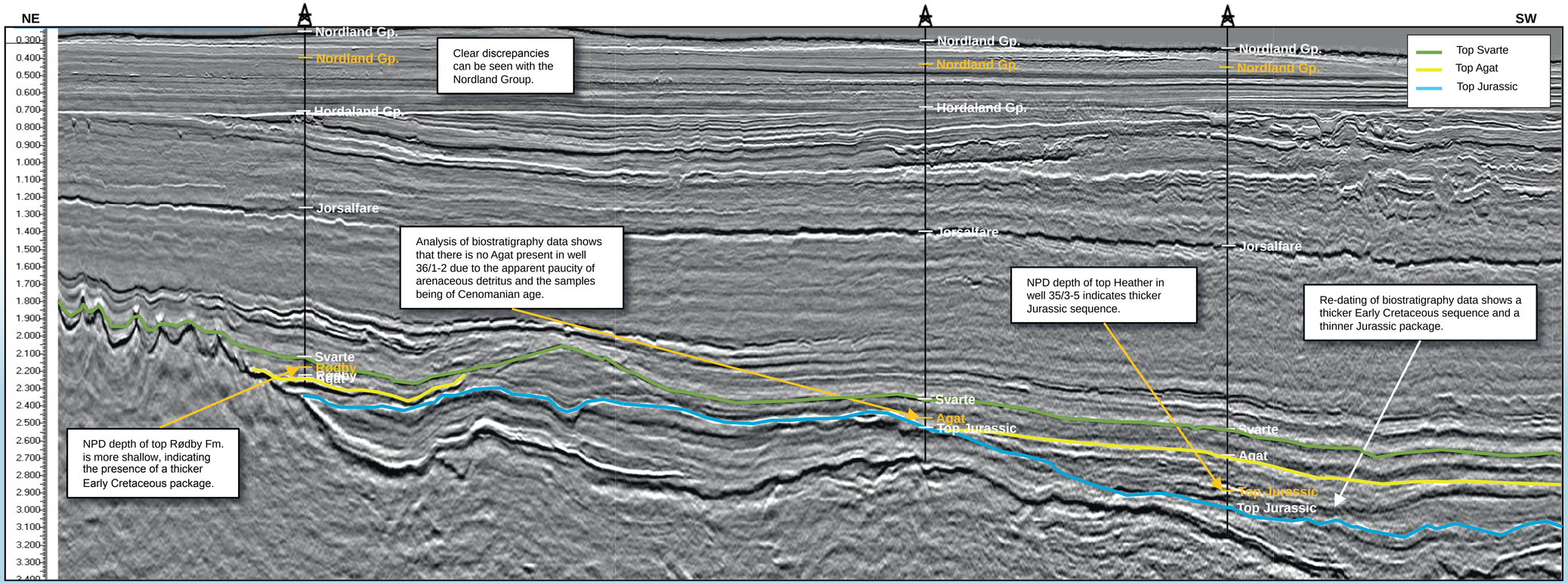
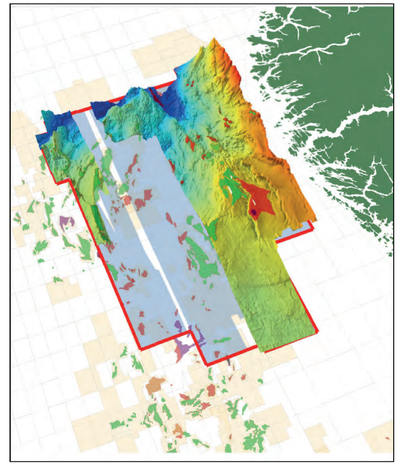
Northern Viking Graben:

Integrated geoscience unlocks greater potential in a mature basin

CGG draws on its integrated geoscience expertise to deliver innovative methods that lead to a new understanding of a mature petroleum basin, reducing uncertainty and exploration risks.

The illustrated seismic section shows an arbitrary line cutting through three wells across the Måloy Slope. Two versions of lithostratigraphic formation tops can be seen on the section. The first, in white, are the revised tops from re-analysing data as part of CGG's Well Study. The second, in orange, are from the original NPD tops, highlighting where changes have been found. A clear difference can be seen from the revised tops due to the re-interpretation of biostratigraphy data, particularly in the sub-BCU interval, showing a much thinner Jurassic section than previously interpreted. This enhances our ability to identify reservoirs within the Agat Formation, therefore refining the thicknesses of the Late Cretaceous/Jurassic sequences.





The seismic line is from the CGG North Viking Graben BroadSeis/BroadSource survey. The 35,400 sq km survey, as shown on the map above, provides contiguous broadband seismic coverage across the Northern North Sea, and is the backbone of the integrated studies described in this article.

Integrated geoscience is the key to future exploration in the Northern North Sea

The Northern North Sea is a highly explored, mature petroleum basin where large discoveries such as Troll, Statfjord and Brage have been made. However, other large accumulations of hydrocarbons are still trapped in the subsurface as proven by recent discoveries, such as Brasse, which have been made as the result of the use of new advances in acquisition, technology and geological concepts.

The use of broadband data in combination with geological understanding, well data and reservoir characterization provides the possibility to fully understand petroleum plays and prospectivity, and to establish new intervals of interest, whilst giving insight into the stratigraphy in the area.

The Northern Viking Graben seismic dataset was acquired using CGG's BroadSeis™/BroadSource™ true broadband solution, which combines a multi-level source and curved variable-depth streamer technology with advanced and customized imaging technologies. The data set covers more than 35,000 km², spanning both the Norwegian and UK North Sea. The high-resolution seismic imaging is a key component of the ongoing integrated studies, which will enhance subsurface knowledge and assist with the identification of prospects and new play models.

These ongoing integrated studies will deliver a comprehensive geoscience package through the incorporation of multiple data types from many disciplines to help reduce exploration risk. Ongoing studies include regional well correlation and reviews of prospectivity, seep studies from satellite imagery and subsurface geochemistry, sedimentology/petrophysical analyses, gravity enhancements and seismic reservoir characterization, alongside broadband seismic data.

The focus of this article will be on just two of the many ongoing studies that form part of CGG's integrated geoscience exploration toolbox.

Well Study

CGG's regional Well Study comprises 50 wells that have been re-evaluated, tied and calibrated to the Northern Viking Graben dataset. The well data used within this study has been gathered from many different sources and consists of edited petrophysical logs, well-to-seismic calibrations, sedimentary descriptions of core, electrofacies analysis with a supervised and unsupervised approach, and re-interpretation of biostratigraphy samples.

These results, as seen on the foldout, go through an interactive quality control process by all experts from the different disciplines. When all the available input has been utilized, the updated well data is correlated and interpreted with the seismic data. The overall aim is to provide a fully integrated and calibrated product in an easily accessible form, that is ready to use for prospect evaluation in the Northern North Sea. All results will be displayed in a series of pdf charts, where all analysis is combined into one summary chart per well **(Figure 1)**. This

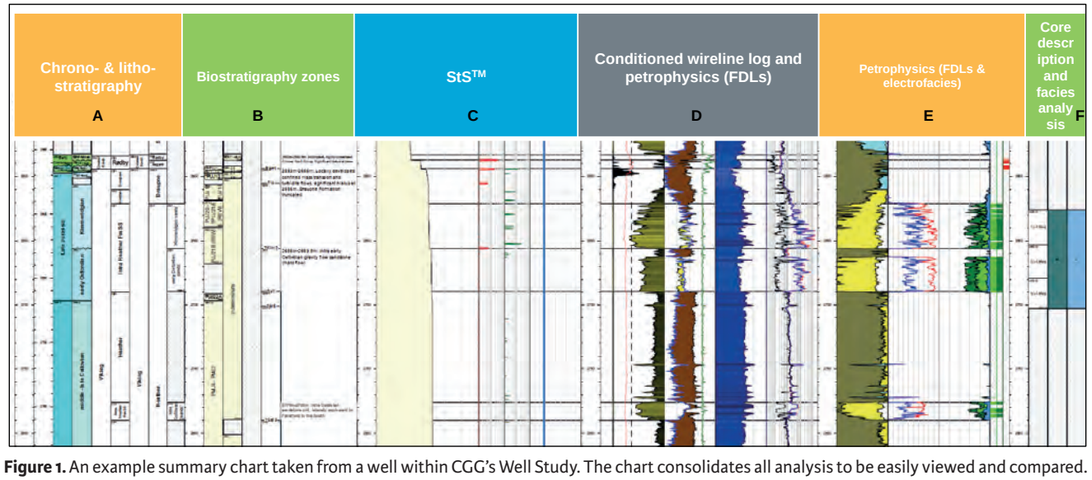


Figure 1. An example summary chart taken from a well within CGG's Well Study. The chart consolidates all analysis to be easily viewed and compared. **A**: Shows the difference between the NPD tops and revised tops due to re-analysis of biostragraphy. **B**: Biostratigraphy zones indicate which biostratigraphy samples were used and the depths they encountered alongside any comments on reworking or non-deposition. **C**: Stratigraphy to seismic curves indicating unconformities, re-working and changes in sea level. **D**: CGG log suite where all original logs have been environmentally corrected, cleaned and conditioned. **E**: Formation Description Logs created alongside interpreted pretrophysical data. **F**: Core descriptions carried out alongside facies analysis.

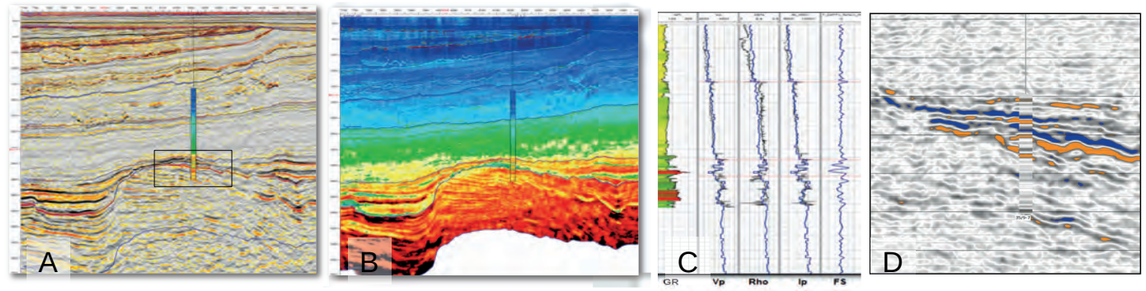


Figure 2. Crossline amplitude display over the Skarfjell structure (**A**) with the eight horizons used as a stratigraphic grid for the inversion and the results of the inversion shown here as an Acoustic Impedance display (**B**). Reservoir intervals are characterized by lower acoustic impedance values and are visible both in the Jurassic and the Cretaceous intervals. The quality of the inversion is confirmed by the very good match between the inverted attribute and the well log, respectively in blue and black (**C**). A zoom on the Skarfjell structure (**D**) shows the similarity between the AVO Intercept attribute as seen in the seismic and the AVO synthetic overprinted at the well location. Both the AVO and inversion products illustrate the quality of the North Viking Graben seismic data and add to the exploration tool box.

method allows for a data rich delivery package, alongside relevant SEG-Y and LAS files.

The study begins with all well data currently available and the cleaning and editing of petrophysical logs. These logs, which are referred to as CGG logs, are ready to use without the need for further quality control.

Checkshots available from the NPD over the selected wells can sometimes show discrepancies and erroneous results, particularly in the shallow sections over the Tertiary. The well-to-seismic calibration is a critical step in the study and a careful assessment of the wavelet character, quality of the wireline used for the synthetics and the general well conditions. This stage in the study gives confidence in the depths of formation tops and sequence boundaries. All edits to the original logs after this iterative QC stage are documented.

Results from revisiting the geological samples show a cyclical process where the core description and analysis is calibrated to the petrophysical analysis. Core description carried out at the NPD is currently available on 46 of the 50 wells, giving a good regional coverage from Tertiary to basement. By using the results from assigning facies to the core it is possible to extrapolate petrophysical characteristics away from the stratigraphic intervals that are calibrated to the cored sections for the electrofacies interpretation.

These results are then applied to the interpretation of biostratigraphy data available at each well. When reviewing the biostratigraphy data, samples and results have been provided through many different sources, such as data collected during drilling, cuttings from core and data available through literature and reports. Once these samples have been dated, a review can be performed on the current lithostratigraphy to help refine formation top boundaries and periods of non-deposition. These results are then tied to the Northern Viking Graben seismic, where all new analysis is correlated and mapped across the extent of the area.

3D Seismic Reservoir Characterization

3D attribute generation is a natural extension of the seismic products, and part of the integrated geoscience package is therefore dedicated to seismically-driven attributes. Based on the available final data, two multi-client Seismic Reservoir Characterization (SRC) projects have already been completed. 3D AVO attributes and 3D deterministic acoustic inversion were derived from approximately 3,200 km² of the BroadSeis™/BroadSource™ seismic data over the Ryggstein Ridge and the Måløy Slope. Targeting the Middle and Upper Jurassic sandstones in the Skarfjell area, and the Albian Agat play over the Måløy slope, these first two projects have benefited from close work between CGG geoscientists.

Working on the prospective intervals requires taking a closer look at the seismic data from which the attributes will be extracted. Extra post-stack flows may be applied, complementing the North Viking Graben main processing sequence in order to optimize the data quality at reservoir level. The extraction of AVO attributes is therefore performed after assessing the quality of the pre-stack data and applying additional filtering where needed. Once the angle stacks are ready, pseudo-gathers are created and a time-misalignment correction (TMC) step is performed prior to analysis of the AVO information. After confirming the AVO compliancy of the broadband data, the Intercept, Gradient and AVO product attributes are generated and used, for example, to map the gas-prone Agat Member.

Quantitative seismic interpretation is a critical addition to the exploration toolbox and the acoustic inversion route was chosen as it can be driven by the seismic data alone. Thanks to the low frequencies inherent in BroadSeis, an acoustic inversion based on scaled seismic velocities provides reliable inverted Vp and Acoustic Impedance (AI) results. While the CGG well logs (created as part of the Well Study) were used to define the local Gardner relationships, they were also used as blind tests for the inversion. The presented example of the Skarfjell discovery **(Figure 2)** shows low seismic residuals and a very good match between the inverted attributes and the recorded logs. Total porosity logs generated from the well logs will be coupled to the AI to generate porosity volumes.

CGG is currently working on more Multi-Client reservoir-oriented projects with the aim of covering the entirety of the North Viking Graben and producing more advanced proprietary reservoir work at prospect level.

These ongoing integrated studies are being carried out to provide a comprehensive understanding of petroleum systems within the Northern North Sea. They deliver tailored solutions to tackle current risks and challenges and can be focused into developing new play models and identifying prospects, as well as improving the understanding of existing fields and discoveries, when used in addition to high-quality broadband seismic. These two studies are just examples of how targeted integration of geology with broadband seismic helps to unlock the key uncertainties experienced today when attempting to fully understand petroleum systems.

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