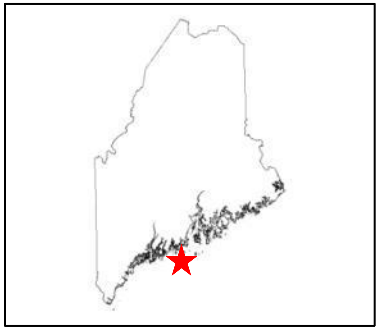
Maine Geologic Facts and Localities

October, 2012

Sampling the Gulf of Maine Seabed from the Ocean Survey Vessel Bold



43° 30' 54.01" N, 69° 30' 40.80" W

Text by
Stephen M. Dickson
Laboratory Analysis by
Kara Jacobacci

Introduction

The geology of the ocean floor of the Gulf of Maine is spatially complex at many scales. Regionally there are areas of shallow rocky ledges adjacent to deeper muddy valleys and basins. Some basins tend to be isolated while other deep areas can be connected around shoals or underwater ridges. The complex spatial relationships between bottom relief (water depths) and sediment types may be important in understanding a variety of marine habitats and ecosystems in the Gulf of Maine (Figure 1; Dickson, 2004).

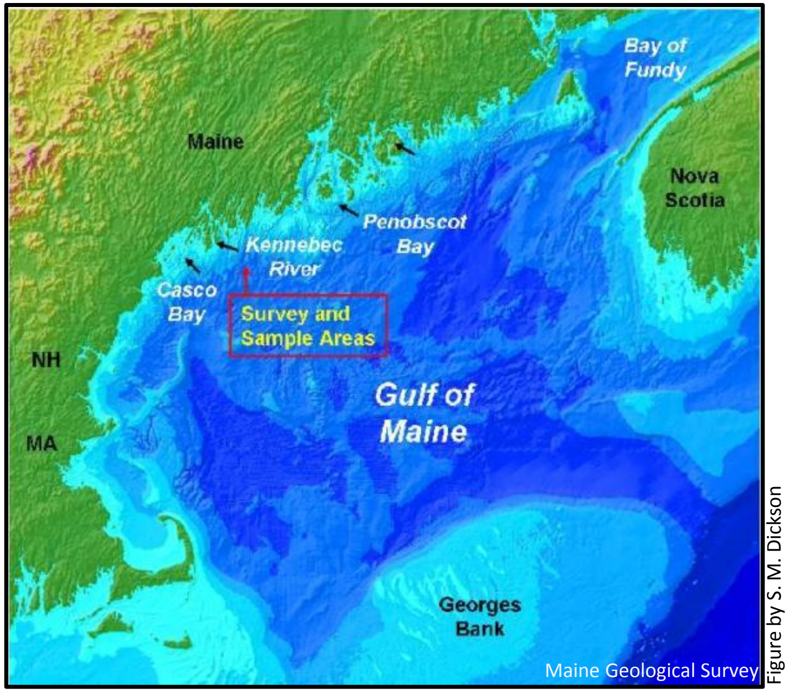


Figure 1. The Gulf of Maine is part of the continental shelf of the North American continental margin that extends seaward to Georges Bank. The area investigated and described here is shown by the red arrow and labeled Survey and Sample Areas. This area of Maine's inner continental shelf is about 15 nautical miles offshore of the mid-coast.

Ocean Survey Vessel *Bold*

The U.S. Environmental Protection Agency Ocean Survey Vessel *Bold* docked at the International Marine Terminal in Portland, Maine. The ship is 224 feet long, 43 feet wide, and has a draft of 15 feet. A crew of about 18 and scientific team of up to 20 can work around the clock while conducting ocean surveys.

Photo by R.A. Johnston

Figure 2. The U.S. Environmental Protection Agency Ocean Survey Vessel *Bold* docked at the International Marine Terminal in Portland, Maine.

Survey Area

This pdf describes the geological aspect of a collaborative investigation conducted in the summer of 2012 to map an area about 12 nautical miles south of Boothbay Harbor and Pemaquid Point (Figure 3).

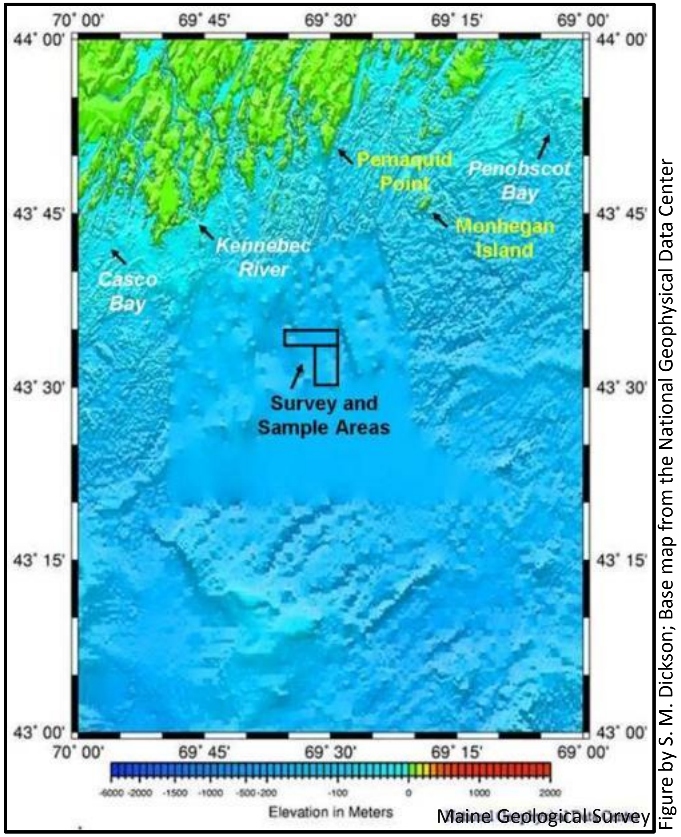


Figure 3. This map shows the mid-coast peninsulas of Maine between Casco Bay and Penobscot Bay. The survey and grab sample area is outlined in black rectangles. Note the bathymetry (ocean depth) is not well represented in the survey area and to the south.

Marine Geology

Maine's inner continental shelf is primarily composed of rock and mud environments. Together these two geological categories make up about 80% of the seafloor (Figure 4; Kelley and others, 1998). The remainder of the sea bed is composed of sand or gravel.

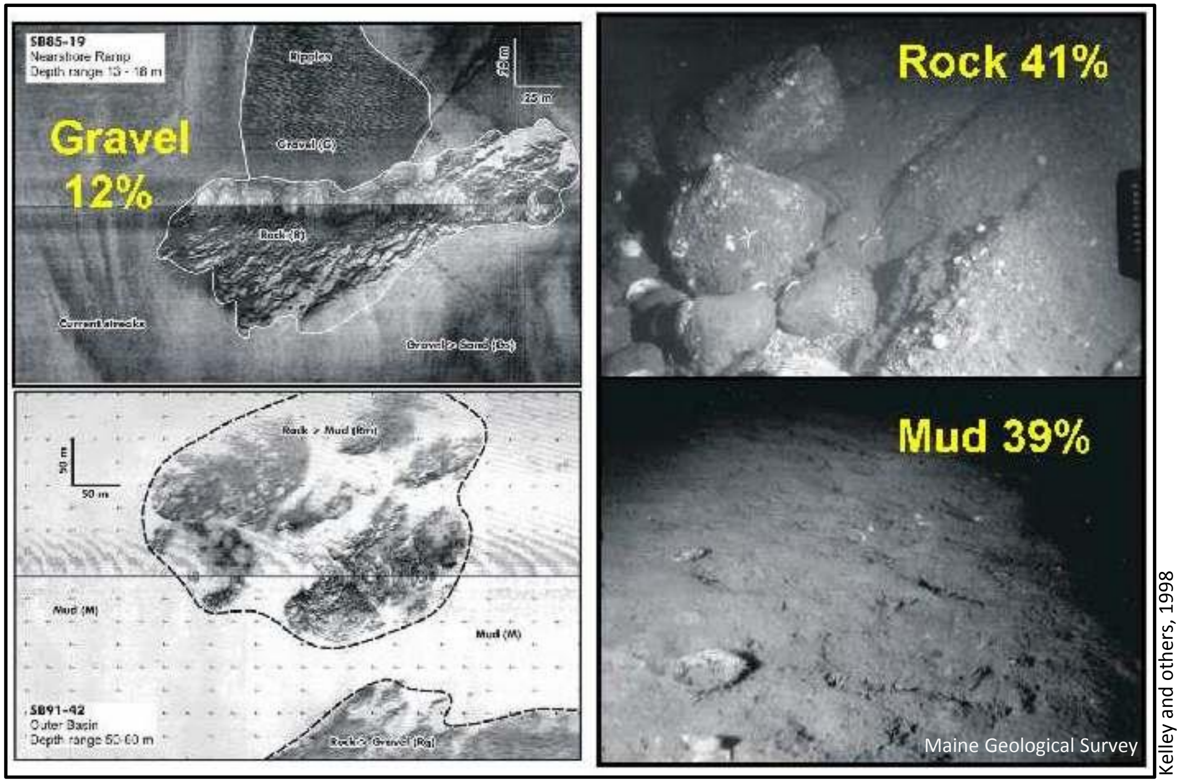
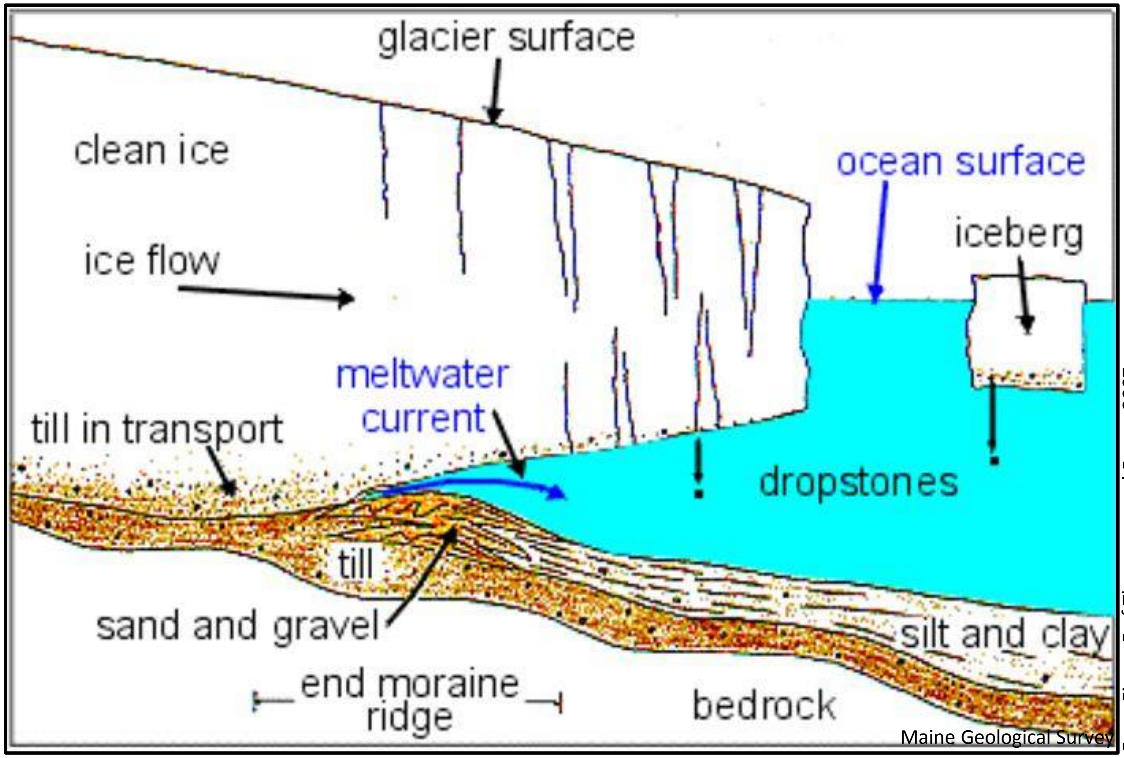


Figure 4. Examples of side-scan sonar images (left) from the Maine inner continental shelf and seafloor photographs (right). Mapping has determined that rocky seafloor makes up about 41% of the bottom while mud makes up 39%. Gravel and sand areas are less common and usually found in shallow water.

Marine Geology

In the mid-coast region, prior investigations (Kelley and others, 1987; see also other Maine Geological Survey Open-File Reports) determined that sediments are often a legacy of the last Ice Age. Deposition of sediment such as sand, gravel, and boulders in the form of glacial till occurred either under ice or at the ice margin (Figure 5) as the glacier retreated northward (Kelley and others, 1987).



From Figure 5 of Thompson and Borns, 2007

Figure 5. Cross section of the glacier margin in coastal Maine, showing formation of a moraine ridge where the edge of the ice sheet was in the sea. This moraine consists of till interlayered with sand and gravel washing out of the ice.

Marine Geology

Following the Ice Age, fine silty and muddy sediments have been deposited in the open Gulf of Maine and often bury the glacial sediments. In some areas these post-glacial or "modern" mud deposits can be thick while in other areas they can be so thin that glacial boulders are not yet buried. Geologists can investigate these same relationships with remote sensing and sampling on land in areas that were once submerged by marine waters (Thompson and Tolman, 2011). Maine's Ice Age Trail (Thompson and Borns, 2007) as well as MGS Surficial Geology Field Localities provide examples and land locations to visit in Maine.

Prior Investigations

The Maine Geological Survey and University of Maine have collaborated to map the Surficial Geology of the Maine Inner Continental Shelf (Barnhardt and others, 1996) to reveal the complexity of the seafloor using a combination of acoustic surveying using side-scan sonar and seismic reflection profiling and bottom sampling with grab samples and cores (Kelley and others, 1987, 1998). Sediment samples from the Gulf of Maine have been compiled by the U.S. Geological Survey (Poppe and others, 2005; Reid and others, 2005).

Depth measurements in some areas are sparse and lead to low-resolution bathymetric maps that only represent broad characteristics of the bottom over wide areas (Figure 3) so interpretation of sediment characteristics with low-resolution maps can be challenging. On a small spatial scale of a nautical mile or less there can be dramatic changes in water depth, slopes, and geology.

Maine Seafloor Mapping Survey

From July 3 through 9, 2012 the U.S. Environmental Protection Agency Ocean Survey Vessel (OSV) Bold conducted a benthic mapping research cruise under the direction of EPA Chief Scientist Matt Liebman and Principal Investigators Matthew Nixon of the Maine Coastal Program, Stephen Dickson of the Department of Conservation, Maine Geological Survey, and Carl Wilson of the Maine Department of Marine Resources. Additional scientists from the Maine Geological Survey, University of Maine, University of New Hampshire, and the Biodiversity Research Institute of Gorham, Maine collaborated in a multidisciplinary effort that included multibeam bathymetric mapping as well as seabird and marine mammal observations.

Mapping with Side-scan Sonar

One of the best ways to map the ocean floor is with side-scan sonar. Using sound sent out from a "towfish" sound waves are bounced off the bottom, received back at the tow-fish, and processed into images based on the strength of the returning sound energy.

Figure 6. The L-3 Klein Model 3000 side-scan sonar on the rear deck of the OSV Bold. Sound waves are transmitted and received from the black transducers that run along each side of the instrument. Returned signals are transmitted by wire to the ship's sonar lab.

Mapping with Side-scan Sonar

Sonar imagery is the equivalent of aerial photographs that are used by geologists on land to study landforms and sediments. The OSV Bold uses a Klein side-scan sonar (Figure 6) that sends signals into the sonar lab (Figure 7).

Photo by S.M. Dickson

Figure 7. The sonar lab. Using a joy stick, the towfish can be raised and lowered to optimal distances above the sea floor. Sonar data is streamed into the lab in real time to computer monitors. Screens also display conditions on the deck, winches, and movement of people.

Mapping with Side-scan Sonar

Screen images of the sea floor are selected and stored by scientists and technicians on board the ship in real time (Figure 8). These images are about 650 feet (200 meters) in width and have the ship track in the center. Data collected can be later processed to produce a nearly complete image of the survey area, much like an air photo of the ground.

Figure 8. Displays in the sonar lab. The left screen shows a log file created by scientists on watch. The middle screen shows a real-time image of the seafloor. The vertical center line of the screen is the ship's course. Left (port) and right (starboard) images in brown represent the seabed. The right screen displays planned (white) and completed (green and red) ship track lines. After the completion of a line, the bridge is notified and executes a u-turn to transit a new line.

Mapping with Side-scan Sonar

This collection of sonar images (Figure 9) is then analyzed and prioritized to select images representative of various bottom types and broad areas of the sea floor. The description provided below is on the geological sampling that was done in order to "ground truth" side-scan sonar images and document sediment types offshore of mid-coast Maine.

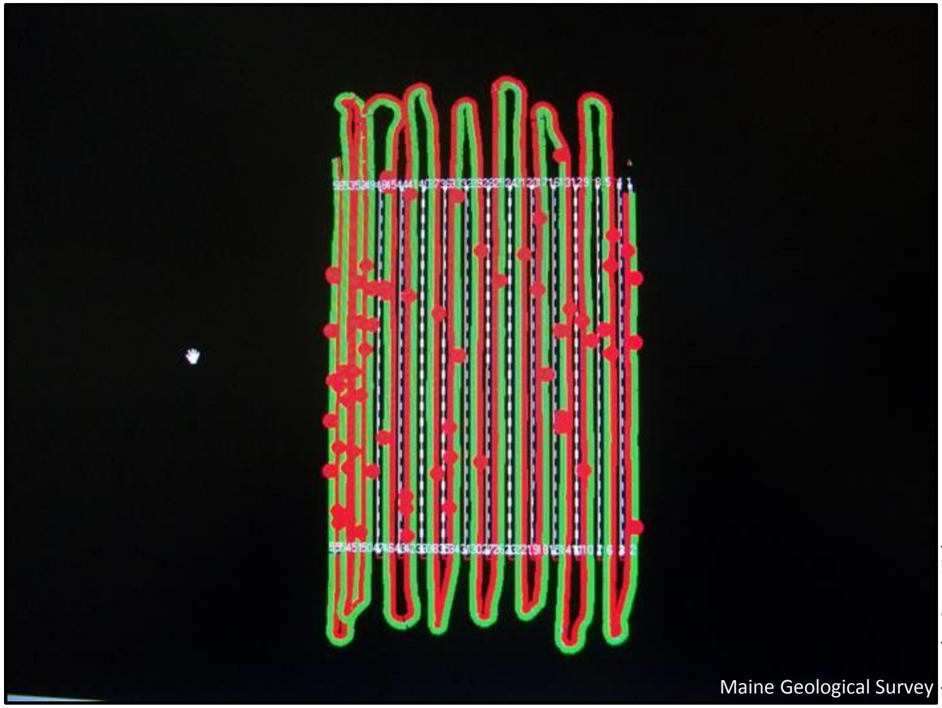


Photo by S.M. Dickson

Figure 9. An image of a computer screen shows side-scan survey lines. The left (port) and right (starboard) data are shown by red and green lines respectively. The red circles represent potential targets for grab sampling based on sonar images. Of these targets, 12 were sampled to represent the geography and geology of the 2012 Maine Seafloor Mapping Survey area.

Seafloor Sediments

On the ship, 12 samples were collected with a grab sampler (Figure 10) by Kara Jacobacci, Robert Johnston, Patrick Ryan, and Robin Arnold with the technical assistance of the crew of the OSV Bold. All of the samples were taken from water depths - not corrected for tidal stage - between 440 and 525 feet (134 to 160 m) with the exception of one sample (MSMS_0135L) that was from a shallower depth of 390 feet (118 m).

Figure 10. A Van Veen grab sampling device awaits deployment on the deck of the OSV Bold. The sampler is weighted and within a metal frame that is lowered to the seafloor by a cable on a winch. In the center are two open metal parts that close, much like a clam shell, to grab a sample of sediment on the seafloor. The sample is brought back on deck and transferred to bags for later analysis.

Seafloor Sediments

The color of all the samples was dark yellowish brown (Munsell color 10 YR 4/2; GSA, 1994). Table 1 summarizes the location of the samples and what was noted in the sonar images.

Station Name	Latitude (°N)	Longitude (°W)	Depth (m)	Color	Sonar Image
MSMS_0120	43.5428	69.5305	158.7	10 YR 4/1	M, SP
MSMS_0135	43.5408	69.5251	118.0	10 YR 4/1	G, SB
MSMS_0136	43.5201	69.5249	134.0	10 YR 4/1	M, SB
MSMS_0147	43.5327	69.5107	144.2	10 YR 4/1	M, TM
MSMS_0148-1	43.5552	69.5101	146.7	10 YR 4/1	M
MSMS_0148-2	43.5561	69.5110	148.4	10 YR 4/1	M
MSMS_0158	43.5389	69.4875	151.4	10 YR 4/1	M, TM, P
MSMS_0162	43.5214	69.4887	140.5	10 YR 4/1	M, S?, BB, SP
MSMS_0168	43.5356	69.4807	142.7	10 YR 4/1	M, G?, old TM
MSMS_0170	43.5067	69.4741	147.8	10 YR 4/1	M, PM
MSMS_0172	43.5436	69.4735	141.3	10 YR 4/1	M, LB, old TM
MSMS_0192	43.50735	69.4848	134.3	10 YR 4/1	M, SB

Maine Geological Survey

Compiled by S.M. Dickson

Table 1. Maine Seafloor Mapping Survey stations with latitude, longitude, depth, color and sonar image descriptions. Sonar abbreviations are: M = mud; S = sand; G = gravel; SB = small boulders; LB = large boulders; TM = trawl marks; P = pockmark (pit); and SP = small pockmark. Munsell color 10 YR 4/2 is dark yellowish brown. Depths are not corrected for tidal stage (+/- 3 m).

Seafloor Sediments

Figure 11 shows sample locations on a map.

Figure 11. This map shows the location of grab samples from the 2012 Maine Seafloor Mapping Survey area.

KML file of the grab sample locations

Seafloor Sediments

Grain size analysis was completed at the University of Maine by Jacobacci (2012) with the methods of Folk (1980) using settling tubes for the silt and clay fractions. Results are shown in Figure 12-14.

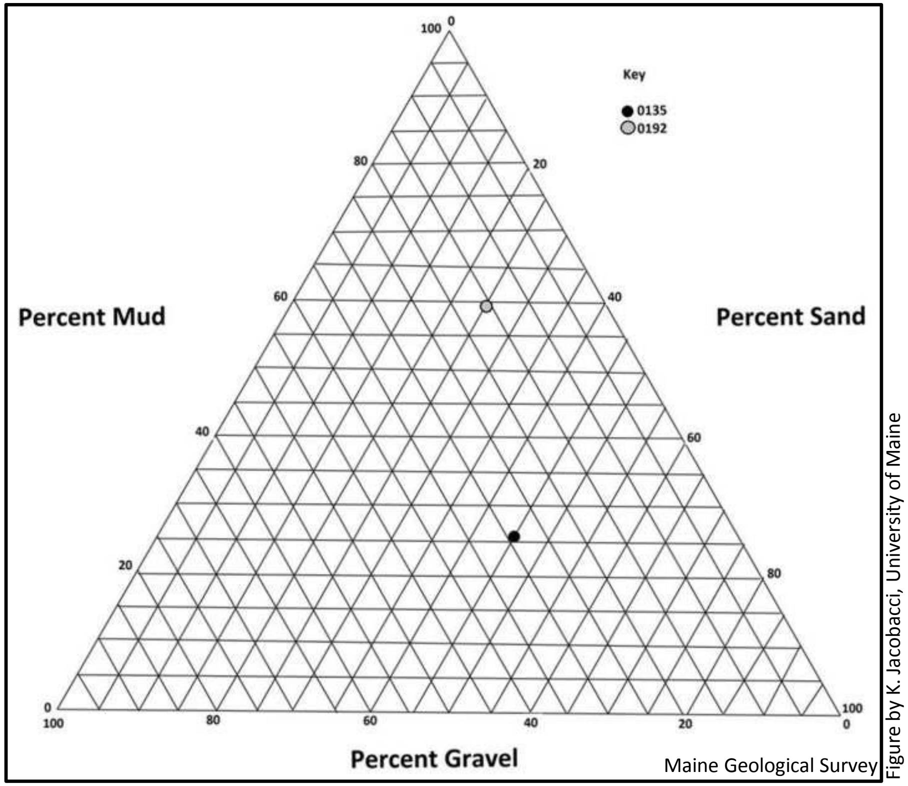


Figure 12. A ternary diagram of the two coarsest sediment samples from the 2012 Maine Seafloor Mapping Survey area. The sample with the most sand and gravel (black circle) was from station MSMS_0135 and was classified as a gravelly muddy sand (Table 2). This grab was from the shallowest depth 390 feet (118 m) and also contained a sea mouse. Another sample with gravel (open circle) was MSMS_0192 from 440 feet (134 m) depth.

Seafloor Sediments

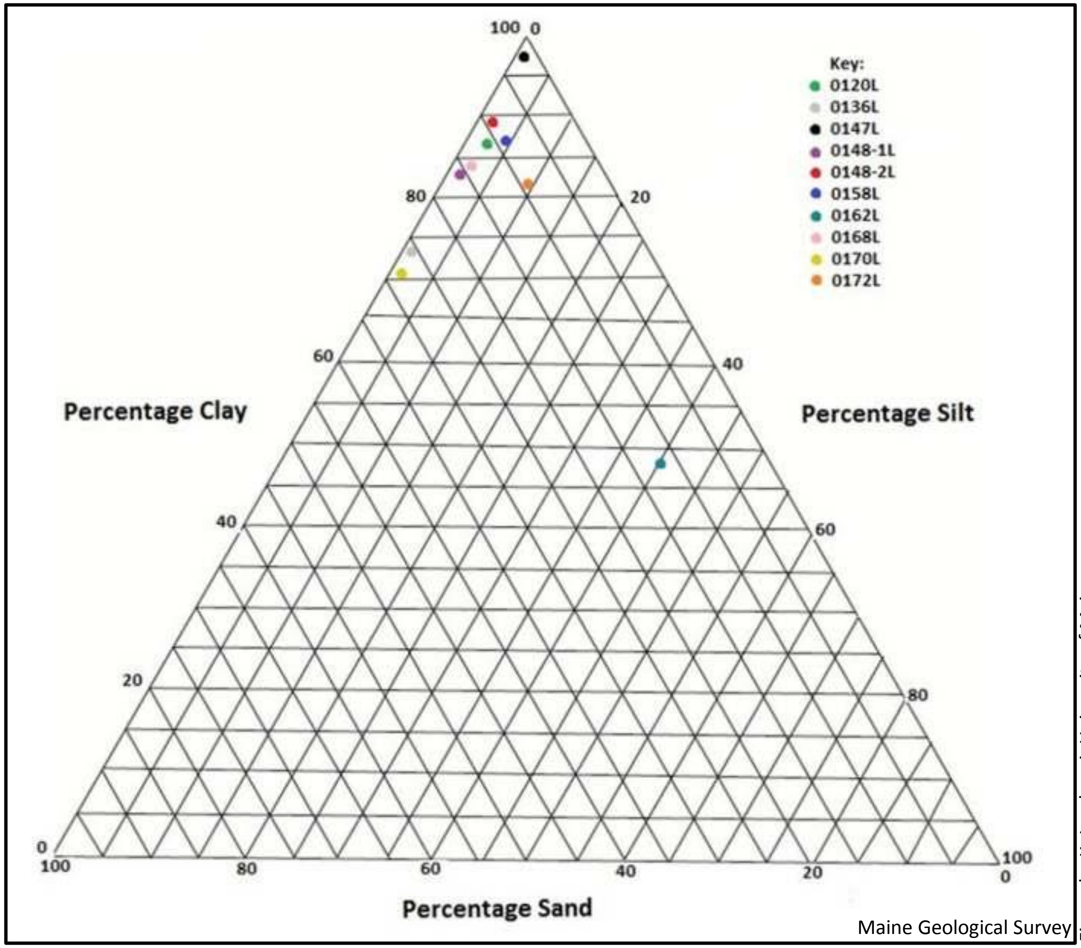


Figure by K. Jacobacci, University of Maine

Figure 13. A ternary diagram that graphs the fine-grained sediment samples from the 2012 Maine Seafloor Mapping Survey area. Most samples were very similar. Sandy clay was the most common sedimentary texture (Table 2).

Seafloor Sediments

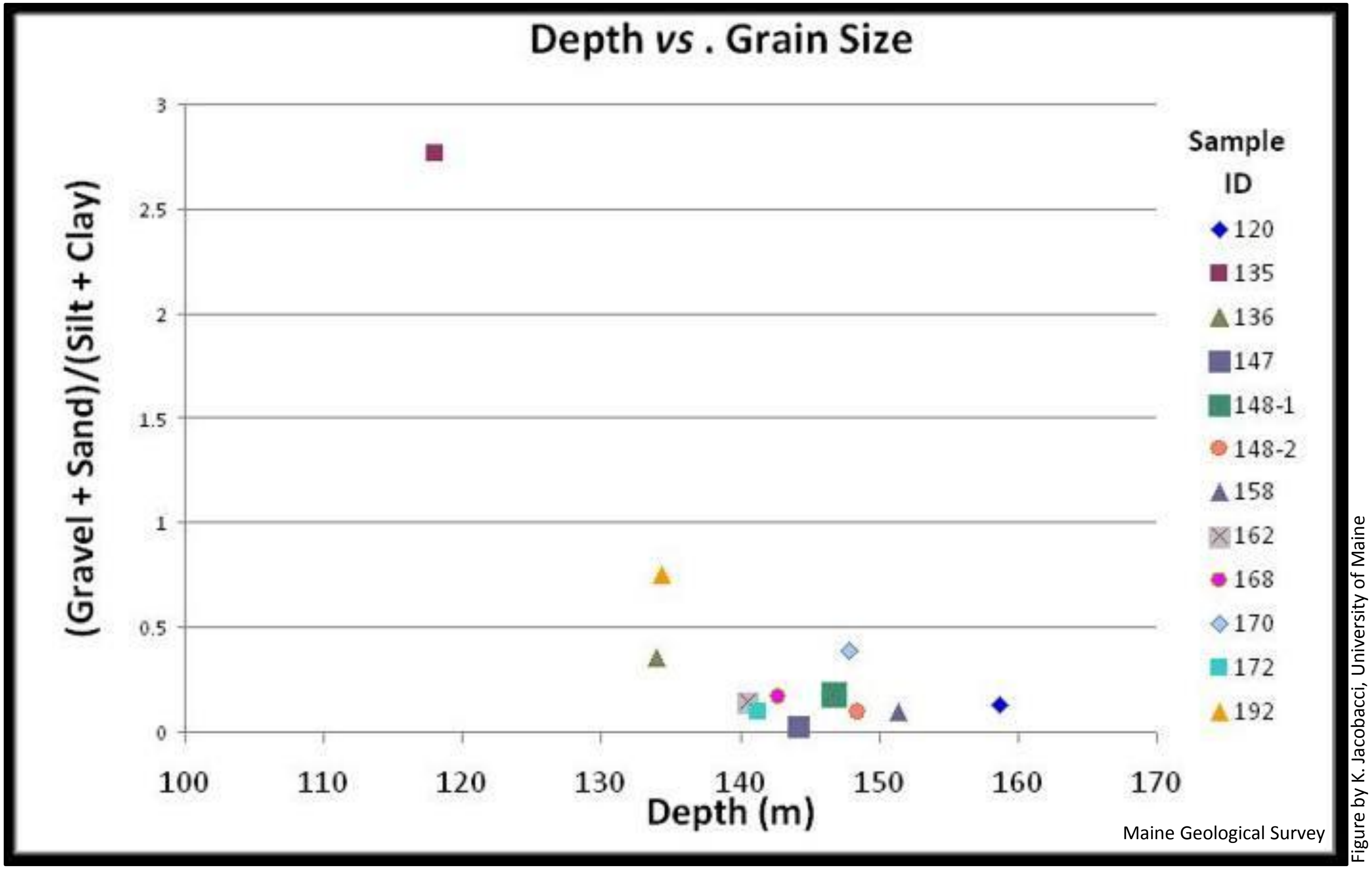


Figure 14. A graph showing the proportions of coarse sediment (gravel + sand) to mud (silt + clay) versus depth. Most of the samples cluster together due to the dominance of clay-sized particles.

Seafloor Sediments

Most of the samples can be classified as clay or sandy clay with very little silt. Two samples were coarser and contained gravel. The shallowest sample (MSMS_0135L) was gravelly muddy sand but a gravelly mud was also recovered from a water depth of 485 feet (148 m; MSMS_192L; Table 2).

Station Name	Sand %	Silt %	Clay %	Gravel %	Sediment Class
MSMS_0120	11.63	2.62	85.75		Sandy clay
MSMS_0135	44.70	.08	26.50	29.19	Gravelly muddy sand
MSMS_0136	26.02	.98	73.00		Sandy clay
MSMS_0147	3.26	.21	96.54		Clay
MSMS_0148-1	15.36	.85	83.79		Sandy clay
MSMS_0148-2	9.09	1.85	89.06		Clay
MSMS_0158	9.08	4.04	86.88		Clay
MSMS_0162	12.76	39.78	47.46		Sandy mud
MSMS_0168	14.67	1.91	83.43		Sandy clay
MSMS_0170	27.85	.69	71.46		Sandy clay
MSMS_0172	9.12	9.28	81.61		Sandy clay
MSMS_0192	27.24	16.62	40.60	15.59	Gravelly mud

Maine Geological Survey

Compiled by S.M. Dickson

Table 2. Grain size analysis determined the sedimentary composition at 11 locations with one replicate (MSMS_0148). See Figures 12-13 for graphs of these data. Sediment class is based on Folk (1980). Results from Jacobacci (2012).

Seafloor Sediments

In addition to grain size, both the water content and organic content of the sediments was measured. Water content averaged 57% with a range of 45% to 62%. Organic matter averaged 9% by weight within a range of 5 to 16% (Table 3). Marine worms or worm casts were common in all samples and a sea mouse was recovered at station MSMS_0135.

Station Name	% Water	% Organic
MSMS_0120	61.67	16.01
MSMS_0135	44.68	4.98
MSMS_0136	55.73	7.80
MSMS_0147	60.23	9.28
MSMS_0148-1	59.69	10.14
MSMS_0148-2	61.54	10.06
MSMS_0158	57.145	8.71
MSMS_0162	51.45	7.36
MSMS_0168	55.45	7.99
MSMS_0170	60.80	9.58
MSMS_0172	57.43	8.14
MSMS_0192	52.96	6.44

Maine Geological Survey

Compiled by S.M. Dickson

Table 3. Water and organic matter breakdown. Water content averaged 57% with a range of 45-62%. Organic content ranged from 5-16% of samples by weight. The average organic content was 9%. Results from Jacobacci (2012).

Conclusion

The area investigated with grab samples represents conditions over about 9 square nautical miles across a section of the Gulf of Maine sea floor that is about 500 feet deep. The seafloor is predominantly sandy mud containing nearly 60% of its weight in water and 10% of its weight in organic matter. Side-scan sonar images show boulders ranging in size from a few feet to tens of feet in diameter are scattered across this muddy bottom. Sonar images also detected bottom trawl marks, some new and some perhaps old, from fishing activity. These data, combined with processed side-scan sonar mosaic maps, will be critical to geological mapping a new area of Maine's inner continental shelf.

References and Additional Information

Barnhardt, W. A., Belknap, D. F., Kelley, A. R., Kelley, J. T., and Dickson, S. M., 1996, Surficial Geology of the Maine Inner Continental Shelf, a series of 7 maps covering coastal Maine, scale 1:100,000: Maine Geological Survey, Augusta, Maine.

Dickson, S. M., 2004, An Underwater View of the Gulf of Maine Sea Floor, Maine Geological Survey, May 2004 Site of the Month.

Folk, Robert L., 1980, Petrology of Sedimentary Rocks, Hemphill Publishing Company, Austin, Texas, 184 p.

GSA, 1984, Rock-Color Chart, prepared by the Rock-Color Chart Committee, E. N. Goddard, Chairman, Geological Society of America, Boulder, Colorado, 16 p.

Jacobacci, K., 2012, OSV Bold Grab Sample Report, July 2012 Maine Seafloor Mapping Survey, prepared for the Maine Geological Survey and Maine Coastal Program, Maine Department of Agriculture, Conservation and Forestry, September 25, 2012.

Kelley, J. T., Barnhardt, W. A., Belknap, D. F., Dickson, S. M. and Kelley, A. R., 1998, The Seafloor Revealed - The Geology of the Northwestern Gulf of Maine Inner Continental Shelf: Maine Geological Survey, Open-File Report 96-6, 55 p.

Kelley, J. T., Belknap, D. F., and Shipp, R. C., 1987, Geomorphology and Sedimentary Framework of the Inner Continental Shelf of South Central Maine: Maine Geological Survey, Open-File Report 87-19, 76 p.

References and Additional Information

Maine Geological Survey Open-File Reports on the Geomorphology and Sedimentary Framework of the Maine Inner Continental Shelf.

Poppe, L. J., Eliason, A. E., Fredericks, J. J., Rendigs, R. R., Blackwood, D. S. and Paskevich, V. F., 2005, USGS East-Coast Sediment Analysis: Procedures, Database, and GIS Data, U.S. Geological Survey Open-File Report 2005-1001.

Reid, J. M., Reid, J. A., Jenkins, C. J., Hastings, M. E., Williams, S. J., and Poppe, L. J, 2005, usSEABED: Atlantic coast offshore surficial sediment data release: U.S. Geological Survey Data Series 118, version 1.0.

Thompson, W. B. and Borns, H. W., Jr., 2007, Maine's Ice Age Trail, Maine Geological Survey, July 2007 Site of the Month.

Thompson, W. and Tolman, S., 2011, Lidar Imagery Reveals Maine's Land Surface in Unprecedented Detail, Maine Geological Survey, December 2011 Site of the Month.

U.S. Environmental Protection Agency, 2012, Ocean Survey Vessel (OSV) *Bold*.

Acknowledgments

Through the advocacy of Maine's Senators Olympia Snowe and Susan Collins, the U.S. Environmental Protection Agency, under the leadership of Lisa Jackson, provided ship time in August. Chief Scientist Matthew Liebman from EPA provided great knowledge and leadership on board at all hours of the day and night. Principal Investigator Matthew Nixon of the Maine Coastal Program was visionary in arranging a large collaborative effort that integrated several marine sciences and maximized ship time.

We are very thankful for the exceptional skills and cooperation provided by Captain Jerel Chamberlain, mates, technicians, and crew of the OSV *Bold* provided through Seaward Services, Inc. of Dania Beach, Florida. With their strong commitment to safety and success, the research cruise and data quality are sound and will advance our scientific understanding and maximize use of our ocean resources.