BOEM/New Hampshire Cooperative Agreement (Contract M14ACOOO10) Technical Report

New Hampshire and Vicinity Continental Shelf: Morphologic Features and Surficial Sediments

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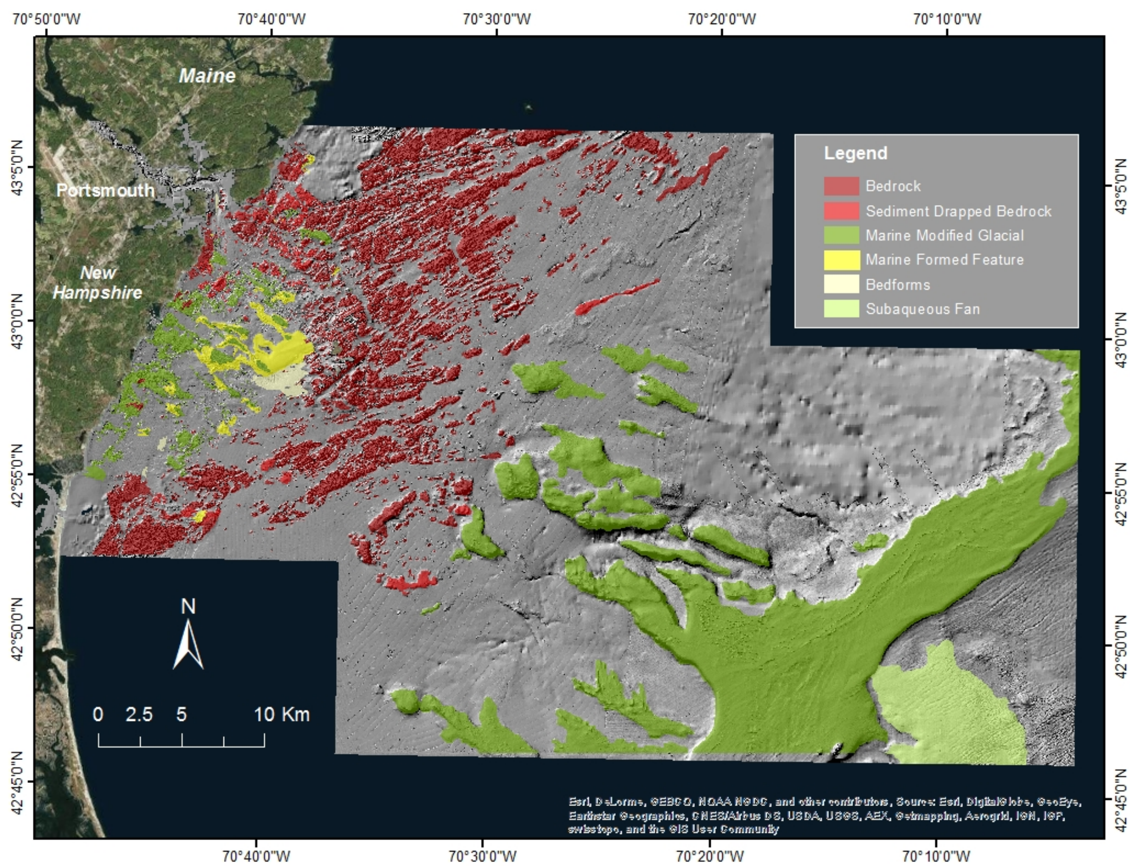
University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center



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Map Coordinate System, Projection and Datum

Coordinate System: WGS 1984 UTM Zone 19N

Projection: Transverse Mercator

Horizontal Datum: WGS 1984

Vertical Datum: MLLW

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Table of Contents

Acknowledgements i

Map Coordinate System, Projection and Datum i

Recommended Citation i

Table of Contents ii

Table iii

Table of Figures iii

Appendices iii

Abstract 1

Introduction 1

Methods 3

Seafloor Classification 3

Major Data Sources for Mapping and Substrate Identification 6

Bathymetry and Backscatter 7

Bathymetric Derivatives 7

Hillshade 7

Bathymetric Positioning Index (BPI). 9

Roughness. 9

Slope 9

Aspect. 10

Surficial Sediment Databases 10

Results and Discussion 11

Geoform Map 12

CMECS Substrate Subclass Map 13

CMECS Substrate Group Map 14

Summary 16

References 17

Table

Table 1. CMECS substrate classification. Modified from FGDC (2012). 4

Table of Figures

Figure 1. Location map of the study area. 2

Figure 2. Multibeam backscatter for the study area. 8

Figure 3. Bathymetry map showing the boundaries of the 2 m, 4 m, and 8 m gridding used for developing the bathymetric derivatives. 8

Figure 4. Hillshade of the study area 9

Figure 5. Bathymetry Position Index (BPI) of the study area. 10

Figure 6. Seafloor roughness of the study area. 11

Figure 7. Major physiographic features (geoforms) of the New Hampshire and vicinity continental shelf. 13

Figure 8. Surficial sediment map of the New Hampshire and vicinity continental shelf based on the CMECS classification for Geologic Substrates Subclasses (FGDC, 2012). 14

Figure 9. Surficial sediment map of the New Hampshire and vicinity continental shelf based on the CMECS classification for Geologic Substrate Groups (FGDC, 2012). 15

Figure 10. Surficial sediment map of the New Hampshire continental shelf based on the CMECS classification for Geologic Substrate Groups (FGDC, 2012). The map presented here is an enlargement of Figure 9 nearshore regions. 16

Appendices

Appendix 1. Western Gulf of Maine surveys used to create the bathymetry and bathymetric derivatives for the New Hampshire continental shelf. 19

Appendix 2. Sources of surficial sediment grain size data and seafloor photographs. 21

New Hampshire and Vicinity Continental Shelf: Morphologic Features and Surficial Sediments

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Abstract

The New Hampshire continental shelf is extremely heterogeneous and includes extensive bedrock outcrops, sand and gravel deposits, and muddy basins. Many of the depositional features are glacial in origin and have been significantly modified by marine processes as sea level fluctuated since the end of the last major glaciation. The apparent glacial deposits (e.g., drumlins) have been eroded, leaving very coarse lag deposits while supplying sand to develop wave-formed features (shoals). Many of these features have positive relief standing above the seafloor, lending evidence of their formation by waves and shallow water currents. Of particular interest is a large sand body that is ~3.2 km in length, ~1.3 km in width and has a maximum relief of ~7 m (in comparison to the surrounding seafloor). Some of these deposits may represent significant sand and gravel deposits on the New Hampshire continental shelf that have the potential for future use for beach nourishment and other efforts to build coastal resiliency.

Recent high resolution multibeam echosounder (MBES) bathymetric and backscatter surveys have revealed features of the New Hampshire shelf and vicinity seafloor in exceptional detail that has not been previously described. Synthesis of the MBES bathymetry and backscatter, coupled with an extensive archived database consisting of subbottom seismics, bottom sediment grain size data, and vibracores, was used to develop new surficial geology maps and significantly improve our knowledge of the character and origin of the major depositional features. The new surficial geology maps depict the exposed bedrock distribution, morphologic features, and sediment distribution. These maps are only the first step in developing high resolution and accurate surficial geology maps for the New Hampshire and vicinity continental shelf and need extensive field verification. However, they represent a major improvement over previous mapping efforts. When completed and verified, the surficial geology maps will be the most detailed ever published for the New Hampshire continental shelf.

Introduction

A Cooperative Agreement between the Bureau of Ocean Energy Management, the University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC), and the New Hampshire Geological Survey (NHGS) seeks to determine the potential sand and gravel (mineral) resources on the New Hampshire (NH) and vicinity continental shelf for the primary purpose of beach nourishment to enhance coastal resiliency.

Assessment of mineral resources on any continental shelf requires a knowledge of the seafloor geology and the shallow subsurface geology. This understanding starts with the seafloor bathymetry, morphology, and surficial sediments. Subsequently, the shallow subsurface can be studied within the context of the surficial geology. Presented here are surficial geology maps depicting the major morphological features (geoforms) and the distribution of surficial sediments (where present databases permit) of a largely unmapped region of the NH and vicinity continental shelf extending from the coast seaward ~50 km to Jeffreys Ledge and bound by the Massachusetts continental shelf to the south and the Maine shelf to the north (Figure 1). In total, the study area encompasses ~3250 km^2.

The surficial geology maps were developed from a high resolution bathymetry synthesis for the Western Gulf of Maine and an accompanying backscatter mosaic for much (~50 %) of the study area (http://ccom.unh.edu/project/wgom-bathbackscatter; accessed June 15, 2016), extensive bottom sediment grain size databases, and some video. A number of derivatives developed from the bathymetry (hillshade, roughness, bathymetric position index, slope, and aspect) were also used to characterize and map the surficial geology of the seafloor (Appendix 1). Surficial geology maps of the NH and vicinity continental shelf include the distribution and characterization of major physiographic features or geoforms and surficial sediment classifications based on the Coastal and Estuarine Ecological Classification Standard (CMECS) (FGDC, 2012).

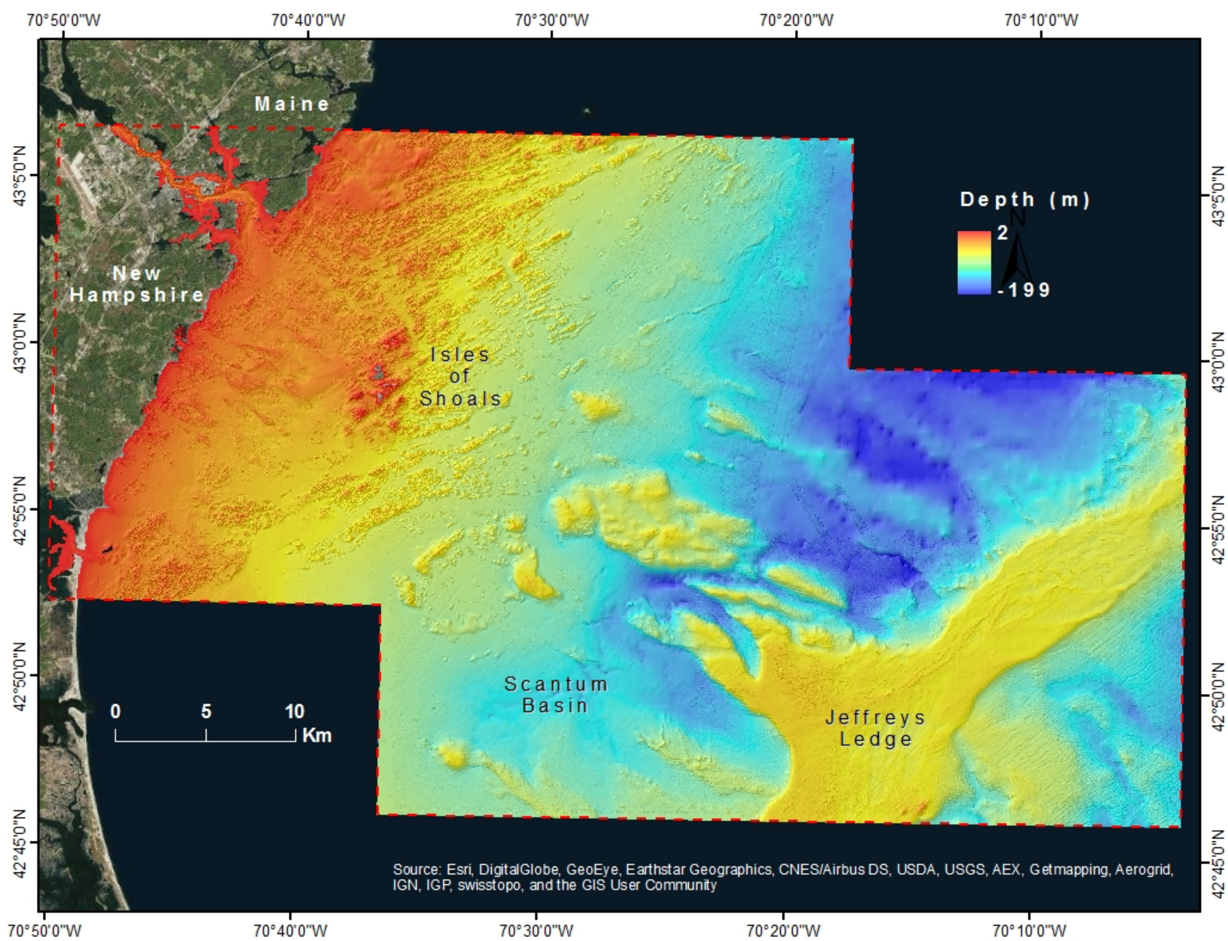

Figure 1. Location map of the study area.

Methods

Seafloor Classification

The surficial geology of the NH and vicinity continental shelf is depicted in several different maps including: a map to identify the major morphologic or physiographic features (geoforms); a map of the geologic substrate subclass; and a map of the geologic substrate groups. The identification of the geoforms and the classification of the surficial sediment follows the Coastal and Marine Ecological Classification Standard (CMECS) (FGDC, 2012), which is built on a simplification of the Wentworth (1922) and Folk (1954; 1980) classification schemes. The primary sediment grain size database used for this project (updated and significantly modified from an earlier database developed by the University of New Hampshire CCOM/JHC) is based on the Wentworth size classes and Folk classifications. In addition several other sediment databases were utilized where available (described below and listed in Appendix 2).

Geoforms, as identified here and based on an adaption of CMECS (FGDC, 2012), are morphologic features that are formed by geologic processes. For example, exposed bedrock, drumlins, moraines, or sand shoals would be considered geoforms. Also included as geoforms are flat or low-slope seafloor plains. Many of the geoforms or morphologic features are classified based on their interpreted mode of formation, which has implications to their textural characteristics. They are identified by bathymetry, bathymetric derivatives (e.g., hillshade, BPI, slope, aspect, and roughness), and backscatter patterns. The main geoforms identified in the study area include: bedrock outcrops; sediment draped bedrock; aprons; marine formed features; nearshore ramp; bedforms; marine modified glacial feature; depression; channel, seafloor plain; subaqueous fan; and undefined.

As stated above, the mapping of the surficial sediments utilized CMECS geologic substrate classifications (Table 1). This facilitated grouping the sediments into broader categories which proved advantageous in many areas where the databases were incomplete. Thus, the seafloor was mapped by the following process: first, the major geoforms were identified and mapped; secondly, the substrate subclass, which generalized the bottom into bedrock, coarse unconsolidated mineral substrate, or fine unconsolidated mineral substrate, was determined for the entire study area; and finally, the seafloor was classified at the substrate group level where possible. The seafloor was not further divided into substrate subgroups due to the lack of ground truth in many areas. The mapping criteria is discussed below.

The database developed for this study is relatively large (and entirely from existing sources). Nevertheless, the coverage is somewhat inconsistent in quality and distribution. For example, the bottom sediment grain size database includes studies conducted from 1972 to 2016. As a result, the positioning uncertainty of the stations varies over an order of magnitude. Also, the distribution of sample locations is uneven. The most recent studies, which have the most accurate positioning and the highest quality data, tend to be concentrated in specific areas and not evenly distributed as would be expected. Although the extent of the high resolution multibeam bathymetry is large, there are still major gaps in the coverage of the seafloor. In these areas, the much lower resolution regional coverages fill the gaps, but the quality is far lower. This is also true for the acoustic backscatter coverage which overall is much smaller than the bathymetry in extent and varies a great deal in quality.

Table 1. CMECS substrate classification. Modified from FGDC (2012).

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate Subgroup
Geologic Substrate	Rock Substrate	Bedrock		
	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
				Cobble
				Pebble
				Granule
			Gravel Mixes	Sandy Gravel
				Muddy Sandy Gravel
				Muddy Gravel
			Gravelly	Gravelly Sand
				Gravelly Muddy Sand
				Gravelly Mud
		Fine Unconsolidated Substrate	Slightly Gravelly	Slightly Gravelly Sand
				Slightly Gravelly Muddy Sand
				Slightly Gravelly Sandy Mud
				Slightly Gravelly Mud
			Sand	Very Coarse Sand
				Coarse Sand
				Medium Sand
				Fine Sand
				Very Fine Sand
			Muddy Sand	Silty Sand
				Silty-Clayey Sand
				Clayey Sand
			Sandy Mud	Sandy Silt
				Sandy Silt-Clay
				Sandy Clay
			Mud	Silt
				Silt-Clay
				Clay

Therefore, mapping of the surficial geology of the NH and vicinity continental shelf used the following protocol.

1. Geoforms were identified and mapped based on bathymetry, bathymetric derivatives, backscatter, and ground truth. As indicated above, not all of these database were available for most locations. Consequently, the best input available was used. The major geoforms identified for the NH and vicinity continental shelf are described below.

Bedrock Outcrops are identified by bathymetry, hillshade, roughness, and acoustic backscatter. The bedrock is largely oriented in a regional trend (northeast-southwest) and has obvious ridges separated by bathymetric lows or swales with sediment. (Defined in this report.)

Sediment Draped Bedrock appears as distinctive bedrock, but the texture is more subdued and obvious sediment deposition has occurred on and around the bedrock. (Defined in this report.)

Aprons are a blanket-like deposits of unconsolidated material surrounding and derived from an identifiable source such as a bedrock outcrop or a marine modified glacial feature. They are identified by bathymetry, hillshade, roughness, and acoustic backscatter. Modified after CMECS.

Marine Formed Features tend to have relief, but are generally smooth in appearance with obvious wave or current-formed features (bars, shoals, etc.). Where bottom samples exist, the sediments tend to be sandy to slightly gravelly sand. Although defined here, the features are similar in some cases to moraine shoals or other drowned, elongated offshore ridges defined in CMECS.

Nearshore Ramps are gently sloping sandy or gravelly seafloor areas that lies offshore of a beaches. The nearshore ramp generally exhibits shore-parallel bathymetric contours and is primarily covered with sand-rich sediment, although locally small exposures of ledge, cobbles, and boulders may be present. Modified from Barnhardt et al. (2007).

Bedforms are areas of larger bedforms or subaqueous dunes that are identifiable with bathymetry, hillshade, and backscatter. Thus, they must have wavelengths that exceed the grid size. They are assumed to be largely composed of sand or gravelly sand and are formed by waves and currents. Modified after CMECS.

Marine Modified Glacial Features tend to have high backscatter and roughness. The surface can appear eroded and rough, presumably due to the presence of cobble to boulder gravels. Examples include eroded drumlins, eskers, and small moraine deposits. In the study area, eroded drumlins tend to be relatively large (≥ km) and oriented northwest-southeast. Small glacial moraines also occur that are less than a few hundred meters in length, linear to arcuate in shape with low relief, and tend to be oriented in a northeast-southwest direction. These are likely De Geer moraines which formed close to the ice front. More broadly, a general term for any submarine geomorphologic feature that was once supraglacial, or subglacial including drumlins, till surfaces, moraines, or eskers. Modified after CMECS.

Depressions are very small, shallow basins or sunken areas of the seafloor with no natural outlet. Modified after CMECS.

Channels are linear or sinuous depressions on an otherwise flat seafloor. Modified after CMECS.

Seafloor Plains are aresa between geoforms or large areas of the seafloor that are relatively flat or have a low slope. They can have local areas that are undulating or slightly rougher than adjacent areas. Seafloor plains tend to be composed of finer-grained sediments. (Defined in this report.)

Subaqueous Fans are identified by location, bathymetry, and ground truth. A single location on the seaward side of Jeffreys ledge was identified during this study. The feature is interpreted as a depositional fan formed from sediment released at the ice-contact margin of a glacier into a marine environment. (Defined in this report.)

Undefined are apparent geoforms or features which cannot be identified with the available database.

2. The sediment type (based on grain size) composing the seafloor was mapped using a combination of bathymetry, bathymetric derivatives, backscatter where available, and ground truth consisting of grain size data and photographs**.** The seafloor was mapped at three levels depending on the availability and the quality of data.

Seafloor regions where high quality bathymetry and bathymetric derivatives exist, acoustic backscatter occurs, and there are reliable ground truth stations with either grain size data or video, are classified and mapped using the CMECS hierarchy and include the substrate subclass and group. The mapped substrates in these regions are well vetted and reasonably verified.

Seafloor regions where high quality bathymetry and bathymetric derivatives exist and acoustic backscatter occurs, but there are no reliable ground truth stations are classified and mapped with the substrate component subclass with reasonable confidence. However, mapping the more detailed substrate group is based on proximity and comparisons to other mapped regions with similar morphology and acoustic characteristics. In these regions, the substrate group is inferred and ultimately needs ground truth for verification. These areas are mapped, but are typically identified with a diagonal line pattern overlay.

Seafloor regions where the database is weak either due to lack of acoustics, high resolution bathymetry, or ground truth are not mapped. These regions are left open and the underlying hillshade displays the bottom topography.

Major Data Sources for Mapping and Substrate Identification

The main databases used to develop the seafloor maps of the NH and vicinity continental shelf included: high resolution bathymetry for almost the entire study area; an acoustic backscatter synthesis for much of the study area (~50%); a series of bathymetry derivatives including hillshade, bathymetric position index (BPI), roughness, slope and aspect, and extensive surficial sediment grain size databases. The development of each of these databases are expanded upon below.

Bathymetry and Backscatter

Over the last 15 years, a number of high resolution multibeam echosounder (MBES) surveys were conducted in the Western Gulf of Maine (WGOM). A number of the MBES surveys had associated acoustic backscatter included. As part of this study and associated work by the University of New Hampshire CCOM/JHC, these surveys were assembled, along with a lower resolution regional bathymetry synthesis, and archived. The bathymetry for the entire database was then gridded at 4 m and 8 m resolution (the coarser gridding included the lowest resolution regional compilation). In addition, the MBES backscatter available for the NH shelf area was gridded at 2 m resolution and compiled into a grayscale mosaic (Figure 2). The WGOM synthesis is used here for the general bathymetry of the area (Figure 1). However, for the development of the bathymetric derivatives for the surficial geology mapping, the original MBES surveys were retrieved and re-gridded (discussed in the next section).

The WGOM bathymetry synthesis and the backscatter for the NH continental shelf area is described at http://ccom.unh.edu/project/wgom-bathbackscatter.

Bathymetric Derivatives

In order to develop the bathymetric derivatives at the highest resolution possible (and practical), the multibeam surveys for the study area were re-gridded with regard to their location and data source (original resolution). To accomplish this, the multibeam bathymetry was divided into a nearshore region and an offshore region and gridded at 2 m and 4 m, respectively (Figure 3). In the areas where only low-resolution bathymetry was available, the grid size was 8 m. The multibeam acoustic surveys used are given in Appendix 1.

The bathymetry was gridded using the “Mosaic to New Raster” tool from the Data Management Toolbox in ERSI ArGIS 10.3. The new bathymetry datasets were stored in geodatabases in FGDBR (File Geodatabase Raster) format; the pixel type and depth were set to 32-bit supporting decimals (32_BIT_FLOAT), and the number of bands to one. The Mosaic Operator for the overlapping areas was configured to be the average value of the overlapping cells.

The bathymetry was then used to create the derivatives including hillshade, BPI, roughness, slope and aspect.

Hillshade. Developed from the bathymetry, hillshade creates a shaded relief surface that highlights the changes in bathymetry (Figure 4). The hillshade is developed by generating an imaginary light source and casting shades and shadows to create the shaded relief effect. The output values range from 0 to 255, with 0 representing the shadow areas and 255 the brightest. Here, a default azimuth of 315° and altitude 45° were used for the illumination. The vertical exaggeration was 10x.

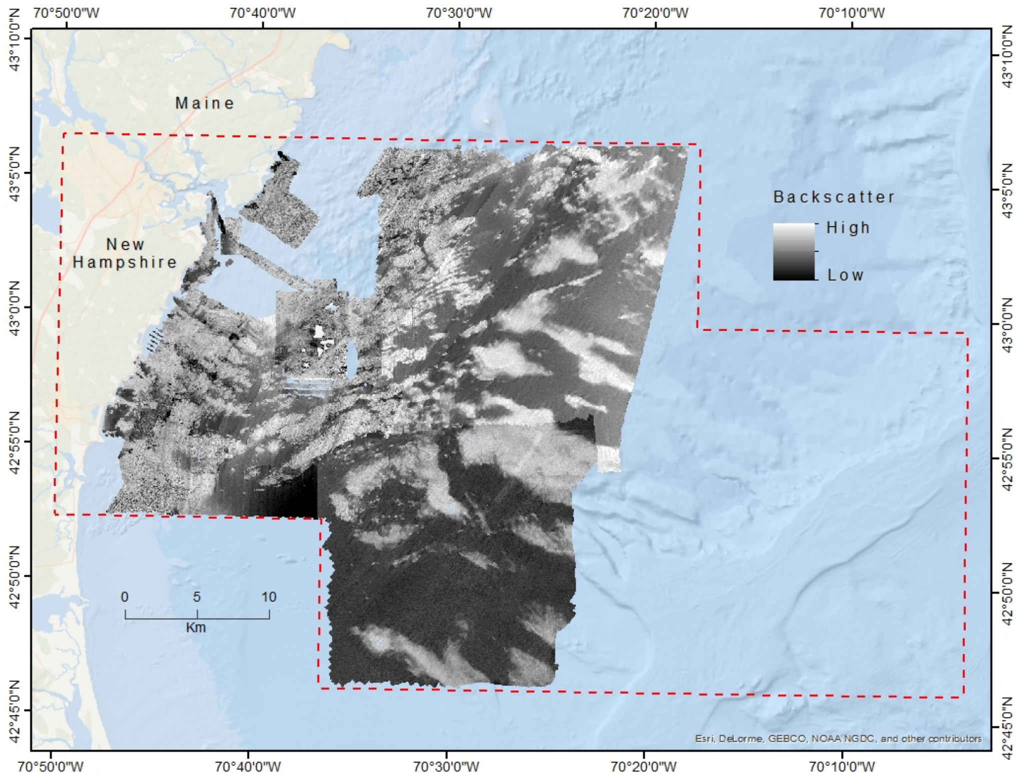

Figure 2. Multibeam backscatter for the study area.

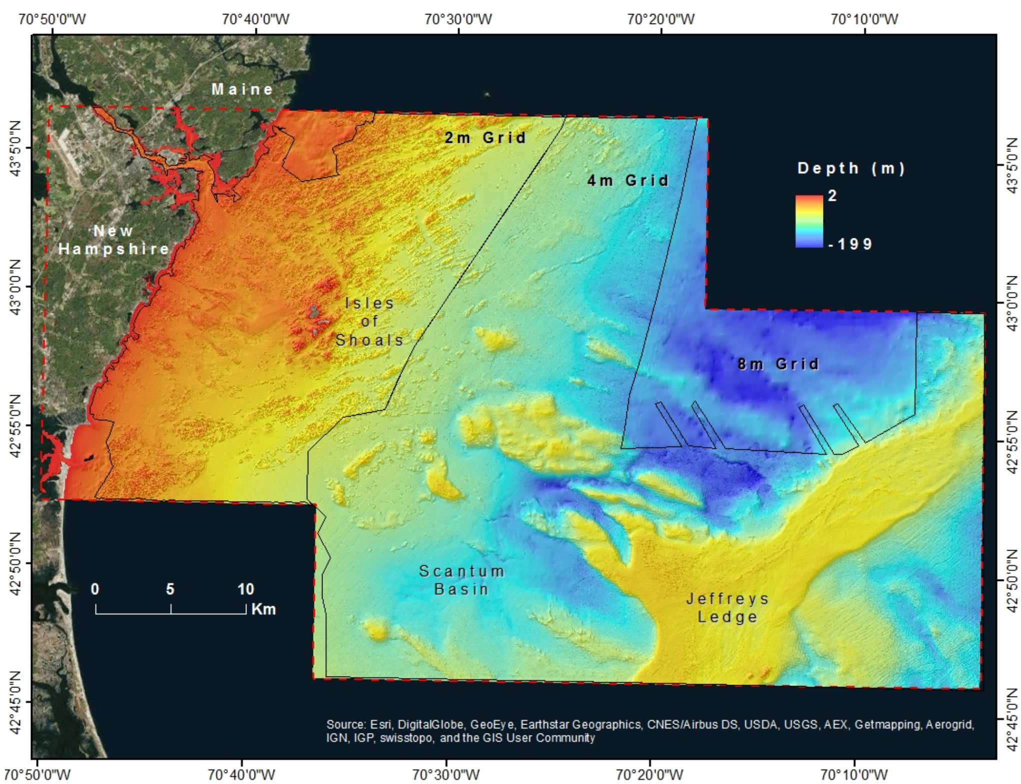

Figure 3. Bathymetry map showing the boundaries of the 2 m, 4 m, and 8 m gridding used for developing the bathymetric derivatives.

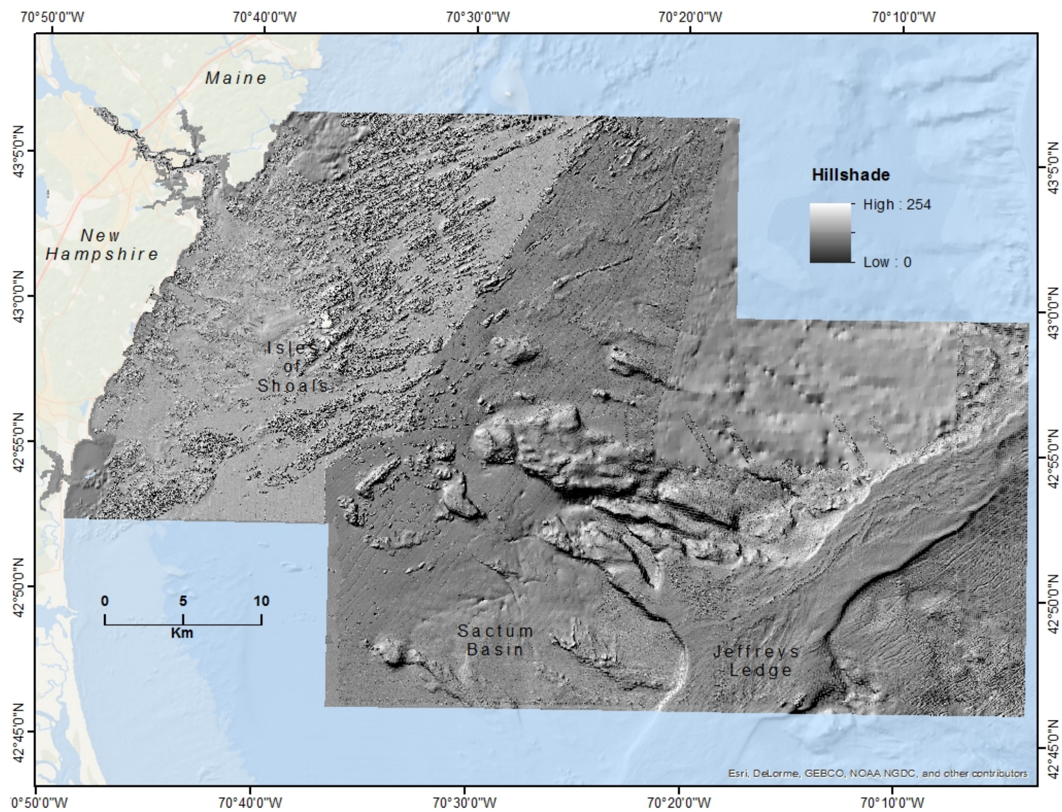

Figure 4. Hillshade of the study area

Bathymetric Positioning Index (BPI). Compares the elevation of each gridded cell within the inner radius of an annulus to the mean elevation of the surrounding area defined by the outer radius of the annulus (Verfaillie et al., 2007). A negative BPI value is assigned for depressions and a positive BPI value to positive relief features. The index was derived from bathymetric raster surfaces using the "Benthic Terrain Modeler toolbox" in ArcGIS, and was calculated for a broad scale (B-BPI). The B-BPI was applied with different inner and outer radii depending upon the resolution of the grid, in order to maintain the same scale factor for both nearshore and offshore areas. The 2 m nearshore grid used a 20 cell inner radius and an 800 cell outer radius. The 4 m offshore grid used a 10 cell inner radius and a 400 cell outer radius. Therefore, both the nearshore and offshore B-BPI derivatives have a scale factor of 1600 (Figure 5).

Roughness. Indicates the heterogeneity of the seafloor in terms of its morphology (Riley, et al., 1999). The roughness value equals the sum change in elevation between a central grid cell and its eight surrounding grid cells. The roughness surfaces were generated in ERSI ArcGIS 10.3 using the Surface Texture toolset from the Geomorphometry and Gradient Metric toolbox. A circular analysis window was used with a radius of 3 cells for the Neighborhood Settings (Figure 6).

Slope. Characterizes the steepness of a defined area of terrain by calculating changes between the elevation values. The slope is calculated based on the rate of change of the surface within a 3x3 moving window around the center cell (Environmental Systems Research Institute, 2012) using the Surface toolset from the Spatial Analyst Toolbox in ArcGIS 10.3.

Aspect. Identifies the direction of the maximum slope calculated within a 3x3 cell moving window (Environmental Systems Research Institute, 2011). The aspect values are referenced to north and are reported in degrees (0 to 360) and -1 for flat surface values. The Aspect tool from the Spatial Analyst toolbox in ArcGIS 10.3 was used.

Surficial Sediment Databases

The primary surficial sediment database utilized was developed at the University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center and updated during the present study. The database consists of the known surficial sediment databases generated by research conducted at the University of New Hampshire since the early 1970s. In addition, several other sediment grain size databases and sources of photographs developed by the USGS and NOAA NOS were utilized for this study. The sources are listed in Appendix 2.

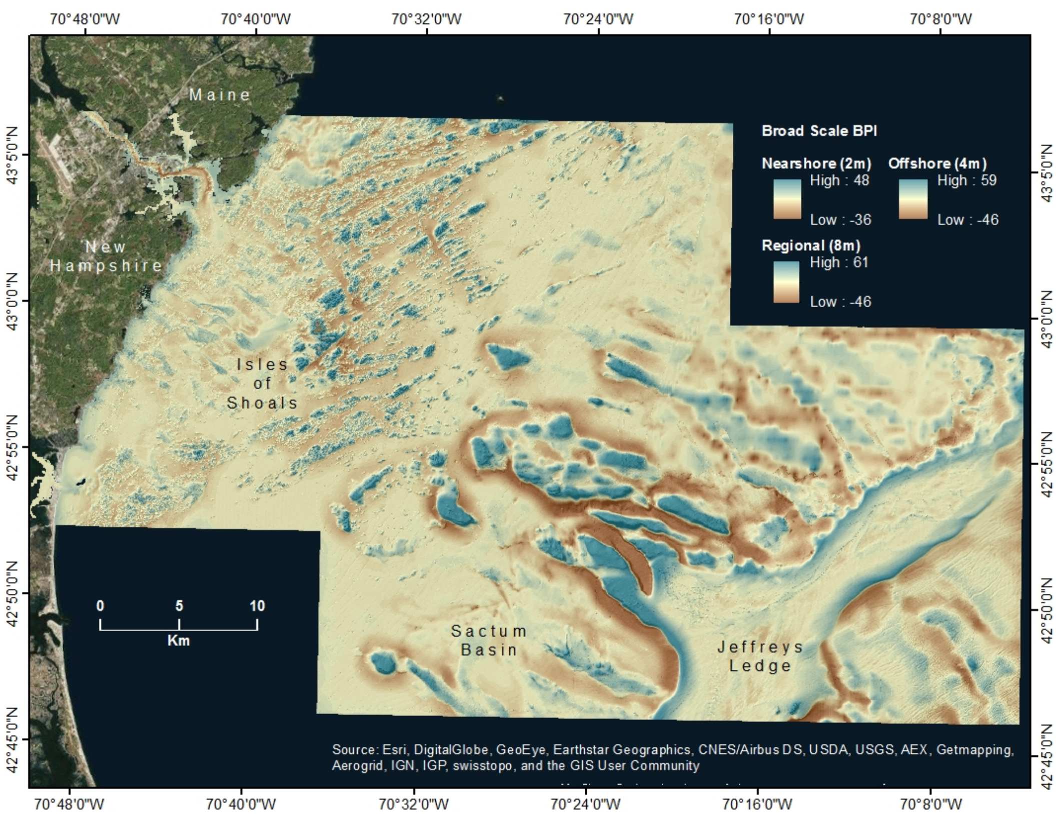

Figure 5. Bathymetry Position Index (BPI) of the study area.

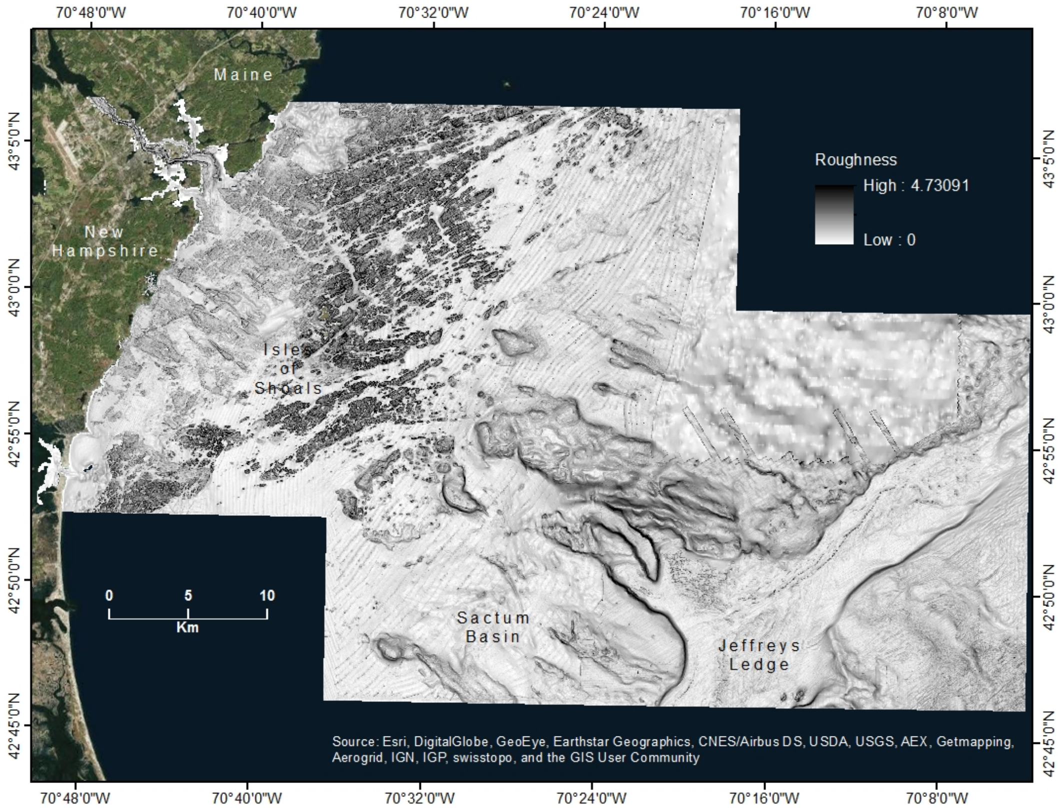

Figure 6. Seafloor roughness of the study area.

Results and Discussion

The surficial geology maps of the NH and vicinity continental shelf provide an overview of the major physiographic features or geoforms found in the study area (Figure 7); the general composition of the substrate broken into three classes including exposed bedrock, coarse unconsolidated substrate, and fine unconsolidated substrate (Figure 8); and a much more detailed description of the seafloor types or groups (Figure 9). These three types or levels of mapping serve several purposes. First, the morphologic or geoform maps depict the major seafloor features and provide insights into the origin and controls of the physiographic features and potential sediment types and sources. Second, the map showing the CMECS subclass (Table 1) provides a very broad overview of the bedrock and the general nature of the surficial sediments between coarse-grained and fine-grained unconsolidated mineral material. Finally, the maps depicting the sediment groups provide the most detail of the seafloor surficial sediments. Collectively, these maps, although incomplete and in need of verification, dramatically advance our understanding of the NH and vicinity continental shelf. Each of the map types are discussed below.

It should be noted again that the size of the study area is large, Despite having relatively extensive databases including the surficial sediment grain size, high resolution bathymetry, and acoustic backscatter, many areas have sparse or incomplete coverages. In addition, the quality of the data varies depending on age and location. As a result, the mapping of the seafloor includes locations where the evidence is strong, locations where less information is available (shown by diagonal lines on the maps), and locations where the database is too weak at this time to allow interpretation of the seafloor (simply shown as greyscale hillshade).

Geoform Map

The geoforms identified and classified on the NH and vicinity shelf show very clear trends (Figure 7). From several kilometers seaward of the Isles of Shoals to past (and including) Jeffreys Ledge, the geoforms are very large and dominated by marine modified glacial features. During the last sea-level lowstand, approximately 11-12 kybp (thousands of years before present), sea level was between 40 m to 55 m below present (Oldale, 1983; Belknap et al., 1987; Kelley et al, 1992; Barnhardt et al., 1995, Belknap et al., 2002; Barnhardt et al., 2007), essentially exposing or nearly exposing the surface of Jeffreys Ledge and the nearby drumlin like features to wave activity. Wave action likely modified the surface of Jeffreys Ledge and eroded the tops of the drumlins. In addition, the eroded material, which may have included sand and gravel, was deposited as aprons around the glacial features. Furthermore, a large fan shaped structure composed of gravels to gravel mixes located on the seaward side of Jeffreys Ledge was deposited. This feature is interpreted as a subaqueous fan resulting from subglacial discharge from beneath the glacier during the period when the ice front was close to or at Jeffreys Ledge. This hypothesis remains to be tested.

The inner NH continental shelf within 15 km of the coast contains extensive bedrock outcrops, often separated by troughs or swales with sediment, and surrounded by aprons of coarse sediment (Figure 7). The general trend of the outcropping bedrock is northeast-southwest. The bedrock becomes more subdued south of the study area, and is ultimately buried by sediment, probably from the Merrimack River.

Landward of the Isles of Shoals to the coast the seafloor is extremely complex. The bedrock that dominates the seafloor north of the entrance to Portsmouth Harbor transitions into sediment draped bedrock as the sediment cover becomes more prevalent. The sediment draped bedrock category tends to have modified glacial features intermixed in some of the inner shelf areas. Extensive marine modified (eroded) glacial features are found landward of the Isles of Shoals and south of Portsmouth Harbor. Features that appear to be the roots of eroded drumlin and eskers are common. Associated with these eroded glacial features are marine formed features or shoals. It is hypothesized that many of these shoals formed from sediments eroded from glacial features (Carter and Orford, 1988). The largest sandy shoal in the study area is located just landward of the Isles of Shoals (named here the Northern Sand Body) and appears to lie between two eroded drumlins. Also present on the NH shelf are numerous De Geer moraines. The marine formed features, as well as some of the offshore eroded drumlins, are hypothesized to be possible targets for marine mineral resources and will be examined in greater detail in future studies.

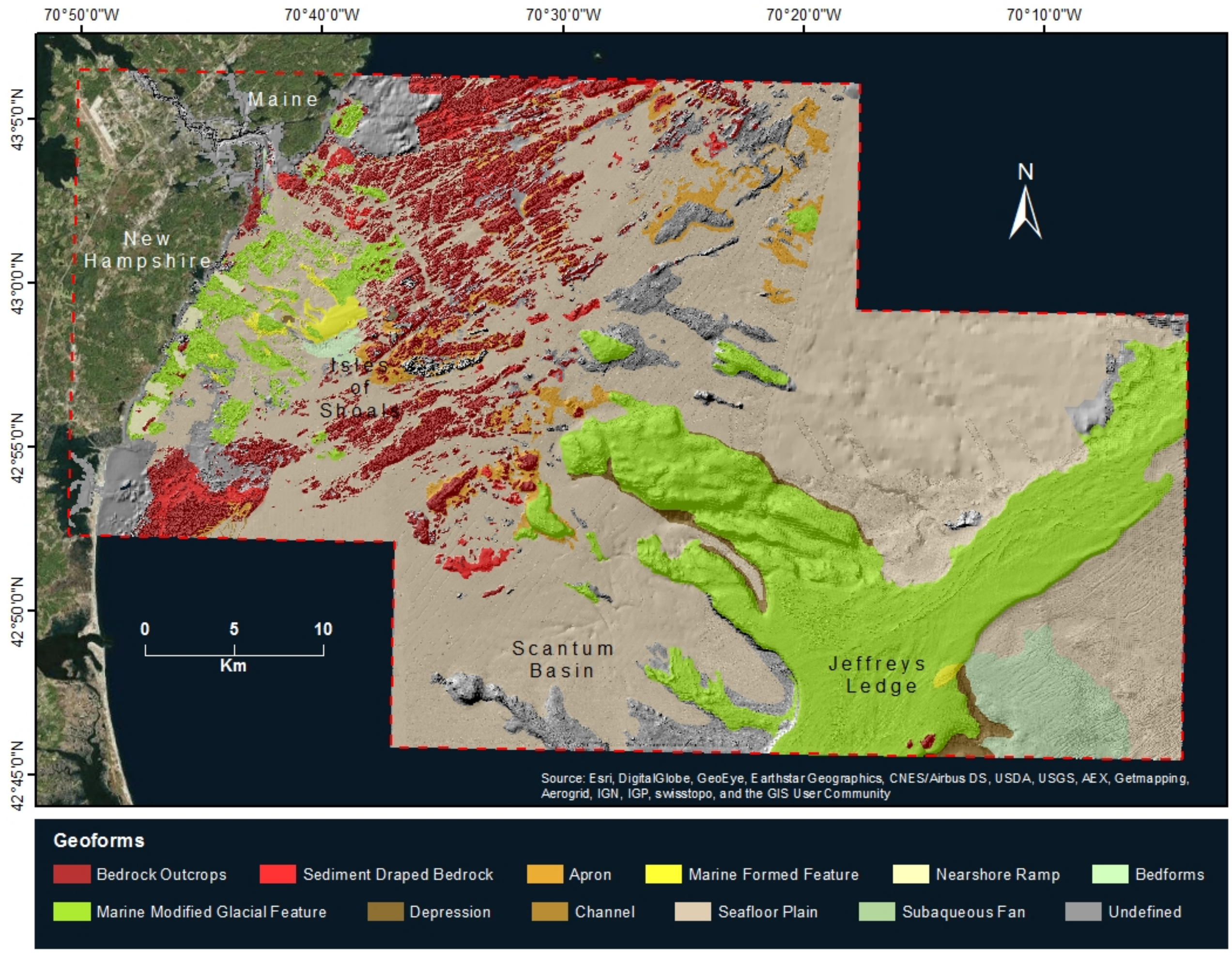

Figure 7. Major physiographic features (geoforms) of the New Hampshire and vicinity continental shelf.

CMECS Substrate Subclass Map

The substrate subclass map depicts the composition of the NH and vicinity continental shelf in general terms, characterizing the seafloor as bedrock or unconsolidated mineral substrate. The unconsolidated substrate is further divided into coarse and fine. The coarse substrate includes gravel, gravel mixes, and gravelly sediments which encompass the Wentworth size classes from boulder gravels to gravelly sand or gravelly mud. The fine unconsolidated sediments range from slightly gravelly sand to mud (Table 1).

As would be expected, the NH and vicinity continental shelf tends to be dominated by fine unconsolidated substrates seaward of the Isles of Shoals with the exception of the glacial deposits (Figures 7 and 8). The marine modified glacial deposits tend to be composed of coarse unconsolidated sediments ranging from poorly sorted muds, sands, or gravels with boulders. The fine unconsolidated sediment is typically muddy to sandy muds, but can be coarse depending on proximity to glacial features or bedrock. Landward of the Isles of Shoals the seafloor has a large amount of outcropping bedrock that tends to have coarse sediments between the ridges. The unconsolidated sediments around this area are frequently coarse which is expected due to

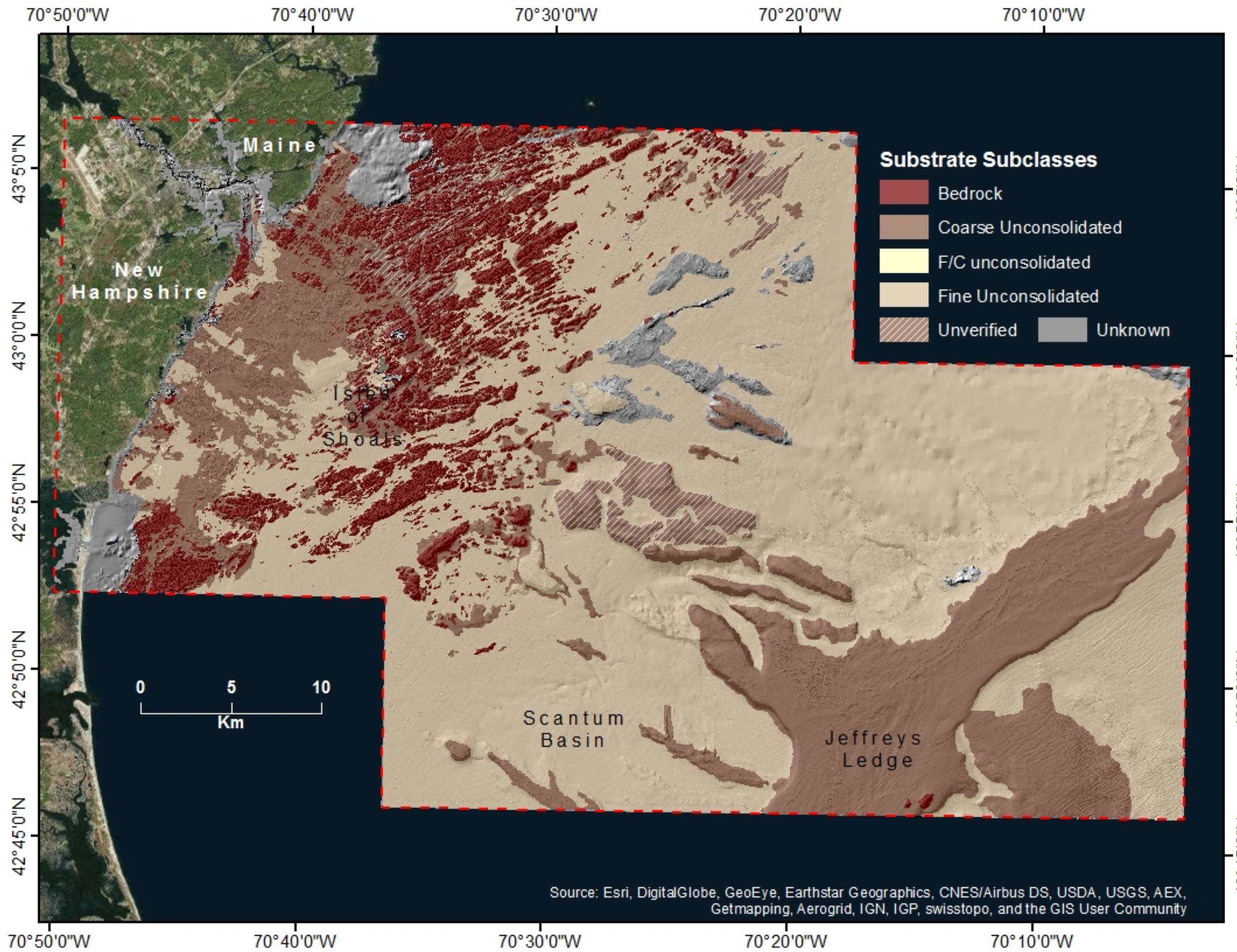

Figure 8. Surficial sediment map of the New Hampshire and vicinity continental shelf based on the CMECS classification for Geologic Substrates Subclasses (FGDC, 2012).

the extensive amount of marine modified glacial deposits. These sediments tend to be gravelly, although they may contain appreciable quantities of sand. The fine-grained, unconsolidated sediments are found closer to shore.

CMECS Substrate Group Map

The substrate group describes the composition of the unconsolidated mineral sediments of the seafloor in much greater detail than the substrate subclass. The substrate groups are closely aligned to the Wentworth scale and have the advantage of simplifying the Wentworth size classes by combining similar ranges (Table 1).

The NH and vicinity continental shelf seaward of the Isles of Shoals is somewhat complex as a result of marine modified glacial features providing coarse sediments to the region (Figures 7 and 9). Jeffreys Ledge is composed of gravel and gravel mixes (e.g., sandy gravel), while the adjacent seafloor is mostly gravelly (gravelly sands, gravelly muddy sand or gravelly mud). At least one large sand body occurs in the offshore area. Note that several of the marine modified glacial

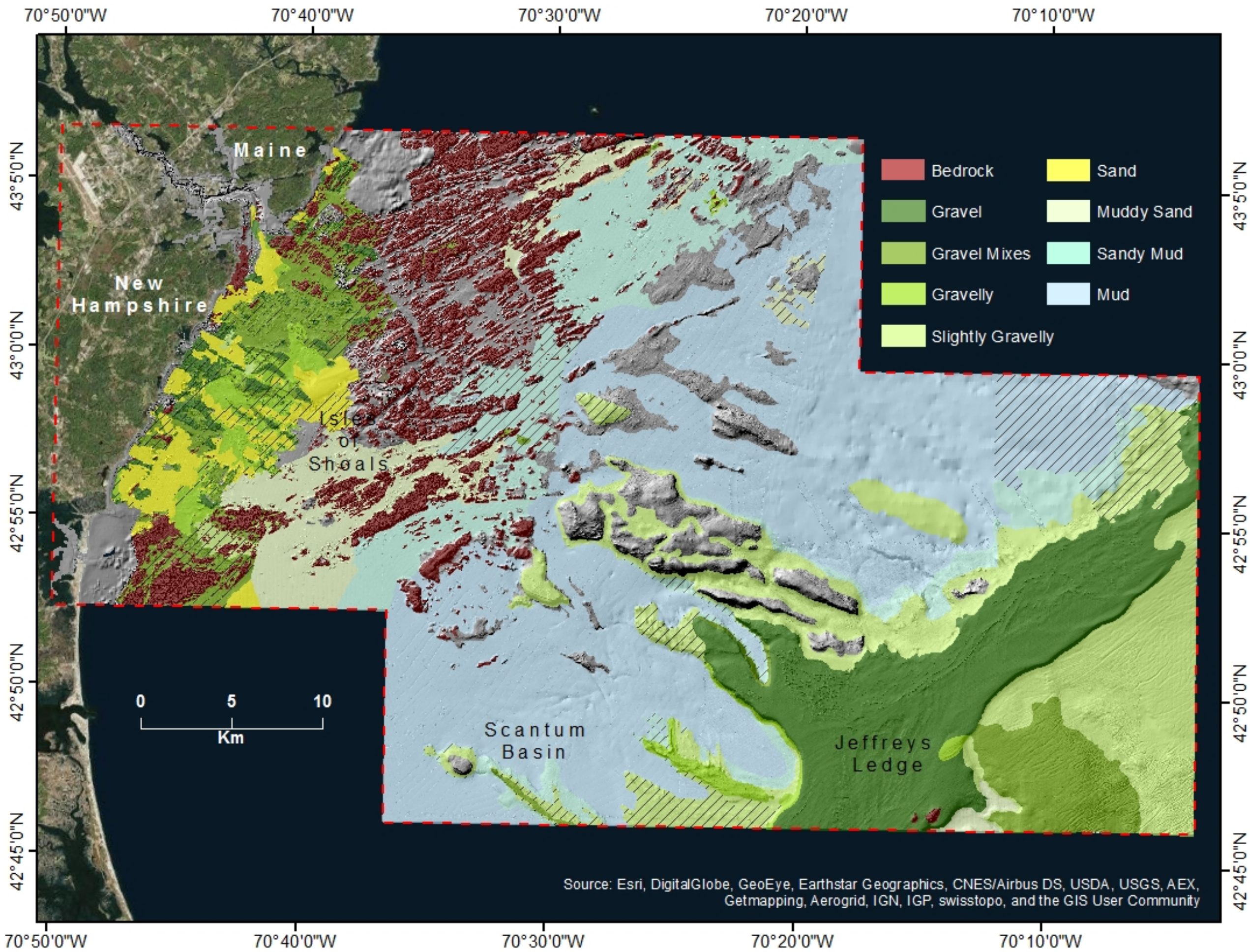

Figure 9. Surficial sediment map of the New Hampshire and vicinity continental shelf based on the CMECS classification for Geologic Substrate Groups (FGDC, 2012).

features (Figure 7) are not mapped (shown as grey hillshade), as their composition is presently unknown. Away from the glacial features the seafloor is mostly muddy, transitioning into a sandy mud in a landward direction.

Landward of the Isles of Shoals, the seafloor is again extremely heterogeneous due to the mixture of bedrock, marine modified glacial features, and marine formed features or shoals (Figure 10). Here the seafloor is frequently composed of gravel mixes interspersed with gravel areas, presumably associated with eroded glacial features such as drumlins. Close by are gravelly mixes to gravelly sediments which are frequently gravelly sands. The exposed bedrock likely has gravel mixes to gravelly sediments in the troughs between the bedrock outcrops as well. The nearshore regions have relatively large areas of sand which are found close to shore on the nearshore ramps. Sandy areas are also found further offshore associated with eroded glacial features or marine formed shoals. One large marine-formed feature, the Northern Sand Body, is a potential source of sand for beach nourishment.

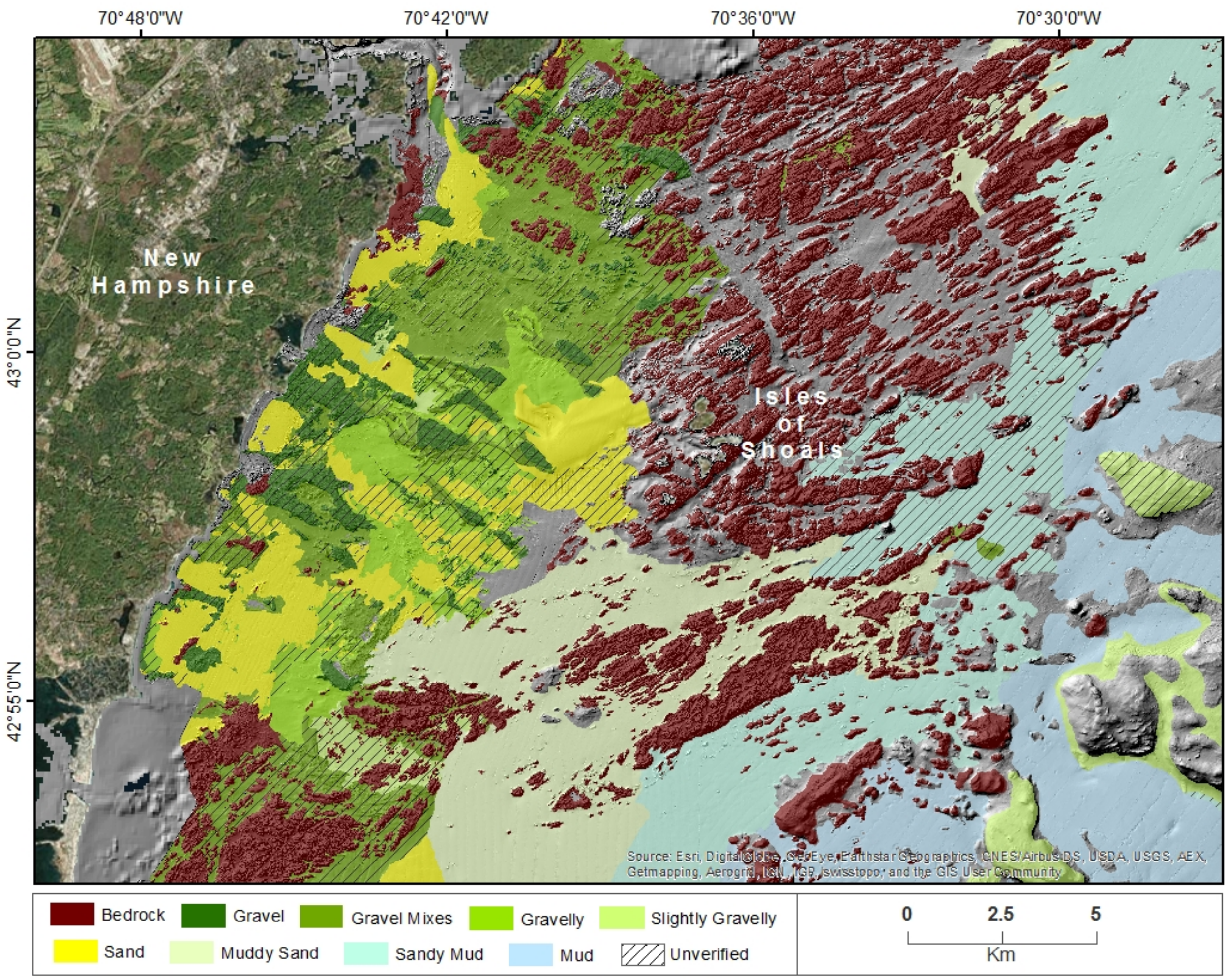

Figure 10. Surficial sediment map of the New Hampshire continental shelf based on the CMECS classification for Geologic Substrate Groups (FGDC, 2012). The map presented here is an enlargement of Figure 9 nearshore regions.

Summary

The NH and vicinity continental shelf is a complex assemblage of exposed bedrock, glacial features that have been modified by marine processes, and depositional features such as shoals that have been shaped by waves and tidal currents. The erosion of the glacial features likely provided the sediments that compose many of the marine formed shoals. Thus, the NH and vicinity continental shelf reflects the major processes that shaped its morphology and sedimentology: glaciations; sea-level fluctuations; and marine processes.

Development of seafloor surficial geology maps is the first step in unravelling the development of the NH and vicinity continental shelf and the nature of the deposits constituting the seafloor. At present, the recent availability of high resolution multibeam bathymetry, along with acoustic backscatter and archived sediment databases allows mapping of the surficial geology and the identification of potential marine mineral resources.

Presented here is a series of newly developed maps that depict the surficial geology of the NH and vicinity continental shelf in greater detail than previously was possible. Although extensive field verification and ground truth is needed, the surficial geology maps are a major advancement and provide the groundwork to design future field campaigns to verify the maps and explore potential marine mineral resources (i.e., sand and gravel).

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Appendix 1. Western Gulf of Maine surveys used to create the bathymetry and bathymetric derivatives for the New Hampshire continental shelf.

Survey	Survey Year	Agency	Frequency	Multibeam System	Highest Resolution Available
D00185 Scantum Basin	2013	NOAA	200 kHz	Reson 7125	4m
F00574 Offshore York Harbor ME	2009	NOAA	200/400 kH & 455 kHz	Reson 7125 & 8125	1m
F00574 Offshore York Harbor ME	2009	NOAA	200/400 kHz & 455 kHz	Reson 7125 & 8125	1m
F00603 Vicinity of Boon Island	2011	NOAA	200/400 kHz	Reson 7125	50cm
H10763 Approaches to Portsmouth Harbor NH	1997	NOAA	455 kHz	Reson 9003	3m
H10771_1_Murray Rock to Duck Island	1997	NOAA	455 kHz	Reson 9003	3m
H10771_2_Murray Rock to Duck Island	1997	NOAA	455 kHz	Reson 9003	10m
H11014 Portsmouth Harbor NH	2000	NOAA	240 kHz	Reson 8101	1m
H11296_1_Bigelow Bight and Isle of Shoals	2005	NOAA	N/A	SHOALS-1000T Bathymetric and Topographic LiDAR	5m
H11296_3_Bigelow Bight and Isle of Shoals	2005	NOAA	N/A	SHOALS-1000T Bathymetric and Topographic LiDAR	5m
H12613 Vicinity of Isles of Shoals	2013	NOAA	400 kHz	Reson 7125	2m
H12614 Hampton Beach to Little Boars Head	2013	NOAA	100 kHz	Reson 7125	2m
H12615 York Harbor Entrance to Cape Neddick	2013	NOAA	100 kHz	Reson 7125	2m
H12696	2014	NOAA	400 kHz	Reson 7125	2m
H12697	2014	NOAA	400 kHz	Reson 7125	8m
H12698	2014	NOAA	200 kHz	Reson 7125	2m
Jeffreys Ledge 8125	2003	CCOM	455 kHz	Reson 8125	2m
W00037 to W00048 Approaches to Boston	2003	NOAA	95 kHz	Kongsberg EM1002	10m
W00050 to W00053 Approaches to Boston	2003	NOAA/CCOM	95 kHz	Kongsberg EM1002	4m
Sweep Day 60_62	2000	CCOM		N/A	1m

Appendix 1. Continued

Survey	Survey Year	Agency	Frequency	Multibeam System	Highest Resolution Available
Jeffreys Ledge 8101	2002	CCOM	240 kHz	Reson 8101	5m
Mussel Geo Summer Hydro	2004	CCOM		Kongsberg EM3002	1m
Isle Of Shoals Summer Hydro	2005	CCOM	293/307 kHz	Kongsberg EM3002 Dual Head	1m
W00178 Gerrish Island Summer Hydro	2006	CCOM	300 kHz	Kongsberg EM3002	1m
W00195 GOMMI NW	2005	NOAA/CCOM	240 kHz	Reson 8101	25m
Cape Ann Salisbury Beach MA	2007	USGS	240 kHz & 234 kHz	Reson 8101 & SEA SwathPlus 2000	5m
South Gerrish Island Summer Hydro	2007	CCOM	300 kHz	Kongsberg EM3002 Dual Head	1m
Cod Survey Summer Hydro	2008	CCOM	293,300,307 kHz	Kongsberg EM3002 Dual Head	1m
W00206 Isle Of Shoals Summer Hydro	2009	CCOM	300 kHz	Kongsberg EM3002 Dual Head	1m
Isle Of Shoals Summer Hydro	2010	CCOM	300 kHz	Kongsberg EM3002 Dual Head	1m
Boon Island Summer Hydro	2011	CCOM	200/400 kHz	Reson 7125	2m
W00244 Offshore Gerrish Island Summer Hydro	2012	CCOM	300 kHz	Kongsberg EM2040	1m
Near Shore Rye Summer Hydro	2013	CCOM	300 kHz	Kongsberg EM2040	50cm
Concord Point Summer Hydro	2014	CCOM	400 kHz	Kongsberg EM2040	1m
Massachusetts Bay & Stellwagen Bank	1998	USGS	95 kHz	Simrad EM1000	10m
Open Aquaculture Summer Hydro	2003	CCOM			1m
South White Island Summer Hydro	2007	CCOM	300 kHz	Kongsberg EM3002 Dual Head	50cm
Rye Ledge to Great Boars Head Summer Hydro	2015	CCOM	300 kHz	Kongsberg EM2040	1m

Appendix 2. Sources of surficial sediment grain size data and seafloor photographs.

Authors	Publication	Organization	Web Site	Date Accessed	Data type
L. G. Ward M. Vallee-Anziani Z. McAvoy	Unpublished	UNH CCOM/JHC			Synthesis of Sediment Grain Size Data for the New Hampshire Shelf and Vicinity
L. Poppe V. Paskevich J. Williams P. Hastings J. Kelley D. Belknap L. Ward D. FitzGerald P. Larsen	*Open-File Report 03-001* June 2003, Upd. December 2004 Surgical Sediment Data from the Gulf of Maine, Georges Bank, and Vicinity: A GIS Compilation	USGS	http://pubs.usgs.gov/of/2003/of03-001/index.htm	2/2/2016	Synthesis of Sediment Grain Size Data for the Western Gulf of Maine
P. C. Valentine L. B. Gallea D. S. Blackwood E. R. Twomey	*Data Series 469* Seabed Photographs, Sediment Texture Analysis, and Sun-illuminated Seafloor Topography in the Stellwagen Bank National Marine Sanctuary Region off Boston, Massachusetts	USGS	http://pubs.usgs.gov/ds/469/	1/25/2016	Synthesis of Sediment Grain Size Data and Bottom Photographs for Stellwagen Bank and Vicinity
W.A. Barnhardt B. D. Andrews S. D. Ackerman W. E. Baldwin C. J. Hein	*Open-File Report 2007-1373* High-Resolution Geologic Mapping of the Inner Continental Shelf: Cape Ann to Salisbury Beach, Massachusetts	USGS	http://pubs.usgs.gov/of/2007/1373/index.html	1/25/2016	Synthesis of Sediment Grain Size Data and Bottom Photographs for Inner Shelf Off Cape Ann to Salisbury Beach
UNH CCOM/JHC 2012 Hydrographic Field Course ESCI 972; OE 972	*Report for W00244*	NOAA National Center for Environmental Information	http://www.ngdc.noaa.gov/docucomp/page?url=http://surveys.ngdc.noaa.gov/mgg/NOS/hsmdb/W00001-W02000/W00244_hsmdb.xml&view=hydro/survey&header=none	1/31/2016	Sediment Description and Photos of Seafloor Offshore of Gerrish and Cutts Island
UNH CCOM/JHC 2014 Hydrographic Field Course ESCI 972; OE 972	*Unpublished* *Report W02014*	UNH CCOM/JHC			Sediment Description and Photos of Seafloor Offshore Concord Point to Rye Beach