Geohazards Seminar
Arranged by the FORCE Geophysical Methods Group
TUESDAY 6th December
Programme

08:00 – 08:30: Registration and poster display.

Introduction:

08:30 – 08:40: Introduction and HSE
08:40 – 09:00: Setting the scene
Fritjov Riis, NPD
09:00 – 09:20: What is a GeoHazard – A drilling perspective
Terje Skar ,ConocoPhillips

Acquisition and Processing Technology:

09:20 – 09:40: Site Survey Geophysical Acquisition – A recent history and an idealized future,
Gavin Douglas, Fugro Geoconsulting
09:40 – 10:00: High resolution PCable 3D seismic acquisition from shallow to deep water in shallow gas hydrate areas.
Stefan Buenz, UiT

10:00 – 10:30: **Break and poster display**

10:30 – 10:50: Integrated solutions for Geohazard surveys.
Robert Soubaras, Yves Lafet, Shuki Ronen*, Bob Dowle, Dominique Boitier, Roar Nygaard, CGGVeritas
10:50 – 11:10: Ghost-free seismic acquisition – a step change in data resolution and interpretability
Per Eivind Dhelie, PGS
11:10 – 11:30: Processing of high resolution seismic data
Ian Stennett, Gardline
11:30 – 11:50: Advances in 2D and 3D GeoHazard Processing
Andy Cowlard, Fugro Seismic Imaging
11:50 – 12:10: 3D Hi-res seismic in deep water.
Best practices **Floris Striijbos or Rian de Jong, Shell**

12:10 – 13:30: **Lunch and poster display**

Analysis and case studies:

13:30 – 13:50: Integrated Geohazard assessment – The case for correlation, calibration and careful consideration
Michael Clare and Stephen Thomas, Fugro Geoconsulting

13:50 – 14:10: Submarine landslides offshore Norway – summary of observations and implications.
Jan Sverre Laberg, UiT

14:10 – 14:30: **Break and poster display**

14:30 - 14:50: Geohazard investigations using seismic techniques – current approaches and applications
Richard Orren and Francis Buckley, Senergy

14:50 – 15:10: Limitations in HR2D seismic: not understood then and not understood now,
Karen Ware, Andy Malone and RPS Energy Geohazards Group

15:10 – 15:40: Statoil's experience with geohazards evaluation on the NCS
Dag Lundquist, Statoil

15:40 – 15:50: Summary and wrap-up.

Organizing committee: ,
Tim Austin – ConocoPhilips,
Odd Fuglestad – GDF Suez,
Thomas Tvedt – EON Ruhrgas,
Annemieke van den Beukel – A/S Norske Shell
Oddny Svendsen – NPD
Tone Aanestad – NPD

Setting the scene

Fritjov Riis, NPD

Awaiting abstract – notes from presenter

Introduction: Gas in the shallow section, formation of gas seeps and pockmarks.

Examples of shallow gas as a geohazard in exploration drilling (6407/6-2 and 7/8-5 S)

Examples of shallow gas in the production phase (Tordis, Valhall, Gullfaks, Troll)

Evaluation of risk of gas leakage in CO2 storage projects and possible methods of supervision

Gas hydrates, free gas and slope stability

Occurrences of drilling problems caused by boulders and boulder beds

Kicks and identification of overpressured zones

What is a GeoHazard? – A drilling perspective

Terje Skar; John Burgess; Tim Austin

ConocoPhillips Skandinavia

During exploration well planning there is always a lot of discussion between drillers, explorationists and site survey contractors on the definition of potential drilling hazards in the shallow section.

Classification and terminology differs between the groups and thus the perception of the hazard. If not carefully QCed potential mis-communications could lead to unnecessary additional expenditure.

The risk of shallow gas is usually the main issue. The classification of high, moderate and low risk anomalies is critical for the well planning. Unfortunately from the interpreter's side the risk is usually applied to the risk of gas being present and not to the gas being a risk to the drilling operation. Other issues important to drilling are the presence of cobbles and boulders particularly when within overconsolidated intervals.

Another aspect is the definition of the type and variability of shallow soils. These are very important for ensuring sufficient foundation conditions for jack up rigs or anchoring conditions for semi submersible rigs.

In this presentation we will discuss what "geohazards" mean to drillers, when they are a concern, and therefore affecting the well planning.

Site Survey Geophysical Acquisition – A Recent History and an Idealized Future

Gavin Douglas, Geophysics Manager, Fugro GeoConsulting Limited

The recent past has seen some clear improvements in site survey geophysical acquisition. However, many aspects have remained largely unaltered; 2D HR systems, single channel seismic, pinger and side scan sonar methods today are very similar to those of the mid 1990s.

Improved future acquisition solutions for imaging of the tophole section might include

use of a high resolution 3D method, this would solve many 2D-related imaging problems but would significantly increase acquisition costs.

A specific problem with a 'standard' site survey spread can be the effective data gap between about 20 and 80 metres sub seabed – the interval beyond the penetration of shallow profiler systems and the point at which conventional 2DHR seismic becomes really useful. This can be a crucial zone for foundations and setting conductor pipe. New systems are capable of recording high frequency multi-channel seismic data using a small diameter streamer at a sample interval of 1/16th millisecond. With full seismic processing this may be a present-day glimpse of future standard practice for seismic reflection acquisition over the uppermost hundred metres sub-seabed.

If there is to be a revolution in site survey acquisition over intermediate water depths then it could be provided by AUVs. Improvements in battery technology and increased competition throughout the AUV industry make such future cost reductions likely.

Future trends in acquisition will also be shaped by developments outside the acquisition sphere; an example of this is the increasing use of short-offset reprocessed 3D data – this must reduce the incentive for the acquisition of bespoke high resolution 3D data.

Real world uncertainties related to oil price variation, and even future drilling incidents, will strongly influence how much and what type of acquisition development operators will demand from survey providers, and to what extent they will be prepared to pay for improved technologies.

High Resolution Pcable 3D seismic acquisition from shallow to deep water in shallow gas hydrate areas

Stefan Buenz & Juergen Mienert

University of Tromsø

The P-Cable system is a highly mobile and flexible system for the acquisition of high-resolution 3D seismic data in shallow and deep-water environments. The key component consists of a cable towed perpendicular to the ship's steaming direction, a so-called cross-cable, that is spread behind the vessel by two large trawl doors. Up to 24 multi-channel streamers with a length of 25 m are attached to the cross cable. The array of single-channel streamers acquire up to 24 seismic lines simultaneously, thus covering an approx. 240 m wide swath with close in-line spacing and on a short spread in a cost efficient way. Using high-frequency airgun sources, the spatial resolution of such a system is at least one order of magnitude higher than conventional 3D seismic, whereas the temporal resolution is improved 3-5 times. The increases in resolution facilitate a much better target identification and achieve a much more accurate imaging of for example shallow subsurface structures and fluid flow systems. The newly developed P-Cable 3D seismic system allows for high-resolution seismic imaging to characterize upper geosphere geological features focusing on geohazards, geofluid expressions, shallow gas and gas hydrate reservoirs. We will present examples from the mid-Norwegian margin, the Barents Sea and the W-Svalbard margin.

Integrated solutions for Geohazard surveys

Robert Soubaras, Yves Lafet, Shuki Ronen*, Bob Dowle, Dominique Boitier, Roar Nygaard

CGGVeritas

There have been some recent developments in marine seismic which have interesting potential applications for shallow hazard surveys. Developments in broadband seismic streamer techniques mean that there is now the possibility to acquire datasets which are suitable both for reservoir imaging and for shallow hazard detection and characterisation over entire fields with 3D datasets.

In particular, the combination of variable depth streamer acquisition and proprietary deghosting techniques (Soubaras, 2010) are able to provide data with a bandwidth of 2.5 – 150Hz and this can be extended to 200Hz (over 6 octaves) with the use of a broadband seismic source. The images provided by this technique are characterised by a high signal to noise ratio, even at very low frequencies, high temporal resolution and exceptional clarity, with an embedded wavelet which has a sharp peak and minimal sidelobes. This facilitates interpretation, especially for thin beds and subtle facies variations. These data have been shown to provide very detailed images of shallow channels just below the water bottom in the Central North Sea.

Beyond seismic images, the extended bandwidth of these marine broadband techniques, and in particular the low frequency content, has benefits for seismic inversion (both elastic inversion for impedance and rock properties and full waveform inversion for velocity). Soubaras et al (2011) have demonstrated that impedance inversion of the data provides more accurate and quantitative estimates of rock properties as shown by better well ties. The implication for geohazards is that seismic inversion results using these data will produce more reliable discrimination of hazards and reduce uncertainty in their interpretation.

For obstructed areas around infrastructure where streamer acquisition is not possible we have seen (Koster et al, 2010) that ocean bottom nodes are able to provide high-resolution broadband seismic data, suitable for the identification of shallow hazards, both via imaging and potentially through seismic inversion. Even with sparse patches of nodes, processing techniques such as mirror imaging (Ronen et al, 2006) can produce detailed images near the water bottom which compare favourably with conventional site survey results.

We believe that these marine seismic techniques can complement the well established geotechnical and high-resolution / high-frequency 2D seismic surveys currently used in the industry and improve our abilities to delineate geohazards. This will be best achieved through industry partnerships between seismic and site survey contractors (such as Gardline CGGV) which operate multidisciplinary vessels and have the expertise required to properly integrate a range of geophysical and geotechnical data.

Ghost-free seismic acquisition – a step change in data resolution and interpretability

Per Eivind Dhelie, PGS

In 2007, PGS addressed the problem of the ghosts that occur close to the marine receivers by launching the dual-sensor marine GeoStreamer. In 2011, we complemented this technology advance by launching GeoStreamer GS, which combines the dual sensor streamer and a new concept, the GeoSource, to remove the ghosts on both the source and receiver side. By operating these two technologies in partnership, both source and receiver ghosts can be eliminated robustly. The resultant ghost-free source signature now be removed in a deterministic way. At this stage, the nature of the Earth's attenuation clearly is visible and can be compensated for. The end result is ghost-free, broadband data revealing the true earth response. Removal of both the source and receiver ghosts at an early stage in the preprocessing sequence,

offers advantages for subsequent processing steps including de-multiple, velocity analysis, and imaging and produces high-quality prestack as well as post-stack data.

Several new seismic lines were acquired in the Norwegian Sea with a variety of streamer depths and source array parameters. Conventional hydrophone only data were acquired with a streamer depth of 8 m and a conventional source towed at a depth of 5 m, whereas the GeoStreamer GS used the dual-sensor streamer at 25 m, and the sub-sources in the GeoSource were towed at 10 m and 14 m. These comparisons show the effect of removing the various responses imposed by the acquisition system and earth filtering effects. The conventional seismic data are significantly defocused, whereas GeoStreamer GS data are clear and focused and show the detailed structure. The spectrum for the conventional acquisition clearly shows the two sets of notches caused by the source and receiver ghosts and a decaying spectrum caused by the earth filtering effect, while the GeoStreamer GS data show a flat spectrum with all of these effects removed. The frequency range in these spectra is from 0 to 225 Hz, showing that there is a good signal-to-noise ratio in the data all the way up to ~200 Hz. The ghost-free results provide a step change in data resolution and interpretability. Subtle stratigraphic and structural features are easily interpreted using ghost-free data, whereas many of the same geological features cannot be resolved on conventional data.

Processing of High Resolution Seismic Data

Ian Stennett

Gardline

“The up to date techniques used in processing HR2D data will be discussed, with the emphasis on frequency content, resolution and amplitude preservation. A review of the current approach to AVO and the acquisition and processing of HR3D and pseudo HR3D data will also be presented.”

Seismic processing at Gardline has been specialising in the processing of high resolution datasets for more than 20 years, and we have processed nearly 500,000km of seismic data over a wide range of data areas from across the world.

Our processing techniques are focused on maintaining the highest frequency content and preserving the true amplitude range of the data of the data, to maximise its resolution and interpretability specifically for the purpose of identifying potential geohazards.

This presentation details the procedure that we implement to test an individual seismic dataset, progressing through amplitude recovery, noise removal, multiple attenuation, velocity analysis, muting and migration techniques. Each stage is reviewed in detail with the aid of sequenced displays, spectral analyses, and difference displays, and the final processing sequence is presented to our clients in this format, some examples of these presentations will be included in this presentation. In addition to this we will draw on other examples of 2D, 3D and pseudo 3D datasets we have produced.

Data deliverables are often also provided for AVO analysis this may require a processing sequence refined for this dataset, removing additional multiple that may not be evident on a stacked product, and the attention to the amplitude ratios of adjacent offsets that may skew the AVO results.

Finally we will look at the time scales for these projects, and review the constraints we have in producing the final datasets and what further processing developments may be possible without these limitations.

Advances in 2D and 3D Geohazard Processing

Andy Cowlard, Managing Director, Fugro Seismic Imaging

The Short Offset 3D reprocessing method has been routinely available for geohazard evaluation for the last fifteen years or more. However, the processing flows employed have evolved continuously over this period and now only vaguely resemble the original application. In particular, algorithms for attenuating noise and multiples and for enhancing signal have become increasingly sophisticated. By way of update, some examples of this continual upgrading of the product are offered, with emphasis on optimising results in shallow water. 3D SRME is especially relevant for the near offsets of a multi-streamer spread where azimuths vary considerably. A method is also presented whereby shallow events whose incidence angles exceed critical values are reconstituted from the associated multiple energy. In summary, we hope to offer a calibrated answer to the question “How shallow is shallow?”.

2D geohazard processing has also benefited from technological advances, particularly with respect to multiple attenuation. However, the excellent resolution of the 2D data set is compromised by the uncertainty of the structural imaging compared to the 3D product described above, an effect that increases with increasing depth. To address this issue a method of 3D interpolation and migration using a multi-azimuth 2D grid is described.

High-Definition Seismic Imaging for Shallow Hazards

Floris Strijbos (Shell International, the Hague, formerly A/S Norske Shell), Rian de Jong (A/S Norske Shell)

Good quality high frequency data is needed to generate high-definition images, which are required for the safe positioning of platforms, pipelines, and wells. Although high frequency data is recorded in traditional seismic surveys, the high frequency content is weak and the spatial recording sampling is usually too coarse. This is why a dedicated (2D) high resolution site survey is usually required to generate high definition images. However, in our new high-definition (HiDef) seismic processing workflow the careful selection of near offset traces and the intelligent interpolation to de-alias the data allow us to preserve the full temporal and spatial resolution of the acquired data. This process substantially increases the image quality and resolution that can be obtained from a conventional 3D seismic survey. In deep water if effectively eliminates the need for hi-res site surveys.

This HiDef seismic processing workflow was developed in Norske Shell, and was first applied to deepwater exploration prospects and fields. Submarine slides at a prospect along the Atlantic Margin (0-400 m below seabed) were imaged at very high resolution. The correct and detailed imaging of these slides has reduced risks before (planning) and during drilling.

Following the deepwater success in Norway, the HiDef processing technique has become a best practice in Shell that is applied in deepwater locations around the world. More recently, its application has been extended to shallower water. The HiDef technique has now been applied to all of Norske Shell's development assets. A number of HiDef examples will be shown in the presentation.

Integrated Geohazard Assessment – The Case for Correlation, Calibration and Careful Consideration

Michael Clare [1] and Stephen Thomas[2]

Engineering Geology and Geohazards Team, Fugro GeoConsulting Limited, Wallingford, UK

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The development of high frequency geophysical techniques, such as AUV-deployed Chirp, adds significant resolution to the shallow section and greatly benefits geohazard assessment for field developments and pipeline routing. Lateral extents of units with distinct acoustic character can be mapped to give an indication of areas that have featured past mass movement events, and identified as potentially geohazardous zones. Reconstruction of individual events is often attempted directly from Chirp data, with specific respect to magnitude and frequency. This may overreach the limitations of the data however, in that multiple event deposits have been identified from detailed sedimentological core logging within individual seismostratigraphic units. Therefore, interpretation of mass movements solely from geophysical data may significantly underestimate frequency and overestimate magnitude of events.

While this emphasises the importance of detailed sedimentological core logging in a credible geohazard assessment, it does not serve to devalue the AUV Chirp data. Instead it stresses the need to understand the limitations and resolution of the data, and highlights the benefits of a multidisciplinary assessment that should incorporate geophysical, geological, geochronological, and geotechnical data. This improves the confidence in geohazard scenarios, facilitating credible modelling analyses and leads to a more realistic assessment of impact, and thus risk.

References

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Thomas, S., Bell, L., Ticehurst, K. & Dimmock, P. (2011). An investigation of past mass movement events in the West Nile Delta. In Gourvenec & White (Eds.), *Frontiers in Offshore Geotechnics II* (pp. 239-244).

Submarine landslides offshore Norway – a summary of observations and implications for initial deformation and flow dynamics

Jan Sverre Laberg

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Some of the world's largest submarine landslides, i.e. the Storegga and Trænadjupet Slides have affected the continental margin offshore Norway during the Holocene. The slides have mainly affected glacigenic and contouritic sediments on slopes characterized by a very low gradient. The steep headwalls of these events are located at or near the shelf break and reaches up to 120 m or 150 m for the Storegga and Trænadjupet Slides, respectively. The Storegga Slide affected an area of about 95.000 km2 while the area affected by the Trænadjupet Slide has been estimated to 14.100 km2. The upper slide scar morphology is dominated by blocks and ridges of glacigenic sediments. They have steep edges and reach a high of several tens of meter implying that they comprise relatively consolidated sediments. Over a distance of some km most of these blocks and ridges break up and remolds by incorporation of sea-water to form muddy sediments forming the matrix of large debris flows, other blocks did not disintegrate over a flow distance of ~200 km.

The basal slip surface of the slide scar (corresponding to the base of the blocks and ridges) has been found to be sub-parallel to adjacent sea-floor. In some cases this surface includes escarpments separating surfaces of similar morphology at different depth. Down-slope oriented striations imply that they were formed by erosive flows. The striations could have been formed by erosion from consolidated blocks at the base of the flow. These surfaces developed within contouritic sediments implying that they were the "weak layer" that initially failed and onto which the blocks and ridges started to move. The weakness of the contouritic sediments have been ascribed to their physical properties and/or the development of excess pore pressure due to a combination of rapid loading of a thick unit of glacigenic sediments, the low permeability and thus the high sealing capacity of the glacigenic sediments and/or dissociation of gas hydrates. Slip surfaces at several stratigraphic levels implies sediments of these properties at several depths.

These observations indicate that the slides probably were retrogressive events starting within contouritic layer(s) somewhere downslope of the shelf break to successively involve the upper slope. The Storegga Slide resulted in a tsunami wave which impact have been found to have affected coastlines from Scotland to Finnmark with run-ups of up to several tens of meters. Modeling has shown that one implication of the generation of a tsunami of this size is that these retrogressive slides must have been a more-or-less instant events remobilizing enormous amounts of sediments over a very short period of time. The extreme mobility of these giant events is enigmatic. A muddy turbidite sourced from the Storegga Slide have an estimated run-out distance of c. 400 km. Debris flows from the Trænadjupet Slide were bringing sediments to the foot of the slope some 200 km from the headwall. The run-out of the turbidites associated with this event is not known.

Geohazard investigations using seismic techniques - current approaches and applications

Richard Orren and Francis Buckley

Senergy

High resolution 2D (HR2D) seismic data has been in routine use over the past few decades for identifying top-hole drilling hazards principally for wells in shelf environments. In the past few years this practice has become more tightly regulated and controlled by governmental and industry best-practice frameworks. Technological advances in acquisition, processing and interpretation have lead to refinements in geohazards analysis, and the adaptation of the HR2D multichannel method to assist many other aspects of offshore activity, such as foundations analysis for rig siting and the emplacement of field development infrastructure.

In parallel, 3D seismic exploration data has been used increasingly in geohazard assessment. This has been coupled with moves towards higher resolution data acquisition and even HR3D acquisition for site survey purposes. The 3D method has been used in particular for geohazards evaluation for deep water wells, but tightening HSE requirements for more rigorous analysis of top-hole conditions in deepwater wells have resulted in more defined criteria for assessing the adequacy of such data and the need for complementary HR2D data. Re-processing options on exploration 3D data, such as the Short-Offset re-processing algorithm, have also been shown to provide a cost effective alternative to HR2D acquisition in some cases.

Together with these changes, the availability of advanced seismic workstation technology has enabled the integration of all these datasets in a fast and efficient interpretation methodology.

Senergy S&G will review these industry developments, with examples, indicate best practice approaches to address these various geohazard tasks, and indicate the areas where further improvements could be achieved.

Limitations in HR2D seismic: not understood then and not understood now

Karen Ware, Andy Malone and RPS Energy Geohazards Group

Discussion surrounding the requirement for HR2D seismic data is based on a lack of understanding of the value and reliability of 2D seismic data in comparison to 3D data. This is particularly relevant in deep water, where the use of HR2D seismic can result in false positive identification of hazards. It is important not to view temporal (vertical) resolution of HR2D data in isolation without consideration of the impact of spatial resolution, errors and limitations of the data set. In comparison 3D seismic data, although lower in temporal (vertical) resolution, has vastly improved spatial resolution and should remain more accurate in terms of amplitudes and positioning. It therefore has much higher data integrity and accuracy. Spatial resolution is much greater value for the types of hazards seen in deep water (shallow water flow benefits from regional data, over pressure benefits from the ability to map spatially over large areas). HR2D seismic should only be acquired with an understanding of the limitations and with a specific goal in mind.

Unpredicted Shallow Gas Incidents on Norwegian Continental Shelf

Dag Lundqvist

Statoil

During 2009 and 2010 several incidents occurred during drilling operations when pressurized shallow gas was encountered. These shallow gas levels were not predicted during the pre-drilling site investigations. The incidents occurred both in the North Sea and offshore Mid-Norway.

The incidents were thoroughly investigated by the Geohazard team in Statoil and several conclusions were drawn.

During 2009 and 2010 several incidents occurred on Norwegian Continental shelf when pressurized shallow gas was encountered during

- On one occasion, the gas was not visible as an amplitude anomaly but clearly visible as an AVO anomaly.
- On one occasion, the shallow gas was encountered at 800 m (MSL) which was in this area considered too deep for regular 2D High Resolution seismic.
- On one occasion the predicted shallow gas level was tested by a pilot hole. No gas was encountered and for the re-spud well, the well was reclassified as a “No Shallow Gas well”. Pressurized gas was encountered during the drilling of the second well some 50 m away but through the same anomaly.
- On one occasion the shallow gas level was penetrated but the gas was not registered until the well has penetrated into a layer 40 m below the actual shallow gas level.
- Pressurized shallow gas was encountered during the drilling of a geotechnical borehole.

As a result of these incidents several actions were taken to ensure that all the data used during the interpretation were examined to their full degrees. Following actions were taken.

1. AVO analysis are carried out routinely on all site investigations. Both on 2D Hi Res and 3Dseismic data.
2. The single channel Mini Airgun Streamer was changed for a multichannel, shallow-towed streamer to enable the removal of multiples.
3. A better QC system regarding the final well classifications were utilized.
4. A full geohazard classification is carried out also for geotechnical borings