# Process-Based Modeling of Sediment Deposition and Compaction in the Peïra Cava Sub-Basin; Detailed Analysis and Sediments Distribution at Reservoir-Scale*

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Search and Discovery Article #41320 (2014)
Posted April 14, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG 2014 Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014,


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## Abstract

Turbidity currents are the most important mechanism for the dispersal and deposition of sand in the deep-sea setting and thus the main phenomenon leading to the formation of oil and gas reservoirs in deep water deposits. Turbidity currents are difficult to study from the modern environment, while their laboratory representations are typically hampered by scaling issues, unrealistic geometries, and short durations. Computational fluid dynamic (CFD) is being developed to fill the gap between small and large scale, integrating data from theory, nature, and experiments.

The deterministic process modeling CFD software MassFLOW-3D™ has been developed and successfully used to construct a three-dimensional model for the simulation of turbidity currents (Basani and Hansen, 2009; Hansen et al., 2008). All principal hydraulic properties of the flow (e.g. velocity, density, sediment concentration, apparent viscosity, turbulence intensity, bottom shear stress) and it's responses to topography can be continuously monitored in three dimensions over the whole duration of the turbidity current (Basani et al., in press).

At the scale of individual beds the petrophysical characteristics, and hence hydrocarbon reservoir properties, are controlled by the depositional processes (e.g. Barker et al., 2008) and an understanding of turbidite depositional process can be used to predict reservoir properties. A process-based approach is required to achieve a detailed prediction of reservoir properties at the bed scale.

The aim of the current study is to confirm the applicability of process-based modeling to predicting bed geometry and grain size distribution in a single bed (Marker Unit 5, MU 5) from the deep-marine Peïra Cava Basin, part of the Eocene-Oligocene Annot Sandstone, southeast France,

which has been extensively studied (Amy et al., 2007). The confined Peïra Cava Basin comprises sheeted sands separated by mud-caps. 18 beds, or Marker Units (MUs) are regionally correlatable throughout the present day outcrop due to their thickness and/or character.

## Method

The modeling required a seafloor surface to represent the base of this particular bed at the time of deposition, and for this purpose a paleo-seafloor surface was created through stepwise reverse and forward modeling. At present, the outcrop measures 10-12 km (north-south) times 8-10 km (west-east) and records approximately 1200 m of Annot Sandstone succession.

The reverse modeling comprised backstripping and structural restoration to produce a base Annot Sandstone palaeo-surface (Figure 1). Subsequent forward process-based modeling of the basin fill below MU5 was performed to generate the base MU5 paleo-surface, which is situated within the basin-fill.The initial basin floor was topographically complex with the deep accommodation in the north receiving the bulk of the sediment. At some point the basin floor complexity was filled up and continuous sands were deposited across the basin. The first sand that can be correlated across the entire outcrop is termed MU5. Paleo-flow indicators and scouring features in the southern part of the basin suggests that sediments were sourced from the south.

The first stage of the modeling was to recreate the pre-MU5 stratigraphy in order to capture the bathymetry onto which the MU5 bed was deposited. This was done with four composite flow events starting from the base Annot Sandstone surface with subsequent modeling of compaction and isostatic bending after each flow simulation (Figure 2). The flow simulations for the lower beds (simulations 1-4) were initiated from the top of the inbound slope with a velocity of 8m/s. These flows accelerated down-slope and were only confined by the significant sill at the end of the basin. The flows were observed to reflect, as postulated by Amy et al. (2007) and all of the sediment introduced by the flows was eventually deposited in the mini-sub-basins. The cumulative deposited thickness of the four flows matched the observed thickness in the control points, which were the criteria at the onset of modeling.

In a second phase the process-based flow simulation of the MU 5 bed, starting from the so-recreated surface, was performed. MU5 is present in 6 out of the 7 available stratigraphic logs (Amy et al., 2007; Figure 3F), which were used to constrain the input parameters for the flow simulation. Its present thickness varies from 9.5 to 19 m. The calculated thickness at time of deposition, before sediments compaction, was expected to have be 9.5 and 21.5 m. These values were used to estimate the total sediments volumes to provide to the system, and therefore the boundary conditions for the numerical simulations.

Four grain sizes were used for MU5 flow simulation: 80 µm (very fine sand), 200 µm (fine sand), 400 µm (medium sand) and 1 mm (coarse sand). The particle size population was guided by six available data-points distributed throughout the outcrop (Amy et al., 2007).

Available data (Figure 3F) suggested the proportion of each grain-size within the simulations input volume: 35% very fine sand, 35% fine sand, 20% medium sand, and 10 % coarse sand. The source of the flow was located in the southern region of the area (black arrow in Figure 1). The initial boundary velocity, as suggested by experimental values and literature about turbidity currents, was fixed to 2 m/s; nonetheless, after a short distance from the source point, it is the relief of the bathymetry which will control the flow velocity.

The total volumetric concentration was 10%, as suggested from literature for this kind of turbulence-supported gravity flow. The influx of sediment into the basin was simulated with a 15.000 seconds sustained flow followed by 20.000 seconds of quiescence to capture the settling of particles, in particular the finer fractions.

## Results and Conclusions

Detailed modeling of the specific MU5 sand bed resulted in a base-case that showed good match to the thickness at data points from the outcrop (Figure 3). With regards to the distribution of grain-sizes at the same data points, the results were encouraging for the coarse and medium sized particles, and less robust for the very fine- and fine-grain sizes.

Detailed modeling of the key bed resulted in a reasonably good match between the calculated de-compacted thicknesses of the bed at the know data-points and the sediment deposited from the flow simulation. There was a reasonable match between the observed and modeled grain size distributions, although there was some deviation. Overall, the study has confirmed the capability of the software MassFLOW-3D™ to deal with multiple grain sized turbidity currents and that processed based modeling is a useful tool for predicting the distribution of sand thickness and grain size, which in turn is a proxy for reservoir quality. We suggest that such an approach could form a part of a probabilistic workflow and be used to capture likely ranges of parameters for improved exploration and reservoir management.

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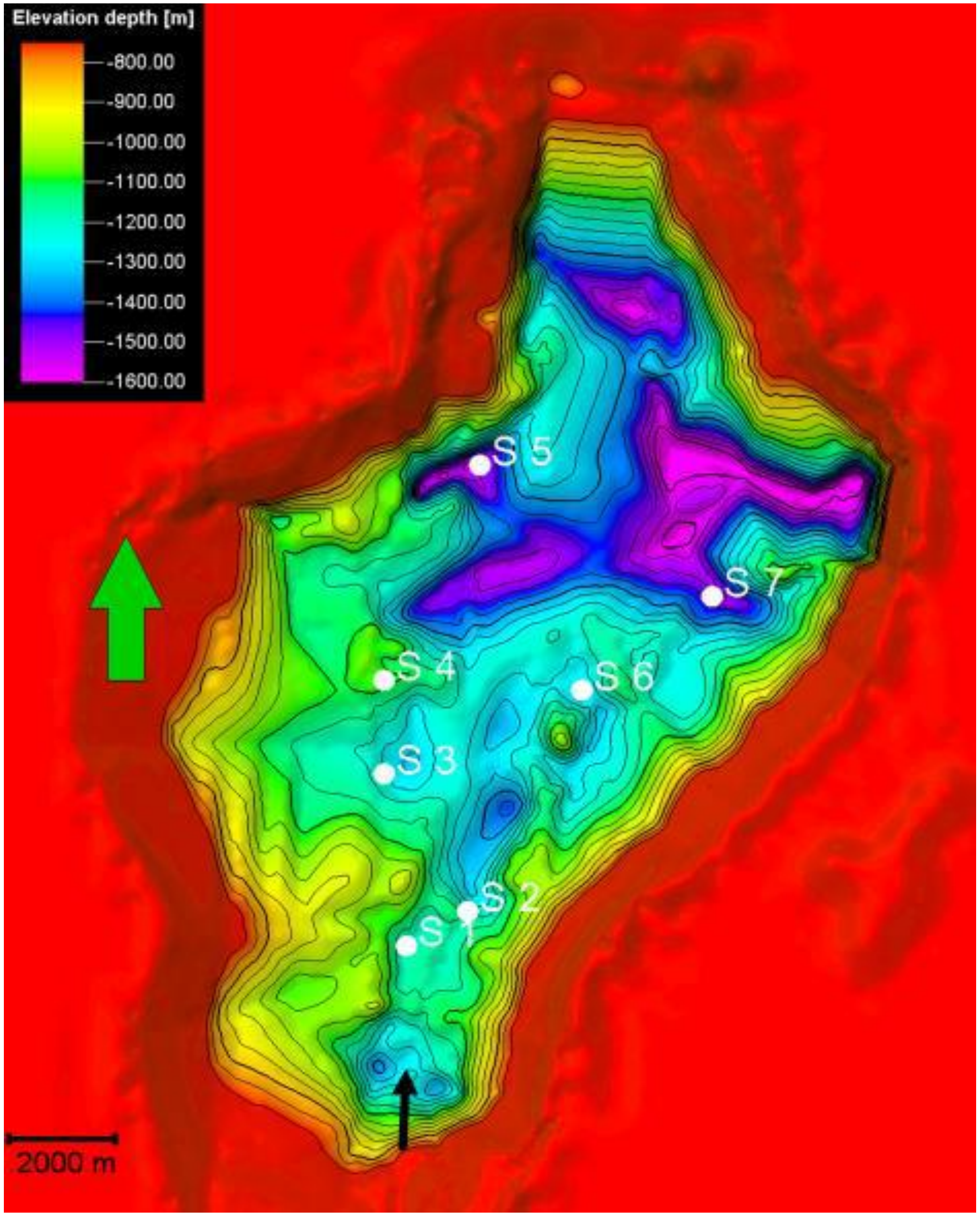


Figure 1. The paleosurface representing the base of the Annot Sandstone at the onset of gravity-flow simulations. S 1-7 are the sedimentary logs available from Amy et al. (2007). The black arrow indicates the source-point for flow simulations.

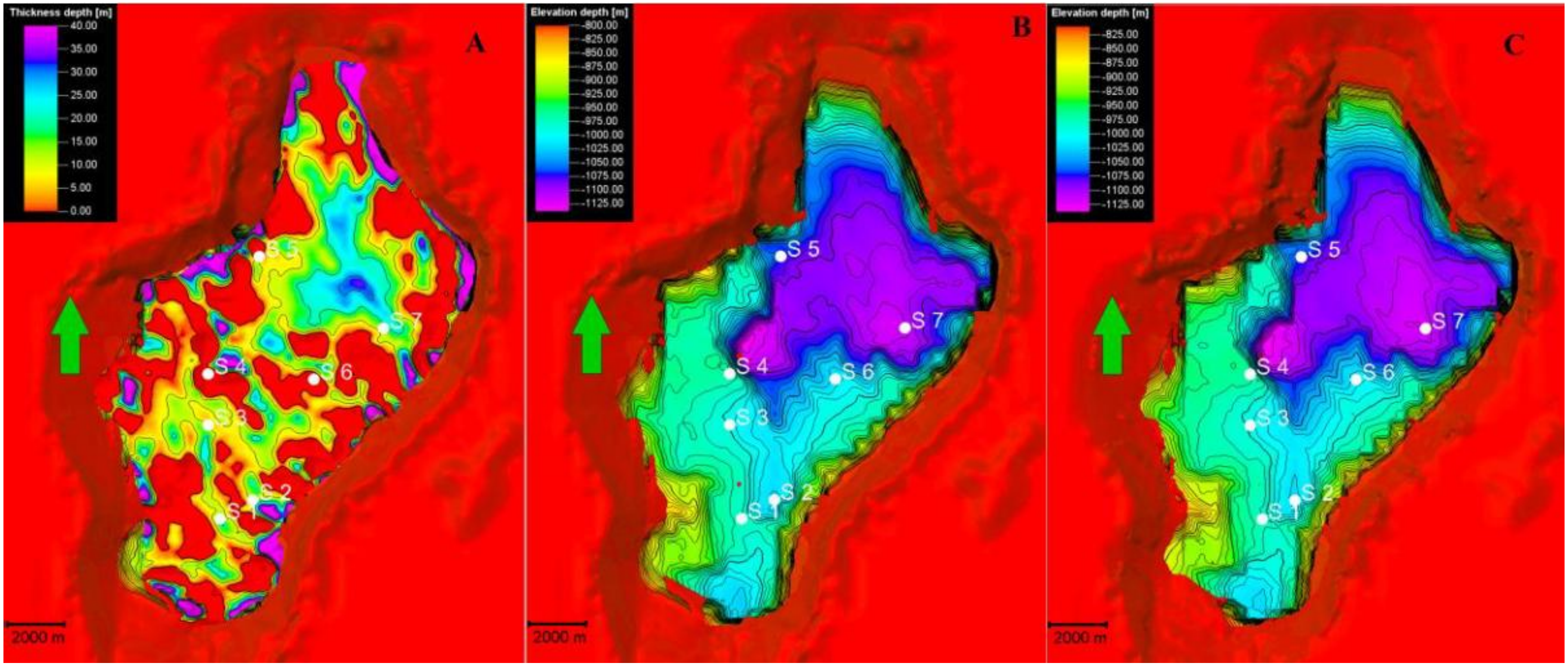


Figure 2. Results from Step 2 forward modeling. (A) Map showing areas of erosion and depositional thickness from the flow simulation of the interval MU1-MU2. The red areas show very thin deposition, non-deposition or erosion into the sediments from the underlying Flow 1. (B) The map shows the new un-compacted MU2 seabed generated by Flow 2. (C) The map displays the updated MU2 seabed after compaction. This surface became the input seabed surface for Step 3 modeling (modeling MU2-MU3 interval).

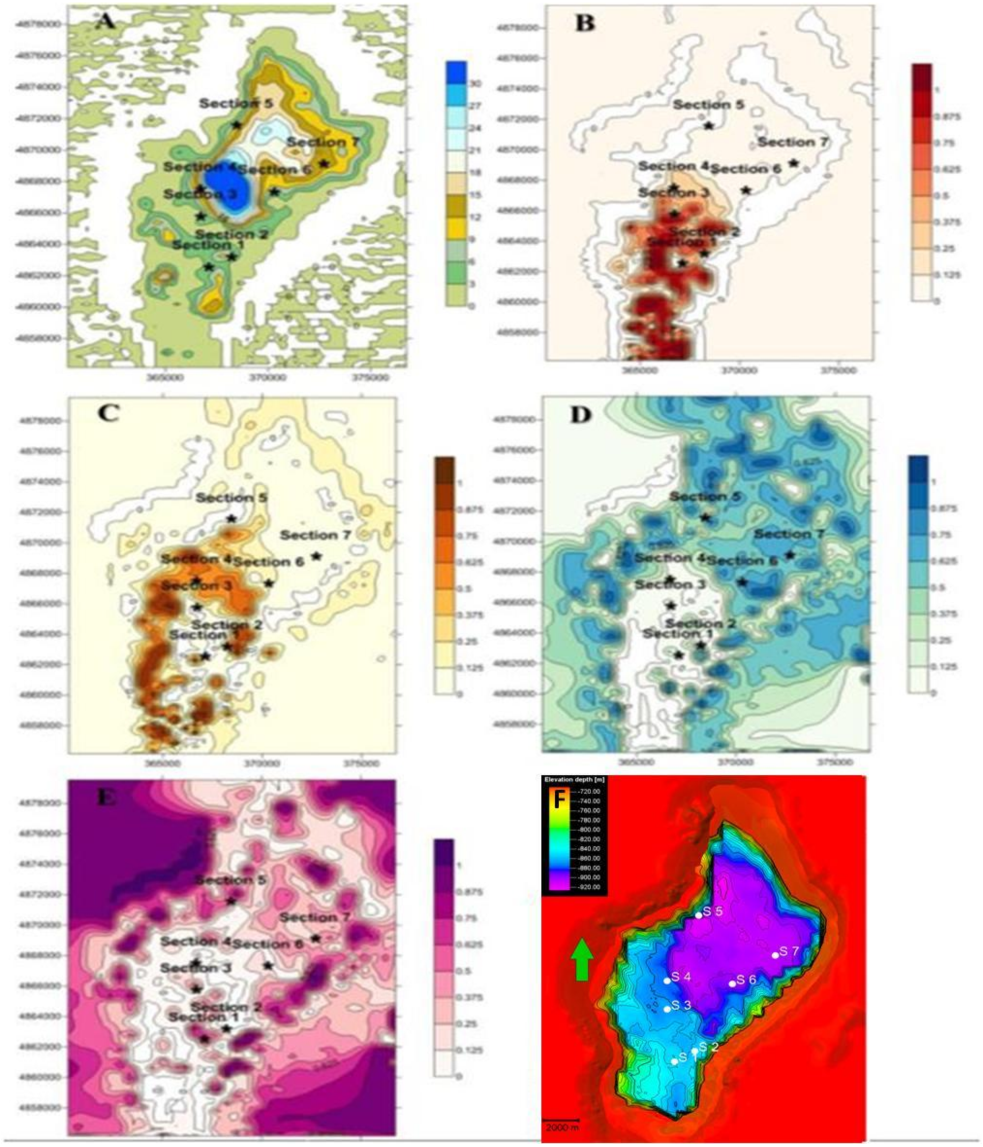


Figure 3. Results of the detailed modeling of bed MU5 and available measured present day thickness map of MU5 bed. (A) Total thickness of sediment deposited from MU5 flow simulation. (B) The fraction of coarse particles deposited from MU5 flow simulation. (C) The fraction of medium particles deposited from MU5 flow simulation. (D) The fraction of fine particles deposited from MU5 flow simulation. (E) The fraction of very fine particles deposited from MU5 flow simulation. (F) Present day thickness of the MU5 bed and distribution of grain-size fractions in the 6 available data-points. The displayed surface is the base-MU5 seafloor used for flow simulation.