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Early post-glacial mass failures in St. Ann's Basin on the Scotian Shelf, south of Cape Breton

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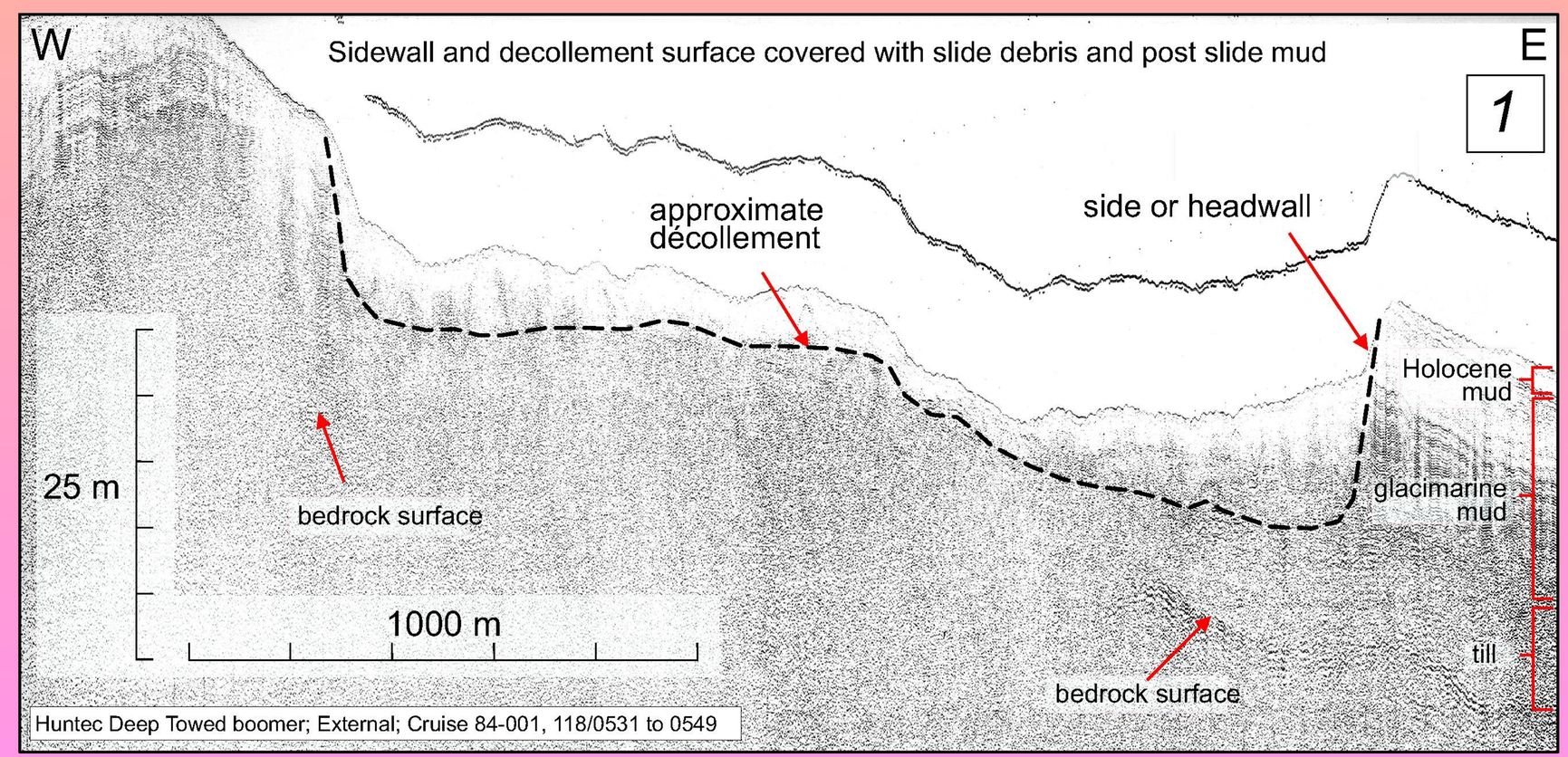
Introduction

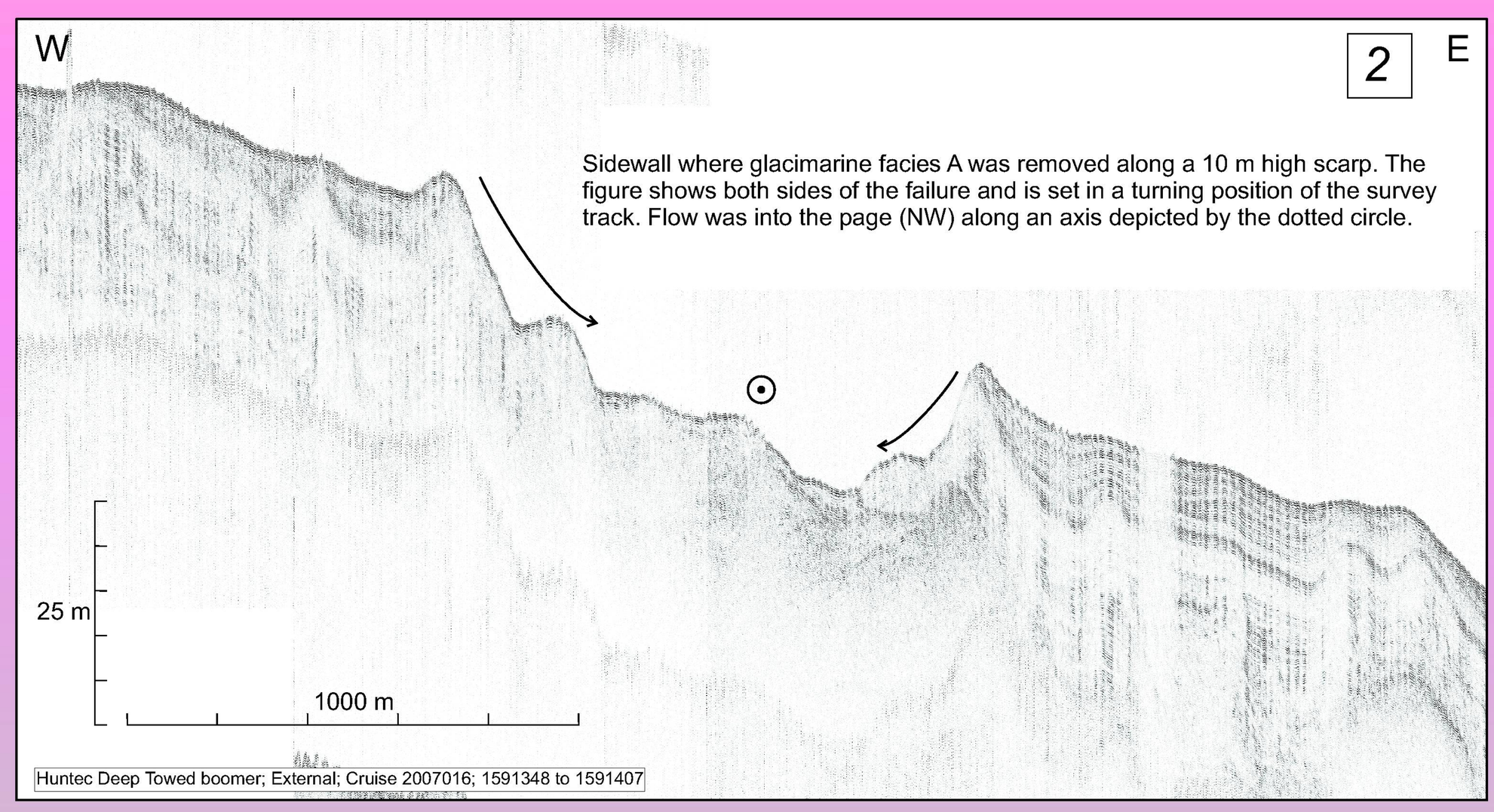
Gravity mass failures at the seabed in St. Ann's Basin, offshore eastern Cape Breton Island have been investigated with very high-resolution reflection seismic, sidescan and limited core and multibeam bathymetric coverage. Recent compilations of shelf-situated potential geohazard features on the Scotian Shelf and Grand Banks of Newfoundland suggests that this basin has a more concentrated occurrence of Quaternary mass failure erosion and deposition features than other surveyed areas. Investigations were spawned by recognition of sediment disturbance on 2003 cruise data which put enigmatic strata disruption features (on 1984 profiler data) in better context. Follow-up surveys in 2007 demonstrated numerous mass failure phenomena. This raises the question if their location may be related to the greater occurrence of seismic events on the eastern Scotian Shelf, specifically the Orpheus Graben and Laurentian sub-basin.

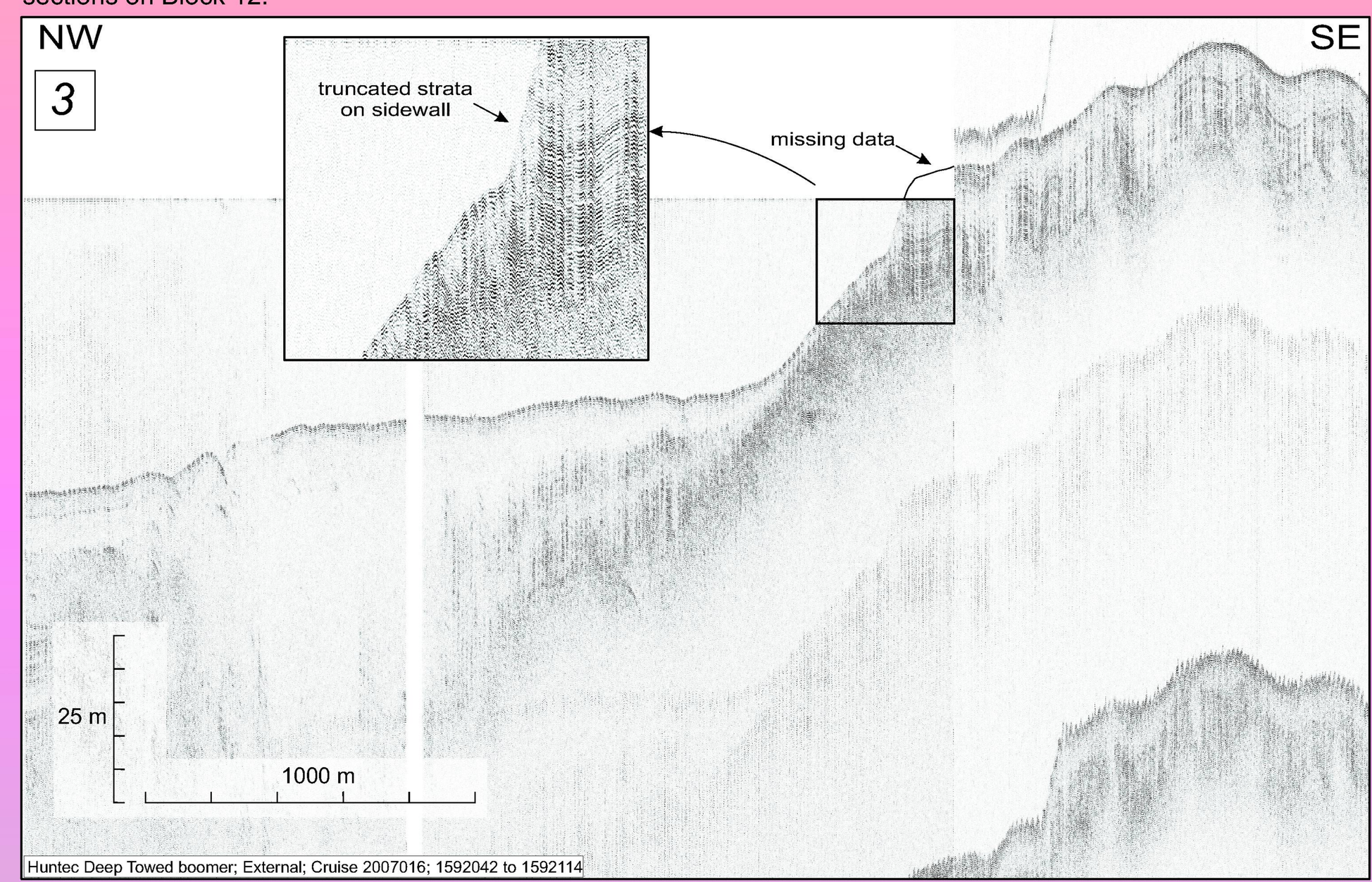
Limited transects of 1984 high resolution seismic profiler data indicated disturbance in thick glacimarine sediments situated mid-basin. Multibeam bathymetric data (from 1996) also registered disturbance but this was not recognized until the 2007 data revealed similar features linked to failures. The structural disturbance in normally well-stratified glacimarine strata can be tied to mass failure originating from a nearby topographic high (Scaterie Moraine). The new data allowed recognition of multiple failure scarps and nearly ubiquitous occurrences of structural disturbance of the basinal glacimarine sediments. Existing cores were already dated (D. Piper pers comm.) which could help constrain the failure timing. A subsequent Remote Operated Vehicle transect (expedition 2008015, joint expedition with DFO) across one of the scarps on the moraine showed continuous sediment cover and a lack of steep scarps.

Seismic profile expression of failure scarps

Most failures are rotational and/or translational slides with associated scarps, sidewalls and depositional debrites. At least seven failure scarps are recognized on the basin flank and on topographic highs within the basin. They have associated depositional debrites occurring at the base of slopes exceeding 5° to 10°. Failure scarps are generally 10 to 15 m high with slopes exceeding 10° and an amphitheater shape. They develop into chutes 1km or less wide with run-out less than 3 km. The parent material comprises stratified glacimarine muds rapidly deposited from meltwater plumes. Generally, the entire glacimarine section is removed, suggesting failure at its base. The failures are distributed on the basin flanks in thicknesses up to 25m. Basinal equivalents are very thick (> 50m). Locations of sections on Block 12.

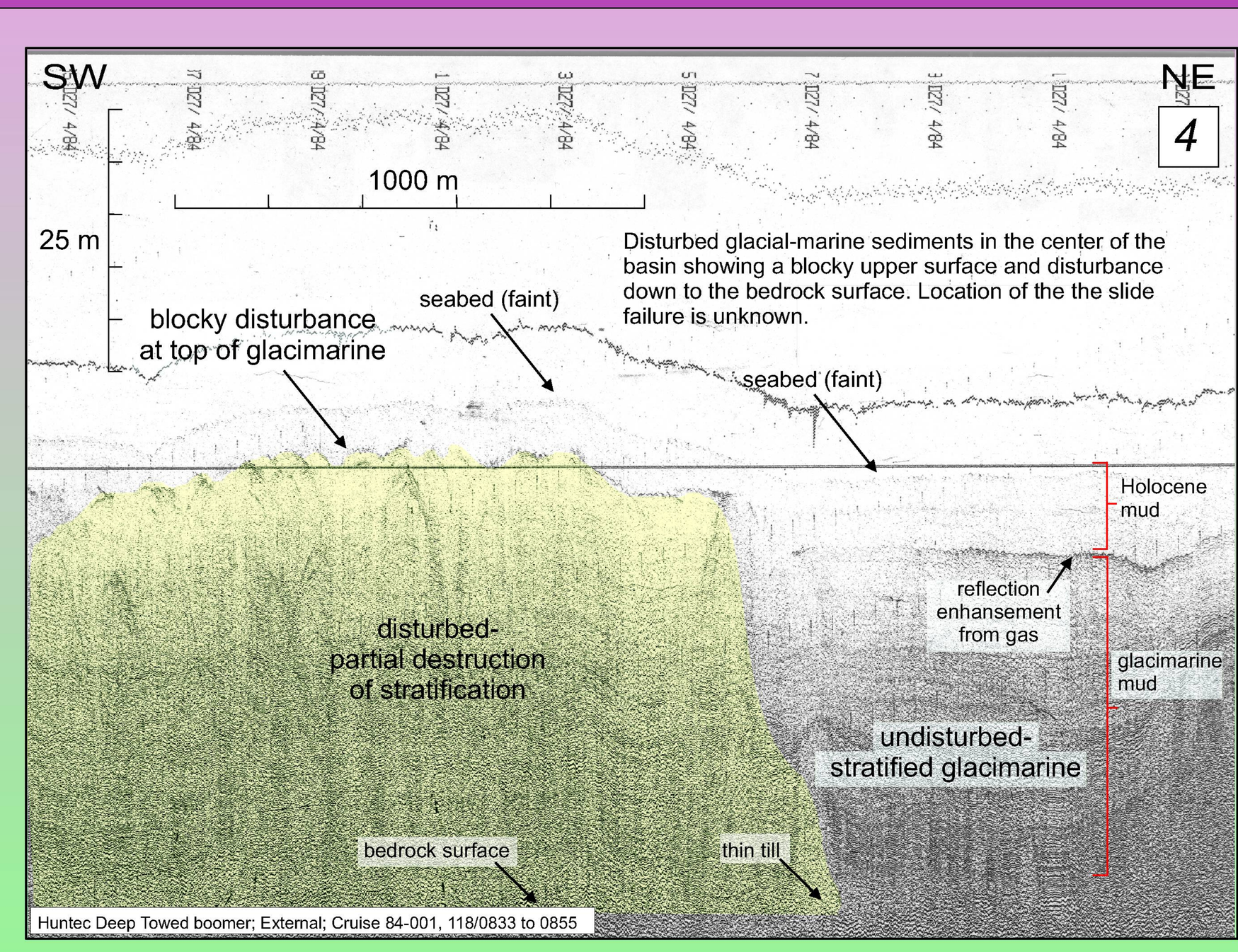


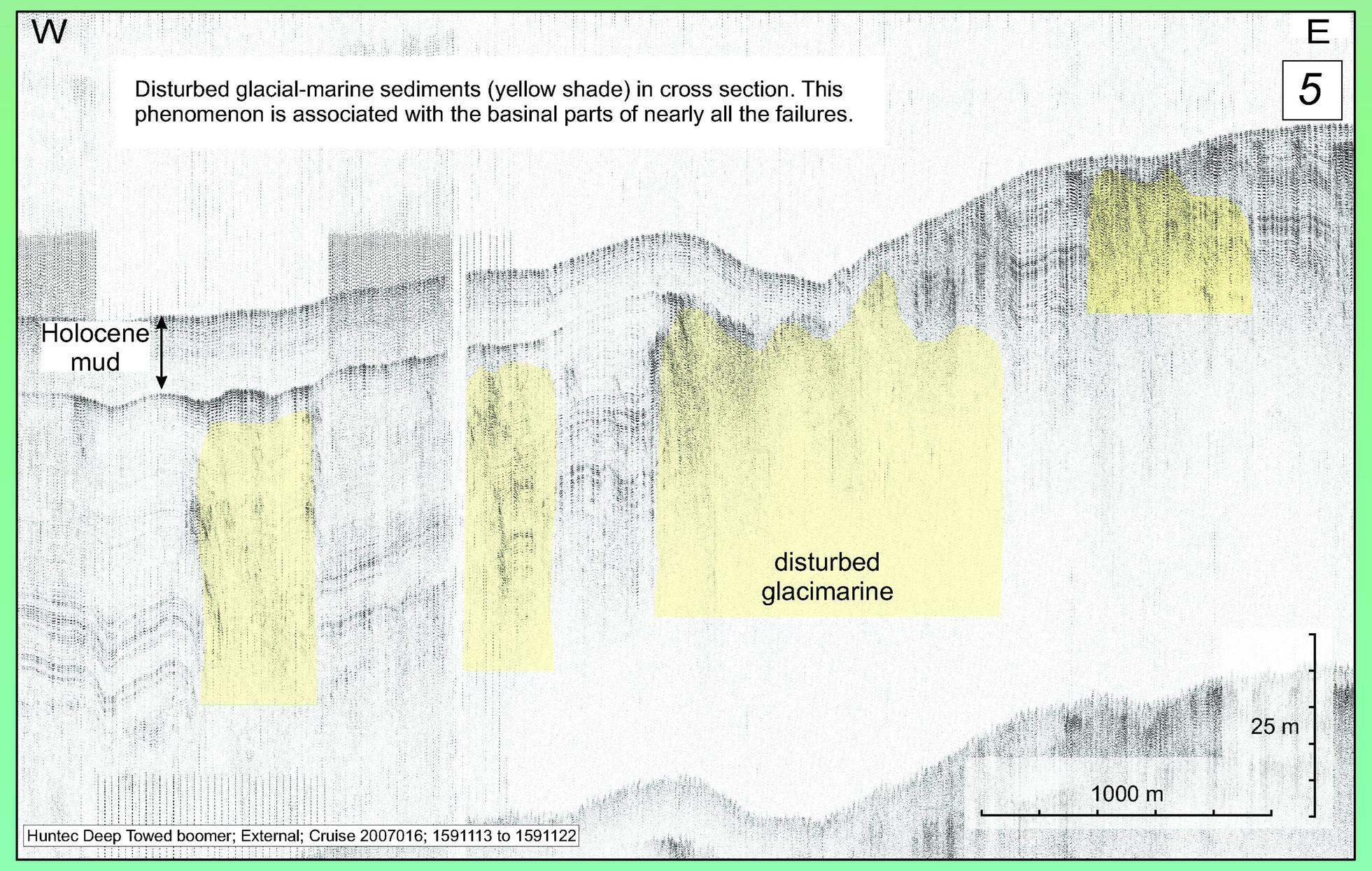


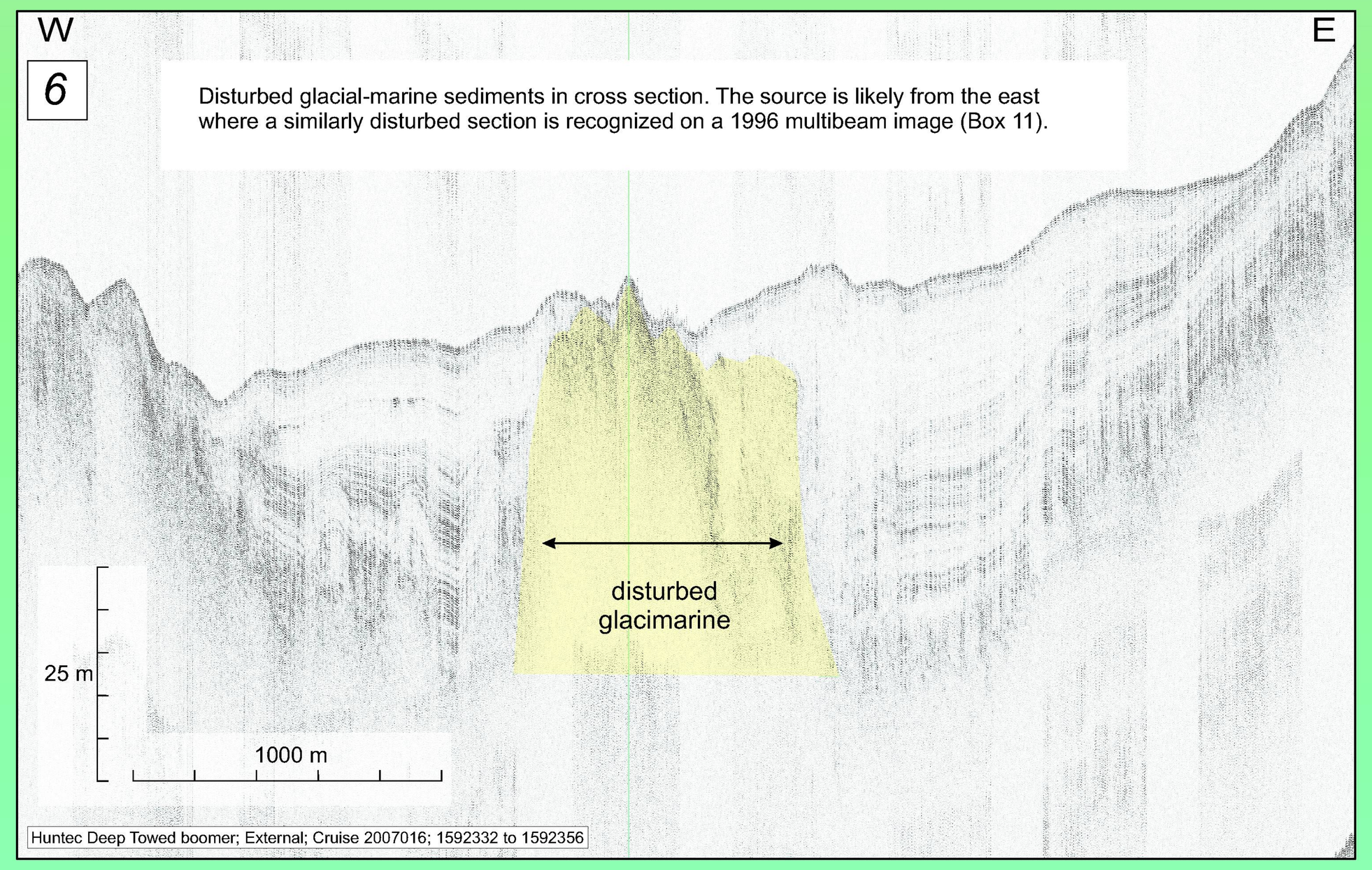


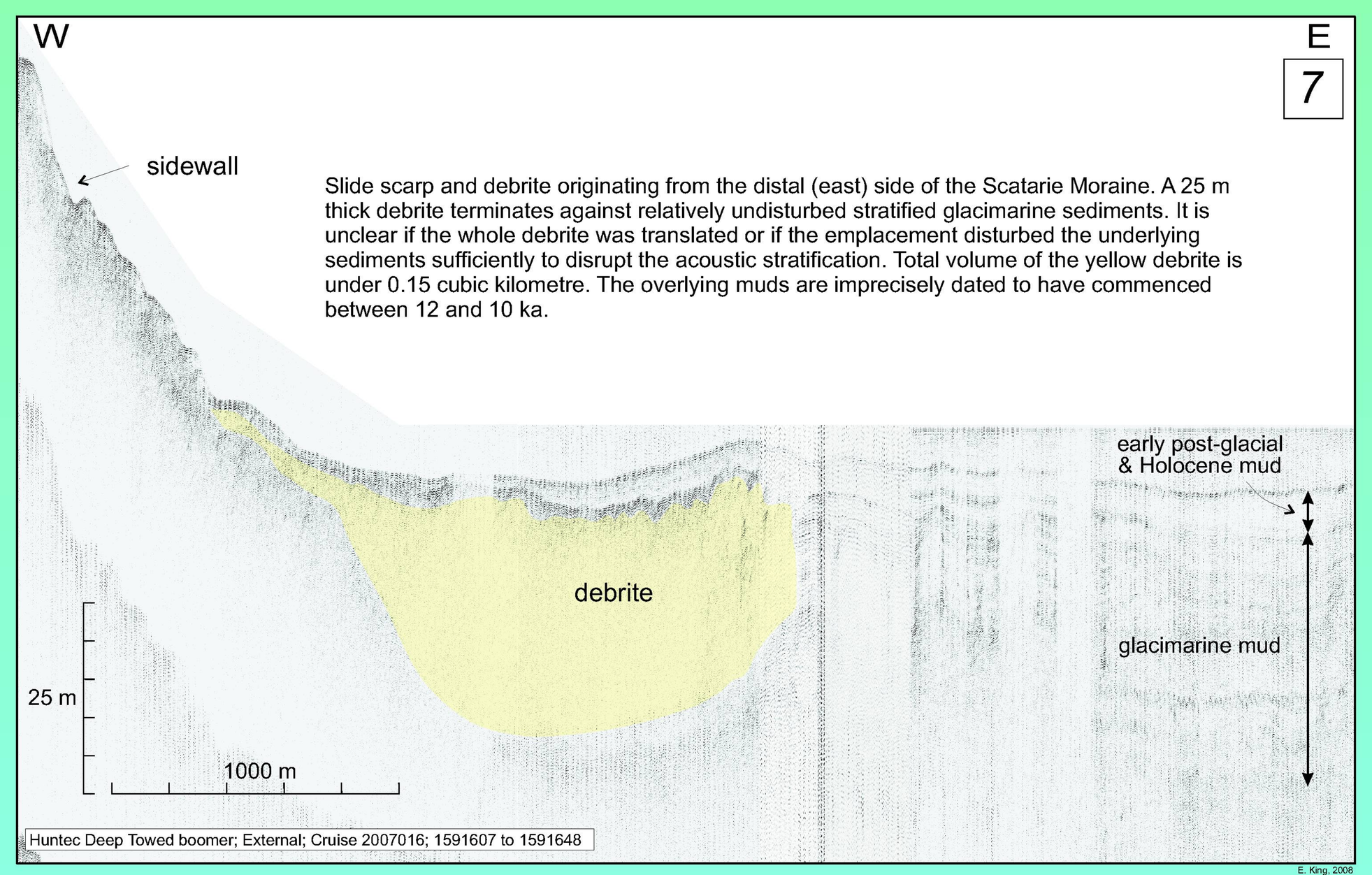
Seismic profile facies and failure architecture

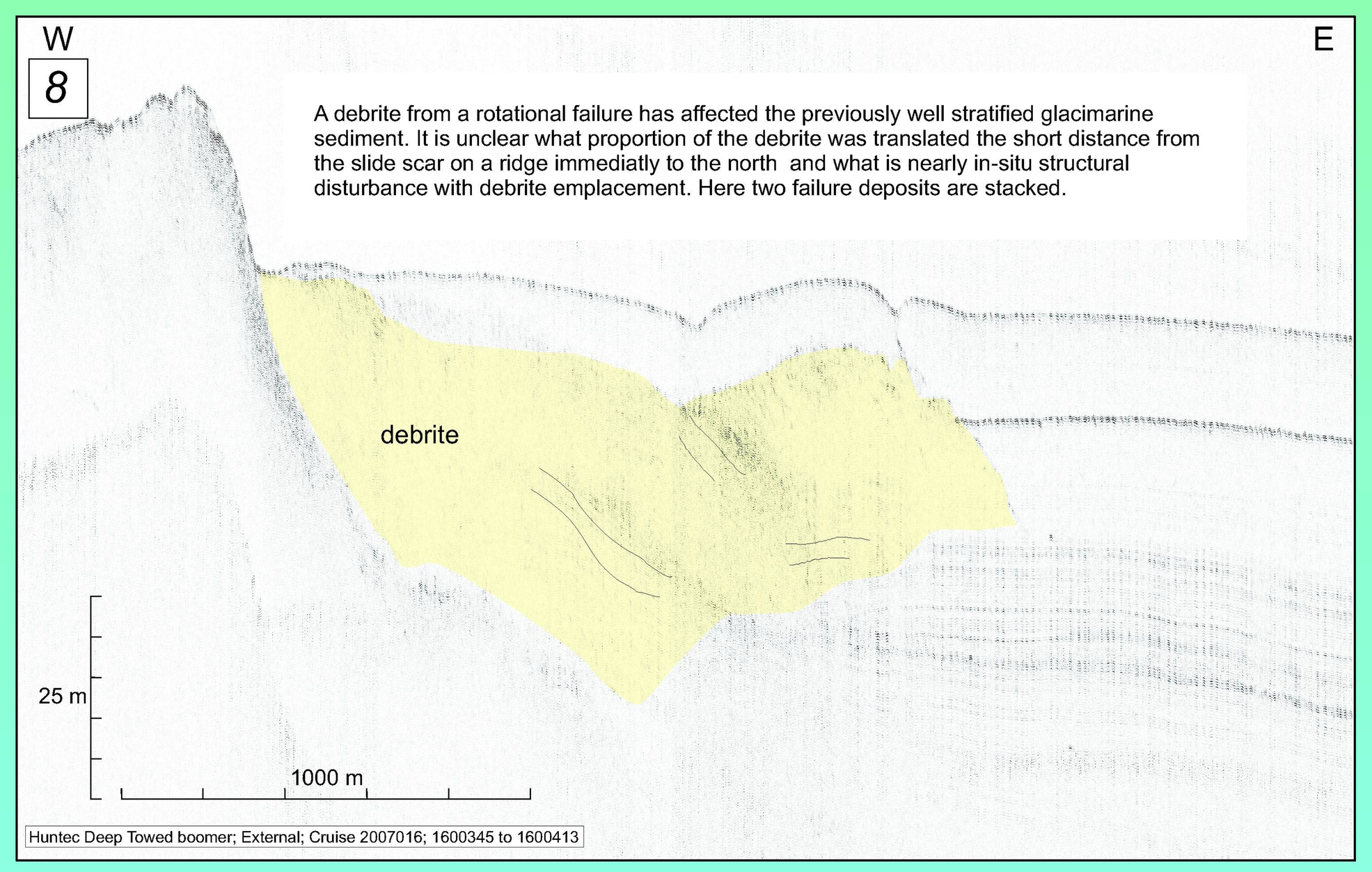
The debrites associated with the slide failures occur at the base of slopes. Lobate debrites generally terminate in the thick glacimarine sediments and structurally disturb them, both through loading with over-riding and through lateral and upward displacement. Locally block-sliding and lobe-stacking is recognized. These debrites can exceed 30 m thickness with volumes typically under 0.2 km^3. Post-glacial muds cover the lower part of the failure scarp and the debrite.







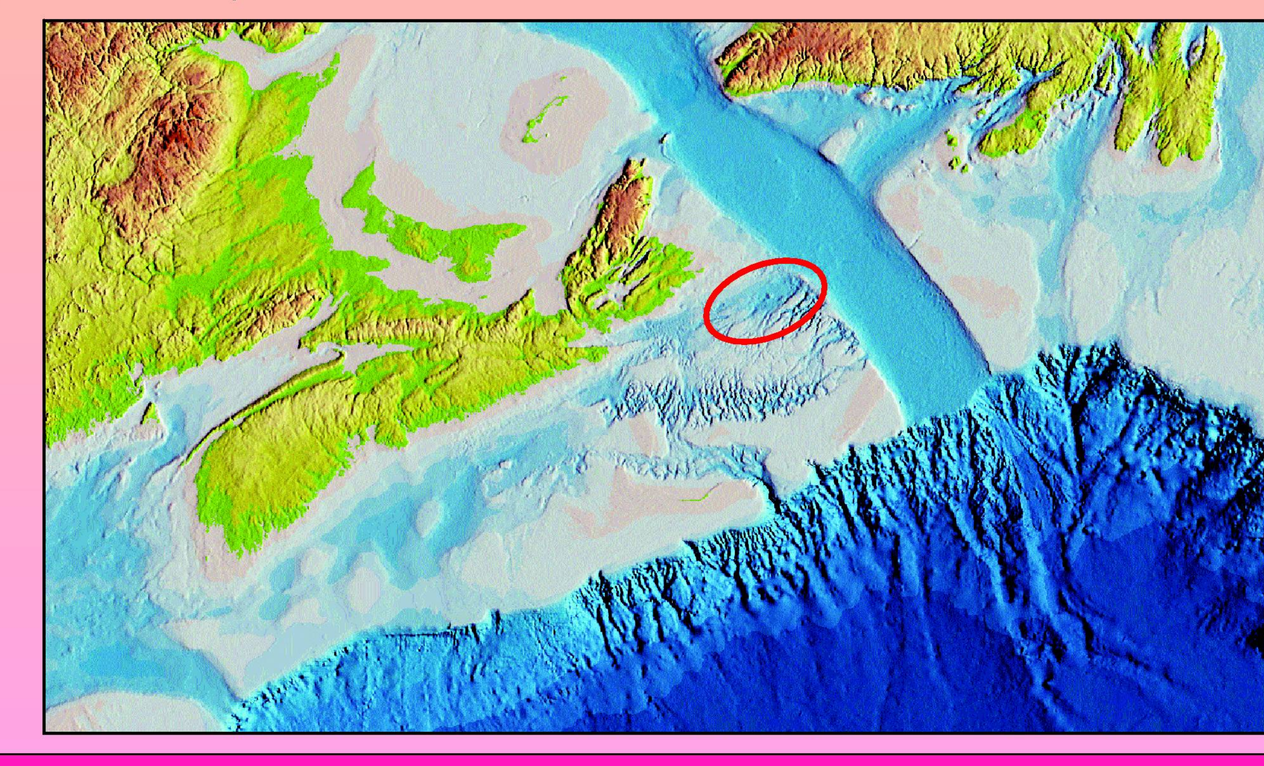




E. King, 2008

Location of study area

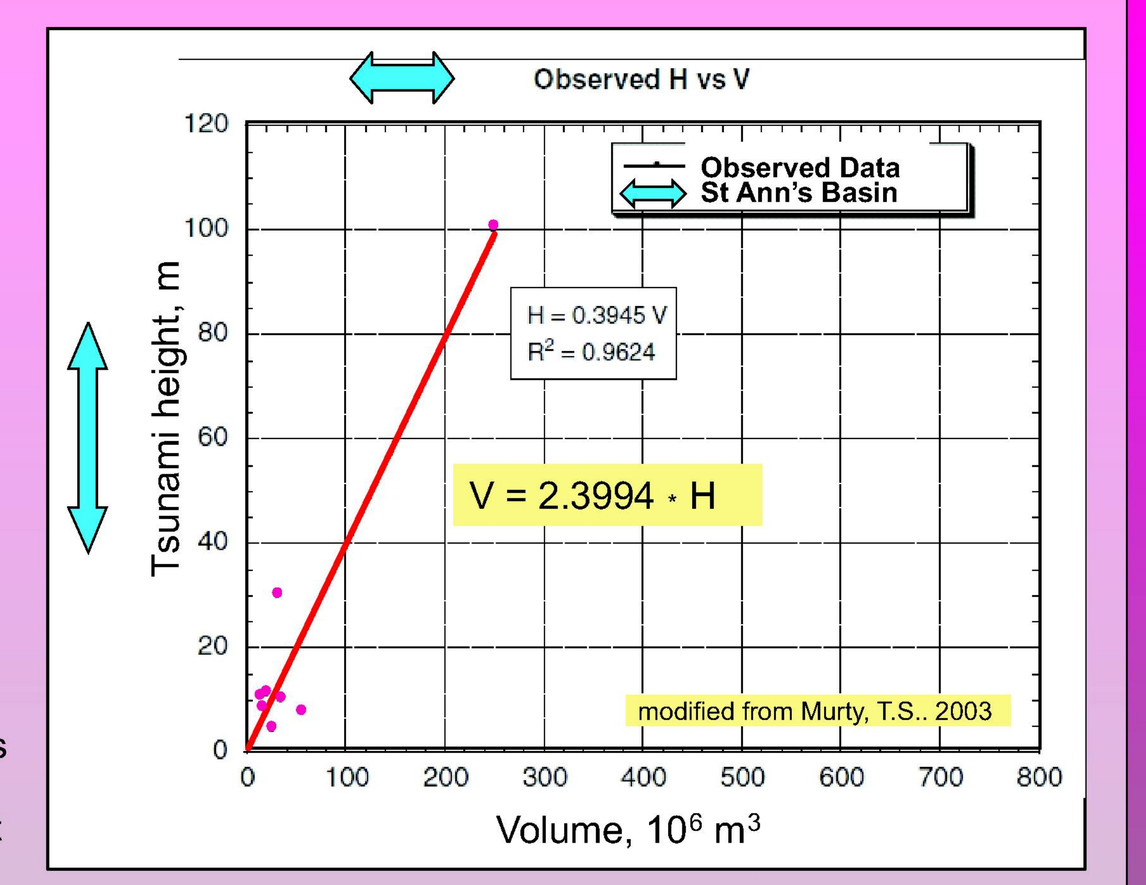
- St. Ann's Basin is located offshore eastern Cape Breton Island, Nova Scotia. It is the seabed expression of the Orpheus Graben and large scale topographic trends reflect this fault-bounding. (see Tectonic and seismic setting box). It reaches over 270 m water depth.
- Glaciation carved broad channels, mainly ESE-WSW here, and glacial retreat left large hummocky moraines and stratified proglacial marine muds. The muds blanket most areas, generally about 10 m thick but exceeding 50 m in the basin. Till crops-out on local topographic highs.
- Post-glaical (primarily early Holocene) muds ponded in the basin, generally about 5-10 m thick and below 170 m water depth.
- Most failures are within 100 km of the coast.
- The Orpheus Graben has been the site of early hydrocarbon exploration (wells in 1970's), mainly in association with diapiric Jurassic salt. The region is a potential utilities corridor for natural gas or hydropower so potential geohazards require an assessment.



Was there a tsunami?

The literature (cf. Murty T. S., 2003) suggests some empirical relationship between slide volume and tsunami generation. (V = 2:3994*H); important factors are:

a) Depth of water
b) Angle from the horizontal direction
c) Runout distance
d) Duration
e) Density of the slide material
f) Coherent nature of the slide
g) Grain size and spectrum
h) Characteristic speed with which the slide moves



The graph does *not* account for any of these variables. Thus the generation of any tsunami at all from these failures is speculative and projected wave height is likely exaggerated, especially given the relatively shallow water depths of the shelf setting. Nevertheless, the potential for significant wave heights given volume estimates of the St Ann's Basin features is suggested. Of course, if the blue arrows represent multiple, rather than one failure event and if the failure had a significant retrogressive component rather than full-volume vertical displacement, the tsunami effect would be much diminished or non-existant.

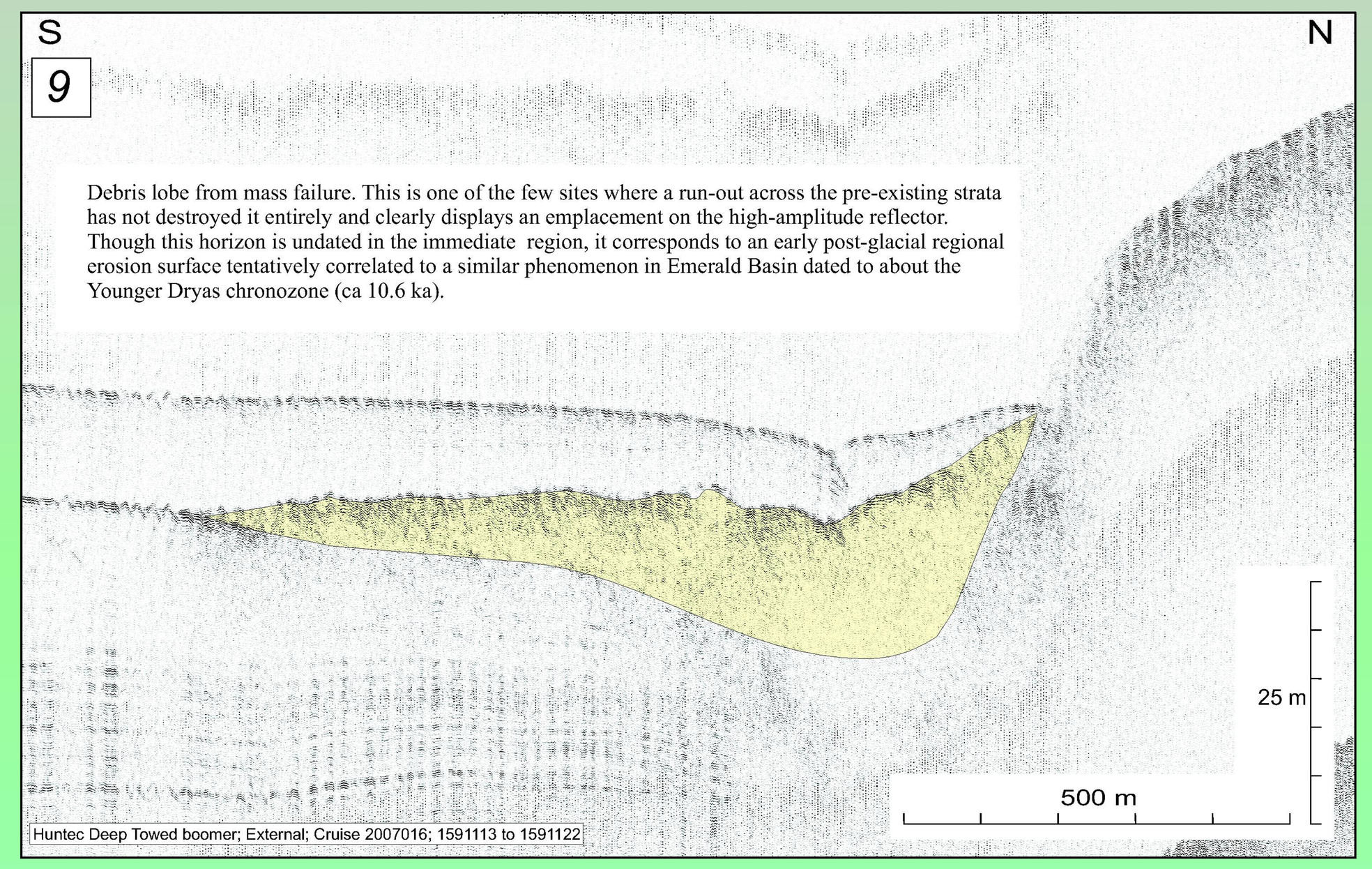
A tsunami, if it occurred, might have impacted adjacent land, especially if there were any topographic focusing into Chedabucto Bay or Canso Strait. However, no tsunami deposits have been recognized in the area.

Timing and triggering of the failures

Timing: The glacimarine muds are not directly dated but this basin was amoung the last to be deglaciated, within the 12–14.5 ka span (conventional radiocarbon age) (King 1996). Ice-free conditions likely pertained in the more recent half of this span. Post-glacial muds cover the lower part of the failure scarp and the debrite. Though not well constrained, all the failure deposits lie near the same stratigraphic horizon suggesting that they are contemporaneous. A stratigraphic marker identified elsewhere as associated with the Younger Dryas chronozone lies stratigraphically near the run-out toe of the debrite, indicating an early post-glacial failure age. Alternately, the debrites were penecontemporaneous, failing more in response to the early post-glacial change in sedimentation regime on the basin flanks, with loading and/or capping by more clay-rich muds which restricted de-watering.

Sediment piston cores provide poor timing constraints yet the potential for improved event age determination (locations, Box 12). Radiocarbon dates on foraminifera from core 84011-12 (Piper pers comm.) yielded 3100±60 (65-75 cm) and 7930±80 (640 to 650 cm). This core does not reach down to the debrite toe horizon; extrapolation of these dates to this depth yields about 10 ka. An existing (though unexamined) core reaches horizon equivalent (# 90031-69) and has the potential for further dating.

Thus, timing between sediment deposition is somewhere between the Younger Dryas (ca. 10.6 ka) and earliest Holocene. Failure occurred less than about 2000 years after deposition.

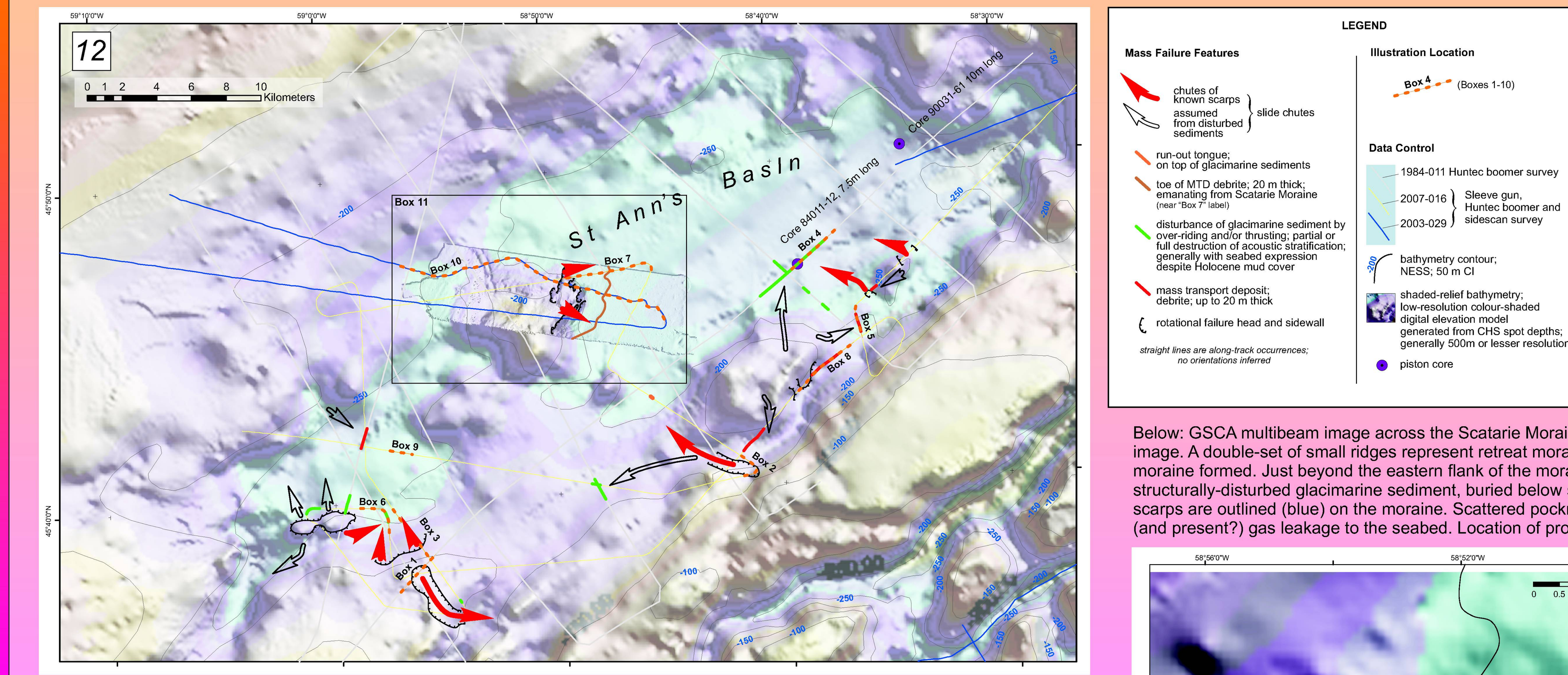


Triggering: Failure triggering in this setting and elevated seismicity, compared with other shelf settings is thought to be seismicity-related. The nest of earthquakes east of St. Ann's Basin (Box 13) might be associated with salt diapir activity (Ruffman 1992). The timing is coincident with maximum isostatic adjustment. A similar but larger failure event on the eastern flank of the Laurentian Channel occurred at about the same time and may indicate a more widespread seismic affect.

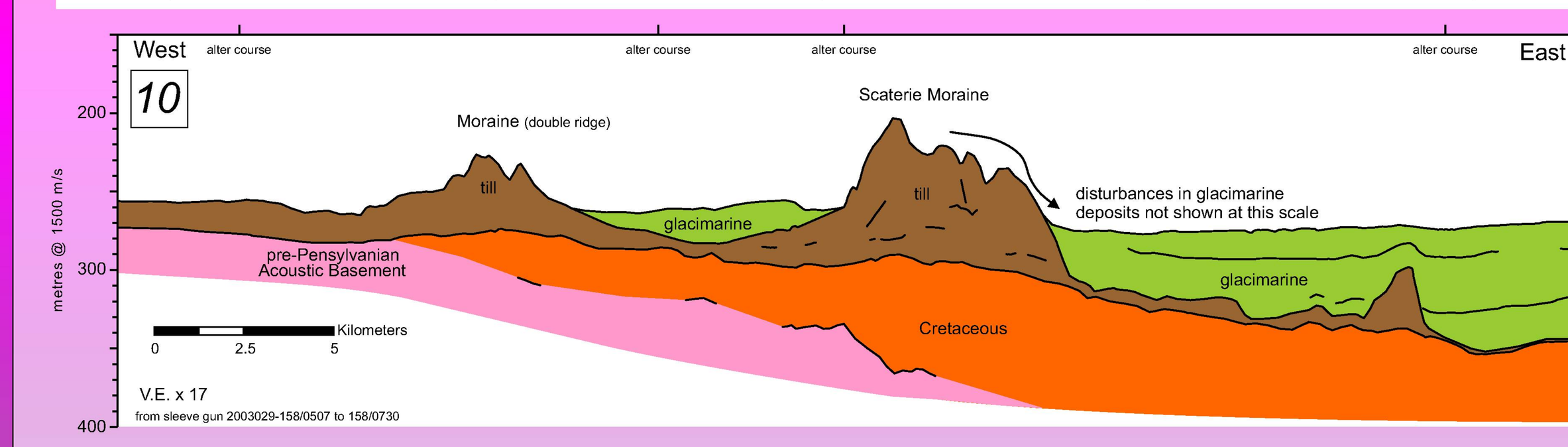
The number and timing of the slides, a distant Laurentian Channel east-flank failure, the elevated occurrence of early post-glacial failure on the slope, possibly due to glacial-isostacy (Piper 2005), together with the tectonic setting and moderate seismicity suggest a seismic event as a trigger.

Other trigger mechanisms may include elevated shallow gas release rates, continued sea-level rise and current erosion events. A controversial hypothesis of Younger Dryas meteorite impact on the North American continent and Laurentide ice sheet (c.f. Firestone et al. 2007), would be sufficient to trigger mass failure.

Overview of the area and distribution of MTDs on the eastern Scotian Shelf

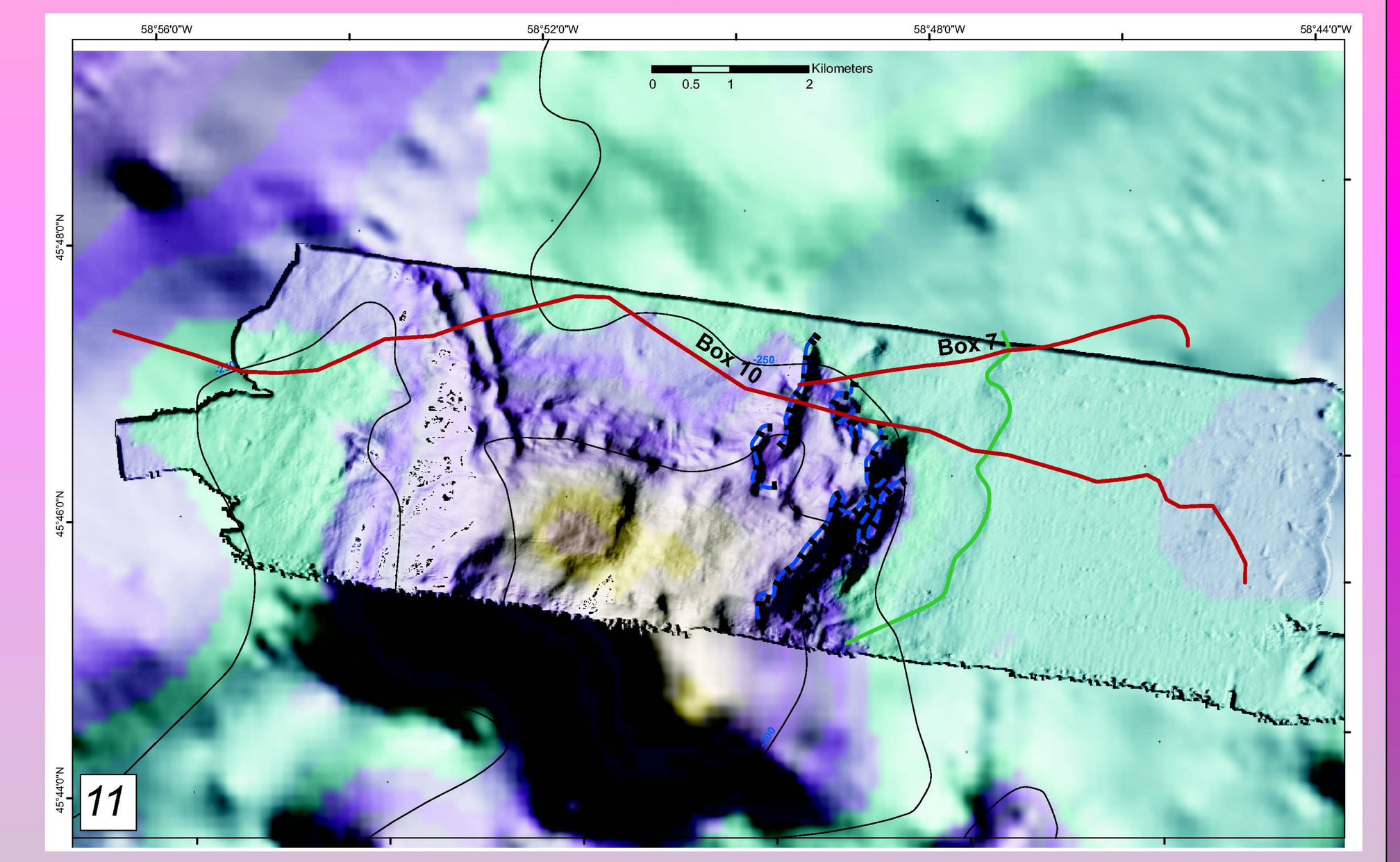


Left: A variety of mass failures are shown with inferred headwalls, sidewalls, transport paths, and basinal sediment disturbances. The sparse geophysical survey lines in St. Ann's Basin precludes identification of all features and some of the paths and directions are conjecture (those near the Box 1 and Box 3 labels especially).



Geologic profile across Scaterie Moraine derived from a high resolution seismic profile (location, boxes 11 and 12). Acoustic basement is overlain by the Mesozoic sediments which are occasionally faulted nearby. Multiple or retrogressive failures on the eastern flank (arrow) disturbed the thick glacimarine sediments. The disturbance apron is visible on the multibeam image, Block11 and on the high resolution seismic profile, Block 7.

Below: GSCA multibeam image across the Scatarie Moraine superimposed on a much lower resolution topography image. A double-set of small ridges represent retreat moraines after the larger, more amorphous (hummocky) moraine formed. Just beyond the eastern flank of the moraine is a bulge in the seabed marking the toe of the structurally-disturbed glacimarine sediment, buried below several metres of Holocene mud. The probable failure scarps are outlined (blue) on the moraine. Scattered pockmarks at the northeastern part of the survey indicate past (and present?) gas leakage to the seabed. Location of profile illustrations also shown in red.

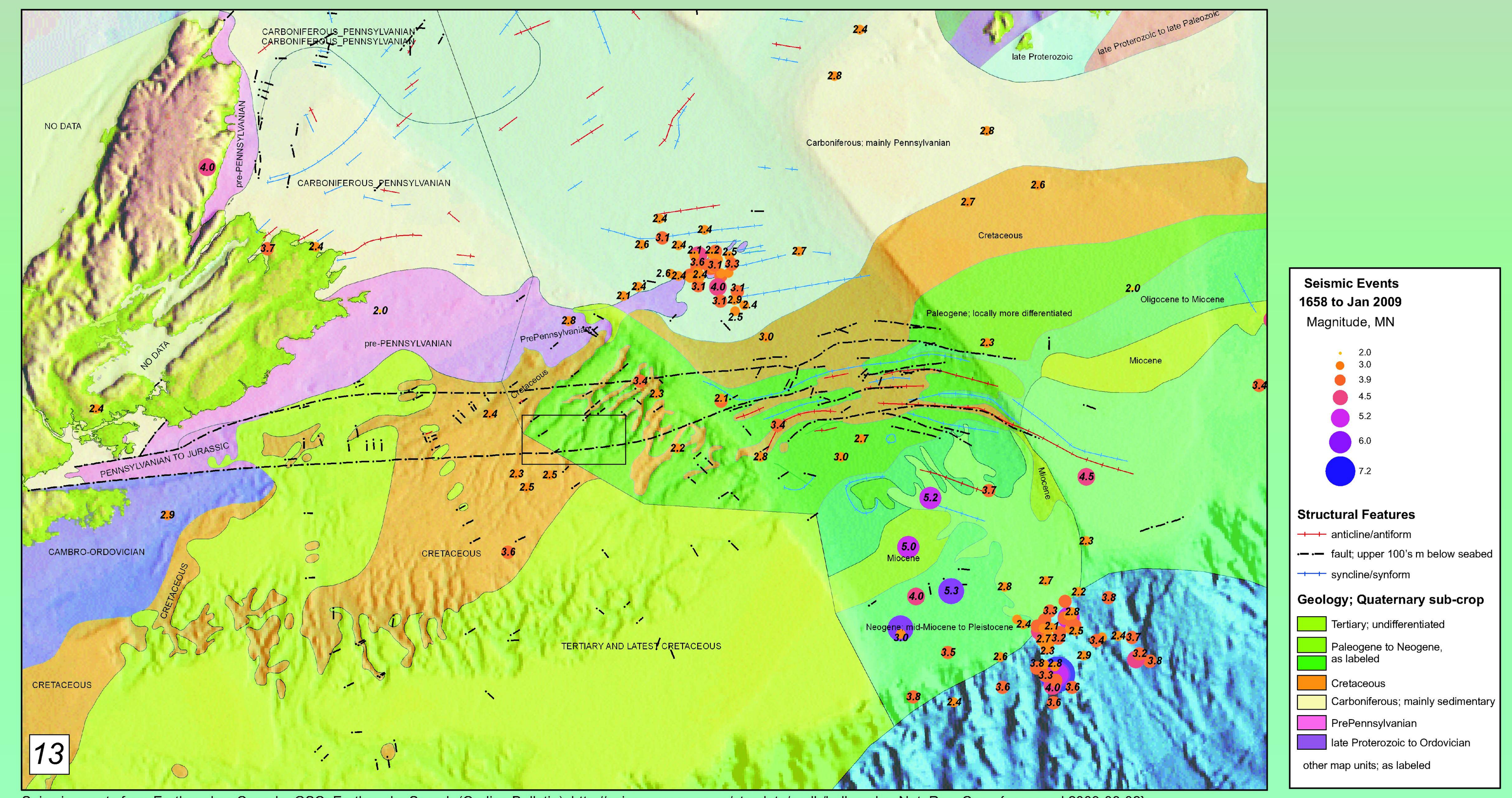


Geologic and seismicity setting

A rectangle marks the area of mass failures with respect to the bedrock geology map (major revisions in progress).

The basin is the seabed expression of the Triassic rifted Orpheus Graben, an offshoot of the Scotian Basin lying between two structural highs, the Canso Ridge and Burin Platform. The latest significant tectonic activity in the area is Cretaceous and Paleogene age, associated with the Cobequid–Chedabucto Fault system (Jansa & Pe-Piper, 1985, Pe-Piper & Piper 2004).

Laurentian sub-basin margin shallow faulting (upper tens to hundreds of metres below the seabed) is prevalent in central Laurentian Channel. None clearly affect mid-late Quaternary beds. Though earthquake events are relatively small and infrequent, events here are more frequent than most areas of the Atlantic coast. A 2.4ML event occurred on the basin flank Christmas of 2006. A cluster of elevated seismic activity in central Laurentian Channel, NW of St. Ann's Basin may be salt diapir-related (Ruffman 1992). Evidence for continued diapiric action into mid-Quaternary blankets near here is equivocal; otherwise planar glacial erosion surfaces are deflected across salt but this might be a primary response to the substrate rather than post-depositional deformation.



Seismic events from Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), http://seismo.nrcan.gc.ca/stnsdata/nedb/bull_e.php, Nat. Res. Can., {accessed 2009-03-02}.

Conclusions

- Mass failures in St. Ann's Basin are common; they number at least seven but may be much more common. They represent the most dense occurrences of late Quaternary mass failure recognized in a shelf setting on the Scotian Shelf or Grand Banks (excludes the upper slope)
- They originate in plume-deposited glacimarine blanket deposits within 2 millennia of deposition
- They are generally rotational failures on moderate slopes (< 6 degrees), with limited translation and run-out and limited dissociation
- Large volumes of glacial muds in the adjacent basins are deformed; apparently from overriding and translational collisions. Distinction between translated volumes and near in-situ disturbance is poorly constrained. Debrite volume is generally under 0.2 km^3(200*10^6 m^3) - large compared to most land event but small for marine occurrences
- Contemporaneous slide events, or nearly so. Imprecise dating by radiocarbon and stratigraphic correlation suggest a Younger Dryas or slightly more recent age
- The Cobequid - Chedabucto fault complex passes nearby; though significant late Cretaceous and some Paleogene offset is evident, no clear Quaternary offsets are recognized despite ubiquitous sediments presumably capable of recording this
- Earthquake triggering is suggested; swarms of events occur in central Laurentian Channel coincident with numerous diapirs
- Nearby pockmarks attest to shallow gas leakage but no failure association is noted
- Their is potential for a tsunami of several 10's m height with these failures, especially if they were coincident
- Follow-up should include multibeam surveying and radiometric carbon date at top of glacimarine sediments

Acknowledgments and References

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