Geo-Marine Letters (1985) 5:193–197

Geo-Marine Letters

Formation of Pockmarks by Pore-Water Escape

P. K. Harrington

Gardline Surveys, Admiralty Road, Great Yarmouth, Norfolk, NR30 3NG United Kingdom

Abstract

During the course of a North Sea rig site investigation, a number of seabed depressions were observed on side-scan sonar records, some of which may be identified as pockmarks. Others are described as pits. A pockmark evolutionary series is proposed on the basis of all these features with a suggested mechanism which would favor release of pore water, but does not exclude gas escape. Acoustic voids are considered to be a related phenomenon.

Introduction

Pockmarks are seabed phenomena that have been found in a number of widely spread localities, notably the East Canadian continental shelf and the North Sea [1]. They are broad, circular depressions typically 30 to 40 m across by 2 or 3 m deep. Figure 1 shows examples on a seismic profiling (deep-towed boomer) record. Generally their distribution is semirandom. There is seldom any particular orientation or lineation except for a tendency to become slightly elliptical, apparently in response to current direction. Moreover, pockmarks are closely associated with silty and clay sediments bearing high water contents.

A number of explanations for pockmarks have been suggested. The most widely held explanation is that of seabed gas escape, whether from an *in situ* biogenic or a deep petrogenic source [1,2]. However, there is little to suggest from core samples that the host sediment contains abnormal quantities of organic material. Occasionally, evidence of gas-charged sediment is detected in pockmark areas (acoustic masking or blanking) but the distribution is not such as to suggest any close link with pockmarks. An alternative permafrost theory [1] is not convincing, because one would expect a single more or less synchronous pockmark episode leading to features of similar age and appearance. In the area described, this does not appear to be the case. Moreover, pockmarks have been reported from warmer climates where permafrost is unlikely to have been an important consideration [1]. Other explanations such as depth charges, meteorites, and fish scouring have been dismissed by King and Maclean [2], who also mention the possibility of water escape, as do Whiticar and Werner [3] in a much more recent paper from the Baltic Sea. The latter idea is pursued further.

Study Area

During the course of a routine 2 km square sonar and subbottom profiling survey in the central North Sea, a wide variety of seabed pits and depressions were identified. Some of these are clearly pockmarks as described by various authors [1,2]; others are not. The features have all been observed by the author singly or in combination elsewhere, and the assumption is now made that the full suite of features is genetically related. Furthermore, the possibility of a man-made origin can almost certainly be ruled out at the present site. The area is located within what is commonly termed a mud-hole. This is one of a series of deposits, occupying broad basins eroded into compact glacial or glaciomarine clay. Here the deposit consists of 10 to 30 m of poorly consolidated water-laid clayey sediments, termed Witch Ground Beds (Fig. 1). The British Geological Survey describe them as "very soft to firm, normally consolidated sandy and silty clays," identifiable seismically as "finely bedded acoustically transparent with numerous pockmarks, some of which are infilled" [4] (Fig. 1).

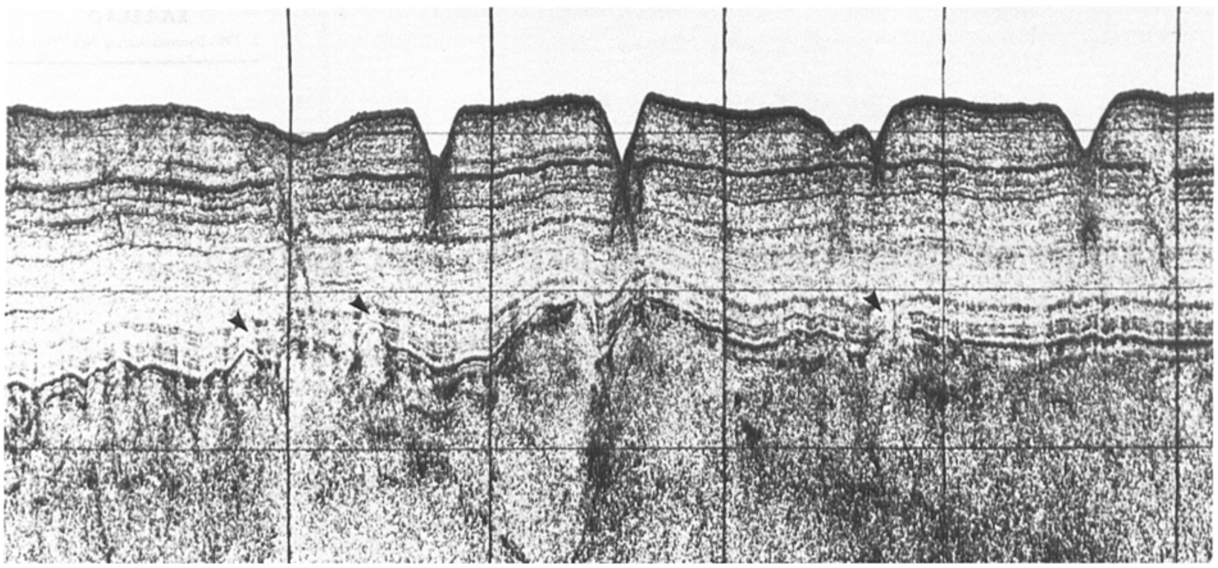

Figure 1. Boomer Record. Pockmarks at seabed and acoustic voids (**arrows**) at base of well layered (Witch Ground Beds) sequence. Scale lines are approximately 10 m vertically and approximately 150 m along track. Water depth is 135 m.

Description of Features

Four main types of features occur. Group 1 consists of pits (Fig. 2). These features are small, but very well-defined depressions, commonly 3 m across and at least 0.5 m deep. There is noticeable uniformity in size. Group 2 consists of pit clusters (Fig. 3). These features consist of a group of pits, individually indistinguishable from the Group 1 features. The cluster might cover an area 20 m across, somewhat less than

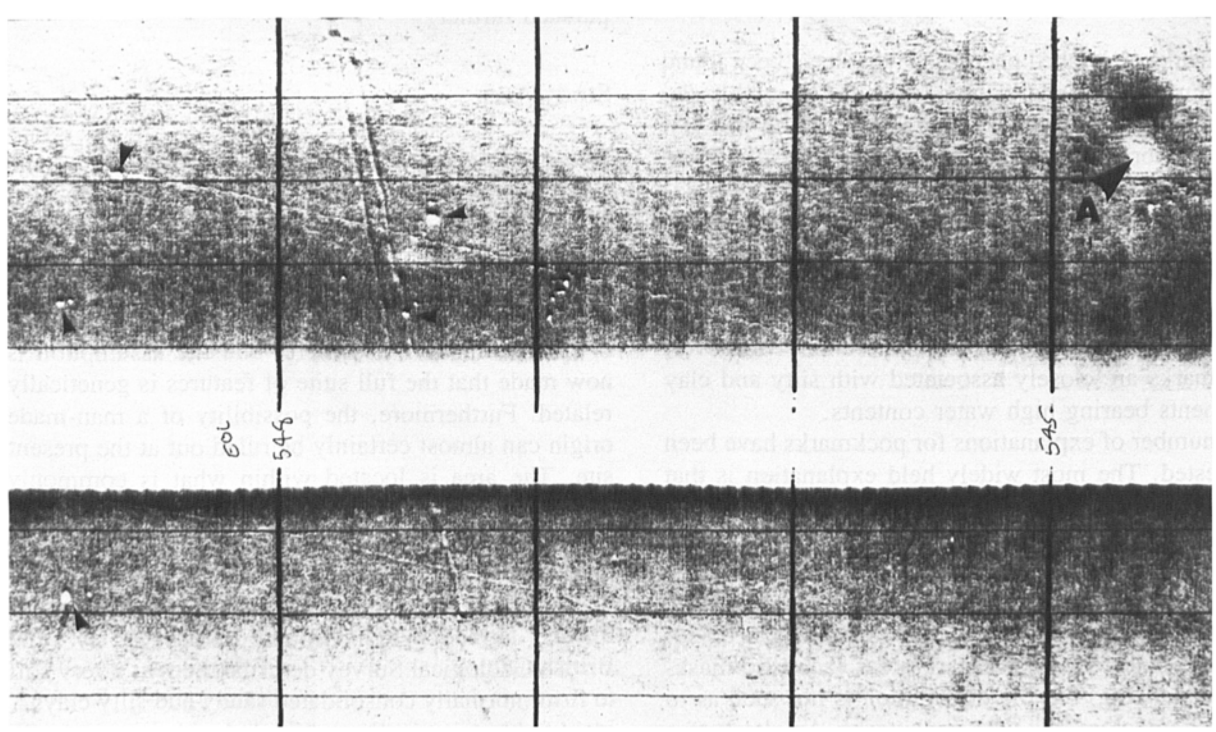

Figure 2. Sonar Record. Mature pockmark (**A**) and pits (**plain arrows**) including some positioned on drag marks. Scale lines are 25 m across and approximately 125 m along track. Water depth is 135 m.

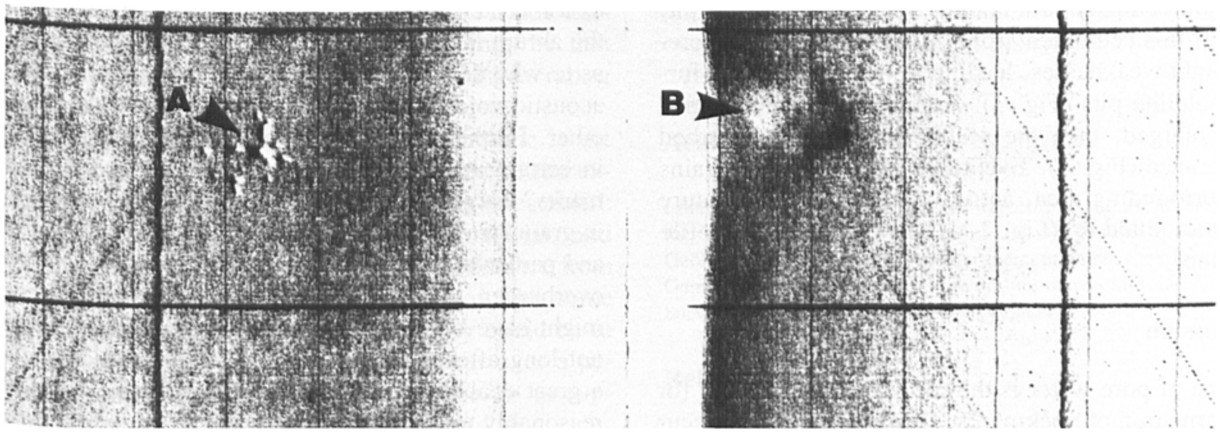

Figure 3. Sonar Record. Pit cluster (**A**) and mature pockmark (**B**). Scale lines are as in Figure 2. Water depth is 135 m.

that of a pockmark. Numerically this group is the least common. Group 3 is the disturbed seabed feature (Fig. 4). In overall size, this feature falls between a pockmark and a large pit cluster. Because the outer fringes are often made up of discrete pits, there would seem to be a clear genetic link with the pit cluster (Fig. 3). Pits are evidently the same features described as unit pockmarks by Hovland and others [1]. Group 4 consists of pockmarks (Fig. 2–4). The examples at this site appear to be particularly broad and shallow, giving every impression that activity has ceased. A typical diameter would be 30 to 40 m, and most probably not more than 1 or 2 m deep. Note that in Figures 2 and 4, examples of pits and mature pockmarks occur, emphasizing the possibility of a common origin.

Proposed Mechanism

Let us first suppose that pore water is trapped within soft cohesive (silt or clay) sediment accumulating on the seabed. Pressure builds and is eventually released at specific points, perhaps triggered by external factors such as earth tremors. Pore water is expelled and sediment disturbed, similar to the method of a mud-volcano. Even if a pit does not form immediately, this allows winnowing to take place so that grain size increases locally with a corresponding increase in permeability. Water could then drain laterally into a sink, especially along the more porous layers, so that water expulsion becomes concentrated at a point. Once a pit has formed (Fig. 2), continued expulsion of water leads

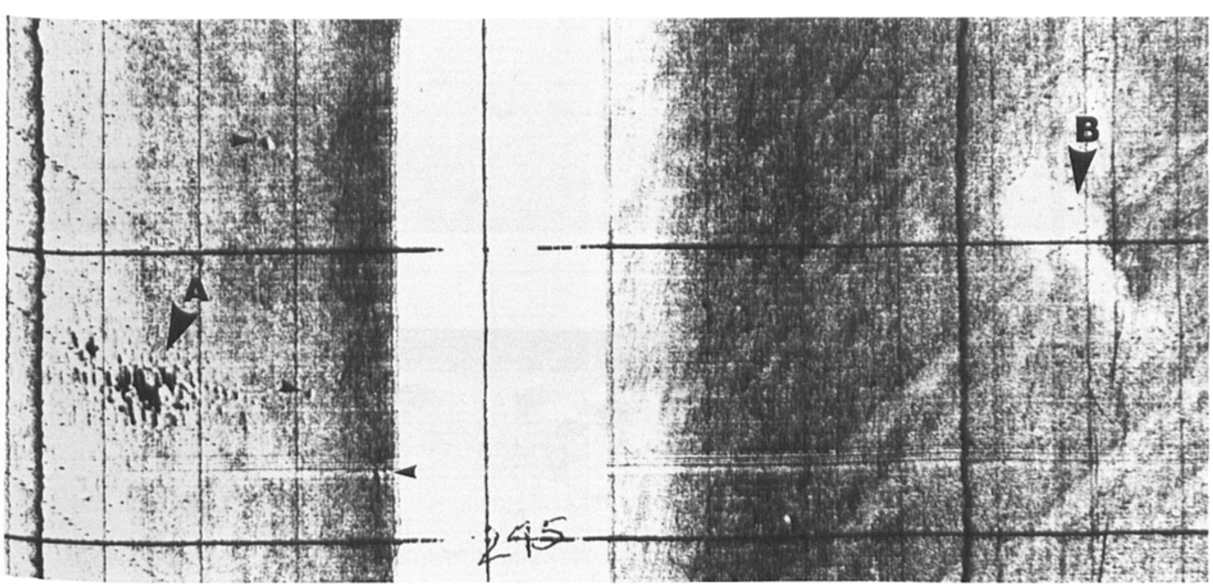

Figure 4. Sonar Record. Disturbed seabed (**A**), mature pockmark (**B**), and occasional pits (**plain arrows**). Scale lines are as in Figure 2. Water depth is 135 m.

to slight compaction in a circular zone around the pit. Within this settlement zone, differential stresses create slight weaknesses, leading to the formation of further satellite pits (Fig. 3). As further pits are formed and enlarged, then the seabed takes on a disturbed appearance (Fig. 4). Eventually the pockmark drains the surrounding area, activity dies away, the feature becomes silted up (Fig. 2–4), and a smoother profile develops.

Discussion

Escape of pore water is the mechanism suggested for the formation of pockmarks. Pockmarks tend to occur in regularly layered acoustically transparent sediment where mass movement is rarely visible, if not completely absent. If mass movement did occur, there would be ample opportunity for release of pore water, and, therefore, little reason to expect pockmarks.

Within the Witch Ground Beds acoustic layering, although generally well-developed, is often locally absent. Such acoustic voids frequently occur toward the base of the deposit (Fig. 1). Lateral and vertical boundaries are abrupt, but with no sign of mass movement. Neither is there any acoustic masking as would be expected if gas were present [1]. The suggestion is that acoustic voids (as distinct from acoustic masking) are generated by dewatering—a kind of mechanical equivalent of bioturbation. Bioturbation as a mechanism seems highly improbable in view of the abrupt lateral boundaries. This poses the question as to why dewatering should lead to the formation of acoustic voids in one situation and pockmarks in another. Furthermore, why should pits be present only in certain areas, assuming a relationship with pockmarks? Factors to examine might include variations in grain size, time of formation, perhaps water depth, and particularly porosity difference between layers and overburden thickness. Acoustic voids, for instance, might have been formed in relatively shallow water, not long after the last ice retreat when sea level was a great deal lower. Pockmark size often seems to be reasonably uniform in any one area, both in diameter and depth (Fig. 1), possibly in response to a particular thickness of impervious overburden.

As to the relationship between pockmarks and differential stress, Figure 5 obtained off Northern Norway in the Troms area, shows a very strong correlation between pockmarks and infilled iceberg ploughmarks. Furthermore, perhaps even drag marks can generate pockmarks, if the coincidence of pits and drag marks shown in Figure 2 is anything more than chance. Presumably this would occur in response to a slight local thinning of overburden.

There is perhaps some direct evidence to suggest gas as another hypothesis: the author has in his possession a copy of a sonar record, apparently showing a gas plume emanating from a pockmark, and has been

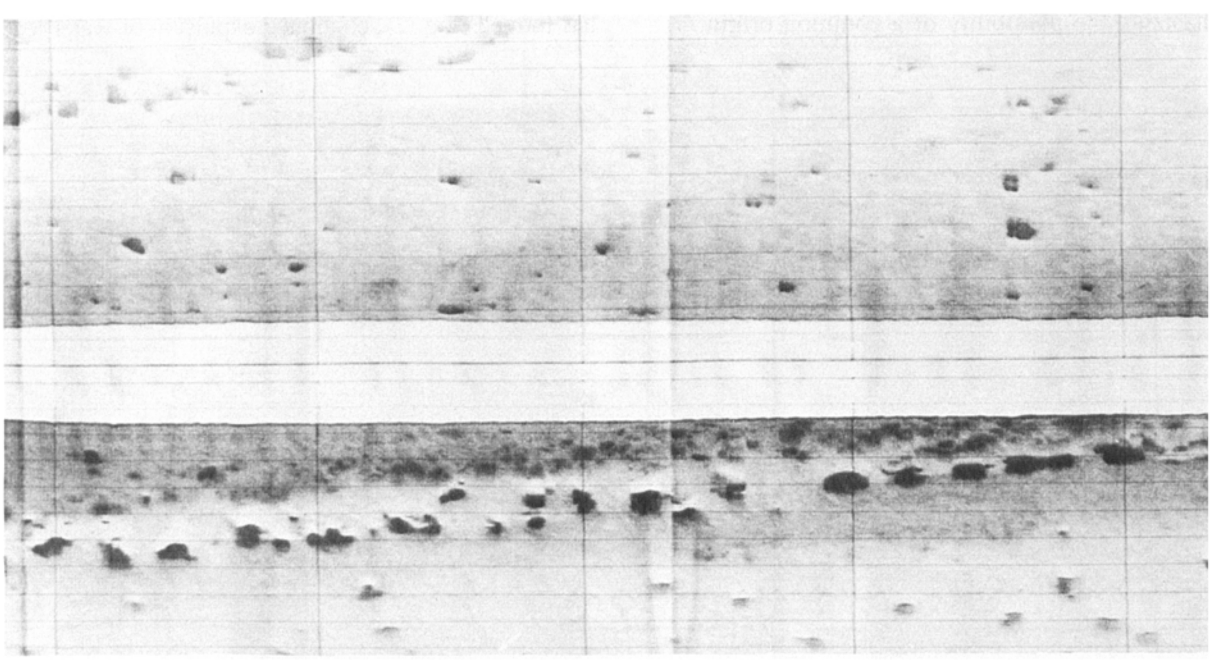

Figure 5. Sonar Record. Alignment of pockmarks along infilled iceberg ploughmarks. Scale lines are 15 m across and approximately 150 m along track. Water depth is 320 m.

told of a gas bubble appearing at the sea surface during a survey over a pockmark area. It may be that both water and gas release are capable of generating pockmarks.

Clearly the problem with this type of topic is the lack of experimental proof. One test might be the examination of cores at least 5 to 10 m long to establish a reliable profile of porosity, organic material, and water content, both adjacent to and some distance from pockmarks. Whiticar and Werner [3] describe some relevant experiments. Another possibility could be to determine whether or not new pits appear over a period of time, since there is evidently reason to suppose that pockmarks are visibly growing [1].

Conclusion

Pockmarks are caused by dewatering in soft cohesive sediment where slopes are too gentle to allow mass movement. The first stage is the development of a pit or unit pockmark, followed by pit clusters and locally disturbed seabed areas. These early stages are of relatively short duration, judging by their comparative scarcity. The final stage is a mature pockmark. Acoustic voids are also considered to be a dewatering phenomenon, possibly related to a thinner cover of overburden and, perhaps, a faster rate of sedimentation.

Acknowledgments

I thank Zapex North Sea Ltd. for agreeing to the use of certain of the data samples, N. G. T. Fannin and B. Fletcher of the British Geological Survey for their encouragement and suggestions, K. P. Games and K. A. Day for reviewing the manuscript and Gardline Surveys for allowing time on the project.

References

1. Hovland M, Judd AG, King LH (1984) Characteristic features of pockmarks on the North Sea floor and Scotian Shelf. Sedimentology 31:471–480
2. King LG, Maclean B (1970) Pockmarks of the Scotian Shelf. Bulletin Geological Society of America 81:3141–3148
3. Whiticar MJ, Werner F (1981) Pockmarks: Submarine vents of natural gas or freshwater seeps? Geo-marine Letters 1:193–199
4. Holmes R (1977) Quaternary deposits of the central North Sea. 5. The Quaternary geology of the UK sector of the North Sea between 56° and 58° N. Reprints of the Institute of Geological Sciences 77/14. HMSO, London

Manuscript received 4 March 1985; revision received 24 May 1985.