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Shallow-water pockmark formation in temperate estuaries: A consideration of origins in the western gulf of Maine with special focus on Belfast Bay

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Abstract

A systematic mapping program incorporating more than 5000 km of side scan sonar and seismic reflection tracklines in the western Gulf of Maine has identified more than 70 biogenic natural gas deposits, occupying 311 km^2 in nearshore muddy embayments. Many of these embayments also contain pockmark fields, with some exhibiting geologically active characteristics including the observance of plumes of escaping fluids and sediment. Pockmarks, hemispherically shaped depressions of various size and depths, formed through fluid escape of gas and/or pore water, are sometimes found within or outside gas fields, although many gas fields lack pockmarks altogether. Although the origin of the natural gas remains unclear, if coastal environments at times of lower sea level were similar to the present, numerous lake, wetland, valley fill and estuarine sources of organic-rich material may have formed on the inner shelf. If these deposits survived transgression and remain buried, they are potential gas sources.

Intensive mapping of the Belfast Bay pockmark field in 1998 produced the first nearly continuous side scan sonar mosaic of a Gulf of Maine pockmark field with a corresponding 3-dimensional geological model generated from seismic data. Statistical analysis of pockmark geometry, gas deposit loci, and subsurface evidence for gas-enhanced reflectors suggest that gas migration from deeper lateral sources along permeable subsurface strata may be the mechanism for pockmark formation in areas lacking gas-curtain seismic reflections. The coarse-grained transgressive ravinement unconformity between Pleistocene glacial-marine mud and Holocene mud may act as a conduit for distributing methane to the field's margins.

Keywords: methane; Belfast Bay; Maine; Quaternary; marine mud; sea-level change

1. Introduction

Pockmarks were first described as "concave, crater-like depressions that occur in profusion on mud bottoms across the Scotian Shelf" (King and MacLean, 1970, p. 3141). They reach diameters of hundreds of meters and depths of tens of meters. Pockmarks are recognized in a variety of continental margin settings

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all over the world (Hovland and Judd, 1988). Pockmark fields are commonly found near deltas (Nelson et al., 1979) and areas of petroleum production (Hovland et al., 1987, Uchupi et al., 1996), or tectonic activity (Field et al., 1982; Hasiotis et al., 1996; Vogt et al., 1994). Shelf basins (Fader, 1991; Josenhans et al., 1978; McClennen, 1989), continental slopes and rises (Orange et al., 1999; Paull et al., 2002) also host fields of pockmarks. In all these locations, fluid escape is invoked as the forcing mechanism for pockmark formation. Thermogenic and biogenic natural gas from petroleum occurrences, organic-rich sedimentary deposits and methane hydrates are probable sources for the fluids and buoyancy required to form pockmarks, although escaping groundwater (Whiticar, 2002) and other more exotic mechanisms (ice rafting, Paull et al., 1999; meteorites, Nelson et al., 1979) have been suggested as causative agents.

Pockmarks are also widespread in mid-latitude estuaries (Fleischer et al., 2001; Missiaen et al., 2002; Garcia-Gil et al., 2002; Ussler et al., 2003), especially in formerly glaciated regions (Scanlon and Knebel, 1989; Barnhardt and Kelley, 1995; Kelley et al., 1994; Fader, 1991; Whiticar, 2002). Biogenic gas (Albert et al., 1998; Fader, 1991; Kelley et al., 1994; Wever et al., 1998), freshwater escape (Albert et al., 1998; Bussman and Suess, 1998; Whiticar, 2002); and ice rafting (Paull et al., 1999) were each invoked to explain the origin of pockmarks within geologically young sediments. In some locations in both shallow and deep water, pockmark fields apparently lacking measurable quantities of natural gas or escaping freshwater, were deemed "inactive" by Paull et al. (2002) and Ussler et al. (2003).

In discussions of pockmark origins it is essential to distinguish between the origin of the fluid(s) and the process by which the fluid(s) form and maintain a pockmark. In coastal Maine (Fig. 1) neither of these origins is established, and both thermogenic and biogenic gas have been postulated to exist (Fleischer et al., 2001). Acoustic wipeout zones, which indicate the presence of gas, are common in seismic reflection profiles of the northwestern Gulf of Maine, as are pockmarks (Belknap et al., 1986, 2002; Kelley et al., 1989b). However, a one-to-one correspondence between pockmarks and gas does not exist in coastal Maine because biogenic gas fields often lack pockmarks, and pockmarks without associated gas are also observed (Kelley et al., 1994; Gontz et al., 2002).

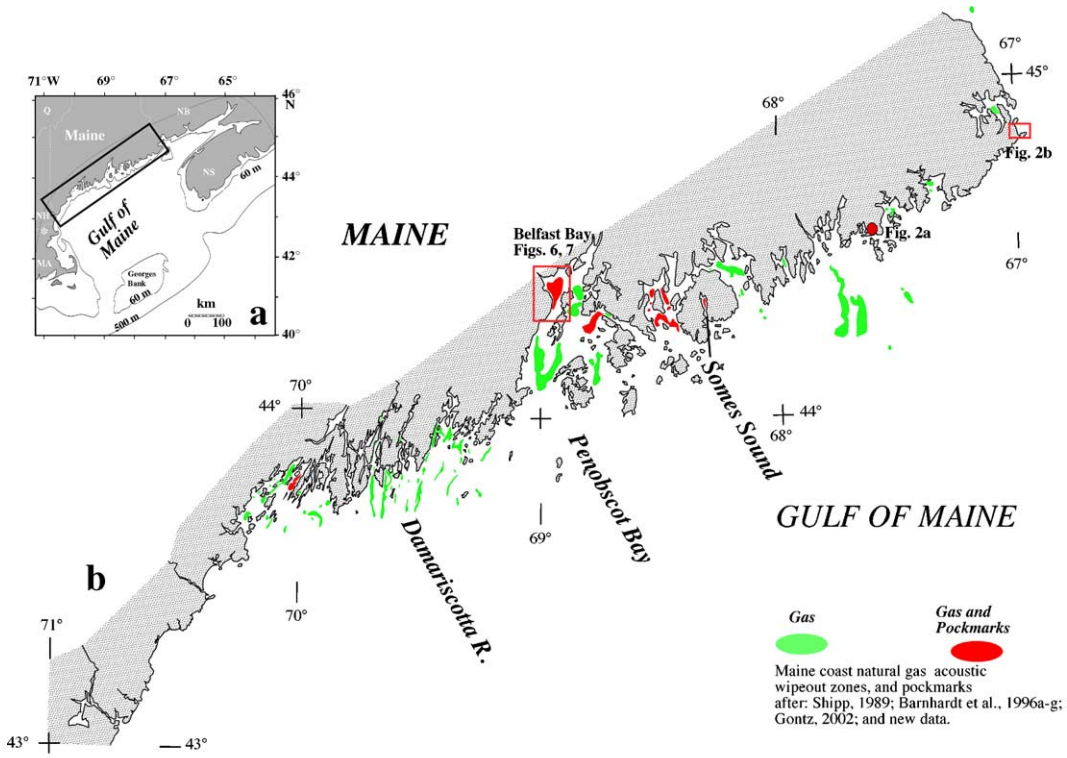

Fig. 1. The location of the study area in the western Gulf of Maine. Boxes locate other figures. (a) The area inside the box is enlarged in b; (b) the shoreline of the State of Maine with natural gas fields shaded green (gas only) and red (gas and pockmarks).