British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Investigation of the origin of shallow gas in Outer Moray Firth open blocks 15/20c and 15/25d (seabed-400 milliseconds two-way time)

Sue Stoker and Richard Holmes

Commissioned Report IR/05/022

BRITISH GEOLOGICAL SURVEY

CSM PROGRAMME

COMMISSIONED REPORT IR/05/022

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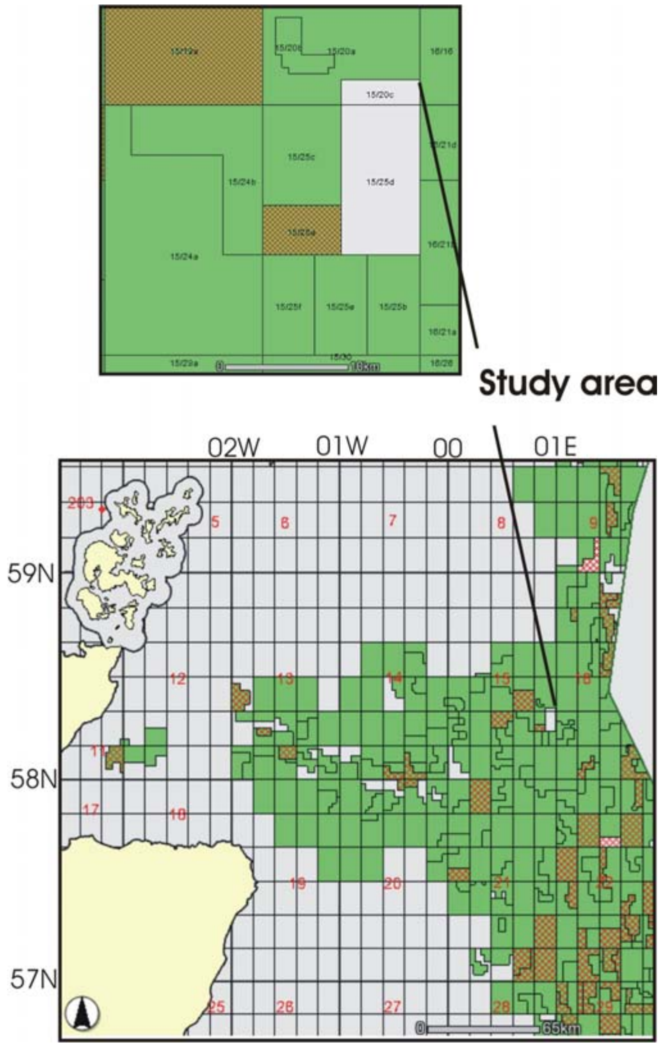

Keywords

Pockmarks, shallow gas, outer Moray Firth

Front cover

Study area

Bibliographical reference

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Edinburgh British Geological Survey 2005

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Summary

1. Interpretations of the BGS shallow seismic data and commercial site investigation data show that gas is seeping from seabed in three large active pockmark complexes in approximately 150m or more water depth. The Challenger pockmark complex is in the north of block 15 / 25d, the Scanner pockmark complex is in the south of block 15 / 25d and the Scotia pockmark complex is adjacent and northeast of the Scanner pockmark.

2. A review of the peer-reviewed scientific publications indicates that the majority of the arguments, based on isotopic analyses, are for a predominantly biological origin for the gas seeping from the active pockmarks. There is not, however, a secure scientific consensus as to whether there is a primary origin for the gas. Thus the possibilities are that the gas originates from a shallow biogenic source, a deep thermogenic source or from mixtures of these sources.

3. Interpretations undertaken for this project indicate that gas seeping to seabed in the largest pockmarks is sited above the shoulders of buried sub-glacial channels. The gas seepages are fed from a laterally almost continuous blanket of buried gas-charged sediments situated between the sub-glacial channel margins at a depth interval of approximately 280-300ms two-way time (down to approximately120m below seabed).

4. An empirical conclusion is that loss of shallow gas from the gas-charged interval at approximately 280-300ms two-way time will cut off the supply of shallow gas to the active pockmarks.

5. The regional unconformity at the Crenulate Rreflector is the focus for shallow gas accumulation and it is a significant conduit for shallow gas ascending from depth to the east of the study area and into the study area.

1 Introduction

The Department of Trade and Industry (DTI) has a policy that Strategic Environmental Assessments (SEA) will be undertaken prior to future wide-scale licensing of the UK Continental Shelf (UKCS) for oil and gas exploration and production. This policy implements the EU Strategic Environmental Assessment Directive (2001/42/EEC). This project, DTI Project GC/04/22, falls within the DTI SEA2 (north) area for which the Technical Reports to accord with the EU SEA Directive already been completed (Dando, 2001; Judd 2001). GC/04/22 follows on from the DTI 2001 SEA published research on pockmarks with an investigation aimed at whether gas seepages in open blocks 15/20c and 15/25d are restricted to shallow levels in the subsurface. If the gas is migrating along a conduit from deeper levels then the open blocks should remain to be excluded from future licensing rounds.

The project tasks for the investigations were defined as:

1. Complete a desk study based on publications in the literature and unpublished reports to determine whether or not there is already a consensus on the derivation of the gas seepages in blocks 15/20c and 15/25d
2. Carry out a quick interpretation of available BGS shallow seismic data and commercial site survey data to determine the extent of the gas in the shallow subsurface.
3. Carry out interpretations of appropriate horizons on the PGS Megamerge for indications of gas seepages from deeper levels. Use seismic attribute analysis to map the locations of Tertiary channels that might be acting as migration conduits into the area. Investigate for gas chimneys, faults extending to shallow levels, amplitude anomalies, evidence for sediment remobilisation and any other evidence for upward gas migration into the shallow subsurface.
4. Compile a brief report summarising the key findings of the work, providing a basis for recommendations as to whether or not the blocks could be made available in future licensing rounds.

This report is an interim record of a contribution to the current investigations by Sue Stoker and Richard Holmes in the project area over the interval from 0-400 milliseconds two-way time (ms twt). A report on the investigations below 400ms twt will be completed at a later date.

2 Methodology

2.1 PUBLISHED LITERATURE

A consensus of published scientific opinion was sought on the origin of shallow gas in the project area. Bibliographical references in the public domain were retrieved using the on-line Georef, Web of Science and Work ISI Proceedings search engines. Search keywords are listed in Appendix 1. The references were compiled in Endnote and then reviewed for relevance before retrieval. Publications cited in this report are listed in section 5. Other publications from the scientific literature associated with North Sea pockmarks have been compiled as a bibliography, section 6 of this report.

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2.2 BGS REGIONAL SEISMIC REFLECTION SURVEYS AND COMMERCIAL SITE INVESTIGATION REPORTS

Data on the locations of and the commercial site investigation survey reports, BGS regional surveys held in the BGS archives were compiled using the BGS Arc8 GIS system and are in Appendices 2, 3 and 4.

The BGS air-gun, sparker, boomer, sidescan survey records and site investigation report data were only available in hard-copy format. Interpretations of shallow gas distributions were compiled on hard-copy maps, digitised and then converted to ArcView GIS shapefiles and Corel images. The Corel image files are contained within Appendix 5.

On boomer 1.5kHz profiles, disturbed and chaotic acoustic facies occurring with reflector high amplitude anomalies are interpreted as evidence for shallow gas seepage and gas charge. When calibrated by seabed photography, patterns of structured high backscatter at seabed are interpreted from sidescan sonar records as likely areas of gas bubbles and authigenic carbonate hardgrounds. Images of strings of mid-water high backscatter recorded on sidescan sonar are also interpreted as evidence for ascending shallow gas plumes (Figure 1).

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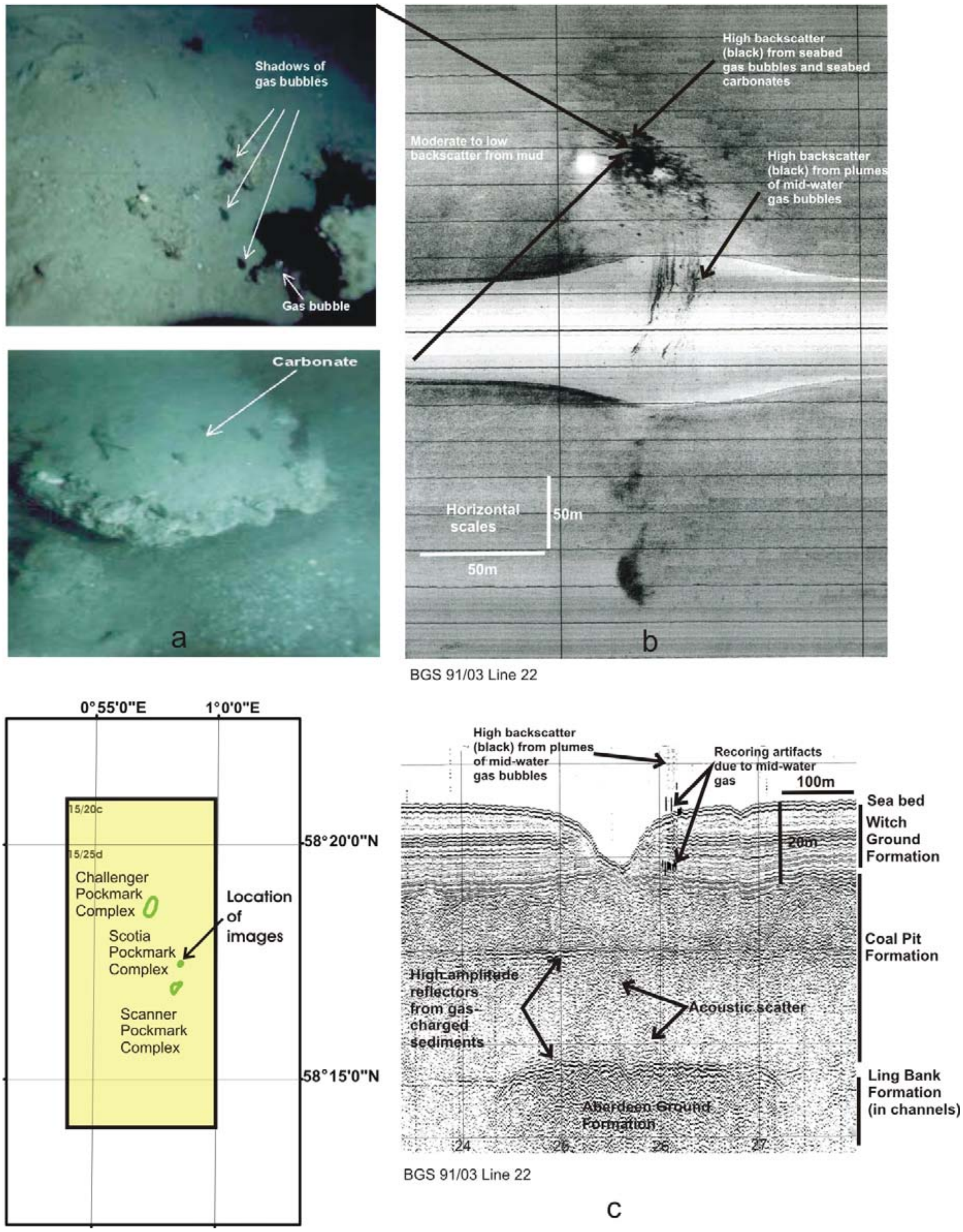

Figure 2 Scotia pockmark: examples of the diagnostic evidence used for interpretations of sub-seabed gas accumulation, gas ascent and gas expulsion from seabed

a. seabed photographs (after Judd, 2001) b. 1000kHz sidescan sonar: areas of high sonic backscatter have been recorded with dark tones c. 1.6kHz BGS deep-tow boomer

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3 Results

3.1 REVIEW OF SCIENTIFIC LITERATURE

An overall sub-horizontal seabed consists of very soft muds at 140-150m or more below mean sea level. Sea bed has been cratered by pockmarks with a population density of more than 20 per km^2. Average pockmark dimensions are approximately 5m depth from shoulder to axis and average 100m diameter (Judd, 2001). Because these pockmarks yielded no evidence at the time of surveys for modern gas expulsion, they are termed ‘inactive’. The distributions of the inactive pockmarks have not have not been mapped for this project.

With more than 200m maximum diameter, the Challenger, Scanner and Scotia pockmarks are anomalously large compared to the average size of the surrounding inactive pockmarks. Photographs and sidescan-sonar images have recorded the seepage of methane gas bubbles from seabed to seawater from these anomalously large pockmarks. Biota which are only associated with the actively seeping pockmarks include the bivalve species *Thyasira sarsi* and *Lucinoma borealis* and the nematode species *Astonema southwardorum*are (Dando et al., 1991). Other unusual biota include methane oxidising bacteria. These build up slabs of methane-derived authigenic carbonate which are exposed as hardgrounds, in the Scotia pockmark complex (Figure 1) and also in the Scanner and Challenger pockmark complexes.

Isotopic ratios derived from the methane-derived authigenic carbonate have been used to infer whether the gas utilised by the bacteria has a biogenic or thermogenic origin, thereon leading to estimates for the depth of origin of the gas seeps at seabed. For example, the gas utilised by bacteria to form the authigenic carbonate in the Scanner pockmark complex has a biogenic isotopic signature consistent an origin from bacterial oxidation of Cenozoic lignite or peat in the relatively shallow section of the basin (Dando, 2001). Isotopes from a carbonate slab in an adjacent region of the North Sea (Norwegian block 25/7) also indicate an origin from bacterial oxidation of shallow seepages of predominantly biogenic methane. However, shows of minor amounts of higher hydrocarbon gases (up to C5) at this site are also consistent with input to the seepages from thermogenic sources (Hovland et al., 1987). Most importantly, biogenic isotopic signatures in the Gulf of Mexico and the North Sea are thought to have been generated when thermogenic hydrocarbons in shallow sediments were re-cycled by bacteria to produce ‘secondary’ methane with an identical isotopic signature to biogenic methane (Thompson, 1996; Brekke, 1997) . Thus, the isotopic data derived from the Scanner pockmark complex do not provide a secure basis for determining the whether the gas escaping from the pockmarks in block 15/25 is primarily biogenic or thermogenic in origin (Judd, 2001).

Table 1 is a summary of the published evidence in blocks 15/20c and 15/25d for seawater, seabed and sub-seabed gas occurrences and sources.

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	UKCS blocks 15/20c and 15/25d			
FEATURE	**UNUSUAL BIOTA**	**METHANE GAS/ BIOGENIC OR THERMOGENIC ISOTOPIC SIGNATURE**	**METHANE-DERIVED AUTHIGENIC CARBONATE HARDGROUNDS / ISOTOPIC SIGNATURE**	**UNDERLYING GAS SOURCE**
1.Seawater in study area	No	Yes: recorded on seismic reflection records and gas samples / mid-water isotopic signatures not tested for biogenic or thermogenic signatures	No	Challenger, Scotia and Scanner pockmark complexes
2.Seabed inactive pockmarks	No	No gas emission from inactive	No	Historical connection with seabed fluid expulsion not proven whether gas or liquid
3.Seabed Challenger complex of large pockmarkS **(Judd, 2001)**	Yes (Dando, 2001)	Yes, recorded on seismic reflection records /biogenic isotopic signature not reported	Yes / biogenic isotopic signature not reported	Indirect evidence from seismic reflection records for connection to underlying gas charges **(Judd, 2001)**
4.Seabed Scanner /Scotia large pockmarks **(Judd, 2001)**	Yes (Dando, 2001)	Yes, recorded on seismic reflection records and photographs / biogenic isotopic signature not diagnostic of primary biogenic origin (Brekke, 1997) (Judd, 2001)	Yes / biogenic isotopic signature (Dando, 2001) not diagnostic of primary biogenic origin (Brekke, 1997)	Indirect evidence from seismic reflection records for connection to underlying gas charges **(Judd, 2001)**
5.Witch Ground Formation	Not observed	Yes/ anomalously high concentrations of 'thermogenic' methane adsorbed onto clay minerals in subseabed sediments (Faber and Stahl, 1984), now interpreted as oxidised biogenic methane (Judd, 2001). Diagnostic evidence from acoustic facies for sub-seabed gas ascent (Judd, 1997)	Not observed subseabed	Evidence from acoustic facies for connection to gas charge in top Aberdeen Ground Formation and top Ling Bank Formation (Judd, 2001).
6.Top Aberdeen Ground Formation and top Ling Bank Formation	Not observed	Yes / isotopic signature not tested	Not observed	Overall connectivity of gas migration implied from stacked configuration of gas sources and gas charged intervals (Fyfe et al., 2003)
7.Crenulate Reflector **(Holmes, 1977)**	Not observed	Yes / isotopic signature not tested	Not observed	Trapping of basin-margin gas ascending upslope from the east implied by distribution of high amplitude reflectors **(Holmes, 1977; Fyfe et al., 2003)**

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Table 1 Summary of published evidence for seabed and sub-seabed gas levels and likely gas sources

The most important conclusions from Table 1 are:

- The isotopic data provides equivocal evidence as to whether the major part of gas expelled from the pockmarks primarily originates from biogenic sources at relatively shallow depths, bacterial oxidation of ascending thermogenic hydrocarbons or mixtures of these.
- A regional perspective is that gas is probably being transferred from relatively deep basin systems from outside the project area via the Crenulate Reflector into the project area

3.2 INTEPRETATIONS OF 1000KHZ SIDESCAN SONAR AND 1.5KHZ BOOMER DATA

Interpretations of the 1.5kHz seismic reflection profiles illustrate that the nearest sub-seabed gas charge under the active pockmarks (mapped from 1000kHz sidescan sonar) is under the Coal Pit Formation and appears to be largely restricted to inter-channel areas at or just above the top of the Aberdeen Ground Formation (Figure 2).

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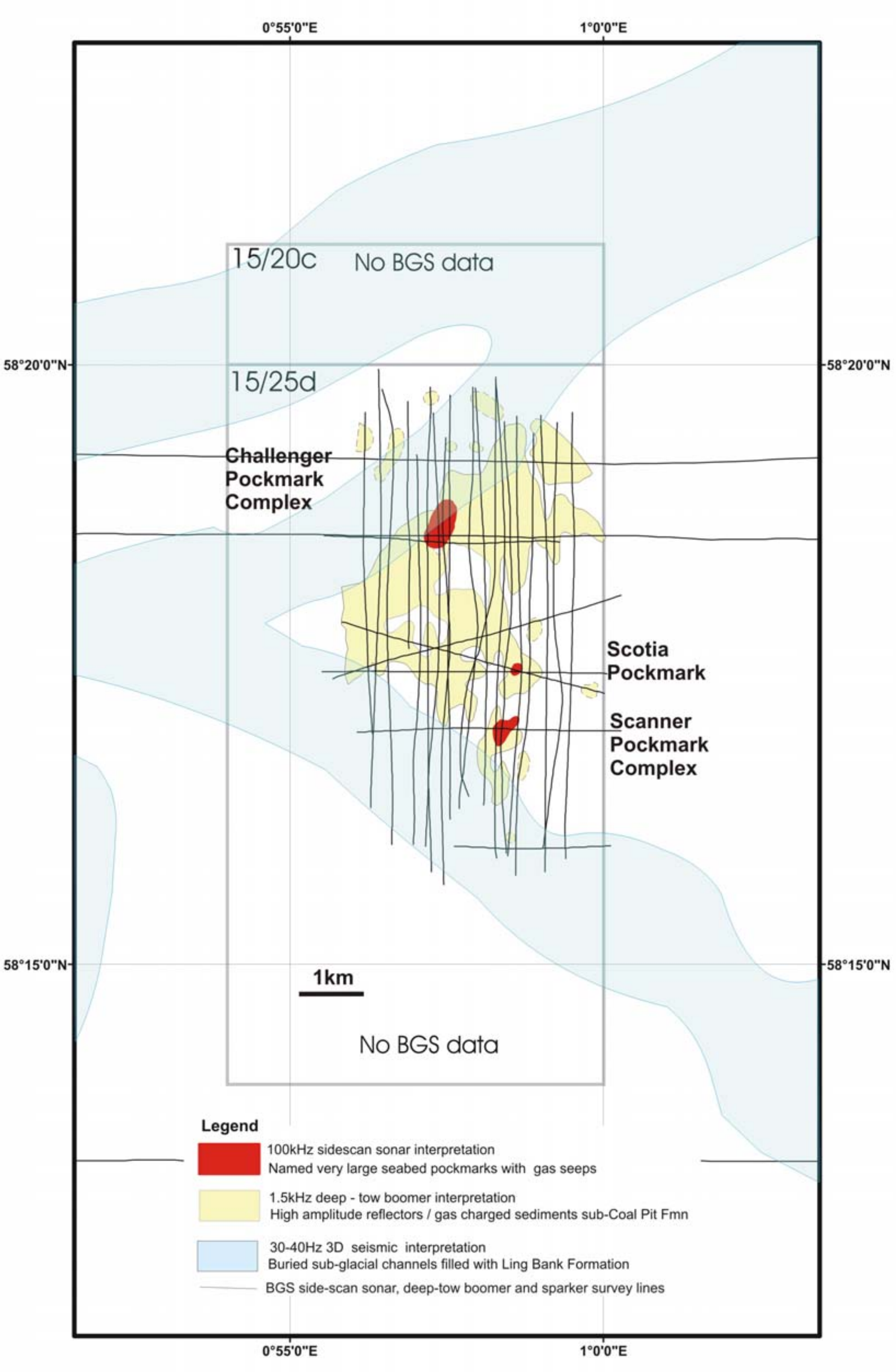

Figure 3 Geospatial configurations of active pockmarks to sub-seabed shallow gas charge and sub-glacial channels in the top 400ms twt . See Appendix 2 for an illustration of the stratigraphy from seabed to 400ms twt. The overall shapes of the active pockmarks are schematically illustrated from data derived from the commercial site investigation reports (Appendix 2).

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The most important conclusions from the relationships illustrated on Figure 2 are:

- The interpretations from the 1.5kHz profiles demonstrate the close relationship between the largest pockmarks and pathways of active seepage above sub-glacial channel margins.
- These seepages appear to be sourced from a gas charge within a vertical interval ranging from approximately 280-300ms two-way time below seabed.
- The gas charge occurs over most of the inter-channel area.
- Because of the seabed excavation associated with the active pockmarks, the potential gas conduit connecting the gas-charged interval to gas escape from seabed is shortcut by 15 milliseconds two-way time (11m) or more under the largest pockmarks. It may be presumed that the shortened pathway has stabilised the gas seepages over sufficient time to deposit the slabs of authigenic carbonate. In this scenario it would be important that future development operations do not generate additional shortcuts for the transfer of shallow gas between the gas-charge interval and seabed, thereby creating a risk of cutting off the supply gas to the active pockmarks.

4 Conclusions

1. Interpretation of the available BGS shallow seismic data and commercial site investigation data shows that gas is seeping from seabed in three large active pockmark complexes in approximately 150m or more water depth. These are the Challenger pockmark complex in the north of block 15 / 25d, and the Scotia and Scanner pockmark complexes in the south of block 15 / 25d.

2. The literature survey indicates that isotope analyses of gas and authigenic carbonate have been interpreted to suggest that there is a predominantly biological origin for the gas seeping from the active pockmarks. Because of a possible dual origin for biogenic isotopic signatures, there is no secure scientific consensus for determining whether the gas expelled from active pockmarks originate from shallow biogenic sources or from deeper thermogenic sources.

3. The literature survey indicated that the unconformity at the Crenulate Reflector is the focus for shallow gas transfer into the study area and is probably a significant conduit for shallow gas ascending from depth from the basin to the east.

4. Interpretations completed during this project indicate that gas seeping to seabed in the largest pockmarks is sited adjacent to the shoulders of buried sub-glacial channels. The gas seepages are fed from an almost continuous blanket of buried gas-charged sediments in or just above the Aberdeen Ground Formation situated between the sub-glacial channel margins at an interval of approximately 280-300ms two-way time (down to approximately120m below seabed).

5. An empirical conclusion from distribution patterns observed in top 400ms two-way time is that loss of shallow gas from the gas-charged interval at approximately 280-300ms two-way time will cut off the supply of shallow gas to the active pockmarks. The area above the gas-charged interval should therefore be avoided for future development operations.

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5 References

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DANDO, P R, AUSTEN, M C, BURKE, R A, KENDALL, M A, KENNICUTT, M C, JUDD, A G, MOORE, D C, O'HARA, S C M, SCHMALIJOHANN, R, and SOUTHWARD, A J. 1991. Ecology of a North Sea pockmark with an active methane seep. *Marine Ecology Progress Series*, Vol. 70, 49-63.

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JUDD, A, DAVIES, G., WILSON, J., HOLMES. R., BARON, G. AND BRYDEN, I. 1997. Contributions to atmospheric methane by natural seepages on the UK continental shelf. *Marine Geology*, Vol. 137, 165- 189.

JUDD, A G. 2001. Pockmarks in the UK sector of the North Sea. *UK Department of Trade and Industry Strategic Environmental Assessment Technical Report*, TR_002.

THOMPSON, K F M. 1996. Postulated generation of bacterial methane from seepage petroleum in sea floor sediments of the Gulf of Mexico in D. Schumacher and M.A. Abrahms, eds., Hydrocarbons migration and its near-surface expression. *AAPG Memoir*, Vol. 66, 331-334.

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Appendix 1 Bibliographical searches

This section contains the digital files generated from the literature searches.

Georef search engine: keywords

pockmark* and north sea

(authigenic carbonate* or biogenic gas*) and north sea

(gas seep* or shallow gas*) and north sea

seabed and (north sea)

pockmarks.enl

Authors:

Judd, A

Hovland, M.

Dando, P R

Clayton, C

authors.enl

Web of Science (SCI) search engine: keywords

pockmark* and (north sea or outer moray firth)

(authigenic carbonate* or biogenic gas*) and (north sea or outer moray firth)

(gas seep* or shallow gas*) and (north sea or outer moray firth)

Authors

Judd, A

Hovland, M.

Dando, P R

Clayton, C

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wokrefs.enl

More general search on

Seabed and (north sea or outer moray firth)

wokrefs2.enl

WoK ISI Proceedings search engine: keywords

Search on 'pockmark*' in the context of the North Sea

isiprocrefs.enl

Appendix 2 Commercial site investigation reports

None of the reports are in digital format. They were retrieved in hard copy from the BGS archives. Most rig site surveys contain interpretations of seabed and subseabed conditions to 1000m below seabed in a 3 X 3km area surveys generating echosounder, sidescan sonar, single channel high resolution seismic reflection profile and multi-channel 2D high resolution seismic profile data.

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ID	OID_	BGS REPTYR	BGS REPTNO	TITLE	AUTHOR	CLIENT	ORIGREF	COMMENTS
1998/1290/A	17589	1998	1290	Cruise report - Challenger deep-tow boomer pock mark survey on Fladen Ground. August	Smith D J and Wallis D G.	BGS	WB/90/49	Used to tie master shotpoints to times
1993/114/A	8187	1993	114	Rig site survey UKCS 15/20b-A		CON	13-503	North margin survey area: high amplitude anomalies associated with Ling Bank Formation indicated by AVO to be associated with low velocity (gas)
1995/57/A	13051	1995	57	Site survey ukcs 15/20b-A		CON	13-502	Report missing
1992/103/A	7213	1992	103	Site survey location UKCS 15/25b-B		CON	1149.1	South margins of project area: no gas
1989/206/A	5519	1989	206	Site survey 15/25b-A		CON	0664 VOLUME I	Gas accumulations, high amplitude anomalies, mapped at approx 300ms twt in Ling Bank Fmn, appear unrelated to overall 'channel sand' topography except that large pockmark is formed over highest elevation of gas acuumulation in the channel sands. Strong acoustic blanking below channels extends down to Crenulate Reflector (which has almost continuous high amplitude anomalies) around 500ms twt
1995/46/A	13007	1995	46	The geochem pockmark ukcs block 15/25		BGS	ETB/323	Scanner pockmark: geochemistry: but no results given

Appendix 3 BGS regional survey lines

The following lines were available for examination

Cruise 91/03 Lines 1-26

Cruise 1981/04 Line 14

Appendix 4 ArcGIS files

see folder on CD /P drive

Appendix 5 Corel Draw files

see folder on CD /P drive

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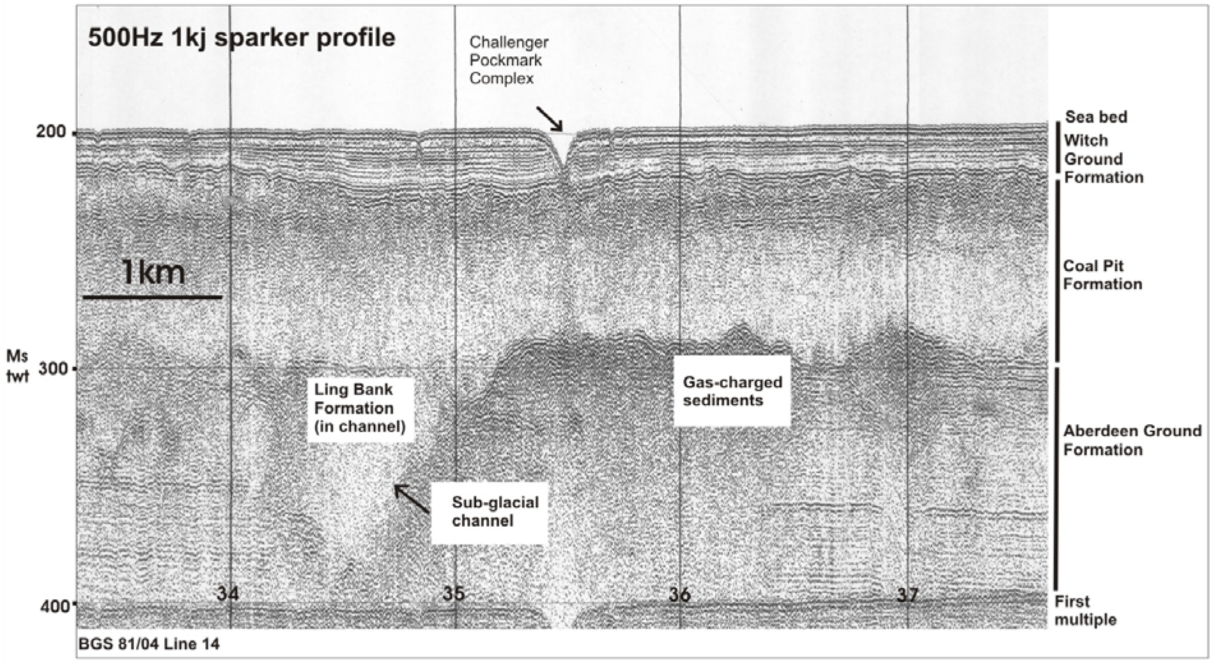
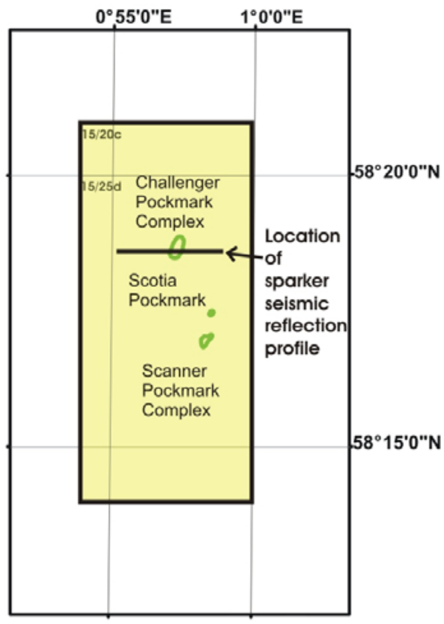
Appendix 6 Stratigraphy of study area from seabed to 400ms twt





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