Mudstone-Clast Breccia Project, LLSW
--Don Cummings--

Diagram:
- **GOOD**
  - Steam chamber
  - Loosely packed breccia
  - Higher permeability breccia (e.g., loose packing)
  - Larger steam chamber
  - Faster initial production

- **Threshold?**

- **BAD**
  - Tightly packed breccia
  - Lower permeability breccia (e.g., tight packing)
  - Smaller steam chamber
  - Slower initial production
Breccia: Definition

Clast content (30%) set low on purpose (palaeohydraulic significance).

Clast angularity set high on purpose (‘transport’ significance).
Questions
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Different genetic types?
Different provenances?
Different depositional processes?
Which ones are “good”? Which ones are “bad”?

1 – Collapse Breccia
2 – Channel Lag Breccia
3 – Tidally-formed Breccia
4 – Breccia related to IHS
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1
2/3
4
Supratidal
Intertidal
Cutbank

Point bar
Questions

- How can we distinguish breccia petrophysically (without core and/or image logs)?
- What type of breccia can we see on seismic? How thick of a deposit does it need to be?
- What cut-offs can be used for breccia for our EBIP/reserves?
- What does a baffle versus a barrier look like?
- What is the spatial distribution of a breccia deposit?
- Continuity? Relationship to reactivation surface? Where are specific types of breccia commonly found (predictability)?
- Can breccia be visually classified to determine discrete ranges of vertical permeability?
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Study area & dataset

45 wells (300 m spacing)
Study area & dataset

3-D seismic
Initial observations (May 2014)
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Almost invariably matrix supported
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Commonly associated with massive sand interbeds
Initial hypothesis (May 2014)
Initial hypothesis (May 2014)

- Turbidite fans
- Glaciofluvial outwash fans
- Huanghe

Brian Rust: Sediment gravity flow from bank failure

Nope...these are definitely hyperconcentrated flood flows
Initial hypothesis (May 2014)

Braided fluvial, Hawkesbury Fm, Australia

Initial hypothesis (May 2014)

River floods: Dirty because of flow, not flowing because of dirt.

Sediment gravity flow: Flowing because of "dirt"
Initial hypothesis (May 2014)
McMurray breccias were deposited by Huanghe-type hyperconcentrated flood flows.
Method

June 15 to Aug 1
- Get oriented using seismic
- Log core
- Bring in Kyungsik Choi (1 week)
- Visit Fort McMurray outcrops

Last two weeks
- Correlate
- Quantify breccia texture using image analysis
Observations
Observations

Seismic

*Large NW-dipping reflections*

4-7° NE dip; 30-40 m thick

*Courtesy of Sean Lovric (Nexen)*
Assemblage 3 paleochannel LLSW

Estimated paleochannel dimensions

- 700 m (minimum) width
- 4–7° dip
- 35° dip??
- Cut bank
- ~50 m height
Observations

14 facies
Observations

Top of Assemblage 2 is commonly muddy

Facies 10
Grey siltstone ("mud plug")

Facies 7
Unbioturb mud & sand

Facies 8
Bioturb mud & sand
Observations

Base of Assemblage 3

Either massive sand + breccia (Facies 4 + 3)

...
Observations

Base of Assemblage 3

Either massive sand + breccia (Facies 4 + 3) or dunes (Facies 2)
Observations

Dune cross-set thickness
(Assemblage 3)

Dune cross-set thickness (cm)

Frequency (%)
Facies 5
Current rippled sand

Facies 7
Unbioturbated mud and current rippled sand
Observations

Rare neap-spring like tidal rhythmites observed within muddy layers.
Facies 8
Bioturbated mud and sand
Observations

SIDERITE

In-situ siderite nodules were only observed in Assemblage 2 and continental.
Observations

MUD PLUG

No mud plug observed at top of Assemblage 3.
Breccia: General observations
Breccias are commonly matrix supported. The matrix is always massive fine sand.

Coarse sand layers do occur, but they are typically associated with dunes.
Breccia: General observations

Detrital coaly bits, which are abundant in dunes, are not observed in the breccias.
Some breccias in Assemblage 3 contain pebble-sized detrital siderite nodules...
Breccia: General observations

...and boulder-sized mud-plug clasts.
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Breccia: General observations
Large, flat clasts tend to have a pseudo-horizontal orientation (± 25°). By contrast, the orientation of smaller clasts between larger clasts tends to be more variable.
Rarely, clasts in breccia are oriented at high angles, much greater than angle of repose.

These steeply dipping breccias were observed in two cores, both times directly at the base of Assemblage 3.
In terms of stratigraphic position, almost all breccia in Assemblage 3 occurs at or near the base of the assemblage.
Thick accumulations (up to 5 m) of massive sand only occur in association with breccia, never with dunes.
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Breccia layers in Assemblage 3 are difficult to correlate from well to well (lithostratigraphy).
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Distribution of breccia at base of Assemblage 3
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Breccia tends to occur where (1) Assemblage 3 is thickest...
Distribution of breccia at base of Assemblage 3

Breccia tends to occur where (1) Assemblage 3 is thickest and (2) underlying heterolithics or mud plug is absent at top of Assemblage 2.
Initial hypothesis (May 2014)
McMurray breccias were deposited by Huanghe-type hyperconcentrated flows.
Current hypothesis

I was wrong.
The weight of evidence seems incompatible with a Huanghe-type hyperconcentrated flood model.

-Why no coaly bits?
-Why only fine sand in breccia zones?
-Why limited downflow continuity?
-Why is the thick massive sand only found where breccia is found?
-Why high-angle breccia?
Current hypothesis

Cutbank failure during floods

Lower Mississippi

Laury, 1971

Nittouer et al., 2008
Levee Failure on the Mississippi River

Julien and Vensell (2005)
Current hypothesis

Cutbank failure during floods

- Why no coaly bits?
- Why only fine sand in breccia zones?
- Why limited downflow continuity?
- Why is the thick massive sand only found where breccia is found?
- Why high-angle breccia?
Breccia facies vs flood stage

1. Rising stage
   - Banks somewhat stable
   - Rounded clasts

2. Falling stage
   - Banks destabilize
   - Massive sand & angular breccia
What about point bar failure?

Nardin et al (2012) argues it is dominant at Syncrude Mine. Definitely occurs at the McMurray type section. However, I do not think it is significant in LLSW. There is very little breccia in the IHS in LLSW.
Breccia facies

I feel confident dividing the LLSW breccia up into four breccia subfacies. Each of these subfacies is visually distinct, and each is interpreted to have a unique provenance and/or mode of deposition. Each is also interpreted to be diagnostic of a particular subenvironment in the point-bar/channel thalweg system.

**Facies 3A**  Rounded large-clast breccia

**Facies 3B**  Angular breccia with massive sand interlayers

**Facies 3C**  Isolated mudstone boulders

**Facies 3D**  Angular breccia with limited lithologies
**Facies 3A**  Rounded large-clast breccia

**Key traits**
- Rounded clasts
- Intergradational with Facies 3B
- Commonly impoverished in smaller, flakey clasts relative to Facies 3B
- Can contain detrital siderite nodules & mud-plug clasts
- Commonly occurs beneath Facies 3B at/near base of channel

**Interpretation**
Cutbank material that *aggraded rapidly beneath highly concentrated flows* in channel base when sand supply from bank failure was high, but not so high to prevent limited down-channel transport (10s of meters?) before being rapidly buried. Because this facies is commonly observed at the base of channels, below Facies 3B, it may in some cases have formed during the rising limb of a flood, when banks were still somewhat stable due to water pressure.

**Rising stage – bank relatively stable**
Limited down-channel transport (<<1 meander wavelength)
**Facies 3B** Angular breccia with massive sand interlayers

**Key traits**
- Typically associated with LOTS of massive sand
- Can grade in and/or out of massive sand
- Typically lots of small flakey clasts
- Commonly occurs above Facies 3A near base of channel
- Thick (up to 5 m) massive sand can occur above

**Interpretation**
Cutbank material deposited very rapidly from subaqueous grain flows in channel base when sand supply from bank failures was high. No down-channel transport; only downslope transport. This facies is commonly observed above Facies 3B near the base of channels. As such, it may have commonly been deposited during the falling limb of a flood, when pressure release on cutbank instigated widespread bank failure and groundwater-sapping flowage of cutbank sand into channel (e.g., Coleman, 1969; Laury, 1971).
**Facies 3C**  Isolated mudstone boulder

**Key traits**
- Big (up to 3 m diameter) and “out of place”
- Typically “mud plug” facies (thrfr cutbank derived)
- Commonly deformed (soft sed or brittle), but not always
- Stratification within mudstone can be tilted, and commonly intersects top or bottom contact at an angle.
- Commonly isolated, near or at base of channel. Not sure these form layers.

**Interpretation**
Chunk of mud plug that sheared off cutbank due to gravity and/or fluid stress, then rolled and/or slid downslope to channel base. Limited to no down-channel transport. May in some cases form part of cutbank-derived sediment gravity flow or slump.
**Facies 3D** Angular breccia with limited lithologies

**Key traits**
- Typically one single mudclast lithology; same one as surrounding in-situ muddy strata
- Clasts may be large or small, but are invariably flakey
- Not interbedded in thicker breccia-massive sand stones.
- Located in IHS

**Interpretation**
Sediment gravity flow evolved from point bar failure and deposited on point bar. In some cases, Facies 3D may fill shallow channels on point bar (e.g., Nardin et al., 2012; also McMurray type section). This type of breccia is very rare in LLSW (I had to struggle to find the above photo).
In terms of volume, it’s all about **Facies 3A & 3B**. The others breccia facies are volumetrically insignificant.

**Facies 3A**  Rounded large-clast breccia

**Facies 3B**  Breccia with massive sand interlayers

**Facies 3C**  Isolated mudstone boulders

**Facies 3D**  Angular breccia with limited lithologies
Lessons learned

Lesson 1. Channel-base indicators
   a) Breccia + massive sand zones
   b) Thick (>50 cm) dune cross-sets
   c) Mud plug boulders
   d) Round-clast breccia +/- detrital siderite nodules
   e) Coarse sand layers

(Breccia by itself is not a good channel base indicator.)
Mississippi River
Allison and Mesehle (2010)
Lessons learned

Lesson 2. Breccias tend to have limited lateral continuity (<200-300 m)
Lessons learned

Lesson 3. Cutbank failure is key in LLSW. Other mechanisms unimportant.
Lessons learned

Lesson 4. Rounded breccias at channel base = Rising stage deposits?

1. Rising stage
   - Banks somewhat stable
   - Rounded clasts

2. Falling stage
   - Banks destabilize
   - Massive sand & angular breccia
Lessons learned

Lesson 5. Angular breccias & massive sands = Falling stage deposits?

1. Rising stage
- Banks somewhat stable
- Rounded clasts

2. Falling stage
- Banks destabilize
- Massive sand & angular breccia
Recommendations

1. Image analysis – Phase 2
Shop out the breccia image analysis if you want to continue with this. ImageJ works fine, especially for (a) matrix vs clast content and (b) c-axis length. Plus, it’s freeware, and there is a “cookbook” how-to guide that I will be submitting with final report. Might as well forget about other measurements (e.g., rounding) due to edge effects. It takes longer than expected to get images ready for analysis: one well with abundant breccia takes 1 to 2 days to process. Don’t worry about genetic breccia classes; just crunch the numbers.

2. Breccia layer thickness-width relationships
Method A: Visit the Syncrude mine and/or outcrops. Measure width & thickness of as many breccia units as possible (in 100 m spaced wells or from pit face). Plot width vs thickness to see if there’s a trend.
Method B: Expensive, but better method. Drill a bunch of closely spaced wells. (Make the well spacing the “critical distance” for steam chamber development, whatever that is → talk to Rudy.) Observe how the breccia changes laterally.
Recommendations

3. Shear-wave seismic?
Try shooting some SH-wave, and compare it against P-wave. In high-res groundwater studies I’ve worked on, reflections beneath thick gravel were commonly obscured in SH-wave data more so than P-wave data, including the high amplitude reflection typically generated by bedrock. We used this method to find gravel aquifers in surficial sediment. Not sure if it would work on breccias in the “bedrock”, but you never know. (For more info, search for references by André Pugin (GSC-Ottawa), or give him a call.)
Recommendations

4. No core? That’s a problem...
Without core, it is difficult/impossible to differentiate massive sand from dunes, to identify the thin layers of coarser sand that commonly demarcate channel bases, and to identify mudclast breccia and mud-plug boulders. At a minimum, core photos plus a detailed core log are needed. One option to minimize costs would be to collect core, photograph and log it, sample it extensively, then discard it. (This is what we do on many groundwater studies due to lack of a core storage facility.) You can go a long way with core photos and a good core log. Without them, mapping lithofacies and lateral accretion packages (“assemblage mapping”) will be problematic, thus reducing the ability to predict steam chamber growth and behaviour.
5. Visit the McMurray type section with Rudy
I learned a lot at the Fort McMurray outcrops, in particular the type section (the only outcrop with considerable breccia). Everyone working on the McMurray should visit the outcrops.
Thanks

Noel, Chris, Vince and Sean