Applications of Forward Stratigraphic Modelling in Modern Settings

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Summary

Forward stratigraphic modelling (FSM) is a powerful tool to predict reservoir potential in sedimentary basins, including both siliciclastic systems and carbonate systems, and it has been widely applied in ancient depositional settings. However, it has rarely been applied in modern siliciclastic settings. It aids to reveal uncertainties in depositional settings such as sedimentation rate, water discharge, and sea level fluctuations which are difficult parameters to verify using conventional research techniques; thus, it is important to test its applications in modern settings. This study examines the applications of FSM in the well-studied Fraser River Delta, Canada. It also tests its potential applications to predict future stratigraphic architecture in modern settings (e.g., coastline morphological changes). These potential applications may help us to prevent and better manage natural geo-hazards, such as slope failures, erosion, and subsidence.

Methodology

The Fraser River Delta is located along the Pacific coast of Canada (Fig. 1). It is the largest natural river in western Canada and it has been prograding into the Strait of Georgia (SoG) for about 10,000 years following the end of the last glaciation (Clague et al., 1998; Hart and Barrie, 1995).

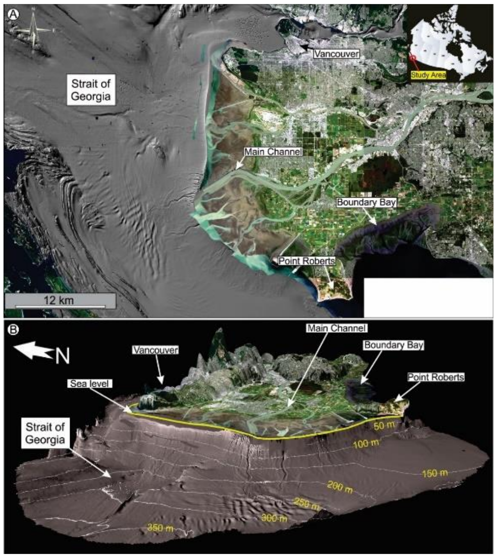

Figure 1. a) Satellite image of the Fraser River Delta. The gray scale is the multibeam-derived bathymetric map provided by the Geological Survey of Canada, Pacific Division. b) Three-dimensional block diagram of the Fraser River Delta. The solid yellow line represents low-tide sea level (contour interval: 50 m).

Between 10,000 BP and 5,000 BP the Fraser River Delta prograded approximately 13 km from the river mouth, and another ~9 km in the last 5,000 years (Williams, 1988; Williams and Roberts, 1989). The river discharge fluctuates significantly throughout the year. The mean river discharge rate is approximately 3,400 m^3/s while minimum discharge is 1,000 m^3/s and maximum discharge can reach 15,200 m^3/s during snowmelt-induced freshet (Kostaschuk et al., 1998; Milliman, 1980; Thomson, 1981). The river annually transports about 17 million tones/year of sediment. The river predominantly transports mud-size particles (i.e., silt and clay) into the SoG, but during the freshet, half of this material is sand-sized (McLean and Tassone, 1991; Pharo and Barnes, 1976).

In order to create a realistic model for the Fraser River Delta and its evolution, a 3D forward stratigraphic modelling software Dionisos© from IFP (Institut Francais du Petrole) was used. This software can handle complex basinal architectures and takes into account a large number of input parameters. The simulation covers a rectangular area of 40 x 60 km^2 with a grid size of 0.5 x 0.5 km. It also covered the last 10,000 years in two steps (step 1: 10,000-5,000 and step 2: 5,000-today) and one additional step (step 3) to test future 5,000 years. In other words, each step was 5,000 years. At first, an initial bathymetric map was generated (Fig. 2), then various parameters were tested to simulate the delta evolution.

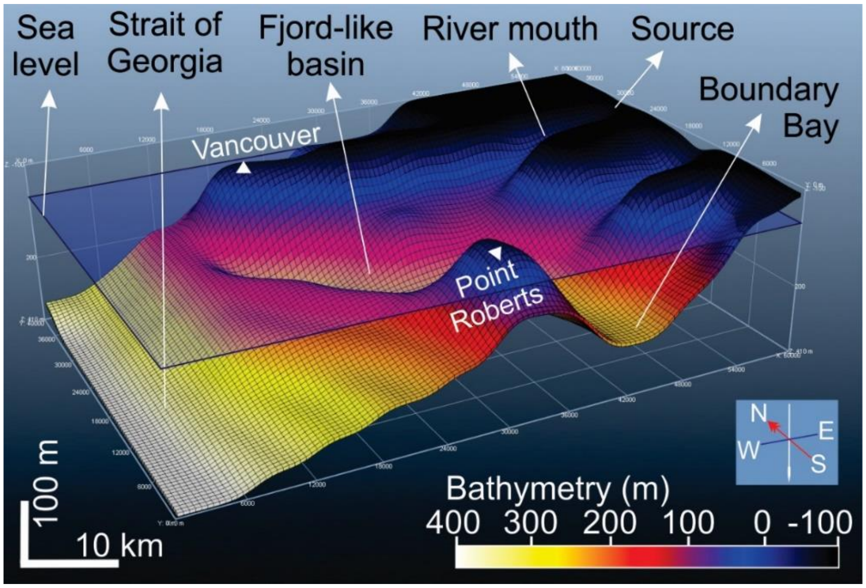

Figure 2. Initial bathymetric model characterizing the Fraser Valley before the delta progradation. The main depo-center is the "fjord-like" basin. This model was created using the thickness of modern sediments (Mazzotti et al., 2009; Ventura et al., 2006).

Results, Observations, Conclusions

Evolution of the Fraser River Delta is successfully simulated using two 5,000-year time span (Fig. 3a-l) and an additional third step representing hypothetical evolution in 5,000 years into the future assuming natural conditions (e.g., without anthropogenic effects) (Fig. 3m-s).

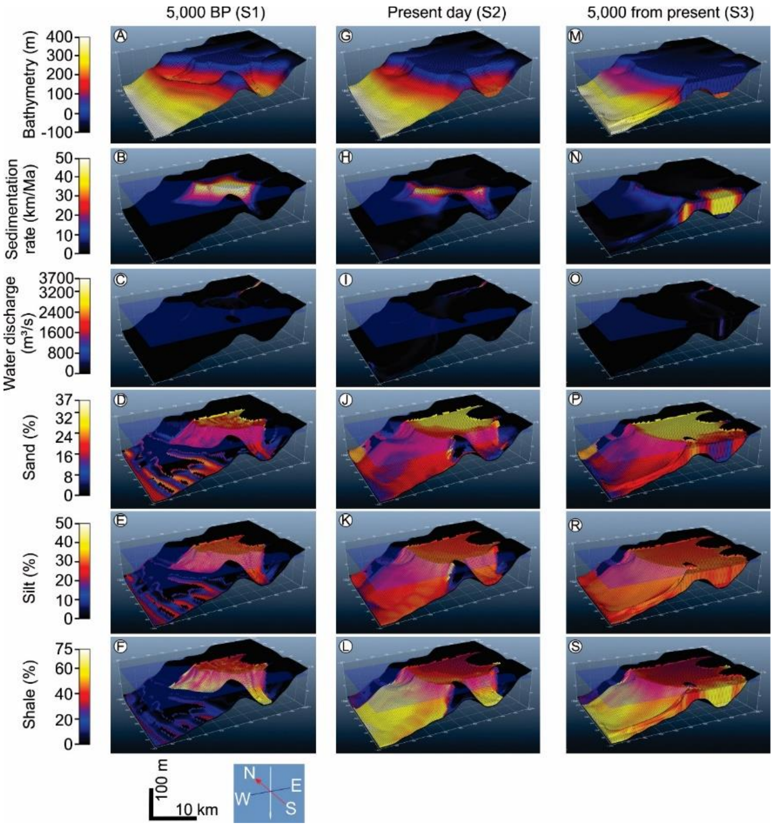

Figure 3. Simulation results demonstrating the delta characteristics and its evolution in three-time steps (S1-S3). (a-f) Modelling results between 10,000 BP and 5,000 BP (S1). (g-l) Modelling results between 5,000 BP and present day (S2). M-S) Modelling results of a hypothetical test run representing the delta's future evolution considering no changes in the input parameters for the next 5,000 years.

In the first step (S1), the model is created using sediment supply and water discharge values that are slightly higher than to those of today's values. Given that the Fraser River Delta is a post-glacial setting, the higher values suggest rapid melting of glaciers increasing both sediment supply and water discharge. The second step (S2) successfully modeled today's delta morphology using sediment supply and water discharge values that are similar to the today's values. Step 3 (S3) represents a future scenario presuming that all the parameters in step 2 continue operating without any modification, including sediment supply and water discharge. Some dramatic changes are observed in the orientation of delta progradation in S3. Delta progradation is recorded to display a shift from west to south direction (Fig. 3m and n).

A possible 100 m relative sea level increase was also tested maintaining all other parameters similar to step 2 (Fig. 4) which roughly corresponds to predicted 2 m increase in the next 100 years (Mazzotti et al., 2009; Samsonov et al., 2014). The results show a dramatic shift in the evolution of the delta: from an overall prograding system to a retrograding system (Fig. 4). Sediments during this scenario deposit mostly on the south, but a clear backstepping deposition is also visible on the delta plain (Fig. 4). Majority of the sand accumulate on the upper delta plain

(Fig. 4a) while silty deposits show uniform distribution throughout the delta (Fig. 4b) and shale units deposit predominate the prodelta (Fig. 4c).

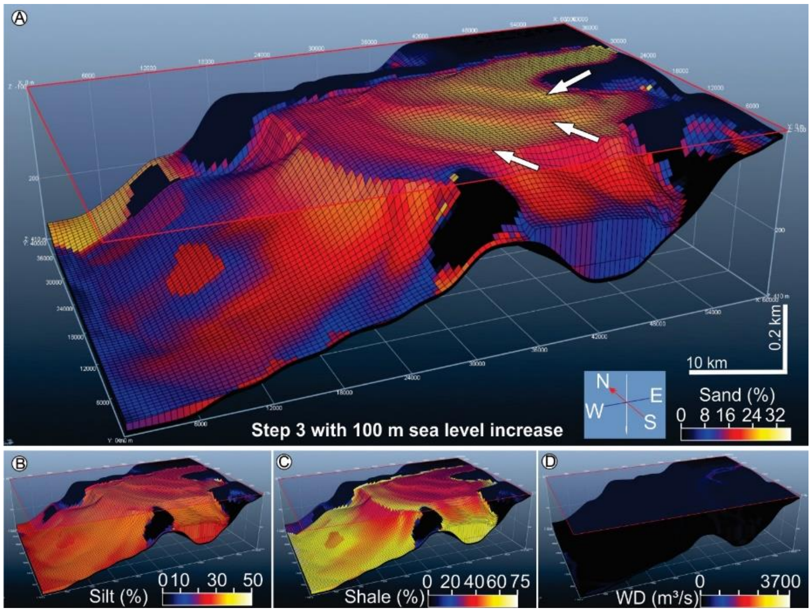

Figure 4. Modelling results representing the effects of a hypothetical 100 m relative sea level increase in the next 5,000 years. It should be notes that in this model, only sea level curve was introduced to the model, other parameters remained similar to the step 2 (Fig. 3 g-l).

The results document that modern siliciclastic systems can be simulated using real-time input parameters and can help us to predict future geomorphological changes and stratigraphic architectures. In this study, the Fraser River Delta was successfully created in two-time steps, and in one further step for its future architecture. The results document that forward stratigraphic modelling is applicable for relatively short (5,000 years) time steps; therefore, can be used in modern systems (e.g., developed following the last glaciation).

Acknowledgements

I kindly thank Dr. Shahin E. Dashtgard and Levi J. Knapp for their helpful review. The study was supported by start-up grants from the College of Petroleum and Geosciences, KFUPM

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