

# Surficial Geology of the Maine Inner Continental Shelf

## Cape Elizabeth to Pemaquid Point, Maine

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### INTRODUCTION

Geological maps depicting topography, surficial materials, geomorphology, and bedrock play an important role in understanding the origin of, as well as the ongoing processes that shape and change the earth's surface. As in the terrestrial environment, maps are also instrumental in understanding the economic development of natural resources. They also provide guidance to natural hazards that exist within the landscape. As people increasingly work on, in, and beneath the sea, the need to better understand regional marine geology just as we understand terrestrial geology, has grown. This map, and others in this series, are intended to provide a better picture of the northeastern Gulf of Maine. Additional information on specific locations and original field descriptions exists in the associated report: *The Surficial Geology of the Inner Continental Shelf of the Maine Inner Continental Shelf* (Belknap et al., 1996).

Many reconnaissance surveys of the seafloor of the northeastern Gulf of Maine were conducted in the past decade. Recently that information along with other previously published data, was compiled into a geographic information system (GIS) to produce this map. The data compiled for this series of maps were originally collected for a variety of research projects, government contracts, and student theses. For this reason there are varying amounts of geophysical data and bottom-sample coverage along the coast rather than a uniform grid. The *Seafloor Revealed* further explains the field techniques involved in data collection, the nature of the seafloor, the late Quaternary glacially geologic history of the Maine coast, previous studies, and sources of other information.

Bedrock geology defines the overall shape of the Maine coastline by controlling the location and orientation of islands, bays, and peninsulas. Bedrock relief is also primarily responsible for variability in water depths of the inner shelf. Glacial deposits mantle the underlying bedrock, and add complexity to regional geomorphology, in forms that range from coarse ridges of boulders to fine-grained silty muds. These accumulations of glacial sediments (gravel, sand, and mud) often result in smoother areas of seafloor with less bathymetric relief. Although all of the Holocene deposits consist of sedimentary material along the coast and offshore, they are derived from erosion and new working of glacial deposits. Physical oceanographic processes, including waves and tides, continue to reshape the seafloor sediments and create productive marine habitats of the Gulf of Maine.

Sea-level change has had a profound effect on the location and duration of sediment deposition and deposition. During the complex changes of sea level over the last 4,000 years, coastal and terrestrial cross-ridge and cross-ridge glacial sediment from shoals and transferred the material to deeper basins. During deglaciation, the sea covered most of the coastal lands of Maine (2). A regression (sea-level lowering) until about 10,500 years ago was followed by a transgression (rising) that is still continuing (3, 4). Areas shallower than the maximum lowering of the sea (less than about 60 m (200 feet) water depth) are generally rockier than deeper regions. The shallower zone lost some of its sediment cover through wave working during both the late Pleistocene fall and the early Holocene rise of the sea. These areas also experienced at least a thousand years of subaerial erosion. The marine geology of the Maine coast records these and many other changes that have taken place since glaciers retreated inland and the sea invaded the western Gulf of Maine (4, 5, 6).

### SURFICIAL GEOLOGY

The surficial materials of the inner continental shelf of the northeastern Gulf of Maine are the most complex of any place along the Atlantic continental margin of the United States. Lignous, metamorphic, and sedimentary rocks spanning hundreds of millions of years of earth history form the regional basement. Glacial deposits, consisting of clasts from boulders to mud, partially mantle the rocks. These materials, in turn, have been reworked by coastal processes during extreme fluctuations of sea level over the past few thousand years to create better modern deposits (5). Biological processes, including shell formation, bioturbation, and organic matter cycling have also altered the sediment composition and left geological imprints on the seafloor (7, 8). In addition to the surficial geology of this map, the geomorphology of the seafloor has also been mapped. The *Physiographic Map of the Maine Inner Continental Shelf* (9) shows the geomorphology of the offshore region covered by this series of surficial geology maps in a single, smaller scale map.

**Rocks Areas**  
Rocky seafloor occupies approximately 41% of the inner continental shelf and is the most abundant seafloor type in this map series. Where little data exist and the seafloor relief is very irregular, a rocky bottom was inferred. By this inference, large areas of rocky bottom were mapped off extreme southern Maine, Penobscot Bay, and Petit Manan Point. Large areas of rock also occur surrounding the many granitic islands in Blue Hill and Frenchman Bays. Elongate, submerged rock ridges follow the linear trend of the Casco Bay peninsula. Although common as seafloor, rocks in water less than 10 m (33 ft) deep, large outcrops of rock are relatively rare in deep offshore basins.

The bedrock geology is more heterogeneous, but still shows some clearly defined parallel fractures and elongate outcrop patterns common in layered metamorphic rocks as well as more rounded bodies of rock often associated with plutonic (granitic) igneous rocks (10). In shallow water, rock outcrops are usually covered with algae (seaweed) and encrusting organisms. Below water depths of a few tens of meters (the photic zone), encrusting organisms and organic matter form bedrock outcrops. "Rock greater than 10 m" (Rg) is a high shell content calcareous carbonate because shells are often the only modern sediment introduced to an area. Gr and "gravel greater than sand" (Gw) are major features of the seafloor from the Canadian border to Englishman Bay. Here, low relief bedrock is mantled by till, which fills in rock depressions but lacks much relief itself. "Gravel greater than mud" (Gm) is very rare along the inner shelf. Gravel and mud are not deposited in the ocean under the same hydrodynamic conditions, but may be found just beneath the seafloor in till deposited by glaciers more than 13,000 years ago beneath glacial ice.

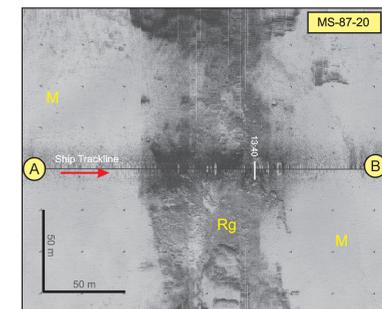
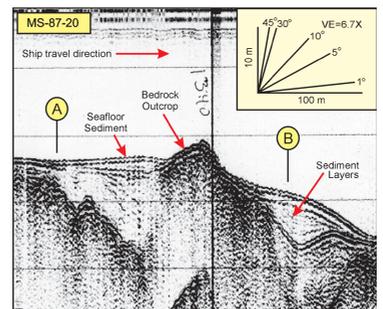


Figure 1. Seismic Reflection Profile. The image above is a portion of an ORE seismic reflection profile from Muscongus Bay and shows a cross-section (side view) of the seafloor. The seafloor surface shape is analogous to a bathymetric profile. A vertical exaggeration (VE) of 6.7 makes all slopes appear steeper than they really are. The subsurface features are from sediment layers and bedrock surfaces. Positions A and B correspond to the same locations in both figures. A time mark is shown by the vertical line at 1:40.

Figure 2. Side-Scan Sonar Profile. The image above is a portion of a side-scan sonar record acquired simultaneously with the seismic reflection profile to the left. This image shows a plan view of the seafloor (much like an aerial photograph). The area shown is about the size of eight football fields. The darker area is a mixture of bedrock outcrop and gravel (Rg). The lighter areas on either side are flat, muddy seafloor (M). The ship track followed the black center line over the bottom. Both of these images were made using sound waves.

### METHODS

**Navigation and Map Compilation**  
Navigation fixes in the outer estuaries and offshore areas were made at 2 to 5 minute intervals with LORAN-C, which provides an accuracy of ± 100 m (330 feet). In the upper reaches of the estuaries, radar and line-of-sight observations on buoys and landmarks provided navigational accuracy that varied from less than ± 10 m (33 feet) to around ± 200 m (660 feet). Recent work used a global positioning satellite system (GPS) for navigation and was accurate to ± 10 m (33 feet). All navigation was converted to Universal Transverse Mercator projection and plotted with geographic information system (GIS) software.

**Surficial geologic maps were prepared in six steps:** (1) use a GIS to plot the geophysical tracklines, bottom sample locations, and bathymetry on large-scale maps; (2) transfer seafloor records and geology based on other geophysical data and samples; (3) digitize the digitized information into a GIS; (4) compile and edit the digital data to generate map polygons; (5) check the mapped geology; and (6) assemble the final product including geologic, bathymetric, and geographic names and symbols. The shoreline and roads are from the U.S. Geological Survey's 1:100,000 Digital Line Graph files.

**Bathymetry**  
Bathymetry was digitized at a 10m contour interval from preliminary National Ocean Service (NOS) Bathymetric and Fishing Maps at a 1:100,000 scale. The NOS bathymetric maps provide a 2 m contour interval in many locations that is too coarse for inclusion on this map. Difficulty in interpretation of positive and negative changes in bathymetry on the poorly labeled NOS maps created many possible errors, especially in areas where accompanying geophysical data were lacking. For this reason, these maps should not be used for charting purposes. More detailed and accurate NOS conventional nautical charts should be used for navigation.

**Bottom Samples**  
Between 1984 and 1991, 1,303 bottom sample stations were occupied (see the Features and Data Source Map for locations in this region). Two attempts were made at each station where the sample initially returned empty, after which the site was considered a rock bottom. A Smith-McIntyre stainless steel grab sampler was used that normally collected up to 0.16 m<sup>3</sup> (0.5 cu ft) of sediment. Small samples were generally collected in a grid pattern with a 2 kilometer (1 nautical mile) distance between sample sites. Focus was placed on the large sandy embayments of Wells, Saco, and the Kennebec River mouth, as well as on muddy Casco Bay. Relatively few bottom samples were gathered off of rocky areas such as Kennebunk or Kittery. Geophysical tracklines were later run over the sample stations to permit extrapolation of the bottom sediment data. North and east of Cape Small, geophysical data were generally gathered before bottom samples. This resulted in a need for fewer samples, and few stations were occupied. Following collection, samples were stored in a freezer at the sedimentology laboratory at the University of Maine. Depending on the level of funding or specific needs of a particular project, samples were analyzed for grain size, organic carbon and nitrogen, carbonate content and/or heavy minerals (see Table 1 of Reference 1).

**Side-Scan Sonar Profiles**  
Along side-scan sonar records along 338 km (180 mi) of the seafloor were gathered with an EG&G Model SMS 200 scan sonar connected to a Model 272-Towfish at a nominal frequency of 105 kHz. The device was most often run at a 100 m (330 ft) range for each channel (200 m width beam) but also ran at 50 m (165 ft) and 150 m (500 ft) ranges. The side-scan sonar system was occasionally employed. The swath of directly imaged and interpreted seafloor areas are depicted in brighter colors on the map. See the Surficial Geology Legend in the lower left corner of the map and the Interpretation of Side-Scan Sonar Images for further details.

**Seismic Reflection Profiles**  
Seismic reflection profiles were gathered along 5011 km (2700 mi) of tracklines, often in conjunction with side-scan sonar data (see bottom sample locations above). A Raytheon RTT 1000's 5.7 m kHz unit with a 200 kHz bathymeter trace was used mainly in relatively shallow water (0 to 50 m (165 ft) or shallower). An ORE Geologic "Boomer" (0.5 to 200 kHz seismic system) was most effective in deeper water (15 to 50 m, 50 to 500 ft) over thicker deposits of sandy or gravelly sediment. Although seismic reflection profiles are most useful in constructing the geological history of an area, the bathymetry and stratigraphic context of the profile, along with the strength of the surface returns, also help identify the seafloor type (6). When used in conjunction with the side-scan sonar data, both the age and nature of the surficial sediment are easily interpreted.

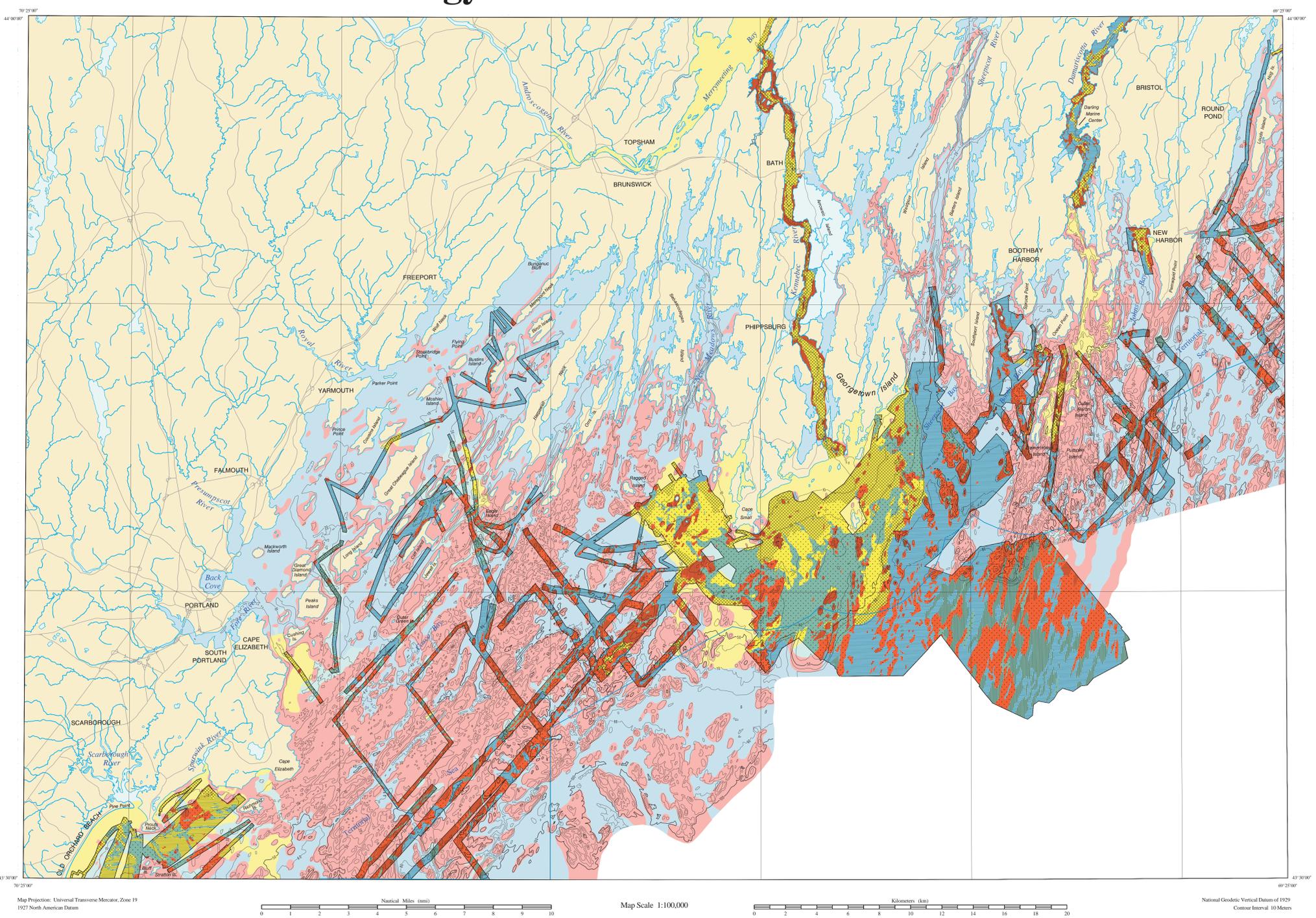
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**Not to be Used for Navigation**  
The information appearing on this map is not complete for navigation. Mariners are cautioned to use National Ocean Service nautical charts for navigation in this area.



## Surficial Geology Legend

The map above shows the geology of the surface of the seafloor. This map of Maine's inner continental shelf is based on geophysical data from bottom samples, National Ocean Service provincial bathymetric maps, and published nautical charts. These data are supplemented with aerial photographs and direct observations from submersibles. Experience with these data, together with side-scan sonar images (the underwater equivalent of aerial photographs), permitted generalized mapping of the inner continental shelf.

The map areas shown by the four colors below were not directly imaged with side-scan sonar. Contacts between these geologic units were inferred, based on bathymetry and other information (see Features and Data Source Map).

The 100m contours on the map and in the Interpretation of Side-Scan Sonar Images legend to the right show areas of seafloor imaged by sonar. The linear colored swaths on the map above follow ship tracklines and have a width that represents the sonar swath to each side of the vessel.

**ROCKY** - Rugged, high-relief seafloor is dominated by bedrock outcrops (ledge) and is the most common type on the Maine inner continental shelf, especially in depths of less than 60 m (~200 ft). Accumulations of coarse-grained sediment occur in low-lying areas and at the base of rock outcrops.

**GRAVELLY** - Generally flat-lying areas are covered by coarse-grained sediments. It thickens up to several meters (yards) in diameter. In some areas gravel and boulders directly overlie bedrock. These deposits are presently accumulating on the shelf but represent Pleistocene (ice age) material. Ripples are common in well-sorted gravel, indicating that some of the older glacial sediments are presently being reworked by waves, currents, and tides.

**SANDY** - Generally smooth seafloor consists primarily of sand- and silt-sized particles derived from rivers, eroding glacial deposits and/or biogenic shell production. This bottom type, although well represented on the map, is the least common on the Maine inner continental shelf.

**MUDDY** - Deposits of fine-grained material form a generally flat and smooth seafloor commonly found in sheltered bays, estuaries, and at depths of greater than 60 m (~200 ft). In some submarine valleys the mud may be meters (yards) thick. Deep depressions (ice-scrape pockets) occur in some muddy bays.

## Interpretation of Side-Scan Sonar Images

On side-scan sonar images, rock, gravel, sand, and mud reflect acoustic energy differently and appear as various shades of gray. The classification scheme above is unique and based on the acoustic reflectivity of the Maine inner continental shelf. The dominant "end member" (Rock, Gravel, Sand, or Mud) is abbreviated with a capitalized first letter. A less abundant, subordinate seafloor type is represented by a lower case letter (e.g., R, G, or M). For example, a predominantly rocky seafloor with gravel infilling fractures is designated Rg. The sixteen combinations of seafloor types shown above are used for areas where side-scan sonar coverage exists and appear in color on the map. In areas beyond the sonar range only four general end members were used: the Surficial Geology Legend.

When individual units of rock, gravel, sand, and mud were greater than 10,000 m<sup>2</sup> in area (about the size of 1 football field), they were mapped as separate features. In many places, however, a heterogeneous seabed composed of numerous small features required composite mapping. In areas where no single seafloor type exceeded 10,000 m<sup>2</sup>, a composite map unit was used. The selection of map units to describe this complexity involves a compromise between providing detailed information where it exists, and generalizing where data are sparse or absent. In many places the seabed is composed of numerous small features, none exceeding the minimum area of 10,000 m<sup>2</sup>. Consequently, not all details in the sonar records could be presented on this map. To describe the realized spatial heterogeneity exists at all scales, even down to areas less than a square meter (see separate text).

Rock yields a strong, dark acoustic return. In areas with steep bathymetric relief and fractures, light acoustic shadows are visible within the dark areas of rock (see adjacent panels A, C, and D). Gravel deposits also produce a relatively strong acoustic return (black to dark gray), and are often closely associated with rock, but lack relief (A, B, C, D). Sand produces a much weaker acoustic return (light to dark gray) than either gravel or rock, and usually lacks local relief (B). Mud yields a very weak surface acoustic return (light gray to white) and, except where it accumulates on steep slopes or near grassy areas, appears as a uniform light gray. The Surficial Geology section in the far right column describes the distribution and abundance of these areas on Maine's inner continental shelf.

## Features and Data Source Map

To purchase copies of this map, contact the Maine Geological Survey, 22 State House Station, Augusta, ME 04333, Telephone: (207) 627-2727, Fax: (207) 627-2727, Web Site: <http://www.maine.gov/doc/terre/ir/mg.htm>

1. Pemaquid Point to Haddock Point (96-7)  
2. Orono to Kennebec River (96-8)  
3. Cape Elizabeth to Pemaquid Point (96-9)  
4. Boothbay Harbor to North Haven (96-10)  
5. Rockland to Har Harbor (96-11)  
6. Mt. Desert Island to Joseph (96-12)  
7. Petit Manan Pt. to West Quoddy Head (96-13)

Legend:  
 - Shipwrecks with DDE, see The Seafloor Revealed for more source information.  
 - Misc. features: dump sites, cable areas, Territorial Sea (3 nm limit)  
 - Seismic reflection profile tracklines  
 - Submersible dives

## Map Series Index

