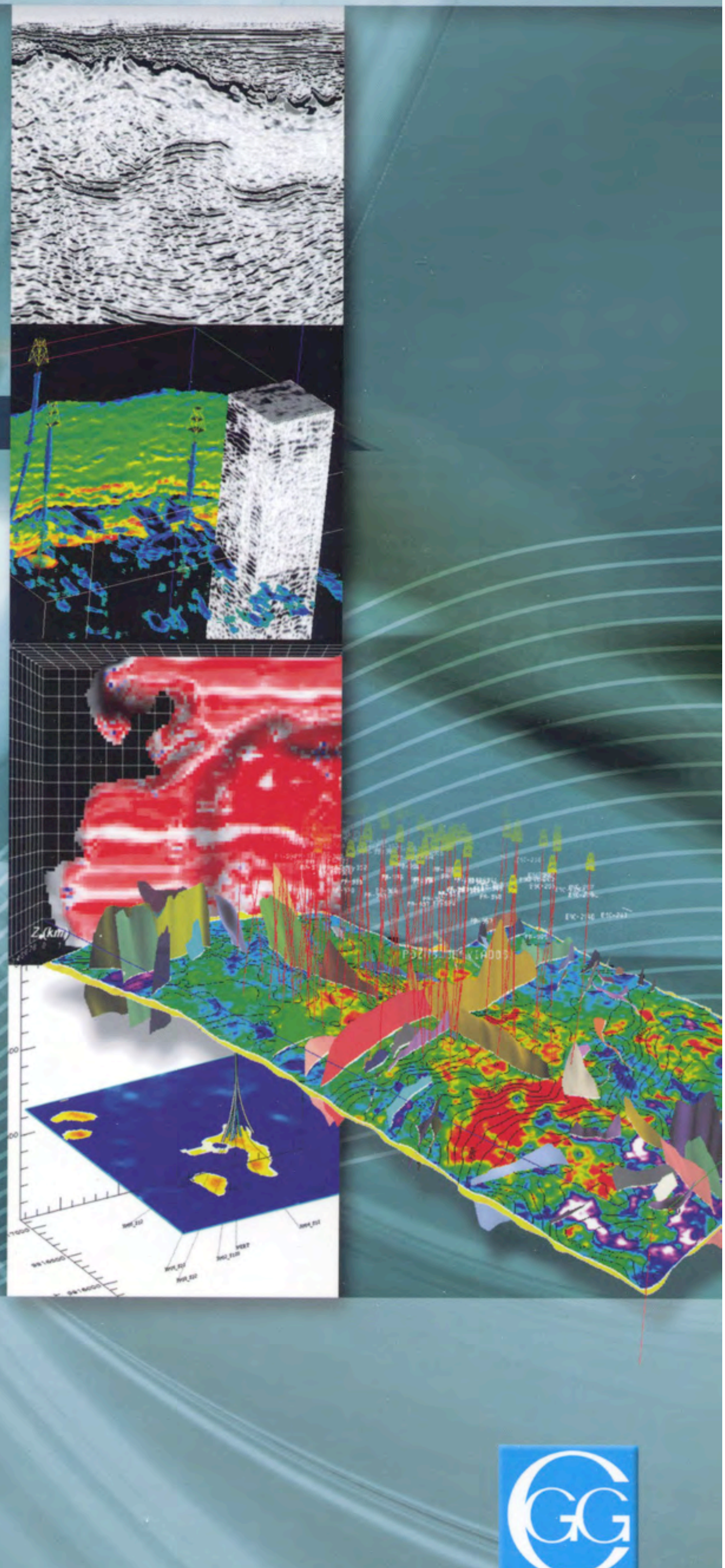
Eye-D™

Enhanced Reservoir Solutions



CGG

Enhanced Reservoir Solutions

The ***Eye-D*** suite of enhanced reservoir solutions is designed to better visualize and understand all dimensions of the reservoir and guide critical decisions on its development and production.

Because each hydrocarbon reservoir is unique, a tailored seismic approach is required to overcome the specific geophysical and geological challenges. Whether onshore, offshore, or on the seabed, the ***Eye-D*** range of dedicated seismic services gives CGG the flexibility to engineer each project individually.

Eye-D integrates full 3D and 4D acquisition, high-end processing and reservoir characterisation technologies, delivering high-resolution, high-quality seismic data to asset teams for improved reservoir development, production and monitoring.

Paris
+33 1 64 47 32 09

London
+ 44 20 8231 8120

Houston
+ 1 281 646 2593

Kuala Lumpur
+ 60 3 2713 0272

Email: mkt@cgg.com
Internet: www.cgg.com

Repeatability
Wave equation
Multicomponent seismic
Imaging the reservoir
Optimum illumination
Anisotropy
Full azimuth
High channel count

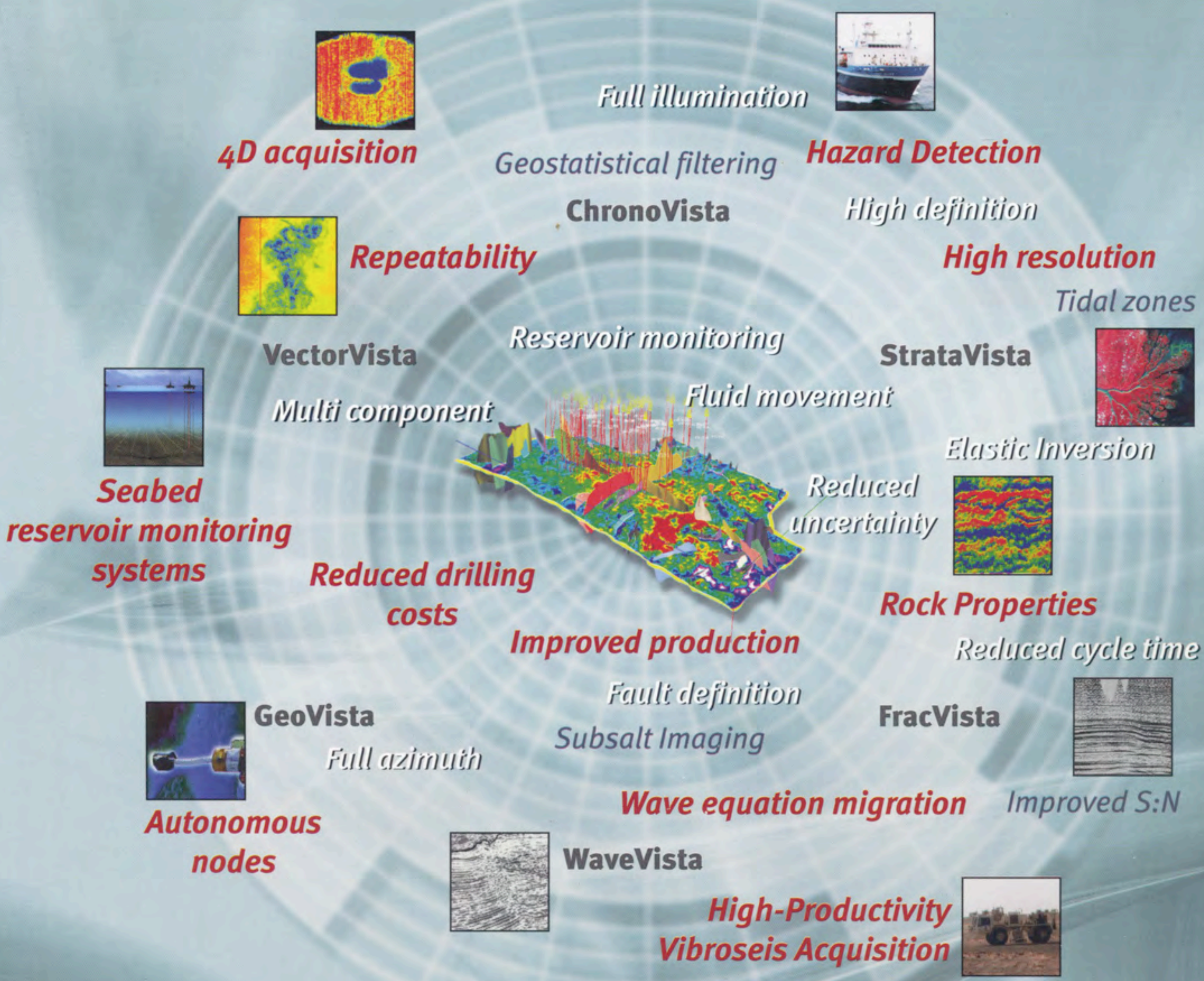
Eye-D™
Enhanced Reservoir Solutions

B6970408 Printed in France by CARACTERE

Eye-D™

Enhanced Reservoir Solutions

Today's hydrocarbon production challenges demand high-quality, high-resolution seismic that can help characterise reservoirs and monitor production. To meet these challenges, CGG has developed *Eye-D* – a suite of technologies that fully integrates advanced acquisition with high-end processing and reservoir services across all dimensions, whether onshore, offshore or on the seabed.



Eye-D™

Enhanced Reservoir Solutions

ENHANCED RESERVOIR SOLUTIONS

Eye-D provides a custom-made service to give you maximum understanding of your reservoir – whatever the need.

High-quality acquisition is the keystone of any seismic project. Without full, even illumination of the reservoir, no amount of processing will image it correctly. Through careful planning and pre-acquisition modelling, CGG is able to determine the optimum surface coverage required to correctly illuminate deep targets. Our state-of-the-art seabed systems provide further improvement by ensuring full-azimuth acquisition.

To gain understanding of more complex reservoirs, acquisition has become increasingly high-resolution. Offshore, CGG achieves this by deploying survey-specific vessel configurations, to allow higher frequency content and smaller bin size. High-resolution seismic is also key to detecting shallow gas-charged bodies around development platforms, thus reducing drilling risks. The rapid turnaround that CGG can deliver from acquisition of a hazard survey, using the AutoGasRisk method, to delivery of a "risk/no risk" verdict allows development teams to plan wells with confidence that all risks have been identified.

To achieve high-quality data with rapid turnaround in land acquisition, CGG has developed High-Productivity Vibroseis Acquisition (HPVA). HPVA is based on the slip-sweep approach but overcomes the obstacle of harmful harmonic noise by accurately estimating and subtracting it. The result is a significant improvement in turnaround and increased resolution at no extra cost. HPVA opens the door to affordable wide-azimuth high-channel count acquisition geometries.

For reservoir monitoring, *Eye-D* technology focuses on the crucial issue of repeatability. Careful planning of conventional land and marine surveys ensures that source and receiver points are as accurately reproduced as possible. Processing during acquisition verifies that the monitor seismic data falls within the specifications defined during the feasibility study phase. Back onshore, geostatistical filtering techniques efficiently remove acquisition footprints while repeatability is optimised so that 4D signatures are only seen at the reservoir. If multiple monitor surveys are planned offshore, then a permanent seabed array is not only cost-effective, it also ensures optimum repeatability.

The *Eye-D* processing suite is designed to give an unparalleled view of your reservoir in terms of time, depth and reservoir parameters. CGG's new high-density velocity picking technique generates geologically sound, anisotropic velocity fields that provide better focusing of events during pre-stack time migration. These velocity fields can also form the basis for reliable pore pressure studies, initial impedance models for stratigraphic inversion and initial velocity models for depth imaging. Very high-resolution processing techniques preserve the maximum bandwidth, whilst improving amplitude and wavelet continuity, with dynamic Q compensation and high-frequency Boost⁺. Dedicated multi-component software, VectorVista, has been developed to take full advantage of the properties of shear waves for eliminating multiples, increasing resolution, imaging through gas clouds and characterising fractures.

Depth imaging has taken a leap forward with the advent of Wave Equation Depth Migration. WaveVista, CGG's no-compromise, explicit shot Wave Equation Depth Migration can output angle gathers for AVA analysis and post migration processing. Compared to Kirchhoff, Wave Equation migration brings exceptionally crisp images under salt bodies and other complex overburdens, giving the high definition required for reservoir identification and interpretation.

CGG's proprietary layer-based simultaneous stratigraphic inversion produces elastic parameters that bring understanding of rock properties away from the wells. When applied to 4D data, this technique generates difference volumes quantifying saturation changes and allowing identification of bypassed hydrocarbon-bearing zones, hydrocarbon propagation pathways and barriers to flow.

The cumulative impact of *Eye-D* acquisition and processing allows you to plan your drilling with the highest degree of confidence. Close collaboration between CGG and our clients through the lifetime of a field results in superior knowledge of the reservoir with the benefits being measured in improved production performance.

F 222.04.09

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com www.cgg.com

Eye-D™

Illuminating Subsurface Structures

ENHANCED RESERVOIR SOLUTIONS

Prediction of the offshore acquisition footprint via illumination and migration amplitude maps can be used to OPTIMISE THE AMOUNT OF INFILL SHOOTING. Results from a Brazilian survey confirmed the required level of infill shooting needed to obtain a good image of the deeper target horizons.

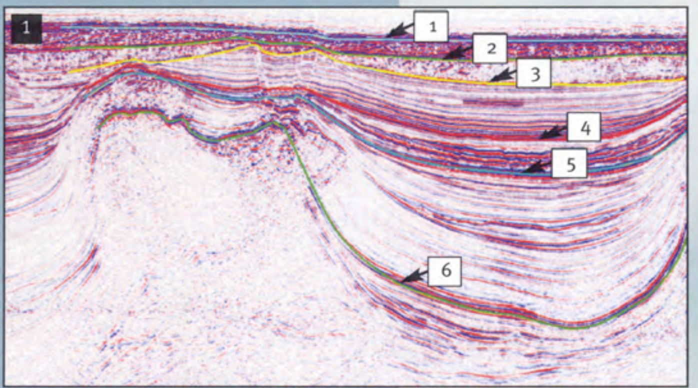


Figure 1: Salt diapirs in the test area offshore Brazil complicate the travel paths of the seismic waves yielding uneven illumination shadow zones.

From surface coverage to subsurface illumination

Uniform coverage at the surface does not guarantee uniform coverage or illumination at subsurface interfaces. This is caused by the bending of the acoustic waves through the geological structures. Insufficient surface coverage, which normally requires infill shooting, will lead to additional anomalies in illumination. Modelling was used on an offshore Brazil survey where complex structures resulting from salt diapirs were known to affect the expected subsurface illumination, particularly at the deeper levels such as horizon 6 (see Figure 1).

Subsurface illumination

The illumination map (Figure 2a) for horizon 6 was produced by modelling the planned acquisition along with the geological model and did not require any seismic data. It shows uneven illumination despite uniform coverage of the survey area. The red areas denoting over-illumination can be compensated for by seismic processing, but the blue areas are shadow zones and the horizons will remain invisible. Moreover, the actual marine acquisition is affected by streamer feathering leading to additional stripes of over- and under-coverage, as illustrated by the map in Figure 2b, produced using the actual sail lines.

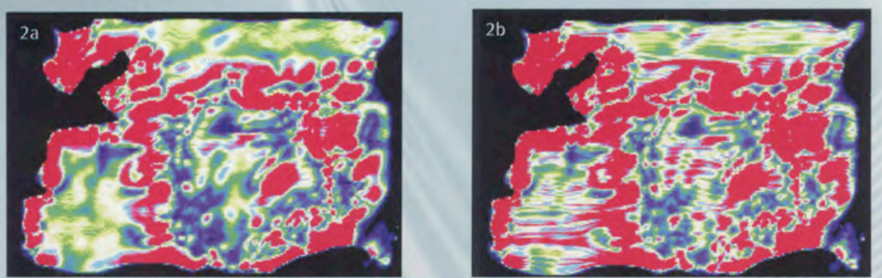


Figure 2: Illumination maps.
Left: Planned acquisition – zero feathering, Right: Actual acquisition - varying feathering.

Note that the raw illumination can be somewhat misleading and processing must be taken into account to obtain a better estimate of the final migrated image. Hence, our modelling process converts these illumination maps into estimated reflection amplitude maps using a prestack depth migration technique.

From subsurface illumination to horizon amplitudes

Illumination maps give a reliable indication of likely shadow zones but do not take into account the effects of the processing sequence. Horizon amplitude maps estimated from the illumination after pre-stack depth migration give a better indication of the need for infill. The left-hand amplitude map (Figure 3a) for the planned acquisition corresponds to the previous illumination map and is more evenly coloured indicating that the migration process has healed some of the smaller acquisition footprints. The map in Figure 3b shows the horizon amplitude on completion of the initial stage of sail line acquisition. The footprint of this incomplete acquisition is clearly visible as reflection amplitude anomalies. The effect is less marked in the depth of the basin on the right, than on the top of the salt structure towards the left, since the effect of the migration increases with depth. Following final acquisition of the guided infill lines, the corresponding map (Figure 3c) now shows that no additional acquisition is needed to fill small holes in the surface coverage.

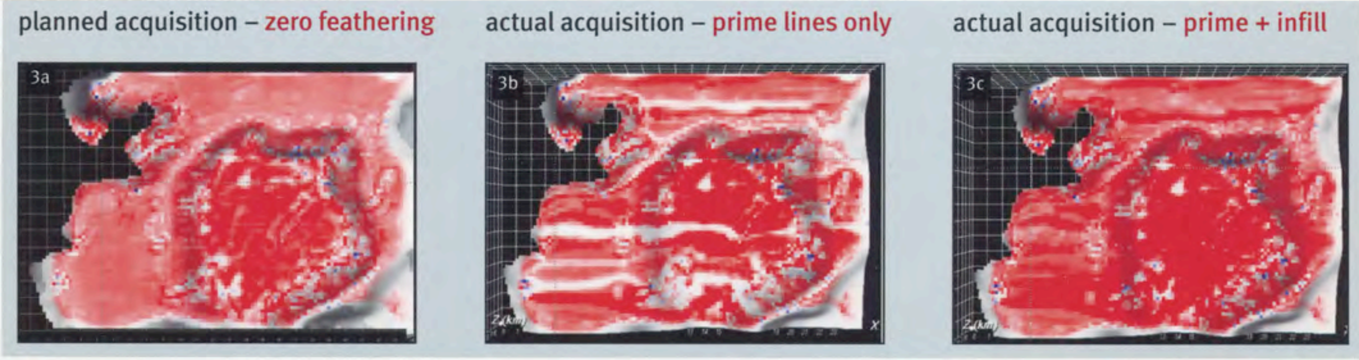


Figure 3: Amplitude maps.

Validation using the seismic data

Normally a hole in the acquisition of more than 50 m is considered unacceptable and the simulation of 100 m and 200 m holes can examine the effect of incomplete acquisition over a full coverage area. The resultant seismic sections (Figure 4) indicate that larger holes can be acceptable since no anomalous effects can be seen. Horizon amplitude maps can predict these effects and avoid unnecessary infill shooting.

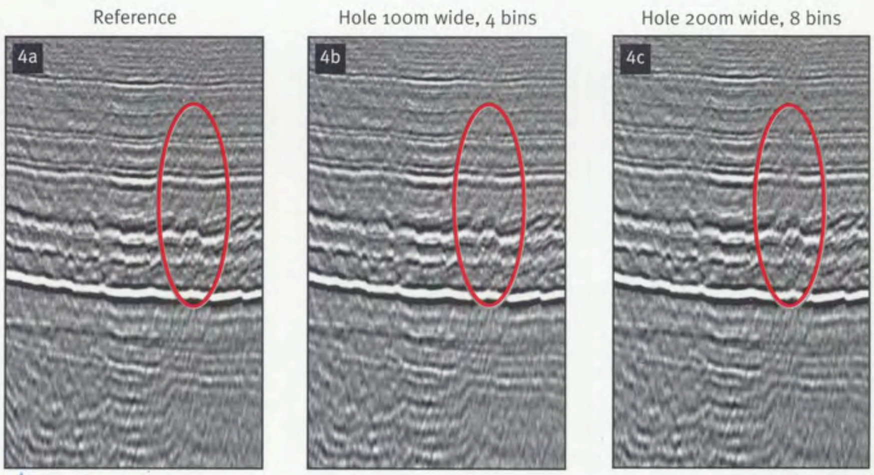


Figure 4: The impact of incomplete acquisition on the seismic image.

From horizon amplitudes to infill decisions

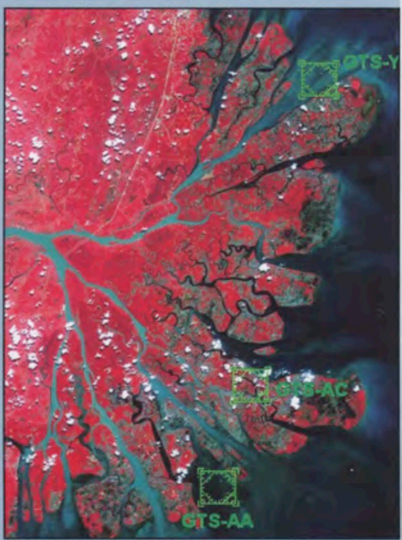
CGG's introduction of illumination and horizon amplitude maps generated during acquisition monitors progress, showing whether sufficient seismic data has been acquired and indicating which infill lines will contribute best to the final image. The outcome is increased data quality achieved in a cost-effective manner.

Worldwide Locations
Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272
Email: mkt@cgg.com • www.cgg.com

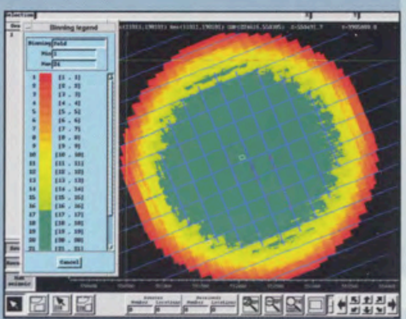
F 219.04.09

Reducing Drilling Risks

Base camp of acquisition crew in Kalimantan.



Location of three proposed platform sites in the Mahakam Delta.



Fold map of 3D site survey around platform.

By imaging gas-charged bodies around development platforms, high-resolution 3D seismic acquired by CGG helped REDUCE DRILLING RISKS on the Tunu North field in Kalimantan, Indonesia.

Drilling risk

The reservoir exploited by Total on the Tunu field in the Mahakam Delta lies under a multitude of shallow gas-charged sand bodies, in the context of a slowly prograding delta front, interleaving sands and occasional carbonates or coals, in a soft clay sequence.

The sands occur in channels and bars, which vary between 150 to 3000 m in width. In places, these cross-cut each other, potentially connecting or stacking, yielding a greater pressure column. This makes for high risk when drilling deviated production wells from platforms.

To reduce this risk, the operator systematically conducts high-resolution 3D seismic surveys around the platform sites. In early 2003, CGG acquired and processed a series of such surveys in the shallow waters of the Tunu field to assess the shallow gas risk at three drilling sites.

High-resolution acquisition

The survey was a key opportunity for CGG to demonstrate the effectiveness of its new acquisition methodology for very shallow water. Survey parameters were designed to detect the presence of gas anomalies down to a depth of 1500 m. A small, very high-resolution square was shot over each platform location, inside a broader high-resolution circle. The square geometry was acquired as a 500 m x 500 m patch, centered on the platform site, in order to image possible gas pockets at depths ranging from 40 to 400 m. The broader circle was acquired to detect gas anomalies at depths of up to 1500 m, within a surface radius of 1500 m from the centre of each drilling location.

Detailed survey planning

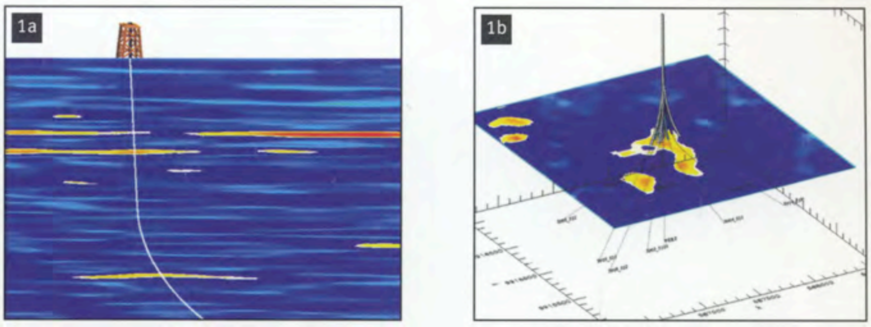
Operations were carefully scheduled months in advance, to take account of tide patterns and local community life. It was critical that the crew was fully operational on the scheduled first day, as any delay would push back acquisition to the next tidal cycle, one week later.
A fixed spread of around 600 active receivers was left in place for over a week in strong tidal currents and water depths of up to six meters. Trouble-shooting could only be conducted during peak high and low tides, when there was no current, leaving limited time for the actual shooting. Despite the difficult field environment, the crew achieved the excellent performance of less than 1% defective traces.

Rapid decision-making tool for the field development team

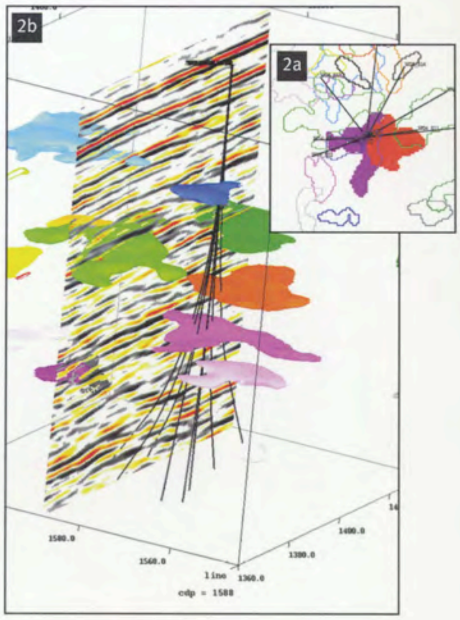
The processed high-resolution seismic cubes were interpreted for geohazards using the AutoGasRisk method developed in close collaboration with Total. The goal was to deliver a "risk/no risk" verdict to the client within a few days concerning the area surrounding each development platform.

After amplitude anomalies had been detected, interpreted and classified according to risk level criteria, the high-resolution 3D seismic data were converted into a risk evaluation map (Figures 1a, 1b and 2a).

A more detailed risk analysis was then performed on any anomaly lying along a well's planned trajectory, using advanced 3D visualization technology (Figure 2b). CGG delivered the results within 48 hours of receiving the coordinates of the proposed well trajectories and, with this information at their disposal, Total could rapidly modify drilling plans in high-risk sectors.



Figures 1a & 1b
Amplitude anomalies that can be related to gas sands are highlighted here in yellow. Each detected anomaly is analysed further in terms of spatial extent and geological interpretation in order to assess the level of risk associated with drilling through it.



Figures 2a & 2b
The most significant anomalies are classified according to the drilling risk and can be displayed in maps or visualized in 3D on a workstation.
The drilling team can use the maps to immediately determine the drilling orientation that minimizes the gas risk.
Using the 3D visualisation, it is possible to superimpose the seismic volume onto the distribution of potential gas sand bodies in order to assess the risk of each well trajectory proposed.

Benefits of 3D site surveys

By extending the scope of traditional 2D site surveys, high-resolution 3D surveys in very shallow water provide accurate delineation of shallow gas-charged bodies. The integrated approach developed by CGG capitalizes on its experience in shallow water acquisition, 3D processing and risk assessment to enable field development teams to make rapid "risk/no-risk" decisions on drilling plans at no additional cost to traditional 2D site surveys.

Reference
Mini 3D for shallow gas reconnaissance by T. des Vallières and D. Enns, Total SA, H. Kühn and D. Parron, Elf Aquitaine, Y. Lafet and D. Van Hulle, CGG (OTC 7986)

F 217.04.09

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com • www.cgg.com

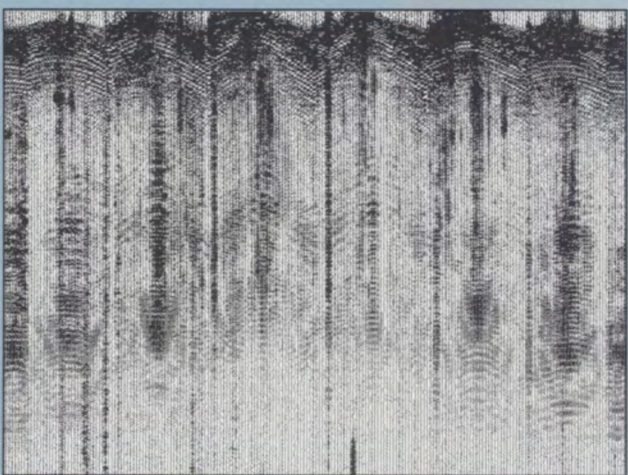
Making High-Resolution Acquisition Affordable

The effectiveness of CGG's new High-Productivity Vibroseis Acquisition (HPVA*) technique for IMPROVED CREW PRODUCTIVITY while PRESERVING DATA QUALITY was recently demonstrated on a 3D survey in the Western desert of Egypt.

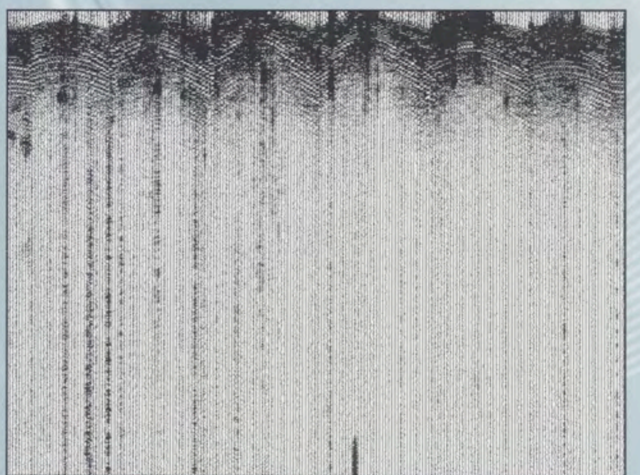
HPVA is inspired by the slip-sweep technique, which is essentially designed to boost crew productivity by allowing a vibrator group to sweep without waiting for the previous group's sweep to terminate. The advantage of the HPVA technique is that it overcomes the technical limitation usually associated with slip-sweep: the recording of harmful harmonic noise, which can contaminate the data.

Harmonic noise reduction

The HPVA technique, patented by CGG, reduces the harmonic noise to an acceptable level. By estimating the harmonic content of each vibroseis record, noise can be efficiently predicted and subtracted from the field data. This process is performed in the field, usually overnight, generating clean data for processing. As a result, the slip time can be reduced without degrading data quality, thereby improving crew productivity and maintaining the same signal-to-noise ratio.



Standard slip-sweep shotpoint with harmonic noise.



Same shotpoint with the HPVA technique. The attenuation of harmonic noise is clearly visible.

* Patent pending

Eye-D™

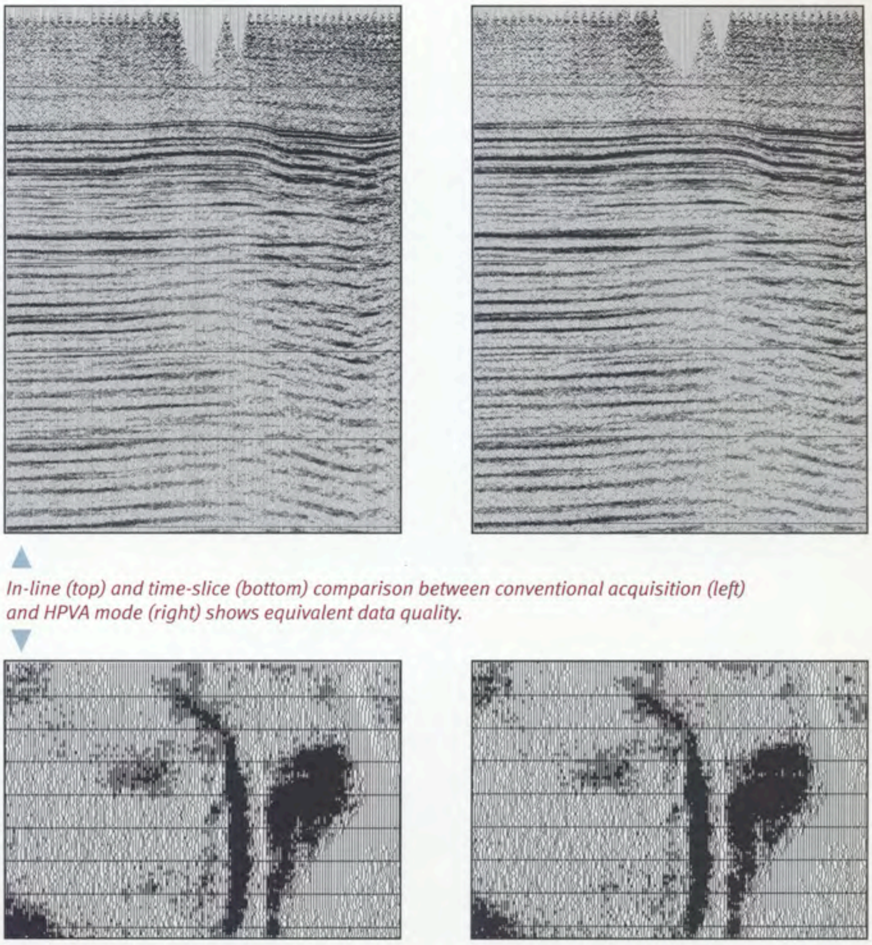
Making High-Resolution Acquisition Affordable

ENHANCED RESERVOIR SOLUTIONS

HPVA survey in Egypt

A 3D survey in Egypt demonstrated the effectiveness of the HPVA technique for implementation on an industrial scale.

After having been recorded following contractual seismic parameters with two sets of four vibrators in flip-flop mode, a full 3D swath of the survey was re-recorded in HPVA mode. For this experiment, a fleet of 12 vibrators was available to the crew.



In-line (top) and time-slice (bottom) comparison between conventional acquisition (left) and HPVA mode (right) shows equivalent data quality.

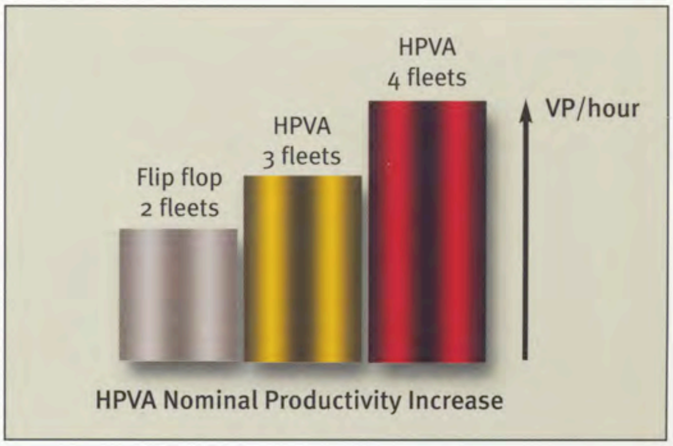
Significant improvement in productivity

HPVA acquisition with three fleets of vibrators achieved a 25% gain in productivity compared to conventional flip-flop acquisition with two fleets of vibrators. This was accomplished with no deterioration in seismic data quality.

Increase resolution - spend less

As oil companies require increasingly detailed knowledge of their reservoirs, demand for larger and larger seismic volumes will escalate. Increasing source productivity will be instrumental in meeting this demand. HPVA offers affordable high-resolution acquisition by dramatically reducing vibroseis cycle time without degrading the signal-to-noise ratio.

HPVA acquisition can be applied, depending on client requirements, to either cut the acquisition cost per square kilometre without parameter changes or to increase resolution by recording higher fold data or smaller bin dimensions at no extra cost.



We would like to thank Apache Egypt Companies for giving us the opportunity to deploy this new HPVA technology.

F 216.04.09

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com · www.cgg.com

Optimising Offshore 4D Repeatability

Positioning is recognised as a critical factor for offshore 4D repeatability. CGG's implementation of integrated survey planning, navigation and onboard QC requirements leads to direct **IMPROVEMENTS IN THE QUALITY OF 4D SIGNATURES.**

4D presurvey planning

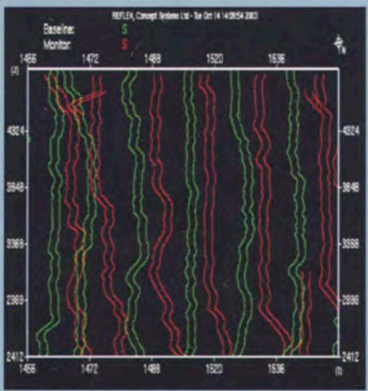
To maximise the imaging of the 4D effect, the best possible repeatability must be achieved between baseline and monitor surveys. The baseline survey data are therefore analysed with the aim of duplicating the source positions and obtaining similar streamer feathering, within predefined limits. The effect of a mismatch on the seismic results can be estimated using advanced modelling software.

Achieving 4D repeatability

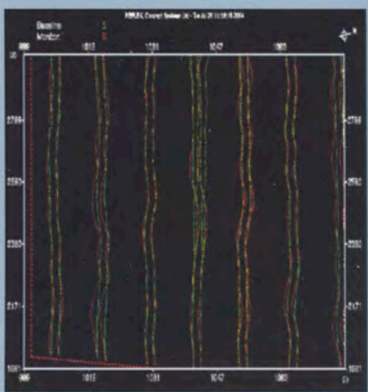
The navigation map of the baseline survey is used to steer the vessel. Sea currents are analysed in real time to predict the resulting streamer feathering. This information is used to synchronise the start of the new sail line relative to the phase of the tide in order to achieve similar feathering. Remaining differences will complicate the duplication of receiver points but can be handled by the deployment of additional streamers on the outside of the spread. If one streamer is displaced from its predicted position and does not cover the intended receiver points, the neighbouring one takes its position.

Analysis of 4D Track plots

monitor vs baseline

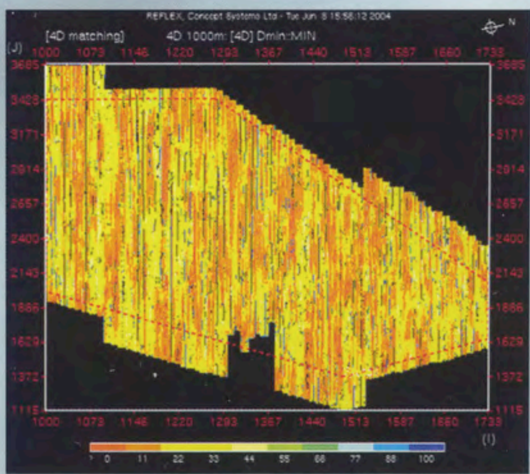


Poor Source Position Matching.



Good Source Position Matching.

Display of matching function



Good Repeatability — Poor Repeatability

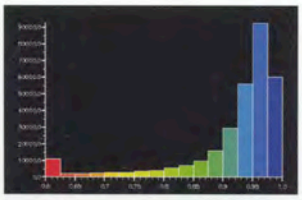
4D Repeatability Quality Control

Duplication of shot and receiver positions is monitored as the survey progresses. The repeatability algorithm uses a matching function under client control (as shown in the plots above).
Additional acquisition can be decided in real time on the basis of these plots.

Onboard 4D seismic verification

The preprocessing sequence of the baseline survey is used onboard to process the monitor survey while the seismic data are being acquired. This allows for a fast-track verification of the 4D seismic repeatability by visualization of typical attributes, such as predictability and NRMS maps (the energy in the difference cube between base and monitor). This verification is done on a line-by-line basis as the acquisition progresses to ensure that the 4D effects, which can sometimes be quite small, will be visible. The final 4D seismic repeatability maps are then used in the onshore processing center to optimise the full 4D seismic processing.

Figure 1: Verification of seismic repeatability during the acquisition. The black stripes indicate areas where seismic data still has to be acquired.



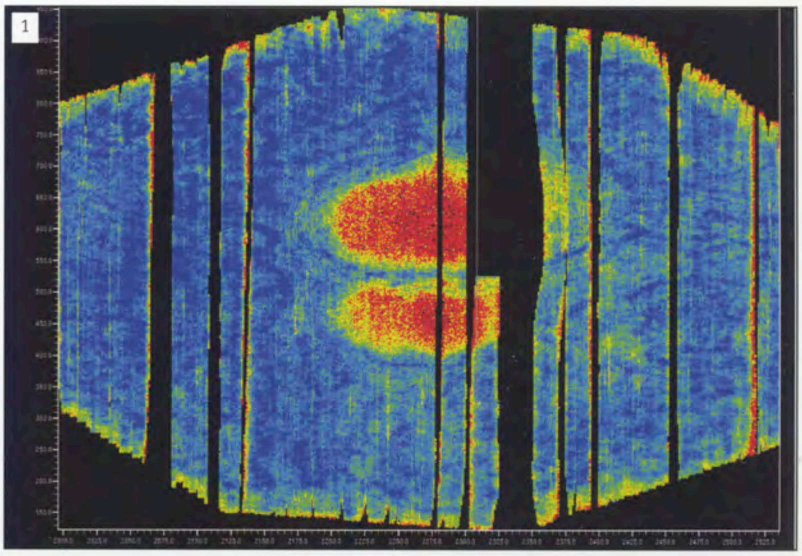
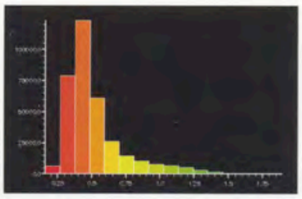
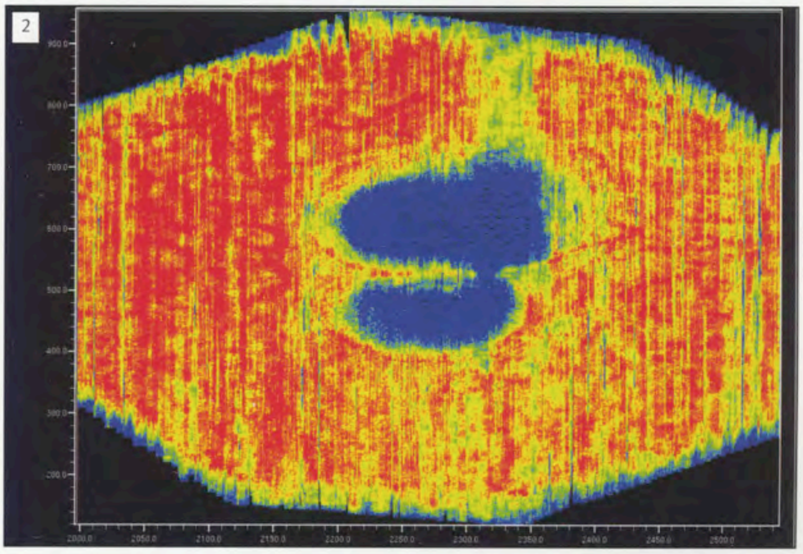


Figure 2: Verification of base and monitor seismic difference cube using an NRMS map at the end of the survey, giving a preview of the 4D effect due to production.





Through a combination of 4D survey preplanning, flexible operations, real-time 4D navigation QC and verification by onboard 4D seismic processing, it is possible to monitor smaller 4D effects for better reservoir management.

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com www.cgg.com

F 218.04.09

Eye-D™

Identifying Bypassed Oil

Results from 4D stratigraphic inversion performed by CGG on the Gryphon field for Kerr McGee enabled them to identify a location for an infill well. The 4D difference revealed an area of poor reservoir sweep, which has been confirmed by drilling results. THE IMPACT OF THE NEW WELL IS A SUBSTANTIAL UPLIFT IN FIELD PRODUCTION.

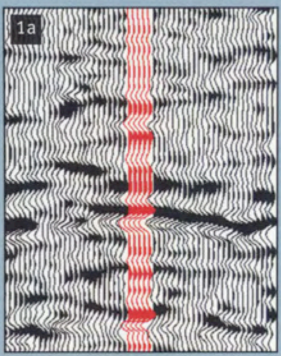


Figure 1a: Excellent match of seismic input (black) to synthetics from a well (red).

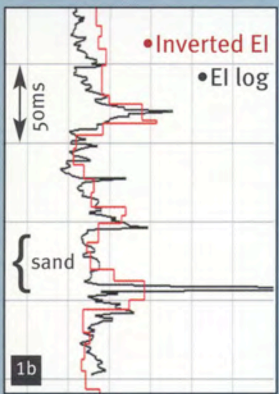
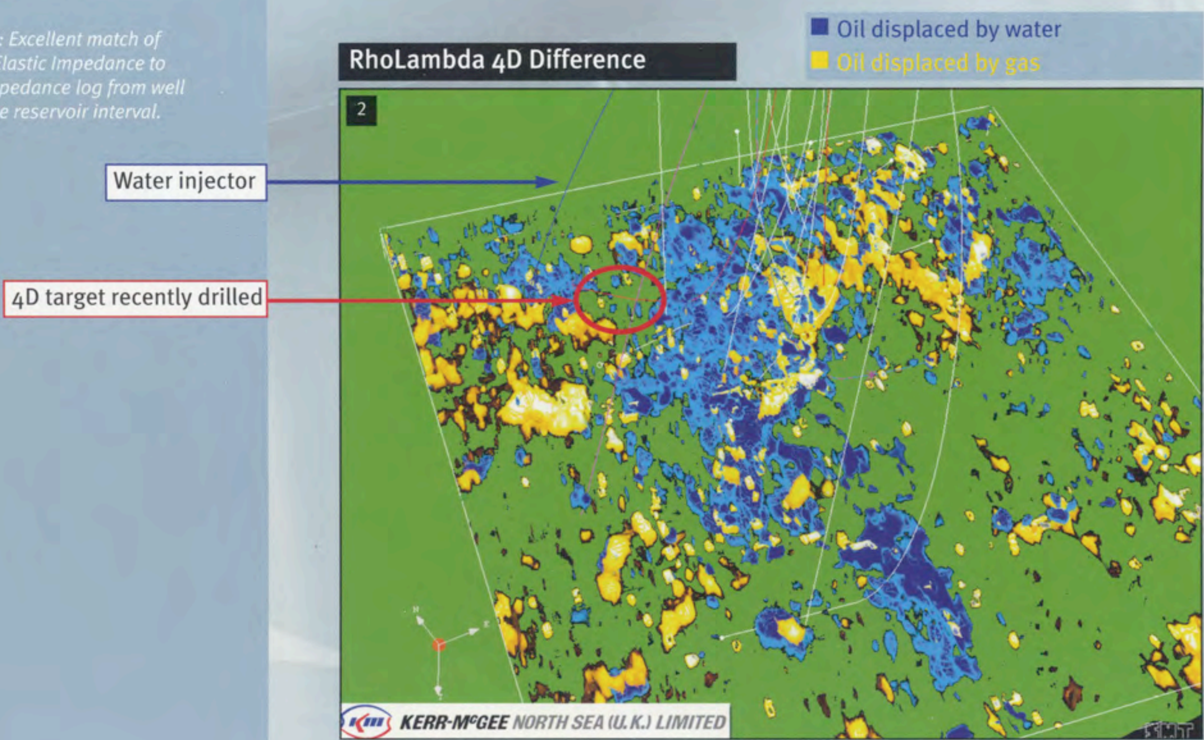


Figure 1b: Excellent match of inverted Elastic Impedance to Elastic Impedance log from well data in the reservoir interval.

Thanks to careful pre-conditioning prior to 4D pre-stack stratigraphic inversion (CGG's proprietary layer-based inversion within StrataVista), both the seismic and derived elastic parameters give an excellent match to the wells at the reservoir interval (Figures 1a-1b). Because well information is not used as an input to the inversion, this allowed the client to have full confidence in the elastic volumes.

The 4D signature is significantly better in the elastic impedance domain than in the acoustic domain and is more readily interpretable on map views: the RhoLambda 4D difference (Figure 2) indicates fluid movement within the Balder formation and within the injected sands in the Upper Balder and Frigg formations. An area of poor reservoir sweep was identified from this map (indicated in red), which has since been successfully drilled.



Identifying Bypassed Oil

Complex reservoir geometry

The Gryphon Field is located in Block 9/18b, 320 km northeast of Aberdeen, U.K. and has been in production since 1993. The reservoir is composed of massive, well-sorted, high-porosity sands of the Balder formation in the Tertiary (Figure 3). Due to compaction and dewatering, the Balder sands are remobilized and injected into the Upper Balder and Frigg formations. This results in the reservoir geometry being highly complex, which means it is especially important to obtain a clear image. Elastic inversion is particularly effective in this case.

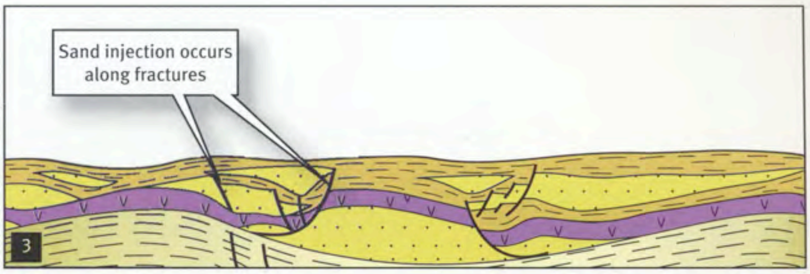


Figure 3: The Gryphon Field: geological description (After Newman et al., The Geology of the Gryphon Field, Petroleum Geology of Northwest Europe, GSL, London, 1993).

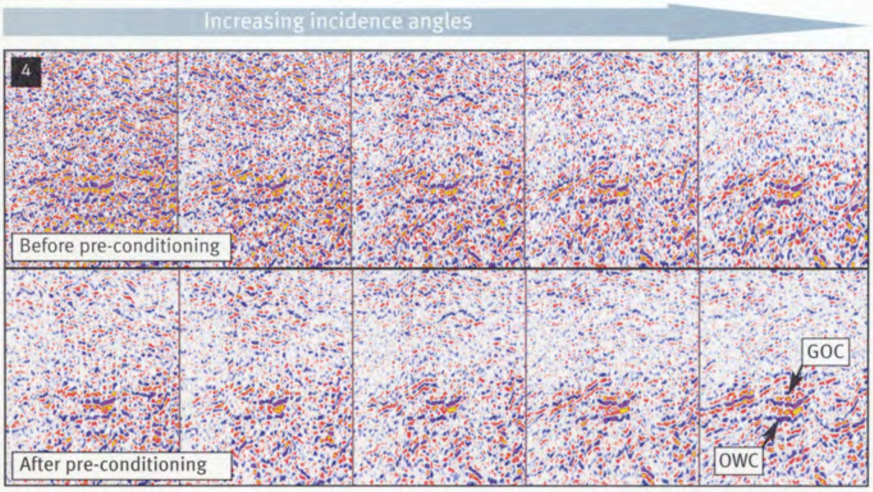


Figure 4: 4D difference.

Careful Preparation

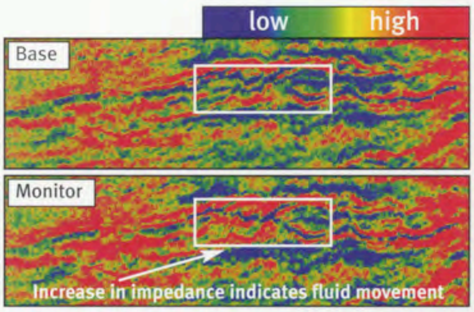
Data pre-conditioning is critical in increasing the signal-to-noise ratio of the data and enhancing the lateral continuity of the seismic events prior to input to inversion (see Figure 4). Geostatistical filtering followed by repeatability optimization, which is achieved by minimising the energy of the 4D difference on a window where no time-lapse effects are expected, significantly improves the 4D signature.

Identifying fluid movement

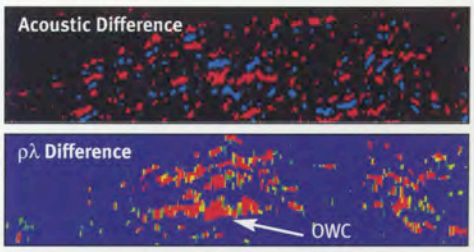
Production from the reservoir causes movement of the Gas-Oil-Contact (GOC) and the Oil-Water-Contact (OWC), and whilst this is observable on the far angle seismic 4D difference, the effects are more clearly seen in the elastic impedance domain (see Figures 5-6). As a result of using a layer-based scheme with a 3D operator, CGG's elastic impedance inversion produces a high-quality, high signal-to-noise RhoLambda volume that is readily interpretable. Identifying areas where production effects are not seen enables the planning of infill wells for optimum reservoir drainage.

Kerr McGee successfully located an infill well guided by the RhoLambda volume and are continuing to use the volume to plan all future drilling in the field.

5 *Far elastic impedance*



6 *4D differences: the OWC is clearly identifiable in the RhoLambda difference*



F 220.04.09

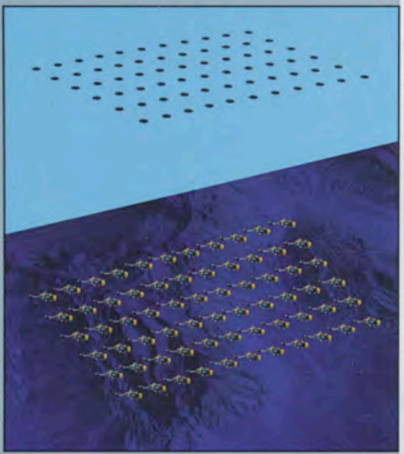
Worldwide Locations

Eye-D and StrataVista are trademarks of CGG

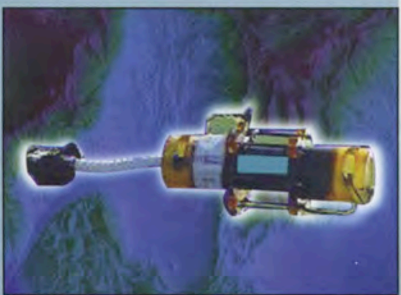
Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com • www.cgg.com

Optimising Field Development and Production



Seabed Node Acquisition
delivers a rich, broadband P and S data set with a wide range of offsets and azimuths to significantly improve target illumination for better delineation and characterisation of the reservoir.



Autonomous Nodes
provide improved vector fidelity by decoupling the sensors on an umbilical. Accelerometers measure the orientation of the sensors whilst vibration of the sensor head at the start of the survey ensures coupling to the seabed.

ROV Millennium
Alliances with industry-leading subsea engineering and ROV capabilities assure robust and fully integrated seabed solutions.

CGG's seabed seismic solutions offer unprecedented signal quality – broadband, high signal-to-noise ratio, with full offset and full azimuth - TO MEET THE REQUIREMENTS FOR BOTH FIELD APPRAISAL AND DEVELOPMENT, AND PRODUCTION MONITORING.

A silent world

Acquiring seismic on the seabed has key advantages for reservoir definition and resolution. Away from surface disturbances, noise is significantly reduced and, by simultaneously recording with geophones and hydrophones, peglegs can be eliminated. Full azimuth illumination and repeatability complete the picture and provide the enhanced image quality required in areas of complex faulting, subsalt or overthrust.

Impacting field appraisal and development

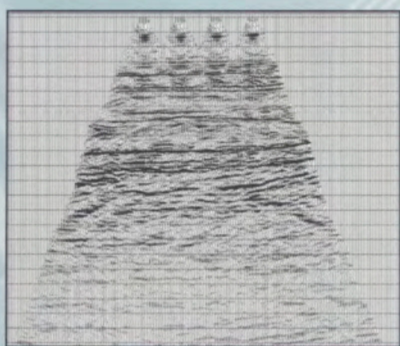
The challenge, post discovery, is to optimally image and characterise the reservoir for appraisal and development, creating the need for high-quality, high-definition subsurface images. Having recognised the potential for improved imaging and shear wave recording, CGG was involved in the first 3D-4C (full wavefield recording) survey, which was acquired using nodes in the North Sea in 1996. The results were encouraging and have led to the development of a new generation of seabed recording systems.

Autonomous Node Data Acquisition

Autonomous nodes, firmly coupled to the seafloor, record 4C data with less ambient noise and significantly improved signal-to-noise ratio. Their deployment on the seabed also enables the recording of finely sampled 3D wavefields with full azimuth illumination, which is ideal for subsalt imaging and improved fault detection. The flexibility of the autonomous system allows placement adjacent to existing seabed facilities while its innovative design removes the need to plant the nodes, thereby reducing layout time and cost. With operational ability to depths of 3000 m, the nodes offer outstanding flexibility in survey design and location. Repeatability is ensured as the nodes can be repositioned at the same locations. Furthermore, our alliance with subsea engineering specialists assures confidence in subsea engineering and project management.

4C processing

Proprietary techniques for vector fidelity and rotation or PZ calibration address the preparation of the multi-component data for full processing. The shear waves can be processed and interpreted in combination with P-wave data through CGG's VectorVista software. The full azimuth recording provided by the nodes ensures the ability to build more accurate velocity models especially when using wave equation depth migration.



Pre-stack time migration results of pressure component from four nodes installed at a depth of 2000 meters.

Eye-D™

ENHANCED RESERVOIR SOLUTIONS

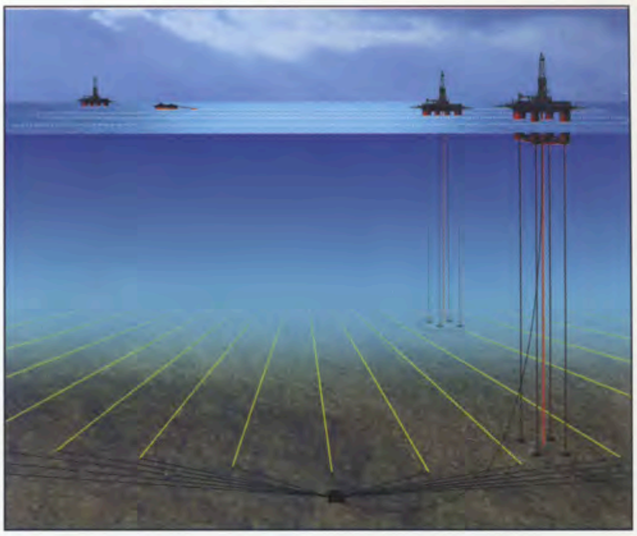
Optimising Field Development and Production

Production monitoring

Monitoring via time-lapse seismic helps production teams to assess saturation and pressure changes in the reservoir. It is recognised as an effective tool for identification of bypassed pay, the location of infill wells, and monitoring of the recovery process. Large and complex offshore reservoirs require robust, cost-effective monitoring systems. Permanent seabed installations offer improved repeatability and better long-term economics over surface surveys.

CGG's seabed reservoir monitoring solutions are scalable and flexible to accommodate any production environment. Customised solutions are engineered to meet both operational constraints and specific imaging objectives, through appropriate selection of buried sensors, seafloor sensors or a combination of cables and nodes for obstructed areas.

Installation of monitoring systems follows a rigorous pre-planning process of survey design and subsea engineering. Where necessary, visual simulations assure an effective and safe workaround for existing production infrastructure. CGG alliances with industry-leading subsea engineering and ROV capabilities offer a unique range of truly integrated reservoir monitoring solutions. CGG is therefore able to manage projects from design and engineering, through system installation, seismic shooting and recording and finally to full time-lapse processing.

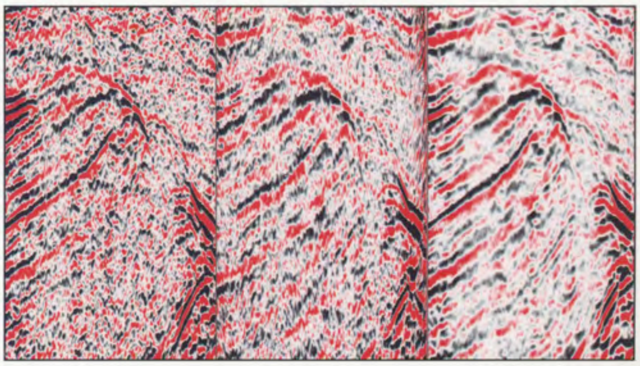


Seabed Monitoring System
CGG uses Sercel's latest generation of seabed sensors – designed for superior coupling and improved vector fidelity. The proven reliability of the system's 408 technology is enhanced by its Seismic Areal Network, a true multi-mode communication protocol, with built-in telemetry and power supply redundancy schemes.

4D Processing

CGG pioneered the processing of time-lapse data and brings its experience as market and technical leader to fully exploit the advantages of seabed monitoring systems: significantly improved 4D repeatability, multi-component data, full azimuth coverage and reduced cycle times. Proprietary techniques, designed specifically for the processing of seabed data, allow CGG to obtain the full benefit of the precise positioning and excellent coupling of seabed monitoring systems in order to extract meaningful and unambiguous 4D signals from the high-fidelity, multi-component dataset acquired. Patented geostatistical methods ensure that baseline surveys previously acquired with streamers can be effectively matched to subsea surveys.

Drawing on experience gained from over 130 4D projects, CGG has developed automated processing sequences with dedicated QC tools yielding very short turnaround. The doors are now open for oilfield monitoring where final images are expected in days.



Surface Seabed Common part

Mixed method 4D processing
Proprietary geostatistical techniques allow the examination of the common part of both surface and seabed acquisition to aid in design of anti-noise filters and for the matching of the 4D datasets.

F 223.04.09

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com • www.cgg.com

ENHANCED RESERVOIR SOLUTIONS

Eye-D™

Defining Sub-Salt Reservoirs

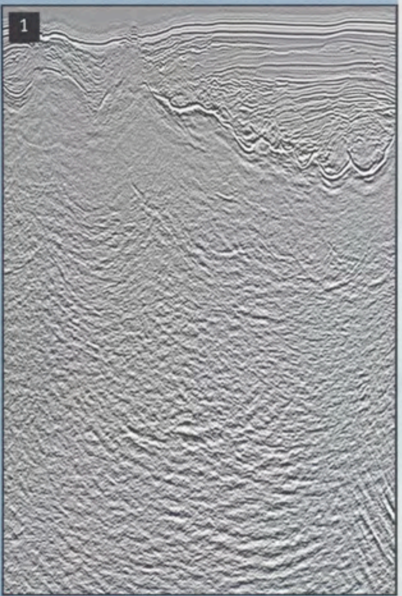


Figure 1: Time migration image illustrating the difficulties of accurate sub-salt interpretation.

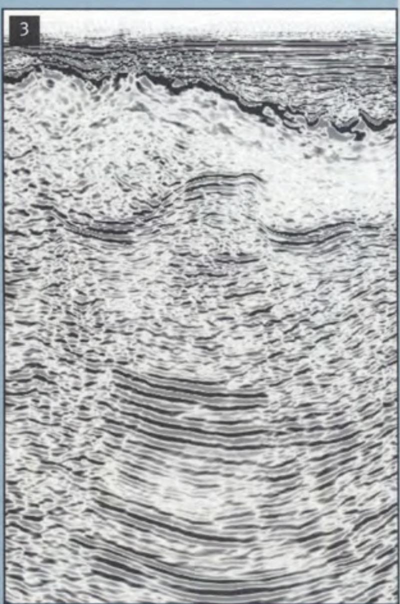


Figure 3: Wave Equation Depth image clarifies sub-salt structures enabling accurate interpretation.

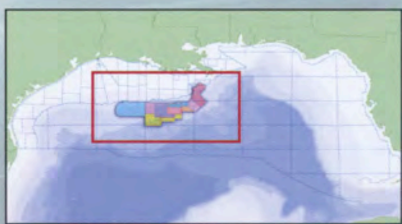
Images from Wave Equation Depth Migration ENABLED THE IDENTIFICATION OF SUB-SALT RESERVOIR POTENTIAL in the Green Canyon area of the Gulf of Mexico.

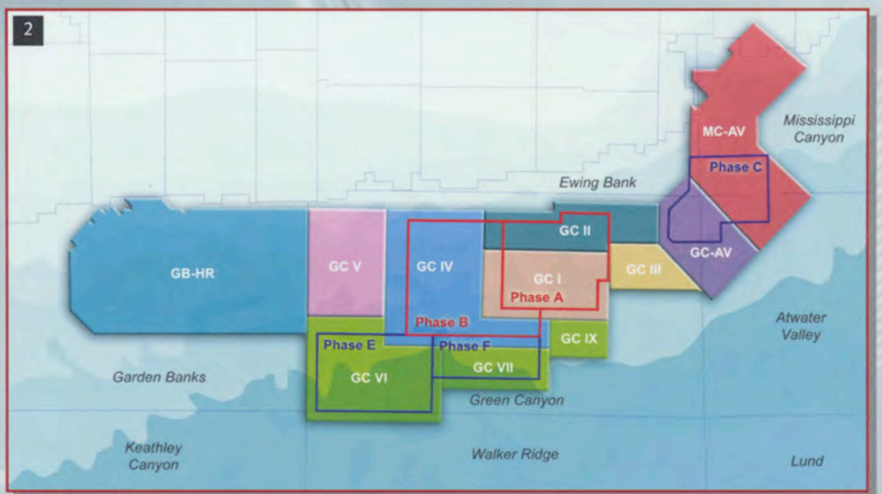
Complex reservoir overburden

In recent years the search for reservoirs in the Gulf of Mexico has moved into deeper and more complex environments. Salt sheets distort the seismic ray-paths, effectively masking the underlying geology from detection. Depth imaging techniques have previously aided definition of the salt and interpretation of the inter-salt basins, however, sub-salt areas have continued to be a challenge (Figure 1).

Imaging through the salt

A solution is available through WaveVista, CGG's no-compromise explicit shot record approach to Wave Equation Depth Migration. It was recently used to migrate a 20-block volume of non-exclusive data from the Green Canyon (Figure 2) after conventional processing through pre-stack time migration had revealed the complexity of both the top and base of the salt. The final wave equation images now clearly reveal the sub-salt sediment sequences, enabling accurate structural interpretation and reservoir identification (Figure 3).





Green Canyon survey from which a 20-block area was reprocessed with Wave Equation Depth Migration.

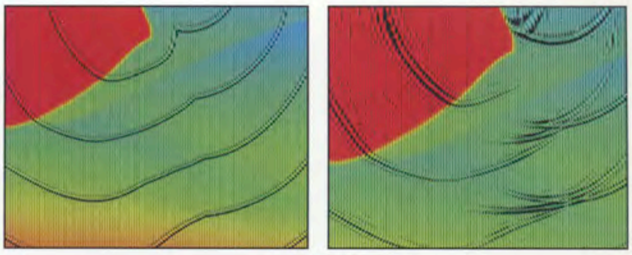
Eye-D™

ENHANCED RESERVOIR SOLUTIONS

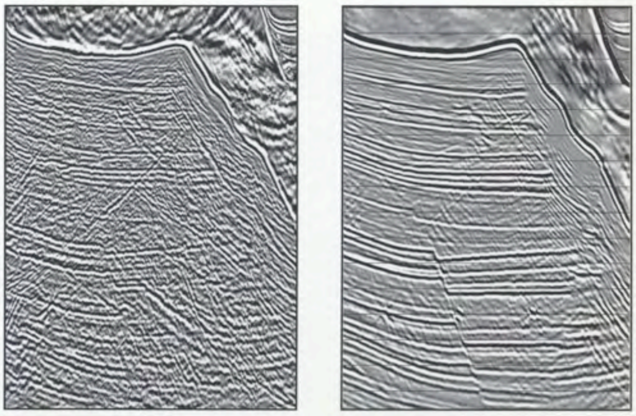
Defining Sub-Salt Reservoirs

Multi-pathing

The large velocity contrast between salt and sediment, coupled with the typically rugose contact, produces a complex wavefield. The assumptions made in normal Kirchhoff migration allow for a single wavefront type to be selected and thus, in areas of complexity, only part of the wavefield is imaged. The images (Figure 4) illustrate this on modelled data at the edge of a high-velocity salt body surrounded by sediments with a typical Gulf of Mexico velocity gradient. The Kirchhoff approach, using only the most energetic arrivals, shows the progress of the wavefront as a continuous line. Wave Equation Depth Migration uses a downward continuation approach to fully migrate the wavefield and resolve all multi-arrivals. The right-hand image illustrates this well – demonstrating three different arrivals under the edge of the salt. The comparison images (Figure 5) reveal the typical improvement seen in the final migrated data and emphasise the benefits for using Wave Equation Depth Migration in the Gulf of Mexico.



4 *Kirchhoff - most energetic arrivals.* *WaveVista – Migrating the full wavefield.*



5 *Kirchhoff Migration.* *Wave Equation Depth Migration.*
Sigsbee 2a Model Data Courtesy of SMAART JV.

Green Canyon sub-salt imaged

Wave Equation Depth Migration generates a much clearer window into the sub-salt geologic realm. The image in Figure 6 provides an insight into a complex tectonic province that does not exist above the salt. The forces that shaped the rock below the salt have a different history to those above. There are clues that can be gleaned from the post salt geologic image that help predict the nature of the pre-salt, but it is only pre-stack depth migration and, specifically, Wave Equation Depth Migration that really defines the detail necessary to explore for the hydrocarbons in this arena.

6

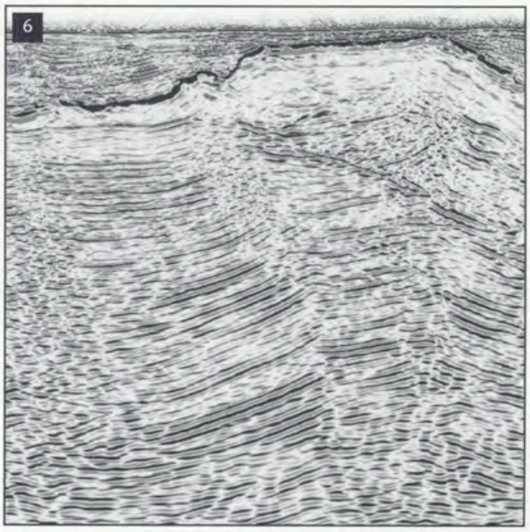


Figure 6: Example Green Canyon line with Wave Equation Depth Migration demonstrates improved sub-salt imaging.

Affordable superior imaging

Recent developments in computing hardware, through the development of PC clusters, have enabled the computationally-intensive Wave Equation approach to be affordable on routine projects. CGG has implemented a high-end solution which delivers superior quality images but also produces pre-stack angle gathers allowing amplitude analysis with angle, velocity model update and post-migration processing. **The benefits for imaging in complex environments become obvious when comparing the results – improved resolution, clearer fault definition, greater signal continuity and positioning. All leading to reduction of uncertainty in defining sub-salt reservoirs.**

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com www.cgg.com

F 221.04.09

ENHANCED RESERVOIR SOLUTIONS

Eye-D™

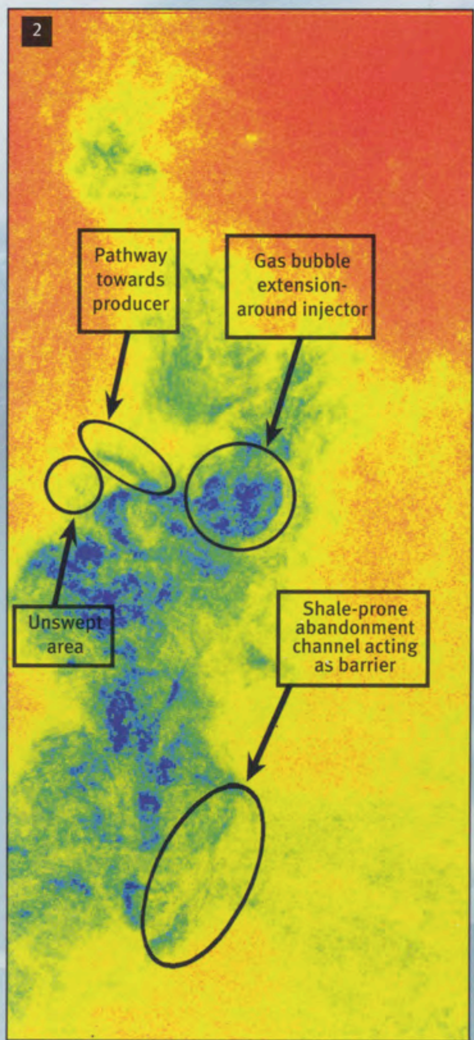
Monitoring Your Reservoir

An outstanding high-resolution 4D signature on the Girassol field offshore Angola allowed Total to detect and interpret SIGNIFICANT DYNAMIC INFORMATION related to gas injection, including GAS BUBBLE EXTENSION, PREFERENTIAL DRAINS, UNSWEPT AREAS AND BARRIERS.

■ 4D Benefits

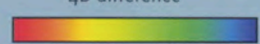
The Girassol field (see Figure 1) consists of large vertically stacked Tertiary turbidite channels. This superimposed channelling system has a highly complex architecture with intra-bed discontinuities and sands of varying thickness. An initial high-resolution survey by CGG over the Girassol field enabled Total to interpret previously unresolved features of the turbidite system. However, the fine-scale boundaries that control the flow could not be picked on the seismic. One year into production, Total asked CGG to conduct a repeat survey to evaluate precisely the dynamic characteristics of the reservoir. Reservoir engineers have drawn significant conclusions from the results (see Figure 2, below).

Figure 1: The Girassol field is located in the Lower Congo Basin, Block 17, offshore Angola.



- ► An unswept massive sand zone was identified
- ► The gas bubble and depletion zones are clearly distinguished in the 4D response
- ► The injected gas is chiefly propagating southwards, contrary to simulations which had also predicted propagation northwards
- ► A shale-prone abandonment channel was confirmed as a barrier in the south
- ► 7% depletion was measured in the injection zone, contrary to a prediction of 40%

Figure 2: Final 4D signature at reservoir level.



High-Resolution Acquisition

The seismic dataset acquired in 1996 was seen to be limited for defining and understanding the geometry of the reservoirs encountered during exploratory drilling (see figure 5, top). Because of the high production cost of the deep offshore Girassol field (at 1500 m water depths), Total drew up a workplan in which seismic would play a key role in optimising their development strategy and reducing risks. To gain a better understanding of the reservoir, Total performed modelling and simulation which demonstrated that high-resolution seismic data would provide a more accurate image.

This was acquired in 1999 by the CGG Føhn, deploying a dual-source, eight-streamer configuration specially designed to obtain maximum resolution. Shallow source and streamer depth gave maximum theoretical response at approximately 100 Hz, boosting the high frequencies; cross-line sampling benefited from smaller streamer separation, while the coverage and hence the signal-to-noise ratio were improved with a reduced shot interval. Along with strict acquisition specifications, which were monitored using onboard processing, this configuration yielded a high-quality, high-resolution dataset.

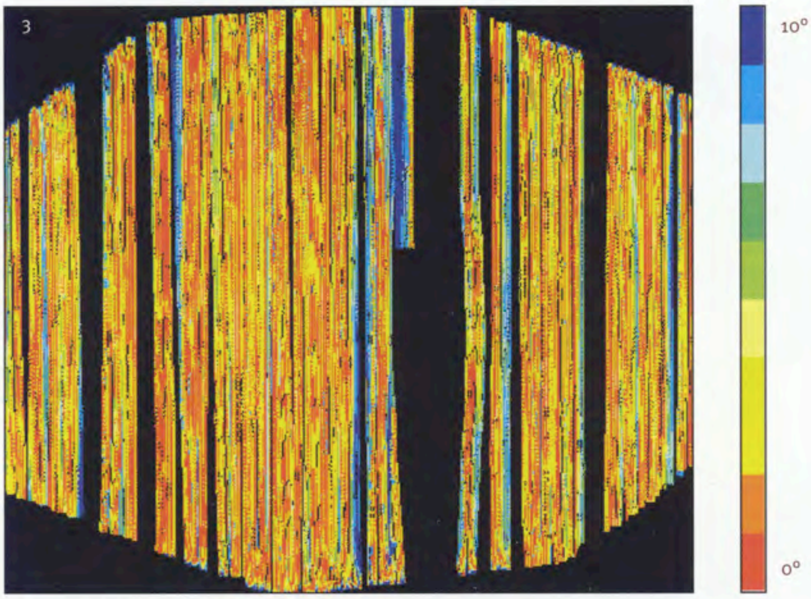
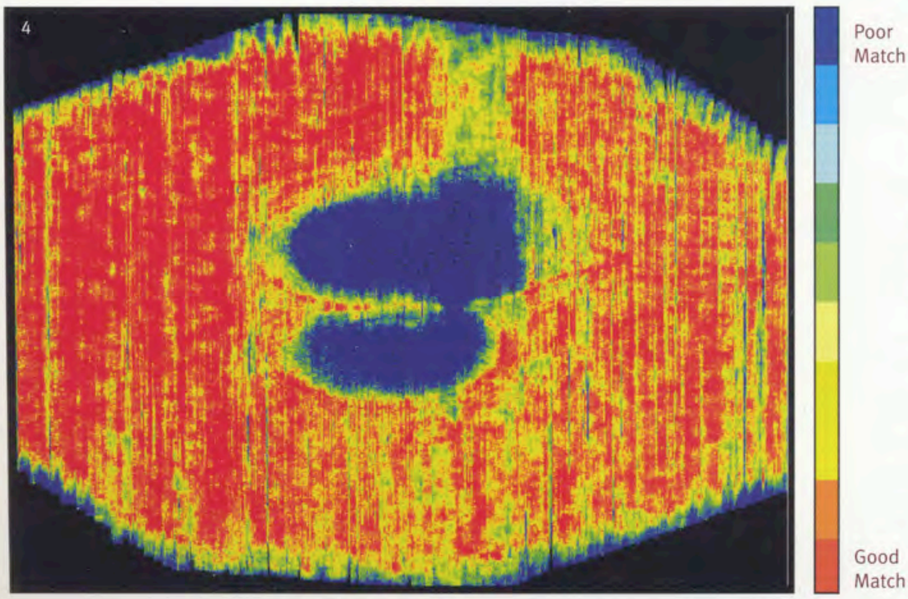


Figure 3: Azimuth difference map.

Figure 4: Seismic match.



The monitor survey was acquired in 2002, again by the CGG Føhn to ensure maximum repeatability. For modern 4D acquisition, the vessel is steered to ensure that the shot positions of the monitor survey duplicate those of the base survey. Streamer feathering is reproduced by using the phase of the tide in the real-time planning of the sail lines and the repeatability of the receiver positions is monitored during acquisition by means of the azimuth difference map (see Figure 3). This is optimised by the deployment of extra outer streamers.

Clearly, the objective is to maximise the quality of the 4D signature. To achieve this, the monitor survey was processed onboard during acquisition. This was compared with the base seismic data to verify that 4D differences due to acquisition had been minimised and that the 4D signature due to production effects was visible (see Figure 4).

■ Reprocessing the Base Survey

The results from initial processing had a significant impact on updating the Girassol reservoir model by allowing the clear identification of the superimposed channelling and four depositional sequences which were the key target of the production team (see Figure 5).
However, upon initiation of the 4D project, the survey was reprocessed, partly to address an acquisition footprint but also to apply new processing technologies, such as dynamic Q compensation, in order to create an ideal cube that would serve as the basis for monitoring the Girassol field. The result was improved definition of the turbidite channels and the generation of valuable AVO information.

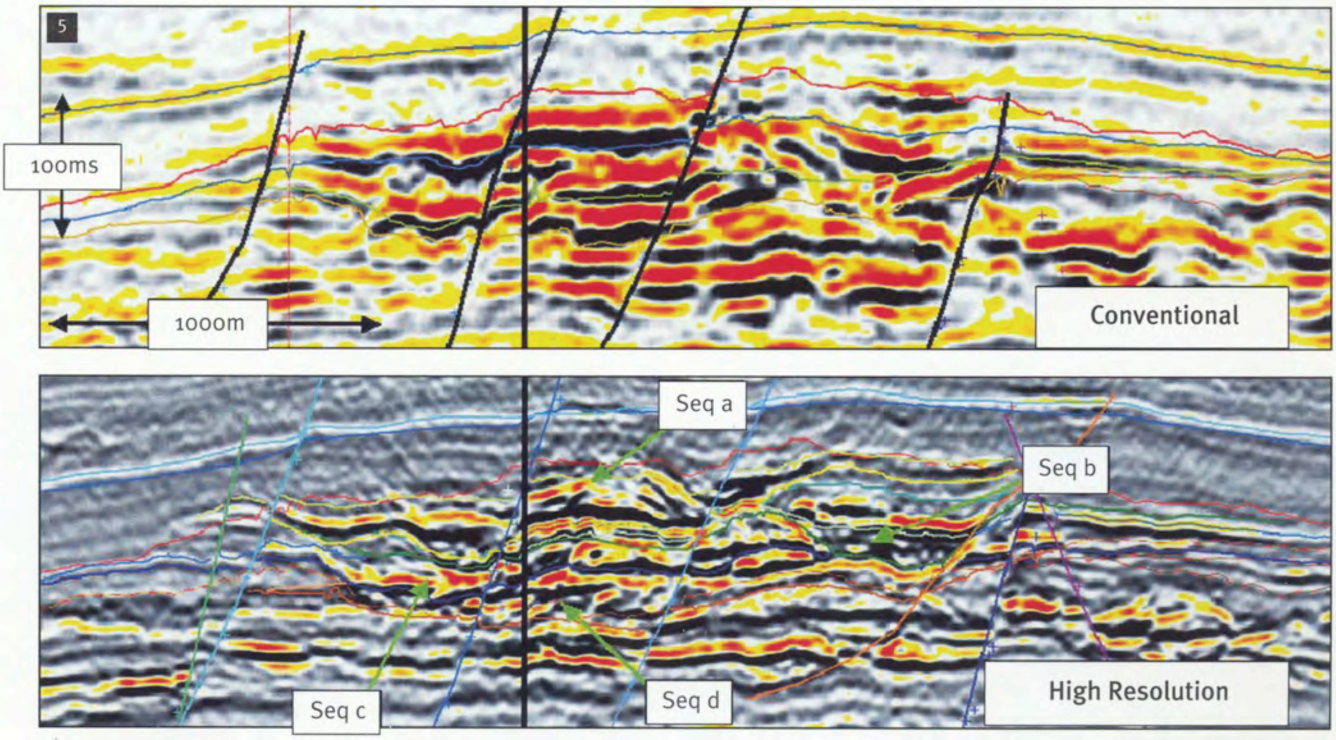


Figure 5: Conventional acquisition, 1996 (top) vs. HR acquisition, 1999 (bottom).

■ 4D Processing - Destriping

The presence of an acquisition footprint was observed on the 1999 high-resolution data with amplitude variations of the order of 10-20% of the amplitude in the target zone. Clearly, this would have a serious impact on the 4D signature in the reservoir.

Geostatistical analysis revealed that the footprint could be decomposed into two parts: striping in the sail line direction and an effect due to water bottom geometry. The water bottom effect was removed using residual statics, whilst state-of-the-art geostatistical filtering removed the sail line effect giving the result displayed in Figure 6.

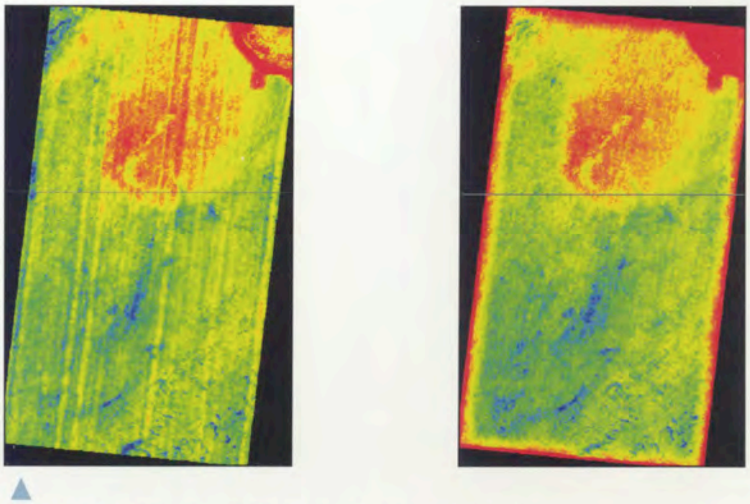


Figure 6: Amplitude map before (left) and after destriping (right).

Eye-D™

Monitoring Your Reservoir

ENHANCED RESERVOIR SOLUTIONS

Absorption Compensation

After final migration, amplitude maps around the reservoir interval revealed a low amplitude area in the north (see Figure 7). This was caused by an anomalously reflective layer (indicated in figure 8, below). CGG's Q compensation methodology (DynamiQ) was applied to this problem to improve amplitude and wavelet continuity through the volume. By correcting both the amplitude and phase spectra and improving wavelet stability, DynamiQ allows more accurate velocity analysis, thus improving the 4D signature. As can be seen on the stacked sections in Figure 8, the events masked by the reflective layer are clearly imaged after application of DynamiQ and interpretability is improved throughout the section.

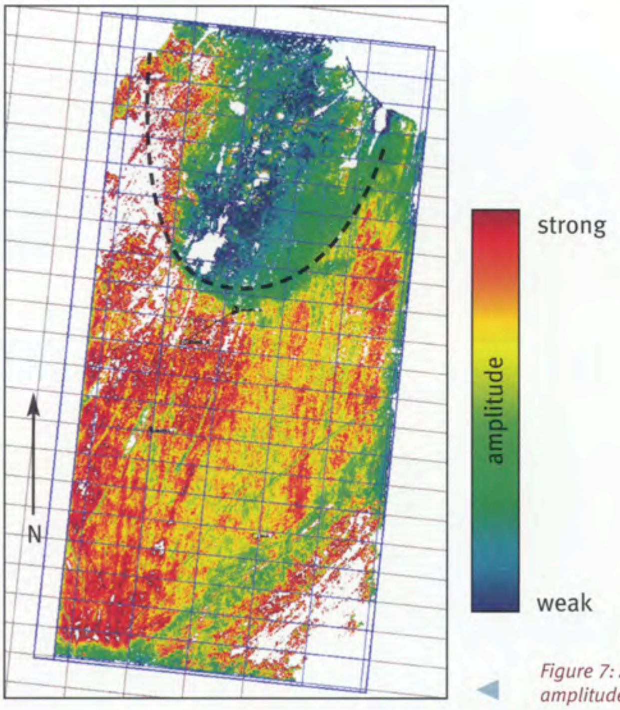


Figure 7: Amplitude map showing low amplitude area to the north.

Reduce risk with 4D monitoring

As exploration moves to deeper water and more complex reservoirs, monitoring using seismic data is becoming increasingly important in reducing drilling costs by minimising risks. With unparalleled 4D experience, CGG has the technical know-how to deliver both the high-resolution seismic required to understand complex reservoirs and the 4D repeatability to gain the maximum value from the 4D signature.

Total are very excited by the outcome of this project. They can see a clear reservoir signature on the 4D difference and are confident that there is valuable reservoir information to be extracted from this. This information will be key to further optimisation of the Girassol field development.

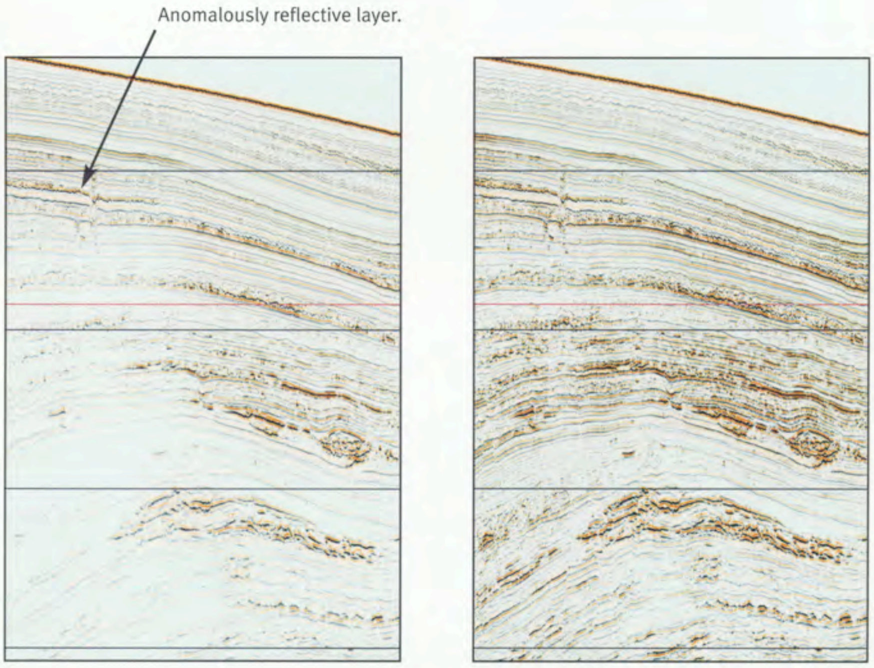


Figure 8: Raw migration (left), raw migration with DynamiQ applied (right).

Worldwide Locations

Paris +33 1 64 47 32 09 • London + 44 20 8231 8120 • Houston + 1 281 646 2593 • Kuala Lumpur + 60 3 2713 0272

Email: mkt@cgg.com • www.cgg.com

B 701.04.09