Full Azimuth Circular Survey in Indonesia: Survey Design, Onboard Illumination QC and Preliminary Processing Results

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Summary

Conventional offshore 3D acquisition is still being performed mainly with narrow azimuth streamer configurations, even in structurally complex areas. Attempt at breaking this paradigm have been recently made by the industry through the successful acquisition of some unconventional "Multi-Azimuth" (MAZ), "Wide-Azimith" (WAZ) and "Rich Azimuth" (RAZ) marine surveys. Eni Indonesia and WestenGeco conducted "the first of its kind" full 3D Circular Shooting survey (Coil) over the Tulip Discovery in Indonesia between August and September 2008. This paper presents design, onboard illumination QC and preliminary processing results of this new "Full Azimuth" (FAZ) seismic effort.

Introduction

Tulip is a complex structural feature located in the Bukat Block offshore Kalimantan (Indonesia). The water depth is varying and ranges from 350 to 1800 meters. Several unfavourable geological conditions cause a very poor seismic response in the whole area. The presence of methane hydrates represents the main problem; this is indicated by the BSR reflection covering the whole structure. The hydrates layer generates in this area a very reflective sea bottom that causes the presence of up to seven multiple bounces. The presence of shallow free gas is suggested by an abrupt frequency-amplitude dimming below the BSR. The well drilled on the structure indicates a Q factor of less than 70. Moreover the rough geomorphology of the water bottom, characterized by canyons and irregularities causes a non homogeneous behaviour of the illumination in the subsurface and a complex 3D raypath for surface and internal multiples. Complex deep geology, a steeply dipping thrust with 2 culminations, represents a third critical factor, posing severe structural illumination doubts as well. Last but not least challenge is the low reflectivity of the target sequence, often falling below the noise level. Due to the mentioned factors, the vintage seismic in the area is of very poor quality (Fig.1). In order to get a better image of the subsurface for the appraisal campaign, it was decided to design a new seismic survey which would adequately address the geophysical problems described above. The survey design was carried out by the geophysical planning group in Company's headquarters. The Tulip depth model was ray-traced using several configurations. These included a single azimuth tested in 4 different directions, 3&4 direction multi-azimuth surveys and a circular shooting configuration [French, 1984; Durrani, 1987]. The latter configuration was investigated together with the Acquisition Contractor, who had tested the "Coil Shooting" technique in recent years. Multi- vessel WAZ techniques were not considered as near offset information is vital to address near surface irregularities. Eventually Circular Shooting was judged to be the most suitable solution for the geophysical challenges of Tulip. The very high azimuthal fold and illumination were deemed beneficial in attenuating diffracted multiples, in giving a more complete subsurface image and in improving the overall signal to noise ratio.

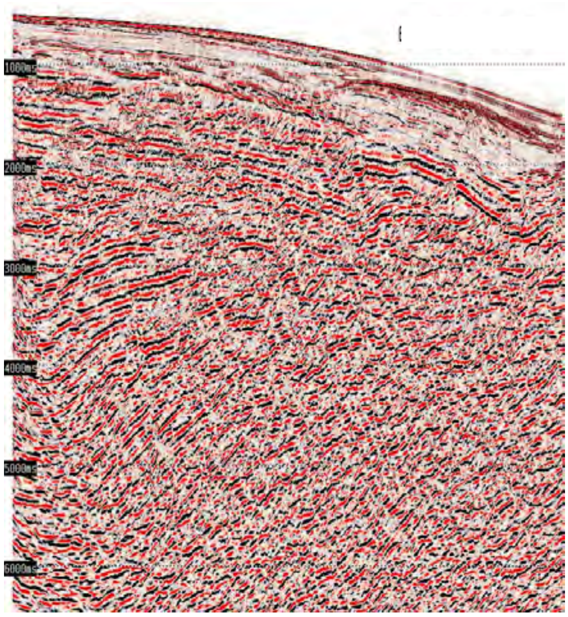

Figure 1: Vintage seismic example

As a consequence of the study, the first industrial 3D circular acquisition (Coil Shooting) started. The survey was acquired safely and very efficiently from August 8^{th} and September 15^{th} 2008. Approximately one billion seismic traces were recorded in 39 effective acquisition days with negligible downtime. Contrarily to what normally happens in conventional surveying, special care was devoted to the "real time" control of the growing target illumination as part of the onboard QC. Planned and actual illuminations were continuously compared using an onboard ray-tracing algorithm to verify the compliance with the original plan. A "near real time" illumination control was performed simultaneously in Company's headquarters using the same software. During the final phase of the survey, a comprehensive program of infilling based on "flower plots" was planned in Milan to recover the residual illumination discrepancies and to optimize the illumination coverage. The Tulip 3D Circular survey data is currently being processed in Jakarta, Indonesia.

Survey Design

The feasibility study focussed on the geophysical problems of the area. Several surveys were modelled using ray tracing on the Tulip velocity-depth model. In particular, 4 single azimuth surveys in 4 different directions, a 3&4 direction multi-azimuth survey and several trials of circular surveys were generated. Obtaining a satisfactory design for the circular survey proved to be a non trivial task. Several options were tested with different unusual industrial parameters such as position, number and radius of the circles as well as X-Y move-up of the centre of the circles. The shooting configuration, initially 6x8000m long, 100m spaced streamers and a 25m interval single source, was kept constant; tests were performed on decimated data and then upscaled. The criteria used for the choice of the best options were based on the higher azimuthal fold of coverage and above all, on the most effective depth illumination of the target horizons. Eventually, a design consisting of 145 circles with a radius of 6500 m each and a circle centre X-Y move-up of 1000 m was selected. Approximately 260,000 shot-points were concentrated in an area of 560 km^2 with a full image area of 285 km^2 (Figs. 2 & 3).

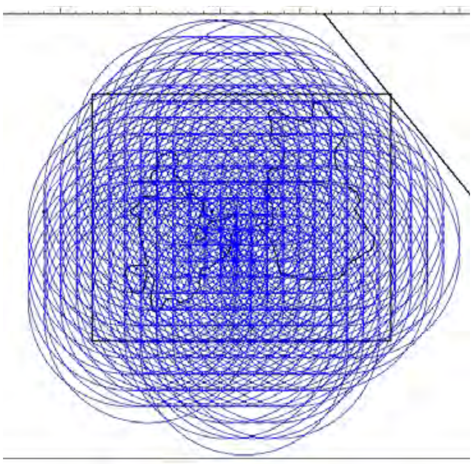

Figure 2: Planned Source Effort

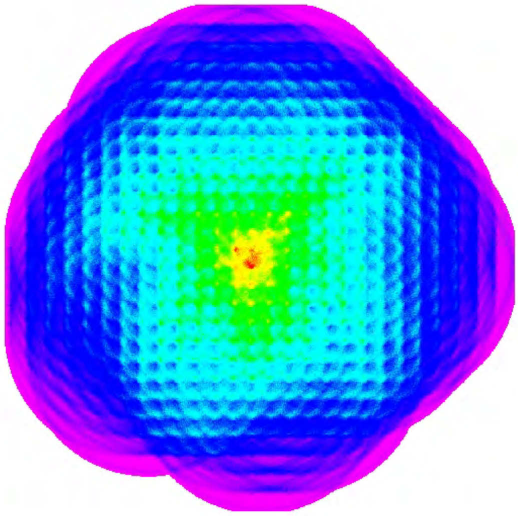

Figure 3: Planned fold of coverage (max around 3300 @ 25X25m bin)

This survey design guaranteed full fold and full azimuth coverage on the two structural culminations of Tulip. With circular shooting the concept of full fold has little meaning; in practice 'full fold' was considered the area where it was possible to achieve at least 6 different azimuths for future processing. Once a satisfactory configuration for the Circular design was achieved, the target illuminations (hit maps) provided by each different kind of modelled survey, were compared. Initially the comparison was performed maintaining constant the total source effort (Fig.4); the Circular shooting was kept as reference. This resulted in a practically unfeasible (8 meter shot interval) single azimuth conventional survey and a quite dense 3 direction multi-azimuth. Successively a second comparison step was performed: in this case the total source effort was left varying as a function of the different kind of survey; here the multi-azimuth model was modelled in 4 different directions. In both comparisons the cable length and spacing remained the same. From these comparative analyses of the illumination it was clear since the beginning that "circular shooting" was capable of reducing undesirable geological shadow effects more effectively than the other methods. It was also apparent anyway that circular acquisition was characterized by severe changes in illumination and "bin to bin" fold, necessitating special care in processing.

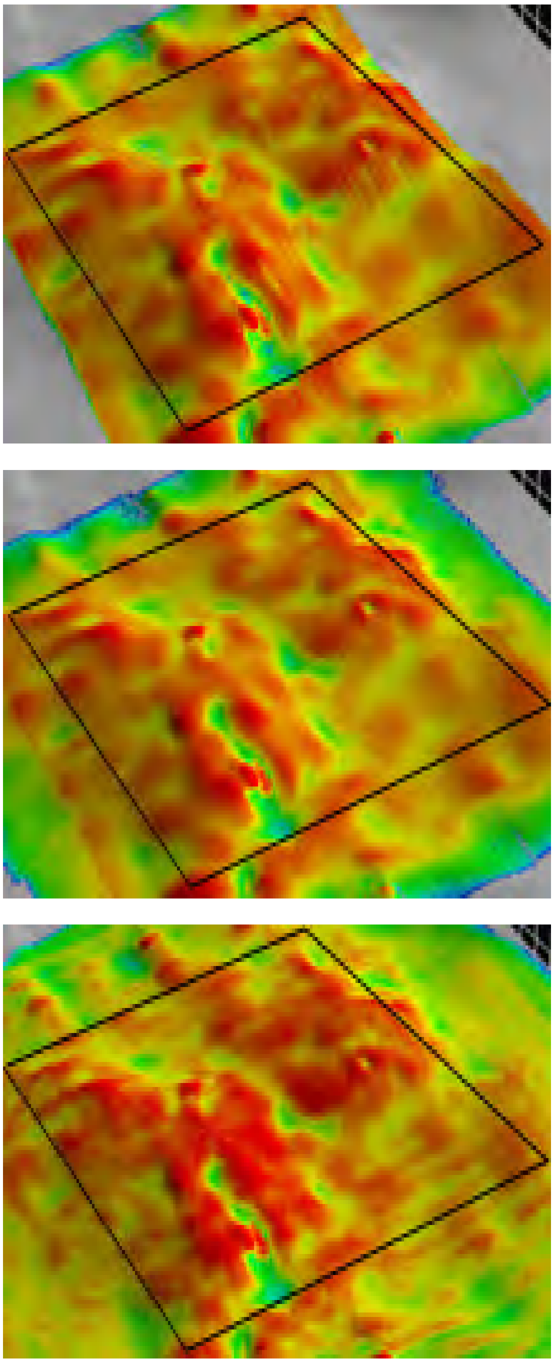

Figure 4: Comparison of 3 different kinds of survey with the same source effort. From the top: single azimuth, multi-azimuth (3 az.) and circular shooting

The illumination comparison was repeated for several ranges of incident angles. Finally, after an "in depth" assessment, the circular shooting was found to be the most efficient way to fill the illumination gaps and to reduce the very strong 3D multiples on Tulip. The drawback, compared to other kinds of surveys, was a more "scattered" fold of coverage and a heavy and characteristic footprint. In order to evaluate the processing issues that could be expected from this unusual shooting geometry a synthetic 3D volume was generated and processed. The investigated topics were multiple removal, in particular 3D multiple attenuation solutions and 3D migration before / after data regularization. This processing exercise demonstrated that a full 3D multiple removal was successfully applicable on Tulip data, the only limitation being related to the quite large aperture needed and then to the CPU time required. Regarding migration issues the tests on synthetics demonstrated that migrated amplitudes were strongly influenced by the acquisition footprint and that data regularization was a critical task, at least when using Kirchhoff algorithms. Voronoi weighting resulted to be a very useful tool to improve migrated amplitude behaviour. Once the seismic vessel parameters became available, a fine tuning of the feasibility study was performed by comparing the planned 6x8000m long streamer with an 8x6000m streamer configuration. After further modelling, the latter was preferred because it showed better data regularity without any significant loss of useful depth illumination at larger reflection angles and of azimuthal distribution.

Acquisition QC

While the QC in conventional surveys is quite straightforward, the QC of circular shooting is more complicated. Firstly, the fold of coverage is generated using intersecting circles [Moldoveanu, 2007] and not straight lines. Secondly, feathering and deviations from the planned route are not necessarily detrimental to the final result. Thirdly, the need for re-shooting and/or infilling can be evaluated only at the end of the survey. As the Tulip 3D Coil survey acquisition was designed to fix severe illumination problems, most of the QC effort was devoted to depth illumination instead of the "traditional" fold of coverage. Monitoring depth illumination further complicates the acquisition QC and requires more personnel and machine effort. To satisfy the requested technical specifications, a ray tracing program was installed on the seismic vessel along with dedicated people to operate it. During the acquisition, "real time" depth illumination was continuously generated and evaluated both standalone and against the model generated during the feasibility study. Contemporaneously, Company's headquarters specialists were monitoring the "P190" navigation files to enable further and more thorough "near real time" modelling and comparison. Towards the end of the survey, the need for re-shooting and infilling was evaluated by comparing the planned illumination with the actual illumination. The scope of the infilling was to infill any gaps and to use the saved acquisition time (as acquisition proceeded more quickly than expected) to fill remnant illumination holes ignored during the planning phase. Thus the original design was improved "on the fly". The fine tuning of the illumination was carried out in Company HQ by reverse ray-tracing (using "flower plots") generated from the modelled horizons. This information was used to determine the proper infilling "courses" (arcs and straight lines) for the seismic vessel. At the end of the survey, after infilling, the actual target illumination was slightly more uniform than the planned one.

Preliminary Processing Results

The processing of the Circular Survey data started onboard and is still ongoing and it is expected to be completed by Q-3 2009. It was clear from the beginning that the new acquisition geometry introduced some new typical challenges in data treatment. The first was the presence of turning noise, with a broad spectrum and amplitude inversely proportional to the curvature radius of the circle. After onboard "digital group forming" and application of adequate signal processing steps in several sorting domain, the "turning noise" was effectively attenuated. This demonstrated that the circle curvature radius of 6500m had been a good choice. The second problem was represented by water velocity statics; this phenomenon has a variable impact as a function of the water depth (varying inside the circle) and is consistent within each circle; on Tulip data anyway statics did not represent a major issue. The third problem was the apparent geometrical distortion of the moveouts and the midpoint dispersion in 2D CMPs. This prevents the application (at least in principle) of a conventional marine processing sequence. It was anyway demonstrated with specific tests, that a full 3D demultiple solution is effective on Tulip data, leaving only few residuals to be dealt with conventional methods. The fourth challenge was a very irregular, even if always very high (in the order of thousands), fold of coverage, that causes amplitude problems to data migration, if not properly treated. Current data regularization techniques (es. Voronoi weighting), successfully tested on synthetic seismic, demonstrated themselves very useful to overcome this challenge.. Data processing is ongoing but a preliminary comparison between the brute stack of 3D circular data and a co-located single azimuth 3D sail line, indicates that hidden target reflections are more visible on the new "Coil" seismic. Successive processing (in particular a proper 3D demultiple) would improve further the image (Fig. 5).

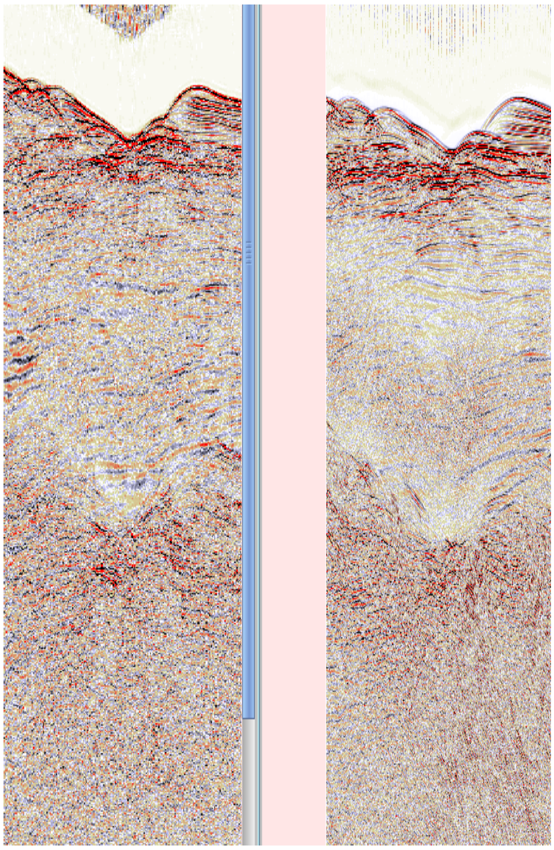

Figure 5: Brute stack comparison; Circular Shooting (left) and Conventional narrow azimuth 3D (right)

Conclusions

We have presented planning, acquisition QC and some preliminary processing tips for the Tulip "3D Coil Shooting" acquired on the Tulip East-1 discovery area, the first full industrial application of a survey of this kind. In particular we have highlighted the different technical approach and demonstrated the Circular survey provide superior target illumination compared to traditional surveys. In addition preliminary data results compare favourably with the pre-existing 3D seismic in the area.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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