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Surface and Subsurface Expressions of Shallow Gas Accumulations in the Southern North Sea

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Expressions of shallow gas, either in accumulations or apparently leaking to the near-surface, can be found on 3D seismic surveys as well as on very high frequency acoustic data. A number of different types of seismic anomalies related to leakage have been distinguished in the Netherlands part of the southern North Sea basin. A hypothesis in terms of migration mechanisms is given to explain the different appearances of different gas-chimneys.

INTRODUCTION

Within the scope of the EU sponsored NASCENT project several European on-and offshore gas occurrences are being studied from a CO_2 storage perspective. The different study sites in Europe have been selected because they represent natural analogues for the geological storage of CO_2. Some of the cases under study in the project are "closed systems", where CO_2 is apparently efficiently trapped and sealed in a setting very similar to that of hydrocarbon accumulations. At these sites information can be obtained about the conditions under which CO_2 can be effectively kept underground at a geological time scale. On the other hand, some other sites in the project represent "open systems", where seepage and leakage to the surface and the near-surface environment can be observed and studied. The shallow gas which is abundantly present in the Southern North Sea – albeit probably mostly of CH_4 composition - provides such a natural analogue for trapping, and migration and seepage mechanisms.

Standard E&P 3D seismic surveys from the Netherlands part of the Southern North Sea have been studied for the occurrence of sub-surface expressions of shallow gas in general, and for leakage in particular. In addition to the 3D surveys we had very high frequency acoustic data available from the same area, showing very shallow (0 – 25 m) subsurface expressions such as acoustic blanking, and surface expressions of venting of gas in the shape of seabed pockmarks. We use the descriptive term "**Seismic Anomalies Indicating Leakage**" for some features observed in the 3D seismic volumes. This term includes anomalies such as the so-called "gas chimneys" or "seismic chimneys", these are more interpretative terms often used for indications of vertical migration of gas or fluids, observed in seismic profiles.

Shallow gas in the southern North Sea

Expressions of gas on seismic data have been of interest for different reasons for quite some time. For the E&P industry shallow gas has always been important, because first of all, the gas can be a hazard and a risk when drilling a borehole, or when positioning an offshore platform. On the other hand the presence of shallow gas can be an indication for deeper hydrocarbon reserves, and thus be an exploration tool.

In the context of our study we refer to 'shallow gas' if the gas occurs between the seabed and a depth of 1000 m below MSL. In the Dutch North Sea sector this means that the geological formations containing the gas are mostly unconsolidated clastic sediments of Miocene – Holocene age. Shallow gas in marine sediments is mostly composed of methane, but the gas composition may also include carbon dioxide, hydrogen sulphide and ethane. The origin of these gases is attributed to either biogenic or thermogenic processes. In both cases the gas is derived from organic material, with the biogenic process relying on bacterial activity and the thermogenic process being essentially temperature and pressure dependent (Davis, 1992). Thermogenic methane is produced from organic precursors at high temperatures and high pressures, and consequently is generated at depths greater than 1000 m. Such gas may, however, migrate towards the surface and accumulate in shallow sediment layers. It is not easy to determine whether methane was biogenically or thermogenically formed (Floodgate & Judd, 1992).

EXPRESSIONS OF SHALLOW GAS ON VHF DATA

Surface expressions

Morphological surface expressions related to the venting of gas include pockmarks. These are rimmed circular depressions, which in the North Sea are normally 10-300 m in diameter and up to 15 m deep (McQuillin and Fannin, 1979. They are thought to be created by either sudden and enigmatic or periodical or semi-continuous escape of gas. They can be detected on (side-scan) sonar or on very high frequency (VHF) acoustic data. In the Netherlands North Sea sector examples were first found in the early nineties during a re-examination of SONIA 3.5 kHz profiler records from the seventies. Actual gas venting has not yet been observed with certainty. Figure 1 shows a pockmark with a diameter of about 40m seen in block A5 on 3.5 kHz data. We have also observed pockmarks in blocks A11 and F10.

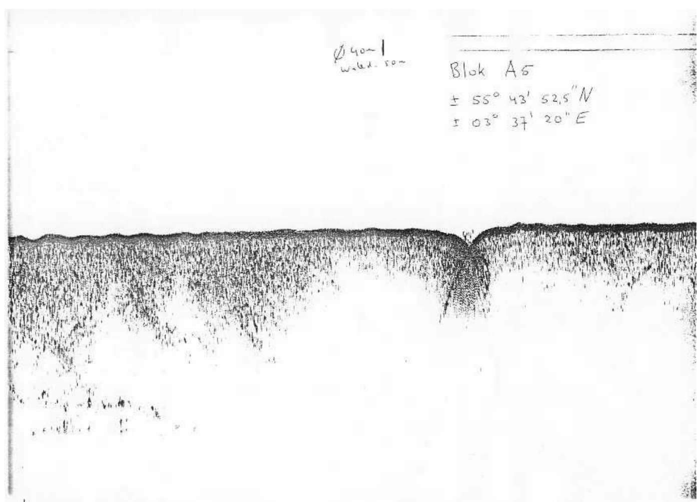

Figure 1. Pockmark observed in Dutch offshore block A5 on 3.5 kHz data of the 1970's.

Sub-surface expressions

Very high frequency (VHF) acoustic measurements, such as 3.5 kHz sub-bottom profiling, commonly show acoustic blanking in the southern North Sea. Especially single-frequency profilers show these expressions clearly. Their distribution, however, is highly variable. In some concession blocks these gas-related phenomena are virtually absent, whereas in other blocks (e.g. in block F3) they may affect up to 50% of the records. Acoustic blanking, and to a lesser extent acoustic turbidity, are locally very common in channel-fill settings (in the northern part of the Dutch offshore in particular), but also occur underneath or within clay caps and seabed muds. Acoustic blanking appears as patches where reflections are faint or absent. These may result from the disruption of sediment layering by the migration of pore fluids or gas, or alternatively may be caused by the absorption of acoustic energy in overlying gas-charged sediments. It may also be caused by the reflection of a high portion of the acoustic energy by an over-lying hard sediment; the reduction in the amount of energy penetrating the hard layer being represented by a relatively low amplitude return signal (Judd & Hovland, 1992).

SEISMIC ANOMALIES INDICATING LEAKAGE

It has been demonstrated that standard 3D seismic surveys can reveal expressions of shallow gas (e.g. by Heggland, 1994 and 1997). However, given the facts that the water-depth in the Dutch sector of the North Sea is less than 50 m, and that the reflections from about the first 100 msec are lost in the "mute" of standard surveys, there is no meaningful seismic imaging of at least the shallowest 30 – 40 m of the sediments. Here the term "seismic anomalies indicating leakage" is being used to describe sub-surface expressions on seismic data that might be related to leakage or seepage. This is a descriptive term, which would include the more interpretative term "gas-chimney", that is often used in relation to hydrocarbon migration. Also included in seismic anomalies indicating leakage are other phenomena such as shallow enhanced reflectors, shallow disturbed zones, and indications of leakage along fault trajectories.

Gas chimneys

Gas chimneys are vertical disturbances in seismic data that are interpreted to be associated with the upward movement of fluids or free gas. Heggland et al. (2000) and Meldahl et al. (2001) have reported on examples of seismic chimneys, and have also demonstrated the added value of automated systems for the detection and analysis of these features in 3D seismic data-cubes. They mention that most of these vertical disturbances are characterised by low seismic amplitudes, and low coherency.

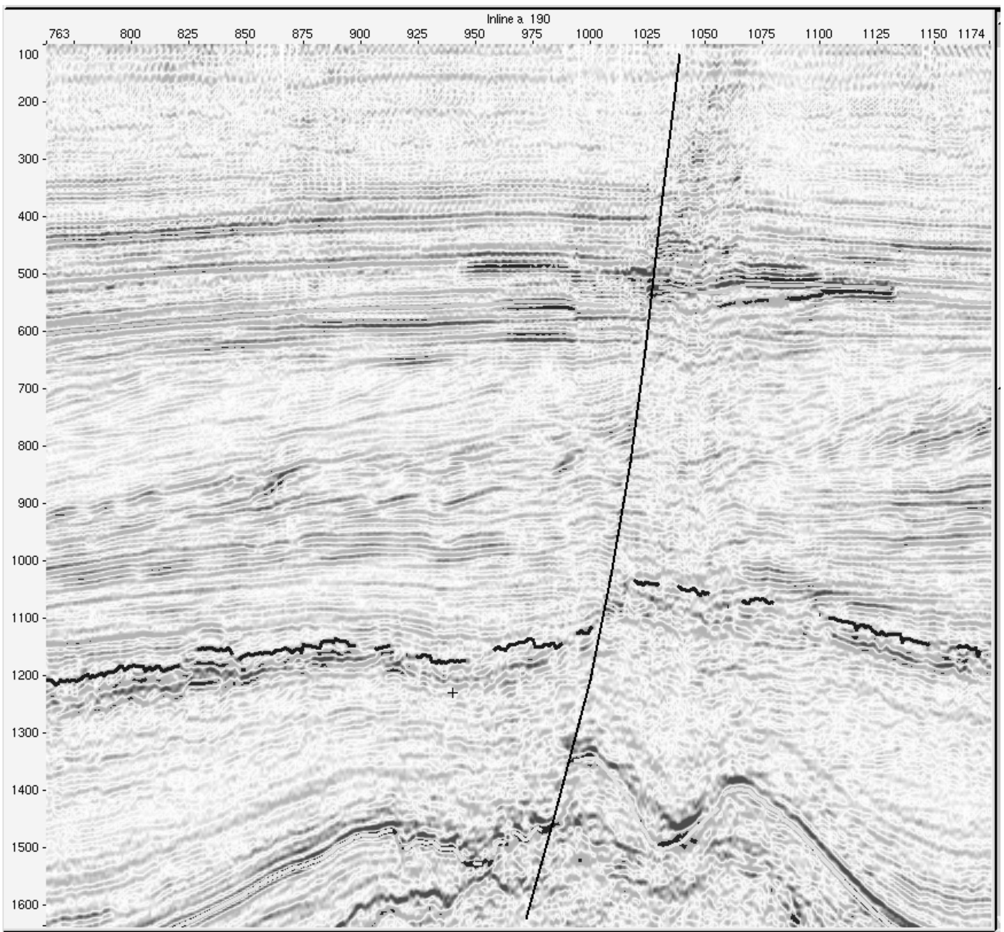

Figure 2. A gas chimney characterised by relatively high seismic amplitudes and maintained coherency over a southern North Sea salt dome.

Figure 2 shows a "chimney" we have found in a 3D survey covering parts of blocks F3 and F6. It is visible both on the vertical sections and on time-slices, and is related to a fault running from an associated underlying salt dome up to the seabed. Associated are bright spots at Upper Pliocene levels, immediately underneath the chimney. This chimney is characterised by increased seismic amplitudes within the chimney, and by the preservation of reflector continuity, and therefore of sedimentary bedding within the chimney. In this respect it contrasts with the examples of seismic chimneys published by e.g. Heggland et al. (2000) and Meldahl et al. (2001). This difference could imply a difference in migration mechanisms. Our hypothesis is that the local increase in amplitudes, and the preservatiuon of seismic coherency are the result of gas-saturation of the shallow unconsolidated sandy intervals, through a mechanism of seepage which has been slow enough not to disturb the original sedimentary bedding. This would be in contrast to examples of other chimneys which are characterised by low amplitudes and low coherency. In the latter case the migration of gas or fluids through the sediments may have caused a thorough mixing of material, and thus destruction of sedimentary bedding.

Our example more resembles the gas chimney over the Machar salt dome in the Central North Sea (UK quadrant 23) presented by Thrasher et al. (1996). They interpreted the Machar dome chimney to represent smaller and localised seepage. With respect to the migration mechanism in case of the Machar dome, Thrasher et al. (1996) comment that overpressure in the Machar reservoir is insufficient for fluid induced fracturing, and that therefore the primary leakage mechanism must have been capillary failure of the top seal.

Shallow enhanced reflections

Many 2D seismic lines in the area contain localised occurrences of enhanced reflections in the shallowest part of the sections (i.e. between 100 – 400 msec TWT, corresponding to 70 - 350 m below MSL). Within these occurrences the seismic amplitudes can be extremely high compared to the immediately surrounding sediments. This is a strong indication for the presence of gas. Although the reflections within the shadow zone are very weak, the reflection pattern is not chaotic, indicating that the cause of the dimming is probably not within the zone itself. The observation that adjacent to many of these features faults can be interpreted cutting all the way to the seabed, indicates that gas may have migrated along these faults from deeper down, and thus that the gas would be primarily thermogenic in origin.

Shallow disturbed zones

Shallow disturbed zones of seismic noise are present in localised patches at shallow levels of other profiels. Like the shallow enhanced reflectors, these features also seem to indicate the presence of shallow gas between the seabed and a depth of about 500m. They differ from the 'shallow enhanced reflectors' because of the total lack of seismic coherency. In a way they are somewhat similar to low-coherency seismic chimneys, but a difference is that we see these shallow disturbed zones mainly in the uppermost couple of hundred meters.

Fault related amplitude anomalies

Seepage of gases or fluids can be interpreted right over salt domes. Some extensional faults related to the salt structure are providing the migration path up to the seabed. Relatively small patches of high seismic amplitudes can be followed upward along the faults (most clearly visible at the westernmost fault). The interpretation is that wherever the fault intersects favourable stratigraphic levels (i.e. sandy layers with good reservoir properties overlain by some sealing shaly beds) migrating gas is temporarily stored, giving rise to the small bright spots. These 'seismic anomalies indicating leakage' are clearly related to the presence of a fault system.

Buried gas-filled ice-scours

Time-slices from 3D seismic surveys can reveal buried iceberg scour-marks. Gallagher et al. (1991) showed examples from the mid-Norwegian shelf. The ice-scours within Upper Pliocene sediments are visible because they are filled with sand, which hosts shallow gas. The resulting display in the horizontal plan is a very typical pattern of straight and narrow lineaments in different directions. In the 3D survey from Dutch block F3 we have found similar examples on several time-slices. A time-slice taken at 528 msec is shown. In this case the age of the marks would be approximately around the Pliocene-Pleistocene boundary of 1.8 Ma. At this time ice-bergs could have drifted into the North Sea area from the north. These features are known drilling hazards. The last major blow-out off Mid Norway was reported to have occurred in a dense grid of such gas-filled sands related to ice-scours.

DISCUSSION AND CONCLUSIONS

Indications for shallow gas in the Netherlands North Sea show that numerous gas-related phenomena occur. Apart from bright spots, which indicate gas accumulations which are efficiently trapped and sealed in shallow reservoirs, there is a range of other features pointing at leakage and migration of gas to the seabed. There is indirect evidence for actual gas venting, e.g. by the observation of pockmarks. There also appear to be more cases of gas-induced carbonate-cemented sediments than previously thought.

From our observations we conclude that many of the seismic anomalies indicating leakage found in the area correlate with the positions of salt structures, and that the normal faults which are very often present over the crests of these structures, provide migration pathways to the shallow realm for the thermogenic gas. In terms of seepage styles, the gas chimney found in blocks F3/F6 best fits the ‘weak and localised seepage style’, often related to focussed seepage over salt structures, defined by Thrasher et al. (1996). In the same area indications on seismic profiles of gas migration along fault systems subscribe to this point of view.

The observed high amplitudes within the gas chimney can be explained by gas-saturation of the more porous layers in the shallow sequence, but an alternative explanation would be carbonate cementation caused by the methane passing through. In either gas we still observe preservation of sedimentary bedding within the chimney, which would be in contrast with other possible style of chimneys where the migration mechanism would have been more destructive.

REFERENCES

Davis, A.M., 1992. Shallow gas: an overview. In: Davis, A.M. (ed.) Methane in marine sediments, Cont. Shelf Res. 12: 1077-1079.

Fannin, N.G.T., 1980. The use of regional geological surveys in the North Sea and adjacent areas in the recognition of offshore hazards. In: Ardus, D.A. (ed.) Offshore Site Investigation. Graham and Trotman, London: 5-22.

Floodgate, G.D. & Judd, A.G., 1992. The origins of shallow gas. In: Davis, A.M. (ed.) Methane in marine sediments, Cont. Shelf Res. 12: 1145-1156.

Gallagher, J.W., Hovland, M., Amaliksen, K.G., Braaten, A.M., Jacobsen, T., Granli, J.R., 1991. Shallow gas on Haltenbanken, Statoil report no. 91023027.

Heggland, R., 1994. Detection of near surface gas seepage by the use of conventional 3D seismic data. In: Extended Abstracts of the EAEG 56th Meeting and Technical Exhibition, Vienna 6-10 June 1994.

Heggland, R., 1997. Detection of gas migration from a deep source by the use of exploration 3D seismic data. Marine Geology 137: 41-47.

Heggland, R., Meldahl, P., de Groot, P. & Aminzadeh, F., 2000. Chimney cube unravels subsurface. The American Oil and Gas Reporter, February 2000.

Hovland, M. & Judd, A.G., 1988. Seabed Pockmarks and Seepages, Impact on Geology, Biology and the Marine Environment. Graham and Trotman, London, 293 pp.

Jeffery, D.H., Frantsen, P., Laban, C. & Schüttenhelm, R.T.E., 1989. Quaternary Geology, Silver Well Sheet 54º N-02º E. 1:250 000 map series, British Geological Survey & Rijks Geologische Dienst, Ordnance Survey, Southampton.

Judd, A.G. & Hovland, M., 1992. The evidence of shallow gas in marine sediments. In: Davis, A.M. (ed.) Methane in marine sediments, Cont. Shelf Res. 12: 1081-1097.

McQuillin, R, & Fannin, N.G.T., 1979. Explaining the North Sea floor. New Scientist 1163: 90-92.

Meldahl, P., Heggland, R., Bril. B., & de Groot, P., 2001. Identifying faults and gas chimneys using multiattributes and neural networks. The Leading Edge, 20-5: 474-482.

Trasher, J., Fleet, A.J., Hay, S.J., Hovland, M., & Düppenbecker, S., 1996. Understanding geology as the key to using seepage in exploration: spectrum of seepage styles, In: Schumacher, D. & Abrams, M.A. (eds.) Hydrocarbon migration and its near-surface expression: AAPG Memoir 66: 223-241.