

# **PUBLISHABLE FINAL REPORT**

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**TITLE :Overpressure Detection with Seismic and Well Data**

**PROJECT CO-ORDINATOR : Altinex ASA (formerly Well Service Technology AS)**

**Bergen, NO**

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# Overpressure Detection with Seismic and Well Data

## Abstract

### Project Objectives:

The prediction and detection of abnormal formation pressure is fundamental to hydrocarbon exploration activities. It is essential for reliable well planning (well design, rig selection, cost estimation and risk assessment), critical while drilling for well control and formation pressure data can be used to predict whether accumulations are commercial or non-commercial as well as the type of hydrocarbon present. Experience has shown that, with good seismic data, a rough estimation of formation pressure can be obtained.

This project followed an integrated approach that combined the standard prediction technique from velocity analysis with a priori geological information, basin modelling and inversion while drilling, wave form (seismic) analysis relating amplitude information (Q) to fluid pressure, and well log calibration.

For an accurate interpretation, all the techniques require an understanding of the relation between the properties of over-pressured sediments and their seismic response. Laboratory data were used to determine velocity -porosity transforms and rock physics models, based on laboratory and well log data.

The methods developed were integrated by means of a prototype software for pore pressure prediction based on seismic modelling and inversion and was tested with field data from North Sea Viking Graben wells.

### Results :

A comprehensive 3D geological model was developed for the Viking Graben region for seismic and basin analysis. Extensive laboratory measurements were carried out to determine the effects of rock properties on seismic parameters. Seismic methods for supporting pore pressure prediction were developed and an integrated approach to pore pressure prediction exploiting prestack migration and seismic tomography was tested against field data.

It was shown that the seismic velocity obtained by careful analysis of pre-stack 3-D data from the deep and complex Tarbert reservoir in the Tune field is sufficiently sensitive to pressure and pore fluid to perform a meaningful analysis. The velocity and pressure distribution complies well with the structural features of the target and the general geological understanding of the pressure compartments in the Tune field.

The partial saturation model used for pressure prediction can conveniently be calibrated against well data, provided that a complete set of logging data are available for the zone of interest. The most important part of the prediction process is the determination of the effective stress coefficients and dry-rock moduli versus effective pressure, since these properties characterize the acoustic behaviour of the rock. The

inversion method based on the shaley sandstone model requires that some parameters are fixed while inverting the others. For instance, assuming the reservoir and fluid properties (mainly, the saturation values), formation pressure can be inverted. Conversely, assuming the pore pressure, the saturations can be obtained. The latter implies that this method may be used in reservoir monitoring where the pressure distribution is known while saturation, i.e., the remaining hydrocarbon reserves, is uncertain.

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## **Objectives**

The prediction and detection of abnormal formation pressure is fundamental to hydrocarbon exploration activities. It is essential for reliable well planning (well design, rig selection, cost estimation and risk assessment), critical while drilling for well control and formation pressure data can be used to predict whether accumulations are commercial or non-commercial as well as the type of hydrocarbon present. Experience has shown that, with good seismic data, a rough estimation of formation pressure can be obtained.

Better prediction of pore pressure requires a better fundamental understanding of the basic rock physics of over-pressured sediments. For instance, shale and sand show a completely different behaviour under pressure. Significant improvements in seismic acquisition and processing enable energy loss to be measured, leading to the correlation of low-velocity and high-loss zones with over-pressuring.

The objective of this project is to improve the predictive modelling capabilities to take advantage of the availability of improved seismic data and its processing.

This project followed an integrated approach that combined the standard prediction technique from velocity analysis with a priori geological information, basin modelling and inversion, wave form (seismic) analysis relating amplitude information (Q) to fluid pressure, and well log calibration. Since the models to be developed required information on rock properties that are not available in the literature it was necessary to include an experimental rock physics program.

## **Technical Description**

In order to obtain relevant experimental and field data for development, calibration and testing purposes a case-study area was selected in the northern Viking Graben on the Norwegian continental shelf for this investigation. The case study data were provided by Norsk Hydro and its partners for the specific objectives of this project, namely

build geological cellular models created with sedimentological and fault data derived from well log and seismic interpretation and incorporating a variety of attributes including lithologies, porosity-permeability properties and seismic velocities.

laboratory measurements of the precise relationships between seismic velocity, attenuation and effective pressure for lithologies of the case study area

investigate sensitivity of seismic data to formation pressure through the generation of full wave-form seismograms and amplitude-versus-offset (AVO) analysis

apply a novel method for the estimation of pore pressure to a well planned for the study area whereby a procedure for basin modelling and inversion is used for the determination of locally valid compaction relations for the sediment column of the case study

integration of pore pressure and petro-physical data for the study area

Comparison of pore pressure prediction based on Q estimation derived from sonic log and VSP data with laboratory measurements of Q

Development of log interpretation techniques for deriving rock physical properties such as porosity, permeability and fluid saturations are to that key predicting pore pressure from seismic

## **Results and Conclusions**

### **Results**

The main results obtained in the project can be summarized as follows.

A complete cellular geological model was created with an associated database for formations of particular practical interest in the study area.

Comprehensive set of experimental data on rock physical properties and seismic parameters derived from rock samples taken from the study area. (This work also required to further development of existing equipment, experimental methods and procedures as well as data analysis techniques.)

A fault-analysis-based flow model was developed for key reservoir sections where overpressure is observed in the study area. Fault property estimates were used to investigate the physical conditions under which over-pressure develops and may be maintained. These results are useful to assess the uncertainty of the fault distributions obtained from the seismic interpretations.

Models were developed for

Comparison of seismic attenuation as derived from sonic logs and VSP data with laboratory measurements by means of a genetic annealing algorithm.

Acoustic model for seismic velocity versus clay content, pore fluid and effective pressure

Overburden corrections in AVO analysis for visco-elastic fine-layering

Neural nets for estimating porosity and permeability from suites of log data (including MWD) accounting for various reservoir fluids.

Committee neural networks for porosity, permeability and saturation estimates from log data

We investigated the seismic detectability of an overpressured reservoir in the case study area by computing synthetic seismograms for different pore-pressure conditions by using an integration of the techniques described above.

The results of the seismic detectability study indicate that changes in pore pressure can be detected with seismic methods under circumstances such as those of moderately deep North Sea reservoirs.

In order to extend this method to obtain pore pressure in shaley sandstones, an acoustic model for seismic velocity versus clay content and effective pressure was required.

### Pore Pressure Prediction with Seismic

Calibration of the model requires log data, porosity, clay content and sonic velocities to estimate the dry-rock moduli and the effective stress coefficients as a function of depth and pore pressure. The seismic P-wave velocity, derived from seismic modelling and inversion techniques, was fitted to the theoretical velocity by using pore pressure as the fitting parameter. The method was applied to the Tune field in the Viking Graben sedimentary basin of the North Sea. We have obtained a high-resolution velocity map that reveals the sensitivity to pore pressure and fluid saturation in the Tarbert reservoir. The velocity map of Tarbert and the inverted pressure distribution agree with the structural features of the Tarbert formation and its known pressure compartments.

### Conclusions

Porous flow modelling within the study area indicates that relatively high fluid flow rates and extremely low transmissibilities across fault blocks are required to maintain the observed pressure gradient for geologically significant periods.

The most likely cause of the high flow rate is gas generation.

Low transmissibilities are most likely due to fault rock properties, possibly exacerbated by a reduction in effective reservoir permeability due to a gas accumulation on the downthrown side of the fault.

The velocity obtained by careful analysis of pre-stack 3-D data from the deep and complex Tarbert reservoir in the Tune field is sufficiently sensitive to pressure and pore fluid to perform a meaningful analysis. The velocity and pressure distribution complies well with the structural features of the target and the general geological understanding of the pressure compartments in the Tune field. The partial saturation model used for pressure prediction can conveniently be calibrated against well data, provided that a complete set of logging data are available for the zone of interest. The most important part of the prediction process is the determination of the effective stress coefficients and dry-rock moduli versus effective pressure, since these properties characterize the acoustic behaviour of the rock. The inversion method

based on the shaley sandstone model requires that we fix some parameters while inverting the others. For instance, assuming the reservoir and fluid properties (mainly, the saturation values), formation pressure can be inverted. Conversely, assuming the pore pressure, the saturations can be obtained. The latter implies that this method may be used in reservoir monitoring where the pressure distribution is known while saturation, i.e., the remaining hydrocarbon reserves, is uncertain.

Unlike previous theories, we have used a Biot-type three-phase theory that considers the existence of two solids (sand grains and clay particles) partially saturated with gas and fluid. The theory was developed by Carcione et al. (2000) and is generalized in this project to include the effects of pore and confining pressure, and a two-phase pore-fill, in order to estimate pore pressure from seismic velocities in a gas reservoir. The method requires high-resolution velocity information, preferably obtained from seismic inversion techniques. As is well known, interval velocities obtained from conventional seismic processing are not reliable enough for accurate pore pressure prediction.

Calibration of the modelling requires well information, that is, porosity and shale volume estimation, direct measurements of pore pressure and sonic-log data. Laboratory measurements of P- and S-wave velocities on cores samples may further improve the calibration process.

In spite of the reasonable success achieved in this first attempt at applying the methodologies of this study to the North Sea study area, Tune, it can be said that there is still a lot of additional development work to be done on all aspects reported here. Additional laboratory and field data will have to be acquired to fully qualify the approach for the North Sea as well as other regions and the seismic modelling and inversion processes and software tools will need to be made more robust in order to make the prediction process more effective.

## Exploitation Plans and Anticipated Benefits

The list of deliverables for the project is as follows.

- Updated 3-D cellular geological attribute model for a northern Viking Graben area. Related to WP 1 and 2.
- Results from laboratory experiments on the effects of pressure on seismic properties. Related to WP 2 and 3.
- Systematic characterisation of seismic wave velocity and attenuation/pore pressure response for sandstone/shale lithologies. Related to WP 3 and 4.
- Modelling package for wave simulation in partially saturated porous media. Related to WP 4 and 5.
- Modelling package for wave simulation in anisotropic Related to WP 4 and 5.
- Software package to extract lithological information from surface seismic data by using AVO techniques and the CSD method. Related to WP 3, 4 and 5.
- Pore pressure prediction method and software prototype. Related to WP 1, 2, 3, 4 and 5.

Each lead Partner for the various work packages is responsible to pursue the exploitation of their results in their research and practical applications of the results.

But there is no question that Norsk Hydro who provided all the field data and had the leading role in the integration of the 3D modelling, laboratory data, seismic modelling methods and the final seismic data migration and inversion techniques to obtain a pore pressure prediction for the Tarbert formation of their Tune field have realized an important exploitation of the project work directly.

In addition Hydro developed some neural-net based log interpretation methods which also have wider application in their work to understand the geology and recovery processes to the fields they are producing.

Altinex (formerly Well Service Technology) was originally expecting to fully capture the results in their pore pressure prediction services but unfortunately this service is no longer offered by Altinex.