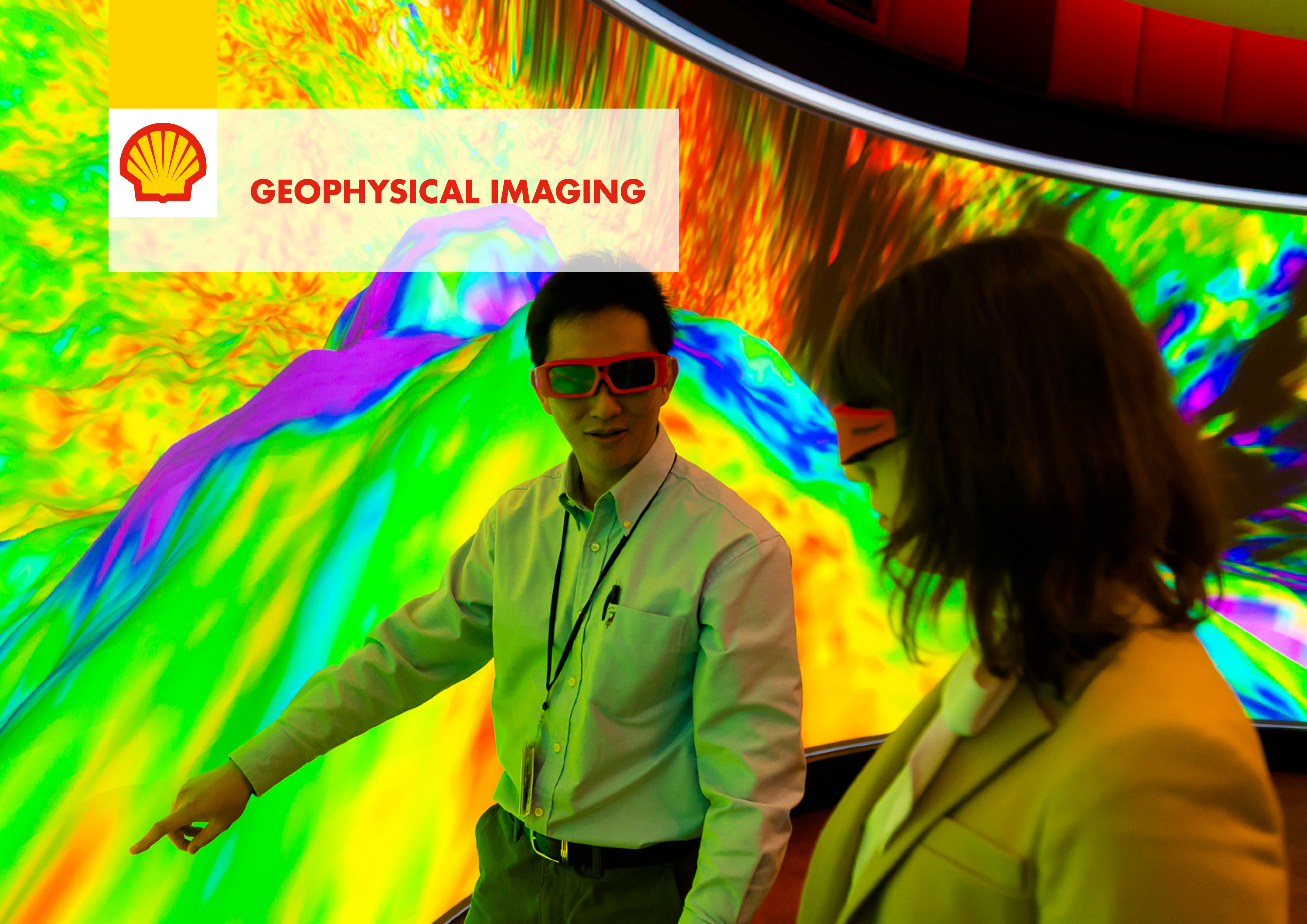
GEOPHYSICAL IMAGING




Shell
GeoSigns

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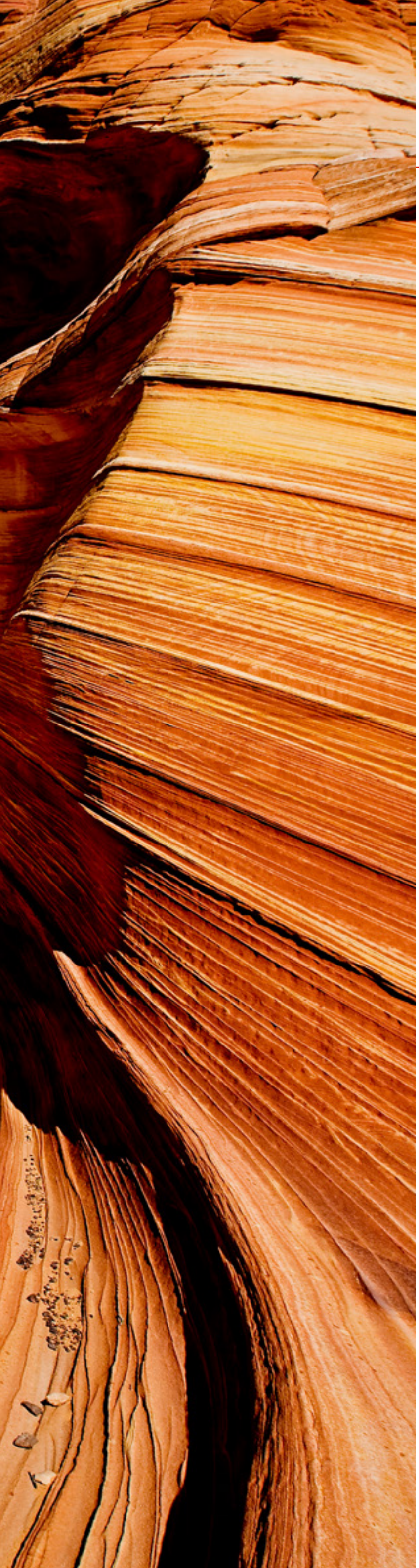
More people and more wealth mean that global energy demand could double over the first half of the century

A world of growing energy demand – more people



The Wave, desert rock formation, Arizona, USA

Global energy needs

Geophysical imaging techniques are established tools for the oil and gas industry. They help guide the search for new resources and enable companies to gain a better understanding of reservoirs that are already in production: crucial tasks for meeting the world's current and future energy needs.

Global energy demand was 270 million barrels of oil equivalent per day in 2012. By 2060, energy demand could rise to 470 million barrels of oil equivalent per day. Population growth and continuing economic development are the driving forces behind this sharp increase. The world's population will grow from 7 billion today to more than 9 billion in 2050. In fact, HSBC Bank estimates that by 2050 almost three billion people will have joined the middle classes. More people and more wealth mean that global energy demand could double over the first half of the century.

Supporting increased population and rising living standards and wealth will require vast amounts of additional energy. This will have to be delivered while urgently cutting the carbon dioxide emissions generated by fossil fuels using methods such as carbon capture and storage. The contribution to supply made by renewable forms of energy is growing steadily but nevertheless leaves a huge balance that will have to be made up from other sources. Fossil fuels are expected to meet more than 50% of primary energy demand by the middle of the century, so oil and gas will remain a substantial part of the global energy mix for decades to come. Natural gas will become increasingly important. It is the cleanest burning fossil fuel and it is abundant. It can make the biggest contribution to reducing the world's CO_2 emissions over the next 25 years as it produces only around half the emissions of coal.

A world of growing energy demand – more cars

Fossil fuels are expected to meet more than 50% of primary energy demand by the middle of the century, so oil and gas will remain a substantial part of the global energy mix for decades to come

A world of growing energy demand – more people in cities

While existing oil and gas fields gradually deplete, the task of finding and recovering new hydrocarbon resources is becoming more challenging. Many of the so-called easy-to-find oil and gas resources have been developed.

The industry responds to the quest for new resources by developing more sophisticated geophysical imaging technologies to find less obvious targets. Shell is building on its heritage of geophysical expertise and creates powerful new solutions to meet this challenge.

THE SIZE OF THE PRIZE: ESTIMATED GLOBAL HYDROCARBON RESOURCES

According to the US Geological Survey (USGS) substantial amounts of the world's conventional oil and gas resources are yet to be discovered. The 2012 USGS world assessment includes 565 billion barrels of conventional oil, 5,606 trillion cubic feet of undiscovered conventional natural gas, and 167 billion barrels of liquids separated from natural gas, yet to be found in priority geological provinces around the world.

In the area of tight and shale oil and gas resources, the Energy Information Administration (EIA) assessment, indicates that there may be technically recoverable resources of 345 billion barrels of world shale oil resources and 7,299 trillion cubic feet of world shale gas resources. Combining the figures for conventional and unconventional hydrocarbon resources, the remaining global hydrocarbon resource base could be 4.3 trillion barrels of oil equivalent.

DEEPER AND MORE COMPLEX TARGETS

Our geophysicists are pushing the boundaries of new technology to image more complex and deeper targets.

Exploration for conventional oil and gas deposits is increasingly focusing on deeper reservoirs below complex overburdens, i.e., the rock sequence above the target reservoir. The knowledge that geologists bring to exploration projects can only be fully applied when geophysical tools provide clear images of the subsurface. To address this, Shell has developed and applied imaging technologies that can locate reservoirs in a range of challenging locations, such as under accumulations of salt, gas clouds and heavily faulted areas or thrust zones. These technologies should also be able to detect over-pressured conditions in order to ensure safe drilling.

The recent upsurge in efforts to develop tight reservoirs and shale oil and gas resources means that more and more exploration acreage is located onshore. This drive to develop new onshore resources has helped to stimulate new thinking and the development of innovative geophysical subsurface imaging technologies. A breakthrough in seismic image quality improvements and hence better interpretation also can open up under-explored conventional resources.

The true value of these new geophysical imaging technologies is that they will allow Shell to see what others may not see and, consequently, to find what others may not find.

MEETING THE CHALLENGES: COST, QUALITY AND SPEED

High-quality images of the subsurface are an essential tool for the multidisciplinary teams who make exploration and production decisions. The key challenge facing the industry is to find more cost-effective ways to deliver the best possible images in the shortest possible time. Hence, in the field of geophysical imaging Shell is focusing on three key areas: reducing cost, raising

3D seismic, Oman

The true value of these new geophysical imaging technologies is that they will allow Shell to see what others may not see and, consequently, to find what others may not find

3D seismic data acquisition, Oman

quality, and increasing turnaround speed. These objectives apply to every stage of field development and management, but are particularly important during exploration when little is known about the rock structures at targeted reservoir depths.

The first step in oil and gas exploration is to quickly, safely and cost-effectively assess target areas on their likely prospectivity. Only then will oil and gas companies commence a programme of exploration drilling. It is of crucial importance to effectively manage risk and ensure money is being spent on those assets that hold the maximum hydrocarbon promise.

Geoscientists can draw on a range of geophysical techniques to select areas they believe are suitable for exploration drilling. They apply gravity and magnetic methods, which can be directly related to, respectively, the density and the susceptibility, very useful physical properties of rocks in the mapping and identification of various rock types. These techniques are used in early exploration to identify prospective locations.

Seismic reflection imaging remains the most widely used geophysical technique in hydrocarbon exploration. Sound waves are used to map the layers of subsurface rock and the resulting images are then used to identify potential hydrocarbon accumulations. Controlled-source electro-magnetic techniques are used to provide indications of hydrocarbons by detecting resistivity changes in the rock and can complement seismic data.

De-risking exploration prospects and optimising field development

Geophysical imaging increases the chances of successful oil and gas discovery, but exploration success is only the start of a process that involves building a detailed understanding of a reservoir's extent and hydrocarbon content. Applying geophysical imaging methods for monitoring once oil and gas production has started enables field operators to maximise the amount of oil or gas recovered.

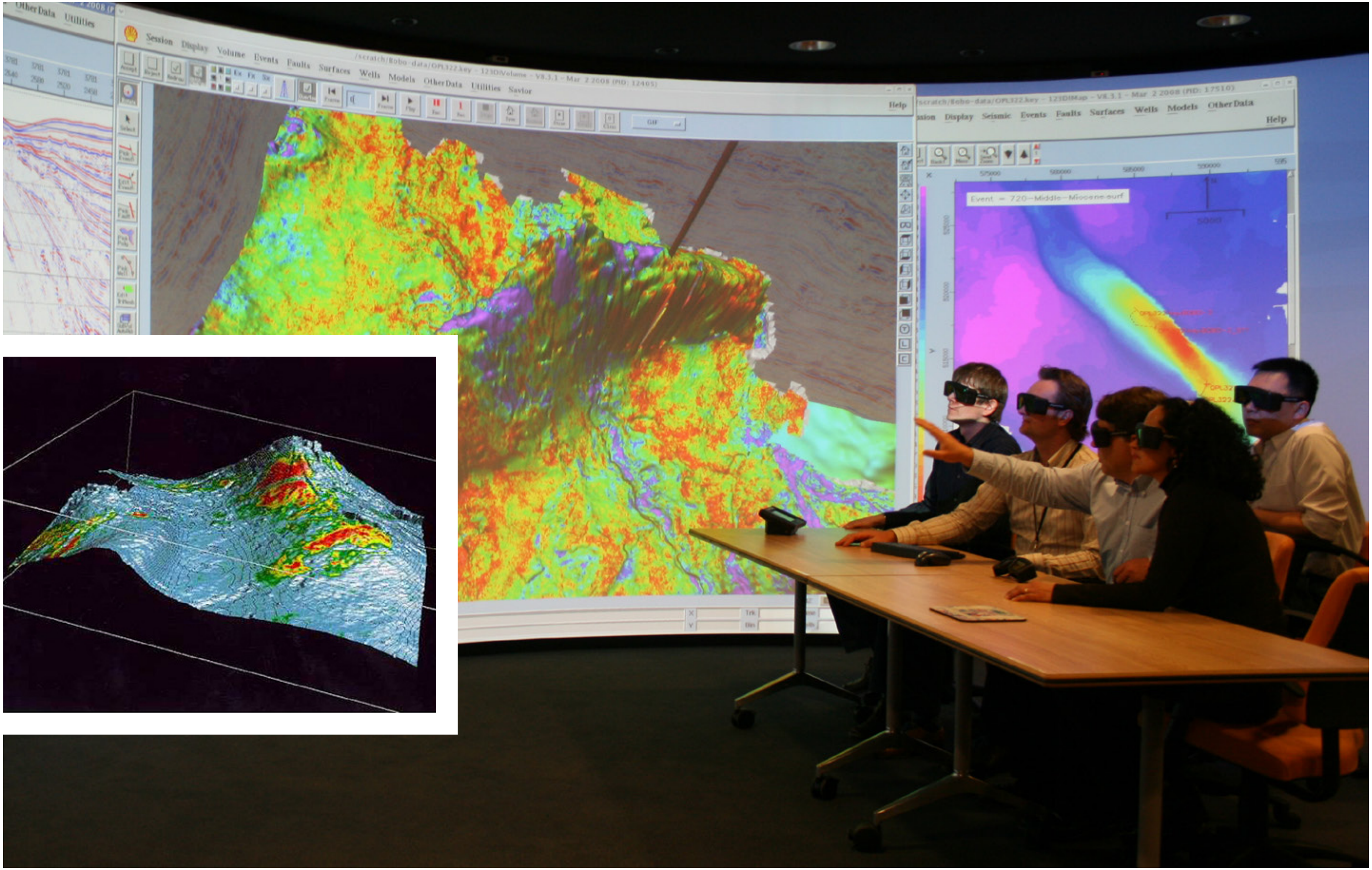
ADDRESSING THE TECHNICAL CHALLENGES

Geophysical imaging involves several vital steps: effective acquisition of data; processing the data to remove noise, and estimating a model of the velocities at which seismic waves travel through the subsurface and use this to generate a final image of the subsurface; and visualizing and interpreting the model in order to draw valid conclusions about subsurface structures and the possible locations of oil and gas accumulations.

A key challenge of seismic imaging is to obtain the full seismic wave field in data acquisition, as this is the only way to capture echoes from deeply buried reservoir formations that may be present under highly heterogeneous rock structures. This is especially true for onshore seismic surveys, where data quality is generally less than for offshore surveys, mainly owing to the presence of strong coherent noise in onshore seismic data. The data quality challenge calls for radical innovation in the area of seismic data acquisition, aiming at making full wavefield acquisition affordable.

The next key challenge relates to processing data. Geophysicists need imaging methods that are firmly based on the physics of the propagation of seismic waves and are robust enough to reveal the details of complex geology. This calls for advanced thinking in fundamental mathematical physics to develop effective processing of complex series of calculations (algorithms) and for access to high performance computing facilities.

Shell addresses these challenges by combining novel acquisition technologies with a significantly improved cost/quality ratio and combining them with powerful new imaging methods and visualisation techniques.



Geophysical imaging Bobo field, Nigeria

Novel seismic methods enable Shell experts to lower acquisition cost, boost accuracy and make better decisions

1940 - workers performing seismic tests

Advances in acquisition: better data at lower cost

Acquisition, the gathering of geophysical data, is the essential first step towards a clear understanding of the subsurface. The impact on the business of subsequent processing, visualisation and interpretation steps that ultimately determine our understanding of the reservoir relies on the quality of data collected during the acquisition phase.

Traditional acquisition techniques, which proved effective for oil and gas developments in the past, cannot provide the detail required for the deep, complex, and unfamiliar accumulations the industry is seeking today. This has prompted the pursuit of radical new approaches.

FROM NARROW AZIMUTH TO WIDE AZIMUTH OCEAN BOTTOM SENSING

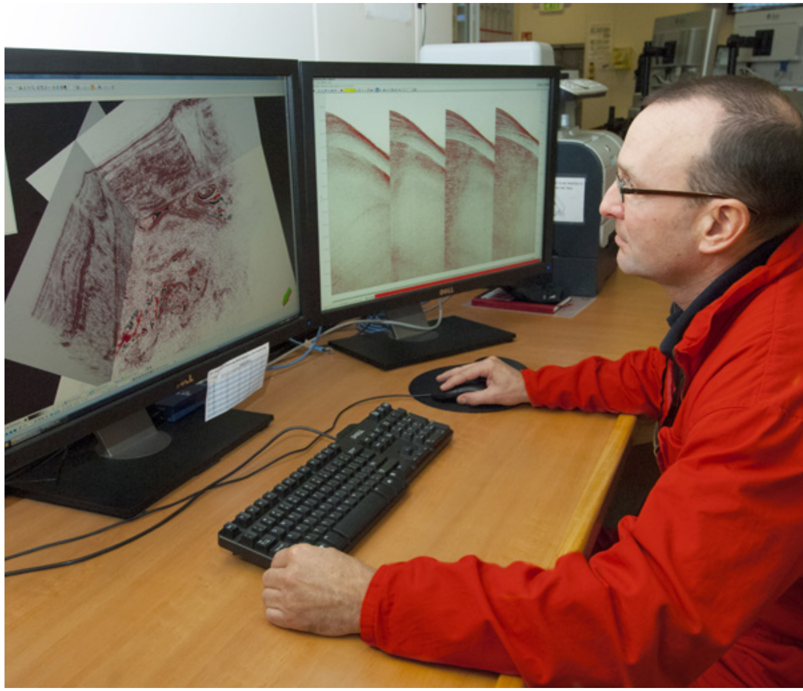
Thick layers of salt in rock sequences that are common in places such as the Gulf of Mexico and offshore Brazil make pinpointing oil and gas deposits very challenging as they obstruct the penetration of seismic waves to these deeper targets.

To overcome this problem, the target rock layers need to be "illuminated" from a wide range of directions (azimuths). This technique, known as wide azimuth (WAZ) seismic, has provided images of geological formations under salt bodies in the Gulf of Mexico that were previously invisible.

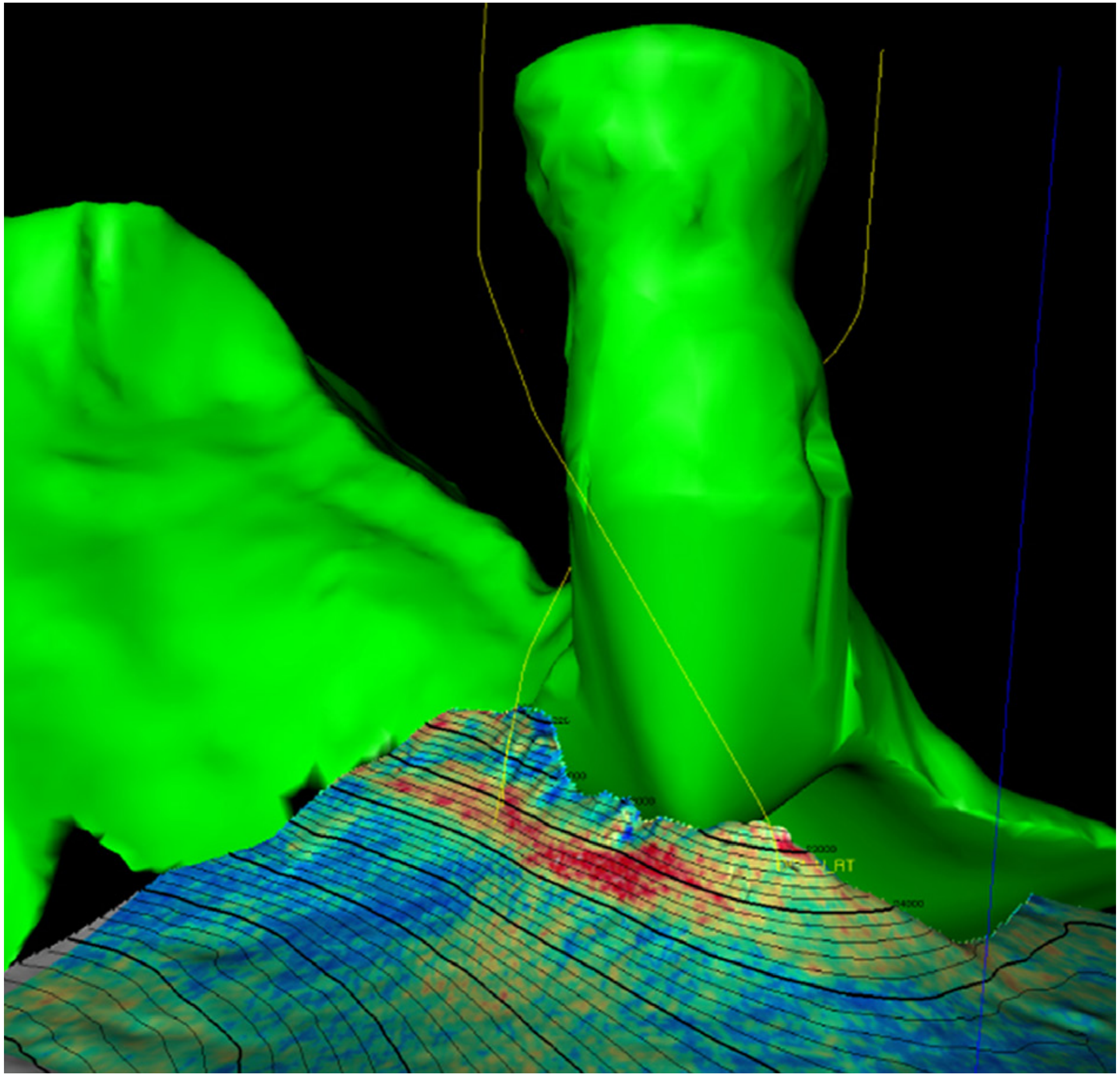
In 2009-2010, Shell's use of wide-azimuth seismic surveys led to the discovery of four major fields in the Gulf of Mexico, adding hundreds of millions barrels of oil and gas to the region's resources.

CGG Geo Caspian - seismic research and survey

Image courtesy CGG



Wide Azimuth seismic survey, Halifax, Canada



Wide Azimuth Ocean Bottom Sensing, Gulf of Mexico, USA

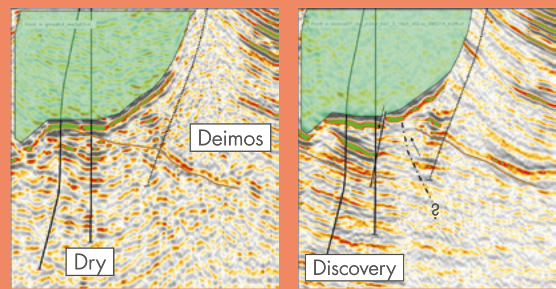
DEIMOS FIELD: UNLOCKING SUB-SALT RESOURCES

In 2004 Shell drilled a subsalt exploration well near the Deimos field in the Gulf of Mexico. The well showed no sign of oil or gas and the exploration programme was suspended.

A few years later, the Deimos area was re-surveyed using a wide-azimuth seismic method. Shell set sensors on the ocean bottom, which allowed the recording of seismic waves that can illuminate the area under the Deimos salt structure from all directions. This ocean-bottom sensing, wide-azimuth survey showed that geological faults were playing an important role in the sub-salt formations and indicated where oil was likely to be found.

Using this updated information Shell drilled another exploration well in 2009. This confirmed the existence of the West Boreas field and, soon after, the South Deimos field was discovered based on the same data. Together, these two discoveries have added more than 150 million barrels of oil equivalent resources.

ADVANCED SEISMIC ACQUISITION IMPACTING PROCESSING/IMAGING



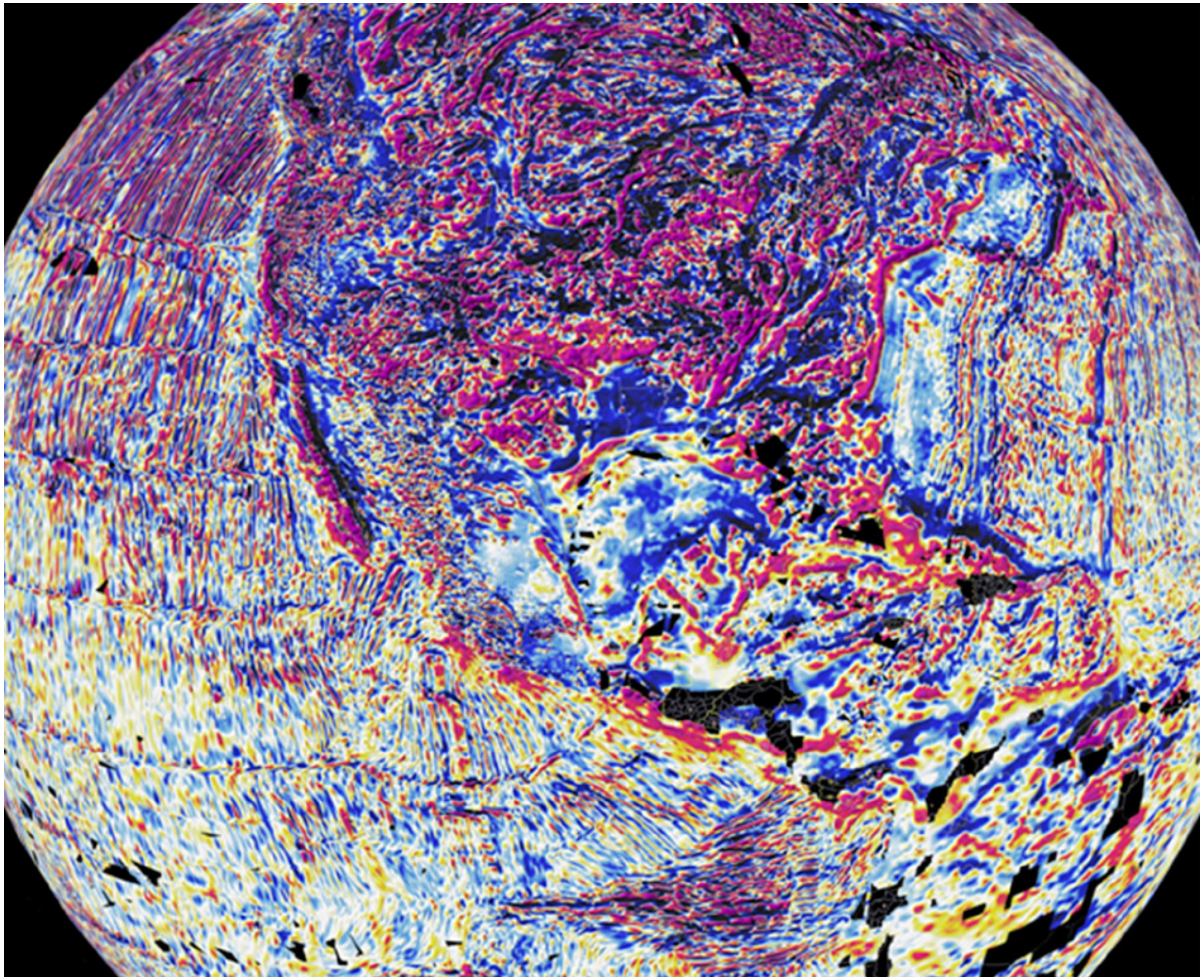
Narrow Azimuth
Wide Azimuth

THE VIEW FROM ABOVE: SATELLITE AND AIRBORNE ACQUISITION

Geophysical surveys from satellites and aircraft facilitate rapid, low-cost investigations over large frontier areas with no direct impact on the local environment and are therefore especially useful in the early stages of exploration. The best known examples are gravity and magnetic surveys.

Another is Shell's LightTouch® technology, an airborne direct hydrocarbon detection technique that maps any hydrocarbon gas seepages at the ground surface. The method can detect live hydrocarbon systems, help us understand hydrocarbon migration pathways, and provide information on reservoir seal integrity.

Shell subsequently applies extensive in-house expertise for interpretation of satellite and aerial data and integrates them with other geophysical methods to provide a more complete picture of reservoir geology.



Satellite acquisition

With careful survey design, the Controlled Source Electromagnetic technique can provide additional key information on the presence and lateral extent of hydrocarbon reservoirs

Acquisition of wide azimuth data goes hand in hand with application of state-of-the-art processing algorithms, which rely on high performance computer architectures. This computing power, combined with Shell's GEOSIGNS subsurface interpretation software, enables exploration teams to visualize substantial amounts of processed seismic data and interpret that data in a more robust, integrated, and collaborative way.

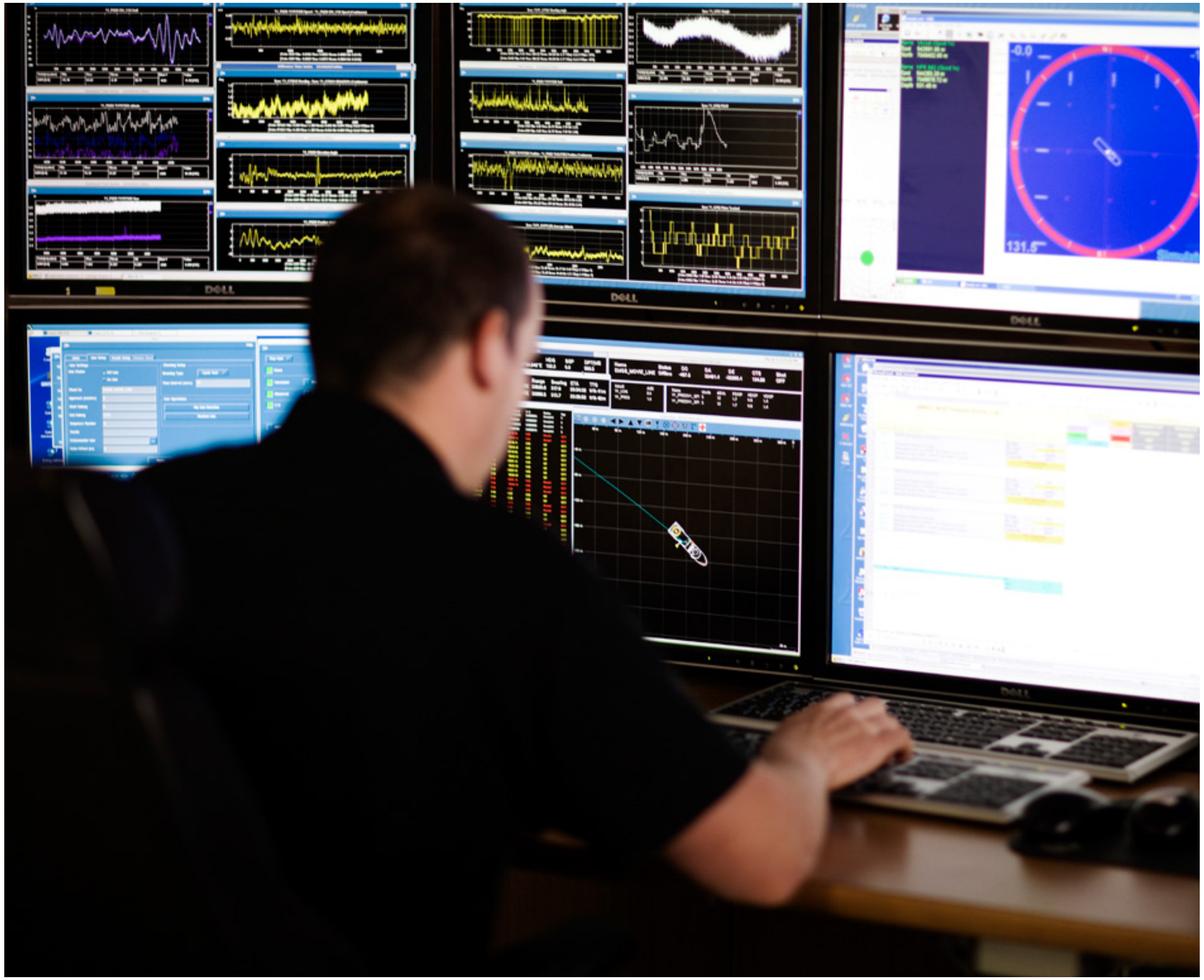
FINDING THE FLUIDS: ELECTROMAGNETIC ACQUISITION

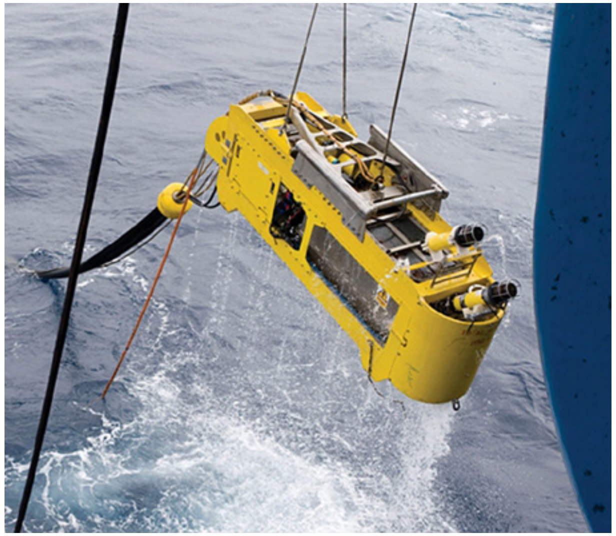
Seismic surveys can provide detailed images of structures in the subsurface, but usually cannot distinguish between different types of fluids, such as hydrocarbons and water. Electromagnetic (EM) signals can provide additional independent information since they measure electrical resistance. This can significantly improve the accuracy of pre-drilling predictions.

The electromagnetic method consists in towing a powerful source of electric current along the seabed while it emits electromagnetic energy at a very low frequency through the underlying rocks to assess their resistivity. The signals returning

RESISTIVITY REVEALED

Electrical resistivity quantifies how strongly a particular material opposes the flow of electric current: low values indicate that the material readily allows the movement of electric charge. Oil and gas typically have higher electric resistivity than water, and the CSEM method can detect the difference.





High power electromagnetic source

Electromagnetic receiver Images courtesy EMGS

from the subsurface layers are detected by sensors on the seabed. This technique is known as Controlled Source Electromagnetic (CSEM) prospecting, and is an established exploration method used by Shell.

Traditionally its application has been limited to shallow targets (< 3km), deep water (>300m) and uniform overburdens. There are also some limitations to the method for certain types of geology, for instance in areas with salt and volcanic rock, which is common in some geological basins. However, in many of the world's prospective basins conditions are favourable so that EM data can contribute important additional information.

With careful survey design, the CSEM technique can complement seismic imaging and provide additional key information on the presence and lateral extent of hydrocarbon reservoirs. Following a large discovery made in Malaysia during 2005, Shell has used EM technology in a number of countries, including Brunei, New Zealand, Senegal, Nigeria, Norway, Brazil and USA. At present, Shell applies CSEM in around 10% of all its exploration activities.

APPLYING ELECTROMAGNETIC METHODS IN BRUNEI AND MALAYSIA

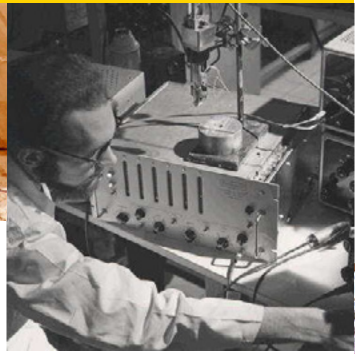
NW Borneo is one of the world's most prolific hydrocarbon provinces, but one in which many disappointing wells are drilled in spite of excellent seismic data.
In 2004-2006 Shell acquired about 20 CSEM surveys in deepwater Sabah. Since then further steps have been taken to improve the quality of CSEM surveys, which yielded information about hydrocarbons that was not available from seismic data.

The value of CSEM is underlined by the 2013 campaign to acquire almost three thousand square kilometres of data for Shell and affiliates in Asia. This is a step change from previous campaigns, which only covered a few hundred square kilometres and focused on individual prospects. The new data will be used to reduce the geological uncertainty for prospects in Malaysia and to establish drilling priorities in Shell's project portfolio in Brunei.

GEOPHYSICAL IMAGING - TECHNOLOGY

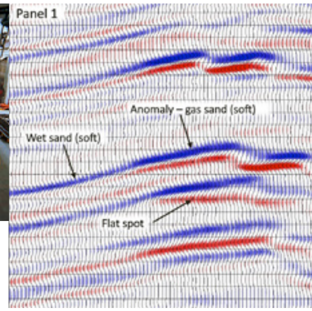
1960 – 1970

- Analogue recording
- 2D seismic on land, dynamite, source, geophone
- 2D signal processing
- Paper displays, hand contouring
- **First computers – IBM 1130, Univac**



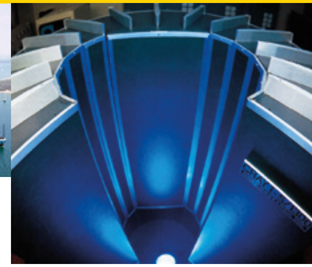
1970 – 1980

- Digital recording
- 2D land seismic, vibroseis source
- **2D marine seismic, airgun, hydrophone**
- **Extensive R&D into airguns and vibroseis sources**
- Multi-channel processing
- 2D post stack wave equation depth migration
- First seismic data libraries – Production library – SIPMAP
- **Bright spot technology**
- Global deployment through mini computers – TIMAP
- First 3D land acquisition and processing – NAM Schoonebeek



1980 – 1990

- Large scale 3D seismic acquisition and processing
- **3D Marine Seismic at Bullwinkle – Gulf of Mexico**
- 3D dip-move-out and time migration
- **2D pre stack Kirchhoff depth migration**
- **2D Surface Related Multiple Elimination**
- Seismic stratigraphy, interpretation with seismic attributes - azimuth, dip
- Global deployment through minicomputers – Digital VAX/VMS
- **Introduction vector computing – Cray, Convex, switch to Unix**
- Introduction interpretation workstations – micro VAX, SUN



In **bold** technology pioneered by Shell

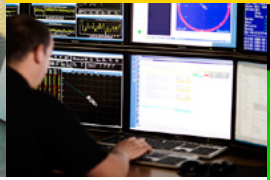
DEVELOPMENT AND NEW HORIZONS

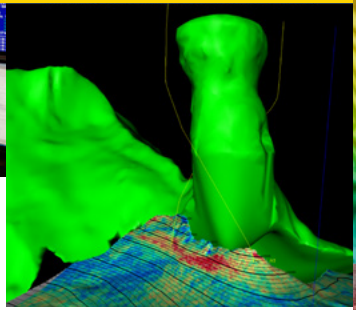
1990 – 2000

- **Probabilistic inversion**
- 3D interpretation
- **Time-Lapse Seismic in the North Sea**
- **3D pre stack Kirchhoff depth migration**
- Introduction Parallel Computers – IBM SP2
- **3D Surface Related Multiple Elimination**
- Volume Interpretation in work station
- **Carpeting North Sea and Gulf Coast with 3D seismic**

2000 – 2010

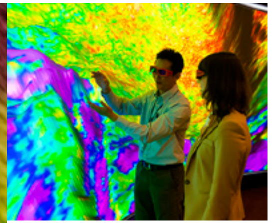
- Reservoir geophysics
- Multi Azimuth marine acquisition – MAZ, WAZ, RAZ, OBS
- Anisotropic model building
- **3D pre stack wave equation migration – Reverse Time Migration**
- Pre stack interpretation, multi-azimuth interpretation, GEOSIGNS
- **First commodity Linux Cluster in Shell**
- **CSEM surveys deepwater**
- Large scale implementation Time-Lapse Seismic

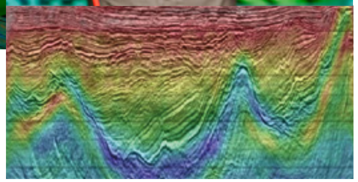




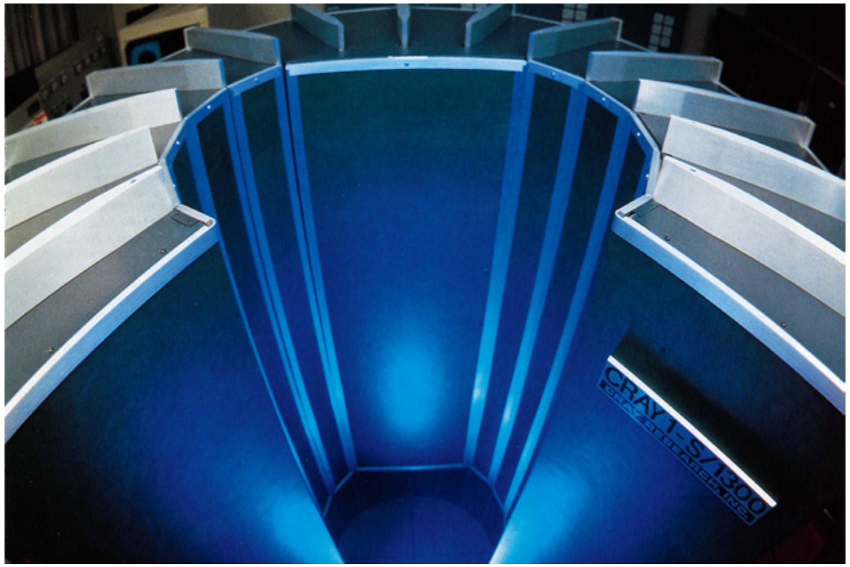
2010 – 2020

- **Wireless seismic MEMS sensors**
- **Ocean bottom seismic autonomous vehicles**
- **Optical land seismic – OptoSeis™**
- Broadband seismic
- **Wide geometries on land, mega channels – Oman**
- Acoustic Full Waveform Inversion
- Towards Elastic Full Waveform Inversion
- **Least Squares Migration**
- Multi-core processors, experimentation with accelerators





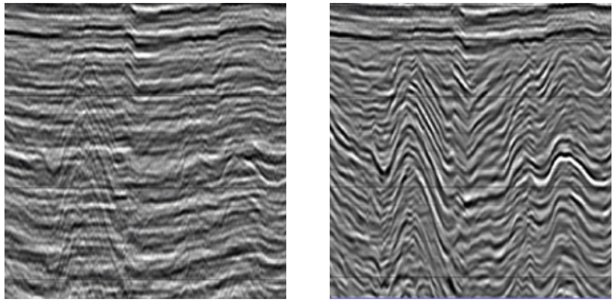
From seismic data to rock properties based on wave equation physics: more accurate and faster through new processing algorithms and high performance computing



1987 – Cray computer, Shell Technology Centre, Rijswijk, the Netherlands

Geophysical processing: from data to image

Data acquired during geophysical surveys must be processed before it is used to create subsurface images. The processing typically involves several different stages where large volumes of data are subjected to complex series of calculations (algorithms) on high performance computers.



Multiple attenuation based on dip filtering, Eastern Flank, Oman
Image of raw data (left), Image after dip filtering (right)

There are many advanced tools and techniques for turning raw seismic data into useful models of the earth and collectively these are known as processing. Processing reduces the noise in the data and helps to present the clearest possible picture of the subsurface.

Shell has been at the forefront of processing research for many years. In the 1970s Shell developed its own in-house seismic processing software called SIPMAP. The software has continually evolved to run on the newest hardware and to incorporate the latest geophysical workflows and algorithms.

Although the associated physics has been completely understood for years, it has so far not been possible to bring our full knowledge of the propagation of the seismic waves through the earth to bear because the mathematical equations that describe it take too long to solve. However, the evolution towards ever-faster computer architectures is starting to change this. Calculations are now many orders of magnitude faster than in the 1970s, allowing us to create clearer pictures of the subsurface. Advances in geophysics go hand in hand with those in computer technology.

ATTENUATION OF MULTIPLES

Multiple reflections in seismic data are generally considered to be unwanted noise that often seriously impedes correct mapping of the subsurface geology. One of the first steps in processing data is to get rid of these multiple reflections. The Eastern Flank exploration area in Oman is a prime example of how better acquisition data combined with better processing can lead to a renewed prospects inventory. As a result, Petroleum Development Oman (PDO) has set new drilling targets.

VELOCITY ESTIMATION: WAVE-EQUATION-BASED MODEL BUILDING

A key step in seismic imaging is estimating the velocities with which seismic waves travel in the subsurface. This process is

Shell is leading the industry with its work on least squares migration. The technique is used to enhance seismic imaging of prospects below complex geologies and has made a substantial contribution to prospect de-risking and improved well-planning activities

highly complex. It requires a lot of time, relies on the experience of the geophysicist and is, therefore, a frequent bottleneck in seismic imaging projects.

Furthermore, in areas of complex geology the velocity estimates are often incorrect. This has an adverse effect on the quality of the images that are produced and therefore on the quality of the exploration decisions.

Shell uses a novel approach to velocity estimation that is known as full waveform inversion (FWI) based model building. This aims to overcome the velocity estimation issues by finding the velocity solution that minimizes the difference between recorded and predicted seismic data. This approach, which requires high-performance computing power, helps to reduce the duration of imaging projects by largely automating velocity estimations and producing better velocity estimates.

A SQUARE DEAL IN COMPLEX GEOLOGIES

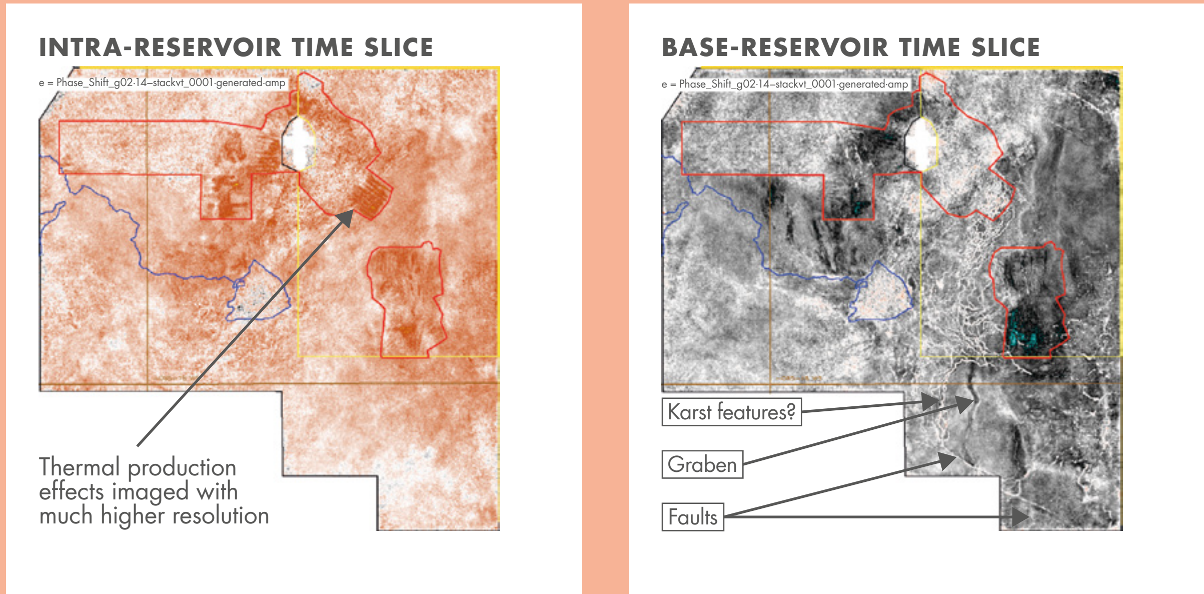
One of the most promising areas in geophysical processing is least squares migration (LSM), an imaging technique that deals with sparse or irregular seismic data and with poor illumination due to complex overburdens.

LSM minimises the migration noise that is caused by irregular acquisition geometries by fitting modelled data to observed data in an iterative fashion. The LSM method, which can be applied to all acquisition geometries, delivers a cleaner image for improved interpretation. It is particularly useful in areas of complex geology, but requires very high processing capacity, approximately 20 times more than conventional migration methods. LSM can also help for velocity model building and reservoir geophysics by providing lower noise prestack data.

Shell is leading the industry with its work on LSM. This new approach aims to improve the quality of seismic images by estimating angle-dependent reflectivity through minimizing the difference between observed data and the primary reflection data synthesized from that reflectivity. LSM has shown huge potential as a tool for enhanced seismic processing.

Shell has used the LSM technique to enhance seismic imaging of prospects below complex geologies, such as subsalt rock sequences or those in fold and thrust-belts, which has made a substantial contribution to prospect de-risking and improved well-planning activities.

The LSM technique can be a key differentiator. In some locations the quality of the processing that can be applied to the data is key to finding reservoir structures.



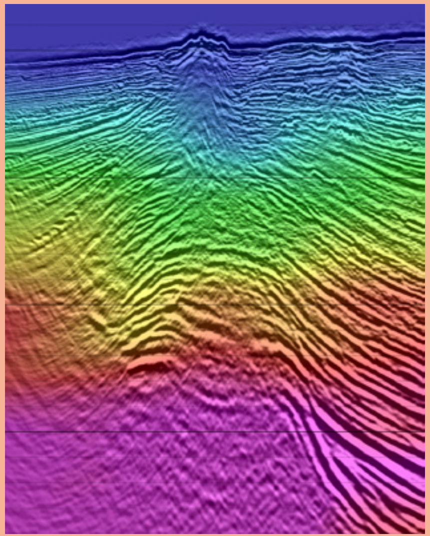
The Peace River Complex imaged by Least Squares Migration in North-western Alberta, Canada

A CLEARER PICTURE OFFSHORE NIGERIA

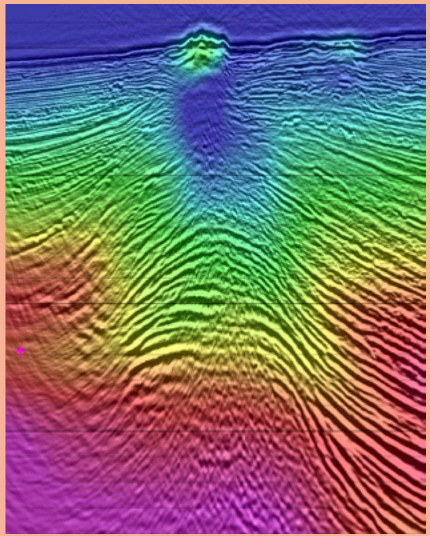
The presence of velocity anomalies in the overburden rock layers at Bonga Main, offshore Nigeria make it difficult to image the complexities of the rock sequence at target depths and produce an accurate, migrated image. Shell's solution was to combine effective preconditioning of seismic data with the latest multi-attribute Full Waveform Inversion (FWI) work process. This significantly improved the imaging and positioning in depth beneath the anomalies.

FWI retrieved both the low velocity associated with gas accumulations and the high velocity associated with a gas hydrate cap. This produced a more accurate model, which improved the event continuity of the migrated image and its position in depth. The method captured details in the velocity model that were extremely challenging to achieve with conventional tomography. The FWI method can be applied to data sets that have recorded sufficiently long offsets, low frequencies, and benefits from multiple azimuths. This method, combined with the acquisition of OBS data, helped where seismic imaging of the reservoir was extremely challenging.

IMPROVING THE NEAR SURFACE VELOCITY MODEL



Seismic depth image and velocity model from tomography only



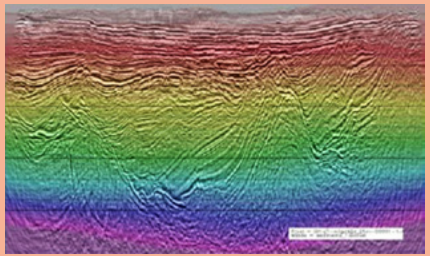
Seismic depth image and velocity model from Full Waveform Inversion

LAND SEISMIC IMPROVED BY LOW-FREQUENCY APPROACH

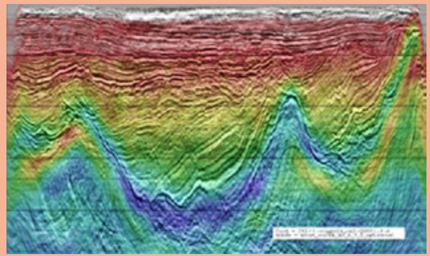
To demonstrate the value of recording low frequencies during seismic acquisition, Shell conducted an experimental survey in Inner Mongolia, China. Using a modified vibrator and a non-linear sweep, the survey recorded seismic data in the frequency range 1.5–80 Hz. The dense single source, single receiver acquisition allowed the research team to carefully de-noise and pre-process the data set and to apply an acoustic processing and imaging approach. Thanks to the long offset and low-frequency data, a multiscale full-waveform inversion between 1.5–5 Hz delivered a velocity model that matches the actual geology and is superior to the velocity model obtained by reflection traveltime tomography.

This approach enabled the research team to obtain an impedance map where the reservoir layer and the reservoir seal are interpretable. This illustrates the value of low frequencies in seismic data and the use of full-waveform inversion to derive background velocity. 3D low-frequency wide-angle seismic data sets are nowadays regularly acquired in the Middle East. 3D full waveform inversion is evaluated on these large data sets.

SEISMIC IMAGING WITH FULL WAVEFORM INVERSION – OVERNIGHT RESULT



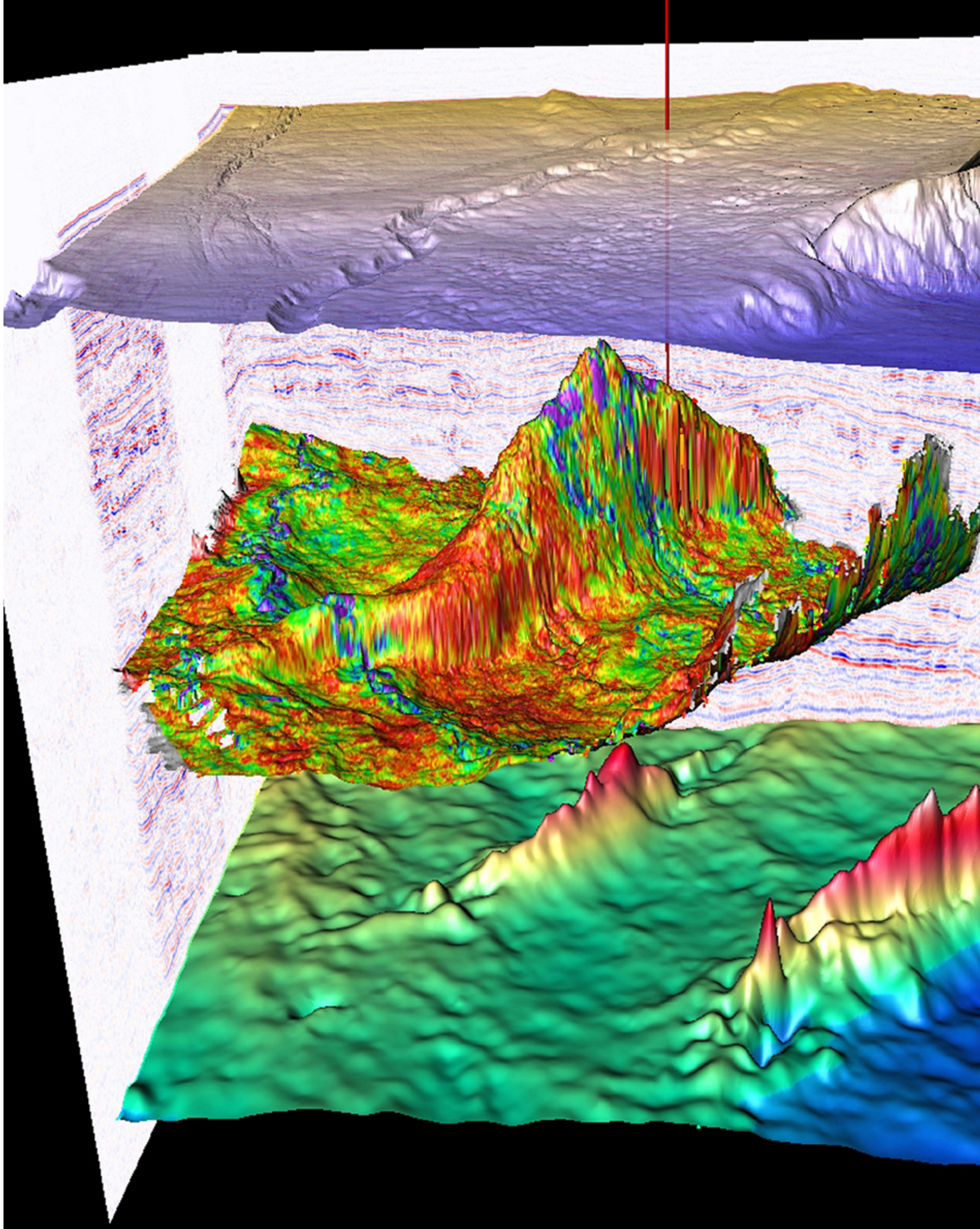
Velocity model and imaging derived with classical methods

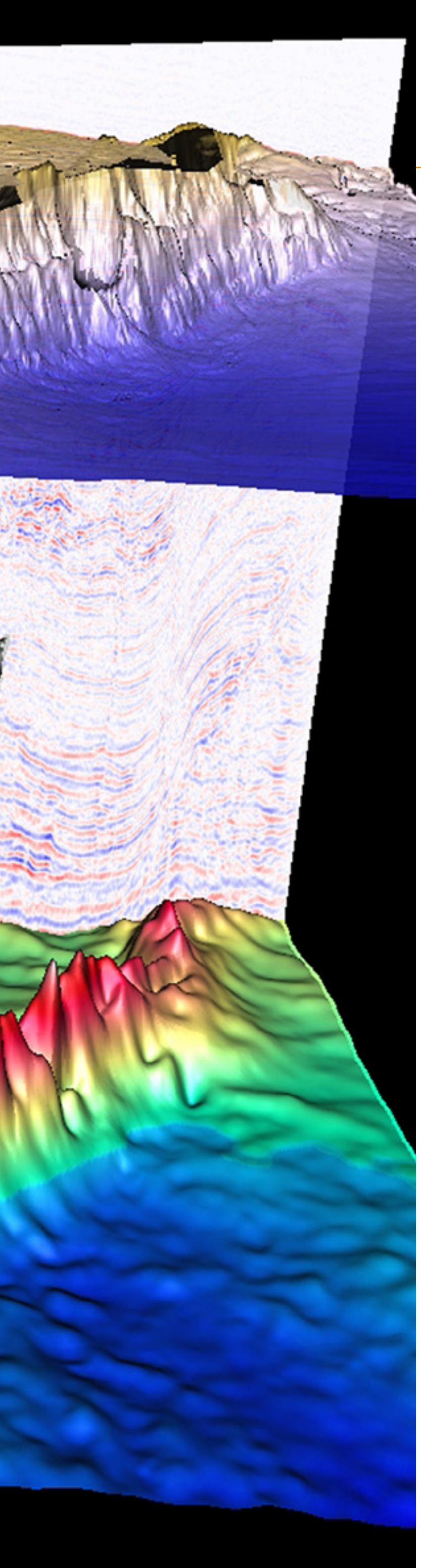


Enhanced bandwith data imaging with velocities from Full Waveform Inversion

Shell's biggest successes in exploration have come as a direct result of step-change visualisation and interpretation tools

1954 – drying seismograms at a seismic camp in the Colon district, Venezuela





Visualisation and interpretation: seeing is believing

State-of-the-art visualisation helps geophysicists and geologists maximise the value of modern seismic acquisition techniques by enabling them to see what others cannot. Having a detailed, accessible model that can be viewed and shared helps them to de-risk exploration prospects and improve the effectiveness of field development decisions.

The integration of numerous tools on a single platform (GEOSIGNS) is a key requirement for the next generation of subsurface interpretation systems

Having acquired and processed geophysical data, exploration and production teams must find fast and effective ways to view the model, share their expertise about what it reveals about the hydrocarbons that may be present in the structure. The ability to present this information clearly and make decisions quickly enables Shell to increase the efficiency of its field development programmes.

GEOSIGNS

Shell's GEOSIGNS subsurface visualisation software offers a variety of tools and functionalities to visualise large amounts of processed seismic data and interpret them in a robust, integrated and collaborative way. In fact, this comprehensive suite incorporates twenty-nine major proprietary technologies for example, industry-leading wide azimuth data visualisation and interpretation, extensive quantitative interpretation tools, and advanced stratigraphic interpretation capabilities. Combining these capabilities enables Shell to create a more complete picture of the subsurface. A key feature of GEOSIGNS is that the software is being continuously improved and extended by expert practitioners.

Using GEOSIGNS, multidisciplinary teams can work together to create more accurate subsurface models by interpreting large amounts of seismic and non-seismic data. The system

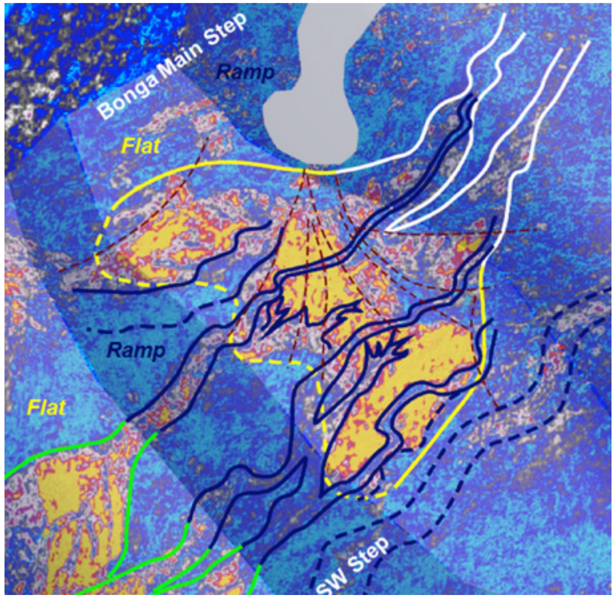
Shell's biggest successes in exploration and production increases have come as a direct result of step-change visualisation and interpretation tools

enables teams to draw on the widest range of data types in order to locate and identify hydrocarbons, assess the economic viability of extraction and highlight previously overlooked opportunities. Shell's biggest successes in exploration have come as a direct result of step-change visualisation and interpretation tools and in many cases the application of GEOSIGNS has played a key role.

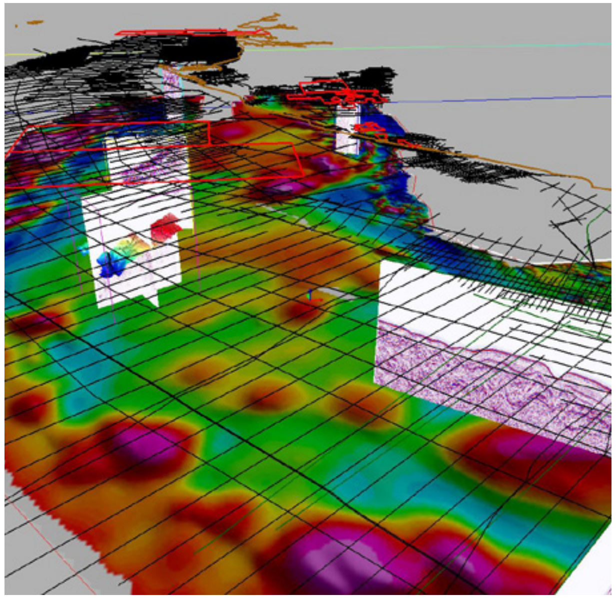
Maximising productivity is a key objective across the oil and gas industry. Shell GEOSIGNS helps to make field development more efficient by highlighting optimised drilling locations and providing better resolution of structural uncertainties. A quantitative interpretation capability within the software can be used to enhance planning and drilling operations and budgeting.

Interpreters can also use GEOSIGNS to enhance their own efficiency through the effective integration of tools, automation, and a common interface for standard and specialized workflows. The flexibility of the system means that users can interrogate data in a way that suits their particular workflow. Furthermore, GEOSIGNS can help to reduce the potential risk of drilling incidents by identifying hazards, providing accurate formation depth information and pore pressure predictions during well planning.

Achieving excellence in exploration and production demands a fully integrated approach between disciplines and the development of tools and processes that encourage and facilitate further integration. Highly-skilled staff and effective collaboration with industrial partners and the brightest minds in academic institutions are some of the key themes for success in this arena.



GEOSIGNS

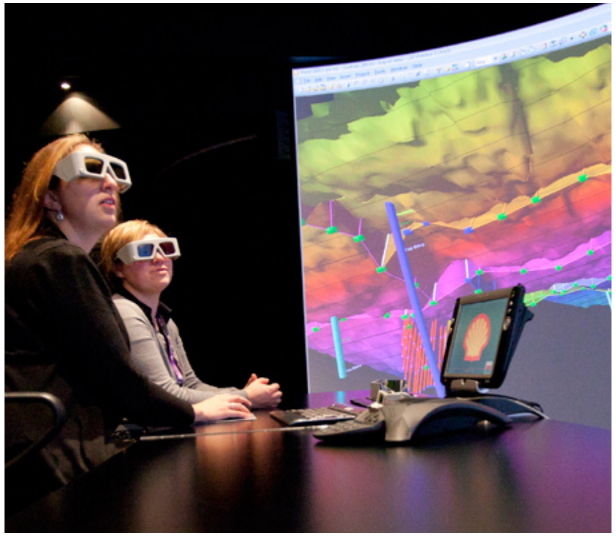


INTEGRATED WORKING ENVIRONMENT

Shell and Baker Hughes have announced a software license and joint development agreement to produce a high-end platform for geological and reservoir modelling.

The new platform will enable Shell's geoscience and petroleum engineering experts to better plan and manage the extraction of oil and gas resources, thereby realizing the full potential of each reservoir.

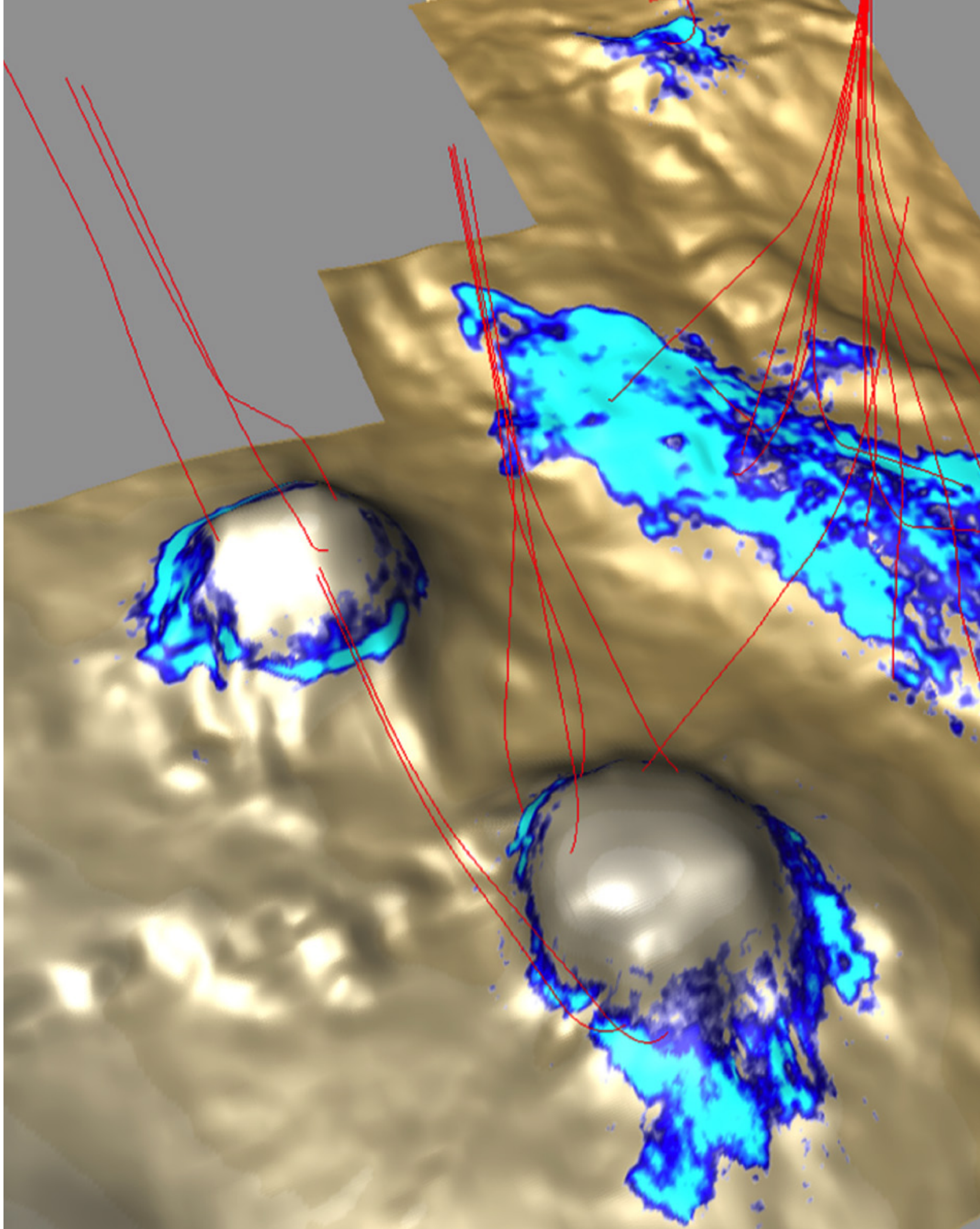
This will complement existing applications, including GEOSIGNS, and form part of an integrated working environment for Shell's exploration and modelling experts.



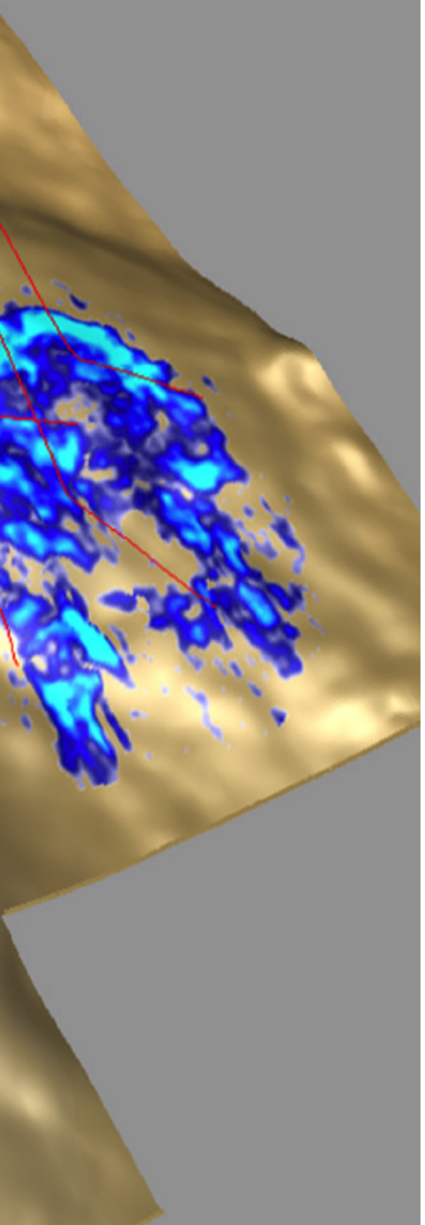
3D visualisation facility Stonehaven, Aberdeen, UK

One of the most important things to understand about an oil or gas reservoir is how the fluids inside it are moving

Instantaneous 4D surveying



Geophysical surveillance: insight in reservoir behaviour



4D seismic,
Gannet cluster, UK

Repeating seismic surveys over the same oil or gas field makes it possible to track the production-related changes that occur within oil and gas reservoirs. Field development teams can then use this time-lapse data to predict future trends and make better decisions about how their reservoirs should be developed.

One of the most important things to understand about an oil or gas reservoir is how the fluids inside are moving. Traditionally, geophysical methods were used to create discrete snapshots of the subsurface, with each survey being acquired to guide a planned exploration or production activity within the field. Geophysicists have always known that they could gain a clearer understanding of the reservoir by running repeat surveys that show changes over time, but there were costs to consider and technical challenges to be overcome.

These challenges included placing seismic sources and receivers in exactly the same locations on two or more surveys and efficiently handling and interpreting the multiple surveys. Advances in technology, such as the development of sensor systems that could remain in place between surveys, helped to make time-lapse, or 4D, methods work. Towards the end of the 1990s, 4D seismic methods started to be used with confidence in field development decisions.

WATCHING THE GANNETS

Since 1998, Shell has been conducting 4D surveys at the Gannet cluster of fields in the UK sector of the North Sea. The main driver for this work has been to enhance reservoir management across the various Gannet fields. The 4D seismic approach enables Shell to track the movement of oil and other reservoir fluids. At Gannet A, for example, Shell is tracking changes in the reservoir's gas cap and oil rim, and monitoring the movement of water towards the producing wells.

This approach enables Shell to get the most from existing wells by managing production rates and tracking the arrival of the water front that will ultimately signal the end of a well's producing life. It guides the decision to change an oil-producing well to one that injects water, in order to maintain reservoir pressure.

The 4D seismic work at Gannet is part of an integrated monitoring programme that includes the use of measurement and calibration at the wells and the use of GPS systems on the platforms to monitor the seabed subsidence that result from production operations.

At the Gannet cluster the typical period between repeat seismic surveys is two to three years. In these large fields, where the water front moves relatively slowly, this rather long repeat period still gives the production team a clear picture of how the reservoir is evolving over time.

i4D helps to maximise the efficiency of reservoir surveillance efforts and to ensure reservoir integrity, safety and production optimisation

INSTANT RESULTS IN THE GULF OF MEXICO

Instantaneous 4D (i4D) surveying is a new method which aims to acquire dedicated high-quality 4D data with short turn-around time at cost levels low enough to make it affordable to repeat such data acquisition programs frequently.

This method enables monitoring of fast reservoir changes such as those occurring in the vicinity of water injection wells. I4D helps to maximise the efficiency of reservoir surveillance efforts and to ensure reservoir integrity, safety and production optimisation. The required seismic seabed (OBS) nodes are positioned and retrieved by remotely operated vehicles.

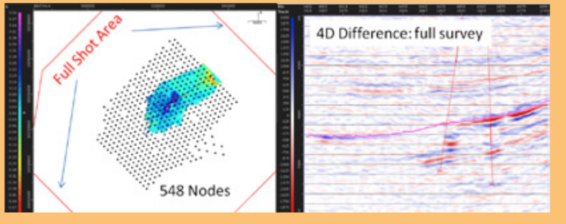
Since 2007, Shell has acquired OBS data over almost all of its producing assets in the Gulf of Mexico. Shell recently completed the first ever practical, successful, demonstration of ocean bottom sensing (OBS) in ultra deep water. The survey was conducted in a water depth of 3,000 metres in the Great White field, Gulf of Mexico. This project showed that OBS can be rapidly deployed in a target area. The field operator used the images acquired by OBS to guide a reservoir management intervention that helped maximise the value of the asset.

Compared to conventional streamer data, OBS delivers dramatic improvements in resolution for below- and near-salt imaging. This includes better definition of reservoir drainage compartments and a clearer understanding of reservoir structure and geological history.

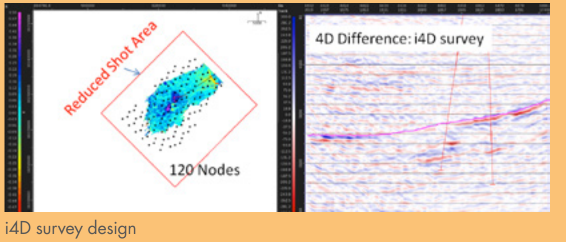
The excellent source and receiver position repeatability that can be achieved with i4D and OBS means that time-lapse surveys can detect small production changes. Seafloor nodes can be placed next to existing infrastructure and so node surveys lack

COMPARISON BETWEEN CONVENTIONAL 4D SURVEY DESIGN AND I4D SURVEY DESIGN

Comparison of time-lapse results obtained using a full-fold OBS survey (top) and low-cost targeted i4D survey (bottom) using a fraction of the nodes and a significantly reduced shot area. Black dots indicate nodes used to create time-lapse difference map for a producing horizon (left) and difference seismic (right) showing a seismic cross section through two water injection wells. For the upper images, 548 nodes and the large shot-outline were used. In lower images, 120 nodes and the reduced shot area were used.



Conventional 4D survey design



i4D survey design

Ocean Bottom Sensing nodes

the problems associated with platform undershooting that is a common issue with 4D streamer data.

Asset teams need information about slow, long-term changes, such as those associated with depletion and aquifer drive, as well as the short-term changes that can occur near injection wells. The high quality of OBS data has enabled Shell to develop low-cost solutions that enable more frequent monitoring in specific areas of interest by deploying small, targeted i4D surveys.

The combination of large-scale surveys and i4D surveys provides a cost-effective way for Shell to monitor rapid changes and gradual changes in various parts of the reservoir. This technique is set to become an important monitoring approach for the company's offshore portfolio.

As OBS technology improves it seems likely that sensor systems will be left on the ocean floor for longer and that i4D could become the technology of choice for on-demand reservoir monitoring offshore.

A PERMANENT SOLUTION

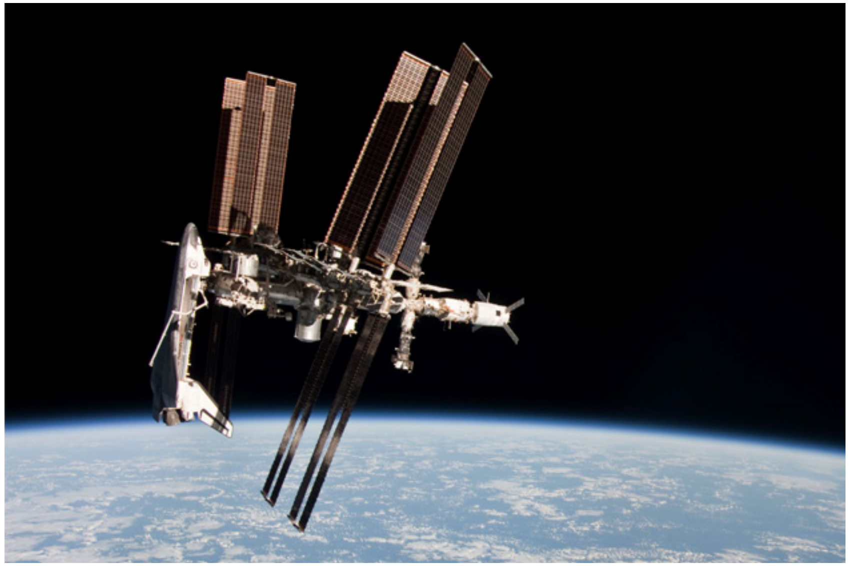
To date, offshore time lapse seismic projects have generally been more successful than those conducted onshore. The issues that face onshore surveys are false time-lapse signals caused by seasonal changes in ground surface and the effects of surface reflections, and these have often led to disappointing results. However, recent experience shows progress in overcoming these problems.

At Schoonebeek in the Netherlands, Europe's largest onshore oil field, Shell produces oil using thermal enhanced oil recovery (EOR) with steam injection. Working in collaboration with CGG, Shell has conducted trials of a permanent field monitoring system. This early prototype uses buried sources and detectors to reduce the issues of false time-lapse signals and novel processing methods to remove remaining surface reflections.

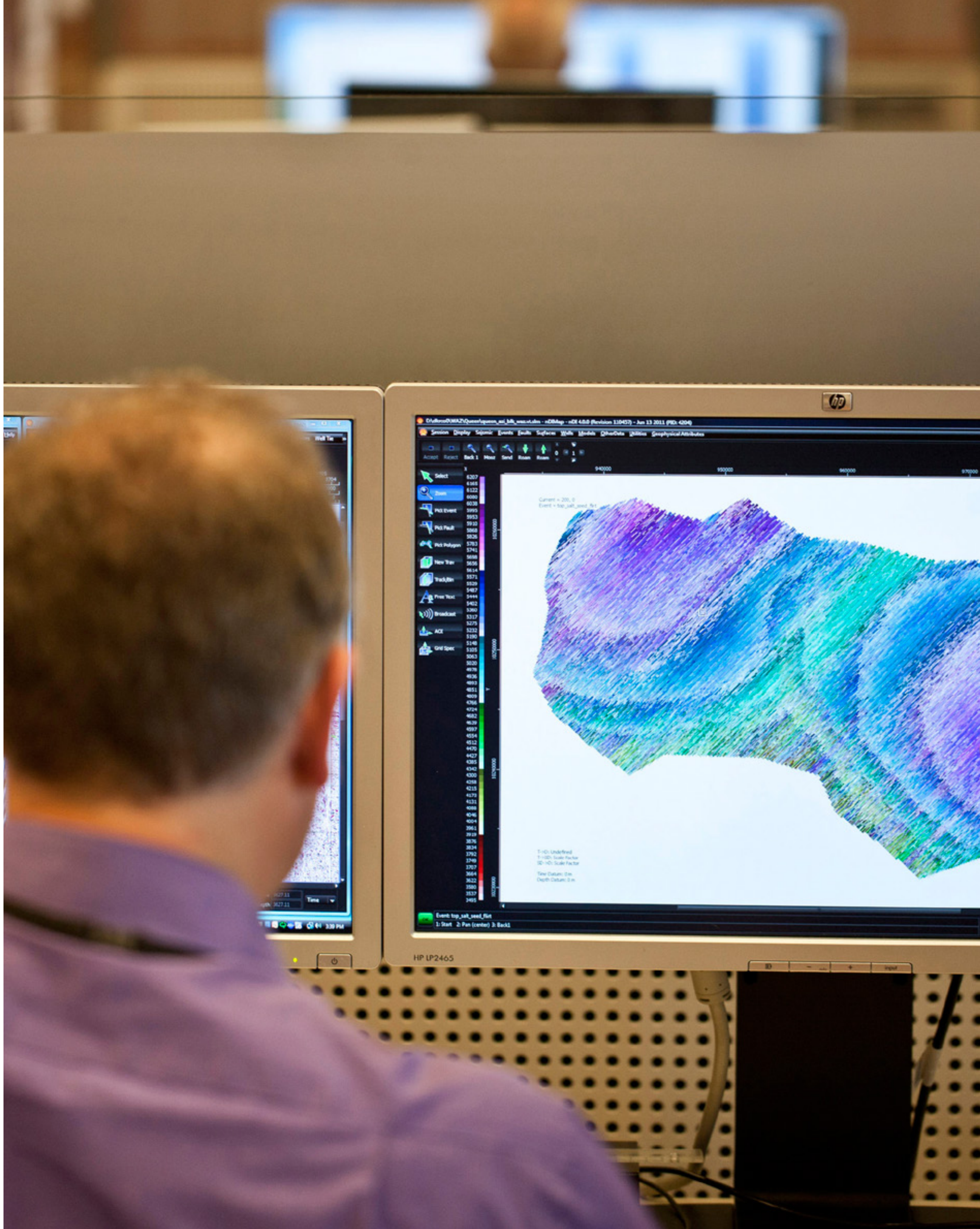
The field has been set up for continuous seismic recording through an unmanned, non-intrusive system with data being collected and relayed through the internet via a satellite link. Successful trials have shown the potential of this method and its minimal environmental impact. Onshore operations must be acceptable to local communities and protect the local environment. At Schoonebeek farming activities resumed on the site a few weeks after installation of the monitoring system.

Permanent field monitoring: trenches for permanent receiver lines and one month after installation, Schoonebeek, the Netherlands

Partnering beyond our industry for novel technology solutions



Unusual partnerships



GEOSIGNS, Rijswijk,
The Nederlands

Looking to the future: bringing it all together

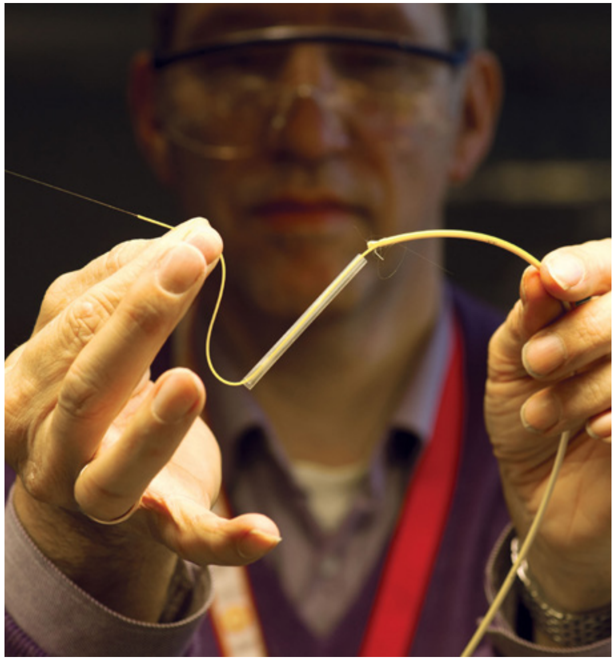
Geophysical acquisition, processing, visualisation and interpretation – each of these steps play an important role in finding more challenging hydrocarbon resources and enhancing control over the processes of oil and gas production. In the age of Big Data, information technology and, specifically, high-performance computing (HPC) are critical enablers to improve imaging and data management insights and maximise business value.

Shell applies research and development efforts along the full chain of geophysical imaging activity: from data acquisition and processing with high performance computing systems to state-of-the-art visualisation and new interpretation platforms that extend the scope for cross-disciplinary integration.

In addition to developing in-house expertise and capabilities, Shell recognises the value of working in collaboration with industry, research institutions and the academic sector to find new ways to enhance geophysical imaging.

Fundamental research, demonstration programmes and commercial deployment call for close collaboration within and beyond our industry. We foster open collaboration and unusual partnerships to gain powerful insights and solutions and accelerate new innovations.

Future exploration and production success will go to those who best integrate talent, technology and working cultures and deploy geophysical imaging and interpretation technologies that make sense of the most demanding reservoirs.



Fibre optic technology

NEW TECHNOLOGIES FOR LAND SEISMIC ACQUISITION

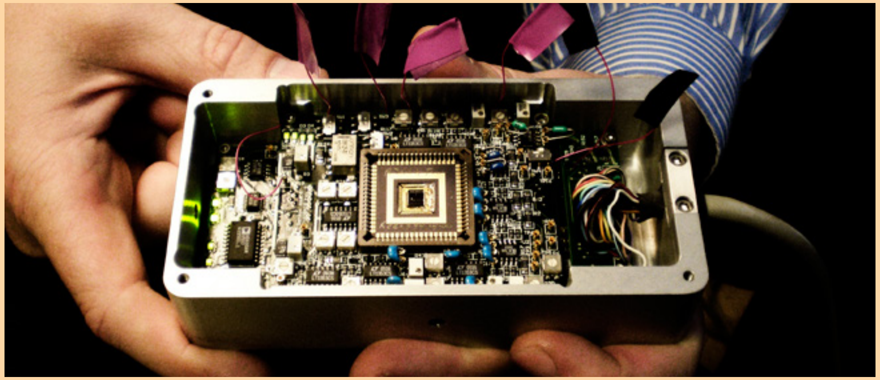
New onshore seismic acquisition systems will enable cost-effective reservoir monitoring of onshore assets during production, a capability that does not currently exist within the industry. Shell's seismic acquisition R&D program aims for cost-effective, ultra high channel count onshore systems and cheaper ocean bottom seismic acquisition.

WIRELESS SEISMIC SYSTEM

One way to improve the quality of onshore seismic surveys is to increase the number of sensors that are deployed in the survey. Shell is working to develop a wireless microelectromechanical system (MEMS) that can be scaled up to one million onshore channels.

These new generation sensors have minimal power requirements, reduced weight, low cost and a design that delivers low-noise performance. This will allow much denser imaging of onshore fields and reveal much greater detail of vital geological structures. The project involves constructing a system that includes a wireless network, high-performance computing, software applications, software architecture and system integration that can not only collect the data from a million channels but also make sense of it.

Key for this system is rapid deployment (up to 50% faster than current systems) and suitability for difficult terrain.



Wireless microelectromechanical system (MEMS)

SCALABLE, LIGHTWEIGHT FIBRE-OPTIC LAND SEISMIC SYSTEM

Shell has teamed up with Petroleum Geo-Services (PGS) to create a scalable, lightweight fibre-optic system that provides superior quality for land seismic surveys.

PGS is primarily a marine-based seismic company and has developed the OptoSeis™ fibre-optic seabed monitoring system. This helps operators reduce overall costs and can reveal hidden resources and so improve recovery from offshore fields.

Shell technologists recognized the potential breakthrough innovation of applying the technology that underpins the OptoSeis marine technology for onshore seismic. In 2010, an OptoSeis onshore prototype was tested in Oman.

This showed sensitivity and signal-to-noise ratios that were in line with design expectations and very promising seismic image quality. A second trial, successfully completed in Qatar during 2013 used a significantly higher channel count than in the prototype trial.

The field testing is intended to demonstrate a capability to provide enhanced images of the subsurface and the potential for large-scale deployment. The data collected from the 2013 test in Qatar is being analyzed at Qatar Shell Research and Technology Centre. If successful, the new technology could represent a significant advancement in onshore oil and gas exploration, as well as monitoring and enhancing production.

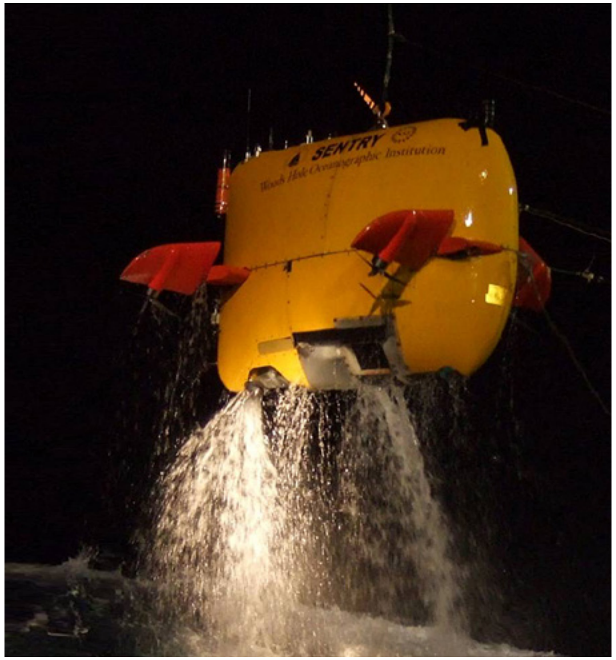
PGS OptoSeis fibre optic sensor

PGS OptoSeis fibre optic sensor

Future exploration and production success will go to those who best integrate talent, technology and working cultures and deploy geophysical imaging and interpretation technologies that make sense of the most demanding reservoirs

AUTONOMOUS UNDERWATER VEHICLES (AUVS)

In the area of offshore acquisition, there may be significant developments in smaller and more power-efficient underwater robots that can work autonomously to help monitor and image structures beneath the deep ocean floor. Shell is collaborating with internationally recognised partners such as the Woods Hole Oceanographic Institution and a number of robotic design companies to extend capabilities in autonomous underwater sensor technologies.



The Sentry, Autonomous Underwater Vehicle Image courtesy Woods Hole Oceanographic Institute

HIGH-PERFORMANCE COMPUTING: CALCULATIONS YOU CAN COUNT ON

Without high-performance computing (HPC) it is impossible to process exponentially higher volumes of data into geologically meaningful images. The computational challenges facing the energy industry and the technologies available in information sciences are both undergoing a period of transition with rapid disruptive changes. The energy industry wants to gather, process and visualize more data. To achieve this there will have to be urgent improvements in the scale and flexibility of high-performance computing infrastructure.

Wide azimuth seismic in onshore and offshore settings and in-well distributed sensing technologies for instance have led to an explosion of data rates and the resulting data volumes that require novel and automated processing solutions. Developing automated solutions in data processing calls for a concerted effort in technology development, particularly in high performance computing, and effective cross-disciplinary collaboration.

In 2008, Shell established a global HPC Center of Expertise with staff at the three technology hubs in Houston, USA, Rijswijk, the Netherlands and Bangalore, India and selected Intel as its strategic technology partner. This partnership is addressing current and future seismic data processing challenges and enabling "future-proofing" of Shell's technology and investment in new algorithms. Results achieved to date include an order-of-magnitude improvement in HPC throughput, which means Shell can do more seismic processing for the same compute cost. This has enabled cost-effective deployment of the latest and most accurate algorithms, resulting in fewer, safer wells and reduced risk in our exploration program.

Shell is working with NVIDIA and Intel to develop and improve the processing and visualisation of data for our cutting edge subsurface applications. One area of collaboration is a project to greatly extend the amount of data that can be displayed in real time.

High-performance computing

DISCLAIMER

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this publication "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this publication refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Companies over which Shell has joint control are generally referred to "joint ventures" and companies over which Shell has significant influence but neither control nor joint control are referred to as "associates". In this publication, joint ventures and associates may also be referred to as "equity-accounted investments". The term "Shell interest" is used for convenience to indicate the direct and/or indirect (for example, through our 23% shareholding in Woodside Petroleum Ltd.) ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

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We may have used certain terms, such as resources, in this publication that United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov. You can also obtain these forms from the SEC by calling 1-800-SEC-0330. Scientists use 3D technology to review seismic data to help locate oil and gas reservoirs. Rijswijk, the Netherlands.

Any supply of the technology is subject to agreement on a contract and compliance with all applicable export control regulations.

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