Tailored Multi-Vessel Acquisition and Design

for complex geologies

by Jo Firth, CGG

As the easy oil is discovered and exploration and resulting development expands into more challenging areas and increasingly complex geologic settings, it becomes ever more important to get the right seismic data to ensure wells are drilled in the correct locations. Successful development of known fields requires high-quality seismic data in order to accurately delineate the reservoir through processes such as seismic inversion and reservoir characterization studies. In the new oil price regime this has become even more important as oil companies try to keep the total cost of production down while at the same time optimizing the life of the field. Tailored seismic acquisition designs with complementary imaging technology matched to the local geology provide seismic data that better meets the objectives for each reservoir.

As an integrated geoscience company we use our geological knowledge, subsurface imaging expertise and survey evaluation and design (SED) experience to design the optimum acquisition configurations to image specific objectives, within any constraints of regulations, time or budget. New large multi-client programs are being designed as comprehensive, fully integrated geoscience packages, which can include regional geological analysis, potential field data, satellite imagery, key wells and seismic interpretation studies, in addition to high-quality seismic data. The integration of geological knowledge, well and gravity data with the seismic data, combined with advanced imaging including extensive QC using AVO tools, ensures delivery of high-quality, broad-bandwidth data volumes that can address the geologic challenges. When designing proprietary surveys, our GeoConsulting teams, subsurface imaging and marine technology experts collaborate with the oil company specialists to design bespoke surveys with optimized acquisition parameters that best image and characterize the reservoir objectives within budgetary and timeline constraints. Acquisition design has evolved in conjunction with other key improvements in seismic acquisition and imaging technology to allow optimized configurations to be provided for specific imaging challenges.

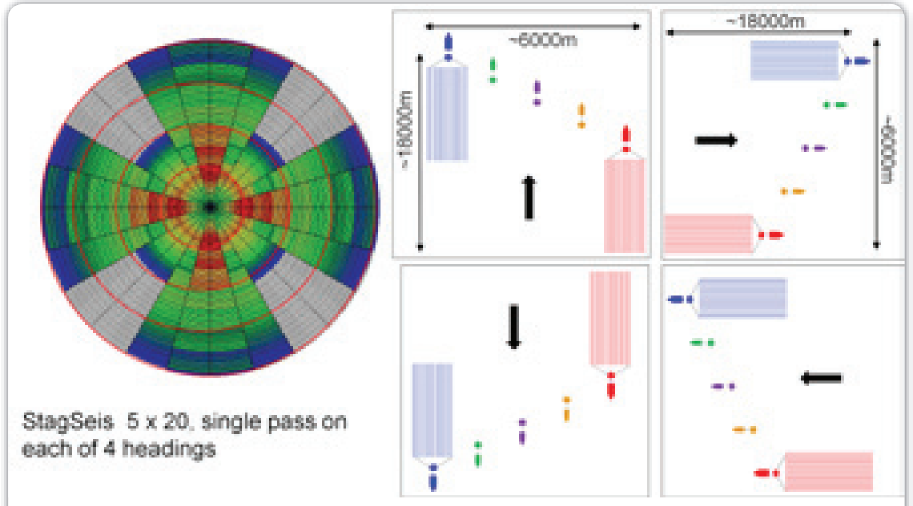

Figure 1 – StagSeis vessel configuration; two 10-streamer vessels plus three source vessels in a staggered formation (courtesy of CGG).

The StagSeis™ surveys in the Gulf of Mexico are good examples of improved data quality being delivered in challenging areas by this collaborative approach. Simply stated, the objective for the design of the surveys was to deliver a seismic data volume with significantly improved illumination beneath the complex salt structures using the latest technology and acquisition techniques in low-frequency recording, ultra-long offsets and full-azimuth coverage. By designing an acquisition geometry that used five vessels in a proprietary staggered configuration, it was possible to deliver full azimuths to 9km and ultra-long 18-km offsets on four azimuths in an efficient manner (see figure 1). This acquisition design employs two multi-streamer, single-source vessels and three additional source vessels, with the vessels being staggered in the inline direction. The position of each vessel and the overall size of the pattern is a function of the spread width and length which also determines the maximum offset and azimuth distribution (Mandroux et al 2013). The acquisition is antiparallel and orthogonal, with the

Image courtesy of CGG

relative positions of the vessels being different for each sail line direction, providing a variety of azimuth directions in the super-shot gather, and allowing us to take advantage of the reciprocity principle to maximize the azimuth distribution.

This design also benefits from a linear tow, so that standard wide-azimuth imaging techniques can be used to deliver regular fold, offset and azimuth coverage. The rose plot (figure 1) shows the number of traces recorded in different offset bands within azimuth sectors for a super shot gather, with reciprocity. Although these diagrams are a familiar way of looking at offset and azimuth distributions, they are of limited use, as they can be biased by changing the area covered and the azimuth sector size, and give little indication of the range of offsets and azimuths in any given processing bin. The map of the offset distribution in the actual processing bins (figure 2) clearly demonstrates the regular and consistent fold, offset and azimuth distribution from bin to bin. This homogeneity of coverage between all bins favors efficient regularization during processing and avoids the irregular coverage and data redundancy created by some other configurations.

The main challenge for the staggered acquisition design is turning the whole fleet at the end of each sail line in a safe and efficient manner. Compared with conventional wide-azimuth acquisition, the staggered acquisition technique has an advantage in that each vessel can start to turn in succession, as soon as they no longer contribute to the full fold area, while the vessels behind are still completing their production line. This allows acquisition in swathes without the lengthy turns required to maintain safe distances between vessels when they are aligned, and so improves efficiency when compared with conventional wide-azimuth. In the staggered acquisition that has been deployed in the Gulf of Mexico since June 2012, significant reductions in line-change times have been achieved compared to a conventional wide-azimuth survey, making the staggered design a cost-effective solution for such a large fleet.

Extension of the frequency spectrum to include lower frequencies, thanks to recent developments in broadband acquisition techniques, also improves the resolution of subsalt data. The BroadSeis™ curved variable-depth streamer broadband acquisition solution (Soubaras 2010) uses differences in receiver depths to produce receiver ghost notch diversity, allowing the streamer to be towed up to 50m deep to improve the low-frequency signal-to-noise ratio without compromising the high frequencies. The variability of the

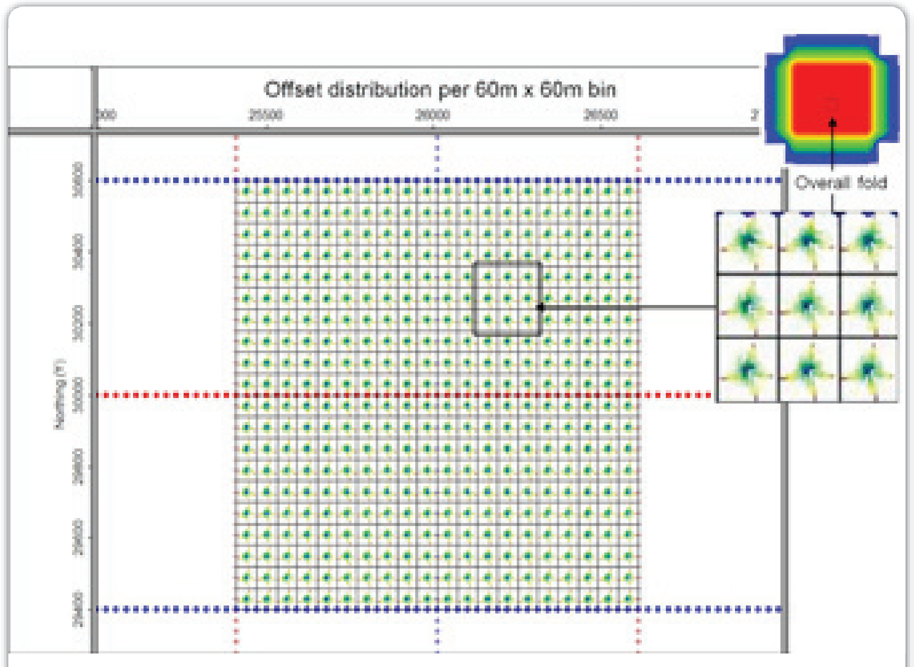

Figure 2. Fold, offset and azimuth distribution per 60m processing bin.

streamer depth and shape of the cable are tuned for the water depth and target using legacy velocity information, so that the notch diversity and output spectra are optimized for each survey. The technique capitalizes on the extremely good signal-to-noise characteristics and low-frequency response of solid streamers (Dowle 2006) to provide the lowest-frequency recorded signal available. Proprietary 3D deghosting algorithms (Wu et al, 2014) exploit the ghost notch diversity to produce a wavelet with both high signal-to-noise ratio and maximum bandwidth. Recent advances in both receiver deghosting and source designature, using far-field signatures derived from near-field hydrophone measurements, enable accurate phase and amplitude control, even at the ultra-low frequencies delivered by this technique.

Although low frequencies are required for subsalt penetration, high frequencies provide the detail necessary for accurate velocity modelling in the near surface, and the resolution necessary for detecting shallow hazards, such as gas pockets and methane hydrates. The six octaves of bandwidth provided by variable-depth streamer acquisition produce sharp wavelets with minimal sidelobes, reducing interpretation uncertainty, enhancing the fine stratigraphic detail and clarifying impedance contrasts. As well as increasing penetration, the extra low frequencies shape the larger-scale impedance variations, providing clear differentiation between sedimentary packages and increasing confidence in correlating interpretation across faults and other major structural features. The increased bandwidth and resolution provide the best data for processing to deliver great improvements in seismic structure and stratigraphy as well as for increased understanding of lithology and fluid effects in the data. The improved low frequencies also provide greater accuracy and stability for quantitative seismic inversion.

A major advantage of the staggered technique is that it can be used in conjunction with all other recent acquisition developments for optimizing operations, such as continuous recording and fanned streamer acquisition, as well as with variable-depth streamers for optimizing bandwidth (in this case the streamer depth varied from 10-50m in a customized curve). It is also compatible with acquisition and processing of a priority area and is easily repeatable for use in 4D. In the Gulf of Mexico, the StagSeis design delivered the hoped-for improved illumination of the subsalt (figure 3). Based on this success, the initial 221-block survey was extended by two further surveys to over 871 contiguous OCS blocks (over 20,000 sq. km.).

The West Africa Atlantic margin is also known for its complex subsalt geology characterized by extensive salt bodies and dipping seismic reflectors, but in this case the water depth is shallower and the salt bodies are of a different shape, having relatively flat tops and rugged undersides. Legacy data suffers from poor pre-salt illumination and multiple contamination.

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Image courtesy of CGG

Here fold density and penetration are more important than ultra-long offsets. The shallower water means that multiples are more of a challenge, so sufficient near offsets are required for good-quality model-building. To meet the target of providing the absolute best data to processing to ultimately enable imaging of the reservoirs in the deep Oligocene and Cretaceous subsalt structures, a high-density

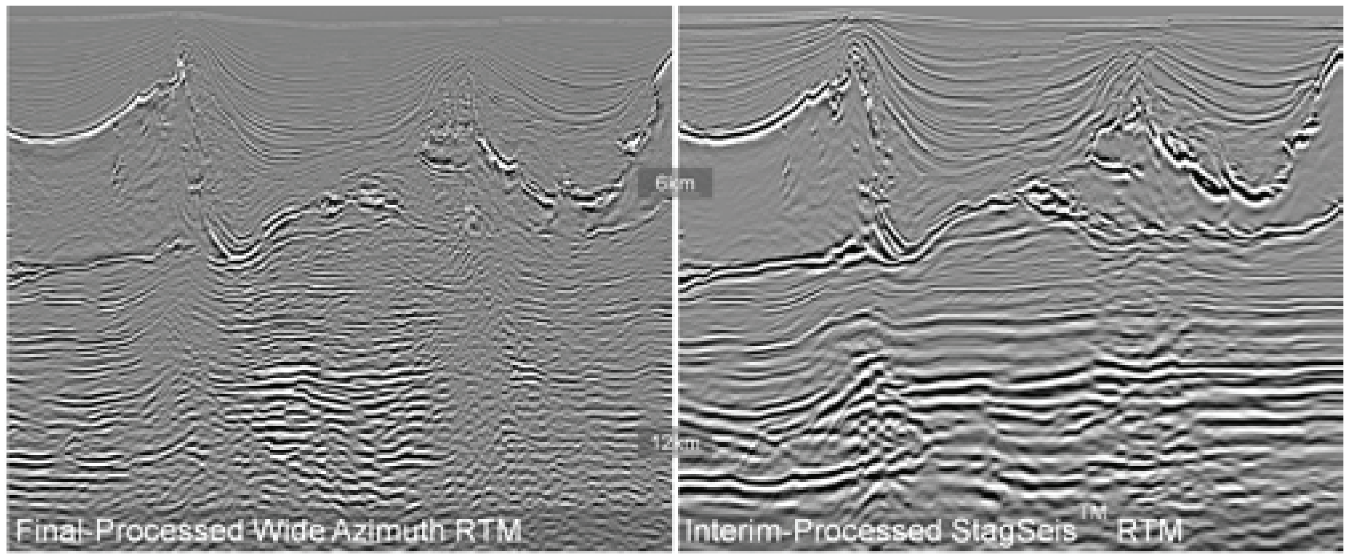

Figure 3. Full azimuths, low frequencies and long offsets deliver improved subsalt illumination (courtesy of CGG Data Library).

broadband dataset combined with WAZ sampling was required (Duval et al., 2013). Strong low-frequency energy was necessary to illuminate the deep target, as well as a broad bandwidth to provide high-resolution imaging above the salt.

The solution devised for this geology was B-WATS (broadband wide-azimuth towed-streamer) combined with bespoke subsurface imaging technology. B-WATS has a higher shooting plan flexibility and shorter acquisition time than conventional WAZ geometries. This new design (Landais et al, 2014) involved a multi-vessel and multi-pass configuration, consisting of one streamer/source vessel and two additional source vessels, with all vessels deploying two sources. The acquisition of a survey line was completed by the combination of three successive acquisition passes on one heading, with offsets of up to 8 km provided by the long streamers. Combining these sail line passes on 2 x 2 headings enabled a full-azimuth distribution within a 6-km radius (figure 4) to be obtained and provided high spatial resolution, yielding a bin size of 6.25m x 25m with a consistent and regular combined fold of 446. The shot interval was 100m inline and 50m crossline.

This design provided the dense broadband wide-azimuth data needed for the prospect, delivering a higher proportion of data at near offsets, enabling more effective demultiple. The bespoke design also freed up more time for source maintenance, as for each sail line (consisting of three passes), the streamer vessel made two passes without using her source, and one pass required only one source vessel. Due to the rugged water bottom topography a complex multiple wavefield was anticipated so a wavefield modelling approach (Pica et al. 2005) to multiple attenuation was expected to yield optimum results, as this is known to be more effective than alternatives for complex water bottoms. This approach involves propagating the seismic trace (containing primary and multiples) using a reflectivity model of the water bottom derived from a legacy 2007 dataset, in order to predict the associated multiple. The increased computational resources required for this wavefield modelling approach necessitated the installation of the latest generation of processing hardware on the vessel, to achieve the run time within the demanding deadline set for the fast-track sequence. As a global imaging company we were able to provide this equipment swiftly, with the necessary supporting personnel, so that the multiple attenuation could be performed onboard and the overall turnaround time shortened for delivery of a fast track volume.

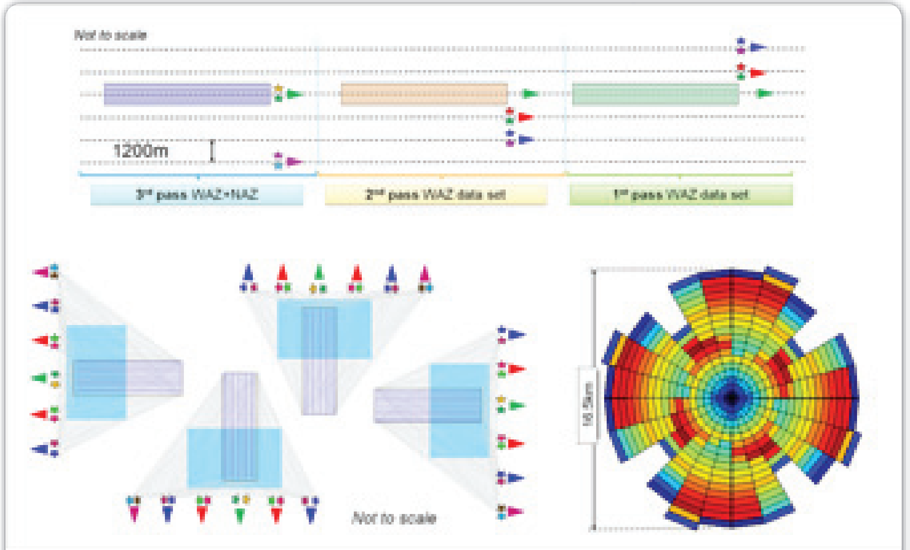

Figure 4: B-WATS illumination – Multi-pass acquisition on four headings leading to the full-azimuth and offset distribution contained within the super shot-gather (courtesy of CGG).

Our combined expertise in all the geoscience disciplines enables us to devise bespoke acquisition geometries for any individual survey in order to address the specific challenges, rather than a "one-size-fits-all" design. In addition to the solutions for complex geology described here, we have also designed multi-vessel strategies for reducing acquisition times by up to 50% without compromising data quality caused by seismic interference when vessels are working closely together. In frontier areas we have used wave equation modelling to determine whether larger bin sizes can be used so that wider spreads can be deployed in order to acquire more data more quickly.

By combining the results of detailed modelling and analysis with information from our clients and the geological expertise of our GeoConsultants, it is possible to design the optimum acquisition parameters for a survey to enable the best data to be acquired to image the target. Incorporating advanced subsurface imaging technologies customized for the local geology and reservoir-oriented QC ensures the highest-quality seismic images.

Understanding how the data will be used, the specific geological challenges and the imaging techniques that will be required gives us a unique insight into the data that needs to be acquired. Innovative marine technology R&D and a flexible fleet enable us to deploy customized solutions to best meet the specific needs of our clients.

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