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EXPRESSIONS OF SHALLOW GAS IN THE GDANSK BASIN

ABSTRACT

In the paper, a short introduction to present-day acoustic and seismoacoustic inventory of shallow gas occurrence and its expression in the Gdansk Basin is presented. Signals of various frequencies and beamforming were employed during surveys conducted from the board of r/v 'Oceania'. Such a set of diverse acoustic signals was exploited in order to obtain a better recognition of different forms of shallow gas existence in the area. The utilized frequency started from about 1 kHz once a boomer was used in sounding, up to 40–60 kHz in the case a chirp echosounder. At acoustic transects classical echosounders working at 12 and 38 kHz were applied. Some details of the qualitative analysis and the technicalities of the algorithms are given. Variety of examples of echo images obtained in different frequency bands, associated with different forms of gas occurrence is presented.

Keywords:

gas, methane, marine sediments, Gdansk Basin, acoustic anomalies, gas pockmarks, Balic.

INTRODUCTION

Several previous and contemporary seismoacoustic surveys in the Baltic Sea indicate a widespread and appearing in considerable amount the shallow gas [5, 8, 11]. As in other shelf seas, gas in the Baltic sediments, consists predominantly of methane [3]. Despite the fact that commercially available gas reservoirs of the Baltic Sea occur more than 1 km deep under the sea bottom [1], the significant shallow gas accumulations has place in near-bottom layers. Characteristic images of contemporary and former blow-outs of an accumulated gas, observed acoustically in the Gdansk Gulf Basin, classified as pockmarks are also reported [2, 10].

In the Polish Economic Zone of the Baltic Sea, we have both unwritten information and printed reports on the relatively frequently detection of shallow gas not only within the topmost 10 m of soft sediments [12] but in the form of the free bubbles at the surface of sandy sediments [6]. The fields of gas bubbling from the bottom, in the Bornholm Basin and in vicinity of the Hel Peninsula, under specific environmental conditions, were reported by Orłowski [9]. Moreover, we have personal announcement about methane's bubble releases in the very shallow near shore zone of the Hel Peninsula (personal communication by dr Lech Kotwicki, IOPAS).

Usually, the recognition of gas bubbles presence in bottom sediments is performed employing seismoacoustic profiling. Different types of echosounders and sonars are used to locate gaseous seeps, or to identify the sediment structures associated with gas presence.

Gas bubbles due to their significant influence on acoustic properties of the sediments in which they reside, especially in the shallow sea are capable to affect the far range propagation of the low frequency sound. Moreover, the dispersed gas bubbles seeping from the bottom can influence the high frequency propagation and increase the local ambient sea noise level. So far, the both aspects have not been considered appropriately in a forecast of sound propagation conditions or soundscape in this sea.

In distinction to commonly accepted definition, in this paper we will denote 'shallow gas' as the gas which occurs below seafloor to depths of tens of meters. The gathering of the data aimed at the detection and inventory of the shallow gas bearing sediments were performed in the Polish EEZ from the board of r/v 'Oceania' in the surveys in February 2009, September 2010, April 2010 and March 2011.

Collecting data along more than 2 000 NM of transects with different equipment and additionally analyzing historical data collected in IOPAS during 1990's (at 30 kHz) we reach capability to generalize in which form the shallow gas exists in the area under investigation. The data presented in this report have been collected during experiments and trials performed for the BalticGas grant purposes.

SCIENTIFIC EQUIPMENT

To identify sea bottom gassy sediments, presence of pockmarks and for seeking gas seepages, diverse acoustical equipment was used in different years and areas. The trials and experiments could be grouped depending on the purpose of investigations associated with area and system's configuration:

— mutual use of the boomer and classical echosounder in the fault zones with acoustically hard bottom (sand, gravel);
— simultaneous use of the side scan sonar and classical echosounder in the areas where extremely high concentrations of methane in the water or in the upper layer of sediments implied gas seeping;
— mutual sounding classical echosounder and chirp sonar or multibeam echosounder.

Acoustic echo registrations were performed using:

1. Chirp/classical narrow band echosounder assembled and programmed in IO-PAS mainly used to recognize presence of pockmarks and to raise the probability of detection of potential gas seepages. Two Reson TC2116 broadband transducers (one as a transmitter and other as a receiver), inside a fairing mounted along the shipboard were towed at a depth of 1m below the sea surface. The echosounder emitted pulses 0.3–20 ms long, depending on the sea depth and the bottom type, the chirp signals were in frequency range 40–60 or 40–80 kHz alternately with the pulse signals at 40 kHz, with a repetition rate 1 ping per second. The chirp echosounder could be towed at speed <3.5 knots.
2. Kongsberg EA400 echosounder attached to the shipside at a depth 1 m below the sea surface. Soundings at two frequencies 38 kHz and 200 kHz were performed (in cooperation with the Atlantic Branch of the Institute of Oceanology RAN, in Kaliningrad — Russia).
3. Kongsberg EM3002 multibeam echosounder working at frequency 300 kHz mainly used to search pockmarks or methane flares and visualizing sea bottom. Echosounder used 160 acoustic beams with swath width at a range 130–160°. Maximum repetition rate was four pings per second (depending on the sea depth), (in co-operation with Technical University of Gdańsk).
4. Edgetech DF-1000 side-scan sonar hauled behind the ship, at depths to 40 m below sea surface. Data were collected in two independent channels at frequencies 100 kHz and 500 kHz. Horizontal beam width was 1.2° at 100 kHz and 0.5° at 500 kHz. Digital high-resolution sonar images of seafloor were pre-reviewed by means of Coda DA50 signal analyzer.
5. SIG Energos 300 Boomer used to visualize deeper layers of the sea bottom. Pulses power was 250 J or 300 J (in co-operation with Maritime Institute in Gdańsk).
6. Odom MK III echosounder working at frequency 12 kHz was set to ping rating from 2 to 4 ping per second. The echosounder transmitter was mounted on the bottom of the vessel.
7. Nonlinear equipment for detection of gas bubbles in the uppermost layer of the sediments with the thickness of the order of one meter.

To ground truth our acoustic observations at the most promising sites, cores were taken for geochemical analysis (A. Brodecka, Institute of Oceanography — Gdansk University)

GEOLOGICAL CHARACTERIZATION OF INVESTIGATED AREA

Depending on the geological structure in the various Baltic Sea basins, the shallow gas could be a consequence of bacterial activity on an agglomerated organic matter or of the thermogenic origin migrated from deeper layers through abundant faults in the area.

In the Baltic Sea Deep Basins, the topmost layers of Holocene sediments are acoustically transparent mud, marine-silty-clay, clayey silts with patches of and sand-silt-clays. Contemporary sedimentation rates of rich in organic content matter in the Gdansk Deep are excessively high and range from 1.5 to over 2 mm per year. Probably most of the gas in this area was generated mainly by bacteria activity in Holocene sediments. The thickness of the Holocene deposits could exceed 15–20 m [4] which is the limit of sounding of echosounders working in the tens kHz frequency range.

The inner Gdansk Gulf area is complex from the geological point of view. We observe there various geomorfological structures and a broad spectrum of sediments from the coarse-grained sands to the clayey silt. In the deeper part of the Gulf layering is hard to recognize using both shallow seismic or high resolution high--frequency chirp echosounder probably due to homogeneity of their physical parameters and turbidity.

Going from the Gulf of Gdansk towards the North-West we have a zone where numerous mostly meridional faults have been detected with the deep seismic measurements and at the depth above 1 km the commercial gas and petroleum deposits are situated [1]. In the faults zone the sea depths are from about 100 m near the Gulf of Gdansk up to 30–40 m. It was expected that in the Fault Zone due to vertical migration to the sea floor the presence of the very shallow gas could be observed. The topmost sediments are soft clays and mud in the deeper part and the acoustically hard sand or gravel in shallower area. In this zone, the two PETROBALTIC oil platforms operate.

According to reports of Polish Institute of Geology in the Slupsk Furrow vicinity, areas with exceptionally high concentrations of the methane in the near-bottom water layer were found (originally in the uppermost 1 cm layer of sediments). In addition, in the same report, in our opinion groundlessly, had hypothesized that saline warm water fluxes were found in the same area. The Kongsberg Multibeam System was used to monitor the seafloor in the Slupsk Furrow in search of gas flares in the water body.

GAS FORMS PRESENCE

Performed acoustic imaging shows various features of shallow gas accumulations as gas charged layers, pockmarks, acoustic turbidity in a wide variety of geological environments. In the recorded boomer echosignals the reversed polarity is also observed.

Examples presented below were obtained at the sea during the surveys of 'Oceania' in 2009–2011, in the Southern Baltic Sea.

Acoustic blanking

Acoustic blanking (or shadowing) was relatively simply recognized in the entirely investigated region with the boomer and the 12 or 38 kHz echosounders. Locally, the shallow gas was found transforming acoustical properties of the low-reflectivity and acoustically transparent soft sediments into a strong volume scatterer with high attenuation.

Single-beam subbottom profiling across these shallow gas areas shows distinct blanking effects from one to four meters below the seafloor. In a good number of cases, when typical image of the blanking area was found, no other backscatter anomalies were recognized while crossing the transition zone between mud and gas-bearing sediments. The examples of acoustics blanking in a soft bottom area in the Gulf of Gdansk are depicted on the echogram in Fig. 1. The sounding have been carried out at frequency 12 kHz.

Inside of the inner part of the Gulf of Gdansk, at transects between the Hel Peninsula and Gdynia we observed abrupt changes in the character of echoes when going in the Gdynia direction. However, coming up to the Hel Peninsula it was not possible to find the sudden limits of distribution of the gas charged sediments. Localized limits of spots of the gas-saturated sediments near the Hel Peninsula are presented in Fig. 2. Red arrows and the square represent the areas where gas was acoustically detected. Red dot lines show the transects where gassy sediments were detected but it was not possible to determine accurately the North-Eastern boundary between sediments with and without gas. Green color represents the areas where no gas was observed.

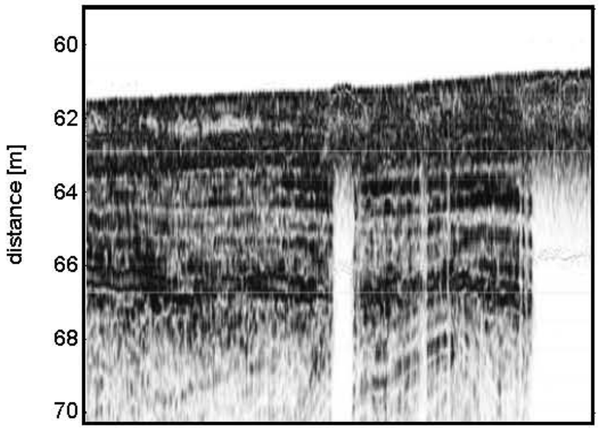

Fig. 1. The example of acoustics blanking in a soft bottom area;
echogram for the sounding frequency of 12 kHz

Source: own analysis.

The resulting bathymetric data in the Gdansk Deep obtained by low frequency echosounder frequently repeat the subbottom morphology of a silt layers rather than the seafloor. The reason is strong penetration into the mud up to ten meters, even though the system was manually optimized for correct bottom detection. It makes the 12 kHz system prone to subsurface mapping of strong reflectors within very soft sediments.

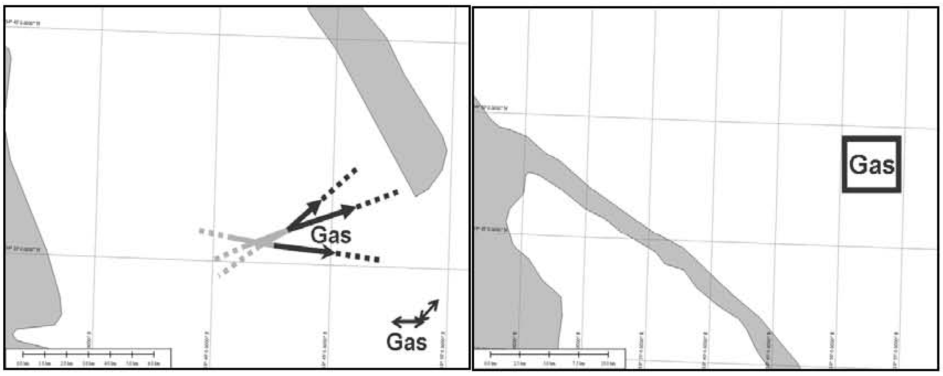

Fig. 2. Location of the gas-saturated sediments near the Hel Peninsula (February — April 2011).
Darker grey arrows (on the left) and the square (on the right) represent the areas where gas
was acoustically detected. Darker grey dots show the area where gas may occur but it was
not possible to determine the exact boundary between sediments with and without gas.
Lighter grey color represents free of shallow gas areas

Source: own analysis.

The fault zone where the bottom is regularly covered by acoustically hard material sounding was performed with the boomer and the 38 kHz echosounder. The blanking was identifying at different depths. It should be noted that acoustic gas blanking in this area observed at 38 kHz may lowering one-frequency acoustic sediments recognition algorithms reliability. In the bottom panel of Fig. 3 we present the example of an echogram in the fault zone with consistently homogeneous surficial sediments, where with high probability shallow gas (shadowing) was observed.

In the three upper panels the sets of first three moments of the echo envelope used in different configurations in the bottom classifying algorithms are presented.

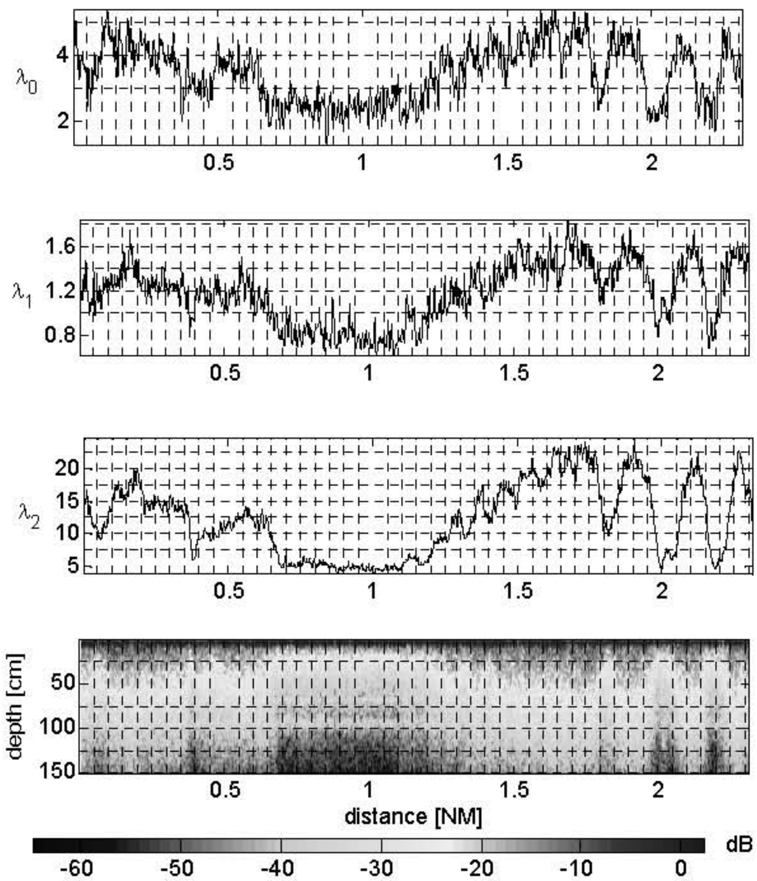

Fig. 3. Example of an echogram in the fault zone at 38 kHz, where with high probability gas blanking was observed. In the three upper panels the sets of three first moments of the envelope

Source: own analysis.

Pockmarks

Several patches of higher gas content in sediments in the Gulf of Gdansk have been classified as the pockmarks. The employed chirp echosounder together with classical echosounders provided good results in detection of gassy structures such as pockmarks and various type of sediment structure inhomogeneity — probably results of the gas presence. Many sea bottom structures classified as pockmarks were detected on the Gdansk Deep (eastern part of the Polish Economic Zone) and all of them occur in the Holocene unit. One example of these structures is shown in Fig. 4. Small gas pockets of only a few meters horizontal extension were also observed with the 12 kHz echosounder to the north from the Hel Peninsula and with the 38 kHz echosounder on the Slupsk Furrow area. Similar categorisation was obtained with a chirp echosounder 40–60 kHz. Cross-sections values of identified pockmarks were determined along line transects and their histograms and statistical distributions were calculated for different sediments provinces.

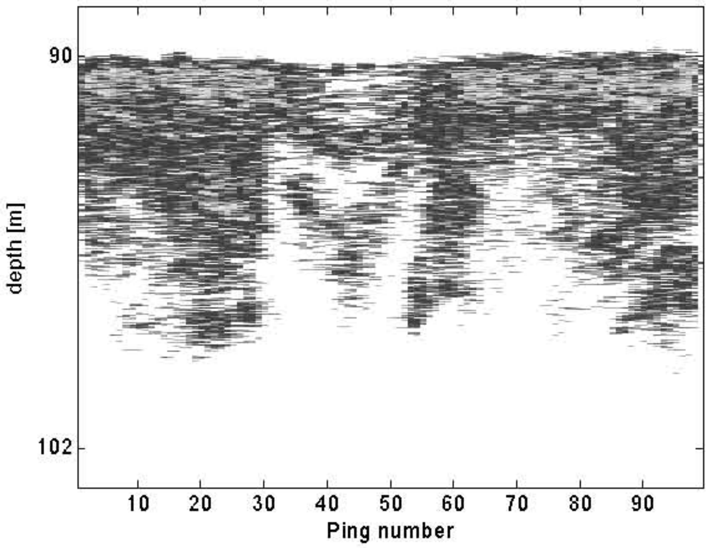

Fig. 4. Acoustic image of the pockmark's cross-section (the depth in the sediment is approximately) obtained using the chirp echosounder, in the Gdansk Deep area; the cross-section from side to side of the pockmark is about 80 m

Source: own analysis.

SUMMARY

1. In our studies of classification of shallow gas presence in the Polish EEZ we employed a combination of different seismoacoustic and acoustic techniques. Some of them covered a seafloor e.g. multibeam echosounder and sidescan sonars images, to map the sea-floor surface gas presence.
2. Acquired acoustic images manifested a broad spectrum of evidences of gassy sediments as acoustic turbidity, enhanced reflections, acoustic blanking, and negative phase presence.
3. The trial results suggested that the proposed both narrowband pulses and chirp sounding signals technique utilized in inventory of buried and modern pockmarks reproduces qualitatively similar images.
4. Moreover, gaseous bottom structures such as pockmarks and various types of inhomogeneities or chaos in stratification of surficial sediments caused by the withholding of movement of gas bubbles toward bottom surface have been possible to identify.
5. Acoustic images obtained both by chirp and 12 kHz echousounders classified very probably as pockmarks have been mapped in semiliquid fine grained sediments in the Gdansk Deep and Slupsk Furrow.
6. Pockmarks recognized from boomer images occur also in coarse grained sediments in the fault zones.
7. Pockmark centers are characterized by increased backscatter values due to gas chimney existence or presence of relatively coarse-grained sediments
8. Occurrence of faults and its coexistence with gas patches indicate an active fluid seepage system although no increase in concentration of pockmarks is associated with it.
9. The diffusive echoes from soft sediments filled craters are frequently observed.
10. However, the acoustic turbidity, frequently recognized around blanking areas was recognized only using boomer soundings.
11. Throughout our investigations acoustic flares in the water column were not observed.

Acknowledgments

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REFERENCES

[1] Domżalski J., Górecki W., Mazurek A., Myśko A., Strzetelski W., Szamałek K., *The prospects for petroleum exploration in the eastern sector of Southern Baltic as revealed by sea bottom geochemical survey correlated with seismic data*, „Przegląd Geologiczny”, 2004, Vol. 52, No 8/2.

[2] *Geoacoustic and Gasometric and Lithogeochemical Investigations in the Baltic Sea* (in Russian), ed. A. A. Geodekyian, V. Ya. Trotsiuk, A. I. Blazhchishin, 164 c, Moscow 1990.

[3] *Geochemical Investigations in the Southern Baltic Sea Aimed at Analysis of Geogenic Origin Threads and Oil Resources* (in Polish), ed. P. Anolik, A. Karczewska, Warszawa 2008.

[4] *Geological Map of the Baltic Sea Bottom, 1:200 000*, ed. J. E. Mojski, Państwowy Instytut Geologiczny, Warszawa 1989–1995.

[5] Grelowska G., Kozaczka E., Szymczak W., *Methods of data Extraction from Sub-bottom Profiler's Signal*, ‘Hydroacoustics’, 2010, Vol. 13, pp. 109–118.

[6] Klusek Z., Sutin A., Matveev A., Potapov A., *Observation of Nonlinear Scattering of Acoustical Waves at Sea Sediments*, ‘Acoust. Lett.’, 1995, Vol. 18, pp. 198–203.

[7] Klusek Z., Tegowski J., Szczucka J., *Characteristic properties of bottom backscattering in the southern Baltic Sea at ultrasound frequencies*, ‘Oceanologia’, 1994, Vol. 36, pp. 81–102.

[8] Mathys M., Thießen O., Theilen F., Schmidt M., *Seismic characterisation of gas-rich near surface sediments in the Arkona Basin, Baltic Sea*, ‘Marine Geophysical Researches’, 2005, Vol. 26, pp. 207–224.

[9] Orłowski A., *Acoustic Tracking Dynamic Phenomena in Marine Ecosystem*, ‘Hydroacoustics’, 2009, Vol. 12, pp. 167–180.

[10] Pimenov N. V., Ulyanova M. O., Kanapatsky T. A., Veslopolova E. F., Sigalevich P. A., Sivkov V. V., *Microbially mediated methane and sulfur cycling in pockmark sediments of the Gdansk Basin, Baltic Sea*, ‘Geo-Mar Lett’, 2010, Vol. 30, pp. 439–448.

[11] Rudowski S., Szefler K., Fajfer G., *Gaz w osadach dna Zatoki Puckiej* (in Polish), 'Geologia i geomorfologia pobrzeża południowego Bałtyku', 2010, Vol. 8, pp. 119–130.

[12] Tęgowski J., Klusek Z., Jakacki J., *Nonlinear acoustical methods in the detection of gassy sediments*, [in:] *Acoustic sensing techniques for the shallow water environment. Inversion methods and experiments*, ed. A. Caiti, N. R. Chapman, J-P. Hermand, S. M. Jesus, Springer, Berlin, pp. 125–136.

RÓŻNORODNOŚĆ FORM WYSTĘPOWANIA GAZU W OSADACH BASENU GDAŃSKIEGO

STRESZCZENIE

W artykule dokonano wprowadzenia do współcześnie prowadzonych metodami akustycznymi detekcji i rozpoznawania różnorodności postaci występowania gazu w osadach dennych Basenu Gdańskiego. W celach lepszego rozpoznania form występowania gazu w górnej warstwie osadów w rejsach badawczych r/v „Oceanii" zastosowano sondowanie dna za pomocą sygnałów akustycznych zróżnicowanych pod względem częstotliwości oraz ukształtowania wiązki. Zakres częstotliwości sygnałów akustycznych wykorzystanych w sondowaniu dna zawierał się w granicach od około 1 kHz (boomer) poprzez 12/38 kHz do szerokopasmowych w granicach 40–80 kHz. Na wielu transektach akustycznych do obrazowania ukształtowania dna i warstwy naddanej zastosowano również sonar boczny i echosondę wielowiązkową. W artykule przedstawiono niektóre elementy analizy jakościowej oraz przybliżono szczegóły techniczne algorytmów pozwalających na identyfikację gazu w osadach. Zaprezentowano także liczne przykłady obrazów echa otrzymane dla sygnałów akustycznych w różnych pasmach częstotliwości, powiązanych z występowaniem gazu w osadach.

Słowa kluczowe:
gaz, metan, osady morskie, Basen Gdański, anomalie akustyczne, kratery gazowe, Bałtyk.