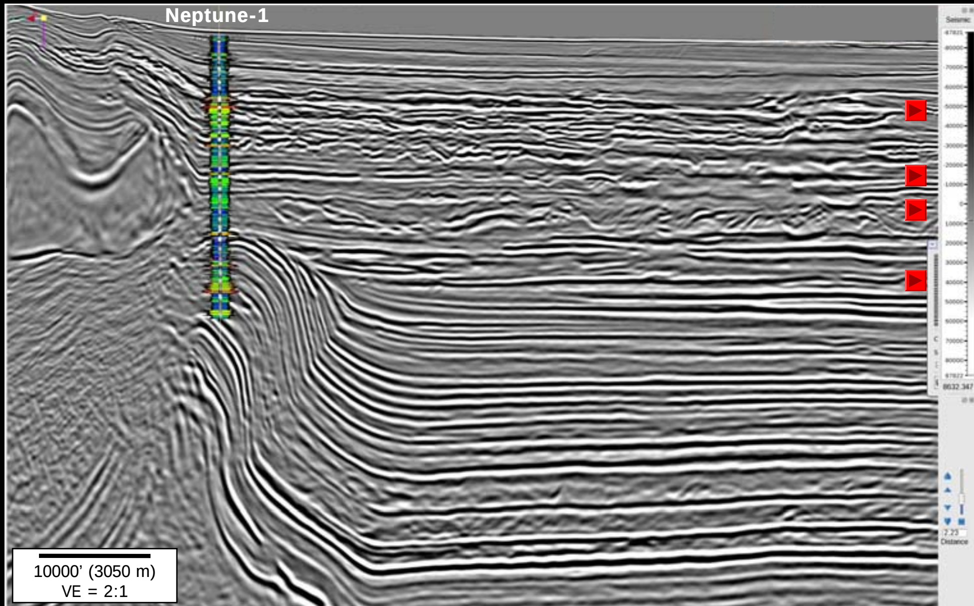
Quantification of previous qualitative observations (cf. preceding slide). Length vs width is a useful tool to compare MTDs to turbidite fan lobes (green polygon), with which they might be confused.



Presenter's Notes:

Quantification of previous qualitative observations (cf. preceding slide). Width vs thickness is a useful tool to compare MTDs (yellow data points and bounding box) to turbidite channels (grey polygon), with which they might be confused.

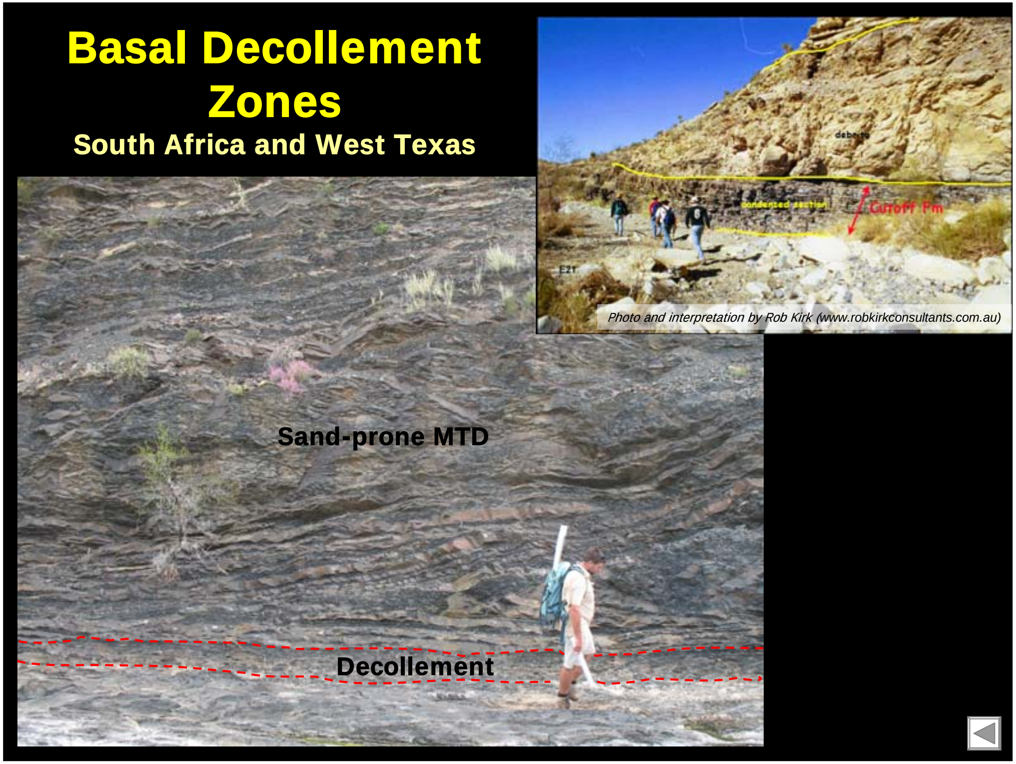
Seismic and Log Characteristics



3D RAZ with Anisotrophic RTM.

Presenter's Notes:

Note chaotic seismic character associated with sand-prone MTDs at top and bottom of well-bore. Next 4 slides illustrate planar base, chaotic internal character, compressional features, and variable log character at outcrop/well scale. Permission to show picture granted by Woodside Energy, BHP-Billiton, Marathon, and Maxus.



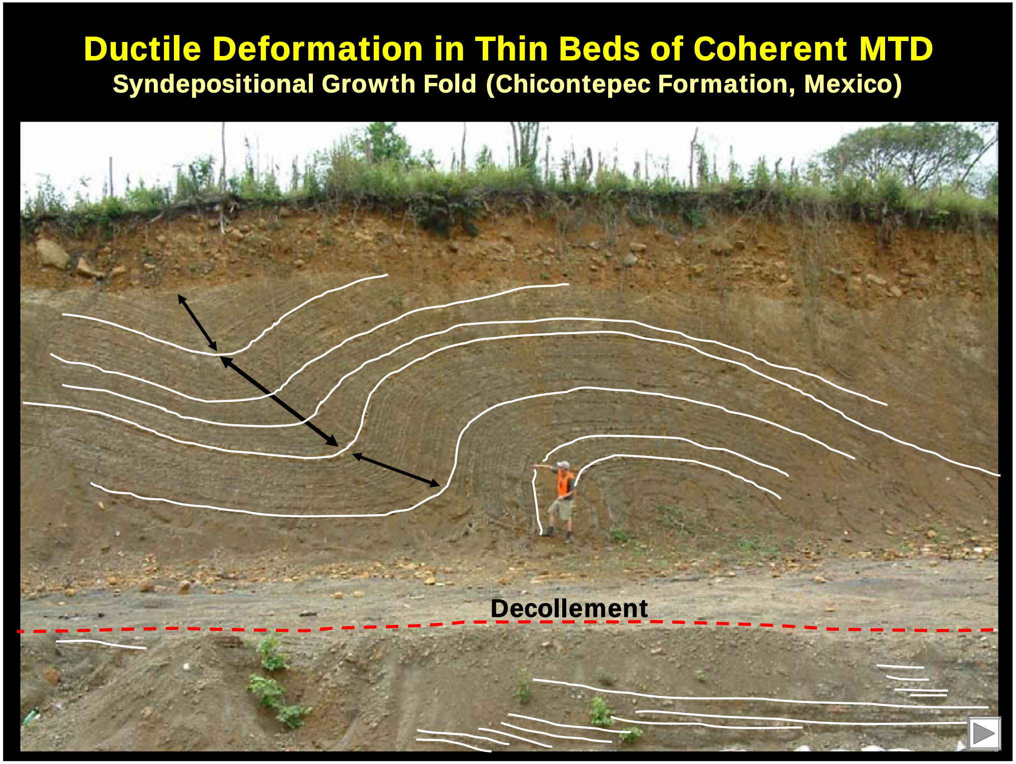
Presenter's Notes:

Planar basal decollements overlain by chaotic beds within MTDs.

Chaotic Internal Character

Chicontepec Formation, Mexico

Photos courtesy Steve Cossey (www. cosseygeo.com)

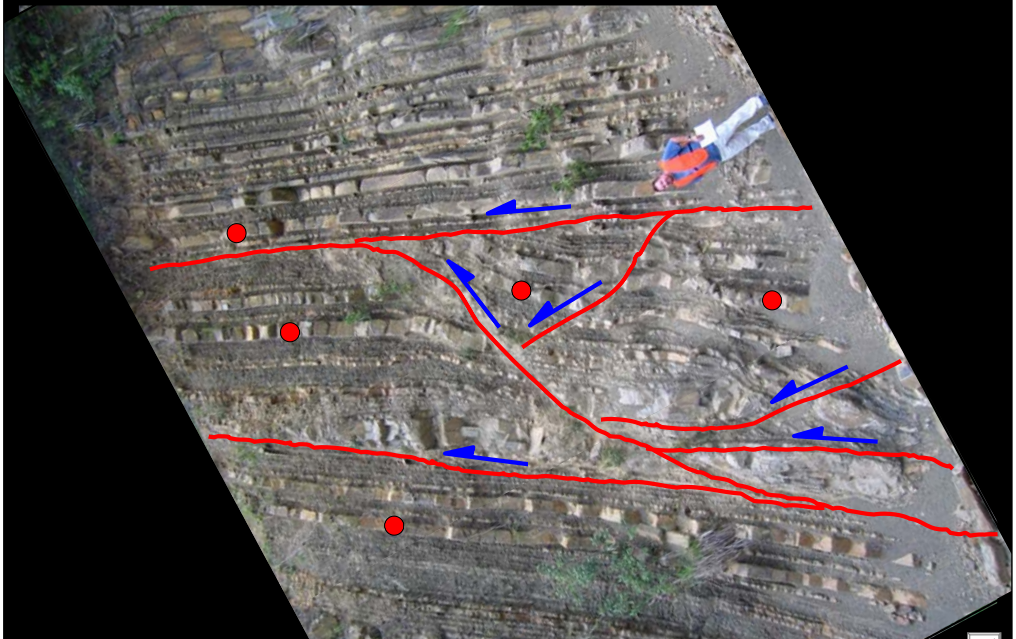


Presenter's Notes:

Growth fold above planar decollement – note expanded strata in synclinal limb.

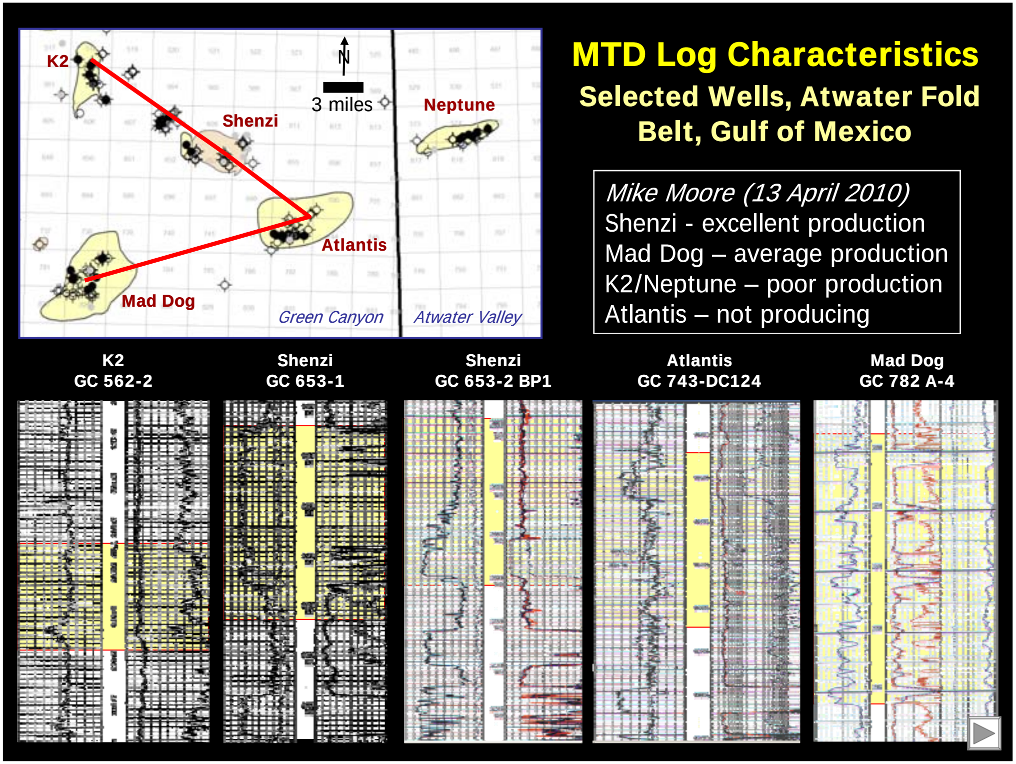
Brittle Failure in Thin Beds of Coherent MTD

Imbricate Thrust Complex (Chicontepec Formation, Mexico)



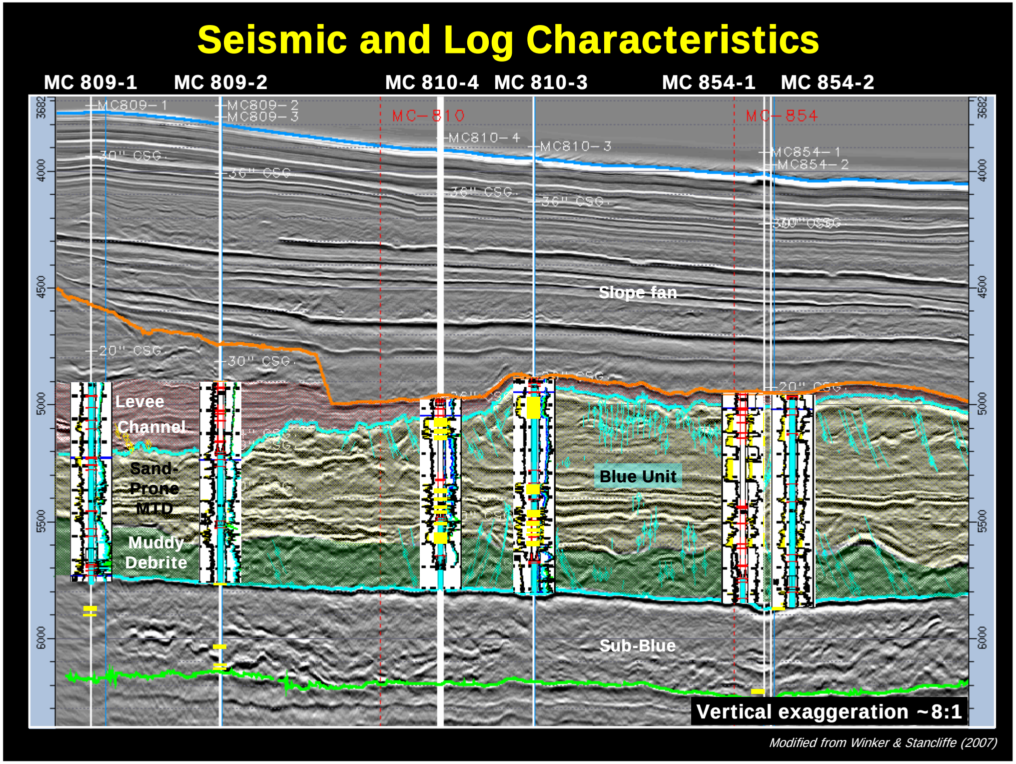
Presenter's Notes:

Red dot indicates same bed repeated 5 times over very short interval. Imagine theoretical wells on either edge of image: LEFT - dipmeters, image logs, core, etc. would potentially indicate undisturbed bedding; RIGHT – same data would facilitate much different (and more appropriate) interpretation. What are key issues regarding connectivity between the 2 wells (even over such short distances)??? What subsurface data would/could you collect to help identify this as an MTD?



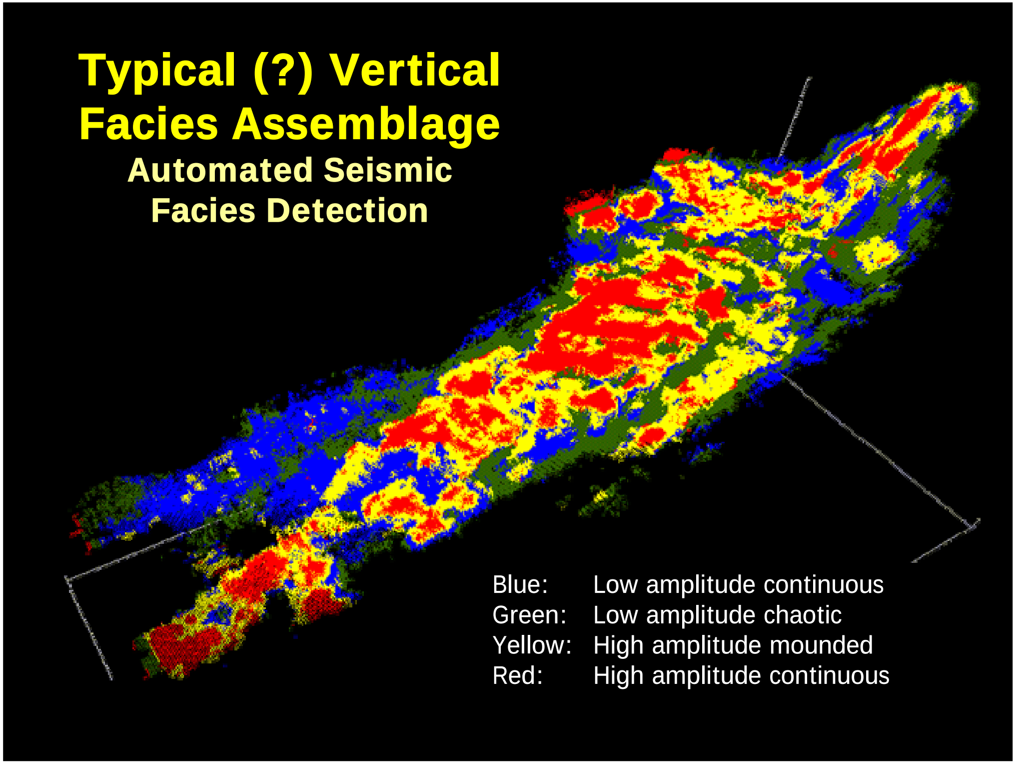
Presenter's Notes:

Yellow boxes highlight interval is of sand-prone MTDs across a significant part of eastern Green Canyon, GOM.



Presenter's Notes:

Note variable nature of sand between these closely-spaced appraisal wells. Also note vertical assemblage of highlighted facies (muddy debrite → sand-prone MTD → Levee Channel). Compare to next 2 slides.



Presenter's Notes:

Note spatial relationship of green, yellow, and red seismic facies, which are vertically stacked, not laterally continuous. Compare with preceding and following slides.

Typical (?) Vertical Facies Assemblage

El Gordo “Megabed”, Spain

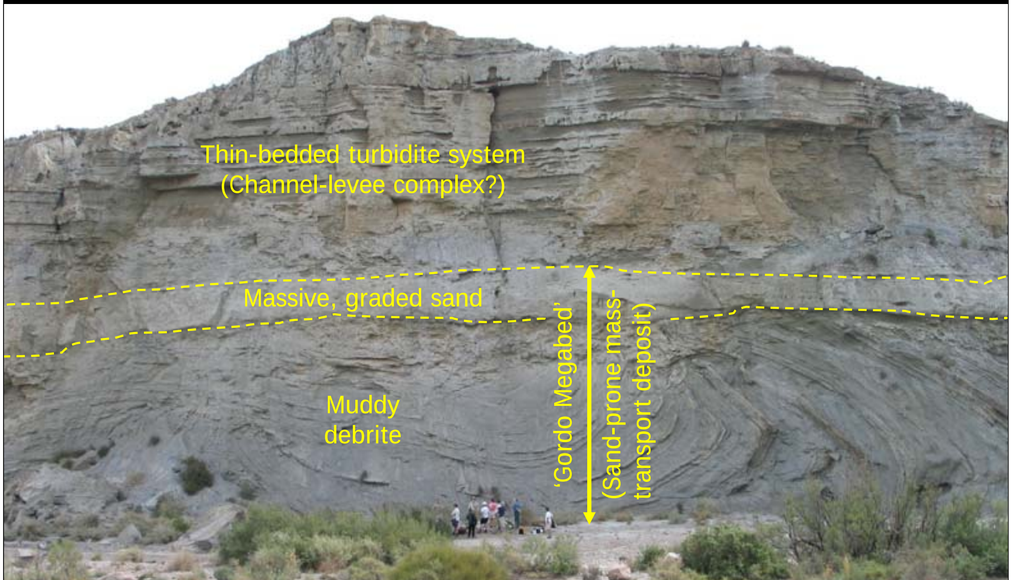
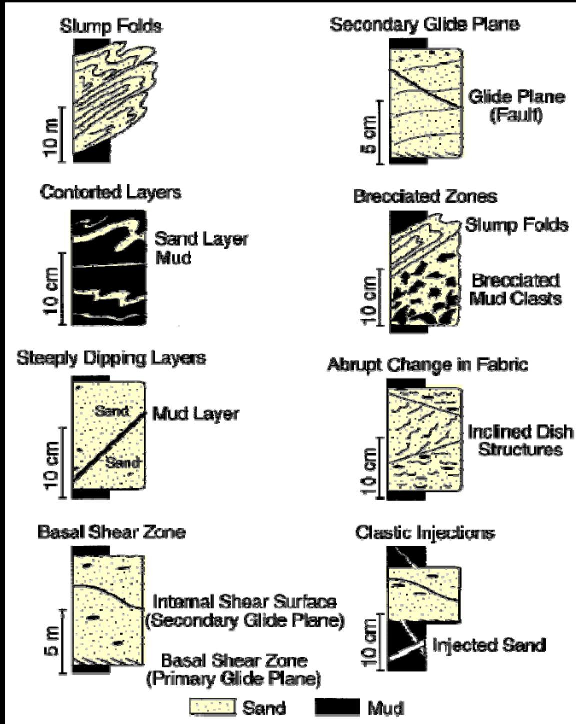


Photo courtesy Steve Cossey (www. cosseygeo.com)

Presenter’s Notes:

Outcrop example of vertical facies assemblage illustrated in preceding 2 slides.

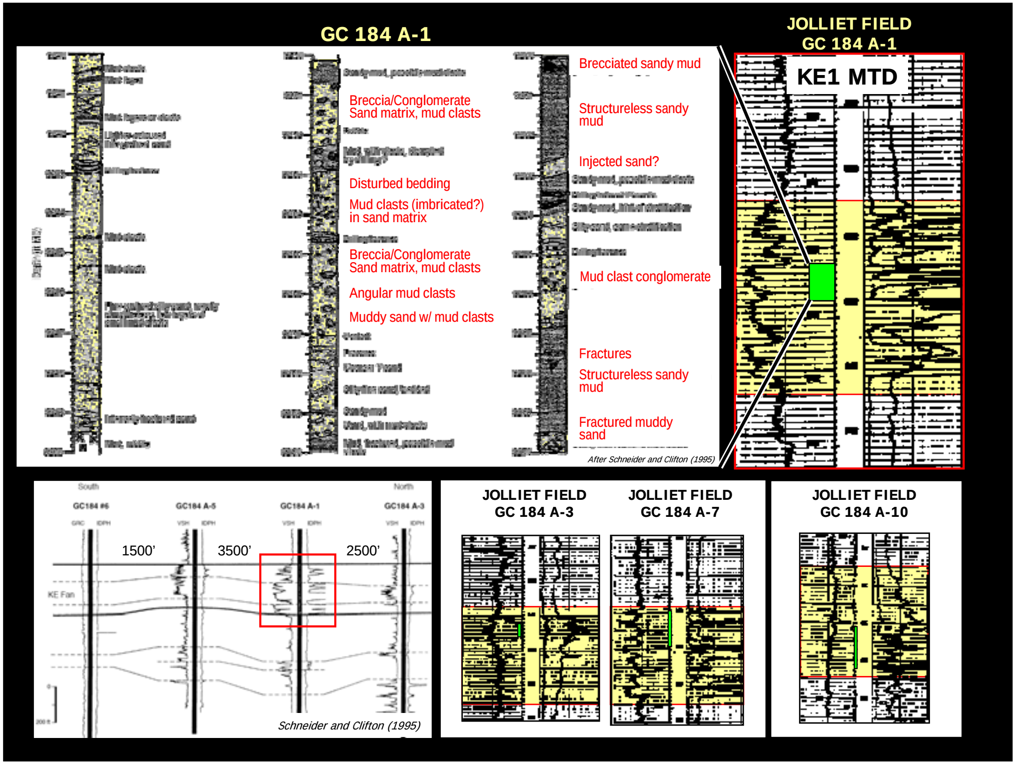


Deformational Fabrics Observed in Cores of Sandy MTDs

(Shanmugam et al., 1995)

Associated Sedimentary Fabrics

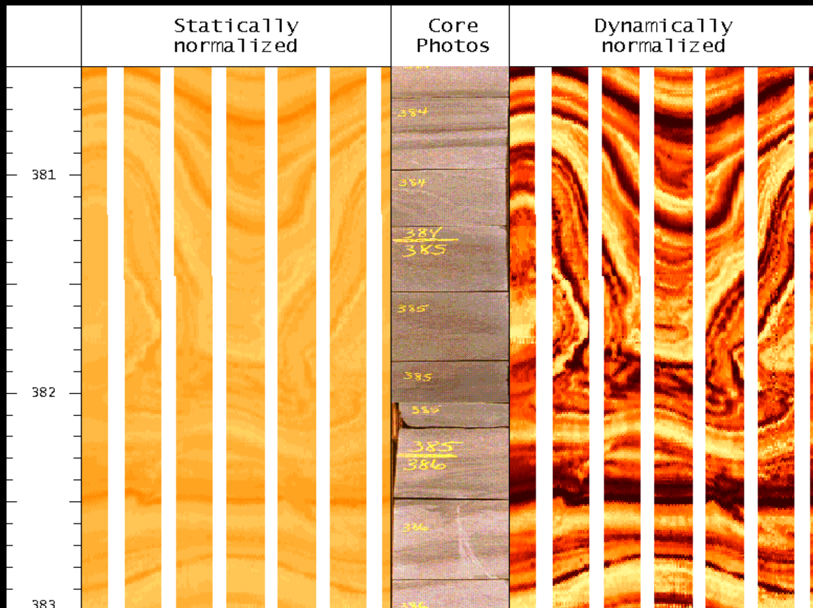
- Massive sands $\pm$ floating clasts
- Conglomerates
- Convoluted shale beds
- Laminated hemipelagic shales and silts



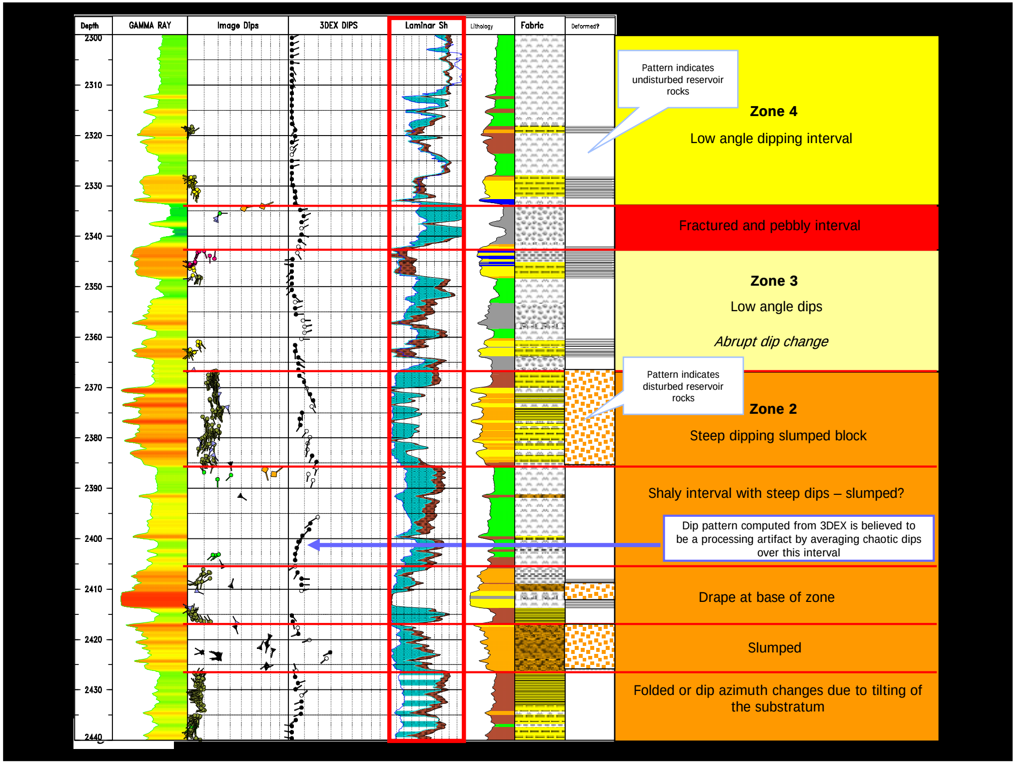
Presenter's Notes:

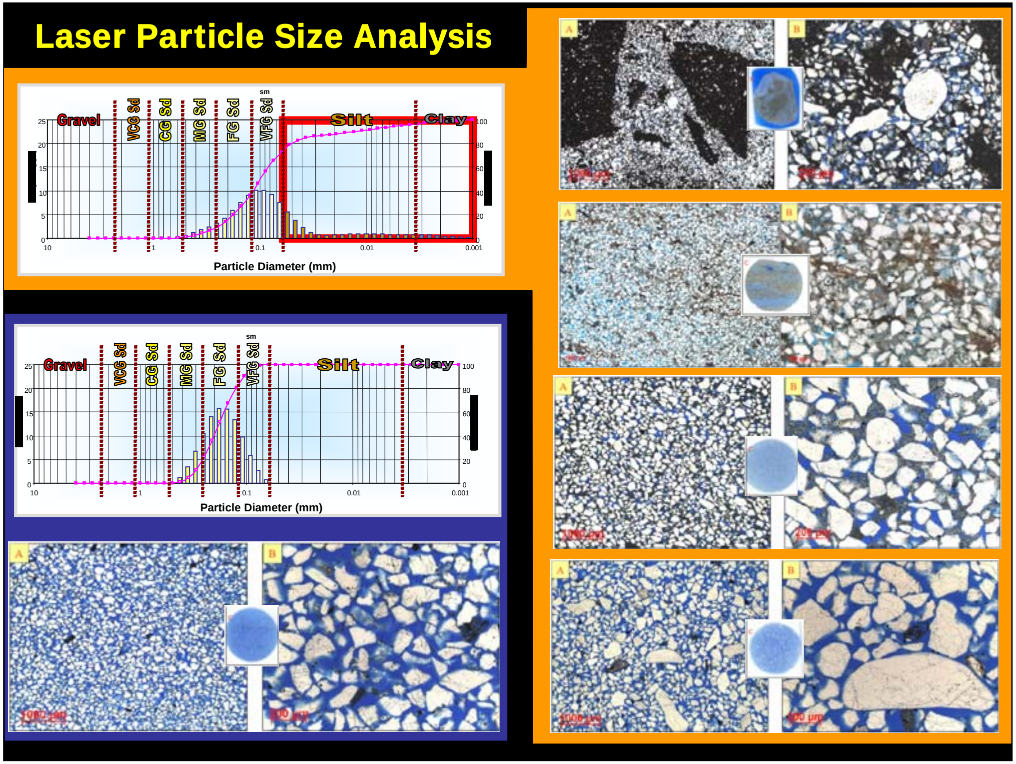
Jolliet is an excellent example of a producing sand-prone MTD. It is instructive to realize that this particular unit was a woeful underproducer –estimated End of Field Life value for Jolliet is NEGATIVE $750 M. Review of reserves estimates (MMS website) for Jolliet and sister field, Marquette, show substantial downward revisions over time, associated in part with reservoir performance issues.

Contorted beds (slump) readily seen on image log but only faintly visible on core



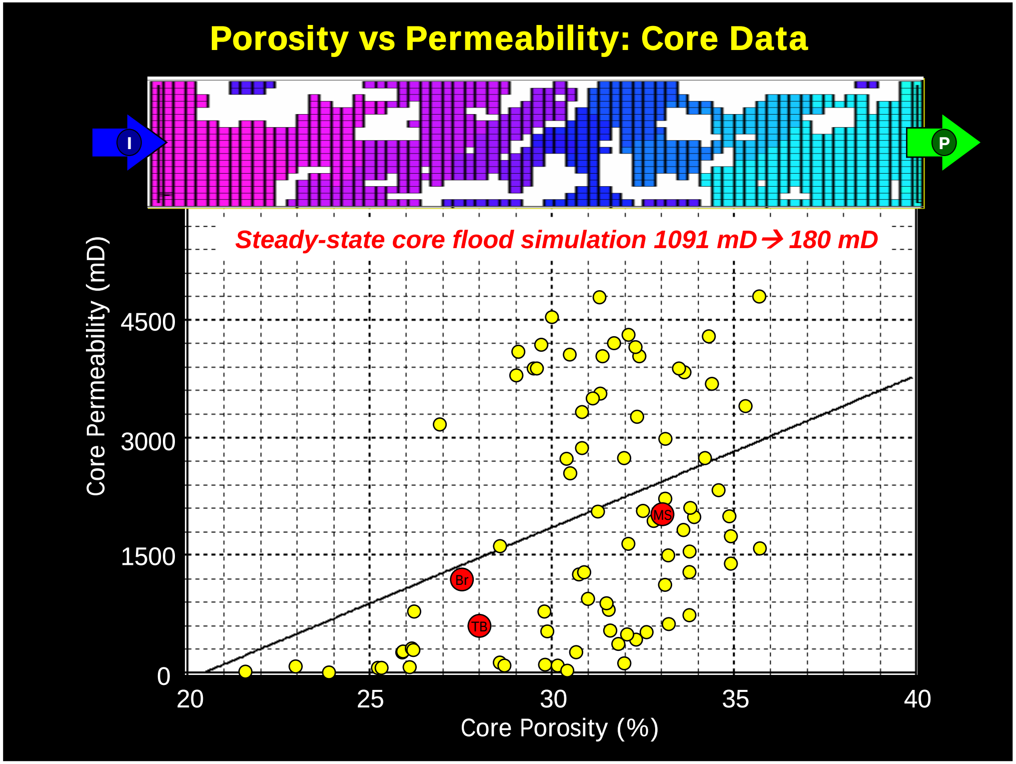
(Kuecher, 2000)


Depth
GAMMA RAY
Image Dips
3DEX DIPS
Laminar Sh
Lithology
Fabric
Deformed?
2300
2310
2320
2330
2340
2350
2360
2370
2380
2390
2400
2410
2420
2430
2440
Pattern indicates undisturbed reservoir rocks
Zone 4
Low angle dipping interval
Fractured and pebbly interval
Zone 3
Low angle dips
Abrupt dip change
Pattern indicates disturbed reservoir rocks
Zone 2
Steep dipping slumped block
Shaly interval with steep dips – slumped?
Dip pattern computed from 3DEX is believed to be a processing artifact by averaging chaotic dips over this interval
Drape at base of zone
Slumped
Folded or dip azimuth changes due to tilting of the substratum



Presenter's Notes:

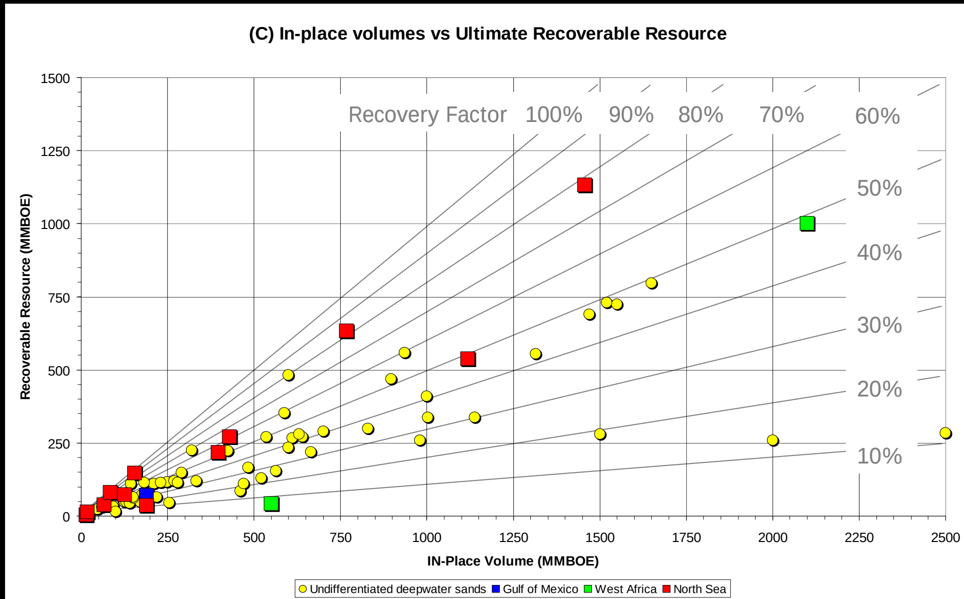
4 representative sand-prone MTD coreplugs (orange background) compared to a representative turbidite coreplug (blue background).



Presenter's Notes:

Core-derived poro-perm relationships for all sand coreplugs within a reservoir interval, and the average values for breccias (Br), thin beds (TB), and massive sands (MS). The grid at top is a digitized version of a 0.5 m long core-barrel in the same reservoir interval. I = injector; P = producer. Color scale represents saturation at end of flow simulation. Static properties were based on core values. Effective perm for this interval is ~20% that of the measured static perm.

Reservoir Performance Paramenters



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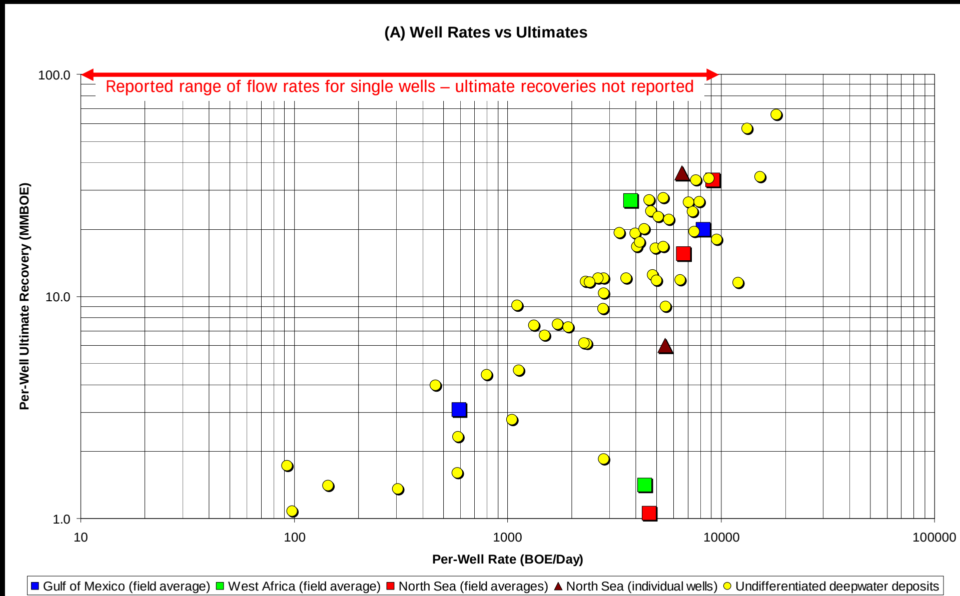

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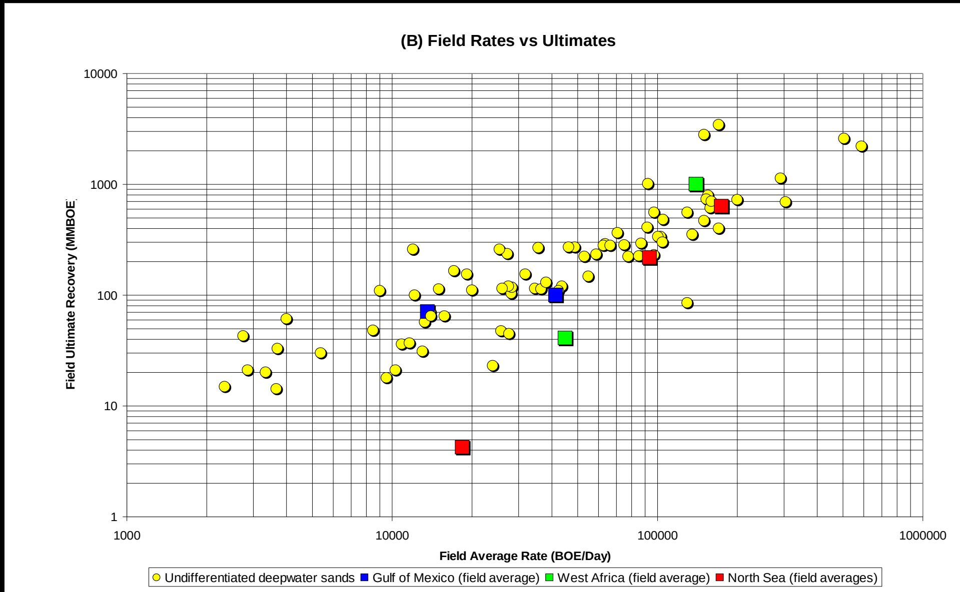

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Acknowledgements

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Mark Partington
Frank Peel
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Mihaela Ryer
Craig Shipp
Ru Smith
Pete Talling
Willem v/d Merwe
Paul Ventris
Paul Weimer
Charlie Winker
Lesli Wood

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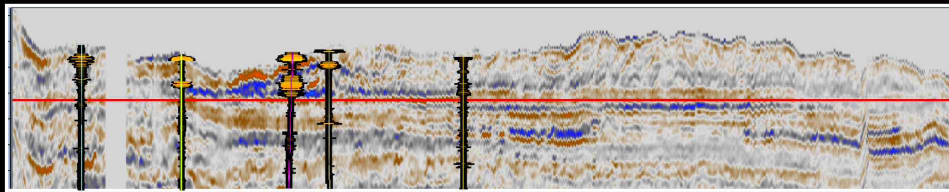
Papers in press: SEPM Special Publication 95 (2010)

Mass-Transport Deposits in Deepwater Settings



- Reservoir Characteristics and Classification of Sand-Prone Submarine Mass-Transport Deposits
- Reservoir Characterization of Sand-Prone Mass-Transport Deposits within Slope Canyons

woodside