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A High-Density Wide Azimuth 3D Survey in Oman

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Abstract

A large high-density, wide azimuth, broadband 3D seismic project was recently acquired in an oil producing area of the Sultanate of Oman. The project aimed to outmatch legacy project results to accurately image a challenging geology, with strong time and budget constraints. This case study presents the key design, operations, and organizational points that enabled achieving the project successfully and record high-quality data.

To provide a clear understanding of the project stakes and fulfillments, the following features will be reviewed:

1. Local geology and geophysical objectives
2. Design of a high-density wide azimuth 3D survey
3. Project acquisition and productivity optimization
4. Crew organization, intensive logistics, HSE commitment, integrated QC chain

The proper imaging of the complex geology – including geological faults, traps, and thin beds - led to the choice of a high-fold full-azimuth geometry with a density of almost 10 million traces per square kilometer. Such a trace density, far above the average for desert projects worldwide, confirms an ever-growing trend and industry requirement, especially in the Middle East. The large block was acquired using the Distance Separated Simultaneous Sweeping (DSSS) technique combined with slip-sweep. With VPs being acquired single source, single point, and the use of super-heavy vibrators (90,000 lbf), the project produced very high quality data, even for the deep targets. Crew organization was paramount to achieve the acquisition on time and within budget. Almost 10,000 shot points were recorded on average daily with extensive HSE commitment.

An excellent dataset with a wide range of offsets and azimuths was acquired, outmatching the previous projects. Currently being processed, this dataset confirms the single-sweep single-source shooting strategy, and promises a new and thorough level of interpretation and understanding of the area that should lead to new productive prospects.

Introduction

A large 3D acquisition project was recently acquired in an oil-producing area of the Sultanate of Oman desert. The multi-million vibrator points shot on the project aim to acquire a wide-azimuth, high-fold set of high quality data over the area at a reasonable cost, in order to provide a coherent global understanding of the local geology, where thin reservoirs can be exploited from precise well locations. This area, which has been producing oil since the 80's, required further detailed high-end studies made possible by equipment and processing progress, in order to improve oil recovery, as well as further exploration for new wells. This case study presents several operational aspects that contributed to the success of the project, which is a good example of the typical advanced acquisition techniques that are currently used in the Middle East.

Since 1980, numerous 3D narrow-azimuth surveys covered most of the area. This data has supported structural-based exploration and field development, but limited spatial resolution, deep imaging and reservoir characterization capability. The current producing zones range in depth from 1,300 to 3,000 m, with exploration objectives as deep as 6,000 m. The production is scattered among dozens of individual accumulations. Traps are most commonly complex fault traps, but some are stratigraphic and trapping faults that can be low throw and subtle.

Field development relies on close well spacing, necessitating accurate spatial resolution and imaging. Strong correlation between acoustic impedance and reservoir porosity means that amplitude preservation (including removal of tuning effect) is important to reservoir characterization. Reservoirs are typically thin, with reservoir thickness economically produced ranging from 5 to 40-m thickness. A quantitative interpretation was henceforth required to improve understanding of the geology and reveal stratigraphic and thin traps. The large area to be covered then required a new 3D acquisition, producing consistent data, with an important constraint on acquisition time, and a productivity level high enough to ensure coverage of such a large area at an acceptable price.



Figure 1—Project area is desert, with mainly stone pavements, djebels and several corridors of dunes up to 60 m high covering 20% of the project

High-density wide azimuth geometry

The dense spatial sampling required for the imaging with the proper resolution (temporal and spatial) of geological faults, traps and thin beds led to the choice of a dense 15-m x 15-m binning, coupled with trace

density high enough to obtain a signal-to-noise ratio at 2,000 m depth a minimum of 1.8 times higher than that of the best legacy survey. The new signal-to-noise ratio was set using the vibrator Signal Strength Estimate (SSE), a representation of the quality of the signal-to-ambient noise ratio (Meunier, 2010).

A dense binning requires a close receiver and source point interval; high fold implies close source and receiver line spacing. The source and receiver spacing (30 m for both) being set by the bin size requirement, source and receiver line spacing had to take into consideration the expected fold and offsets, equipment availability, and budget. The 16,500 channels available were consequently used to form a 22 lines / 8,800 active channel spread, with a 60-m source shot line interval and 180-m receiver line interval. The project was acquired in WAZ-1. This shooting technique supposes repeating each VP twice with a different spread (Figure 3, left and bottom right), but offers two advantages:

Patch lines	44
Stations/patch live	17,600
Stations/line	400
Recorder	428 XL
Receiver line interval	180 m
Shot line interval	60 m
Group Interval	30 m
Shot Point Interval	30 m
Maximum Minimum Offset	171 m
Minimum Maximum Offset	7061 m
Total Fold	2200
Bins/Km ²	4444
Max Trace Density /Km ²	9,777,778
Methodologies	DS3 + Slip-Sweep
Cluster interval	8 km
Sweep type	Log (+2dB)
Sweep length	8 s
Sweep frequency	2-96 Hz
Drive	70%
Listen time / Slip time	8 s / 8s

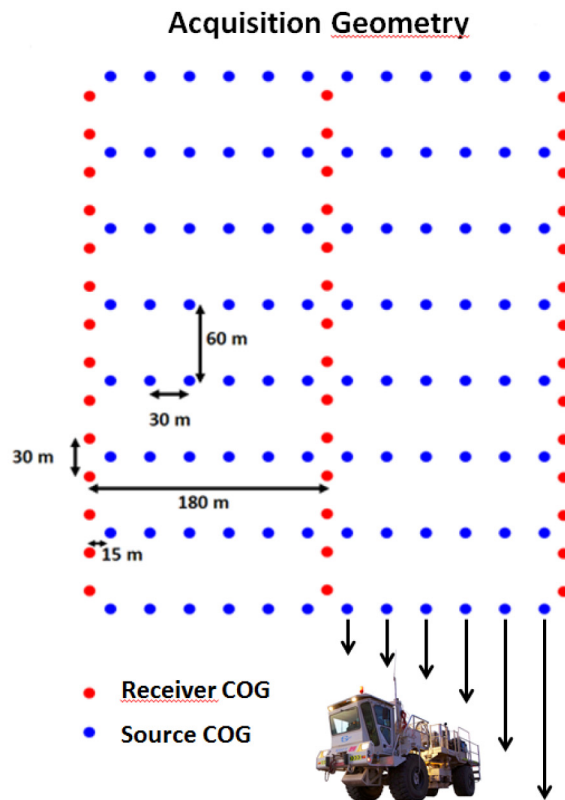


Figure 2—Project parameters and geometry

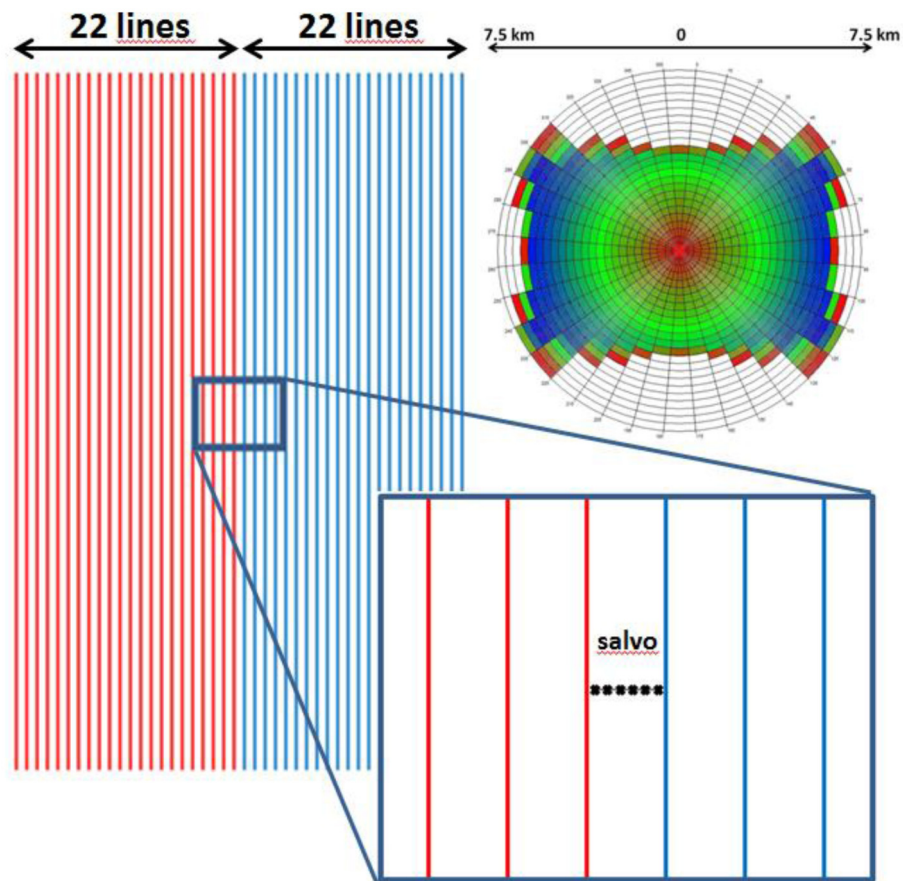


Figure 3—Shooting in WAZ-1: (left and bottom right) each spread of 22 lines is shot at a different time during the acquisition (red, then blue spread with the same 6-VP salvo), forming the 44-line complete spread; (top right) the resulting offset and azimuthal distribution: project is wide azimuth until reservoir maximum depth target at 3,000 m

- Fewer and longer receiver lines are laid out, which is beneficial for simultaneous acquisition based on distance separation, especially with 24-hours operations when the additional VPs can be shot at night when no movement of line is permitted (Sambell, 2010).
- The resulting equivalent spread is double the acquisition spread, i.e., 44 lines / 17,600 active channel spread.

This 12-km x 7.74-km equivalent spread offers full-azimuth coverage in the 1,300-3,000 m target range, with data available up to 6,000 m for deep exploration (Figure 3, top right), and a trace density of 9,777,778 channels per square kilometer. Such trace density, far above the average of worldwide desert projects, confirms an ever growing trend and industry requirement, especially in the Middle East.

Unlike WAZ acquisition, the project subdivision in zippers is due to a block width too important to lay out entire lines and shoot entire swaths, and has no operational advantage. On the contrary, it supposes double shooting some VPs, double laying out some sensors, or a combination of both. This duplicated effort has a negative impact on acquisition time. On the crew, 10,000 additional channels were provided to reduce the quantity of zippers down to two: double shooting and cable laying out could thus be minimized. The project parameters are summed up in Figure 2.

Project acquisition

The huge number of VPs plus the strong constraint on acquisition cost and time led to the choice of a very high productivity technique, in order to record the project's important volume of data in due time and

budget. Distance Separated Simultaneous Sweeps, or DSSS (Bouska, 2009), coupled with slip-sweep, offered the level of productivity required for project completion in due time. The method consists of having two or more groups of vibrators spread on each side of the super-spread with a minimum separation. Vibrators from different groups form a cluster and sweep simultaneously, far enough to avoid data contamination at target depth. Then inside each group, vibrators can operate in a typical slip-sweep method, with no constraint coming from the DSSS method (Figure 4). DSSS advantages include real-time QC in the recorder, no required proprietary or specialized processing steps, and records indistinguishable from single source records (except simultaneous shot contamination, but occurring below target). Only recorder and vibrator electronics (428XL and VE464 on the project) have to support the methodology, particularly the concept of clusters.

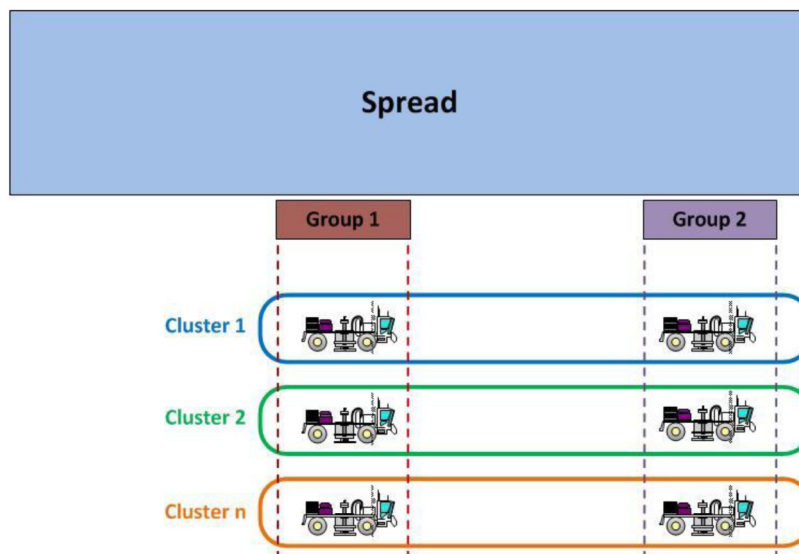


Figure 4—DSSS acquisition: vibrators within clusters operate simultaneously; those within groups operate in slip-sweep

In this project, two groups of six vibrators were disposed alongside the active spread. Two vibrators, one for each group, shot simultaneously providing a minimum 8-km separation was respected. This 8-km separation, selected on the basis of legacy projects and pre-production tests, is the minimum distance for which the energy from one record will not interfere with the target data on the other simultaneous record (Figure 5). Inside each group, the six vibrators shoot in slip-sweep.

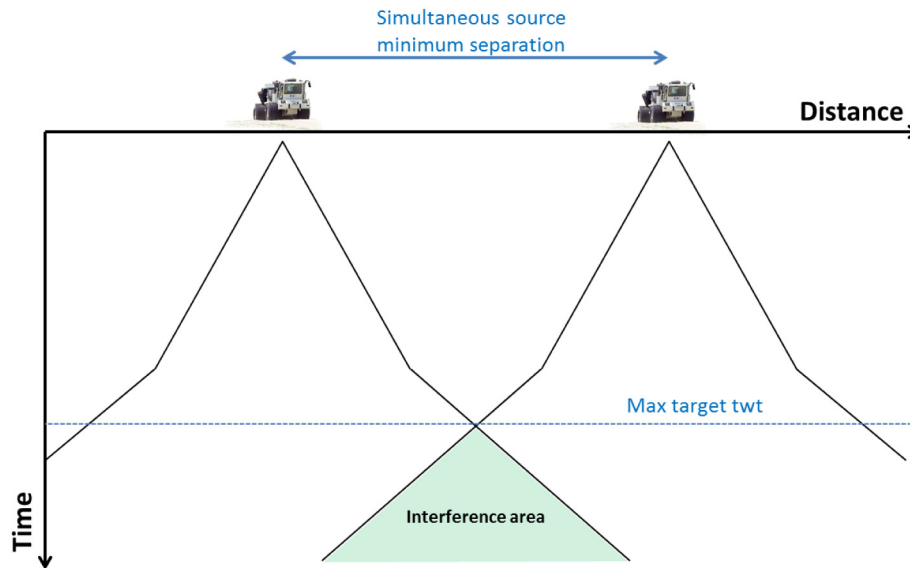


Figure 5—Minimum separation for two DSSS simultaneous shot points

The crew productivity was optimized by two means:

- Shot points are separated 30 m and source lines 60 m. Since each salvo has only six VPs, the best option is to have vibrators shooting in parallel to receiver lines to reduce overall detour time, as displayed in Figure 2. Each of the two groups shall then have six fleets of single vibrators.
- No fixed clusters are predefined between the two vibrator groups. With dynamic group fleeting, any two vibrators that are far enough apart can shoot simultaneously (Bouska, 2010). In practice, the recorder measures the distance between vibrators that are ready to sweep using the GPS data in the "ready" message sent to the recorder. If the separation between two vibrators is sufficient, they will sweep simultaneously, otherwise, only one group will operate in conventional slip-sweep.

The small binning and high density grid made a single source preferable to avoid array effect, with the condition that the single source is strong enough to provide sufficient energy. This was achieved using fifteen super-heavy Nomad 90 vibrators (Caradec and Buttin, 2008), in two fleets of six vibrators with three spares. Moreover, this kind of vibrator is particularly adapted to Middle East operations in large open areas. The vibrator (Figure 6) strong hold-down weight of 80,000 lbf is particularly important as the energy emitted and signal-to-ambient noise ratio (SANR) is directly proportional to the hold-down weight, and only to the square root of the sweep length and the number of sweeps. It is then far more efficient to increase the energy and the SANR by increasing the output force rather than by increasing the sweep length or the number of sweeps that would have a negative impact on cycle time between two VPs. The vibrator's weight applied on both base plate and top plate (to avoid mass rocking), and the 90,000 lbf high peak force exceeding the 80,000 lbf hold-down weight (to compensate for the mass/baseplate phase shift towards high frequency) also contributes to the sweep quality (Tellier, 2015). The sweep chosen, despite a short 8-s length, covered a broad 2-96 Hz bandwidth, and proved adapted to a high-density recording with most noise being shot-generated.



Figure 6—Super-heavy vibrator in one of the project's steep area

Vibrator operations were stakeless except in areas of rough terrain; the several million surveyor stakes necessary for the project being replaced by vibrator guidance that indicates to drivers the location of their next shot point. The vibrator's crossing capability in dune areas, pointed out as excellent by the crew, is ensured by both vibrator buggy performance and the automatic wheel inflation that correlates the tire pressure to the vibrator speed and field conditions. In addition, vibrator automatic pad up avoids time losses at each VP stations.

Intensive logistics and HSE commitment

The crew has been running almost continuously for 24 years and achieved from 2004 to 2012 an 8-years industry record of 23.4 million man hours without LTI. However, acquiring seismic data over such a large desert area implies a strong and continuous HSE commitment. The area is desert, with mainly stone pavements and several corridors of dunes up to 60 m high covering 20% of the project area. Temperatures in the area are amongst the highest recorded, peaking every day up to 50°C from June to September, and unpredictable wadis can flood part of the prospect for several days.

The area is crossed by several types of obstacles: pipelines, oil wells, djebels, and villages. Supply has to be organized for a crew of more than 400 staff, working in a remote area, with good road infrastructure nonetheless, while on daily operations more than 250 staff work on the field, outside base camp. In the dunes, a total of 3,500 km of tracks have to be cleverly opened to enable access for vibrators and cable teams. This mobilizes a team of up to 36 bulldozers on the roughest part of the project. For HSE purposes, these areas are no-go for night operations and require careful operation planning to be acquired day-time while smoother areas are shot night-time, thus optimizing the production. Furthermore, numerous base camp moves (Figure 7) had to be planned. The configuration of such a crew doesn't make the installation of fly camps beneficial. As soon as the recording team joins the surveying ones, the fly camp becomes de facto the main camp, in terms of both operations and staff count.



Figure 7—Base camp move, optimized by the use of 40 by 40-foot mega-skid. Each skid is around three times the size of a standard skid and can accommodate the 50 senior staff kitchen and mess or 24 staff in individual cabins

An average of 150 vehicles was mobilized on the project: 115 light vehicles, 25 trucks, and 15 vibrators. This implied efficient journey management to be in force, in order to detect as soon as possible any deviation from the planned route or missing vehicles. All vehicles were linked by radio to the main camp and traced for position and speed in real-time.

Regarding crew logistics, the use of super-heavy vibrators can reduce efforts, if fewer but more powerful vibrators are used on the crew. It can have a direct impact on staff, as fewer drivers and vibrator mechanics are required. Maintenance effort and spare part stock can be reduced, as well as refueling capabilities. Vibrator autonomy is pushed to 32 h under intensive application using the extended 1,430 l fuel tank, which is very convenient in remote, isolated, and uneven areas with strong HSE exposure.

Production and Integrated QC chain

The DSSS method combined with slip-sweep enabled achieving a very high level of production all along the project, slowed down only during Ramadan when working hours are greatly reduced. Including Ramadan and weather standby due to wadi floods, the crew average production reached 9,365 VPs/day, and daily production peaked 13,175 VPs (Figure 8). Such a level of production was mandatory to achieve the project within expected schedule and cost.

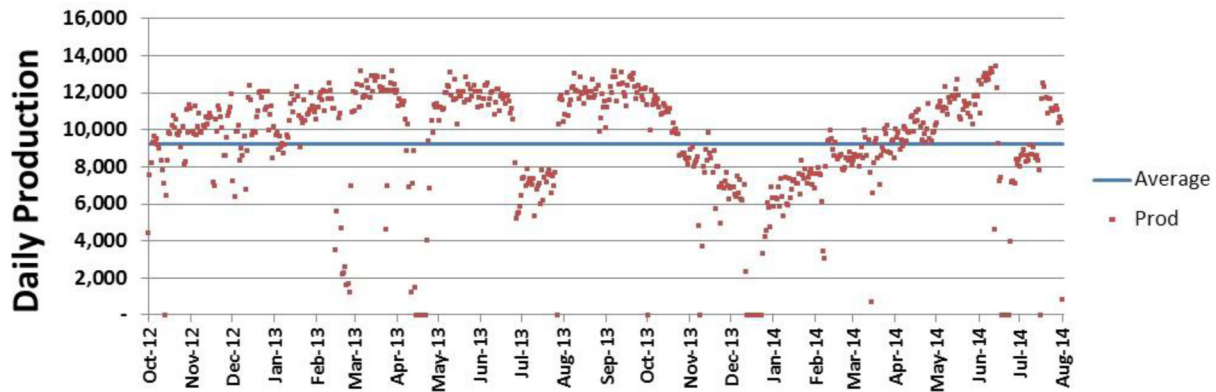


Figure 8—Project recorded VP chart

The quality of the dataset acquired by the seismic crew depends on the choice of proper acquisition parameters and equipment as well as the carefulness with which the data is acquired. All the parameters having an influence over the final imaging need to be carefully tracked and checked. This concerns the seismic data, as well as non-seismic information, such as location files (SPS file) and equipment QC. This starts from the project planning, through surveying, recording, and eventually data processing, forming a metrological chain that needs to be consistent all along the project. Seismic data only represents a daily volume of 600 to 800 gigabytes.

Conclusion

The choice of adequate design parameters, high-end acquisition techniques, and equipment were primordial to the success of the survey. The combination of a high-density wide azimuth survey with the use of energetic super-heavy vibrators enabled acquiring a new set of high quality data. Early stage processing already reveals interesting structures and validates the single powerful single-source single-sweep shooting method. This large acquisition could be achieved in due time, and at a reasonable price that made the project possible. Currently being processed, this data is opening the way for a new and thorough interpretation and understanding of the area.

Acknowledgments

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