

# 3D surface related multiple elimination in the presence of complex water-bottom geometry

*A case study from offshore Nigeria*

**S**imple 2D approaches to attenuating surface-related seismic multiples are inadequate when there are complex geologies or water bottoms that dip in the crossline direction. A fully 3D multiple attenuation algorithm succeeded on a survey acquired offshore Nigeria in an area that exhibits both challenges.

The 3D seismic survey was acquired as part of the fast-track development of a deep-water field offshore Nigeria. The reservoir is sandstone turbidite channels of Miocene age. The objective of the survey was to map these channels to guide placement of development wells. Survey design aimed to deliver improved resolution relative to previous seismic surveys, and also to provide a potential baseline for subsequent repeat surveys in the future for 4D (time-lapse) monitoring of reservoir fluid movement and field management.

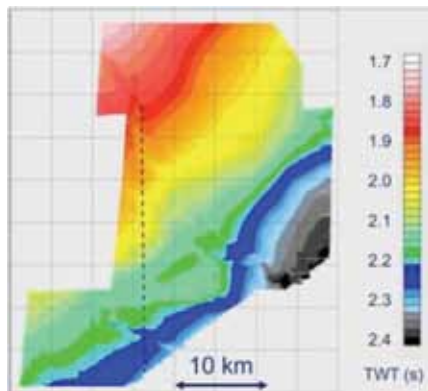
The steeply dipping and irregular topography of the water bottom represents a challenge to the accurate imaging of the reservoirs using surface seismic methods. Water depths in the survey area range from 1,300 m – 1,800 m [4,260 ft - 5,900 ft], which equates to a two-way travel time of approximately 1.7 s - 2.4 s. Water/seabed and air/water interfaces are highly reflective to seismic energy; much more reflective than the interfaces between subsurface rock layers that seismic surveys are designed to image. The reflection from the water bottom can be the strongest event on a seismic section.

Multiples of the water-bottom reflection are also strong events. These derive from upcoming energy being bounced back at the air/water interface, returning to the water bottom, then reflecting again as a repeat “echo.” The first-order

**Example crossline stack and sample gathers before multiple attenuation. The primary target zone is between 2.8 s and 3.7 s. Noise from the first water-bottom multiple and scattered multiple energy can be seen below 3.8 s (as indicated by the black arrows).**

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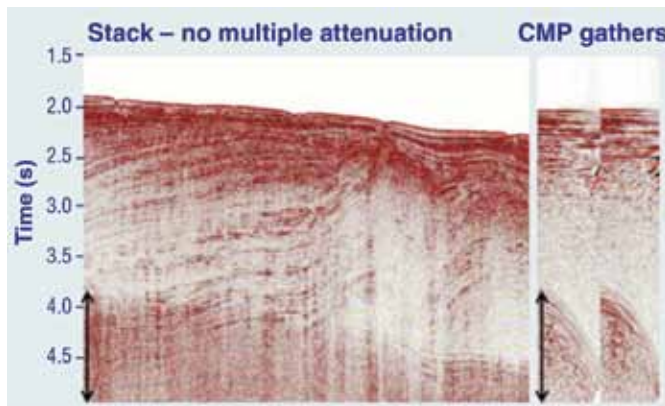
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Map of water-bottom two-way time over the survey area. The dotted line indicates the location of the example seismic section.

multiple of the water bottom has a travel time ranging around double that of the original reflection, so in the subject survey area it is in the range of 3.4 s – 4.8 s two-way time (TWT).

The example crossline stack section and two sample common midpoint gathers show the impact of the first-order water-bottom multiple on the data, particularly below about 3.8 seconds. The strong hyperbolic events



on the gathers are complex multiples of the water bottom and near-seabed reflectors, and diffractions from the irregular seabed topography. These multiples are visible on the stack section as noise is below 4 s on the left and about 4.5 s on the right side.

The zone of interest containing the reservoir sands is between 2.8 s to 3.7 s TWT. Although the water-bottom multiples and related scattered energy are deeper than the primary target zone, previous experience showed that, when poorly attenuated this energy migrates into the target zone later in processing to obscure primary reflection information and to compromise amplitudes. Demultiple schemes applied to previous surveys did not attenuate the multiple sufficiently to prevent contamination of the target.

## 3D general surface multiple prediction

Surface-related multiple elimination (SRME) is a highly effective method to attenuate multiples that originate from the sea surface. The process can be applied while preserving the integrity of primary energy, ultimately enhancing structural interpretation and reservoir characterization.

The subject survey offshore Nigeria was shot using a conventional geometry in which data are acquired in a series of adjacent, approximately straight, lines. Early implementations of SRME applied the algorithm to each of the acquired source/streamer combinations in turn; effectively assuming a 2D geometry.

This assumption is reasonable if surface-related multiples, and their downward reflection point (DRP) on the sea surface, are in the plane of the acquisition sail-line direction. However, the steeply dipping and rugose water bottom in the survey area gives rise to multiple reflections and diffractions whose ray paths lie outside the plane of the acquisition sail-line direction. The combination of complex geology and crossline dip means multiples have 3D ray-paths can be modeled accurately only with a 3D approach to multiple attenuation.

Surface related multiples with downward reflection points (DRPs) in the plane of the acquisition sail-line can be handled with a simple 2D SRME scheme. Complex geology and crossline dip require a 3D approach. Illustration courtesy of David Hill, WesternGeco.

In common with 2D SRME schemes, 3D SRME has two phases. The first phase is to create a multiple model for each target trace. The second adaptively subtracts the multiple model from the input data, usually using filters derived from a least-squares approach.

The first phase (multiple prediction) was performed using an approach to 3D SRME described by Bisley, Moore, and Dragoset (2005). The method, "3D General Surface Multiple Prediction" (3D GSMP), enables high-quality 3D multiple predictions for surveys in areas of complex geology and with irregular acquisition geometry. An important feature of this method is its ability to predict multiples at true azimuth, taking into account the true raypath of the multiple through the water layer.

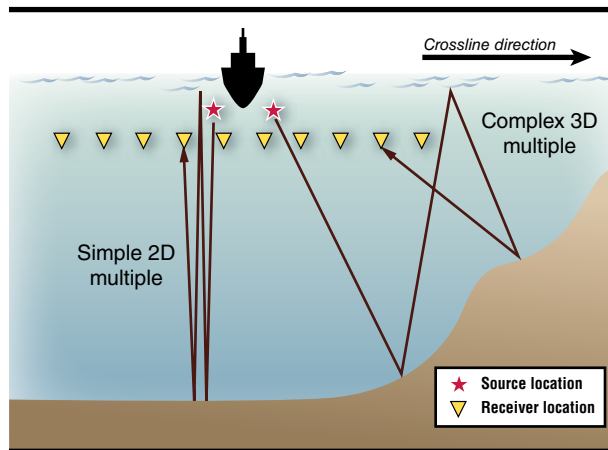
## Data acquisition

The survey, covering an area of 475 sq km (183 sq mi), was acquired in April and May of 2007 using point-receiver acquisition. Sources and streamers were towed at shallow depths of 5 m and 6 m (16 ft and 19.5 ft), respectively, with the objective of achieving a useable bandwidth of 10-90 Hz. Ten streamers, each 5,600 m (3.5 mi) long, were deployed at a separation of 50 m (164 ft). Data were recorded by point receivers spaced 3.125 m (10.25 ft) along each streamer. Dual sources were deployed having a shot interval of 18.75 m (61.5 ft), giving a nominal fold of 75. Throughout acquisition, constant streamer separation was maintained by streamer steering. Some strong currents were encountered, resulting in high feather and variable fold of coverage.

## Data preparation

Unlike other implementations of 3D SRME, minimal preprocessing is required for 3D GSMP. The algorithm can handle irregular geometries, so there was no need to regularize the input data, to extrapolate to zero offset, or to interpolate to harmonize the shot and receiver sampling intervals. Processing focused on removing noise while preserving the integrity of primary energy to optimize structural resolution and to maximize repeatability for future 4D analysis.

Processing at the original 3.125 m single-sensor trace interval included compensation for perturbations between receivers, receiver motion correction, and attenuation of swell induced cable noise and waterborne



noise. A calibrated shot-by-shot designation process was applied to minimize wavelet distortion from source characteristic. Digital group forming, incorporating a digital antialias filter, to 12.5-m (41-ft) trace interval, and temporal resample to 3 m were performed prior to input to 3D GSMP.

## Optimizing 3D GSMP

For 3D SRME, the multiple model for each target trace is predicted by computing a multiple contribution gather (MCG). For 3D GSMP, the MCG is created on a regular 3D grid, each node of which represents a possible DRP within some aperture of the target trace. A trace at each grid node then is formed by convolution of the two traces that best connect the grid point with the source and receiver endpoints of the target trace. Stacking the MCG gives a single trace that is the predicted multiple for the target trace.

Analysis of an MCG will give information about the need for 3D demultiple, and the parameters required for 3D GSMP. The key parameters are the selection of aperture and the spatial sampling, both of which are related and have an impact on effectiveness of the multiple prediction and the cost. Crossline aperture is dictated by the acquisition geometry and the complexity of the geology. Spatial and temporal sampling within the MCG should be selected to minimize aliasing (Dragoset et al 2006), and are related to water depth, aperture, and frequency.

The example MCG was generated using aperture width of 1,000 m (3,281 ft) and a grid spacing of 25 m (82 ft). The central red line on the MCG represents the inline position of the target trace. If the multiple energy apex is centered on the red line, the multiple can be estimated and removed using a 2D method. However, if the apex of the multiple falls to one side of the center, a 3D method is required. MCGs are stacked to form the multiple model. Selecting a too large aperture introduces noise and increases cost,

selecting a too small aperture results in inadequate modeling of the multiple. In the example, the apex of the multiple falls approximately 150 m (492 ft) off center, implying that 3D demultiple is required and that in this location an aperture width of 300 m is sufficient to model the multiple.

MCGs at key locations across the survey were constructed and analyzed leading to the conclusion that a crossline aperture of 375 m (1,234 ft) was sufficient to accurately model multiples throughout the area. This conclusion was further supported by comparison of the multiple models and adaptive subtraction results produced

using different apertures. The spatial sampling (distance between gridpoints) within an MCG was chosen to be 25 m. Spatial aliasing occurs in the example MCG at offsets greater than 500 m (1,640 ft), implying that a finer grid spacing would be required if the geology dictated that apertures greater than 500 m were required to adequately model the multiples.

## Field results

MCGs are created and stacked for every prestack trace in the seismic survey, giving a multiple model that was then subtracted from the input data using a least-squares adaptive subtraction technique. 3D GSMP successfully removed both the water-bottom multiple and the scattered multiple energy generated by the complex overburden in this area. The primary reflection energy underneath the multiple has been revealed un-attenuated.

## The world is 3D

This demonstrates the effectiveness of the 3D GSMP multiple attenuation algorithm as applied to seismic data from offshore Nigeria. The algorithm has been used in many parts of the world on land and marine surveys. The world is 3D and in reality, all marine 3D acquisition geometries, water-bottom geometries, and subsurface geology have 3D aspects, so 2D implementations are always approximations that can be improved with fully 3D algorithms. 3D GSMP also handles irregularities in acquisition sampling and new imaging techniques such as wide azimuth surveys and circular shooting geometries. As computing power increases, fully 3D algorithms are making incremental improvements to the quality and reliability of seismic imaging. ●

## References

- Dragoset, W. H., I. Moore, and C. Kostov, 2006, *The impact of field survey characteristics on surface related multiple attenuation: Geophysical Prospecting*, 54, 781–791.
- Bisley, R., I. Moore, and W. H. Dragoset, 2005, *Generalized 3D surface multiple prediction: PCT patent application publication WO 2005/103764*.