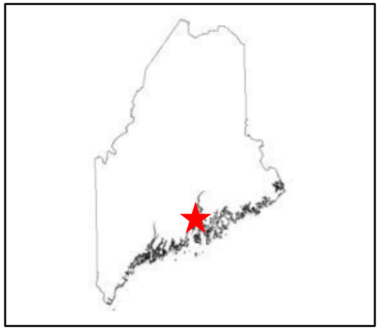
Maine Geologic Facts and Localities

November, 1997

Belfast Bay Pockmark Field, Maine



44° 24‘ 41.01“ N, 68° 57‘ 53.70“ W

Text by
Joseph T. Kelley
Maine Geological Survey

Introduction

Depressions called pockmarks are abundant on the seafloor of Belfast Bay. The pockmarks form through the eruption of methane gas trapped in the sediments of the bay floor. A side-scan sonar image of some pockmarks is shown in Figure 1.

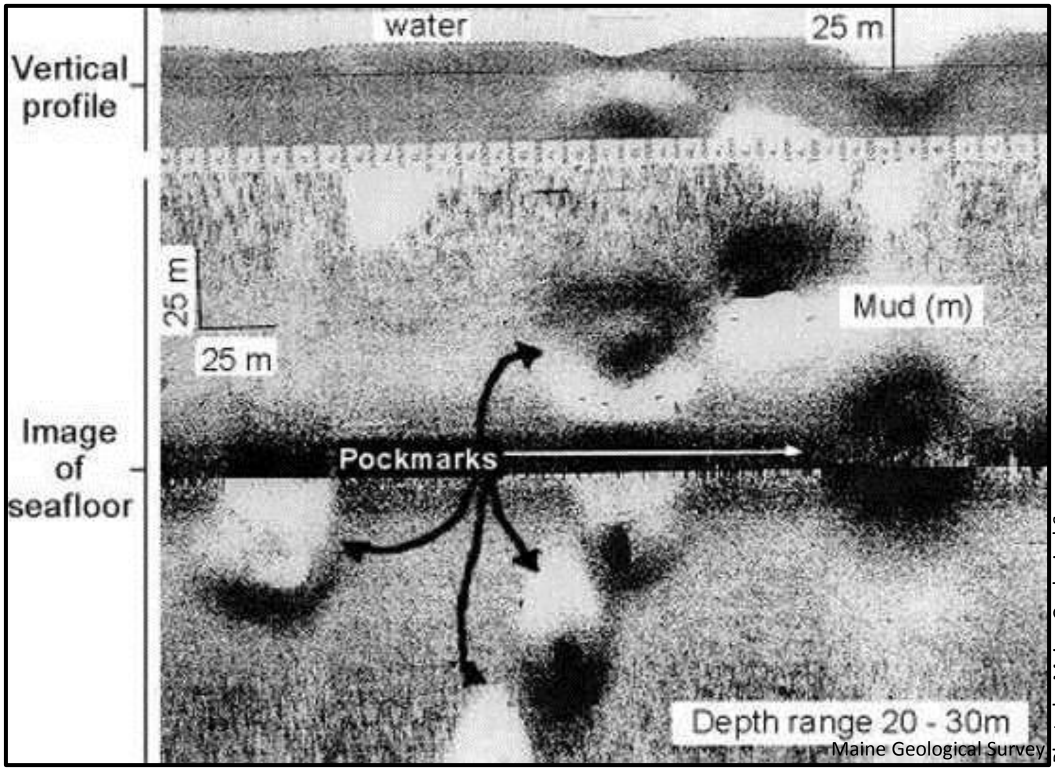


Photo by Maine Geological Survey

Figure 1. A side-scan sonar image of some pockmarks. The center line of the image is the track of the sonar towfish and the bathymetry beneath the line is shown on the upper part of the record with a scale.

Side-scan Sonar

Where the towfish passed directly over the pockmark on the right, it appears all dark because of strong acoustic reflections (echos) from the steeply sloping walls. Pockmarks to one side of the trackline appear dark on the side away from the towfish where the towfish-facing wall of the crater reflects strongly and they appear white where the wall of the crater facing away from the towfish is in acoustic shadow. Acoustically dark "eyes" are seen in the center of some pockmarks. The center line of the image is the track of the sonar towfish and the bathymetry beneath the line is shown on the upper part of the record with a scale. The seafloor is imaged up to 100 m to either side of the trackline of the towfish. The shapes of the pockmarks can be seen from their shading. The image in Figure 1 is from the area of the small black box shown in Figure 3.

Belfast Bay

Belfast Bay forms a small re-entrant in the upper, western side of Penobscot Bay (Figure 2). During routine reconnaissance mapping of the bay, the U.S. Geological Survey (Scanlon and Kneble, 1989), and later, the Maine Geological Survey (Kelley and others, 1994) recorded observations of an unusual type of seafloor in Belfast Bay.

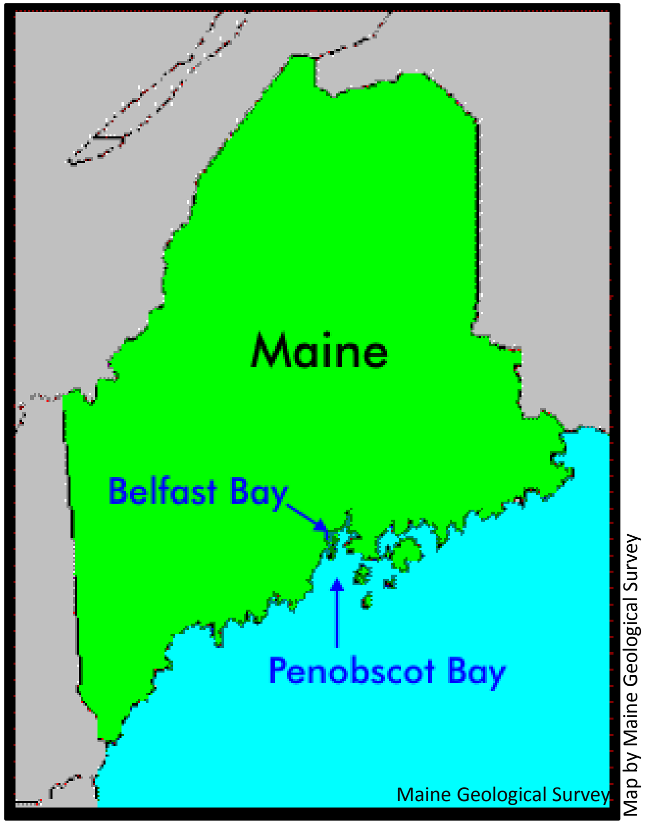


Figure 2. Location of Belfast Bay within Penobscot Bay, on the central Maine coast.

Belfast Bay Pockmark Field

Spread across an otherwise featureless, muddy bottom were a large number of features, termed pockmarks, which increase in size offshore (Figure 3). First used by Canadian geologists to describe crater-like features on the Nova Scotian continental shelf, seafloor pockmarks are hemispherical depressions in the seabed. Although their exact origin remains unknown, they are associated with the escape of methane gas from below the seabed.

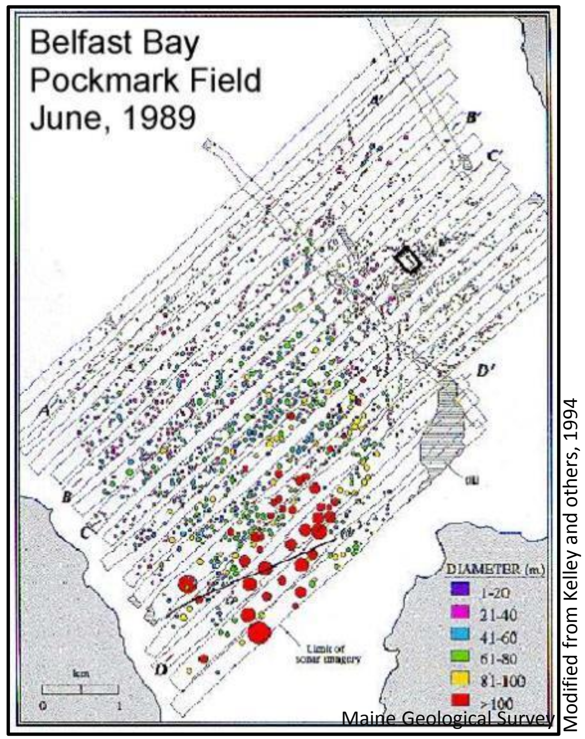


Figure 3. The Belfast Bay pockmark field as mapped by the Maine Geological Survey in 1989. The rectangles are areas observed by side-scan sonar. Land is in gray, with Islesboro Island on the lower right and mainland on the lower left. A-A', B-B', C-C', and D-D' refer to the location of bathymetric lines in Figure 4.

Pockmark Formation

Most pockmarks are found over petroleum fields where the methane, or natural gas (CH4), forms from the high temperature breakdown of oil. Off oil producing regions in Canada and in the North Sea, formation of pockmarks is a hazard to oil production platforms. As the natural gas is formed at depth (hundreds to thousands of feet down), its growing pressure causes it to rise through layers of sand and mud and erupt at the seabed, causing a crater on the seafloor. Pockmarks formed in this fashion are relatively small, however, and rarely exceed ten meters in depth and a hundred meters in diameter.

Pockmarks in Belfast Bay (also in Blue Hill Bay, Oak Bay and Eggemoggin Reach) have probably not formed from petroleum generation, however, because the rocks in the region are metamorphic and igneous rocks, that formed at temperatures and pressures too high for oil and gas to exist. The pockmarks of Belfast Bay appear to have formed relatively recently from the production of methane in mud of Holocene age, or younger than 10,000 years before present. Methane is produced in modern mud by the bacterial breakdown of organic matter, or the carbon-rich remains of formerly living things. Such methane production is not unusual; what is unusual is the size of the pockmark field caused by gas escape.

Belfast Bay Side-scan Sonar

Using side-scan sonar (Figure 4), the Maine Geological Survey mapped the Belfast Bay area and documented the presence of more than 2,000 pockmarks (Figure 3). The device sends out pulses of acoustic energy to either side as it is towed behind a boat. An on-board computer records the echos returned from the seabed and forms a black and white image, on a special roll of paper, of the seafloor up to 100 m to either side of the boat. The vessel may travel up to ten knots while gathering the data.

Photo by Maine Geological Survey

Figure 4. The side-scan sonar towfish that made the images for the map.

Pockmarks

The pockmarks, up to 350 m in diameter and 50 m deep, are possibly the largest in the world (Kelley and others, 1994). Their occurrence dominates the bay's bathymetry, with small pockmarks inshore, and increasingly larger features in a seaward direction (Figure 5).

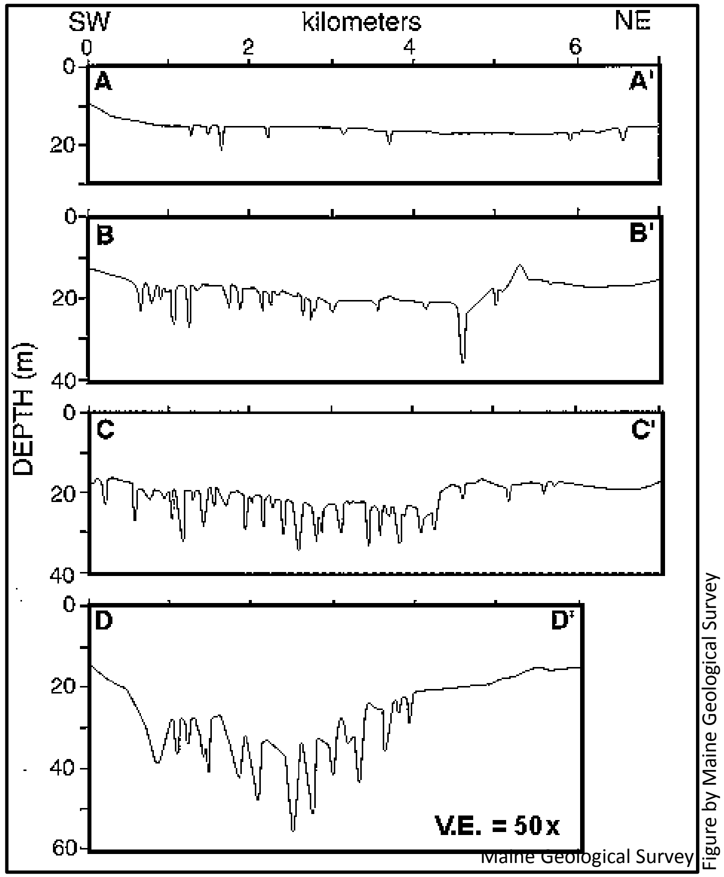


Figure 5. Fathometer traces gathered while collecting the side-scan sonar information from lines indicated on Figure 3.

Pockmarks

In some areas (the north-central part of the bay), the pockmarks occur in lines hundreds of meters long (refer to Figure 3). Many of the pockmarks have acoustically dark (reflective) "eyes" or central areas of uncertain origin. The side walls of the pockmarks have an average slope of 27 degrees, which is very steep for modern mud. The steepness and the lack of infilling of the depressions at the mouth of the Penobscot River, suggests that gas escape occurs frequently and maintains the field. During earlier work (Kelley and others, 1994) and again in 1997 while developing a more detailed seafloor map of Penobscot Bay, the Maine Geological Survey observed pockmarks while they were erupting. During an eruption, the water turned brown with mud, and the seabed was obscured from side-scan sonar observations, although no gas bubbles were seen at the surface. Seismic reflection profiles provide the primary evidence that escaping gas forms the features.

Natural Gas

Natural gas does not allow penetration by acoustic waves and the only places where seismic observations penetrate through to the bedrock beneath Belfast Bay are where there is no gas and where, coincidently, a pockmark occurs (Figure 6). The excellent layering and general lack of organic matter in glacial-marine sediment suggests gas does not come from that material. The failure of pockmarks to penetrate glacial-marine sediment also suggests that that material, which is denser and, hence, more acoustically reflective than Holocene mud, may be causing the dark "eyes" seen at the bottom of some pockmarks.

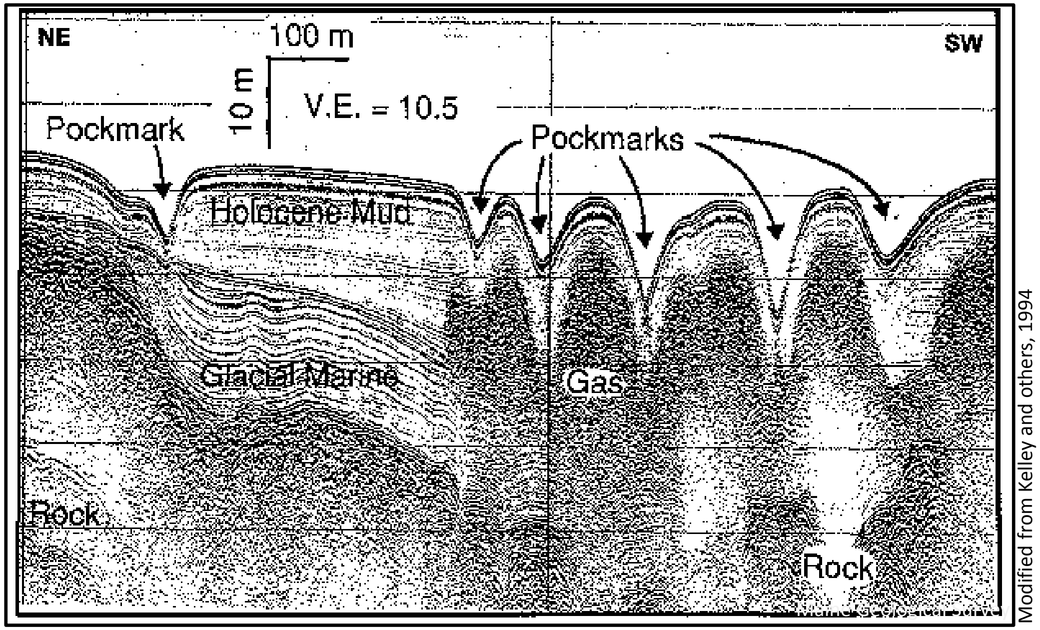


Figure 6. Seismic reflection profile from the Belfast Bay. Glacial-marine material is well layered and occurs on land as eroding bluffs visible along the coast. Its upper surface is a dark reflector formed as the bluffs erode, and is covered by Holocene mud. Natural gas obscures the acoustic signal, but is absent where gas has escaped and a pockmark is seen.

Natural Gas

Though gas escape maintains the present pockmark field, the way that the features originally formed remains unknown. Gas is known from many other bays in Maine (Kelley and others, 1989) and elsewhere, but pockmarks are found in only a handful of places (Barnhardt and Kelley, 1995). One model for pockmark formation suggests that a catastrophic event, an earthquake or a tsunami, generated the pockmarks by shaking normal, gas-rich muddy sediment (Figure 7).

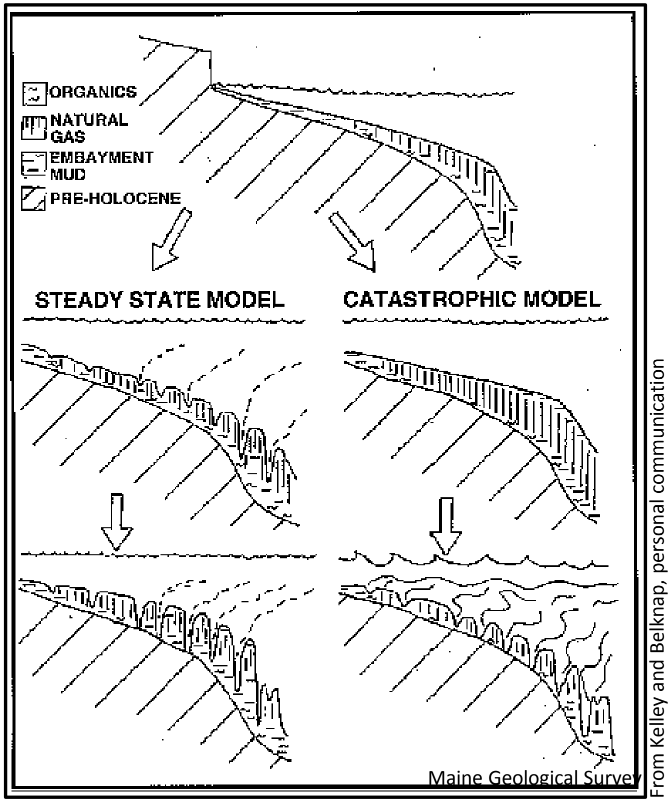


Figure 7. Models of pockmark formation.

Future Work

If true, this model suggests that pockmark locations might tell us where geo-hazards exist along the coast. An alternative model suggests that pockmarks evolve slowly during the ordinary evolution of a muddy bay. In this scenario, sea level rises and erodes glacial-marine bluffs along the coast. As modern mud covers the drowning glacial-marine surface, bacteria consume organic matter in the modern mud and generate gas. After a long time, gas pressure exceeds the strength of the sediment and erupts, causing a pockmark. More gas migrates to this hole and maintains it, as younger pockmarks continue to form in more landward locations. This would explain the observation that larger pockmarks occur in deeper water; they are older and have had more time to grow. It also suggests that more mapping will uncover more fields, a prediction that is becoming true as mapping continues in Penobscot Bay. The ultimate source of the organic matter will remain unknown until samples of the gas can be analyzed for age and isotopic composition and compared to gas from known sources.

References and Additional Information

Barnhardt, W. A., and Kelley, J. T., 1995, Carbonate accumulation on the inner continental shelf of Maine: a modern consequence of late Quaternary glaciation and sea level change: Journal of Sedimentary Research, v. A65, p. 195-207.

Kelley, J. T., Belknap, D. F., Shipp, R. C., and Miller, S. B., 1989, An investigation of neotectonic activity in coastal Maine by seismic reflection methods, in Anderson, W.A., and Borns, H.W. Jr. (editors), Neotectonics of Maine: Studies in seismicity, crustal warping, and sea-level change: Maine Geological Survey, Bulletin 40, p. 157-204.

Kelley, J. T., Dickson, S. M., Belknap, D. F., Barnhardt, W. A., and Henderson, M., 1994, Giant seabed pockmarks: evidence for gas escape from Belfast Bay, Maine: Geology, v. 22, p. 59-62.

Scanlon, K., and Knebel, H. J., 1989, Pockmarks in the floor of Penobscot Bay, Maine: Geo-Marine Letters, v. 9, p. 53-58.