Geological Survey
of Canada

Current Research
2000-D8

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2000

Natural Resources Canada
Ressources naturelles Canada

Canada

Catalogue No. M44-2000/D8E-IN
ISBN 0-660-18051-0

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Campbell, D.C., 2000: Relationship of sediment properties to failure horizons for a small area of the Scotian Slope; Geological Survey of Canada, Current Research 2000-D8, 7 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Abstract: A small area west of Verrill Canyon on the Scotian Slope, between the Shubenacadie H-100 and Acadia K-62 deep-water well sites, was examined to address the question of whether sedimentological and geomechanical features of piston cores would explain the localized occurrence of sediment failures. The seabed in the area was divided into zones of disturbed, undisturbed, and erosional areas. Six continuus acoustic reflectors were traced throughout the area from high-resolution acoustic records. The acoustic surveys showed that failure planes are restricted to specific horizons. Nine sediment cores, providing a composite stratigraphy of the acoustic section, were described for lithological variation and measured for a suite of physical properties. Failure planes appear to correlate with sandier intervals in cores. This provides some predictive capabilities elsewhere on the slope.

Résumé : Une petite région à l'ouest du canyon Verrill, sur le talus Néo-Écossais, entre les puits en eau profonde Shubenacadie (H-100) et Acadia (K-62), a été l'objet d'une étude visant à déterminer si les caractéristiques sédimentologiques et géomécaniques d'échantillons de carrotiers à piston pouvaient servir à expliquer le déclenchement de glissements de terrain localisés dans les sédiments. Le fond marin de la région a été divisé en zones dérangées, intactes et érodées. À l'aide d'enregistrements acoustiques à haute résolution, six réflecteurs acoustiques continus ont pu être suivis à la grandeur de la région. Les levés acoustiques indiquent que les plans de glissement sont limités à certains horizons spécifiques. Neuf carottes de sédiments, dont on a décrit les variations lithologiques et mesuré un ensemble de propriétés physiques, ont été choisies afin d'obtenir une coupe stratigraphique composite du profil acoustique. Les plans de glissement semblent être associés aux intervalles les plus sableux des carottes. Ces observations pourraient servir d'outil de prévision applicable ailleurs sur le talus.

INTRODUCTION

Recently, the search for petroleum has extended out into the deeper waters of the continental slope. This has introduced a variety of challenges to companies, both in terms of exploration and production. Major sediment failure is a potential hazard to petroleum development on the continental slope (Piper et al., 1999). Many parts of the continental slope off eastern Canada are covered by Quaternary sediments up to 1 km thick (Piper et al., 1985). Evidence of failure of late Pleistocene sediment on a variety of scales is present on the Scotian Slope just west of Verrill Canyon (Mosher et al., 1994). In this report, the question of whether sedimentological and geomechanical features of cores would explain the localization of sediment failure in the upper ~50 m of seabed, thus allowing predictive capabilities elsewhere on the slope, is addressed for a 4500 km^2 area that includes the Shubenacadie H-100 and Acadia K-62 deep-water well sites (Fig. 1).

METHODS

High-resolution 3.5 kHz subbottom profiler, deep-towed sparker, and Huntec Deep Towed System (DTS) seismic records collected on expeditions during the early 1980s, and up to recently, were examined. In soft sediments, these systems can penetrate the upper 80 m of seabed. Sediment cores up to 9 m in length collected during the same period as the seismic data were examined. For many of theses cores, geomechanical measurements were available.

SEABED TYPES

The seabed of the study area can be divided into three types:

1. *undisturbed sediment* In the undisturbed areas, high-resolution profiles show well stratified, continuous reflectors over the entire record (approximately 80 m

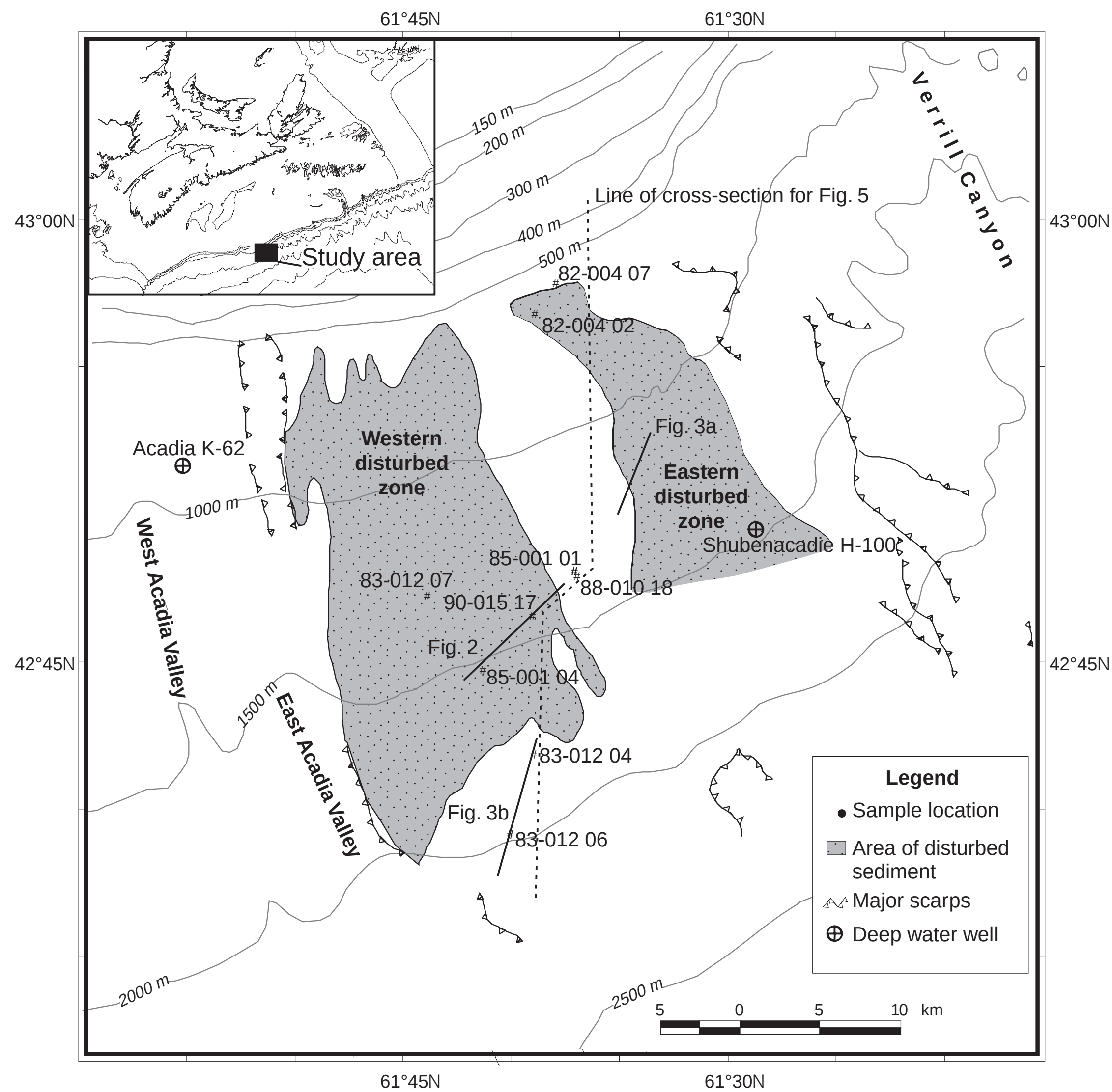

Figure 1. *Location map showing disturbed zones, core locations, figure locations, and some surficial features. Modified from Piper et al. (1985).*

below seafloor). Upslope, on airgun seismic-reflection profiles, these reflectors interfinger with large wedges of acoustically incoherent sediment, interpreted as slumped diamict and glacial outwash, which in turn, pass upslope into acoustically incoherent sediment interpreted as outer shelf tills (Mosher et al., 1989). The undisturbed sediments in the area consist of complex alternations of turbidites, ice-rafted debris, hemipelagic deposits, and thin smooth debris flows (Mosher et al., 1989).

2. *disturbed sediment* The disturbed seabed comprises two geographically distinct areas of sediment failure and were mapped by Piper et al. (1985) using deep-towed sidescan sonar. The disturbed areas have been designated as the Western disturbed zone and the Eastern disturbed zone (Fig. 1). In high-resolution seismic profiles, the disturbed zones appear as irregular seabed having a transparent or acoustically incoherent subbottom. The majority of the disturbed zones consist of complex rotational slumps which pass downslope into thin surface deposits of distal debris flows and turbidite sediment (Piper et al., 1985).

3. *scoured and erosional areas* South of the disturbed zones, areas of eroded and scoured seabed are present. Erosional depressions are generally narrow, flat floored, and pointed at both ends, and may have been formed by fast-flowing downslope currents selectively scouring easily erodible sediment, then eroding laterally once a less-erodible stratum was reached (Piper et al., 1985). In addition, there appears to be extensive evidence for bedding-plane slides and rotational failures south of the disturbed zones, resulting in large arcuate scarps up to 80 m in height, as illustrated in Figure 4 of Mosher et al. (1994).

ACOUSTIC STRATIGRAPHY AND FAILURE HORIZONS

Six continuous shallow reflectors, defined by Mosher (1987), were traced throughout the area on high-resolution seismic records. The relationship of these reflectors to failure horizons was examined. Baltzer (1994) gives a definition of each colour-coded reflector and estimates an age based on extrapolation of ^{14}C dates (Table 1). Re-examination of core 90-015 17 revealed that the dated shell was within the disturbed sediment and may have been reworked, therefore the 20.8 ka date is stratigraphically suspect. The age estimates are confined by a new date on core 83-012 06 of 36.4 ka (Table 2).

Table 1. Definition of reflectors and estimated age (Baltzer, 1994).

Reflector	Approximate depth below seafloor (m)	Estimated age (ka)
Brown	2	13.5
Orange	6–7	16
Green	10	18.2
Yellow	19	20.8
Red	26	30
Pink	32–33	32

Table 2. New radiocarbon data.

Core	Interval	Dated material	Weight	Lab no.	Age*
8312 06	445-448 cm	*N. pachyderma* foraminifers	20 mg	TO-7747	36420 ± 420 BP

*without reservoir correction

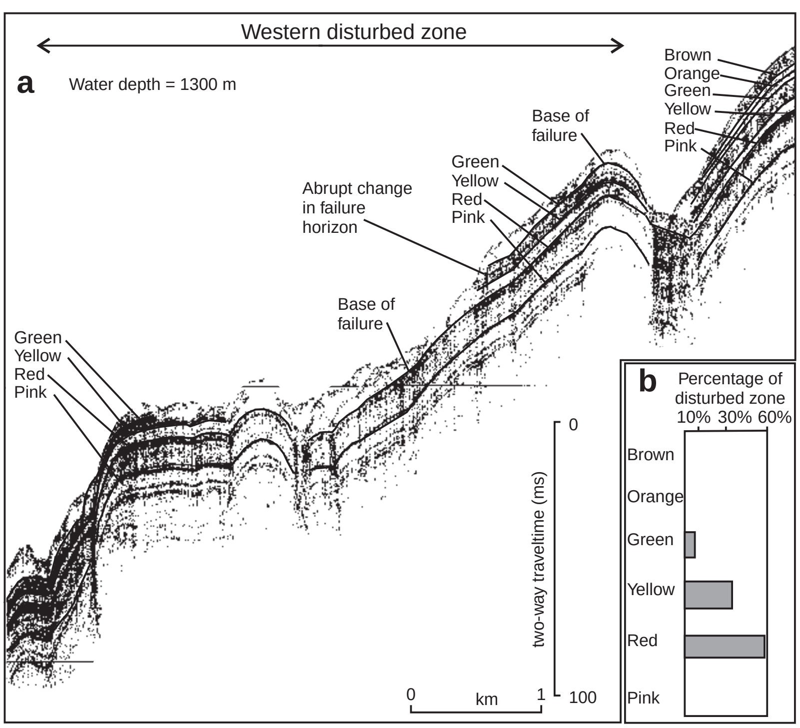

Figure 2.

a) *Strike line across the Western disturbed zone, 3.5 kHz profile, cruise 90-015.* ***b)*** *Histogram showing percentage of disturbed zone where mass movement has occurred at a specific horizon.*

In the acoustic profiles, disturbed areas appear transparent or incoherent, with an irregular surface and occasional internal hyperbolic reflections. Failure in the area appears restricted to planes between the green and red reflectors (Fig. 2). Survey lines perpendicular to slope indicate that the transitions from undisturbed to disturbed zones and from shallower to deeper failure planes are near vertical (Fig. 2), which would be expected in rotational type failures. The estimated total volume of debris-flow deposits is 3 to 5 km^3 (Piper et al., 1983; Mosher et al., 1994). Figure 2b shows a histogram of the percentage of total disturbed area that failed at specific horizons based on a map from Piper et al. (1983). Of the total disturbed area, approximately 7.4% failed at the green horizon, 34.5% failed at the yellow horizon, and 58.1% failed at the red horizon.

Along much of the western edge of the Eastern disturbed zone, there is a zone of internal deformation (Fig. 3a; Figure 3 of Mosher et al., 1994). The overlying sediments appear undisturbed. Mosher et al. (1994) estimated that this internal deformation increases the total volume of deformed sediment by 0.5 km^3. The failure horizons of the internal stratigraphic deformation occur within the same interval of reflectors as the failures at the surface.

Further down the slope, there is evidence of erosion, bedding-plane slides, and more rotational slumping (Fig. 3b). The erosion allows for coring of deeper reflectors.

CORE LITHOLOGY AND PHYSICAL PROPERTIES

It is possible to obtain cores for a composite stratigraphy of the 32 m sequence down to the pink reflector (Fig. 4), because the reflectors examined in this area thin downslope, and south of the disturbed zones the seabed is erosional. Figure 5 is a cross-section of a transect from the upper slope to the eroded area and shows where there is sample control of the sediments above and below the reflectors. Note that there is no reliable sediment information for the green reflector which appears to be related to many of the failures.

Nine sediment cores covering a transect from the upper slope to the lower erosional zone were examined (Fig. 1). The original core descriptions were abridged to the classification of Piper and Skene (1998). Typically, the upper 0.5 to 1.5 m of core consists of olive grey, silty or clayey mud, interpreted as Holocene sediment. The late Pleistocene sediments consist of alternating brown and reddish-brown muds, silty muds, and sands interpreted as turbidites, ice-rafted debris, and thin debris-flow deposits. Bulk density (g/cm^3), water content (weight per cent), and shear strength (kPa) measurements were available for several cores (Figure 4).

Four cores were examined from the upper and central slope and are believed to contain undisturbed sediment (Fig. 4). In general, the Holocene mud has a high water content and decreasing shear strength with depth (Mosher et al., 1994). Baltzer et al. (1994) described an apparent overconsolidation of Holocene sediment on the continental slope to 50 cm subbottom which decreases to 150 cm and is caused

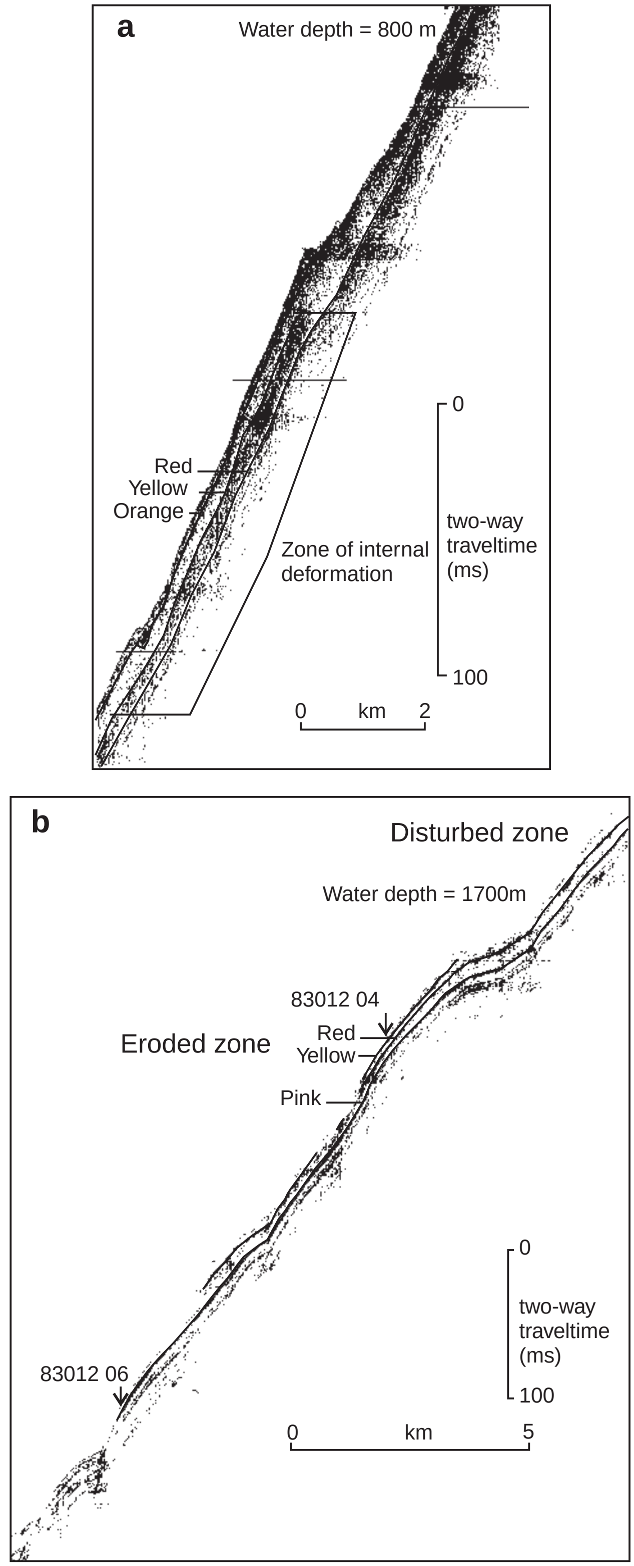

Figure 3. a) *A 3.5 kHz. profile showing internal deformation along the western edge of the Eastern disturbed zone, from cruise 90-015.* ***b)*** *A 3.5 kHz. profile showing erosion features south of disturbed area, from cruise 90-015.*

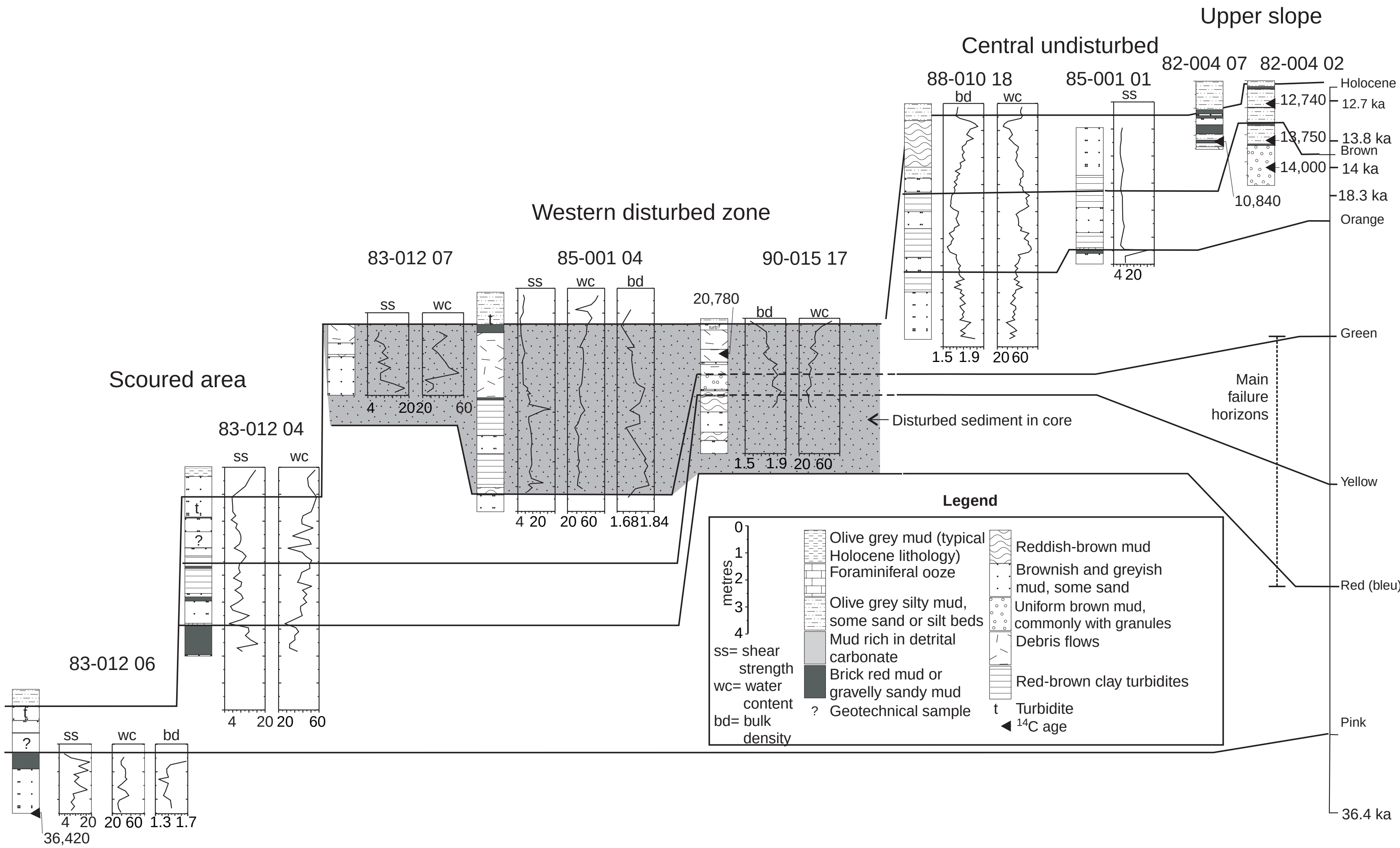

Figure 4. *Summary of core lithology, physical properties, and relationship to acoustic stratigraphy.*

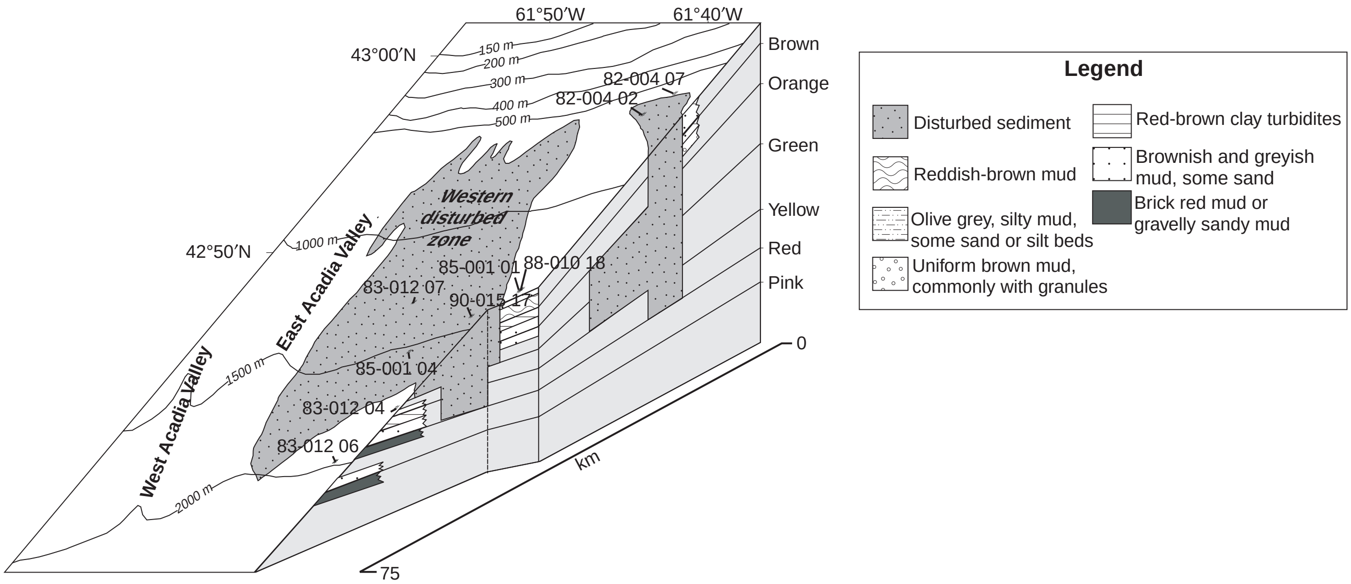

Figure 5. *Schematic cross-section showing relationship of acoustic reflectors to failure horizons and cores.*

by Zoophycos burrows, and may explain the decreasing shear strength with depth. Below the Holocene sediments, decreasing bulk density and increasing water content continues to 5.5 m, below which the core shows normal compaction (i.e. core 88-010 018, Fig. 4).

Three cores were examined from the Western disturbed zone and show an increase in bulk density and decrease in water content with depth, which may indicate a dewatering and draining of the sediments during disturbance. Indicators of deformation in these cores include soft-sediment folding, tilting of laminae, and concentric clay balls (Mosher et al., 1994).

In the erosional area, cores show a normally compacted decrease in water content with depth. The Holocene sediments in these cores unconformably overlie late Pleistocene sediments.

Increases in shear strength in cores appear to be related to sandier intervals, with the exception of core 85-001 04 which may be caused by a large clay ball.

DISCUSSION — RELATIONSHIP OF FAILURE HORIZONS TO CORE LITHOLOGY AND PHYSICAL PROPERTIES

The failure planes appear restricted to specific horizons in the acoustic record, specifically the interval represented by the green to red reflectors. The acoustic reflectors associated with failure planes were traced into areas of undisturbed sediment and were correlated to depth within the sediment cores using a traveltime-to-depth conversion based on 1500 m/s sound velocity in near-surface sediments. The reflectors correlate to sandy and silty intervals that are overlain and underlain by finer sediment. In some cores, the coarser intervals are interbedded with muddier layers on the scale of several centimetres.

In the undisturbed areas, the high-resolution acoustic profiles show continuous parallel reflectors that correspond to sandier and siltier beds in cores. Cores from the undisturbed areas show increasing water content and decreasing bulk density to a depth of several metres. In the disturbed areas, the acoustic record shows transparent and incoherent profiles. Cores from the disturbed areas show soft-sediment deformation features and tilted strata, and have increasing bulk density and decreasing water content with depth.

The reflectors corresponding to failure horizons (green to red) appear to correlate to prolonged sandier intervals in cores. For example, the orange reflector corresponds to a 5 cm thick sand bed in core 85-001 01, and does not appear prone to failure, whereas the red reflector corresponds to a 100 cm thick, poorly sorted, muddy sand interval in core 83-012 04 and appears to be related to failure throughout the study area (Fig. 4).

The idea that sediment is failing at coarser grained intervals agrees with the evidence that acoustic reflectors correspond to failure horizons, but does not agree with the geomechanical measurements that show increased shear strength in sandy and silty beds. Although the mechanism for failure is not completely understood, the fact that failure horizons are associated with sandier intervals allows some predictive capabilities elsewhere on the slope. The creation of synthetic seismograms would allow a more precise correlation of cores to failure horizons.

Further coring and in situ geomechanical measurements of the reflectors associated with failure should be performed to examine how the sediment changes up and down slope and laterally across the slope.

ACKNOWLEDGMENTS

This work supported by GSC A-based funding, PERD through project 532210 (Deep-water geohazards), and Mobil Oil Canada Ltd.

REFERENCES

Baltzer, A.
1994: Dynamique sédimentaire des marges de Nouvelle-Écosse et des entrées de la Manche au Quaternaire; Ph.D. thesis, l'Université de Bretagne Occidentale, France, p. 25–92.

Baltzer, A., Cochonat, P., and Piper, D.J.W.
1994: In situ geotechnical characterization of sediments on the Nova Scotian Slope, eastern Canadian continental margin; Marine Geology, v. 120, p. 291–308.

Mosher, D.C.
1987: Late Quaternary sedimentology and sediment instability of a small area on the Scotian Slope; M.Sc thesis, Memorial University of Newfoundland, Newfoundland, p. 75–150.

Mosher, D.C., Moran, K., and Hiscott, N.
1994: Late Quaternary sediment, sediment mass flow processes and slope stability on the Scotian Slope, Canada; Sedimentology, v. 41, p. 1039–1061.

Mosher, D.C., Piper, D.J.W., Vilks, G.V., Aksu, A.E., and Fader, G.B.
1989: Evidence for Wisconsinan glaciations in the Verrill Canyon area, Scotian Slope; Quaternary Research, v. 31, p. 27–40.

Piper, D.J.W. and Skene, K.I.
1998: Latest Pleistocene ice-rafting events on the Scotian Margin (eastern Canada) and their relationship to Heinrich events; Paleoceanography, v.13, no. 2, p. 205–214.

Piper, D.J.W., Farre, J.A., and Shor, A.
1985: Late Quaternary slumps and debris flows on the Scotian Slope; Geological Society of America Bulletin, v. 96, p. 1508–1517.

Piper, D.J.W., Skene, K.I., and Morash, N.
1999: History of major debris flows on the Scotian Rise, offshore Nova Scotia; *in* Current Research 1999-E; Geological Survey of Canada, p.203–212.

Piper, D.J.W., Sparkes, R., Farre, J.A., and Shor, A.
1983: Mid-range sidescan and 4.5 kHz subbottom profiler survey of mass-movement features, Scotian Slope at 61E40N W; Geological Survey of Canada Open File 938, p. 1–17.

Geological Survey of Canada Project 980013