Deterministic, Process Based Modeling of the Deepwater Fill of the Peïra Cava Basin, SE France*

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Abstract

Basins in which turbidity currents are completely or partially trapped are common in many tectonically active, deep-water settings. The Eocene-Oligocene Grès d'Annot Formation which crops-out in the Peïra Cava region of south-eastern France is a 1200 m thick succession of sandstones and mudstones deposited in a confined, synclinal sub-basin plunging to the north. The Peïra Cava turbidite system is dominated by interceded high- and low-concentration turbidity deposits with several marker beds that can be correlated throughout the basin fill, providing a robust stratigraphic framework for analysis (Amy et al., 2007).

Using deterministic process based simulations it is possible to recreate the flow events that deposited the basin fill. The aim of the present study is to test this methodology and investigate the role of the confinement, relief, and the size of the turbidity currents events required to reproduce the observed stratigraphy. MassFLOW-3D™ is a computational fluid dynamic (CFD) software for the numerical simulation of the physical equations describing fluid flow and sediment transport for turbidity currents. The software has been developed to model erosion, deposition, and transport of sediment in high and low-density turbidity currents, solving full 3D transient Navier–Stokes equations by a finite-volume-finite-differences method, in a fixed Eulerian rectangular grid. Flows are simulated on a structural restored, back-stripped, and decompacted palaeo-bathymetry. Given that confinement, tilting, and topography are key parameters for the development of turbidity currents and their deposits particular attention was given to recreating by-pass, fill-spill, and deflection phenomena, documented in the outcropping succession (Amy et al., 2007; Aas et al., 2010).

Discussion

The process for recreating the bathymetry involves the backstripping and structural restoration of the basin fill and overlying stratigraphy using the 3D Move software from Midland Valley. Given that there are uncertainties associated with input parameters to many of the steps in this restoration process a range of possible surfaces was produced (Aas et al., 2010). The study uses two possible palaeo-bathymetries (Figure 1A:

palaeo-bathymetry 7 (P7); Figure 1B palaeo-bathymetry 5 (P5); Aas et al., 2010). These two bathymetries offer two different degrees of confinement (P5 is 16.5 km x 21 km while P7 is 16.7 km x 27 km) and maximum depths (1000 m for P5 and 1200 m for P7).

Study of the outcrops show that the infilling was the results of 18 major events (the marker units of Amy et al., 2007) and many thousands of minor ones. To run every single one of these turbidity currents would be to time consuming for realistic deterministic process modelling so the overall stratigraphy was packaged into ten major units (MU), with a thickness of 20 and 300 m. Each stratigraphic package includes a major flow and numerous minor ones having similar characteristics (flow entry point, sediment species and concentration, velocity inlet). The numerical modelling aimed to reproduce these 10 major units as the result of 10 major gravity flows. Although this is an approximation it is believed to be adequate for studying the large scale fill of the basin and the response of flows to changing topography (fill-spill). The source point, (inflow to the basin) was located on the southern rim of the basin with a northward flow direction. The different boundary conditions, such as the turbidity current inflow dimensions, inlet velocity, grain size, and sand concentration used were based on outcrop observations and analysis found in the literature. A bi-dispersed grain size distribution of 150 µm and 75 µm was used, with constant total sediment concentration of 20% in volume (10% in volume for each sediment species) and surging flows allowed an approximation for separate events.

Figure 1 shows the bathymetries and the sediment infilling process of the two palaeo-bathymetries. The study was performed in two steps for both bathymetric surfaces. The first step was to calculate the flow duration of each surge individually in order to match the dimensions (thickness and extent) of the corresponding major unit in the outcrop. The second step performed the run on all ten flows based on the flow durations found during the first step. A defined resting time was set between subsequent surges, in order to allow the suspended particles to settle out. Cross-sections of the simulated basin fill were compared to the stratigraphic thickness observed by Amy et al., (2007) in the outcrops (Figure 2E).

Comparison of the results to the outcrops suggests that using bathymetric surface 5 did not provide a good match to the stratal packaging that was observed and the bathymetry did not confine the flows sufficiently (Figure 1B). Using Bathymetric surface 7 provided an overall good match and correctly produced areas of erosion, bypass, and deposition that matched the outcrop (Figure 1 and Figure 2E). The fill of this basin initiated with deposition that was ponded within topographic lows and the earliest units are less continuous than the subsequent, more sheet like deposits. There was a clear up-slope back-lap of the basin fill and the retrogradation of the base of slope caused a reduction in the degree of erosion by successive surges (flow events) at the slope to basin transition (Figure 2A and Figure 2D). During the simulations the interaction of the flows with topography showed both reflection and refraction as had been predicted by previous workers studying the outcrops (Amy et al., 2007).

Overall the process based modelling was able to reproduce the distribution of deposits observed in the outcrop. This suggests that while non-uniqueness may be an issue, the assumptions made for flow size, flow velocity, sediment concentration, surge time, and grain size were reasonable. Modelling the stratigraphy as 10 discrete surges rather than several thousand beds does not appear to have impacted the ability to reproduce the large scale stratigraphic architecture and mimic the fill of the basin. It does not capture however the distribution of bed scales heterogeneities. The modelling process is sensitive to the palaeo-bathymetric surface that is used.

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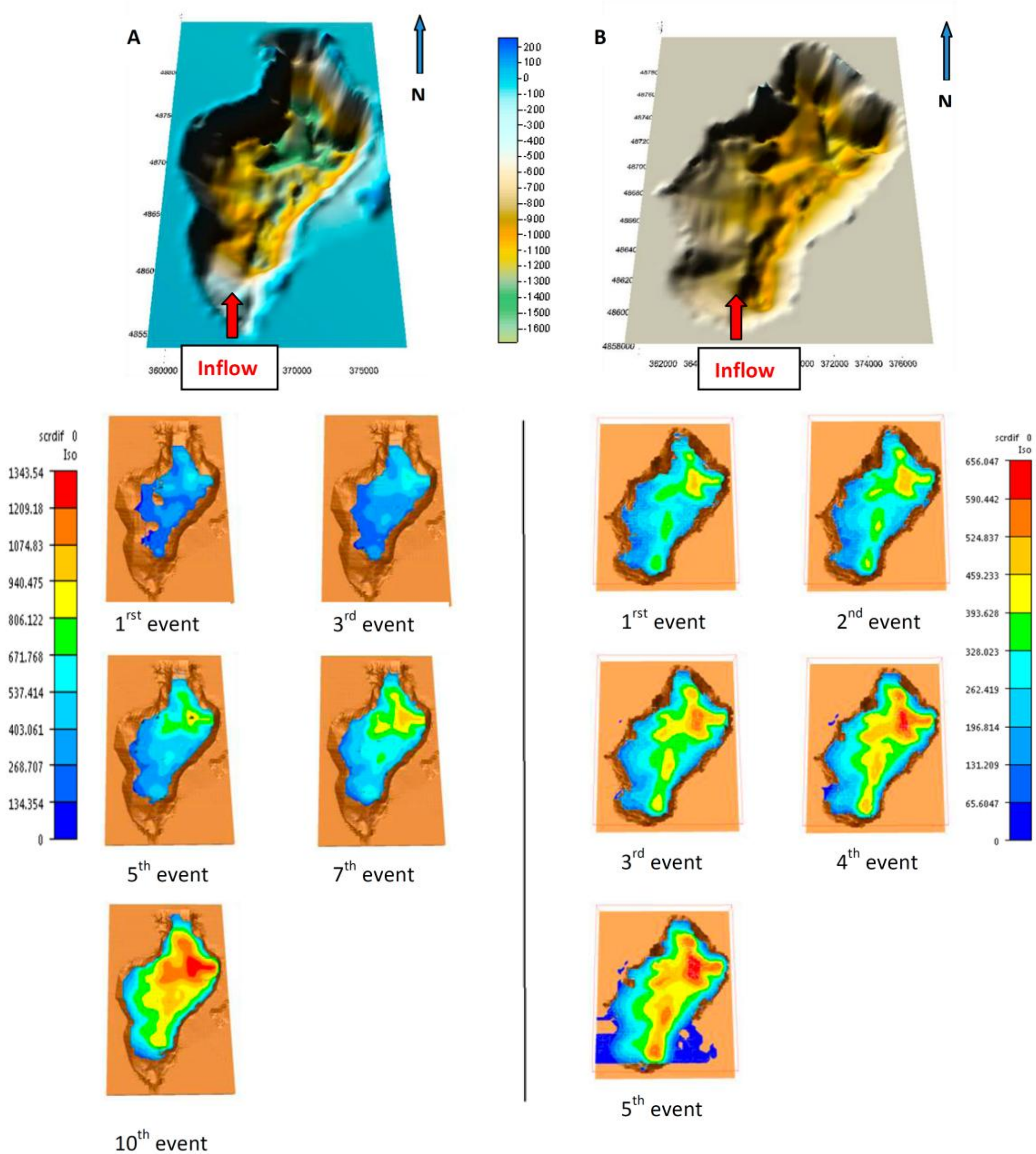

Figure 1. (A) Palaeo-bathymetry 7 colored by depth and the packed sediment thickness after the 1st, 3rd, 5th, 7th, and 10th event. (B) Palaeo-bathymetry 5 colored by depth and the packed sediment thickness after the 1st, 2nd, 3rd, 4th, and 5th event, due to a too low confinement.

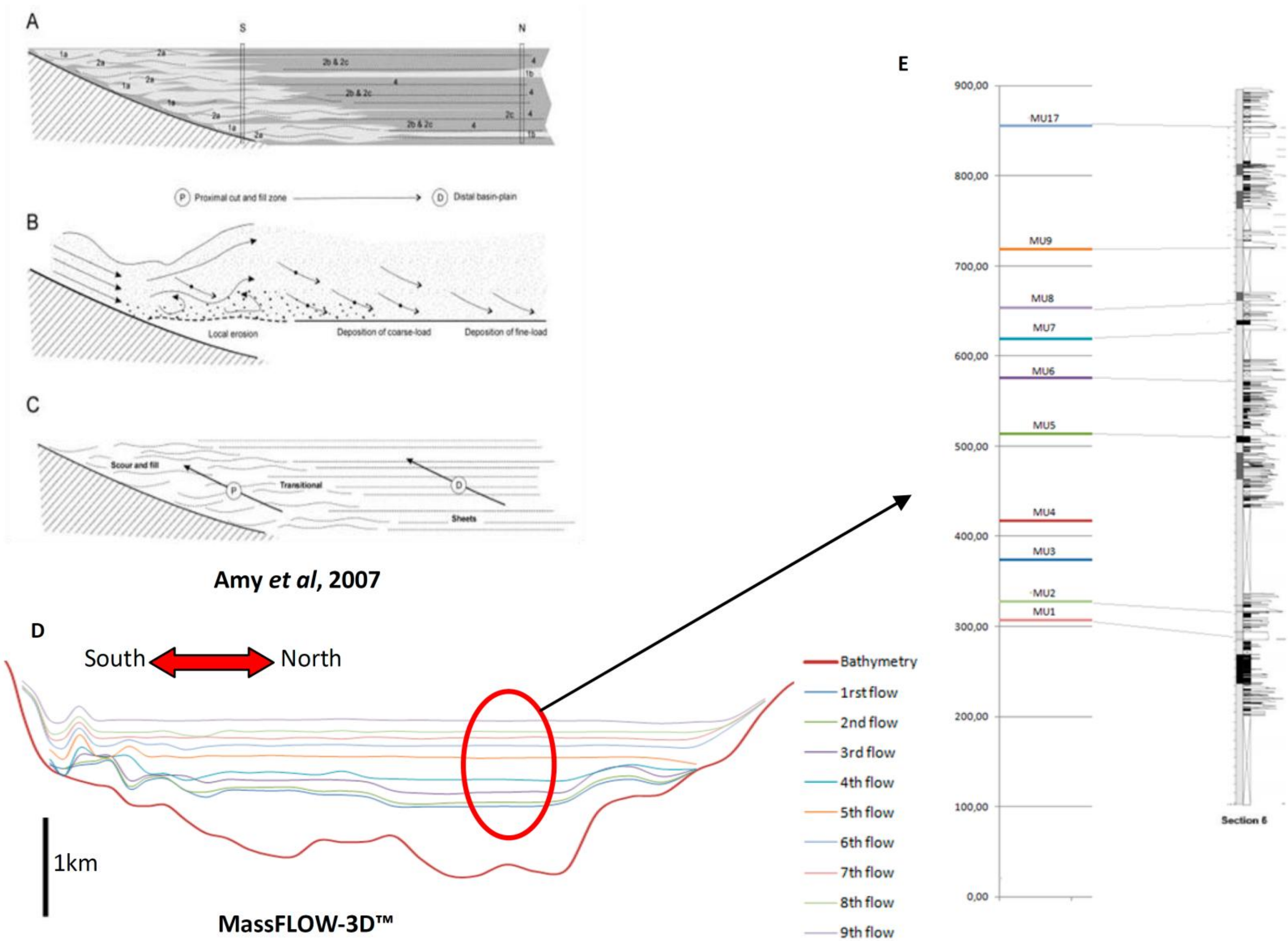

Figure 2. (A) Summary diagram of the sedimentary architecture in relatively proximal and distal environment of the Grès de Peïra Cava showing the distribution of elements (Amy et al., 2010). (B, C) Process model proposed to explain the development of different facies types (B from Amy et al., 2007) and the backward migration of depositional environment (C from Amy et al., 2010). (D) North-South cross section of palaeo bathymetry 7, with observation of aggrading and scouring behavior of the palaeo-flows with back ward migration of the depositional environments and slope break (MassFLOW-3D™). (E) Comparison between the sediment units observed in the North-South cross section and the stratified units observed on outcrop section 6 (Amy et al., 2007).