Process, time and architecture: lessons from slope contourites and their failures in the path of the Labrador Current

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Abstract: *The southeastern Canadian continental slope is swept by the powerful Labrador Current. Over the past glacial cycle, changes in ocean circulation, meltwater supply, and glacial ice extent produced strong changes in current strength and pathways which are reflected in sediment drift architecture. Previous studies show that failure of sediment on steep (>3°), canyoned slopes off eastern Canada recurs every ~10-30 ka and are likely related to earthquakes. On gently dipping (1–1.5°) flanks of drifts in Flemish Pass, Atterberg limits show that some silty winnowed sediment is susceptible to liquefaction by cyclic loading. Here, failures occur every ~10-30 ka as on steeper slopes, followed by ~200–400 ka periods of stability and sediment accumulation. Build up of pore pressure from migrating sub-surface gas and fluids then allows earthquake-triggered failure on such low slopes. The style of failure is mostly lateral spreading with partly retrogressive failure upslope. Sediment drifts respond in a complex manner to changes in current flow on at least millennial and longer time scales, with resulting spatial variation in sediment type. Failure preconditioning on low slopes requires winnowed silty sediment capable of liquefaction and less permeable muddier plume sediment that allow build up of gas, followed by triggering by M>7 earthquakes.*

Key words: *drift architecture, current strength, liquefaction, spreading failure, earthquake trigger.*

INTRODUCTION

The Labrador Current is a powerful southward-flowing western boundary current with its main core along the upper slope of the southeastern Canadian margin (Piper, 2005). The current transports relatively cold and fresh water derived from the Arctic Ocean, river discharge from much of Canada, and water from the West Greenland Current (Fig. 1). Blockage of the Arctic Island Channels by glacier ice and changes in the North Atlantic sub-polar gyre resulted in significant changes in Labrador Current strength over the last glacial cycle (Marshall et al., 2014). Two perched slope basins east of Newfoundland, Orphan Basin and Flemish Pass (Fig. 1), record these changes in the Labrador Current; in addition, the basins contain a record of varied sediment failures which were studied because of their geohazard potential in light of recent oil exploration in the region. This work was facilitated by multibeam bathymetry collected by TRAGSA, Spain, as part of the NEREIDA project on vulnerable marine ecosystems.

This study is focused on sediment drifts in Flemish Pass, particularly a prominent detached drift known as Sackville Spur. It was constructed in the Neogene-Quaternary at the northern end of Flemish Pass and its northern slope is continuous with the southern fault-bound margin of Orphan Basin (Tripsanas et al., 2008). Piston cores from the region provide a stratigraphic record of the last glacial cycle since MIS 5e. Heinrich layers rich in detrital carbonate provide important lithostratigraphic markers that return strong reflections in high-resolution seismic reflection profiles. Thus the chronology of core records and of shallow seismic profiles can be easily determined.

CURRENT STRENGTH AND DRIFT ARCHITECTURE

The sortable silt proxy was used to estimate past Labrador Current strength. A 30 ka record in Flemish Pass (Marshall et al., 2014) shows lower current strength during full glacial conditions, increasing at ~ 15 ka, and increasing again in the mid Holocene. Carbonate-free sortable silt in Heinrich layers H1 and H0 indicates greater current strength during and immediately preceding Heinrich events. A lower resolution 130 ka record shows high current strength, similar to the early Holocene, immediately before some Heinrich events and in MIS 5e, but otherwise fluctuating lower speeds from MIS 5d to 2. A set of 180 box cores from the NEREIDA project in Flemish Pass and on Flemish Cap provide a synoptic view of spatial variation in sortable silt at the modern sea floor (Weitzman et al. 2014). The response of drifts to changes in current strength is most pronounced downflow from a constriction in central Flemish Pass. Under full glacial conditions, sedimentation rates of 0.1–0.2m.ka^{-1} are relatively uniform across the drift and adjacent moat; during late glacial and early Holocene sediment accumulated on the drift at >1m.ka^{-1}, with little accumulation in the moat. In the mid to late Holocene sedimentation rates reduced to <0.01m.ka^{-1}.

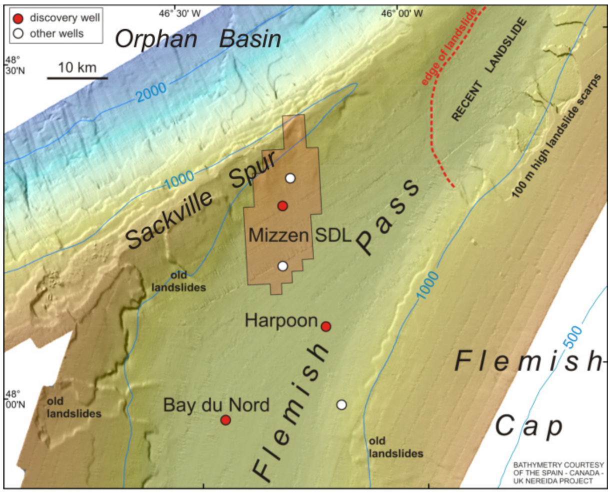

FIGURE 1. Map of northern Flemish Pass showing petroleum wells, sediment drifts and landslides (from Cameron et al., 2014).

SEDIMENT FAILURES ON DRIFTS

Sediment failures on the plastered drift on the steep southern slope of Orphan Basin and the north flank of Sackville Spur have a recurrence interval of 10–20ka (Tripsanas et al., 2008 and unpublished work). Several large failures in drift sediments on the NE flank of Flemish Pass, affecting the upper 100 m of sediment, are dated at 28ka, 21.5ka, 13ka and 7ka (Cameron et al., 2014), a recurrence rate similar to Orphan Basin and to elsewhere on the southeastern Canadian margin where canyons provide local slopes >10° (Piper 2005). Regionally, other local failures of these ages are known, with the widespread occurrence suggesting a seismic trigger. Geotechnical studies from piston cores show that sediments are normally consolidated and silty sediments have Atterberg limits showing susceptibility to liquefaction during cyclic loading.

The NE Flemish Pass failures produced a composite mass-transport deposit (MTD) on the floor of Flemish Pass >80 m thick. Three similar composite MTDs of Quaternary age are present in Flemish Pass, sourced from now buried failures on Sackville Spur, with a recurrence interval of 200–400ka (Piper and Campbell, 2005). These buried failures are of similar size to the surface failures on NE Flemish Pass and all occur on slopes of 1–1.5°. The multibeam bathymetry shows a seabed expression of the youngest buried failure. The corresponding MTD in 3D seismic shows numerous dispersed blocks and the headscarp morphology suggests that liquefaction and lateral spreading may be the mode of failure.

The recent NE Flemish Pass failures are located on a drift that had not experienced significant failure earlier in the Quaternary. They demonstrate that after a long period of stability, earthquakes may be sufficient to trigger a series of failures over tens of thousands of years. By analogy, the buried failures on Sackville Spur may also be composite in origin. Some other process must be responsible for episodic preconditioning of failure. This is most likely the build-up of high pore pressures by thermogenic gas rising up dip and along the fault zone that marks the southern edge of Orphan Basin. Blanketing muds of glacial plume origin, deposited at times of low current speed, provide a low permeability barrier to gas migration.

CONCLUSIONS

1. The Labrador Current experienced highest speeds during interglacials and at some times preceding and during Heinrich events. More generally, oceanographic processes can result in significant changes in current speed on millennial to 0.1Ma time scales.

2. Such variations in current speed result in large variations in the amount of sortable silt in drift sediments, with silty sediment liable to liquefy during cyclic loading by large rare passive-margin earthquakes.

3. On canyoned steep slopes, drifts fail every 10–30ka during earthquakes. On slopes of <1.5°, excess pore pressure builds up in permeable silts due to migrating thermogenic gas that is trapped by blanketing muddy sediments accumulated at times of lower current speed.

ACKNOWLEDGEMENTS

D.C. Campbell, K. MacKillop, G. Cameron, G. Li, L. Mao, N. Marshall, F. Saint-Ange, and E. Tripsanas did the work. Funded by GSC, PERD and NEREIDA.

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