New Views of the U.S. Continental Margins

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Introduction

The Center for Coastal & Ocean Mapping/Joint Hydrographic Center, University of New Hampshire was directed by Congress through funding by the National Oceanic & Atmospheric Administration to conduct multibeam mapping of many US continental margins in areas where there is a potential for a claim under Article 76 of the United Nations Convention on the Law of the Sea. In 2003, two areas in the Bering Sea and one area in the Arctic Ocean were mapped. In 2004, about 75% of the US Atlantic margin and an area of the Alaskan Arctic margin were mapped. The US Atlantic margin and a large area of the Gulf of Alaska margin will be completed in 2005. The mapping objectives in all these areas are to locate the 2500-m isobath and map the zone of maximum change in gradient of the continental margin that is defined by Article 76 as the *foot of the slope*. In practice, we have, where possible, been mapping the entire area of the margin between the ~1000-m and ~4800-m isobaths.

We use multibeam echosounders (MBES) to map the areas where a potential claim may exist. The MBES systems are capable of producing maps with at least 100-m spatial resolution and a vertical precision of <1% of the water depth. Navigation on all cruises has been inertial-aided DGPS navigation with position accuracies of < ±5 m. All of the MBES systems used produce acoustic backscatter as well as bathymetry but the backscatter quality varies amongst systems and conditions. The processed data, as well as images from the data, are posted on http://www.jhc.unh.edu/unclos/html/index.htm within a few months of the completion of each cruise.

Bering Sea

The north flank of Bowers Ridge and a portion of the southern Beringian margin (Fig.1) were mapped in 2003. The objective of this cruise was to map the entire area between the ~1000 m isobath and the foot of the slope. Bowers Ridge is an aseismic ridge thought to be a Mesozoic to early Tertiary island arc that was rafted northward during Late Mesozoic to Early Tertiary spreading while riding on the Pacific or Kula plates (Ben-Avraham and Cooper, 1981). When subduction shifted south to the Aleutian Trench, the plate upon which Bowers Ridge sits was isolated and became docked to the Aleutian Ridge. The few rocks that have been dredged from the ridge are composed of albitized volcanic rocks (Scholl et al., 1975), and those samples, together with large positive gravity and magnetic anomalies directly over the crest of the ridge, support the interpretation that the ridge is a remnant volcanic arc. The ridge is draped with sediments and at least one large landslide has occurred along the north flank (Karl et al, 1996).

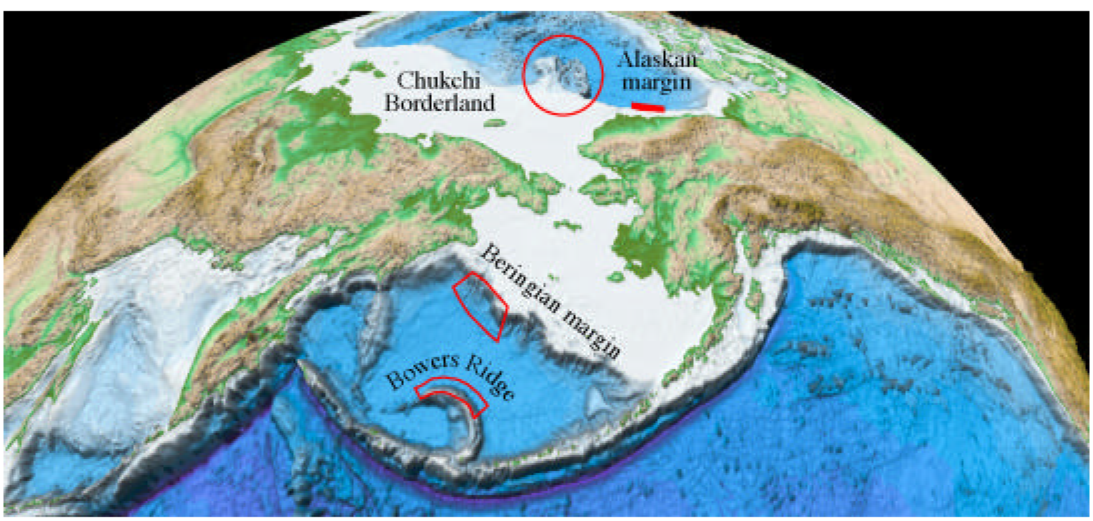

Figure 1. Red lines are areas mapped in the Bering Sea and Arctic Ocean.

The new mapping reveals the northern flank of Bowers Ridge as steep (~20°), heavily incised and complex, with an abrupt foot of the slope. The flank is dissected with numerous straight canyons and channels, presumably cut into bedrock. The mapping discovered a series of three plateaus along the northern flank, two of which have eastward-projecting ridges (Fig. 2) that are located about 15 km north of the main flank margin and follow the general curvature of Bowers Ridge. One of the ridges is more than 50 km long.

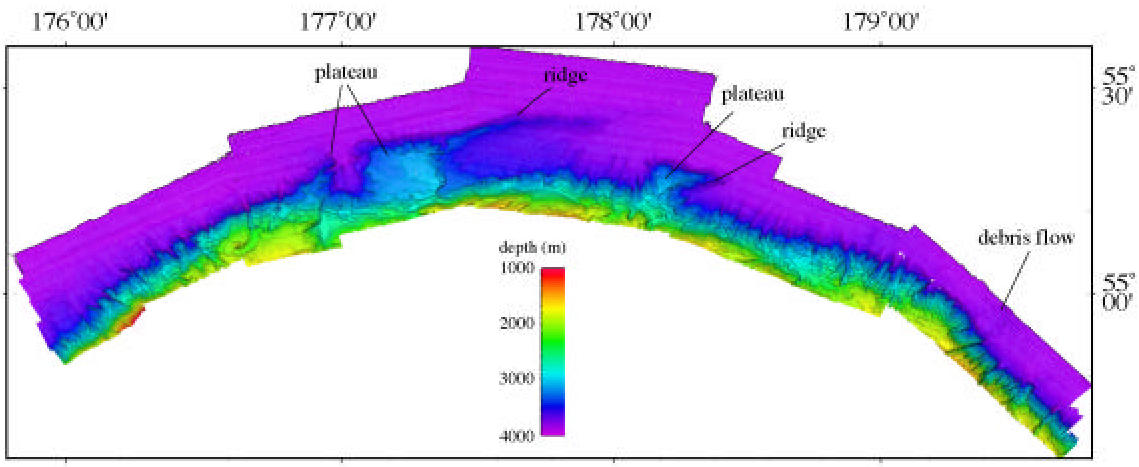

Figure 2. Color-coded shaded relief map of northern flank of Bowers Ridge. Note the plateaus located north of the flank margin as well as the eastward-projecting ridges.

The mapped area of the Beringian margin (Fig. 1) lies between Pervenets and St. Matthew Canyons. The base of the Beringian margin is thought to have been a subduction zone in the latest Mesozoic to early Tertiary, that may have consumed the Kula plate (Ben-Avraham and Cooper, 1981). As with Bowers Ridge, the Beringian margin subduction zone died with the formation of the Aleutian Trench subduction zone about 50 Ma ago during the early Tertiary. Today, the margin appears to be collapsing with large landslides and debris flows deposited along its base (Karl et al., 1996).

The new data show that even with a similar geological history as Bowers Ridge, the Beringian margin has a considerably different morphology (Fig.3). The Beringian margin is composed of a series of seaward-projecting sediment tongues or drifts, some of which reach more than 40 km beyond the steep margin. These features occur every 5 to 10 km along the length of the margin and some have attained heights of more than 150 m above the surrounding seafloor. The individual sediment tongues have relatively sharp crests and are deeply eroded only on their south-facing flanks.

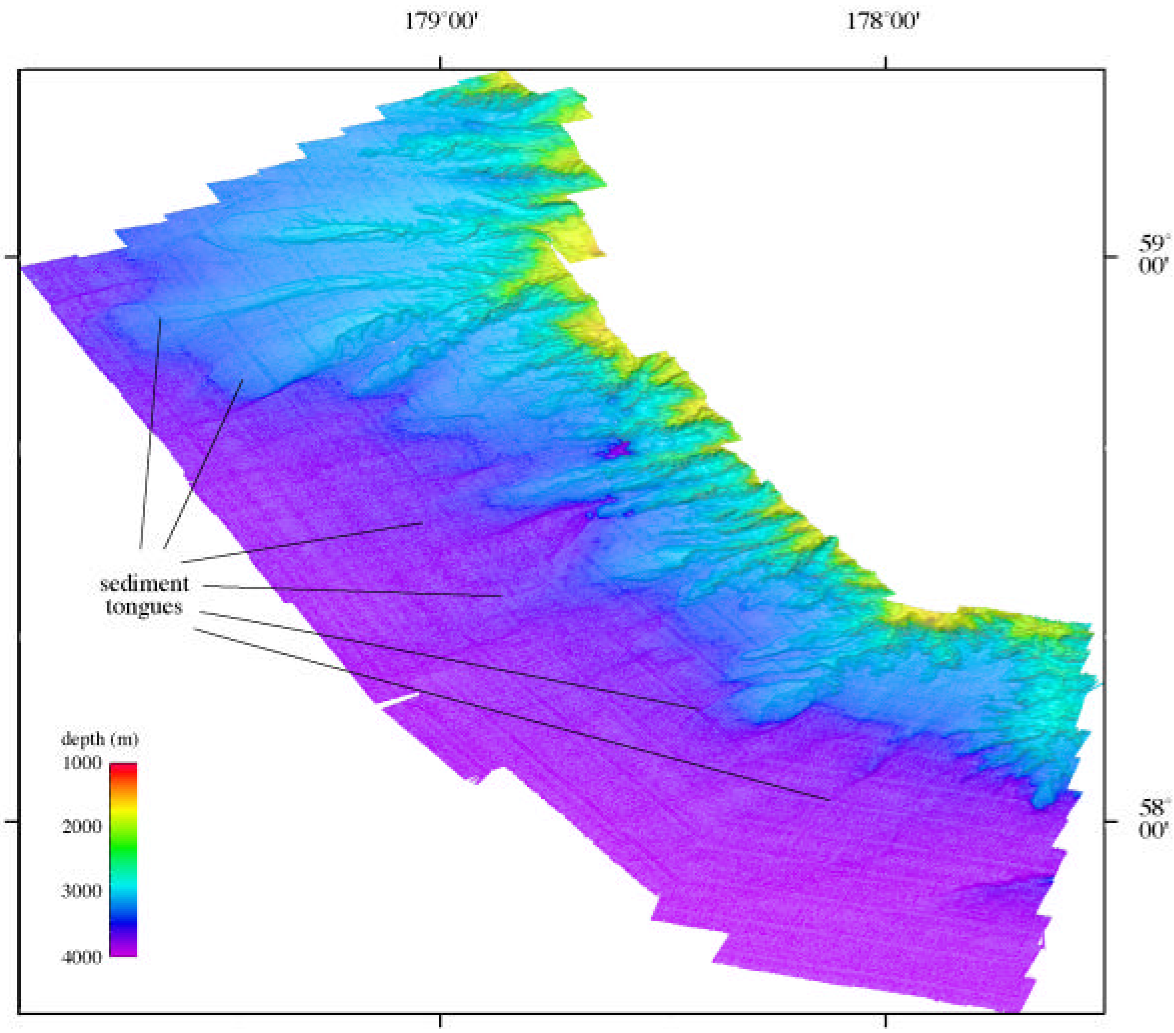

Figure 3. Color-coded shaded relief map of NW Beriingian margin. Note the large sediment tongues extending far out onto the basin floor.

Some of the submarine canyons have what appear to be plunge pools at some point along their course. Plunge pools are rare in the deep sea and on land they indicate energetic waterfalls. Clearly, a different, but unknown, submarine process has created these negative bathymetric features.

Arctic Ocean

Two cruises, one in 2003 and another in 2004, have been conducted in the Chukchi Borderland and the Alaskan Margin in the Amerasian Basin of the Arctic Ocean. The Chukchi Borderland is composed of continental rocks with a range of ages from as old as 500 million years to as young as a few hundred years. The older rocks were part of Arctic Canada and Alaska prior to the rifting that created the Amerasian Basin (Grantz, et al., 1999). Counterclockwise rotational rifting of Arctic Alaska away from North America began in early Jurassic time (~200 Ma) and created the Amerasian Basin. The "natural prolongation" of the Chukchi Borderland from mainland Alaska as well as the thick accumulation of sediment in the Amerasian Basin makes this region a viable target for an extended shelf claim under UNCLOS Article 76. As with our other Law of the Sea cruises, the objectives of our survey in this region were to map the 2500-m isobath and the foot of the slope. However, severe constraints imposed by pervasive ice in this region limited our mapping thus far to the 2500-m isobath.

Both Arctic Ocean cruises were conducted on the U.S.C.G Icebreaker *Healy* using its hull-mounted 12-kHz Seabeam 2112 MBES system. Our first cruise, during August and September 2003 was designed to explore the feasibility of using an icebreaker-mounted MBES system to locate and follow critical bathymetric targets in this region. Our exploratory mission demonstrated the viability of this approach because in 10 days we were able to collect about 3000 km of MBES bathymetry along the 2500-m isobath reaching 79°30'N in 8/10 ice conditions. The collection of these data substantially changed the mapped position and complexity of the 2500-m isobath, found further evidence for pervasive ice and current erosion (flutes and scours) in deep water, found evidence for gas-related features (pock-marks), and discovered a previously unmapped seamount rising more than 3000 m above the surrounding seafloor. The limited time available prevented us from collecting more than one or two swaths over any area of the margin, with the exception of the seamount that we fully mapped and named "Healy Seamount". Unfortunately, because of the limited coverage, this survey offers little insight into the detailed morphology of the Chukchi Borderland margin.

A 20-day Arctic cruise in 2004 had the objective of completing the mapping the 2500-m isobath and locating the foot of the slope on the Chukchi Borderland. This cruise was conducted later in the season (October and November) and encountered very heavy ice (9/10 to 10/10). We were able to progress to 78°45'N in these ice conditions and added an additional 370 km to our mapping of the 2500-m isobath but we were unable to survey the foot of this slope. As a fallback, we proceeded to completely map an approximately 18,500-km^2 region of the Alaskan margin northeast of Barrow that encompassed a depth range from approximately 800 m to 3700 m (Fig. 4).

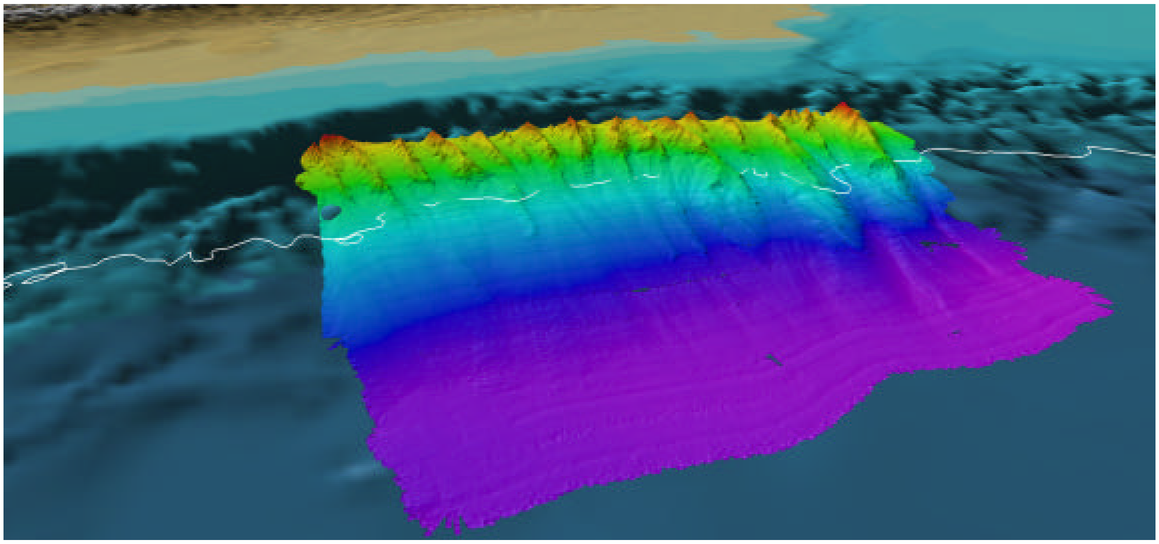

Figure 4. Perspective color shaded relief view of the Barrow margin, Arctic Ocean. Background bathymetry is from IBCAO (Jakobsson, 1999). White line is 2500-m isobath. Vertical exaggeration 6x. View is looking south.

The MBES coverage of the Barrow margin shows a remarkable set of parallel, asymmetric ridges and valleys spaced ~10 km apart and rising >500 m high (Fig. 5). The ridges consistently have gentler eastward-facing slopes and steeper westward-facing slopes. High-resolution subbottom profiler records show that the gentler, eastward-facing slopes are typically covered by well-stratified sediments whereas the steeper slopes are not, implying that sediment has been transported from east to west with sediment accumulation on the stoss slopes. The source of this sediment was most likely the MacKenzie River drainage system, because the Alaskan margin has had few major sediment sources (Grantz et al, 1990).

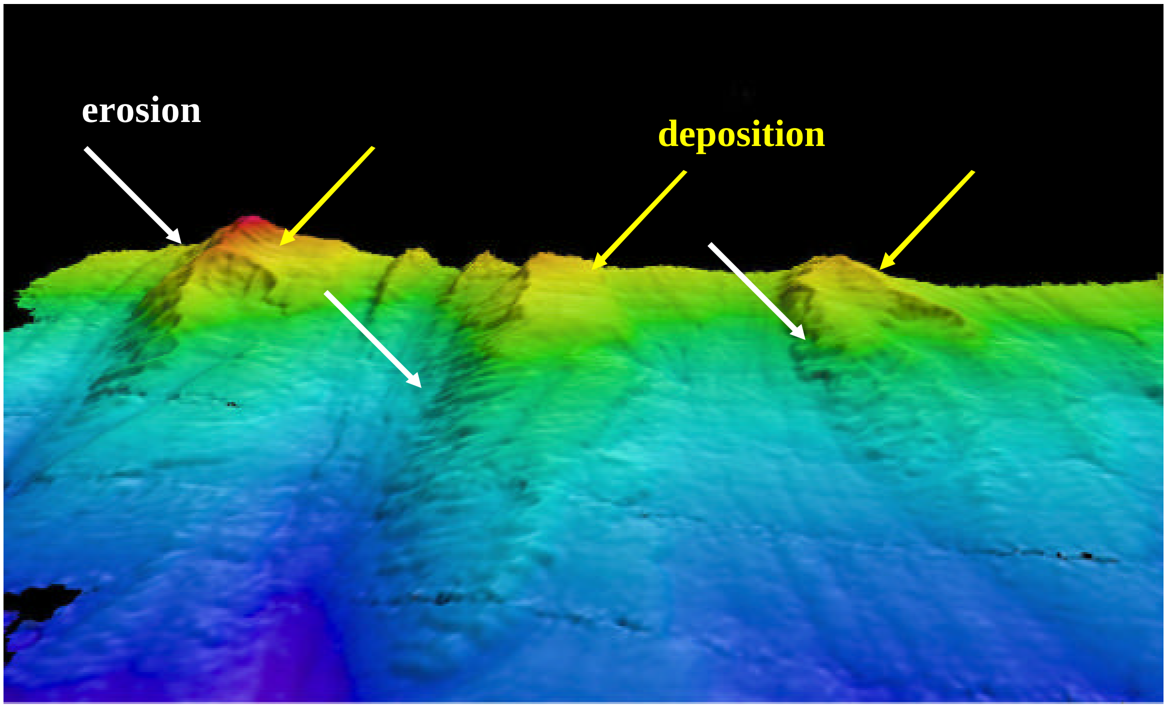

Figure 5. Perspective color shaded relief view of a small portion of the Barrow margin, Arctic Ocean. White arrows point to erosion, yellow arrows point to sediment deposition. Vertical exaggeration 6x. View is looking south.

US Atlantic Continental Rise

About 75% of the US Atlantic continental slope and rise was mapped in 2004 (Fig. 6). The objective was to map the slope and rise between ~1000 m and the foot of the slope. Although we planned to complete the entire area, a series of hurricanes interrupted our mapping efforts but the remainder of the area will be mapped in 2005.

The US Atlantic continental slope and rise is the product of processes that began with the initial breakup and rifting of Pangaea about 185 million years (Ma) ago that formed the Atlantic Ocean (Manspeizer, 1988). The U.S. Atlantic continental rise is underlain by ~10 km of sediments that have been, and still are, shed off the eroding Appalachian Orogen for almost the entire 185 Ma (Poag, 1992). The area has been influenced by numerous periods of sea level fluctuations, large swings in climates that altered erosion and deposition rates, strong geostrophic currents that helped shape the seafloor geomorphology and even an Eocene meteorite impact that hit the Chesapeake Bay region ~35 Ma ago (Poag, 1997).

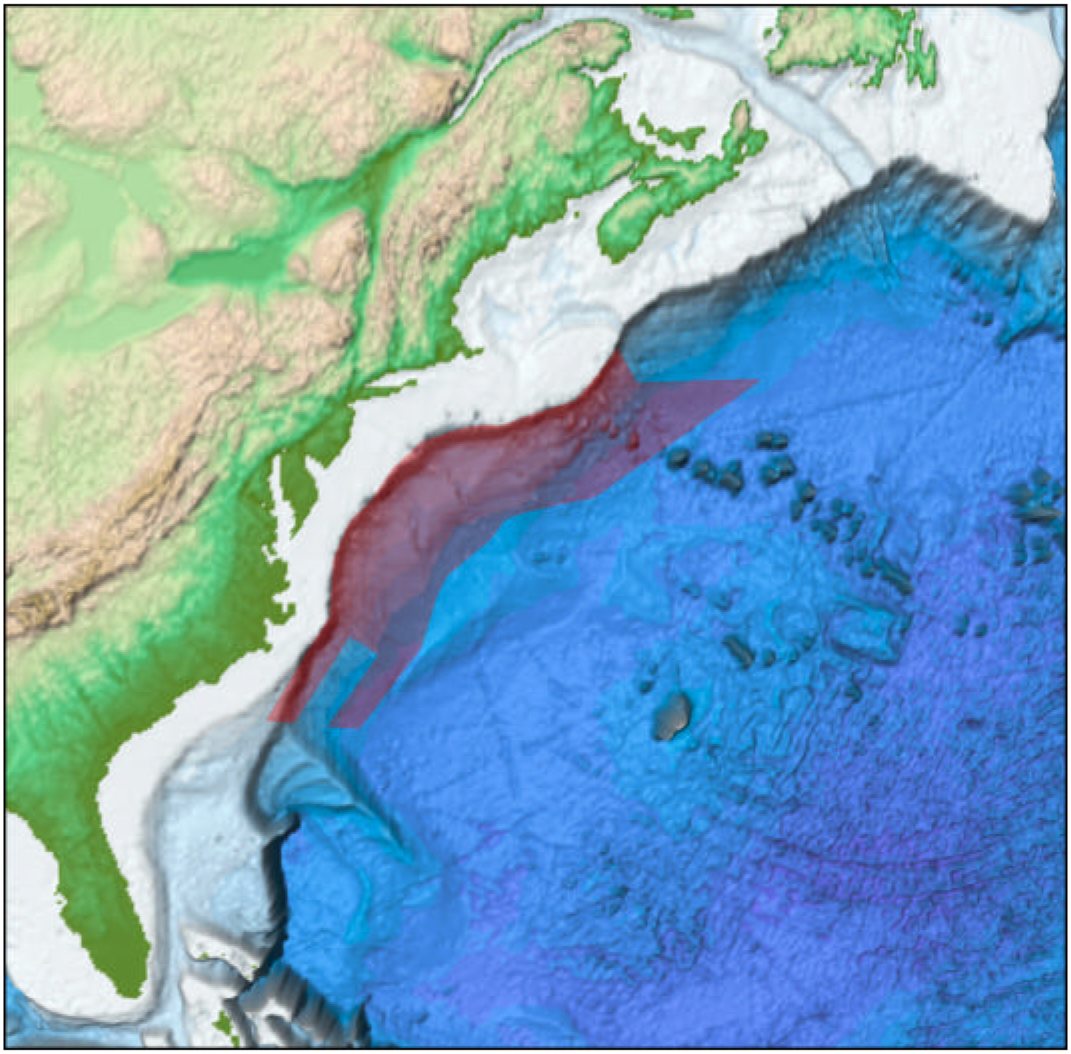

Figure 6. Red polygon is area of the US Atlantic continental rise mapped in 2004.

The major features revealed in more detail by the new bathymetric data include the numerous submarine canyon channels, most of which have been known for decades and have been mapped only to some degree, the western portion of the New England

Seamounts, also known for decades but only some of which have been mapped in detail, and the broad areas of sediment failures that blanket the present seafloor (Fig 7).

The upper continental rise has a dense network of submarine canyons and canyon channels. Here, canyon channels form a coalescing system, with some channels occurring as hanging channels giving evidence of capture, and some channels that join with simple junctions. Many of the submarine canyons in the NE part of the mapped area appear to be undergoing a new generation of incision. This rejuvenation is seen as a relatively broad (up to 10 km), flat-floored "flood plain" that has formed within a broad valley that is now incised by a narrow, deep, gently meandering canyon channel with only minor levees. The rejuvenation suggests a change in the equilibrium profile of the canyon channel system has recently occurred. The canyon channels SW of Hydrographer Canyon are less complex than those to the NE, are larger and more deeply incised. However, these canyon channels also show a renewed incision.

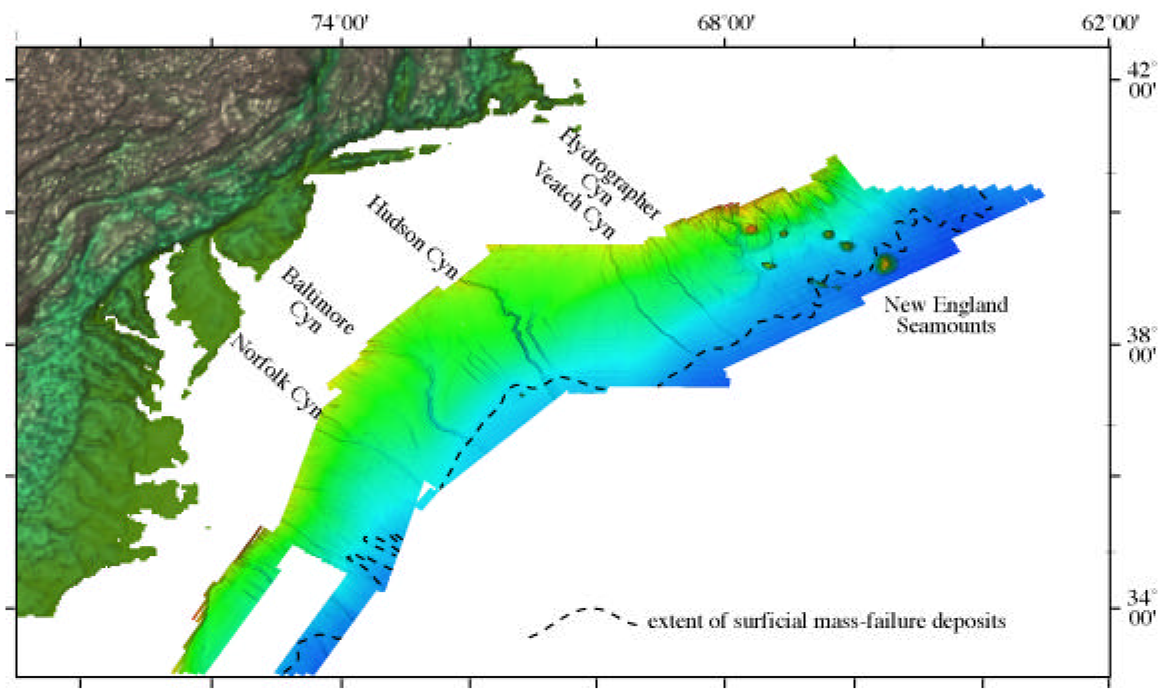

Figure 7. Multibeam color-coded bathymetry of the US Atlantic continental rise. Only a few of the submarine canyons have been labeled. Dashed line shows approximate extent of surficial mass-failure deposits.

There are several areas on the lower rise where channel heads abruptly appear, with no upslope continuity with any observable feature. The heads of these channels typically are somewhat rounded and are broader than the subsequent downslope channel widths. These channels are rarely incised more than a few decimeters. The locations of these features, together with their plan-view geometry, suggest they may represent locations of seeps (Dugan and Flemings, 2000).

The entire length of the mapped area and about 80% of the mapped width is mantled by mass-failure deposits (Folger, 1988; O'Leary and Dobson, 1992; O'Leary, 1996). The mass-failure deposits are organized in the area NE of Hydrographer Canyon as tongues of sediment that stream to the SE for more than 100 km over slopes <0.2°. Southwest of Hydrographer Canyon, the mass-failure deposits represent a continuous wedge of sediment that extends to the limit or beyond the mapped area. This difference might be simply the proximity of the SW area to major river systems compared to the NE area.

The complexity of the Atlantic continental margin as revealed by the new multibeam data makes identifying the foot of the slope equivocal. Although locating the 2500-m isobath on the Atlantic margin is a simple task, there is no simple zone of maximum change in gradient, no simple break where slope meets rise, so that placing such boundaries in these process-rich, complex, environments will require careful and inovative analyses.

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