3D Seismic Operational Optimization in the Lusitanian Basin, Portugal

Ron McWhorter,[1] Gehrig Schultz,[2] Andrew Clark,[2] Tim Branch[2] and Malcolm Lansley[3*] discuss the challenges of an operationally problematic 3D seismic survey carried out in Western Portugal where the solution was found in careful planning plus the use of multiple sources and a cable-free recording system.

The survey area for the proposed 3D seismic survey in Western Portugal presented many operational problems caused by small farms and vineyards, hilly terrain, many small roads, and houses. A survey had been attempted previously using a cabled recording system but was abandoned before completion.

The geologic background leading to the survey acquisition will be discussed, together with the careful planning that was necessary to enable the successful completion of the survey. Two of the key solutions to the operational difficulties were the use of different source types and a cable-free recording system (Sercel UNITE).

In recent years there has been much discussion about improving productivity on seismic crews through increasing channel count and the use of innovative source techniques. The application of these techniques has generally been in the more remote desert wilderness terrains. Increasingly however seismic contractors are being required to acquire longer offset and denser data sets in complex environments including urban, agricultural, historic, and environmentally sensitive areas.

In 1981, 2D lines were acquired with Vibroseis in the Torres Vedras area of Portugal. These lines indicated a Jurassic reef trend was present within this part of the Lusitanian basin (Figure 1). Jurassic reefs exist in many parts of the basin. For instance, to the north, limestone quarries were dug where reefs outcropped. More importantly, on and around the Montejunto anticline, northeast of the Torres Vedras 3D area, oil was found in numerous wells but has been never commercially exploited.

Based on the 1981 vintage 2D lines, Mohave Oil and Gas drilled its TVR G-1 well in 2005 near one of the 2D lines to evaluate what was thought to be a Jurassic reef. Unfortunately, the well saw little in the way of reefal material, and, in fact, most indications in the well pointed to a backreef environment (Figure 2). Where were the reefs? It was time to use 3D seismic.

In 2007–2008, Mohave Oil and Gas set out to acquire the first 3D seismic survey in Portugal on its Torres Vedras concession. About 40 km^2 was acquired before the project was postponed for various reasons. One reason for the difficulty in this first attempt was the use of cabled receiver units in the difficult terrain. Cable crossings over the numerous small roads winding through the countryside created a logistical and maintenance nightmare, and cables were often damaged during farming and vineyard operations. In 2010, Mohave set out to complete the survey with an additional 87 km^2 of 3D seismic. In August of that year, it contracted with Prospectiuni to acquire the Torres Vedras 3D survey. The next step was to figure out how to conduct the survey.

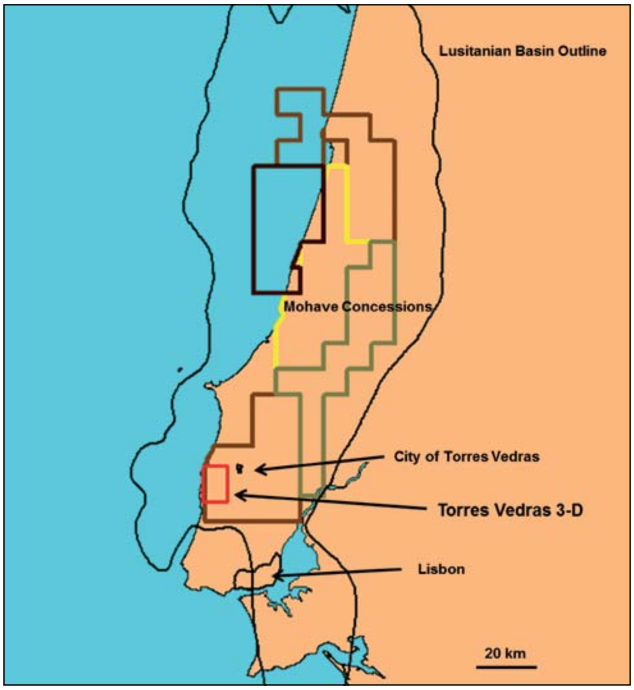

***Figure 1** Location of the Lusitanian basin, Portugal.*

Fundamental design considerations

The primary targets of the Torres Vedras 3D were basin-margin reef buildups of the Montejunto limestone of the Upper

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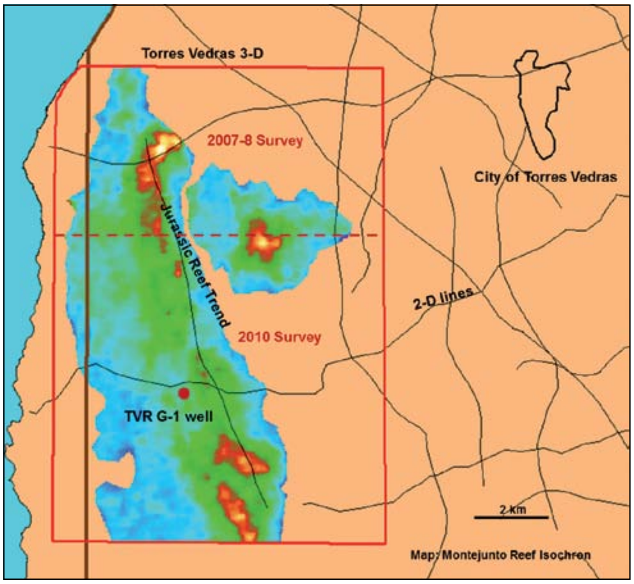

Figure 2 *Area of Torres Vedras 3D survey and Jurassic reef trend.*

Number of receiver lines	16
Number of live receivers per line	100
Total number of live channels	1600
Receiver line interval	200 m
Receiver station interval	50 m
Source line interval	200 m
Source point interval	50 m
Record length	4 sec
Source type	Vibroseis and explosives
Full fold	96–104

Table 1 *Recording parameters.*

Jurassic (Oxfordian). The depth to reefs in the prospective area is typically about 400 m with thicknesses up to and over 400 m. Additional reef or shelf-margin carbonate complexes were thought to exist throughout the rest of the Jurassic, down to the Dagorda evaporite (Upper Triassic to Lower Jurassic in age) as deep as 2000 m. In addition, seismic indications of rafted carbonate reefs in the middle of the Turcifal sub-basin presented an additional target, at depths of 1200 m to 2000 m. The data acquisition parameters (see Table 1) were determined to image these two targets.

Although Mohave recognized that proper survey design was important to image the reef targets, its main concern was the logistical problem of acquiring data in the area of Torres Vedras in both a safe and environment friendly manner. Like much of Portugal, the area has rolling hills with altitude ranges from 5–230 m, covered with small orchards and vineyards, crisscrossed by winding roads, and populated with small farms and villages which dominate the landscape. Although scenic, the landscape offers considerable challenges to efficient acquisition of 3D data whilst maintaining good fold coverage with a regular layout of receivers and sources.

Hazards and logistical problems

The working area was southwest of the urban area of Torres Vedras (population 22,000) and encompasses several residential areas, Feiteira in the north; Mafra, Ericeira in the south; Freiria, Azueira in the east and Ribamar, Barril in the west, all with populations in the 500–1000 range.

The area is also traversed by a national road, the N247, and there is an extensive network of roads and tracks some of which are used by frequent and fast moving traffic. The volume of traffic further increases during the summer holiday season as the area is a popular tourist destination. Although these roads provide access for the vehicles and personnel required for a seismic survey, they also represent a major health and safety hazard. The minor roads are unsurfaced and become muddy and slippery when wet. This can make them treacherous and sometimes totally inaccessible during rainfalls. Other hazards included road construction, seasonal coastal fogs reducing visibility, numerous cyclists and pedestrians, houses and cottages lining many of the roads, and the small towns and villages.

There is extensive agricultural activity including commercial orchards, olive groves, and vineyards (Figure 3), and also a variety of forestry types including pine, eucalyptus, and mixed deciduous, with thorny vegetation and undergrowth. Low-lying, permanently flooded areas support fragile reed bed habitats. In addition, in the summer the area receives little rainfall and pine and eucalyptus forest represent a significant fire risk.

Specific HSE risks identified included exposure to road traffic accidents due to the very narrow nature of many roads with blind bends, and slippery surface conditions. Extensive hunting in the area presents a seasonal hazard, and the presence of livestock on many small farms leads to encounters with bulls and electric fences.

Preparations

Extensive scouting of the working area utilizing both satellite imagery and first hand observations was essential to ensure all hazard and omission areas such as houses, electrical power lines, difficult terrain with steep slopes and areas of no-permit access were identified so that a comprehensive shot and receiver plan could be formulated.

A prime goal during the operations was to maintain good relations with the local communities and land owners to both facilitate the progress of this survey and future

Figure 3 *View of vineyards and hilly terrain.*

E&P operations. Field operations commenced only after three months of a proactive community liaison and permitting campaign using locally employed personnel supervised by client and contractor staff. A database was maintained of all permit permissions and contacts. More than 7000 land owners were eventually permitted in the 87 km^2 work area. Despite this, during the operations, problems were still encountered with unidentified land owners, and staff from the permit department accompanied all operational units.

Source and receiver lines were laid out using a combination of two surveying methods: conventional and GPS-RTK (real time kinematic). Total stations were used especially in thickly wooded areas with limited GPS coverage.

Mixed source solution

The parameter specifications required source points every 50 m spaced on sources lines spaced at 200 m apart. Due to the very varied nature of the terrain, lack of access, and frequent omission areas and obstructions, a mixed source solution was used to maintain adequate source density.

Two different vibrator types were used. Large 275 kN (62,000 lb) vibrators (ION AHV-IV) were used in pairs as the main energy source and in as many locations as possible. Where access restrictions or proximity to buildings or other structures prohibited the use of the large vibrators, then two 66 kN (15,000 lb) IVI EnviroVibes were deployed to ensure that source density and near offset sampling were maintained. A PPV (peak particle velocity) meter was used to establish the minimum distance between sensitive structures (such as houses) and the vibrators, in addition to the safe shooting distance restrictions already in place. Care

Figure 4 *EnviroVibe operations in town.*

Figure 5 Equipment deployment in a very busy urban setting utilizing available geophone planting sites between roads.

was taken to identify old, sometimes historic structures, the construction and condition of which made them particularly sensitive to seismic operations.

By the conclusion of the survey a total of 5668 VPs (78% from the total recordings) were recorded using Vibroseis, 37% with the larger vibrators and 41% with the smaller units. The remaining 22% source points utilized an explosive source as vibrators could not be used due to limited access in forests, orchards, areas of extensive crops, and places where land owners simply refused permission for vibrators to work. Shot point locations were chosen at safe distances from buildings, pipelines, power lines, and roads. A charge size of 1.5 kg per hole at 6 m depth, in well tamped holes, was used.

Recording operations

One of the most challenging aspects of the survey was the deployment of the 3D spread over such a varied terrain and surface usage whilst still maintaining an efficient level of recording productivity. One of the prime obstacles to achieving this were the very large number of road crossings in the survey, often more than 300 at any one time on the active spread alone with many more to be managed over the full area of the deployed recording equipment. The decision was therefore made to use a cable-free system, the Sercel UNITE. This project was the first major 3D survey undertaken in Europe using such a cable-free system and 4500 channels were deployed on the project.

The system provided greater flexibility in station location outside of the strict design grid to compensate for obstructed or omission areas (Figure 5). The absence of cables reduced disruption of operations, equipment damage, and general hazard of the numerous road crossings. The real time retrieval of selected data that the system provided through repeater units in addition allowed ambient noise levels to be monitored to avoid data degradation in the urban areas. Although some equipment theft occurred (over the course of the survey 45 line units (RAUs) and over 200 batteries were stolen) less than 0.1% data was affected as full data collection or 'harvesting' was accomplished every three days allowing full-shot QC. The key to this timely data collection was the ease of data harvesting provided by the system and a coordinated and efficiently managed harvesting procedure. The location of stolen or lost RAUs was also possible using the system's 'anti-theft' capability, which is similar to the LoJack system used on cars. This

Figure 6 Receiver positions, pre-plot (left) and actual post-plot (right).

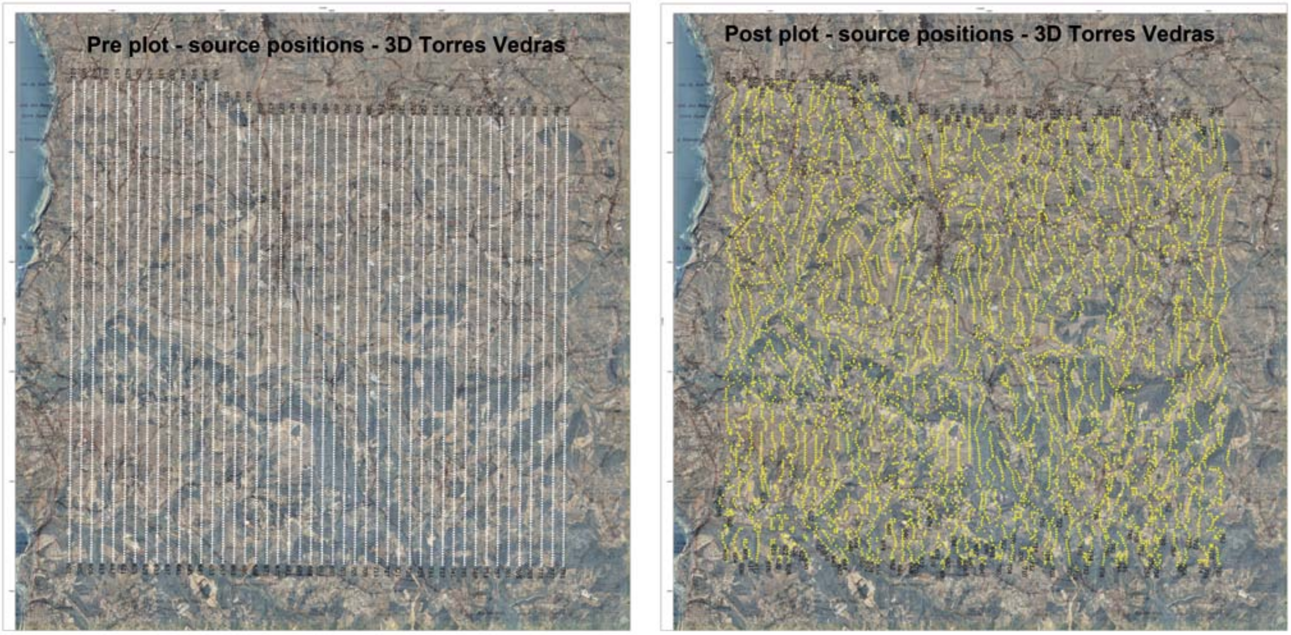

Figure 7 *Source positions, pre-plot (left) and actual post-plot (right).*

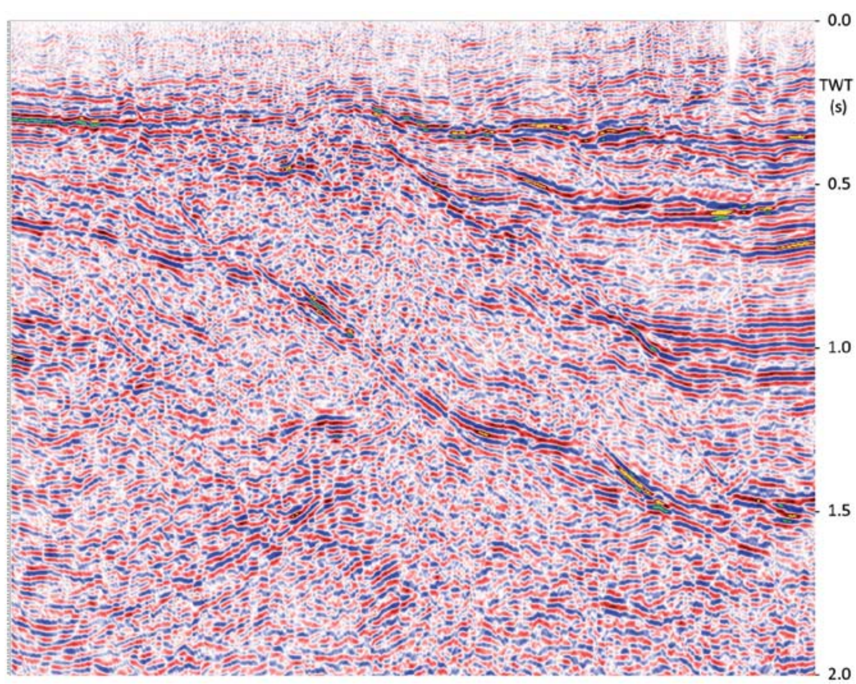

Figure 8 *1981 2D Vibroseis line from west (left) to east.*

then permitted the remote harvesting of the data so that actual data loss could be minimized.

Another advantage of the cable-less system in a survey using multiple source types is that the quality control process and in-field processing is simplified and efficient as data is managed in the shot domain rather than in the receiver domain as is typical in other systems. This greatly facilitates the organization of data for stacking and correlation.

Data acquisition began on the 5 November, 2010. Bad weather (rain and strong winds) delayed production; however, recording was completed in 80 days with 7235 records successfully acquired on a total of 89.77 acquisition km^2. It is estimated based on prior experience that the cable-less system enabled at least a 50% improvement on productivity over the use of a cable system.

The pre- and post-plot location maps for receivers (Figure 6) and shots (Figure 7) indicate the required flex-

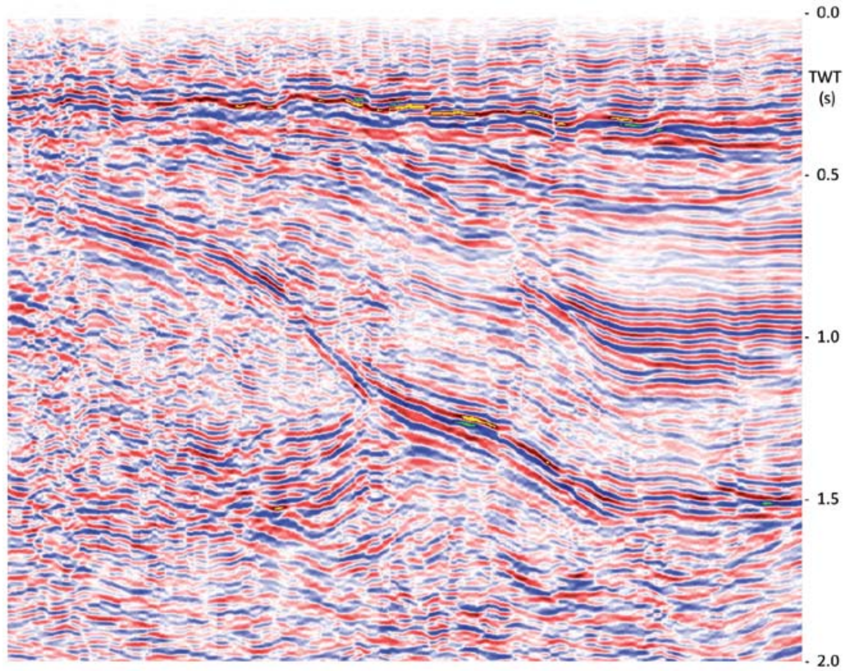

Figure 9 *2010 line extracted from 3D volume at the same location as Figure 8.*

ibility of recording operations which would have been very much more difficult using a traditional cable system.

Environmental management and protection

There were no modifications of the terrain features and all waste materials were collected in plastic bags and disposed of in designated containers at the base camp. No fuel or waste oil, spare parts, or other materials were left in the field. Spill kits were provided in places where there was a risk of an environmental accident, such as on the Vibroseis crews (in the vibrator technician's vehicle), the mechanical workshop at the base camp and the fueling area.

During and after rainy weather, vibrators and other vehicles along the source and receiver lines occasionally made tracks on the land. Where necessary, the land has been restored to its original condition. No other environmental issues occurred on the project.

One vehicle accident was classified as high risk, although nobody was injured. All other vehicle incidents resulted in only minor damages to the vehicles.

Comparison of new and old data

A comparison of a 2D Vibroseis line acquired in 1981 (Figure 8) with a 3D line in the same location (Figure 9) shows that a superior image of the subsurface was obtained despite the operational issues faced by the crew.

Conclusions

It is an obvious statement that ensuring adequate scouting, planning, and design review helps to ensure the success of a survey. However in practice the pressure to meet commitment deadlines and complete projects as fast as possible often results in inadequate preparation. Within reason, the old adage 'less haste, more speed' applies to seismic surveys. However, careful preparation often suffers in the pressure to be seen to commence operations and make 'progress'. Priority is given to starting recording when, in fact, what is most important is the date when data collection will be completed. This haste to commence recording can be attributed in many cases to contractual terms which tie first revenue payment solely to the commencement of recording.

The success of the Torres Vedras survey lies in allowing time for the careful planning and preparation for the survey, including the careful selection of recording instrumentation that provided the maximum flexibility in locating receivers and working around obstruction omission areas. The addition of multiple source capabilities enabled both efficient operations and the ability to acquire short offset data in all areas. Finally, an essential factor was ensuring adequate and proactive liaison with the host communities both before and during operations which cannot be over emphasized.

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