

# The Mara turbidite system in the Jeanne d'Arc Basin: Architecture, fan evolution, and modern analogues

Mark E. Deptuck\* (Dalhousie University)

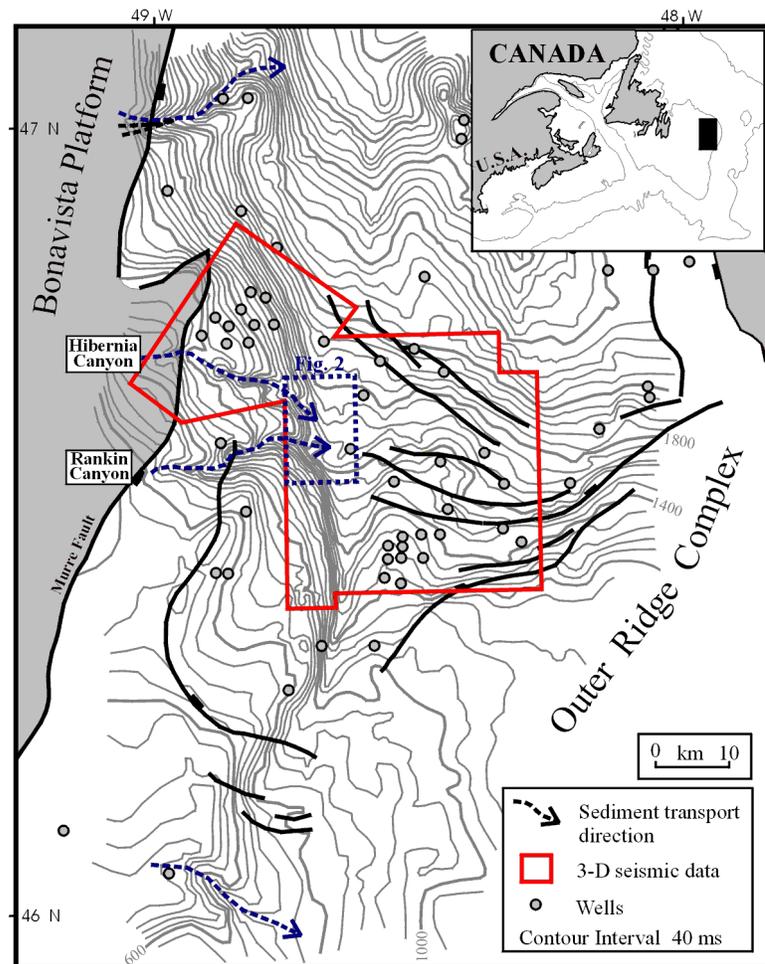
Department of Earth Sciences, Halifax, NS; [mdeptuck@is2.dal.ca](mailto:mdeptuck@is2.dal.ca)

## Basin setting

The Jeanne d'Arc Basin (Fig. 1 - inset) is one of five interconnected Mesozoic basins which underlie the Grand Banks of Newfoundland, offshore eastern Canada. These basins developed along the margins of the incipient North Atlantic Ocean during a complex rift-drift history. The central Jeanne d'Arc Basin covers an area greater than 6000 km<sup>2</sup>, and locally contains more than 20 km thickness of strata (Enachescu, 1987) spanning the Triassic through to the Quaternary. The deeper-water early Paleogene succession, which is now buried under 1-3 km of younger strata, is the focus of this study. This succession was deposited in an epicontinental sea, bounded by continental platforms along its eastern (Outer Ridge Complex) and western (Bonavista Platform) margins (Fig. 1). During the latest Cretaceous, a thick offlap sedimentary package prograded into a 350 to 450 m deep basin (based on clinoform height, without accounting for compaction). At the offlap (shelf) break water depths were probably between 50 and 100 m (based on data presented in Burgess & Hovius, 1998) deepening to greater than 200 m by the Early Eocene (middle to upper bathyal - Thomas, 1994).

## Approach

The 3-D seismic data used in this study cover an area of 2000 km<sup>2</sup> (Fig. 1). Additional coverage was provided by a regional 2-4 km grid of migrated 2-D reflection seismic profiles and data from over 30 wells. These data reveal the detailed characteristics of the deeply buried Paleogene Mara turbidite system in the Jeanne d'Arc Basin. Three-dimensional seismic data were used to dissect the Paleogene turbidite succession into its constituent architectural elements, the basic mappable components of both modern and ancient submarine fans (Mutti & Normark, 1991). Architectural elements were defined on the basis of lithology, log character, and 3-D seismic geometry. Careful calibration between well and 3-D seismic data in some parts of the basin allows the prediction of lithofacies in seismically defined architectural



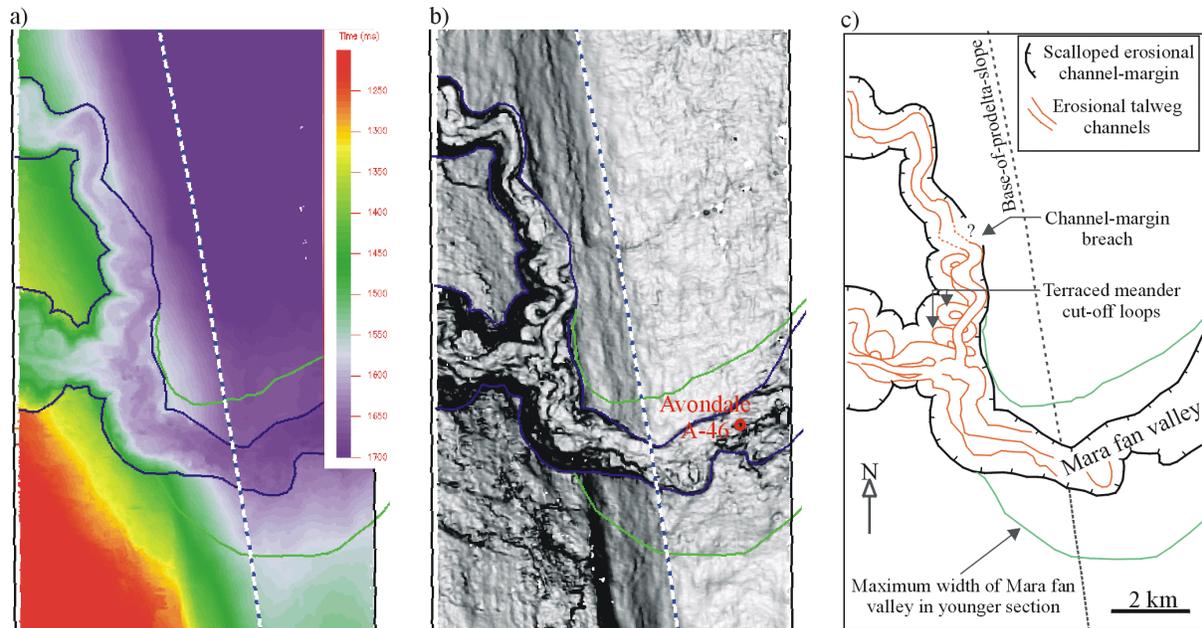
**Figure 1:** Location of Jeanne d'Arc Basin (inset) and contoured time-structure map on the Early Paleocene unconformity using a 2-4 km grid of 2-D migrated multi-channel seismic data. Also shown are the Early Paleocene sediment transport directions, the location of 3-D seismic data available in this study, and the location of figure 2.

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elements where no well control is available. In addition, this elemental approach allows the study of ancient systems without “fitting” them to predefined depositional models, like those developed in the 1970's and 80's which do not adequately account for the natural variability in turbidite systems.

### Planform geometry

The Mara turbidite system developed in the Early Paleocene and persisted intermittently until the Early Eocene, a duration of approximately 10 Ma. The proximal reaches of this turbidite system consist of the Hibernia and Rankin canyons which incise the narrow latest Cretaceous prograding shelf and slope along the western edge of the basin (Fig. 1). These canyons funneled sediment beyond the slope into submarine fans of the South Mara Formation (de Silva, 1993). Three dimensional seismic data indicate that the Hibernia Canyon, which ranges in width from ~ 1km to > 5 km and in depth from 150 to 220 m, has a low sinuosity curvilinear erosional talweg channel (Williamson et al., 1996) that probably developed during the maximum lowstand in relative sea level. The Bonavista Platform, located west of the Murre Fault, was subaerially exposed during these lowstands, with rivers - which once fed sediment into the prograding Late Cretaceous slope - draining directly into the heads of the Hibernia and Rankin canyons. Several erosional notches on the Hibernia Canyon walls (Williamson et al., 1996) also indicate that sediment entered the canyon from the sides either through canyon wall slumping or fluvial incision. At the Late Cretaceous offlap (shelf) break, the width of the Hibernia Canyon narrows significantly. Here, the canyon makes an abrupt 90 degree turn towards the south where it passes into a scalloped 1 km wide,



**Figure 2:** Close-up of a) time-structure and b) regional dip maps, with c) line drawing showing the scalloped erosional base and sinuous talweg channels extending eastward towards the Mara fan valley. Note the terraced meander cut-off loops and channel-margin breach.

curvilinear erosional channel which incises the Late Cretaceous slope (Fig. 2). In this region, the erosional base of this scalloped channel consists of several ~250 m wide meandering talweg channels, with at least two terraced meander cut-off loops. At least one channel-margin breach and several small discontinuous overbank channels are interpreted from 3-D seismic data. Further south, the narrow extension of the Hibernia Canyon intercepts, and merges with, the broader ~ 2 km wide east-trending Rankin Canyon. At the base-of-slope these merged erosional valleys form a single, broad fan valley that

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extends towards the east. This fan valley, herein referred to as the Mara fan valley, has a general “left hook” planform geometry that extends at least 20 km into the basin. Similar planform geometries are observed on the modern Var and Hueneme fans (Piper & Savoye, 1993; Piper et al., 1999). The Mara fan valley was an active bypass region through which turbidity currents transported sediment into depositional lobes in the deeper basin to the northeast. It shows an overall increase in width from its initial inception to a maximum width shown in figure 2 (green outline) and consequently the inner levees, most proximal to the channel axis, are eroded. The development of broad channel-bounding levees indicates that a significant proportion of the throughput turbidity currents overbanked the channel margins.

### **Architectural elements and vertical stacking patterns**

The architectural elements defined in this study show considerable spatial and temporal variability in the basin, and in some cases their geometry has been significantly modified by compaction. First-order submarine fan architectural elements like canyons, channels and depositional lobes are well imaged. Other first-order architectural elements like levees are recognized with less certainty, and have probably been significantly modified by compaction. Second-order architectural elements like mounded overbank deposits, overbank channels, and narrow linear gullies are also interpreted in the basin. Mapping the spatial and temporal distribution of these architectural elements, through a variety of 3-D seismic interpretation methods and wells ties, provides a detailed understanding of the architecture and evolution of the Mara turbidite system.

The geometry of the Mara upper fan is dominated by the Mara fan valley and its fill. Down-fan, the system shows an overall decrease in channel-levee relief with a corresponding increase in lobe relief. On the slope, the narrow erosional extension of the Hibernia Canyon is filled with aggradational channel deposits which are constrained by the slope and a minor levee on the right-hand-side of the channel (facing down-fan) and a larger levee on the left-hand-side. A prominent prograding levee is developed basinward of the juncture between the Hibernia and Rankin Canyons, where significant overspill (flow stripping) is expected. The fill of the Mara fan valley on the upper fan consists of a broad lens that pinches-out abruptly against the fan valley walls. Progressing downfan, and progressing up-section into younger fill, the Mara turbidite system consists of several stacked, laterally offset lenses that are not confined to the Mara fan valley. These stacked lenses have an overall aggradational-progradational character and are commonly cut by both linear and moderately sinuous channels. Further down-fan, towards the northern limits of available 3-D seismic data, the laterally offset lenses show an increase in internal mounding character. Work is still underway to characterize the lobe geometry in this system.

### **Modern Analogues**

Comparative studies with possible modern analogues located along the California Continental Borderland provides detailed information on the architecture of small, relatively shallow water submarine fans. In terms of fan geometry, and in spite of the tectonic setting, the Hueneme fan located in the Santa Monica Basin appears to be a good modern analogue. The Hueneme fan is a small (25 by 50 km) sandy submarine fan fed by two primary canyons (Mugu and Hueneme) which incise the narrow continental shelf and slope along the northern margin of the Santa Monica Basin. These, along with three other less prominent canyons, acted as conduits which funneled sediment into the Hueneme fan located in 600-900 meters of water. In terms of the physical dimensions of the fan and the dimensions of the component architectural elements, as well as water depths and basin structure (small fault-bounded basin with a narrow continental shelf), the early Paleogene fans of the Jeanne d'Arc Basin and the modern Hueneme fan are quite similar. In contrast, modern passive-margin fans like the Amazon or Mississippi are inappropriate geometric analogues because they represent much larger systems developed seaward of wide continental shelves in very deep water.

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On Hueneme fan, both high resolution (~0.5 m vertical), shallow penetrating (~ 50 m) boomer seismic profiles and lower resolution (~10-20 m vertical), deeper penetrating (~1000 m) single-channel seismic data are available. These two data-types, collected over the same fan-reaches, provide insight into what architectural elements look like at different seismic resolutions, and help to partially bridge the gap between lower resolution 3-D seismic and very high resolution modern studies. Although the Hueneme fan is a good geometric model for the Paleogene fans in the Jeanne d'Arc Basin, it is a poor temporal analogue. For example, the sedimentation rates on the Hueneme fan far exceed (by as much as an order of magnitude) the Paleogene sedimentation rates in the Jeanne d'Arc Basin, even when correcting for compaction effects. The larger sedimentation rates on the Hueneme fan may result from higher magnitude and more frequent Quaternary eustatic sea level fluctuations, higher propensity for earthquake induced sediment failures, and the presence of a mountainous drainage basin which supplies a greater quantity of sediment to the continental shelf. Three-dimensional seismic data allow for meaningful comparisons between the Mara turbidite system and modern geometrical analogues, but caution is still required as careful consideration must be given to compaction effects in the ancient record and differences in the spatial and temporal resolution of different data-types.

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### Biographical Note

Mark Deptuck graduated from Saint Mary's University in 1998 with an Honours - Co-op B.Sc. degree in Geology, and is currently conducting graduate work in Earth Sciences at Dalhousie University and the GSC-Atlantic, under a Natural Sciences and Engineering Research Council (NSERC) of Canada postgraduate scholarship. He has practiced as an exploration geologist/geophysicist at Chevron Canada Resources for the past two summers and as a research assistant at the GSC-Atlantic for four workterms.

\*\*3-D Seismic data owned by, and used with the permission of, Chevron Canada Resources, Norsk Hydro Canada Oil & Gas Inc., Mobil Oil Canada, Petro-Canada, Husky Oil, Mosbacher Operating Ltd., Murphy Oil Company Ltd., and Hibernia Management and Development Company (HMDC). I am grateful to these companies for their continued support of my research and David J.W. Piper for helpful discussions.