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Geophysical evidence for widespread Cenozoic bottom current activity from the continental margin of Nova Scotia, Canada

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ABSTRACT

Two-dimensional and three-dimensional multichannel seismic reflection data are utilized to examine previously unrecognized contourite depositional systems along the continental margin of Nova Scotia, Canada. Prior to this study these features were thought to be of limited extent in the study area. The new data show that contourite drifts are widespread with greatest drift development during the Late Miocene to Pliocene. Giant sediment waves form stacked, aggrading sequences of bedforms and their development is linked to pre-existing seafloor morphology. Small sediment drifts developed locally throughout the late Paleogene and Neogene, either southwest and down-current of seafloor obstacles or form channel fills. Major erosional pulses form regional seismic markers; first along the continental rise in the Early Oligocene, then along the continental slope during the Late Miocene and Pliocene. Three-dimensional seismic data show that erosion surfaces preserve along-slope amplitude anomalies, two-dimensional, low-relief sediment waves, and barchanoid bedforms. The geophysical evidence implies that a northeast-to-southwest, along-slope bottom current influenced Cenozoic depositional patterns throughout the study area.

1. Introduction

Contourite depositional systems (CDS) develop when along-slope geological processes, in part driven by contour-following bottom currents, dominate over down-slope geological processes, driven by gravity (Locker and Laine, 1992; Hernández-Molina et al., 2008; Mulder et al., 2008; Hernández-Molina et al., 2010). In the North Atlantic, contour-following bottom currents flow southward and westward along the continental margin of North America (Worthington, 1976; Pickart, 1992; Schmitz and McCartney, 1993). Evidence of interaction of these bottom currents with the seabed during the Cenozoic is demonstrated by the widespread presence of contourite drifts that flank the continental margins, from the Labrador Sea to the northern Antilles margin (Fig. 1a) (Heezen et al., 1966; McCave and Tucholke, 1986; Faugères et al., 1993; Wold, 1994; Faugères et al., 1999; Faugères and Stow, 2008). Evidence of bottom current interaction with the seabed is also shown by the development of regional unconformities on the continental slope and rise, when bottom current strength was sufficient to hinder deposition or even erode the seabed (Tucholke and Mountain, 1979; Mountain and Tucholke, 1985; Laberg et al., 2005; Miller et al., 2009).

The paleoceanography of the western North Atlantic is largely based on the analysis of seismic reflection data, supplemented by ocean drilling data, from the United States Atlantic margin (Heezen et al., 1966; Tucholke and Mountain, 1979; Mountain and Tucholke, 1985; Tucholke and Mountain, 1986; McCave and Tucholke, 1986). On the U.S. Atlantic margin, bottom current controlled sediment drifts and major erosional periods attributed to strengthened bottom current circulation are recognized from regional 2D seismic data from the continental slope to the lower continental rise. Sediment drift growth likely began in the Early Miocene and continued until the Pliocene, occasionally interrupted by pulses of along-slope erosion or non-deposition (Mountain and Tucholke, 1985; Locker and Laine, 1992). The most extensive Cenozoic erosional pulses resulted in the formation of regional seismic unconformities A^U (Lower Oligocene), Merlin (Middle Miocene), and Blue (Pliocene) (Tucholke and Mountain, 1986; Miller et al., 2009) (Fig. 2).

Compared to the U.S. Atlantic margin, the Cenozoic paleoceanographic record along the continental margin of Nova Scotia (herein the Scotian margin, Fig. 1) has not been investigated to the same level of detail, in part due to limited data coverage and in part because of tenuous seismic correlation between the U.S. and Scotian margins. Analysis of the modern bottom current regime along the Scotian margin shows that a southwest flowing western boundary current sweeps the seabed (Smith and Petrie, 1982; McCave and Tucholke, 1986; Pickart, 1992; Pickart et al., 1999) (Fig. 3). High suspended sediment loads are observed in the nepheloid layer on the Scotian Rise (Amos and Gerard, 1979; Biscaye and Eittreim,

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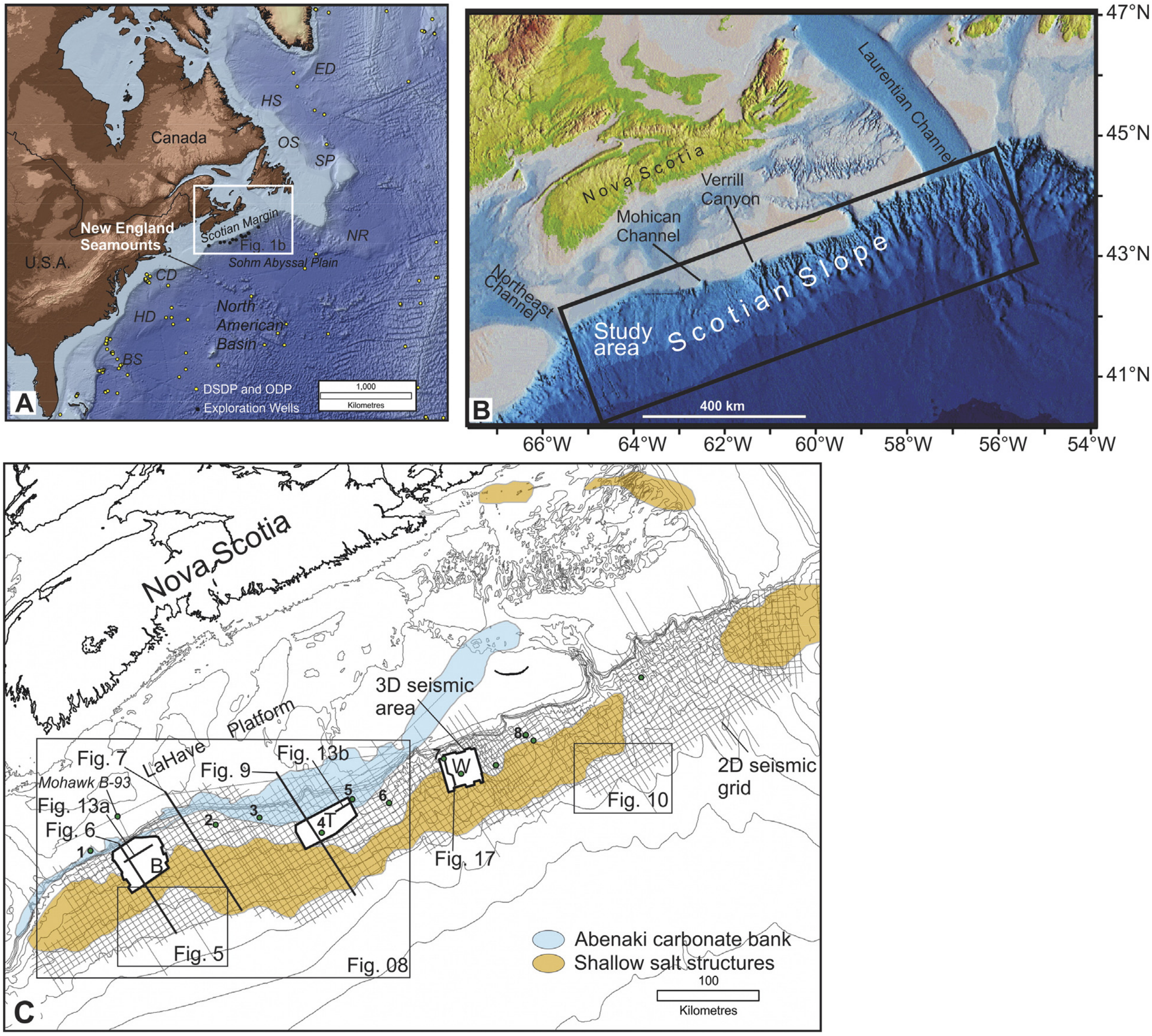

Fig. 1. A) Map of the western North Atlantic showing locations discussed in the text along with the named drifts that flank the continental margin, Eirik Drift (ED), Hamilton Spur (HS), Orphan Spur (OS), Sackville Spur (SP), Newfoundland Ridge (NR), Chesapeake Drift (CD), Hatteras Drift (HD), and Blake Spur (BS). B) Location map of the continental margin of Nova Scotia showing locations discussed in the text. C) Map of data used for this study and major structural elements. Regional 2D seismic reflection data shown as a grid. 3D seismic datasets are shown as white polygons and consist of the Barrington (B), Torbrook (T), and Weymouth (W) survey areas. Exploration wells used for the study are Bonnet P-23 (1), Shelburne G-29 (2), Albatross B-13 (3), Torbrook C-15 (4), Acadia K-62 (5), Shubenacadie H-100 (6), Newburn H-23 (7), and Annapolis G-24 (8). Structural elements were modified from Shimeld (2004).

1977). These currents and high sediment loads suggest that modern conditions are suitable for contourite development. The HEBBLE (High Energy Benthic Boundary Layer Experiment) (Fig. 3) demonstrated that Holocene contourites are present on the lower Scotian Rise (Nowell and Hollister, 1985). However, Piper et al. (1987); Hughes Clarke et al. (1992); Mosher et al. (2004) among others demonstrate that the Pleistocene geological record is dominated by down-slope processes. Additionally, a number of studies report that pre-Quaternary sediment drifts are absent or of limited geographical extent compared to the continental margin to the south and north, although erosional features are recognized on the continental rise (Swift, 1987; McCave and Tucholke, 1986; Ebinger and Tucholke, 1988; Faugères et al., 1993; Faugères et al., 1999; McCave et al., 2002; Faugères and Stow, 2008) (Fig. 1a). The main objective of this study is to revisit the apparent lack of contourite depositional features along the Scotian margin through analysis of two-dimensional (2D) and three-dimensional (3D) seismic reflection data. The new geophysical datasets on the Scotian margin allow detailed investigation of CDS along the western North Atlantic margin not previously attainable. In addition, this study improves understanding of the Cenozoic paleoceanography of the western North Atlantic and provides new insights into along-slope processes.

2. Background and regional setting

2.1. Geological setting of study area

This study is primarily focused on upper Paleogene and Neogene deposits along the outer Scotian margin in present-day water depths between 200 and 3500 m below sea level (mbsl) (Fig. 4). The Scotian margin consists of the continental shelf, slope and rise south of Nova Scotia and forms most of the northern margin of the North American Basin, a large bathymetric depression in the northwest Atlantic Ocean (Fig. 1) (Jansa et al., 1979). The basin margin formed during the late Triassic and early Jurassic rifting of Pangea and the opening of the Central North Atlantic Ocean (Wade and MacLean, 1990). The morphology of the modern Scotian margin includes a >200 km wide continental shelf

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