CCS assessment and Near field exploration: a UK Southern North Sea dual-purpose reprocessing case study

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Summary

In mature basins such as the UK Southern North Sea (UK-SNS), energy companies face many challenges to optimize their exploration and production efforts along with growing environmental regulations and commitments to reduce carbon emissions sooner than later. Using existing released seismic datasets (26 surveys) and reprocessing them from field tapes on a regional 3D basis represents an effective and scalable data source for the development and implementation of advanced carbon capture and storage (CCS) site screening-characterization and infrastructure led exploration (ILX) activities. In this paper, a case study with these dual-purpose objectives will be presented focusing on the Triassic Bunter Formation deep saline aquifer for the CCS (post-salt) and Permian Rotliegend Group, Carboniferous ILX (pre-salt). These challenges have been addressed by a depth imaging reprocessing to enhance seismic imaging integrity from shallow to deep. To complement this effort a regional interpretation and quantitative interpretation (including regional rock physics, seismic inversion, and reservoir properties estimation) have been performed for a regional screening of around 12,000 sqkm for ILX and CCS site selection. This case study will demonstrate that an integrated geoscience approach can have a dual efficient benefit for the energy security and transition challenges we are facing today.

Introduction

Accessing high quality seismic data is an essential foundation for geoscience projects in general. The timing of accessing these products is critical, especially in today's environmental and political conditions. On the hydrocarbon exploration aspect, accessing high fidelity seismic data in a timely manner is crucial for effective exploration close to infrastructure. On the carbon capture and storage (CCS) side, recognized as a key technology to reduce our CO_2 emissions, there is an urgent need to find and develop suitable sites for storage, to evaluate the expected "performance" of such a store and make an early assessment on future monitorability. An integrated geoscience project has been developed in the mature UK Southern North Sea (UK-SNS) Basin, an area of significant hydrocarbon (mainly gas) production from the prolific Zechstein and Rotliegend stratigraphic intervals and identified also as one of the key areas for CCS. This paper covers the main steps, methodologies used and the main results over this area.

Database

The UK-SNS area (Figure 1) has a long history of petroleum exploration and production, and recent exploration success (Perenco, Ravenspurn South near field gas discovery, late 2023, in the Lower Leman sandstone, Rotliegend Formation and the Shell / Deltic Pensacola discovery, early 2023, in the Zechstein geological play) has renewed the interest in conventional energy resources. In addition, planned and ongoing energy transition projects (CCS and subsurface energy storage) indicate the significance of the Southern North Sea for the net zero economy and the UK-SNS. High quality seismic data is an essential foundation for these energy projects. The region is characterized by the presence of complex geological structures, including faulted and folded pre- and post-salt formations, mobile salt, and stratigraphic and lithological variations. In addition to these very relevant considerations for hydrocarbon exploration, the shallow gas and shallow-water environments, near surface sub-cropping old stratigraphy and structural modification of reservoir sections add a significant complexity to overall subsurface imaging starting from the very shallow, very relevant for the potential deep saline aquifer store (Triassic Bunter Formation). The Bunter Sandstone is thought to have significant potential to store CO_2 in this area (Chadwick, 2004). It has been extensively studied, with the storage potential evaluated by the British Geological Survey. The Bunter sandstone overlies the deformed Zechstein evaporite sequence, the proven regional hydrocarbon top seal. This holokinetic deformation commonly forms anticlines at Top Bunter level. 29 separate closures have been identified (Brook et al., 2003) and one of them, Bunter Closure 28 or BC28, representing a sizeable potential carbon store with the Triassic Bunter Sandstone Formation (BSF) is studied as a particular example.

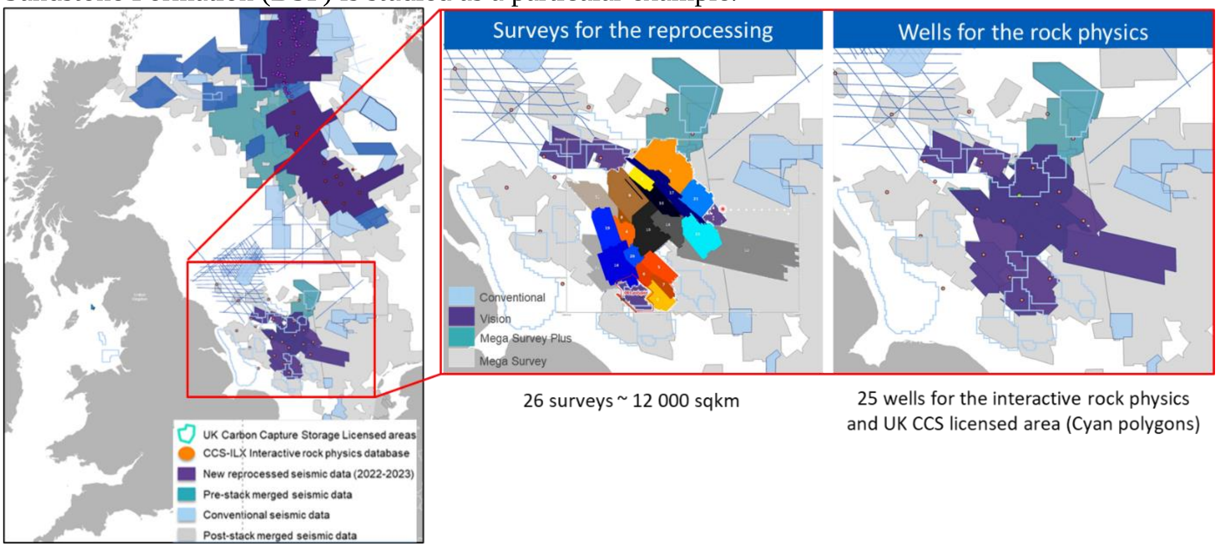

Figure 1: *Seismic coverage (26 surveys covering around 12,000 sqkm) and interactive rock physics well database distribution (25 wells) in the UK Southern North Sea (UK-SNS) used for near-field exploration and carbon capture storage site screening.*

Seismic reprocessing workflow

This case study aims at addressing effectively and efficiently two elements: screening for storage sites (focusing on the BC28) and evaluating new opportunities for hydrocarbons. To tackle this, access to high quality seismic data and a reprocessing effort has been conducted including 26 legacy data sets acquired between 1998 and 2006 including the integration of close to 100 wells for the velocity model building (VMB) and the elaboration of a regional rock physics analysis (further details thereafter).

The reprocessing sequence for this area includes: a combination of 2ms processing, modern day deghosting, a complex demultiple flow optimized for shallow water depth (3D SRME, 3D wavefield extrapolation SRME) and Full Waveform Inversion (FWI) for better imaging of shallow and complex velocity anomalies. This resulted in a seamless volume with improved resolution covering approximately 12,000 sqkm suitable for both conventional exploration and CCS projects (Figure 2) from shallow to deep. Imaging of complex geology and salt tectonics was effectively addressed through depth VMB, tomography, FWI updates, and Kirchhoff Pre-Stack Depth Migration (PSDM). FWI successfully resolved shallow features, revealed shallow salt and cap rock details as noted on the Figure 2. An accurate depth velocity model with well control coming from 31 wells spread over entire project area was crucial for achieving high-quality seismic imaging in the SNS. We illustrate examples of features to assess the uplift in subsurface imaging compared to legacy processing. One of such examples is accurate imaging and mapping of salt flanks and intra-salt heterogeneities such as salt stringers.

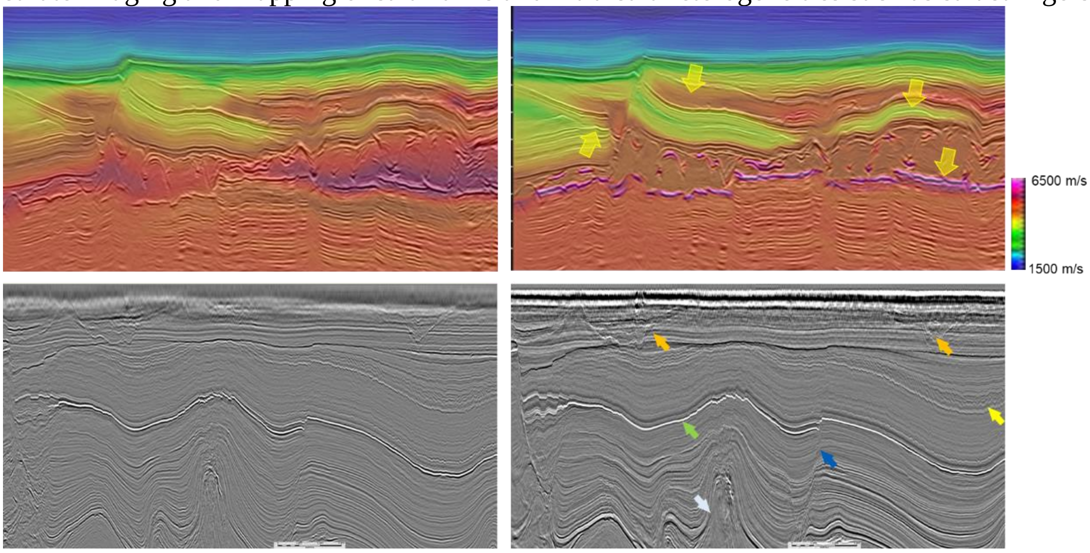

Figure 2: *Seismic example illustrating the seismic velocity improvement (top row with the legacy velocity model on the left and the updated one on the right). The FWI velocity model and reflection tomography highlighted by the orange arrow is sharper and geologically conformable. Geobodies representing some stringers in the salt have been automatically detected and integrated into the velocity, capturing some high velocity contrast. This has led to an uplift in the seismic amplitude (bottom row with the KPSTM on the left and KPSDM). Improvement can be observed from the shallow section: shallow channel (orange arrows), enhancement in the fault sharpness (blue arrow), in the clarity of the top Chalk (strong white event in the middle of the section, green arrow), polygonal faulting (yellow arrow) and definition of the top salt (light blue arrow in the deep section).*

High resolution seismic interpretation

Following this seismic reprocessing and the quantitative interpretation efforts, an automatic regional horizon interpretation (Pauget, 2009) was performed to rapidly interpret the volume and particularly the CO_2 storage horizons namely the BSF interval. This technology aims to work at the seismic scale to automatically derive a consistent geological model that encompasses structural and stratigraphic discontinuities, such as faults and stratigraphic changes. It relies on computing a model-grid from the extraction of billions of polarity-consistent micro horizons directly from the seismic image. The auto-tracked horizons after refinement can rapidly achieve a high quality geologically consistent interpretation. Once validated, the user computes a Relative Geological Time (RGT) model from the interpolation of the previously refined horizons within the model-grid. These depositional time surfaces can be extracted as a dynamic series of horizon stacks. This enables an interactive stratal slicing through the seismic volume where sedimentary and structural features for the overburden, the store and the pre-salt interval can be highlighted and mapped with accuracy. The RGT model can be used to rapidly generate detailed horizon stacks upon which any derived attributes, inversion data, seismic facies volumes, spectral decomposition, etc. can be extracted and visualized at a chronostratigraphic level. This method has proven to be very efficient at interpreting without much a-priori seismic interpretation over a significant area of around 12,000 sqkm (Figure 3) in less than 1 month after the seismic deliverables.

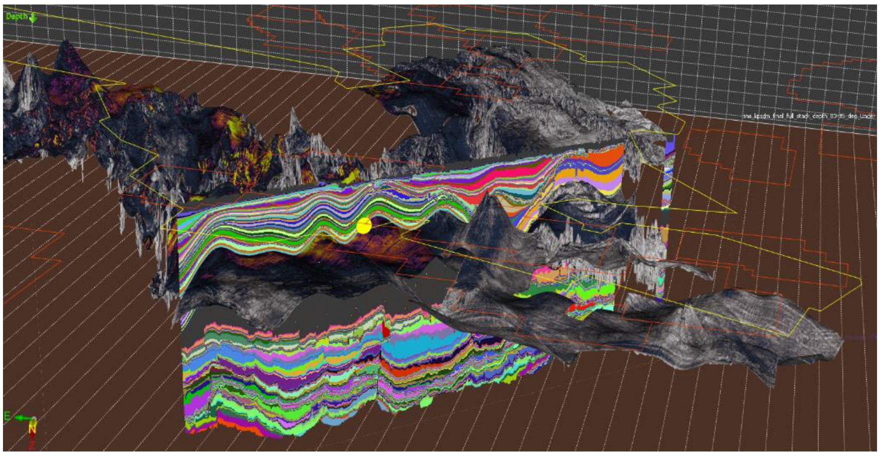

Figure 3*: 3D representation of the Relative Geological Time model and the top of the salt over the 12,000 sqkm of reprocessed seismic data. The internal salt structure as such has been excluded from the seismic interpretation and the focus has been on the top and base salt.*

Quantitative Interpretation workflow and porosity estimation

The overall workflow for the quantitative interpretation (QI) for the characterization of this dataset includes: petrophysics and rock physics analysis, well-to-seismic calibration, seismic stack(s) optimization or conditioning prior to seismic inversion for elastic property estimation, transform to reservoir properties (porosity) and integration of the below with the detailed seismic interpretation. To establish a proper reservoir understanding one of the elements to develop was the rock properties. 25 wells out of 2,000 wells screened (represented on Figure 1), were selected based on log data availability, length and quality. To fill the log gaps in some of the wells, an Artificial Intelligence (AI) and Machine Learning (ML) workflow was used (Ruiz, et al., 2021) based on a trained model established in the region as well as augmented elsewhere in a similar geological context.

On the rock physics side and for the BSF, the contact cement rock physics model (RPM) has been used to determine the change in Vp and density arising with changes to volumes of clay, porosity, and cement. Based on the RPM, reservoir parameters can be perturbed by the user. The parameters include volume of clay, porosity, dense phase CO_2/hydrocarbon saturation, the pressure aspect and the halite cementation-precipitation making the rock frame stiffer. Perturbational modelling shows the effect of changing these properties on the elastic and modelled seismic domain. The cleanest rocks exhibit higher acoustic impedance (Ip) and lower Vp /Vs ratio values than more clay rich lithology. Porosity changes also exhibit a strong impact on the Ip. For the fluid substitution, and to calculate the acoustic properties of the dense phase CO_2, we use the laboratory measured values for pseudocritical pressure and temperature in the Batzle-Wang (1992) equations. For the fluid mixture (CO_2 and brine) the decision was made to use either the standard homogenous or the patchy mixture saturation as they represent the endmembers of fluid compressibility. This interactive rock physics modelling platform in a very active area for CO_2 storage and near field exploration, provides the user with the tool to interactively change reservoir parameters assessing the seismic data response to understand its AVO sensitivity to a significant number of rock, fluid, and seismic property scenarios.

The next step was the conditioning of seismic data. With the size and the timing to take into consideration, the seismic conditioning was optimized considering the large size of the seismic and the timing (as soon as possible). The simple conditioning flow included: denoising and spectral angle frequency matching. Subsequently to this, a seismic inversion (relative and absolute) was performed over the entire area for acoustic/shear impedance and Vp/Vs estimation.

The absolute inversion was performed using a driven seismic velocity based low frequency elastic model and an elastic rock physics transform. For the BSF specifically, the reservoir properties derivation and porosity estimation, it was thought to use the absolute inversion results, but testing suggested that the best transform would be done in the relative domain and mainly using the relative acoustic impedance product (Figure 4 right hand-side). This porosity transform result was then compared to the previous results done in 2022 using the legacy pre-stack time migration results available on the BC28 (Reiser et al., 2023). The difference between the two clearly show the improvement on the imaging side and subsequently to the porosity distribution and variation inside the BSF. Validation at the regional level is on-going but the map already shows a porosity distribution in line with a braided river channels system environment.

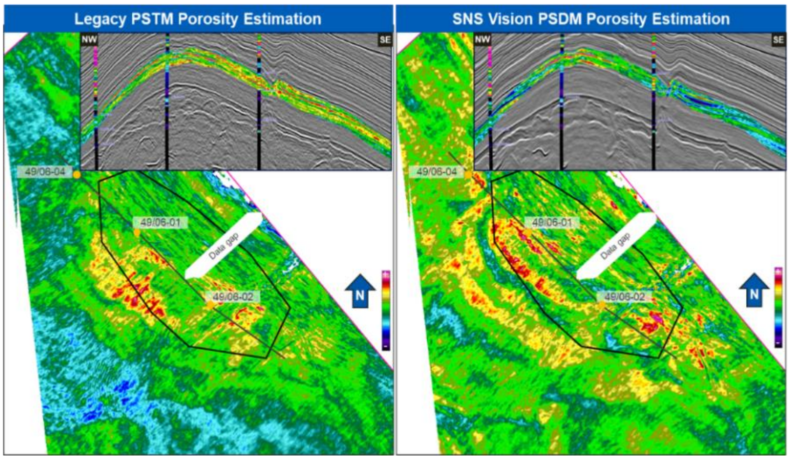

Figure 4: *Porosity estimation comparison based on legacy KPSTM (left) and on the newly reprocessed KPSDM dataset (right). The porosity distribution (20m interval in BSF) highlights the improvement of the match at the wells and the structure conformance of the porosity distribution inside the BSF, demonstrating the imaging and amplitude uplift of this dataset compared to the previous one.*

Conclusions

The case study demonstrates that rejuvenated regional data using high-end imaging workflow and integrated with a regional interactive rock physics modelling, seismic inversion can have significant benefits. This offers an effective approach to advanced evaluation and derisking of storage sites and for near field exploration. This also demonstrates the benefit of applying appropriate imaging and quantitative interpretation workflows for characterizing critical geological heterogeneity in the BSF interval for the potential carbon store and addressing the challenging imaging of pre-salt near-field exploration targets. This not only supports optimization of subsurface characterization efforts for sustainable energy and energy transition purposes in the UK-SNS, but also contributes to the broader understanding of mature basin rejuvenation strategies, guiding future activities in similar basins worldwide.

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References

Brook, M. S., Holloway, S., Shaw K., Vincent, C. [2003] GESTCO Case Study 2a-1. Storage Potential of the Bunter Sandstone Formation in the UK Sector of the Southern North Sea and the Adjacent area of Eastern England. C J. British Geological Survey Commissioned Report CR/03/154.

Chadwick RA, Holloway S, Brook M, and Kirby G. [2004] *The case for underground CO2 sequestration in Northern Europe. London:* Geological Society Special publications; **233**: 17-23.

Reiser, C., and Lee, N. [2023] The importance of an integrated regional workflow for carbon storage site evaluation, de-risking: a UK Southern North Sea case study. The Fourth EAGE Global Energy Transition Conference and Exhibition, Nov 2023, Volume 2023, p.1 – 4. https://doi.org/10.3997/2214-4609.202321092

Ruiz, R., Roubickova, A., Reiser, C., and Banglawala, N. [2021] Data mining and machine learning for porosity, saturation, and shear velocity prediction: recent experience and results, First Break 39.