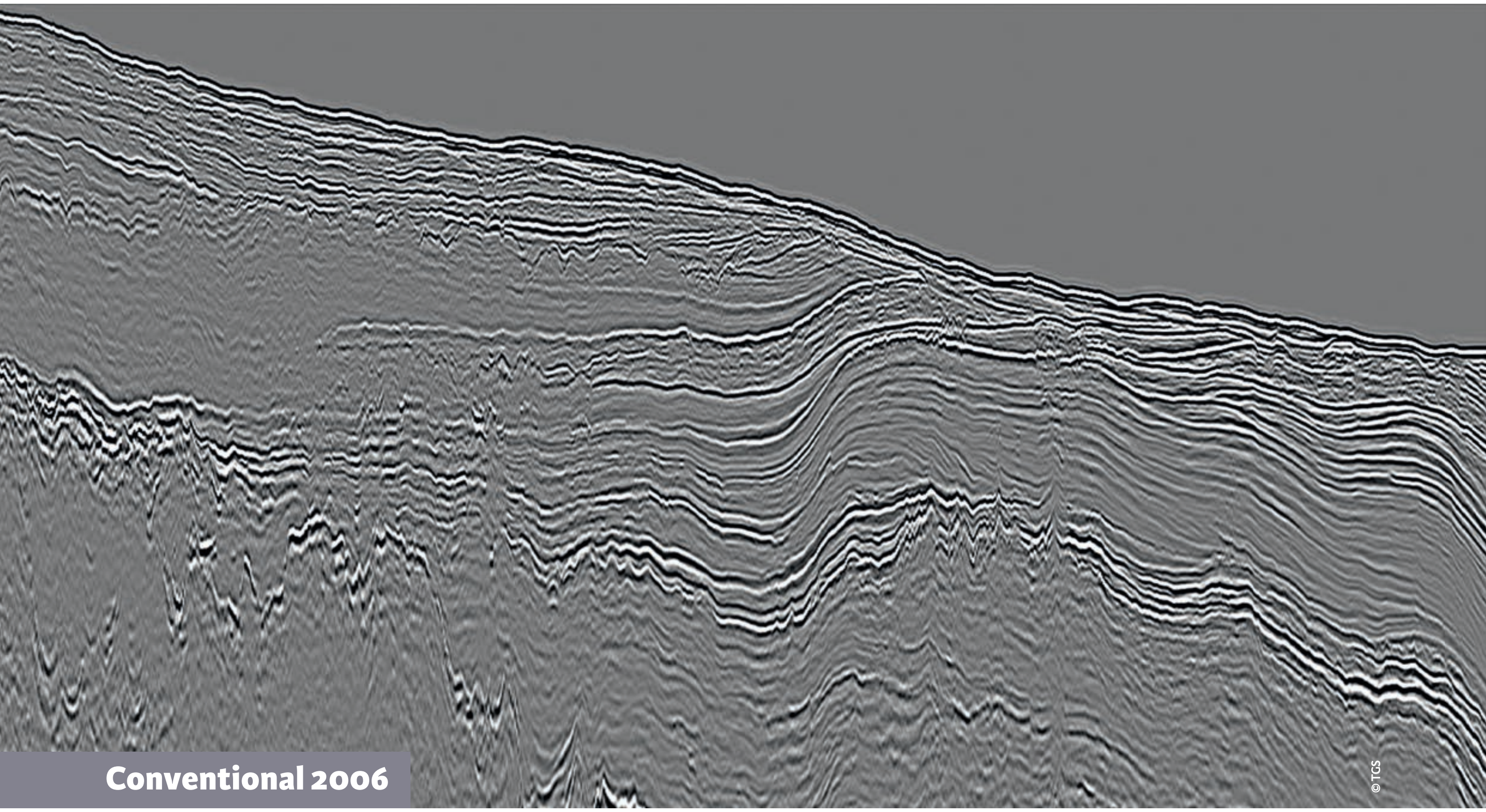
Seismic Acquisition and Processing: The Technology Race

Both incremental and disruptive advances in the development of seismic imaging technology have been crucial for regional geological mapping as well as prospect definition. While revolutions in offset, broadband, azimuthal and density implementation have been crucial in streamer seismic development over the last 15-20 years; the next generation of seismic is likely to be shaped by OBN, with steadily increasing amounts of sources and new advances in processing.

Text: BENT KJØLHAMAR (Chief Geologist), ADRIANA CITLALI RAMIREZ (Chief Geophysicist) and SINDRE JANSEN (Geophysicist, Project Development), TGS

The North Sea is among the most explored areas on the planet. Seismic data has been the key measurement throughout its history and countless incremental improvements have happened since the early 1960's, the decade when the UK and Norwegian authorities opened the area for oil and gas exploration. Lately, the northern European waters and the northern Gulf of Mexico have been two very active testing grounds for new technological advances. The bulk of the seismic fleet has for long been on Norwegian hands.



The sequence illustrates the progression from conventional seismic to modern broadband technology. This single sensor data was acquired over the outer Møre Basin on the Norway-UK border by TGS. The leftmost section was processed in 2006, with no attempts to deal with the ghost events created by the presence of the sea surface. The middle section (AMR) was processed with a low frequency boost in 2010. The rightmost section is the broadband solution. It was fully deghosted (source and receiver ghost events were removed), extending the frequency bandwidth both in the low and high end, healing the ghost notches within the effective bandwidth emitted by the source and convolved with the Earth's reflectivity.

Three advances that matter

In the Norwegian part of the North Sea we have experienced the third generation of seismic 3D **acquisition**; nearly all mature areas have two generations of streamer 3D.

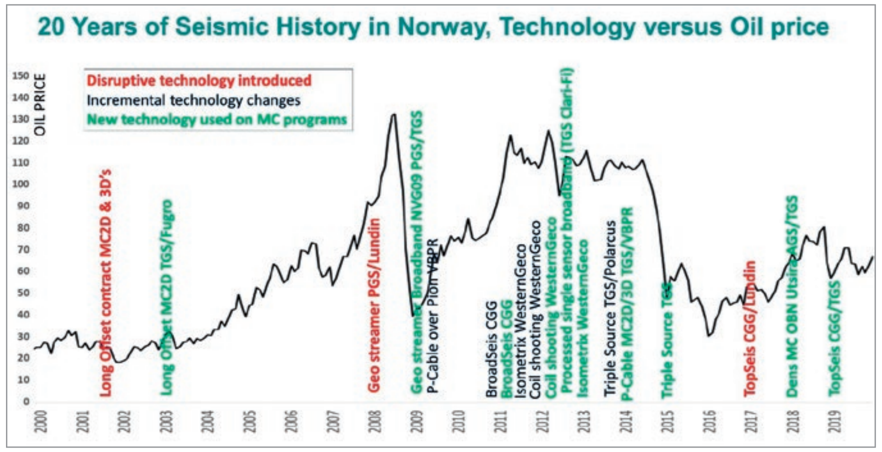
Additionally, the processing technology of seismic data has seen a similarly steep learning curve as hardware capabilities and disk space have increased. These days, new steps in processing technology are occurring in the cloud where compute power and disk space can be expanded as needed.

We can group these technological advances over the last two decades into three categories:

- **The offset revolution**,
- **The broadband revolution**, and
- **The azimuthal and density revolution**

Prior to 2000, the North Sea database consisted of seismic with 3 km streamer lengths in general. The offset revolution occurred around the start of the millennium when we started to see a few 2D and 3D surveys using 5-6 km streamers. The new prevailing standard was cemented when TGS and Fugro acquired their North Sea Renaissance multi-year 2D program using 6 km offsets for 3D and 8 km for 2D. Since then, "Long Offset" became a buzz word in the industry and all vessel owners bought more streamer sections to remain competitive.

In 2007, PGS introduced a 2-component streamer, **GeoStreamer**. The streamer was engineered to measure both the pressure field and the vertical particle velocity. In 2008-2009 PGS, TGS, and Lundin utilized dual sensor streamers for the first time in production. The vertical particle velocity and the pressure field in this new streamer technology can be used as complementary measurements that allowed better removal of the effect of the free surface or, more specifically, of ghost events on the receiver side. The advent of this acquisition technology brought a renewed interest in general de-ghosting technology that included wave-based de-ghosting for single component measurements such as TGS' pressure-only solution Clari-Fi. De-ghosted seismic has a broadened bandwidth at both ends of the frequency spectrum, no ghost-related frequency notches, and a sharper, more compact wavelet. The demand for broadband seismic lead to it becoming the new standard and motivated massive investments in acquisition technology.



Incremental and disruptive changes in acquisition technologies for the past 20 years. During 2011-2013, a cluster of new technologies was developed driven by high oil prices.

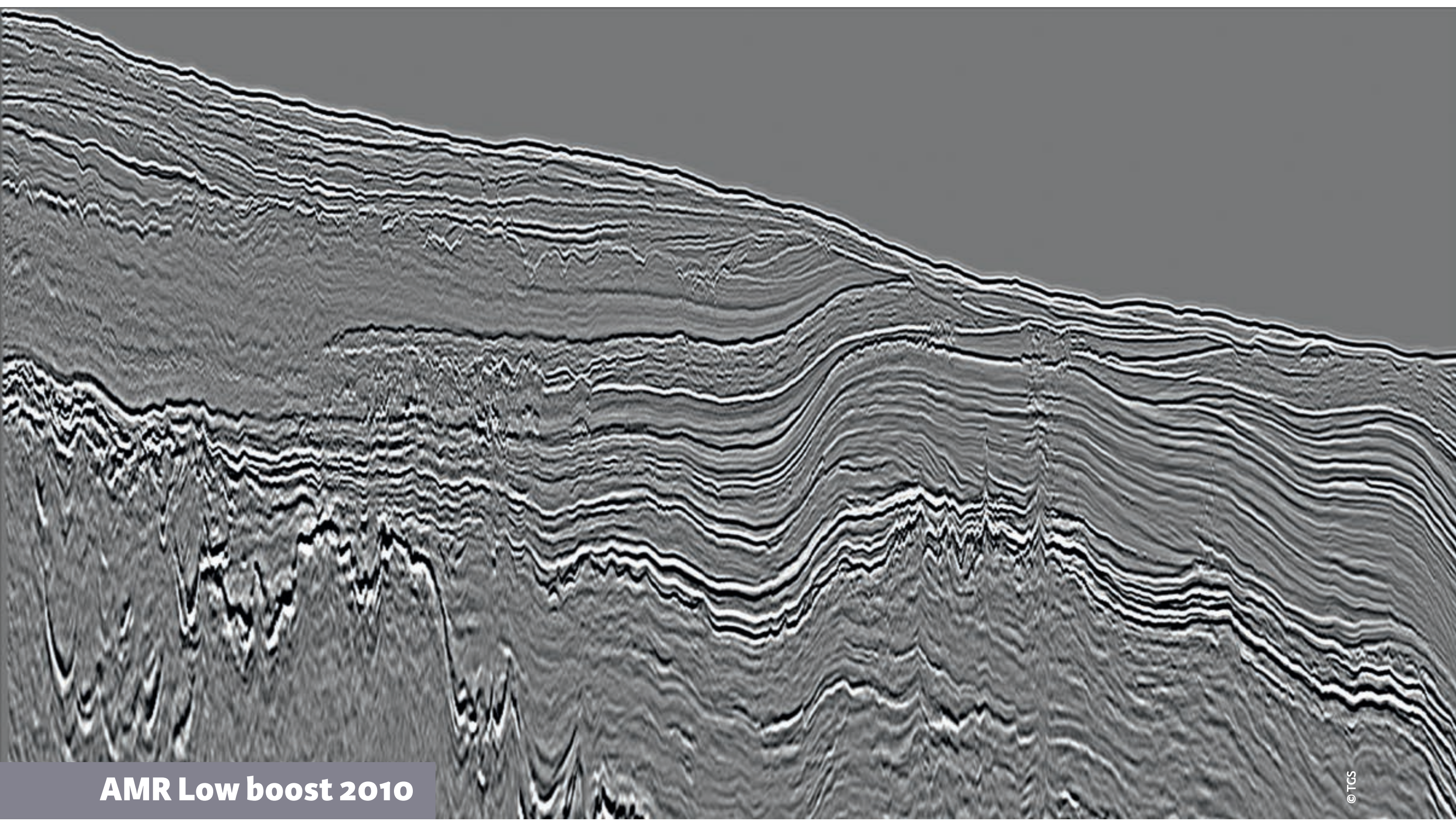
The current azimuthal and data density step change

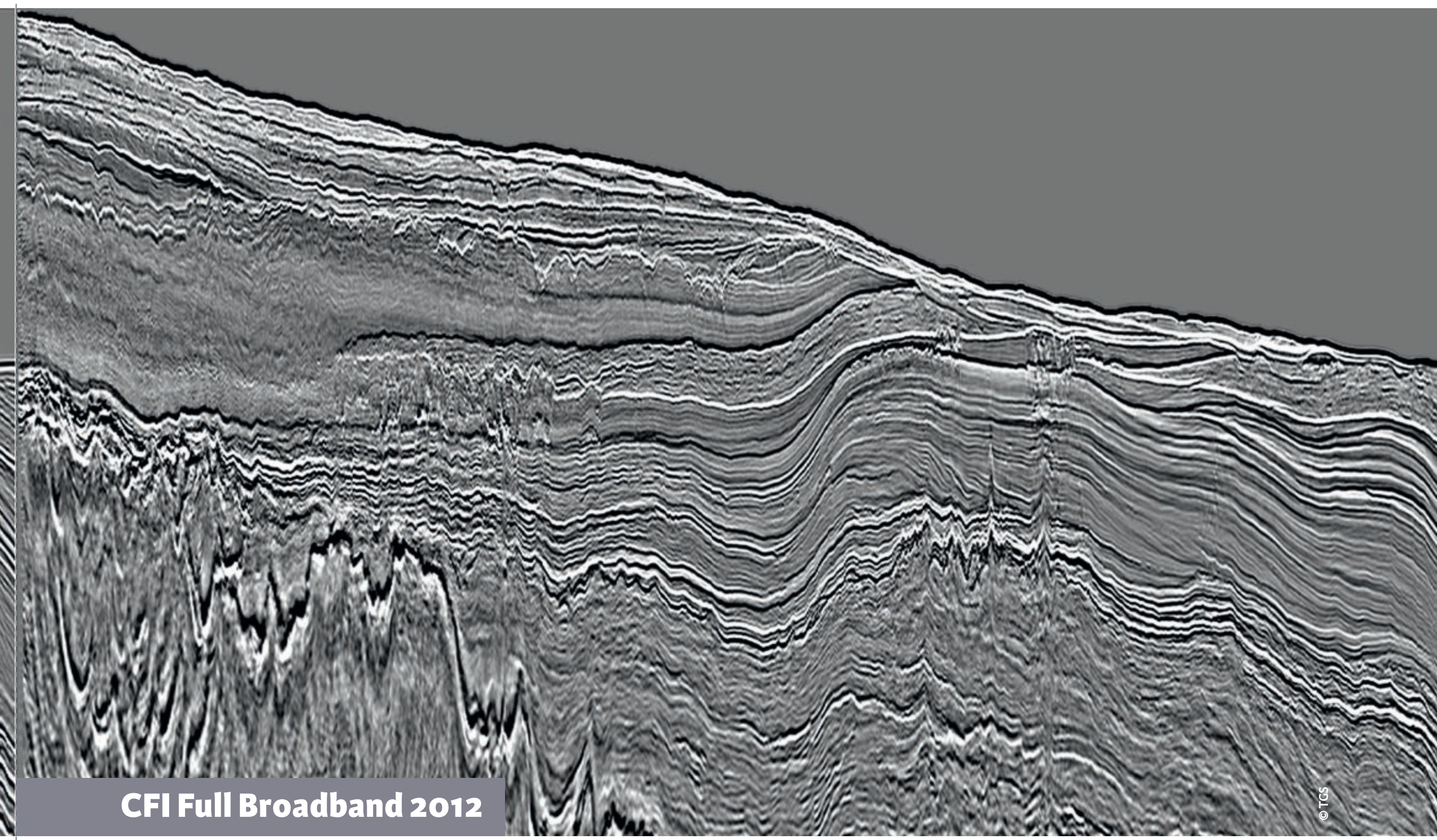
Since the dawn of 3D acquisition in the 1980's almost all improvements have happened on the streamer side. Dual source based air-gun arrays became a standard and, besides some alterations of output volume and frequency of the outgoing signal, little else happened.

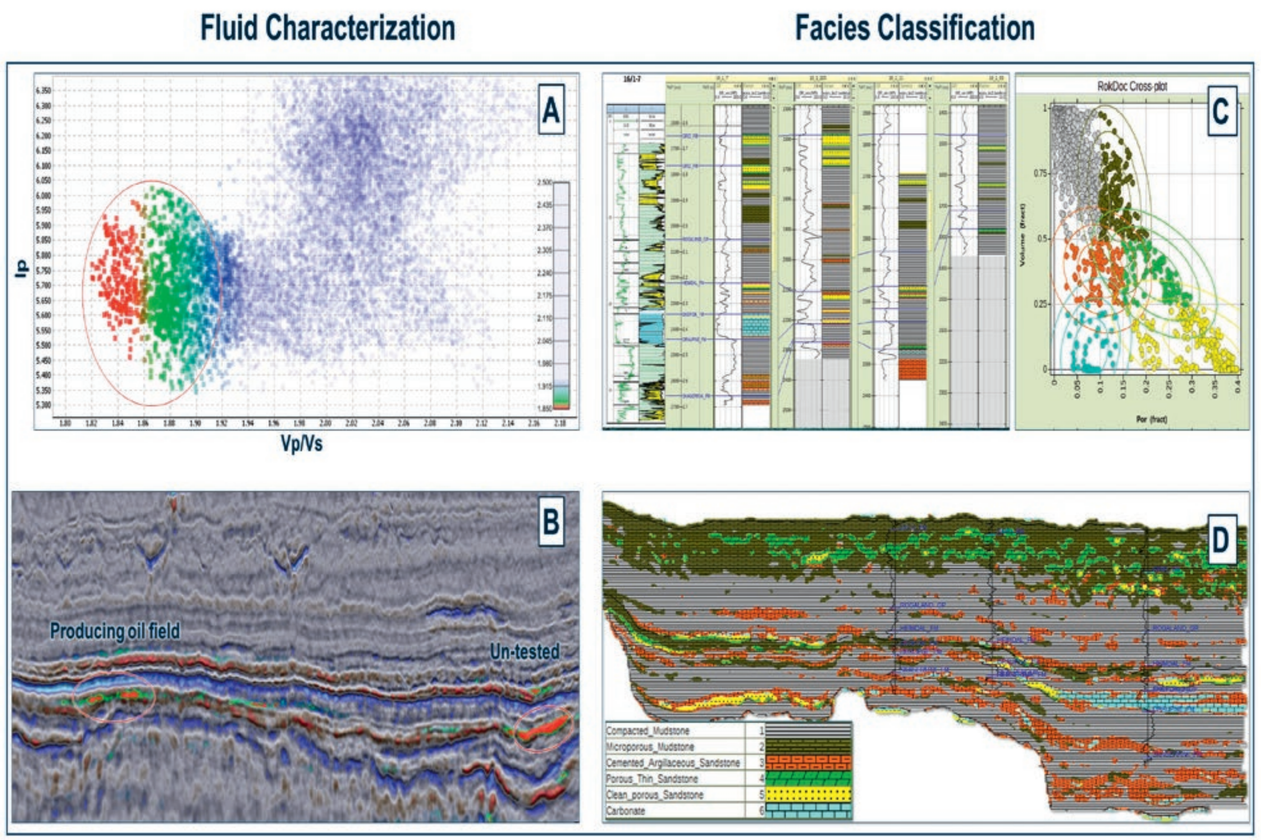
Whenever dense sampling was required, the streamers were simply towed closer together and slightly shorter shot point intervals were used. However, this setup is expensive due to a smaller footprint. Thus, alongside the possibility of robust de-ghosting with two components, a third component (horizontal) was included in the design of Isometrix with the goal of advanced interpolation. A few years later, this third component was also part of Sercel's **Multi-sensor Streamer.**

The introduction of multi-sensor streamers, fueled a technology race not only to test and commercially implement different de-ghosting solutions, but also to test different streamer profiles, towing depths, source configurations, etc. All with the goal of better data quality with sharper (de-ghosted) wavelets and broader bandwidth. The playing field for bandwidth is more leveled today and the market has moved on to focus on the density and quality of the measurements.

In 2014 TGS and Polarcus performed a **triple source** test and in order to keep standard inline sampling density, overlapping shots were needed. These overlapping shots were then successfully separated or deblended in processing. Today, triple source has become the new standard and many deblending approaches exist and are continuously being improved. The source battle is still ongoing and configurations of 5 or 6 sources have been used in production. Up to 10 sources are now a future prospect.







The OBN Utsira 3D is robust for both fluid characterization (left) and facies classification (right). Cross plotting (A) inverted acoustic impedance versus Vp/Vs show anomalies conforming to existing oil field (B) and highlighting un-explored opportunities. Facies classification shows good conformance to wells (C, D). The 4-component sampling power of OBN data, up and down going wavefield, full azimuth and offsets up to 20 km will generate value for decades to come.

The current best practice in the Barents Sea, for example, is a wide towed penta-source over a dense streamer spread like the one used on the **GC19 TopSeis 3D** acquired by CGG and TGS. This design gives rich dual azimuth, including zero-offsets and a comprehensive near- trace coverage. This is important for the shallow targets at hand.

Lying almost dormant for 30 years since the first tests in the NCS, due to their immensely high acquisition cost, is the **Ocean Bottom Node (OBN)** full azimuth technology. Per definition, this seismic technology can outperform streamer seismic in nearly all quality aspects, all but for very shallow targets. New approaches in deployment and the use of triple source vessels has made large scale dense OBN possible, like the Utsira OBN in the North Sea acquired by TGS and AGS.

Challenging complex targets like sand injectites are now illuminated from all sides and sampled up to 25 times better than with a narrow azimuth streamer 3D. The natural continuous recording of OBNs combined with deblending, allow us to extract extremely long records in processing, both in time and offset. This has been tested on Utsira OBN data extracting node gathers with maximum offsets of 20km and the resultant gathers have been used as the input for model building based on diving wave FWI. The latter was motivated by the recent successes in subsalt inversion and imaging with Sparse OBN surveys in the Gulf of Mexico, where advance model building with ultra-long offset FWI has been leveraged (refer, for example to Amendment and Engagement surveys by TGS and WesternGeco).

Finally, **hybrid acquisitions** combining streamer seismic with sparse nodes are also gaining momentum.

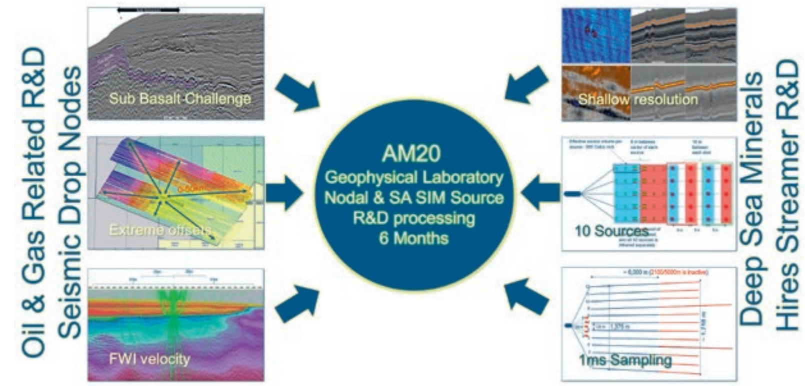
OBN: The next generation seismic

The future is hard to predict but surely **OBN**, steadily increasing amounts of sources and new advances in processing will together play an increasing role in North Sea exploration activities. The OBN Utsira dense nodal (300x50m) project just west of the Johan Sverdrup field has recently been delivered and portions of the data have already been utilized for de-risking prospects. In addition, several reprocessing projects targeting specific fields or drilling prospects are ongoing within operator's offices and at TGS.

This is a clear indication that OBN with its full azimuth, ultra-long offsets (20 – 60 km, depending on bathymetry), 1,300-fold measurements (vs. 80 in standard streamer seismic), upgoing, down-going and shear-wave measurements will be reprocessed again and again at least for the next decade. Historically, the big hurdle has always been the acquisition cost. However, with the combination of multi-client projects, new deployment techniques, and the utilization of multiple semi-simultaneous sources; the cost for a typical production license has made large scale OBN more accessible.

Still, cost is just one of the challenges presented by OBN, another one is data volume and turnaround time. The OBN Utsira project is the world's largest when it comes to recorded data weight so this has called for new ways of thinking in terms of processing, transport, and storing facilities. The next large scale OBN project conducted by TGS will deliver a decimated, efficient fast track full volume. This will be the only regional product. The rest of the data will be carefully processed in bespoke sub-volumes, where the specific geological challenges will be addressed in a target-oriented way. The bespoke processing will include advanced model building with long offset FWI, and both the preprocessing sequence and migration strategy will match the complexity of the specific geology covered by the bespoke sub-volumes. This will speed up the timelines, provide a timely valuable regional product, and an efficient delivery of valuable target-oriented bespoke products for the interpreters and end-users to leverage. Nevertheless, the long-term value here lies in having the raw data available in readiness for reprocessing, scenario testing, new processing technologies or new blocks awards.

Sparse nodes (300-1000m spacing) or hybrids of sparse nodes in conjunction with dense streamer acquisition provide an adequate interim solution until the dense node coverage is there. TGS, in conjunction with Western Geco, now holds two vintages of sparse nodes for deep sub-salt imaging in the Gulf of Mexico (Amendment). BGP and MCG have also acquired the first of such programs in the Horda platform north this year.



The geological challenges tested with the AM20 Geophysical Laboratory are illustrated herein. The goals are two-fold: Ultimate high resolution for deep sea mineral exploration and sub basalt imaging for oil & gas exploration.

A new geophysical Laboratory

As part of TGS' AM20 penta-source 3D seismic program, free-fall nodes were dropped receiving 350,000 shots from the streamer acquisition. Here, offsets up to 50km will be utilized to improve the velocity field for sub-basalt imaging. In addition to the drop-nodes, a unique blended source test over a single sail line was performed with both streamer and nodal recording with 10 regularly blended sources following a seismic apparition shooting scheme. This set-up is intended for ultra-high resolution and shallow targets, that is needed for Deep Sea Mineral mapping at water depths averaging 2,000 m. The processing efforts of this multi-dimensional geophysical laboratory are about to begin. The objectives of the tests in the AM20 Geophysical Laboratory are for both oil & gas and mineral exploration. the project is still open to new partners who wish to actively participate to obtain new understandings from the further analysis of this new data type.

We hope that the findings and knowledge drawn from these tests will steer the next generation of seismic technologies. In particular, the mineral exploration tests may open a new business area and jobs for geophysicists both newly qualified and those with experience on offshore exploration.

Driving forward

The industry has seen both incremental and disruptive technology changes during the past 15 years. TGS has taken part in almost the full spectrum of geophysical technology currently available. TGS strives to be involved in driving technology forward, not just in terms of acquisition but also imaging technology and data insight, for both frontier and mature areas of exploration. As an experienced multiclient organization, scale is combined with deep technical understanding to match the right tools to the geological and business challenge, while aiming at a cost-effective solution that brings value to clients. The focus is on economy of scale and long-term value.

New markets for 3D seismic

Two new playing fields outside of oil & gas are also on the horizon: (1) **Deep Sea Minerals** (DSM) found along the mid ocean spreading ridges and (2) seismic used for **Carbon Capture and Storage** (CCS).

These markets will most likely not be as profitable as the oil & gas market historically has been and consequently, a new threshold for cost-efficiency must be set.

The global shift toward green sources of energy is generating a desperate demand for rare metals for batteries in use for applications such as cars, public transport, shipping and even aeroplanes. Sulphide deposits are rich in copper, cobalt, zinc, and Rare Earth Elements (REE) - much of the metals needed in new battery technology. We expect these shallow targets to be small, sparse and in a complex seismic terrain.

Nevertheless, TGS has strong reason to believe that the latest streamer 3D seismic technologies, including 5 times (!) the number of seismic sources as used until recently, would be the geophysical tool of choice for this endeavour. The high resolution, cost-effective 3D imaging of shallow targets is the key.

TGS and CGG have already sold 3D seismic to be used for carbon capture and storage (CCS) in the North Sea. The seismic is used to analyze the best saltwater aquifers to store super critical CO_2 safely. One might assume that abandoned gas fields would be the ideal storage facility and this can indeed be the case such as the project planned in Liverpool Bay. However, projects like Northern Lights or the UK Teeside initiative have chosen saline aquifers. Therefore, for economical and safety reasons, large sandstone reservoirs close to shore evidently provide an ideal storage solution. However, this is far from the epicenter of current major 3D coverage - in the middle of the basin.

As an early planning tool TGS's J-Cube, for example, which is a low-resolution 3D product with coast-to-coast coverage, can play a role in the CCS market. As this market grows, we may begin to see customized CCS-related new seismic acquisition, but the major work for the seismic industry will relate to 4D monitoring of stored carbon.

Super critical CO_2 typically gives a strong soft reflection in seismic at intermediate depths. Following the movement of CO_2 within the reservoirs and early detect any leakage, high resolution seismic optimized for shallow targets will be on demand, not unlike that for deep sea minerals.

For both deep sea minerals and carbon capture and storage finding cost effective seismic solutions is key since these markets are expected to have lower budgets than the O&G industry. Lightweight seismic acquisition like P-Cable or the new, in-well or directly on the seafloor, Distributed Acoustic Sensing (DAS) fiber optic seismic systems may be ideal tools for the CCS 4D monitoring work of the future.