Supporting the search for large scale carbon storage sites

PGS is focusing our efforts to support the cost-effective and timely development of new CCS projects, and in particular to meet the needs of site identification, characterization and monitoring. First through the rejuvenation of legacy data, which offers a gateway into new insights within old datasets. PGS' SNS Vision project across the Southern North Sea is a great example of this. Secondly, the opportunity to think differently about our existing MultiClient data library and to explore and develop new concepts within the data. PGS' Elephant project in the Norwegian Sea has demonstrated significant large-scale storage opportunities on library data. Finally, continued investment in technology, R&D and the commitment to new innovation is the third strand of PGS' efforts to support the delivery of new CCS projects. Here, we are focused on delivering the right solutions to new site developments with baseline and development surveys as well as building and delivering new collaborations to support the future of time-lapse monitoring where the developments are retaining the gold standard of 4D seismic monitoring. Part of this effort is to address the cost and efficiency imperatives required by these projects.

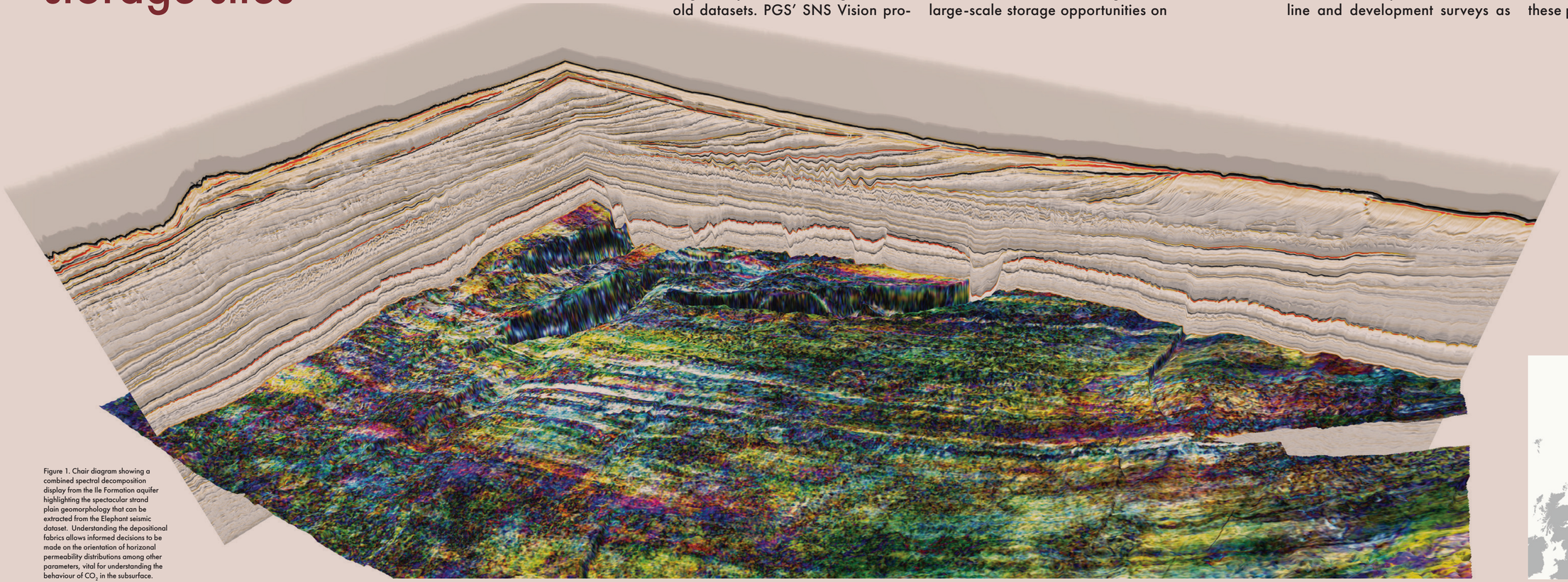

Figure 1. Chair diagram showing a combined spectral decomposition display from the Ile Formation aquifer highlighting the spectacular strand plain geomorphology that can be extracted from the Elephant seismic dataset. Understanding the depositional fabrics allows informed decisions to be made on the orientation of horizonal permeability distributions among other parameters, vital for understanding the behaviour of CO_2 in the subsurface.

The role of the seismic industry in delivering successful CCS scale-up

NICK LEE, BILL POWELL, TILMAN KLUVER AND CYRILLE REISER, PGS

THE SEISMIC INDUSTRY has, for a long time, been involved in helping to support the development and successful operation of CCS projects. PGS' own involvement stretches back to the early days of the Sleipner project, operated by Statoil (now Equinor). The operator wanted an effective technology to monitor the developing CO_2 plume within the Utsira sandstone reservoir – that effective technology was 4D time-lapse seismic, and according to the UK's NSTA it remains the best available technology for such applications.

However, there are challenges to the scaling up and the development of more carbon storage projects. Cost and efficiency are two significant ones as the wider industry seeks to get more CCS projects moving towards the end of the decade and drive towards gigaton-scale capacity. These next generation of projects are not add-ons to hydrocarbon processing activities to address Scope 1 emissions, but pure abatement projects in their own right. Hence the economics of oil and gas projects are therefore not available to support projects through the life cycle, making the cost-value trade-off even more of an imperative for the technologies and solutions used to bring them to fruition.

Seismic operators like PGS are looking to play their part in helping to keep energy data relevant to these new projects, and to account for these challenges, while providing effective solutions to the ongoing development of this new segment as it scales to meet the storage targets laid out in international and national plans.

CCS SPECIFIC REJUVENATION OF SEISMIC DATA

Modern seismic reprocessing workflows offer an exceptional opportunity to rejuvenate old datasets using a variety of vintages to create new data that can drive fresh insights into the subsurface for CCS characterization.

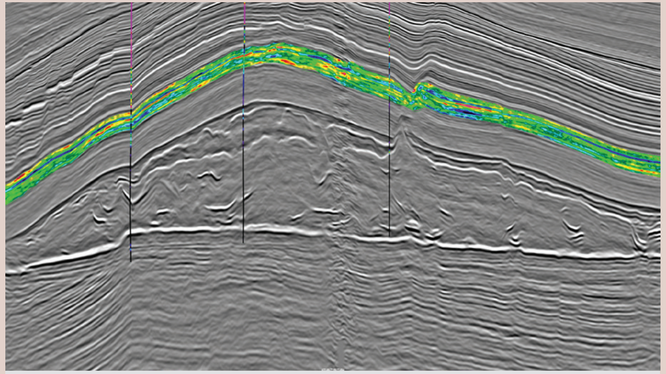

Figure 2. Seismically derived porosity over the BC 28 structure in the SNS Vision dataset allows a 3D understanding of the distribution of aquifer parameters which can be utilized directly in geological modeling and more sophisticated volumetric calculations beyond simple equations.

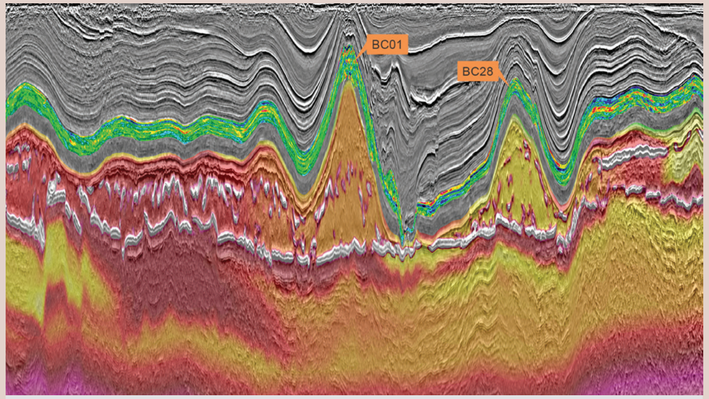

Figure 3. Seismic cross-section through PGS' SNS Vision data illustrating a co-rendering of the final PSDM stack, estimated porosity for the Bunter Sandstone Formation and the seismic velocity.

Reprocessing and merging of data have long been a mainstay of the seismic industry and PGS' own MegaSurvey projects are well known to provide exceptional coverage over large areas, making them excellent resources for early screening. However, as their original intent was to target often deeper petroleum prospects as off-the-shelf products, they are not optimized to resolve some of the challenges encountered on CCS projects.

PGS' SNS (Southern North Sea) Vision project is an excellent example of this (Figure 4). Historically, much of the data across the project area in the Southern North Sea has been focused on resolving structures and geology within the presalt section for gas exploration and development. While the presalt Rotliegend remains relevant for gas exploration and CCS, the focus has shifted to investigating potential within the post-salt section and the Triassic Bunter Sandstone Formation and its overburden to the seabed. With only a handful of fields developed in the post-salt section, less attention has been paid to imaging this interval and consequently this is sub-optimally imaged on pre-existing data and merge products.

An additional complication is the sparsity of well data, and this is particularly important where the calibration of rock physics models is required for quantitative seismic interpretation. This approach is particularly suitable for derisking saline aquifer targets in lean data environments. PGS' study of the Triassic Bunter Sandstone Formation BC28 structure, a candidate CO_2 storage location in the UK Southern North Sea (Figure 2 and Figure 3), is a case in point, where the inversion and rocks physics workflow demanded more data in the overburden than the wells could provide. A methodology was developed to address this, and a machine learning algorithm was used to fill the overburden data gaps and to allow the generation of reliable attributes for reservoir characterization.

UNLOCKING STORAGE OPPORTUNITIES ON MULTICLIENT LIBRARY DATA

With the extensive availability of high-quality, well-curated data sourced via online portals (e.g. Versal) accessing library data has never been easier, and within it lie excellent opportunities to develop robust concepts for future carbon storage sites.

Importantly, there is the opportunity to think differently about carbon storage prospecting within these datasets and thinking about data quality when identifying specific areas of interest for evaluation. This is because, in some senses, the ingredients necessary for a successful site can be relaxed when generating early storage concepts for consideration. Good aquifer and seal properties are of course required, but the risks around hydrocarbon charge to specific structures are absent, and there are large areas where subsurface understanding is sufficiently mature to make future oil and gas exploration activity unlikely. In saline aquifer exploration and screening it can be beneficial to look for high-quality data in areas where prospectivity is perceived to be challenging for oil and gas.

Over time, data has been acquired in areas peripheral to successful producing trends as attempts have been made to expand them. Where this data is modern and of high quality, a data-led approach to screening can be considered where advanced site characterization can be achieved on an existing dataset. This is both time and cost-effective. PGS' Elephant project in the Norwegian Sea area is an example of this (Figure 1). The Norwegian Offshore Directorate initially outlined a large migration-assisted saline aquifer concept within the Norwegian CO_2 Atlas in an area south of the Elephant dataset. We have been able to advance the development of this concept because of the availability of off-the-shelf high-quality data in an attractive location. The modern broadband 3D seismic data is more than sufficient to enable facies inversion workflows and seismic interpretation to be completed to screen and define the concept, as well as to assess in detail the subsurface risks associated with the aquifer distribution, seal and overburden units. This project has demonstrated how high-quality regional data can be used to great effect to define storage concepts within regional depositional systems, in this case the CCS-prospective Jurassic sandstones of the Norwegian Sea and North Sea (Figure 1 & Figure 5).

TECHNOLOGY AND INNOVATION DRIVING PROGRESS

PGS' acquisition of bespoke and high-end seismic surveys over the Northern Lights (Aurora and Smeaheia), Northern Endurance in the UK SNS, and Poseidon on the Norwegian SNS demonstrates that advanced geophysical solutions are very much in demand for carbon storage site development. While the acquisition of all these CCS projects (and others) utilized different survey designs and parameters, what they did have in common was the use of innovative seismic acquisition solutions.

The faith placed by the operators of these projects in novel solutions demonstrates that developers at the forefront of scaling CCS deployment in Northwest Europe, like Equinor and BP, appreciate the value that advanced seismic technology brings to the subsurface challenges presented by carbon storage site development. While legacy data may be sufficient for initial screening studies, high-end geophysical solutions remain relevant to take the projects through final investment decision development and into operation. The subsurface challenges are no less complex than oil and gas reservoir development and so it is natural that these advanced solutions, including innovative source-receiver configurations, are finding a home in the

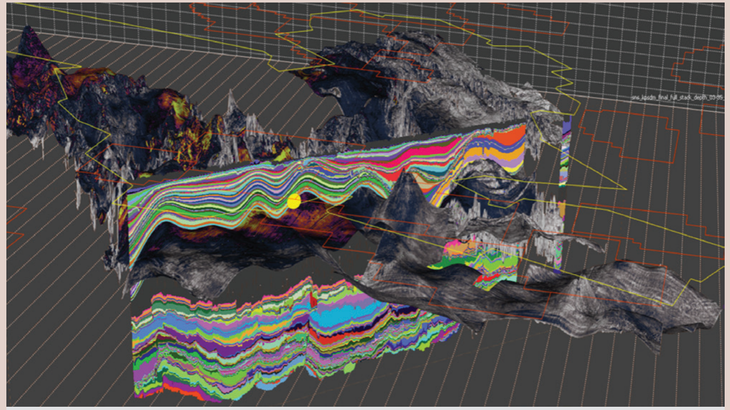

Figure 4. 3D representation of the Relative Geological Time model and the top of the salt over the 12 000 km² of reprocessed seismic data. The internal salt structure has been excluded from the seismic interpretation and the focus has been on the top and base salt. Interpretation RGT model produced using Eliis PaleoScan with PGS data.

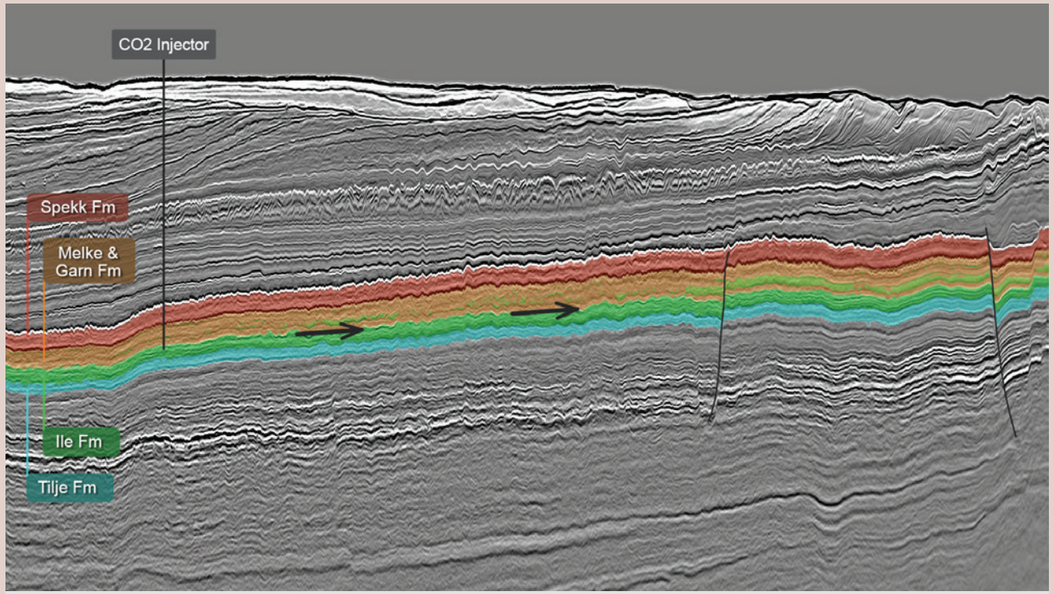

Figure 5. Regional schematic section through the proposed Elephant open aquifer storage site illustrating the prospective aquifer packages and the overlying Spekk Formation regional seal for carbon storage within Jurassic sandstones. The concept is a large-scale migration assisted store, with down-dip injection, allowing residual and solution related processes to contribute to the CO_2 storage.

subsurface development toolbox for the next generation of sites.

Looking to the future, PGS is also investing in R&D to support future site development and monitoring using seismic methods. An example of this is the CLEAN4D program, a collaboration between PGS and SINTEF, partly funded by the Norwegian Research Council. This project aims to deliver cost-effective, low emission options for time-lapse seismic surveys. The CLEAN4D aspiration is to enable time-lapse surveys using any acquisition technique that provides sufficient illumination to image the reservoir (or a specific target within the reservoir) to the required resolution, without the need to closely reproduce the acquisition geometry of previous surveys. By relaxing geometric repeatability, these new techniques have the potential to significantly reduce costs of acquisition while taking advantage of novel processing, imaging, and inversion techniques all the while ensuring that data quality for time-lapse monitoring is maintained or improved. As well as technical innovation, the project will also demonstrate the value benefits, addressing the cost imperatives for future carbon storage site monitoring programs. Strategies for optimum acquisition design will be developed, applying value-of-information (VOI) concepts to identify the best trade-off between added value and cost, including the contribution to reducing CO_2 emissions related to time-lapse seismic acquisition.

CHALLENGES FOR THE FUTURE

Until as recently as a few years ago offshore marine geophysical activities were focused on oil and gas site surveys and seismic acquisition projects. With the energy transition gathering pace the demands for these services and their capacity are now being spread across a wider range of segments – carbon storage and offshore wind adding directly to the draw on existing survey capacity within the industry. The development of these projects side-by-side also creates new challenges related to co-location of different industries vying to occupy and operate on the same areas of the seabed. Economic challenges also arise because of the different business models attached to the nascent carbon storage sector as well as other renewable segments. Cost effective, but technically robust options will be required.

PGS has already begun to meet these demands for innovation and to provide solutions to these challenges. Novel solutions for acquisition of 3D over storage sites have provided operators with the seismic surveys needed to resolve subsurface risks to capacity and containment. Investments and collaborations in future monitoring technologies will fulfil the promise of bringing cutting edge geophysical solutions to the next generation of monitoring for carbon storage sites. And products like SNS Vision and PGS' off-the-shelf library products mean that the sector does not have to wait to gain the benefits of PGS' advanced geophysical solutions.

NORTHWEST EUROPE

"We are about to drill unprotected into the reservoir. If you want to go on drilling this afternoon, you can put your arse on the rig in place of mine."

Wellsite geologist – Irish sector (1980s)