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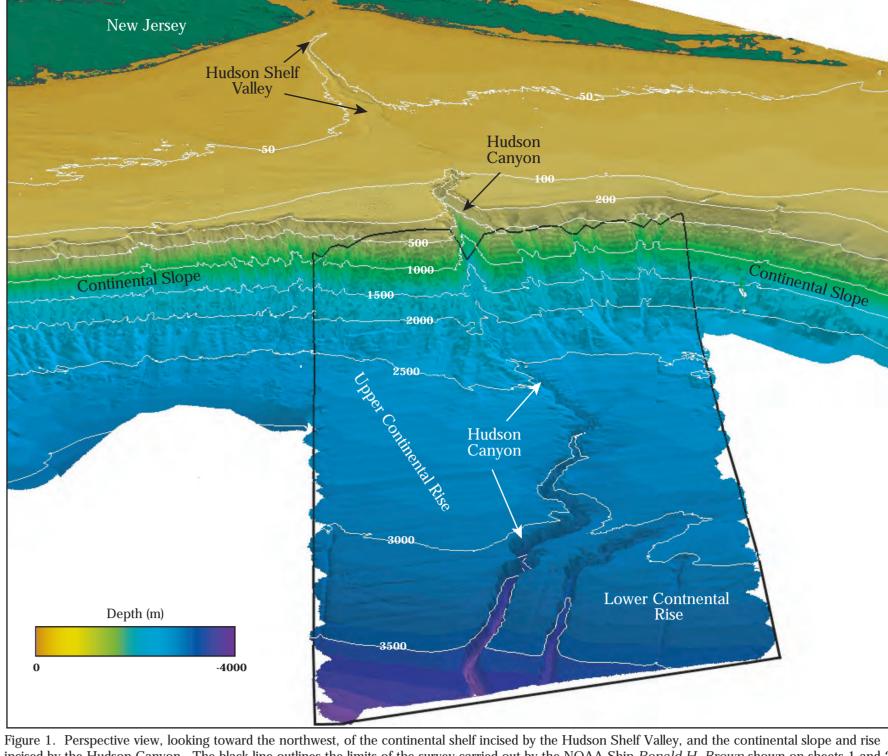
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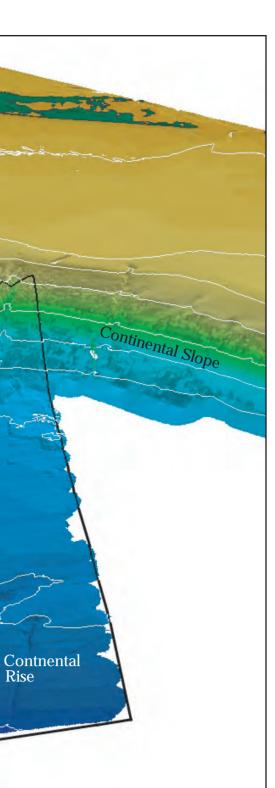
U.S. Geological Survey,

SEA FLOOR TOPOGRAPHY AND BACKSCATTER INTENSITY OF THE HUDSON CANYON REGION OFFSHORE OF NEW YORK AND NEW JERSEY

Bradford Butman¹, David C. Twichell¹, Peter A. Rona², Brian E. Tucholke³, Tammie J. Middleton⁴, and James M. Robb¹



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a result of this study to commemorate geologists who pioneered studies of the US Atlantic continental margin: Kenneth O. Emery and Elazar Uchupi of Woods Hole Oceanographic Institution, William B.F. Ryan of Lamont-Doherty Earth Observatory, and Robert L. McMaster of the University of Rhode Island. The slope canyons are typically 3 to 4 km wide (rim to rim) and mostly less than 450 m deep (rim to canyon floor). McMaster Canyon merges with Ryan Canyon at about 1,900 m before reaching the base of the slope (Figures 3 and 7). All the canyons to the northeast of Hudson Canyon become narrower downslope (Figure 7). Mey Canyon, the only canyon fully in the survey area southwest of Hudson Canyon, cuts across the continental slope and extends a few kilometers onto the continental rise. Like Hudson Canyon, these canyons exhibit eroded walls and gullies indicative of slope failure. Eroded areas of sea floor associated with canyons cover 13 % $(3,071 \text{ km}^2)$ of the entire survey area (Table 2). Hemipelagic sediment blankets approximately 46% of the survey area but

Hemipelagic Deposit

Base-of-Slope Depressions

others, 2002).

dendritic pattern.

Filled Valleys

Hemipelagic Deposit

Sediment Waves

Regior

Table 2. Sediment facies

Scarps

sea floor environment has a smooth surface with a low-backscatter intensity, and on subbottom profiles it shows a series of closely spaced reflections that

An extensive but subtle network of scarps on the continental slope is

revealed by the multibeam bathymetry (sheet 1, Figures 5 and 8). The shallowest of the scarps occur in 500 m water depth. Most of the scarps, which are attributed to mass wasting, are 20-75 m high (Figure 10 D, E), and the sea floor below the scarps is rough and commonly interrupted by additional scarps. The scarps outline V-shaped areas in plan view, narrowing upslope (for example, see the large scarp between Emery and Babylon Canyons near 39° 32' N and 71° 53' W, and the scarps to the southwest of Hudson Canyon, sheet 1). The multibeam bathymetry indicates that thinsheet slope failures have removed sediment from about 1,450 km² of the continental slope (6% of the survey area, Table 2). Multiple, sometimes intersecting scarps indicate that multi-stage collapse is commonplace on this portion of the continental slope. Seismic-reflection profiles suggest that much of the failed material was transported off the slope and deposited on the continental rise. Prior to this survey, the slope southwest of Hudson Canyon had been interpreted to be smooth based on single-beam bathymetric soundings (Uchupi and others, 2001).

At the base of the continental slope there are a series of narrow, linear depressions (sheet 1, Figure 7). They are discontinuous, trend parallel to the base of the slope, are 0.5-2 km wide and 3-13 km long, and are as much as 23 m deeper than the surrounding sea floor. Over the section of the base of the slope that was surveyed, the depressions occur along approximately 66% of the 45-km length southwest of Hudson Canyon but only about 18% of the 65-km length to the northeast. Base-of-slope depressions have been observed southwest of Mey Canyon (Robb and others, 1981; Pratson and others, 1994) and have been described as submarine plunge pools (Lee and

Upper Continental Rise The upper continental rise lies seaward of the base-of-slope depressions and extends to water depths of 3,000-3,100 m. The slope of the upper rise away from submarine canyons ranges from 0.2-0.9° (Figure 5). Dendritic streamflow networks (Figure 6) drain three areas: 1) the five canyons that reach the base of the slope northeast of Hudson Canyon and merge with it near 39° 01' N, 71° 16' W, 2) an area of the upper rise east of Hudson Canyon (merging with the canyon near 38° 51′ N, 71° 09′ W, and 3) an area of the upper rise southwest of Hudson Canyon (near 38° 39' N, 72° 08' W). A second style of drainage occupies the rise to the southwest of Hudson Canyon (in the western-most part of the map). Here, the channels are shallow, trend downslope to the south-southeast and do not coalesce in a

Hudson Canyon extends seaward from 2,200 m water depth at the base of the continental slope, across the upper continental rise, and onto the lower rise below about 3,000-3,100m. Between the base of the continental slope near 39° 14' N, 71° 52' W and where the drainage network from the northeast merges with Hudson Canyon near 39° 01' N, 71° 16' W, the canyon trends southeast through a series of meanders with wavelengths of about 10 km. The canyon here is 2.5-11 km wide from rim to rim (Figure 9 C, D), and the average slope along this 65 km stretch is 0.6° . The canyon floor varies in width from 0.2 – 2.1 km, appears nearly flat in the shadedlower and less steep than the southern rim (Figure 9); the canyon floor is typically 50-130 m below the adjacent rise to the northeast, but 150-270 m below the rise to the south of the canyon. At the end of this section at about 2,900 m, the canyon turns nearly 90° and then runs toward the southsoutheast, narrowing where it is met by the drainage from the east (near 38° 51' N, 71° 09' W). Down-canyon from this point, the canyon continues toward the south-southeast, narrows to about 5 km, and the floor is typically 400-500 m below the adjacent rise. Near 38° 37.5' N, 71° 05' W the canyon begins four sharp turns, turning first to the northeast, next to the southeast near 38° 40' N, 71° 02' W, then to the southwest near 38° 36' N, 70° 54.5' W before finally shifting back to the south-southwest near 38° 22'N, 71° W and continuing on this trend to the outer edge of the survey

than 300 m wide. The first sharp turn may be controlled by a diapiric structure that underlies this part of the valley near 38° 38' N, 71° 06' W (EEZ-Scan 87 Scientific Staff, 1991; Schlee and Robb, 1991). Northeast of Hudson Canyon, shallow valleys which create the dendritic pattern shown on Figures 6 and 7 can be traced from the mouths of the submarine canyons at the base of the slope onto the upper rise where they coalesce into one valley; this valley then feeds into Hudson Canyon near 39° 1' N, 71° 16' W (sheet 1, Figure 7). This morphology is similar to the 'sediment-gather' areas mapped by Schlee and Robb (1991) along much of the middle Atlantic continental rise. These shallow valleys and two others on the northeastern side of Hudson Canyon (Carstens Valley and one that

area. Through these turns the floor of the canyon is well defined and less

enters Hudson Canyon near 38° 52′ N, 71° 7′ W) are partially filled with

mass-transport deposits (Figure 8, Figure 10 G) that were shed off the

southern New England continental slope (O'Leary, 1993). Hemipelagic sediment occurs in large patches on the upper rise on both sides of Hudson Canyon. This sedimentary facies has a smooth sea floor surface with low-backscatter intensity, and on subbottom profiles it shows a series of closely spaced reflections that parallel the sea floor (Figure 10 B). Such hemipelagic sediments consist primarily of terrigenous silt and clay in core samples from other areas (Damuth, 1980).

A field of sediment waves lies on the upper continental rise on the southwest side of Hudson Canyon, and is shown most clearly on the image of backscatter intensity (Figure 4). The waves begin about 25 km seaward

Canyon for approximately 50 km. These waves have crests oriented roughly east-west and wavelengths of 900-1,500 m. The field of sediment waves covers about 14% (3,749 km²) of the study area. Sediment waves are known to form beneath persistent bottom currents (e.g., Rona, 1969; Mountain and Tucholke, 1983; Masson and others, 2002) and also on the levees of deep-sea channels where they are deposited from turbid flows that overtop the levees (e.g., Damuth, 1979; Normark and others, 2002). Both mechanisms probably operate in the Hudson Canyon area. Contour-following bottom currents flow to the southwest along this portion of the continental rise (e.g. Heezen and others, 1966); these currents would capture suspended sediment from the parts of down-canyon flows that rose above the canyon walls and deposit it on the rise southwest of the canyon. Similarly, the upper portions of turbidity currents that overtop the canyon walls will flow to the southwest because of the Coriolis effect. The orientation of the waves is not diagnostic of flow direction because sediment waves are known to form at nearly all angles to the prevailing currents (Flood and Hollister, 1974; Flood and Shor, 1988). Nonetheless, the slightly radiating pattern of the sediment waves (Figure 4) suggests that portions of turbid down-canyon flows escaping from the canyon near 39° N, 71° 20' W may have a dominant effect in wave formation. Mass-Transport Deposits Southwest of Hudson Canyon several long narrow 'fingers' of high

from the base of the continental slope and extend southward about 80 km

across the upper rise (Figure 8). The sediment waves abut the rim of Hudson

backscatter intensity originate near the base of the slope (39° 12' N, 71° 57' W, and 39° 10' N, 72° W) and extend downslope as much as 120 km to the their distribution and backscatter pattern, these fingers are interpreted as area covering 332 km², is covered by sediment waves (Figure 8), indicating bottom currents. The overlap of the mass-transport deposits and sediment backscatter images (sheets 1 and 2, Figures 3 and 4) also show other interpretation of multibeam data. evidence of down-slope transport from the continental slope onto the upper Northeast of Hudson Canyon there is an area of moderate to high backscatter intensity that begins at the base of the continental slope and covers most of the upper rise (sheet 2, Figures 4 and 8). High-resolution seismic profiles show that this area is characterized by seismically transparent layers and a rough surface (Figure 10 F, G). These layers are interpreted to be mass-transport deposits (Damuth, 1980; Figure 8). Some of the deposits were derived from the slope immediately northeast of Hudson Canyon, but a regional perspective provided by the GLORIA imagery indicates that most of the deposits were derived from the continental slope and upper rise south of New England (EEZ-Scan Scientific Staff, 1991; O'Leary, 1993). Seismic profiles show that these deposits have nearly filled the parts of the shallow valleys on the rise north of Hudson Canyon (Figure 10 G), and they extend to Hudson Canyon but do not fill it. The absence of mass-transport deposits on the floor of Hudson Canyon suggests that subsequent turbidity currents swept this material from the canyon floor. Overall, mass-transport deposits cover about 5,325 km² of the upper continental rise (20 % of the study area, Table 2

Lower Continental Rise The lower continental rise extends from water depths of about 3,000-3,100 m to beyond the southeastern edge of the survey area (Figure 7). The slope of the lower rise ranges from 0.5-1.2° and thus, on average, has a on the lower rise is characterized by numerous individual downslope pathways that trend toward the southeast (note that many drainage pathways in the southwest portion of the map are artificially interrupted by the alongtrack artifacts in bathymetry shown in Figure 6). Hudson Canyon

Hudson Canyon extends across the lower rise to beyond the southeastern limit of the survey. Over this 100 km, the canyon trends south-southeast and its axis has an average slope of 0.5° (Table 1). The canyon is about 5 km wide from rim to rim (Figure 9). The canyon walls are 2-3 km wide and have slopes of 15-20° (Figure 5). The canyon floor is typically less than 1 km wide and 500 m below the adjacent lower rise. There is a large meander, near 38° 21.5' N, 70° 55' W that is nearly replicated by a similar meander in Carstens Valley to the northeast (sheet 1). Hemipelagic Deposit

Hemipelagic sediment covers nearly all the lower rise except for Hudson and Carstens Canyons. This sedimentary facies has a smooth sea floor surface and low-backscatter intensity, and on subbottom profiles it shows a series of closely spaced reflections that parallel the sea floor (Figure 10 B). Such hemipelagic sediments in core samples from other areas consist primarily of terrigenous silt and clay (Damuth, 1980).

The shaded-relief maps (sheet 1, Figure 3) and the drainage network map (Figure 6) show linear valleys that originate on the lower rise in water depths between 3,000 and 3,200 m (the four largest of these valleys are shown in Figure 7). The origin of these valleys on the lower continental rise makes them distinctly different from Hudson Canyon and the other canyonassociated valleys. The rise valleys are shallow, straight features with bowllike heads that are 6-69 m deeper than the surrounding sea floor (Figures 3 and 7). Farther downslope, where they exit the survey area, they have less than 10 m relief. High-resolution seismic profiles show that hemipelagic sedimentary layers are truncated around the heads of these valleys, indicating an erosional origin. Thinning of the layers within the valleys suggests that the valleys are maintained by preferentially reduced deposition (Figure 10 A). Farther downslope the shallower of these valleys have subdued levees to either side, but the deeper valleys continue to have eroded walls. The rise valley at the southwestern edge of the survey area lacks a bowl-like head, and it may have been filled by mass-transport deposits (see Mass-Transport

Deposits in the Upper Continental Rise section above).

removed from the continental slope suggests that they are not formed by turbidity currents, which would have originated on the outer continental shelf or continental slope. Additionally, they do not appear to be the result of erosion by bottom currents, because bottom currents flow roughly perpendicular to the trend of the valleys (Heezen and others, 1966; Pratson and Laine, 1989). Pore-water discharge may be a mechanism for forming these rise valleys (Johnson, 1939; Robb, 1984). Notably, the heads of the valleys originate above the seaward edge of a major gas-hydrate province mapped beneath the continental rise (Tucholke and others, 1977; Dillon and others, 1995). Sedimentary bedding there dips landward (Tucholke and others, 1977), so the attitude of the beds could focus fluid flow (gas and water) and stimulate sapping in this zone.

The origin of the rise valleys is unknown, but the fact that they are well

A relative chronology can be defined from the stratigraphic stacking of the different seismic facies that are recorded on high-resolution seismic profiles. The oldest strata are those exposed by erosion along the canyon walls (Figure 10 B, C). In the section of the canyon that cuts the continental slope, these strata are of Cretaceous, Paleogene, and Neogene age (Weed and others, 1975; Gibson and others, 1968). Neogene sediments are exposed within the canyon where it crosses the continental rise (Ericson and others, 1952; Mountain and Tucholke, 1985). The high-resolution seismic profiles have a maximum penetration of about 50 m subbottom. Although no cores from the survey area are known to be directly dated so as to provide sedimentation rates, we can infer the age of the upper 50 m of sediment from related data. Dated cores from

uneroded areas of the continental slope and rise to the south of our survey indicate sedimentation rates between about 5 and 15 cm/k.y. (Embley, relief image (sheet 1), and is floored with material showing high backscatter 1980; Klasik and Pilkey, 1975). Within the survey area, mapping and intensity (Figure 4, Table 1). Along this section, the north canyon rim is interpretation of seismic stratigraphy shows that up to about 400 m of upper Pliocene and Quaternary sediments are present (Mountain and Tucholke 1985), yielding a similar average sedimentation rate of ~ 11.5 cm/k.y. Thus the shallow seismic facies documented in the high-resolution profiles probably represent between 0.3 and 1.0 m.y. of sediment accumulation (i.e., middle to upper Pleistocene and younger). Scarps are cut into hemipelagic sediment on the continental slope, and

> they presumably reflect source areas for the mass-transport deposits that overlie hemipelagic sediment in several places on the rise (Figure 10 G). These features indicate that the mass-transport deposits generally postdate the hemipelagic sediments (Figure 10 C, D). Most recently, the surfaces of some mass-transport deposits have been reworked into sediment waves, reflecting the action of overbank flow of turbidity currents and/or bottom currents, probably in the Holocene. The shallow stratigraphy and sea-floor features show dramatic changes in

the style of sedimentation during the middle to late Pleistocene and Holocene. Initially, deposits on the continental rise were a mix of turbidites and hemipelagic sediments. Turbidity currents generated on the outer shelf or upper slope were transported across the upper rise through a network of submarine canyons to the Hudson Fan seaward of the study area (Figure 2). Hudson Canyon and several canyons to the east, extending perhaps to Block Canyon, coalesced on the upper rise to form the 'gather area' that supplied sediment from a large part of the continental slope to the Hudson Fan (Schlee and Robb, 1991). Within the survey area during this time, finegrained turbidites were deposited on the levees to either side of the canyons, and hemipelagic sediment including contourites deposited from bottom

A period dominated by mass wasting followed the period of turbidite and hemipelagic deposition. At this time large sections of the southern New England continental slope as well as the slope to either side of Hudson Canyon failed, and the displaced sediments spread as broad sheets and fingers over large parts of the upper rise. These mass-transport deposits nearly filled all the canyons north of Hudson Canyon (Pratson and Laine, 1989; EEZ-Scan Scientific Staff, 1991; O'Leary, 1993). Turbidity currents may have been active at this time, but they were inefficient in eroding and reopening the choked portions of valleys on the rise northeast of Hudson Canyon. The age of these mass-wasting deposits is unknown, but the absence of significant sediment covering them suggests they are latest Pleistocene or early Holocene in age. It is possible that they correlate with the last lowstand of sea level, ca. 15,000 B.P., when the outermost shelf and

currents accumulated on the slope and on areas of the rise away from the

slope were loaded with rapidly deposited, glacially and fluvially derived Along-axis slope Width (Rim to Wall slope (°) Floor width Depth below (km) rim) (km adjacent sea floor (m)

Continental slope	100 - 2,200	1.5	0.8-12	10-15	0.2-0.9	440-1,120
Upper rise	2,200-3,000	0.6	2.5-11	1-8	0.2-2.1	20-521
Lower rise >3,000		0.5	4.5-5.5	10-20	.5-2.2	187-547
Table 1. Physiograph		of Hudson Canyon		Area (km²)	1	Area (%)
Failed slope		Continental slope		1,450		6
Mass-transport deposits		Upper rise		4,993		20
Buried mass-transport deposits		Upper rise		332		1
Hemipelagic deposits		Continental slope, Upper rise, Lower rise		11,469		46
Sediment waves		Upper rise		3,416		14
Outcrop of old strata		Continental slope, Upper rise, Lower rise		3,071		13

canyons

A final stage of sedimentation and erosion from turbidity currents and bottom currents followed the period of mass wasting. During this period, turbidity currents appear to have been restricted largely to Hudson Canyon. Mass-transport deposits in the other canyons were relatively undisturbed, suggesting that they experienced little turbidity current activity. Along Hudson Canyon, much of the sediment in the turbid flows appears to have bypassed the upper rise and was deposited on the deeper Hudson Fan and the Hatteras Abyssal Plain. The only recognizable record of this period of sedimentation is the sediment waves southwest of Hudson Canyon, which indicates that some flows were large enough to overtop the canyon rims. The waves probably reflect reworking and deposition by a combination of the turbid flows and bottom currents. In most places, high-resolution seismic profiles do not resolve sediment covering the mass-transport deposits. However, this is not surprising if these deposits were emplaced as recently as 15,000 yr. B.P., because only about 2 m of sediment would have accumulated at the likely sedimentation rates of <15 cm/k.y. Cores will be needed to define the timing of this and earlier stages of sedimentation more

sediments (Emery and Uchupi, 1984; O'Leary, 1993).

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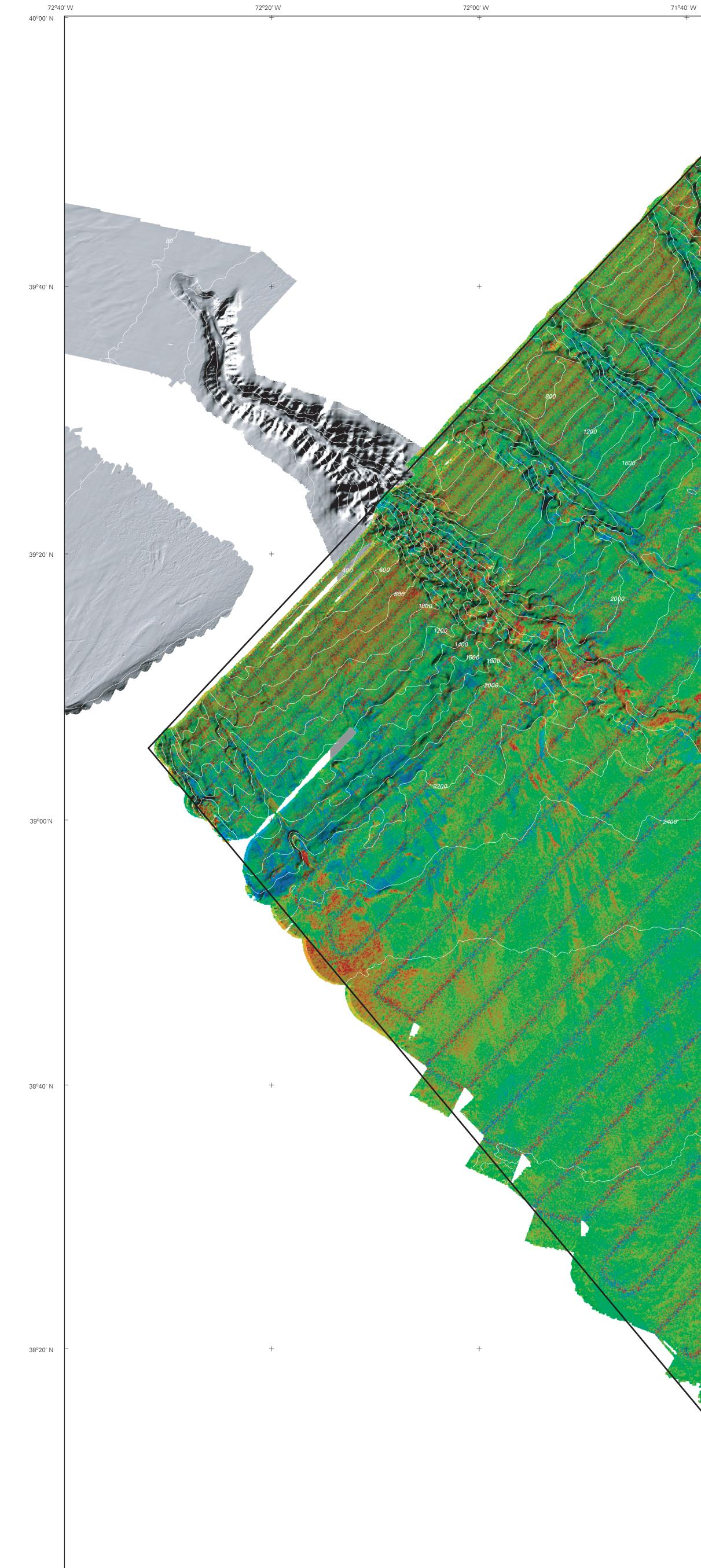
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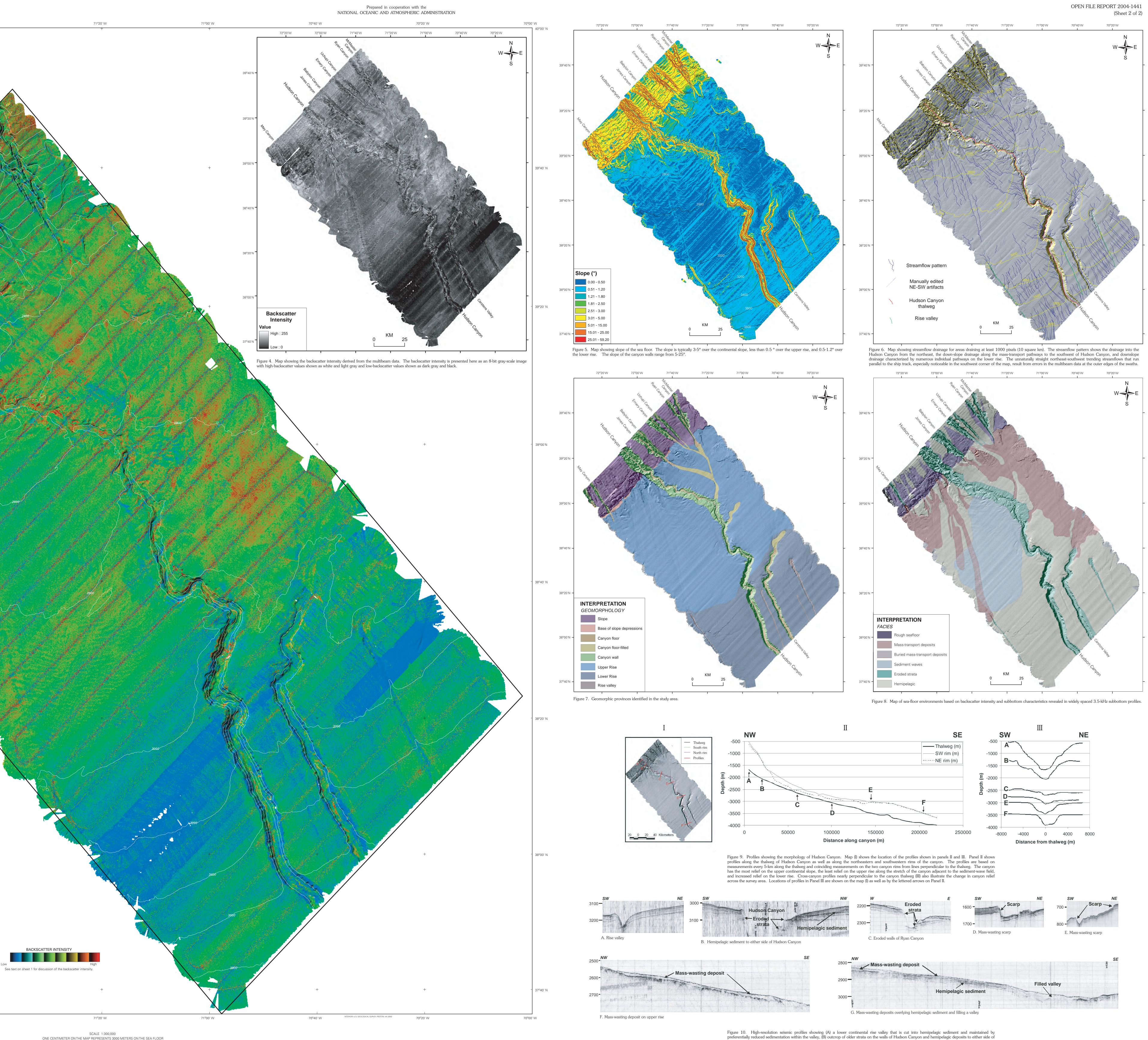
38°00' N + +

37°40' N + + 72°20' W 72°00' W 71°40' W 72°40' W Mercator projection

World Geodetic System 1984 Longitude of central meridian 75° W; latitude of true scale 40° N. False easting 0 m; false northing 0 m. This map is not intended for navigational purposes.

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TOPOGRAHIC CONTOURS IN METERS; INTERVAL VARIES DATUM MEAN LOWER LOW WATER

Sheet 2.—Backscatter intensity draped over sea floor topography in shaded relief view, with topographic contours.

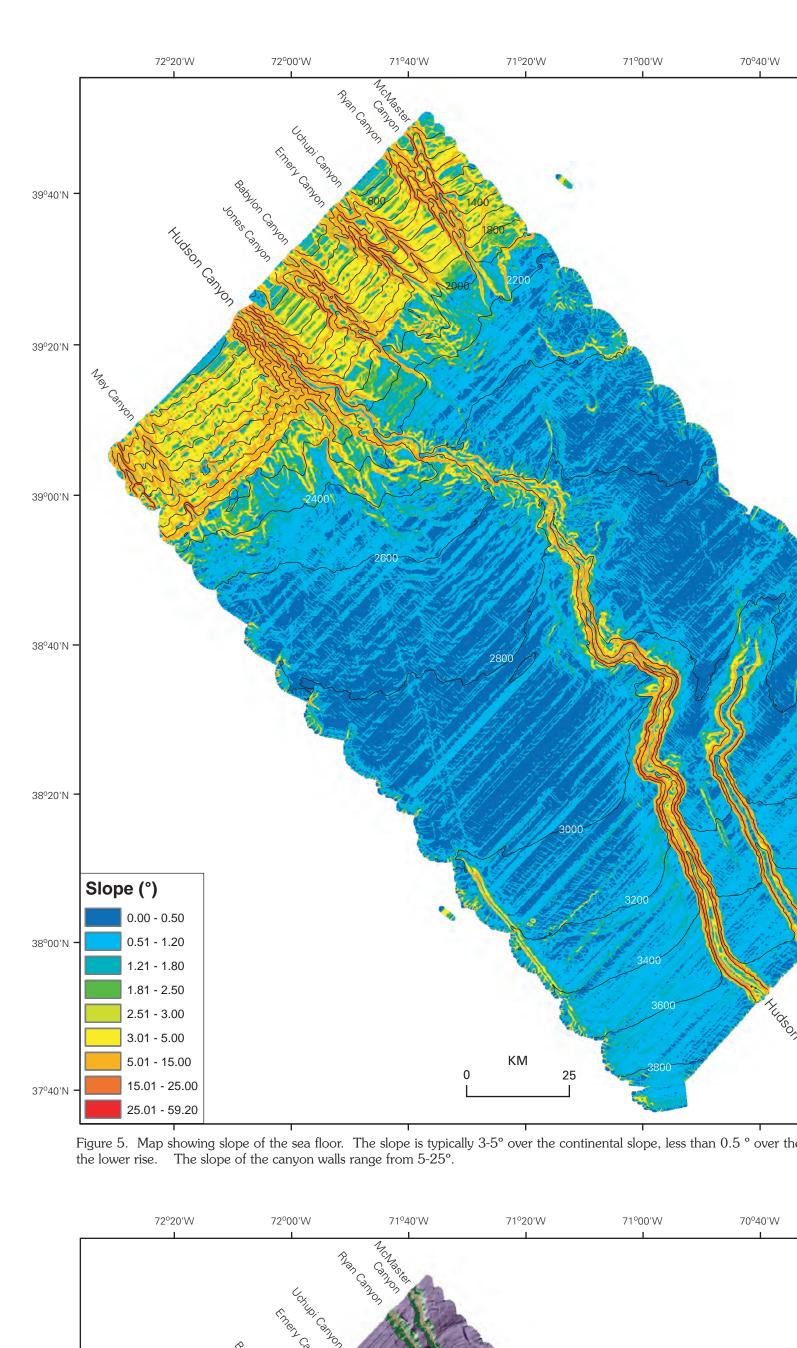
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40 KILOMETERS

20 NAUTICAL MILES

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SEA FLOOR TOPOGRAPHY AND BACKSCATTER INTENSITY OF THE HUDSON CANYON REGION OFFSHORE OF NEW YORK AND NEW JERSEY

the canyon, (C) outcrop of older strata on the walls of Ryan Canyon where it crosses the lower continental slope, (D) mass-wasting scarp on the lower continental slope northeast of Hudson Canyon, (E) mass-wasting scarp on the middle continental slope southwest of Hudson Canyon, (F) mass-transport deposit on the continental rise northeast of Hudson Canyon showing the deposit's seismically transparent nature and rough surface, and (G)

mass-transport deposit overlying hemipelagic sediment and partially filling a valley on the upper continental rise. Profile locations shown in Figure 2.







