Seafloor Features and Characteristics of the Black Ledges Area, Penobscot Bay, Maine, USA.

Authors: Gontz, Allen M., Belknap, Daniel F., and Kelley, Joseph T.

Source: Journal of Coastal Research, 36(sp1) : 333-339

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/1551-5036-36.sp1.333

Journal of Coastal Research	SI 36	333-339	(ICS 2002 Proceedings)	Northern Ireland	ISSN 0749-0208

Seafloor Features and Characteristics of the Black Ledges Area, Penobscot Bay, Maine, USA.

Allen M. Gontz, Daniel F. Belknap and Joseph T. Kelley

Department of Geological Sciences,
111 Bryand Global Science Center,
University of Maine, Orono, Maine, USA04469-5790.
allen.gontz@umit.maine.edu, belknap@maine.edu, jtkelley@maine.edu

ABSTRACT

The Black Ledges, a series of islands, shoals, and ledges in East Penobscot Bay, Maine, was mapped with digital sidescan sonar and shallow marine seismic reflection equipmentA total of 38 km^2 of sidescan and 600 km of seismic data was collected during four cruises in 2000-2001. The sidescan sonar reveals a surficial geology dominated by muddy sediments with frequent, patchy outcrops of gravel and minor amounts of bedrock. There are seven large concentrations of pockmarks with populations totaling over 3500 in the areas of muddy sediments. Generally circular, pockmarks range in size from five to 75 meters in diameter and up to eight meters deep. Calculations show over 2 x 10^6 m^3 of muddy sediment and pore water were removed from the system during pockmark formation. Seismic data reveal a simple stratigraphy of modern mud overlying late Pleistocene glaciomarine sediment, till and Paleozoic bedrock. Seismic data indicate areas of gas-rich sediments and gas-enhanced reflectors in close association with pockmarks, suggesting methane seepage as a cause of pockmark formation. Pockmarks are alsorecognized in areas lacking evidence of subsurface methane accumulations adding further validity to the late stage of development for the field. Elliptical pockmarks, found in nearly 40 m of water, show modification by currents and degradation of the pockmark form. This suggests depletion of methane and a late stage of development. A more intensive investigation of the area, including coring and high-resolution geophysics is currently in progress.

ADDITIONALINDEXWORDS: *Pockmarks, sidescan sonar*

INTRODUCTION

Habitat mapping is currently an area of intense focus by the United States Geological Survey, National Oceanic and Atmospheric Association's National Marine Fisheries Service, and state-level equivalents. In order to properly assess seafloor habitat, knowledge of the surficial geology is essential. Geophysical tools such as sidescan sonar and shallow seismic reflection profiling permit the necessary observations.

Penobscot Bay, a large, productive estuary in the Gulf of Maine has been a focus area for such mapping (Figure 1). Previous studies in Penobscot Bay, specifically the sub-embayment of Belfast Bay, have revealed a dynamic seafloor environment dominated by football stadium-sized features known as pockmarks. KING and MACLEAN (1970) first described these features on the Scotian Shelf. They are believed to form from pressurized pore fluid escape (HOVLAND and JUDD, 1988). While these features are best studied in one part of Penobscot Bay, they also occur throughout the region (BARNHARDT and KELLEY, 1995; FADER 1991).

Pockmarks release methane into the water column and potentially into the atmosphere. Methane is a potent greenhouse gas. It traps infrared radiation up to 21 times more readily than carbon dioxide (LAMMERS *et a*l., 1995). Not only does this release have the potential to alter the global climate system, but it also provides a readily available source of labile carbon for biological activity. The contribution of the marine system to the global carbon cycle is unquantified (LAMMERS *et al*., 1995). Clearly, a better understanding of these features, the relationships between biological and physical processes, and their effects on the marine system is needed.

The Black Ledges area, the focus of this study, is also within Penobscot Bay, but sufficiently removed from Belfast Bay (Figure 1) to be influenced by different water masses and current regimes (XUE *et al*., 1999). Workers from the Maine Geological Survey and the Department of Geological Sciences at the University of Maine collected several reconnaissance lines in the area between 1984 and 1999. These few lines showed a potential for pockmarks and prompted a more intensive investigation.

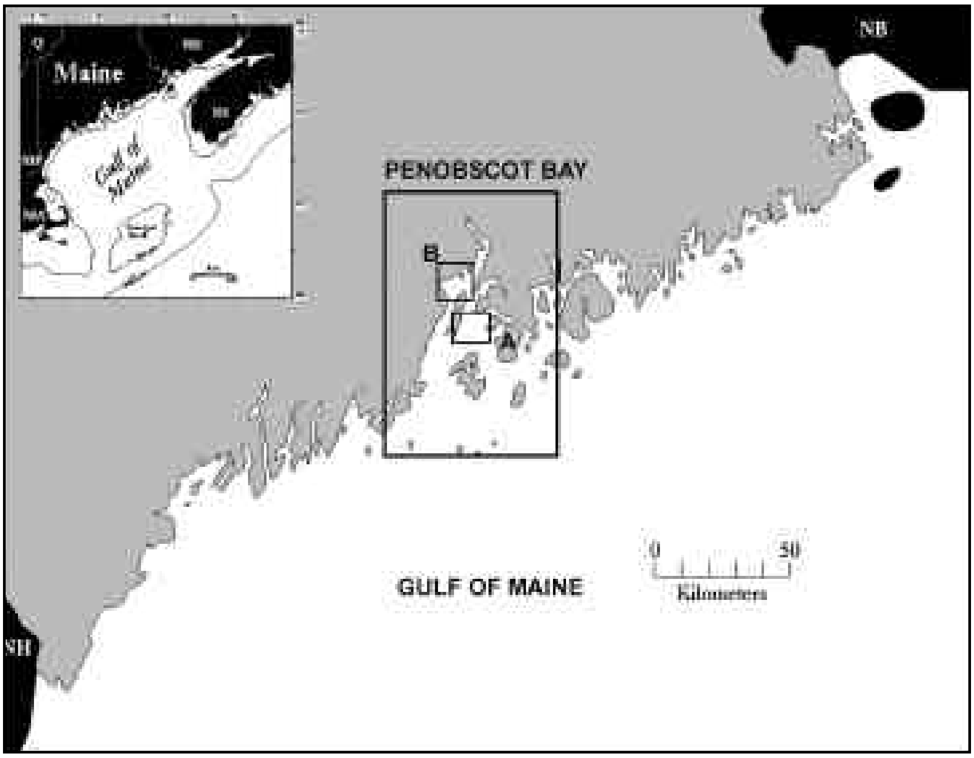

Figure 1. Location of Penobscot Bay. The large box in the center of the figure locates Penobscot Bay. The inset map shows the location of Maine's coast within the Gulf of Maine region. Penobscot Bay is the largest estuary along Maine's coast. Box A shows location of the Black Ledges area, the focus of this study and Box B shows the location of Belfast Bay, which also hosts pockmarks. NH is New Hampshire, NB is New Brunswick, Canada.

This paper reports on the first portion of a major research effort focused on shallow-water, estuarine pockmarks. This portion involves baseline surficial and subsurface mapping of a pockmarked area and the surrounding seafloor to identify features and characteristics of the area. The ultimate goal is to determine the source of methane, the origin and age of the source materials, their role in sea-level changes, potential mechanisms for formation, life cycles, effect on the global climate system, and effects on sedimentation and seafloor habitat. In this report we present new data from a series of newly discovered pockmark fields. More importantly, we develop evidence for a model of pockmark evolution, including, for the first time, the late stages of development and senescence.

METHODS

The seafloor was mapped with sidescan sonar and shallow seismic reflection profiling equipment during four daylong cruises, three in August 2000 and one in January 2001, in the Black Ledges area. The two systems, an Edgetech DF1000 digital, dual-frequency sidescan sonar towfish and a surface-towed boomer seismic system (Ocean Research Engineering's analog GeoPulse during August 2000 and Applied Acoustics Engineering's digital system in later cruises), were towed simultaneously. Sidescan sonar data were collected at 100kHz and 500kHz and seismic data were collected at 700-2000 Hz. A Triton-Elics International topside processing unit was used to acquire and post-process the data for both digital systems.

Sidescan data were collected and processed with Isis Sonar v4.54 and Delph Map. All data were slant-range corrected. Digital seismic data were collected and processed with Delph Seismic and Seismic GIS. Analog seismic data were analyzed without computer technology. Surficial and subsurface mapping and spatial analysis were conducted with ArcView and ArcInfo geographic information systems software. Navigation was supplied via differential global positioning system and converted to Universal Transverse Mercator projection for use. The Capn, a digital navigation package produced by Nautical Technologies, was used for cruise planning, cruise navigation, autopilot interface, and 30-second position logging.

The shallow water (<40 m) allowed for collection of sidescan data at 100 m range. The fish was towed about four to six meters deep at between four and six knots.

RESULTS

A total of 38 km2 of seafloor was imaged with sidescan sonar and over 600 km of seismic data were collected during four cruises. A complete sidescan sonar mosaic was created for the area (Figure 2).

A stratigraphic framework of Penobscot Bay was developed from seismic data and supported with sediment cores. (BARNHARDT *et al.*, 1997; BELKNAP and SHIPP, 1991; KNEBEL and SCANLON, 1985). Seismic records show acoustic basement as bedrock, overlain by till, glaciomarine sediments, capped with Holocene mud. Till was not present in all locations and was thickest on southeastern slopes. Two major unconformities, the basal erosional unconformity created during a sea-level lowstand, and the ravinement unconformity formed during the latest transgression, truncate the glaciomarine sediments (BARNHARDT *et al.*, 1997; BELKNAPand SHIPP, 1991).

Natural gas, methane, is found within the section at many places. It occurs as areas of large-scale acoustic wipeout or gas-enhanced reflectors (Figure 4) (YUAN *et al.*, 1992; FLOODGATE and JUDD, 1992; FADER, 1991). Stratigraphically, the methane occurs within the Holocene muds or along the Holocene-Pleistocene unconformity. Pockmarks have been observed over areas of acoustic wipeout and gas-enhanced reflectors and both indicators of methane have been observed without associated pockmarks. The enhanced reflectors suggest methane is migrating along the unconformity. Methane is hypothesized to be the fluid involved in pockmark formation (KELLEY *et al*., 1994).

The degree of backscatter from the sidescan data was interpreted as a proxy for bottom sediment type. Areas of high backscatter, such as gravel and rock, appear dark gray to black while areas of low backscatter, such as mud, appear light gray to white. The surficial sediment type was mapped following a sixteen-part scheme with four end members of mud, sand, gravel, and rock and 12 intermediates (BARNHARDT *et al*., 1996; 1998).

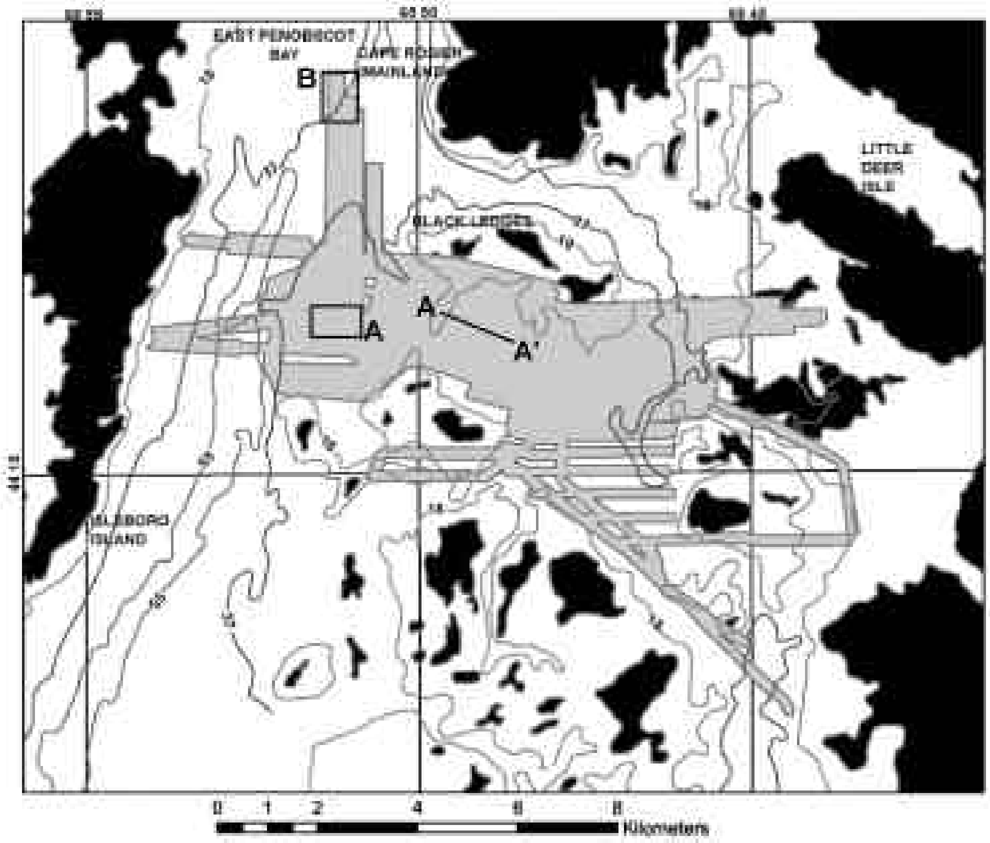

Figure 2. Detailed map of the Black Ledges area. The outlined area shows the limits of sidescan sonar coverage detailed in Figure 4. Shaded polygons within the limits of sidescan coverage represent the seven pockmark fields. Line A-A' is seismic line PB01-26 used in Figure 3. Box A is the location of sidescan sonar data for Figure 5. Box B is the location of sidescan sonar data for Figure 6.

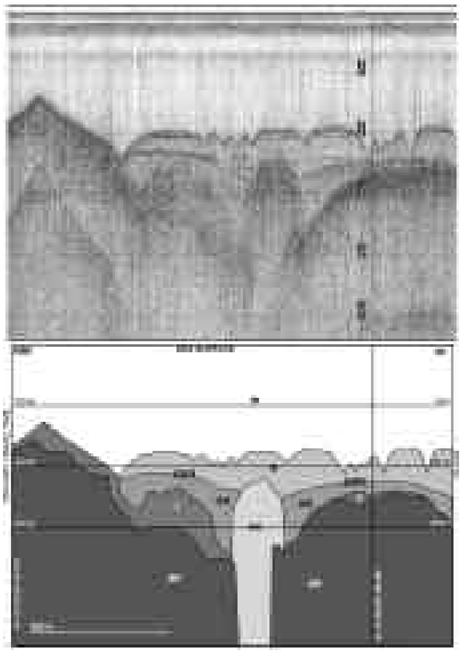

Figure 3. Seismic line A-A'. Location of seismic line is shown in Figure 2. Upper panel shows uninterpreted data, lower panel is interpreted. Gas-enhanced reflectors (GER) originate from large areas of acoustic wipeout (NG) suggesting migration along the reflector. Pockmarks, depressions on the seafloor, (PM) occur directly over NG and GER. Other units include till (T), bedrock (BR), glaciomarine (GM) and Holocene mud (M). VE=14x.

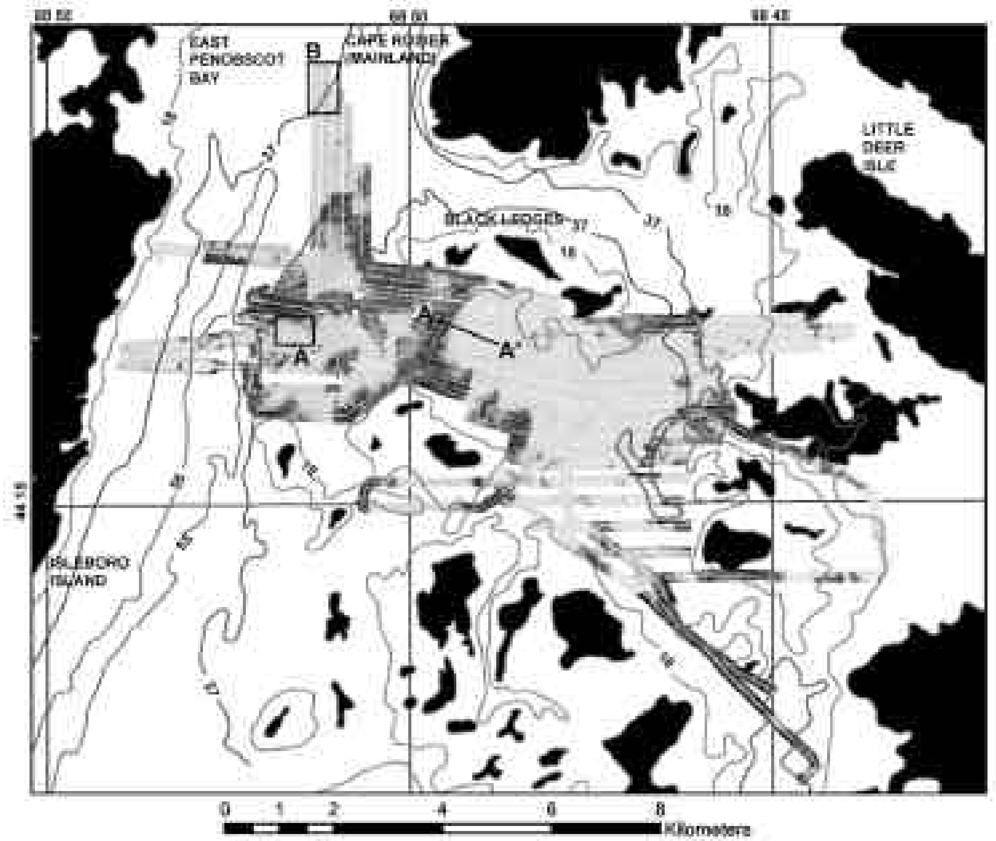

Figure 4. Sidescan sonar mosaic of the Black Ledges area. A mosaic was created from 38 km2 of sidescan sonar data. Light areas, low backscatter, are interpreted as fine-grained sediments (muds) and dark areas, high backscatter, are interpreted as hard surfaces (rock and gravel). Pockmarks are associated with fine-grained, low backscatter areas. Box A locates Figure 5 and Box B locates Figure 6.

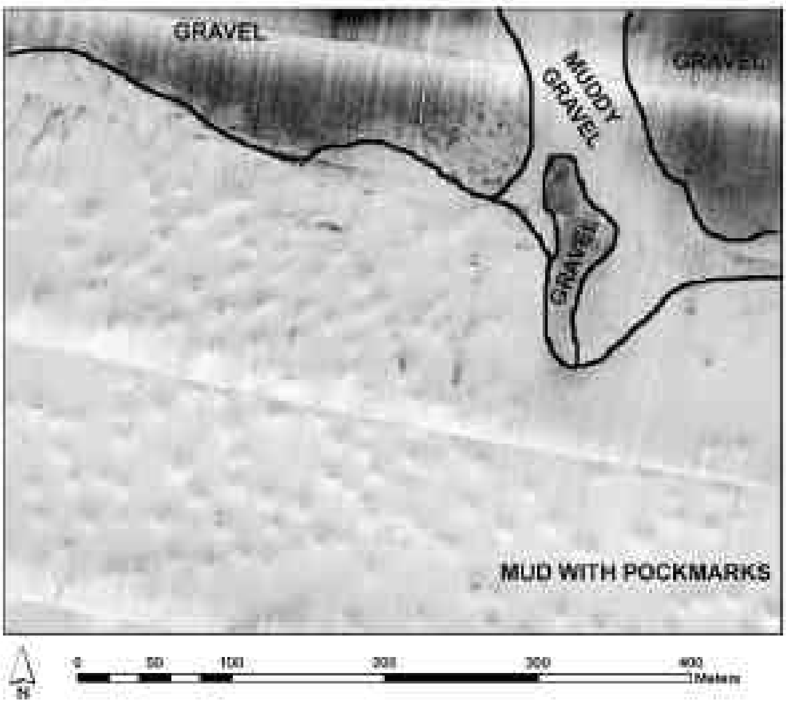

Figure 5. Circular Pockmarks of the Black Ledges. Pockmarks, generally circular in form occur in large concentrations around the Black Ledges. The circular form indicates the pockmarks are active. Refer to Figure 4 for location.

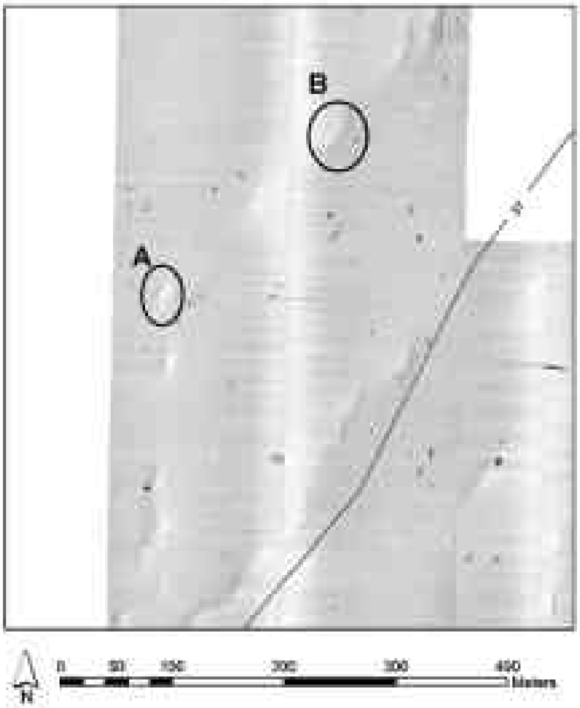

Figure 6. Elliptical pockmarks of the Black Ledges. Elliptical pockmarks indicate that the processes that form and maintain pockmarks (gas-escape) are no longer the dominant processes. The elliptical shape likely arises from scouring by currents. These pockmarks are orientated 045° (true) azimuth and occur sub-parallel to the 37 m isobath. They are only found deeper than the 37 m isobath. Elliptical pockmarks represent a previously unrecognized late stage of development.

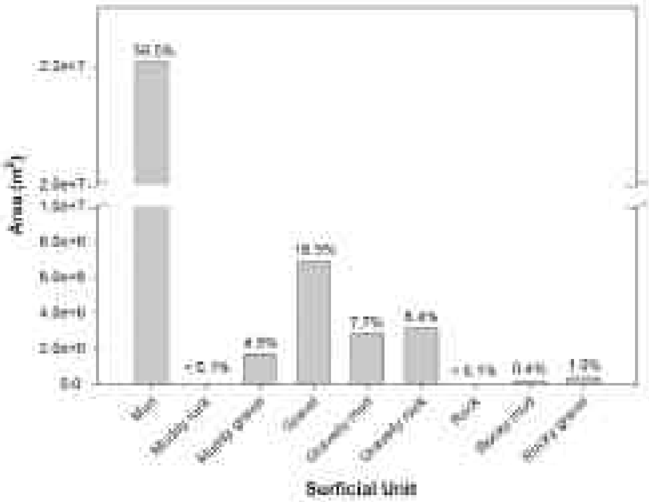

Figure 7. Distribution of surficial units in the Black Ledges. The sidescan sonar mosaic was interpreted for surficial geology. A 16-unit classification scheme was used (BARNHARDT *et al.*, 1998). The area is clearly dominated by muddy units with subordinate gravel units. Rock units are unimportant and sandy units were not observed at the mapping scale.

The majority of the area is covered with mud-dominated classes (about 64%). Gravel (35%) and rock (1%) cover the remainder of the seafloor. Sand is not present at this map scale (Figure 5).

Sidescan sonar images reveal seven large concentrations of pockmarks (Figure 6). The seven fields contain 3528 pockmarks ranging in size from five to 75 meters in diameter and up to eight meters deep (Figure 7). Pockmarks are only associated with muddy sediments. Rough calculations based on a method developed by ROGERS (1999) suggest that over 2.10×10^6 m^3 of seafloor muddy sediment and pore water were removed.

Pockmarks in all but one field appear unmodified by currents or slumping. Features in the northern most area mapped appear elliptical with their long axis orientated at about 045° and sub-parallel to the 37 m contour (Figure 6). All of these features occur deeper than the 37 m contour.

DISCUSSION

BARNHARDT *et al.* (1996) initially interpreted the Black Ledges as a mud and rock-dominated system. Their interpretation was produced from bathymetric analysis and only a few survey lines in the area. New data presented in this study confirms their interpretation of a mud-dominated seafloor, but does not identify rock as a major surficial unit. Our data show that mud covers 64% and gravel 35% of the area; rock crops out on only 1% of the study area.

Pockmarks occur in other regions of Penobscot Bay, most notably in Belfast Bay (ROGERS, 1999; KELLEY *et al.*, 1994; KNEBEL and SCANLON, 1985). These features are attributed to methane escape from the seafloor. Seismic lines from the area show shallow subsurface acoustic masking and gas-enhanced reflectors originating in large areas of acoustic wipeout in close proximity to pockmarks, suggesting that methane is the fluid for pockmark excavation. Pockmarks frequently occur over gas-enhanced reflectors, suggesting methane is migrating from areas of acoustic wipeout. The pockmarks are only observed in muddy sediments. Other researchers (e. g. FADER, 1991; HOVLAND and JUDD, 1988) have presented data suggesting fine-grained sediments are needed to trap migrating methane to allow a pressurized reservoir to develop. An analysis of captured in situ pore fluids confirms methane is the gas (H. A. CHRISTIAN, personal communication, 2000).

The occurrence of elliptical pockmarks suggests subsequent modification by current activity. The elliptical nature also suggests that current activity is more important in the development of the form of these pockmarks than methane escape. This is validated by the present lack of methane (acoustic masking and gas-enhanced reflectors) imaged with seismic devices in the vicinity of the elliptical pockmarks. This implies that the reservoir of natural gas, or the generation potential of organic-rich sediments is exhausted; seismic data from areas with circular pockmarks show larger numbers of gas-enhanced reflectors and large-scale acoustic wipeout. Seasonal variability in subsurface natural gas concentrations (MARTENS *et al.*, 1998) or alignment of survey lines are possible alternate explanations for the lack of gas in the area.

The sediments and stratigraphy of the entire area, which comprises thin Holocene sediments, gravel, and boulder lags developed on glaciomarine sediments suggests an overall erosive environment compared to one of sediment accumulation that characterizes pockmark formation in Belfast Bay. The pockmark formation and maintenance process accentuates the erosion of muddy sediments. Over 2×10^6 m^3 of muddy sediments and pore water were removed from the area by pockmark formation. Thus, pockmarks are an effective method of redistributing sediments in estuaries. Data from other regions of Penobscot Bay show that the seafloor can be resurface in less than two years, filling depressions upwards of 25 m in diameter and five meters deep, in areas with pockmarks (GONTZ, 2001).

CONCLUSIONS

The Black Ledges area is a mud-dominated system that hosts seven major pockmark fields. In one of these fields, the pockmarks are elliptical in form, suggesting that current action has replaced methane venting as the major pockmark-related process. This and the rest of the pockmark fields occur in thin Holocene sediments with few zones of large-scale acoustic wipeout and gas-enhanced reflectors. This suggests the subsurface methane supply is depleting or is exhausted. Both of these observations point to a previously unrecognized late stage of pockmark field evolution. This is in great contrast to pockmark systems recognized in other estuaries which show large amounts of gas-charged sediments and pockmarks (KELLEY *et al.*, 1995; FADER, 1991; HOVLAND and JUDD, 1988).

The volume of gas is unknown at this time. Future research is aimed at determining the source of methane, the age and depositional environment of the source material, and the potential for methane generation. In addition, the flux of methane from estuarine pockmarks to the water column and atmosphere will be investigated.

ACKNOWLEDGEMENTS

We acknowledge Maine Sea Grant (R/CE-235), National Science Foundation (OCE-9977367), and the National Oceanic and Atmospheric Association (shiptime support) are acknowledged for supporting this research. We thank Tony Codega, captain of the RV Friendship, for hours at sea and his willingness to lend a hand when needed. Colleagues at the University of Maine and Maine Geological Survey also assisted with field and lab work.

LITERATURE CITED

BARNHARDT, W. A. and KELLEY, J. T., 1995. Carbonate accumulation on the inner continental shelf of Maine: a consequence of later Quaternary glaciation and sea-level change. *Journal of Sedimentary Research*, A65, 1, 195-207.

BARNHARDT, W. A., BELKNAP, D. F., and KELLEY, J. T., 1997. Stratigraphic evolution of the inner continental shelf in response to late Quaternary relative sea-level change, northwest Gulf of Maine. *Geological Society of America Bulletin*, 109, 5, 612-630.

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: Rockland to Bar Harbor, *Maine Geological Survey, Geologic Map* 96-10, scale 1:100,000. Augusta, Maine.

BARNHARDT, W. A., KELLEY, J. T., DICKSON, S. M., and BELKNAP, D. F., 1998. Mapping the Gulf of Maine with Sidescan Sonar: a complex new bottom-type classification for complex seafloors. *Journal of Coastal Research*, 14, 2, 646-659.

BELKNAP, D. F. and SHIPP, R. C., 1991. Seismic stratigraphy of glacial-marine units, Maine inner shelf. In J. B. ANDERSON and G. M. ASHLEY (eds.), *Glacial-Marine Sedimentation: Paleoclimactic Significance*, Geological Society of America Special Paper 261, 137-157.

FADER, G. B. J., 1991. Gas-related sedimentary features from the eastern Canadian continental shelf. *Continental Shelf Research*, 11, 8-10, 1123-1153.

FLOODGATE, G. D. and JUDD, A. G., 1992. Origins of shallow gas. *Continental Shelf Research*, 12, 10, 1145-1156.

GONTZ, 2001. *Evolution of Seabed Pockmarks in Penobscot Bay, Maine.* Unpublished Masters Thesis, University of Maine, Orono, Maine, 91pp.

HOVLAND M. A. and JUDD, A.G., 1988. *Seabed Pockmarks and Seepages*. Graham and Trotman, London, 144p.

KELLEY, J. T., DICKSON, S. D., BELKNAP, D. F., BARNHARDT, W. A., and HENDERSON, M., 1994. Giant sea-bed pockmarks: evidence for gas escape from Belfast Bay, Maine. *Geology*, 22, 59-62.

KING, L. H. and MACLEAN, B., 1970. Pockmarks on the Scotian Shelf. *Geological Society of America Bulletin*, 81, 3141-3148.

KNEBEL, H. J. and SCANLON, K. M., 1985. Sedimentary framework of Penobscot Bay, Maine. *Marine Geology*, 65, 305-324.

LAMMERS, S., SUESS, E., and HOVLAND, M., 1995. A large methane plume east of Bear Island (Barents Sea): implications for the marine methane cycle. *Geol Rundsch*, 84, 59-66.

MARTENS, C. S., ALBERT, D.B., and ALPERIN, M. J., M. J., 1999. Biogeochemical processes controlling methane in gassy coastal sediments – part 1 a model coupling organic matter flux to gas production, oxidation and transport. *Continental Shelf Research*, 18, 1741-1770.

ROGERS, 1999. *Mapping of Subaqueos, Gas-Related Pockmarks in Belfast Bay, Maine Using GIS and Remote Sensing Techniques*, Unpublished Masters Thesis, University of Maine, Orono, Maine, 139pp.

XUE, H., XU, Y., BRROKS, D., PETTIGREW, N., and WALLINGA, J., 1999. Modelling the circulation in Penobscot Bay, Maine. Estuarine and Coastal Modeling *Proceedings of the Conference of American Society of Civil Engineers*, 1112-1127.

YUAN, F., BENNELL, J. D., and DAVIS, A. M., 1992. Acoustic and physical characteristics of gassy sediments in the western Irish Sea. *Continental Shelf Research*, 12, 10, 1121-1134.