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The Effects of Marine Data Acquisition Practices on Imaging in Complex Geological Setting - Modeling Study

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SUMMARY

Interpreting seismic images in complex geological settings still remains a challenging task. Poor illumination, poor signal-to-noise ratio and high level of uncertainty are some of the imaging issues in complex marine environments such as subsalt Gulf of Mexico and West Africa, sub-basalt and pre-salt offshore Brazil and others (Howard et al., 2007; Ver West et al., 2007). Billet et al. (2010) point out that seismic technology evolution going beyond WAZ geometries needs further progress on both the acquisition and processing fronts.

In this abstract we present results of a modeling exercise and show the effects that survey design choices have on the final image beneath the salt. We change individual acquisition parameters and observing the impact on the image as well as consequences of processing and velocity model building. Besides qualitative notions on what survey design choices have most influence we are also assessing steps needed towards quantifying the uncertainty.
Introduction

Interpreting seismic images in complex geological settings still remains a challenging task. Significant academia and industry effort in the last decade has been devoted to addressing imaging issues in complex marine environments such as subsalt Gulf of Mexico and West Africa, sub-basalt and pre-salt offshore Brazil and others (Howard et al., 2007; Ver West et al., 2007). Billet et al. (2010) point out that seismic technology evolution going beyond WAZ geometries needs further progress on both the acquisition and processing fronts.

In this abstract we present results of a modeling exercise and show the effects that survey design choices have on the final image beneath the salt. We change individual acquisition parameters and observing the impact on the image as well as consequences of processing and velocity model building. Figure 1 shows a Reverse time migration (RTM) image of synthetic data emphasising problems when interpreting a subsalt target – poor illumination, poor signal-to-noise ratio and high level of uncertainty. The target reflectivity in this case is regular grid of semicircles that can only be hinted in the image.

![Figure 1](image1.png) \[RTM stack of synthetic dataset showing combined effects of various acquisition parameters to the subsalt imaging ("How bad can it be?").\]

Realistic models and forward modeling

Recent improvements in marine geometries such as WAZ and newer survey design types have been supported by extensive and advanced modeling that goes beyond designing surveys with optimal fold and economic time lines (Stork 2011). The SEG Advanced Modeling Corporation (SEAM) have developed a complex 3D velocity model representative of a 60-block (1400 km²) area of the deep-water Gulf of Mexico geological settings, that has been used in number of studies. Stork et al. (2010) describe subsalt imaging generated with SEAM 3D model as being of higher quality and overall better subsalt reflectivity then what is usually produced with real data. To better correlate with real problem and create low illumination subsalt image, Cvetkovic et al. (2011) modified the original SEAM model guided by well logs by slowing down the subsalt regime 40%. From this model we created a 248km long 2D velocity section that includes several salt bodies as well as smaller and larger scale sediment basins (Figure 2). As a multi-purpose model we also introduced salt velocity variations (“dirty salt”), anisotropic values within the salt bodies (Landro et al., 2011) and modified top and base of salt features from the original interpretation.

As for the forward modeling we used single scattering modeling with a scalar reflectivity model to generate the shot records. Wave fields are modeled using a finite difference (FD) acoustic propagator and are allowed to reflect only once from a reflectivity model that is defined separately from and independently of the velocity model. For the reflectivity model we used a regular grid of semicircles with 500m radius. Semicircles are useful approximation for a variety of targets as they have full dip range from 0° to 90°. The single scattering approach avoids the creation of surface and internal multiples or salt body reflections, so that we can analyse subtle illumination variations from the target reflectivity events without interference from those other much stronger reflections, which with full FD modeling can overwhelm the subsalt target.
This way we isolate the illumination aspects of survey design from the multiple attenuation aspects. Since the propagator supports full two-way wave field propagation, our method is more capable than either one-way wave equation modeling or ray-based modeling in the faithful representation of complex wave field behavior such as high-angle propagation and multi-path arrivals (Cvetkovic et al., 2011). Reverse time migration was used for imaging. We generate stacks and 2D sub-surface angle gathers from the RTM for each of the datasets to evaluate the effects on the model building capabilities.

**Acquisition impact on imaging**

We simulated multiple variations of 2D surface marine geometry. A summary of all parameters tested for this sensitivity study is shown in Table 1.

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*Table 1* The range of tested individual acquisition parameters. Blue items belong to the “ideal” acquisition design, while orange are parts of “standard” survey.

In order to emphasize the extreme effects acquisition choices can have on the subsalt image we can look at following acquisition geometries. The “ideal” survey design had 50km offsets, 30s of recording time, 50m source and 25m receiver spacing and all the offsets available. The “standard” acquisition used 8km of offsets, 14s of recording time, 400m source and 100m receiver spacing while excluding first 400m (the near offsets). Both are noise-free datasets with exact or true models used in migration. As we already stated we are only interested in the effects caused by acquisition choices and are not investigating pre-processing and velocity model building effects at this time.

RTM stacks from these two tests along with the true reflectivity model are shown in Figure 3. The section of the model is located beneath thick complex salt body that is generally poorly illuminated. For the “ideal” RTM image, interpretation is straight forward although steep part of the semicircles (angles greater than 75-80°) are still not being imaged. The “standard” acquisition image is much noisier and far more difficult to interpret with very low signal-to-noise ratio and maximum imaged dips of 30-40°.

Comparison of RTM angle gathers from the tests presented in Figure 4. The left pair is from the larger basin without salt (CDP 120000) and the right pair of images is from the mini-basin surrounded by salt bodies (CDP 174000). Angle coverage is greater for the “ideal” geometry both close and far...
from salt. Gathers in subsalt regime for “standard” acquisition have limited angle coverage, maximum 20° at best, but true primary events are barely visible. Use of these gathers for estimating and inverting velocities beneath the salt will be limited, especially if we consider this to be “best” case noise free scenario.

**Figure 3** Subsalt RTM stack image comparison of “ideal” and “standard” survey designs. a) Reflectivity model (semicircles placed on the regular grid), b) RTM stack of “ideal” acquisition c) RTM stack of “standard” acquisition. Centre of the image is CDP 153000 referenced earlier.

**Figure 4** RTM angle gathers comparison of “ideal” and “standard” survey designs. a) “Ideal” in the basin area without the salt, b) “Standard” in the basin area without the salt, c) “Ideal” in the basin with salt and d) “Standard” in the basin with salt. Dashed line shows the angle information in “standard” survey design that can potentially be used in model building velocity.

**Observations**

We have modelled the response of all of the acquisition parameters from Table 1 separately to investigate what makes the most impact of the image and model building. Here are some of observations:

- Offset and record lengths have significant impact and can be treated as an interleaved pair of effects. The longer the cable or recorded offsets the better subsalt coverage is in angle domain. Recording of 20km offsets produces 20° more angle subsalt than the 8km offsets and 10° more angles than 14km cables. RTM stack image exhibit better illumination with steeper dip recovery and overall less noise. Longer record length facilitates steep dip imaging which can be explained by undershooting of salt bodies. This can be especially important for imaging steep salt flanks and salt necks although 20s and 30s recording are practically very hard to achieve.

- Missing near offsets does not significantly alter the image in the stack and gather domain but does not heal with depth as we expected. Missing near offset should not be hurting us in velocity model building stage significantly.

- Receiver and source separation are relatively well understood (Regone 2007). In our tests we find that the receiver under-sampling has only minor effects on the image and gathers but could not be neglected due to the contributing effect on gathers used in model building. Better sampling in all domain leads to better signal-to-noise ratio especially on the source side.

- Azimuthal coverage was obviously not addressed with LONG SEAM 2D modeling but has been covered in number of recent studies. Cvetkovic et al. (2011) show that image improves noticeably with wider azimuth geometries while additional azimuth information is even more important in model building stage and velocity inversion.
We can sort acquisition choices and parameters to have significant, moderate and minor to negligible effects in the image and model building. Besides these qualitative notions we are also assessing steps needed towards quantifying the uncertainty.

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References


Stork, C. [2011] Seismic acquisition is moving from a “CMP Fold” perspective to a “Wavefield Recording” perspective which has significant implications on acquisition design. 81st Annual International Meeting, SEG, Expanded Abstracts, 157-162.

