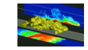
Numerical Simulation of Turbidity Currents within BHP Billiton – 40 Flow Dual Basin Case

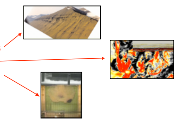


Moshe Strauss (NRCN), Eckart Meiburg (UCSB), Ben Kneller (Univ of Aberdeen), Michael Glinsky, Chris Lerch, Stas Kuzmin (BHP)

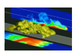
Business Focus

The assets need **predictive models for turbidite reservoir presence, quality, and connectivity**. These are the critical parameters for reservoir performance. One of the ways we arrive at these predictive models is through BHP Billiton's stratigraphic prediction technology program, which includes work on the **self organization of turbidites in space and time**. Components of this technology theme include analysis and documentation on:

- **Outcrop/subsurface analogs**
- **Modern seafloor analogs**
- **Experimental (flume) results**



Various issues relating to incompleteness of outcrop/subsurface data, inability to effectively monitor modern day flows, and experimental scaling issues cause gaps in our full understanding of turbidite processes. **Numerical simulation of turbidites can provide the link between these imperfect datasets**.



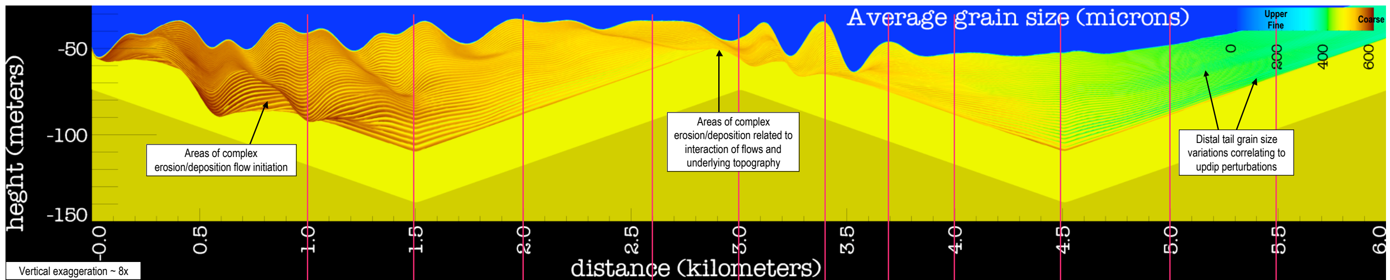
Background and Theory

Models for turbidity currents range from the very simple to the very complex. Simple analytical solutions are computationally cheap but are not accurate and yield little detailed data. Direct numerical simulations are yield accurate solutions but are computationally expensive. **Eckart Meiburg and others at UCSB generated a 3D direct numerical simulation as shown above**. This was the seed point for the simulation shown to the left. However through the funding of BHP Billtion several additional capabilities have been added currently in a 2D mode:

- **Multiple grain sizes**
- **Multiple flows**
- **Varible substrate topography**
- **Erosion of substrate**
- **Resuspension of eroded material**
- **Graphical displays of grain size, sorting, and pseudo well logs**

3D simulation with the capabilities above is currently being tested in a proof of concept model

Average Grain Size of Deposit

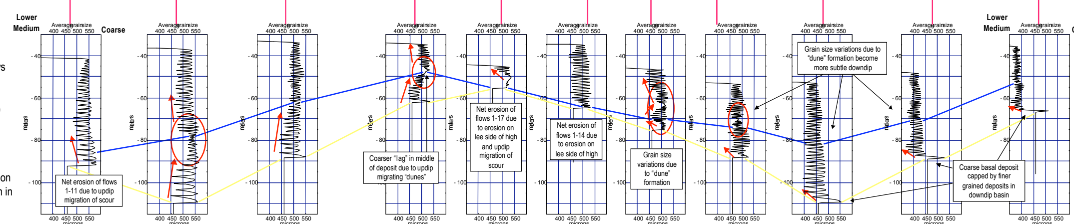


Pseudo-GR Well Logs

Pseudo gamma ray (average grain size) well logs have been generated at numerous points along the profile to show the autocyclic variation in grain size and bed thickness (red arrows and ellipses to right, respectively)

In addition correlation lines for the substrate (yellowish-green) and 15th flow (blue) are shown on the right. It is obvious from this correlation that significant surfaces updip correlate to the subtle vertical variation in grain size downdip.

In particular it appears that the major growth in "dune" formation over the intra-basinal high is correlative to a general reduction in grain size in the distal tail. This appears to be related to a trapping of coarser grain sizes in the dune area due to topographic effects. Other features are noted to the right.



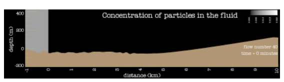
Flow Dynamics

The simulations being run employ a simple "lock exchange" process where a vertical lock on the left side of the model is filled with a particle-laden suspension that is mildly turbulent. The initial concentration of the suspension in this case is 2%.

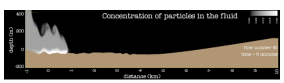
The plane dividing the higher density particle-laden suspension from the ambient fluid is removed and the gravity flow initiates

Erosion and resuspension of the underlying substrate is modeled as a diffusive flux of particles through the bottom bondary or "active layer"

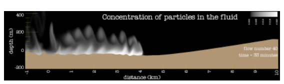
Currently grain to grain interactions are not accounted for, nor are the existence of cohesive particles



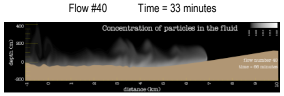
Flow #40 Time = 0 minutes



Flow #40 Time = 6 minutes



Flow #40 Time = 33 minutes



Flow #40 Time = 66 minutes

Deposit Accumulation

The initial grain population is typically defined as a series of 4 to 5 equal proportions of variable size grains. For this simulation grain size ranged from coarse-grained to upper fine-grained

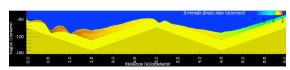
The initial topography is a dual basin profile where each sloping surface slopes at 2.5 degrees either in a downdip or updip direction

The resulting deposit from each gravity flow is quantified in terms of thickness, average grain size, and grain size standard deviation (sorting)

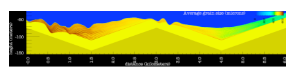
Note the areas of complex erosion and stratification on the initial downslope due to flow initiation and over the intra-basinal high due to interaction of the flows and the subsequent underlying topography.

Particularly of interest are the "dune" shaped features that develop just on the lee side of the high and then migrate with time updip. These are in the process of being more carefully studied and understood, as well as finding potential outcrop analogs

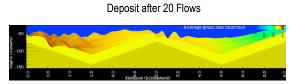
Note also the subtle variations in grain size in the tail of the deposit on the downdip backstop. These subtle variations correlate to variations in the deposit updip



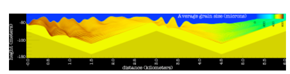
Deposit after 10 Flows



Deposit after 20 Flows



Deposit after 30 Flows



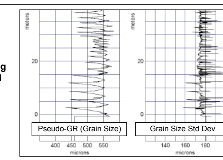
Deposit after 40 Flows

High Resolution Simulation Test

A single high resolution simulation was run here and the results have been used to analyze the detail preserved in the deposit.

Note the fine detail seen in the pseudo-GR (grain size curve) and the standard deviation of grain size. Trends within each separate flow are visible. Note the abundance of flows that first coarsen then fine up. This is most likely due to erosion of underlying flow caps and incorporation in later flow deposits

Pseudo-GR Log at 1.5 km Well



Note: grain size range shown is from upper medium to lower coarse; full deposit varies from upper fine to coarse

Flow Properties of the Resulting Deposit

Note the variation grain size standard deviation (sorting) along the resulting deposit. The updip basin is characterized by overall poor sorting and the downdip basin by transitional to better sorting.

There are also subtle vertical variations in the downdip tail area that correlate with the grain size variations seen to the left.

The "dune" area also shows zones of poorer sorting that correlate to the updip migration surfaces.

Given the variation in grain size and sorting of the deposit, one can calculate the expected flow properties in terms of porosity and permeability. This has not been done yet but it would allow simulated deposits to be analyzed in terms of expected reservoir flow and baffling/barriers

Grain Size Deviation (Sorting)