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

Trey Meckel¹

Search and Discovery Article #50270 (2010)
Posted July 16, 2010

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

¹Woodside Energy (USA) Inc. (trey.meckel@woodsideenergy.com)

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


Classifying and Characterizing Sand-Prone Submarine Mass-Transport Deposits

Trey Meckel

Woodside Energy (USA) Inc.
trey.meckel@woodsideenergy.com

14 April 2010
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.
### 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.
(1) How many of the mass-transport deposits visible in this section are likely to be sand-prone?
(2) Can you find the 500-million barrel (STOIIP) oil field?

**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.
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.
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 injected sands, variable dips, broken/faulted shale beds, and ‘wispy’ saturations at bed boundaries. Also note excellent oil saturations. Compare and contrast with preceding two slides – all three occur in vertical association. This suite of core is shallowest in the 3-slide succession.
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).
**Mass-Transport Deposit (MTD)**

- Size and Shape
- Comparative Morphology
- Seismic, Outcrop, and Log Characteristics
- Core and Petrophysical Characteristics
- Reservoir Performance Characteristics

**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

**Presenter's Notes:**

All images shown at identical scales. Compare and contrast ‘typical’ morphologies of the three major reservoir-prone deepwater facies types.
**Comparative Scales**

**Length vs Width**

![Graph](image)

**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.
Representative Dimensions of Sand-Prone MTDs
- Length: 0.1 – 20 km
- Width: 0.05 – 15 km
- Thickness: 5 – 200 m
- Width/Thickness ratio ~ 50:1
- Cf. channel W/T ratio ~ 40:2 – 20:2
- Length/Width ratio ~ 5.1 – 4.3 (avg. ~ 4.1)
- Aspects Ratio (Length/Thickness) < 100

Comparative Scales
Thickness vs Width

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.
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.
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?
**MTD Log Characteristics**

*Selected Wells, Atwater Fold Belt, Gulf of Mexico*

<table>
<thead>
<tr>
<th>Well</th>
<th>Location</th>
<th>Production Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenzi</td>
<td>GC 653-1</td>
<td>Excellent production</td>
</tr>
<tr>
<td>Mad Dog</td>
<td>GC 782 A-4</td>
<td>Average production</td>
</tr>
<tr>
<td>K2/Neptune</td>
<td>GC 562-2</td>
<td>Poor production</td>
</tr>
<tr>
<td>Atlantis</td>
<td>GC 743-DC124</td>
<td>Not producing</td>
</tr>
</tbody>
</table>

*Mike Moore (13 April 2010)*

- Shenzi - excellent production
- Mad Dog – average production
- K2/Neptune - poor production
- Atlantis - not producing

*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.
Blue: Low amplitude continuous
Green: Low amplitude chaotic
Yellow: High amplitude mounded
Red: High amplitude continuous

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

Thin-bedded turbidite system
(Channel-levee complex?)

Massive, graded sand

Muddy debrite

Typical (?) Vertical Facies Assemblage
El Gordo “Megabed”, Spain

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 ± floating clasts
- Conglomerates
- Convolved 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—it’s 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)
Folded or dip azimuth changes due to tilting of the substratum

Low angle dipping 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 3DSE is believed to be a processing artifact by averaging chaotic dips over this interval!

Drape at base of zone

Zone 4
Low angle dipping interval

Fractured and pebbly interval

Pattern indicates undisturbed reservoir rocks

Steep dipping slumped block
Shaly interval with steep dips – slumped?

Dip pattern computed from 3DSE is believed to be a processing artifact by averaging chaotic dips over this interval!

Drape at base of zone

Pattern indicates disturbed reservoir rocks

Low angle dipping interval

Slumped

Folded or dip azimuth changes due to tilting of the substratum
**Presenter's Notes:**

4 representative sand-prone MTD core plugs (orange background) compared to a representative turbidite core plug (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 Parameters

(C) In-place volumes vs Ultimate Recoverable Resource

Recovery Factor 100% 90% 80% 70% 60% 50% 40% 30% 20% 10%

IN-Place Volume (MMBOE)

Recoverable Resource (MMBOE)

- Undifferentiated deepwater sands
- Gulf of Mexico
- West Africa
- North Sea
(A) Well Rates vs Ultimates

- Reported range of flow rates for single wells - ultimate recoveries not reported

- Gulf of Mexico (field average)
- West Africa (field average)
- North Sea (field averages)
- North Sea (individual wells)
- Undifferentiated deepwater deposits
Reservoir Performance Parameters

(B) Field Rates vs Ultimates

Field Average Rate (BOE/Day) vs Field Ultimate Recovery (MMBOE)

- Undifferentiated deepwater sands
- Gulf of Mexico (field average)
- West Africa (field average)
- North Sea (field average)
Conclusions

MTDs vs Turbidites
- Seismic Morphology
  - Cross Section
  - Map View
- Seismic Facies
- Dipmeter/Image Logs
- Core Facies and Facies 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
Acknowledgements

Tony Almond
Lawrence Amy
Matt Angelatos
Gill Apps
Pete Bekkers
Richard Blythe
Rob Butler
Steve Cossey
Bryan Cronin
Mason Dykstra
Steve Flint
Bill Galloway
Mike Gardener
Dawn Herrington
Dave Hodgson
Rob Kirk
Ben Kneller
Simon Lang
Val Lincecum
Shona MacDonald
Adrian Manescu
Bill McCaffery
Roddy McGarva
Lorena Moscardelli
Mark Partington
Frank Peel
Carlos Pirmez
Mihaela Ryer
Craig Shipp
Ru Smith
Pete Talling
Willem v/d Merwe
Paul Ventriss
Paul Weimer
Charlie Winker
Lesli Wood

Woodside Energy (USA) Inc.
BHP Billiton, Marathon Oil Corporation, Maxus Energy Corporation
Reservoir Characteristics and Classification of Sand-Prone Submarine Mass-Transport Deposits

Reservoir Characterization of Sand-Prone Mass-Transport Deposits within Slope Canyons