G017

Beyond WAZ - A Modeling-based Evaluation of Extensions to Current Wide Azimuth Streamer Acquisition Geometries

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SUMMARY

We modeled three enhancements to the typical wide-azimuth streamer (WAZ) acquisition, evaluating sub-salt illumination, angle coverage, and velocity error tolerance. The enhancements studied are overlapping orthogonal WAZ datasets, doubly wide WAZ, and very long offset WAZ. We find that, for the salt model and target structures studied, the long offset extension brings the most apparent uplift in all of the three aspects evaluated, and especially in the aspect of angle coverage sub-salt.

Introduction

WAZ acquisition has re-energized the sub-salt imaging business by greatly enhancing our ability to attenuate multiples and to illuminate sub-salt targets [Regone 2007]. A great amount of WAZ data have been acquired in the last few years in the Gulf of Mexico (GoM), offshore West Africa, and elsewhere. The most commonly used geometry in these surveys builds a cross-line fold of 8 and inline fold of around 24, with cross-line offset ranging from -4200m to +4200m, and inline offset ranging from ~400m to ~7600m. Other geometries generally do not provide offset coverage much wider or longer than this setup, which we will refer to as the "baseline" WAZ for brevity.

It has been recognized that although WAZ data of such specifications bring a step change in sub-salt imaging, many tough targets remain out of their capability to sufficiently illuminate. Several streamer based efforts have already been made to compliment or go beyond this template of WAZ acquisition, generally with good success. In particular the Rich Azimuth (RAZ) dataset acquired over the deep water Shenzi field – the processing of which one of us was involved in – provided greatly improved image [Howard 2007 and 2010].

These efforts to enhance the common WAZ have all focused on improving azimuthal coverage, or improving shot density, or both. We want to investigate whether the added acquisition effort should be devoted to enhance the geometry in another dimension, namely the maximum inline offset. To achieve larger offsets, one can choose from many different acquisition configurations, with which we will not concern ourselves for now. Our study focuses on the aspects of 1) providing enhanced illumination to better image subsalt targets and 2) providing larger range of incidence angles subsalt to enable reliable velocity estimation or even AVO attribute extraction subsalt.

Forward modeling

We choose the SEG SEAM 3-d salt model for this study. This model contains complex salt bodies that are representative of real world situations. However, it's clear that the SEAM model as distributed is seriously flawed if we are to use it to represent geology typical of the GoM – sub-salt, the sedimentary velocity in the original model is about 45% faster than typically encountered in the GoM. We modified the model to match representative well logs from the GoM, an example of which is plotted in Figure 1 against the original and modified models. This modification is an important step as most illumination disruptions are caused by the velocity contrast between salt and sediments. Our modified model is likely somewhat atypically slow in places such as near the bottom of deeper mini basins like the one shown in Figure 1 b on the left hand side of the salt diapir.

The baseline WAZ geometry is as outlined above. A total of four surveys are simulated. 1) A baseline WAZ dataset is acquired in the N-S orientation, 2) another one in the E-W orientation. 3) In addition, a long-offset WAZ is acquired also in the N-S orientation, with cross-line offset range equal to that of the baseline WAZ, but with maximum inline offset of 20km. 4) Furthermore, a double-wide WAZ, with cross-line offset range twice of that of the baseline, but the same inline offset range, is acquired in the N-S orientation.

We used single scattering modeling with a scalar reflectivity model (Figure 2e) to generate the shot records. Wave fields are modeled using a finite difference (FD) acoustic propagator, but are allowed to reflect only once from a reflectivity model that is defined separately from and independently of the velocity model. This single scattering modeling approach avoids the generation of surface or internal multiples or salt body reflections, so that we can analyze subtle illumination variations from the target horizons without interference from those much stronger reflections, which with full FD modeling can overwhelm the subsalt target. We want to isolate the illumination aspects of survey design from the multiple-attenuation aspects. Additionally, because our 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 behaviors such as high-angle propagation and multi-path arrivals.

Reverse time migration (RTM) was used to image the modeled shots. Note that stack-only RTM is the adjoint of our modeling operator. We also generated 2-d sub-surface angle gathers from the RTM for each of the datasets.

Results and discussion

Four migration results are obtained, one from each of the four surveys outlined above (Figure 2 a, b, c, & e). Additionally, the images from the N-S and W-E surveys are summed together to simulate an overlapping orthogonal double-wide WAZ configuration (Figure 2 d), for a total of five images. A straight sum is used in this study. In Figure 2 the upper half displays the five results from an inline, as well as the reflectivity model for that inline. The red crosses are placed at the same subsurface location in each panel. The lower half displays images from a cross-line.

Comparing these results, it clear that the N-S baseline (Figure 2 b) is slightly better than the W-E baseline (Figure 2 c), but there are a few select regions where the opposite is true. However, simply summing them (Figure 2 d) does not effectively combine the best features of the two together; as illumination gap induced swings from either one seem to survive the sum. In comparison, the double-wide WAZ (Figure 2 e) provides a visible step of uplift from either the individual baselines or their combination. The best result, however, is obtained from the long-offset WAZ (Figure 2 a). This is particularly evident for the image area near the red crosshairs.

Comparing target horizon image amplitude extractions from the two baseline WAZ results (Figure 3 a and c), their sum (Figure 3 d), and long-offset WAZ (Figure 3 b) result, we make similar observations: the long offset acquisition is the more effective method to enhance sub-salt illumination, particularly for the circled area in the displays.

The difference between the long-offset WAZ and the baseline WAZ is even more remarkable when we compare the angle gathers generated from them (Figure 4). With the baseline WAZ, we get the typical ~20 degree angle range sub-salt in good areas and ~5 degrees in bad areas. The long offset WAZ in contrast provides ~45 degree angle range in a majority of the sub-salt area. Such enhanced angle range can greatly improve our ability to estimate velocities sub-salt, and might one day, with the help of full two-way illumination compensation based on single scattering FD modeling, lead to meaningful sub-salt attribute extraction.

We have also experimented with migrating the datasets with a velocity model with a distorted base of salt geometry. We observed that such velocity errors can reduce large portions of sub-salt image from the baseline WAZ to incoherent noise, but that the target image from the long-offset image can often survive the distortion and still appear as coherent signal, albeit somewhat misplaced in its position.

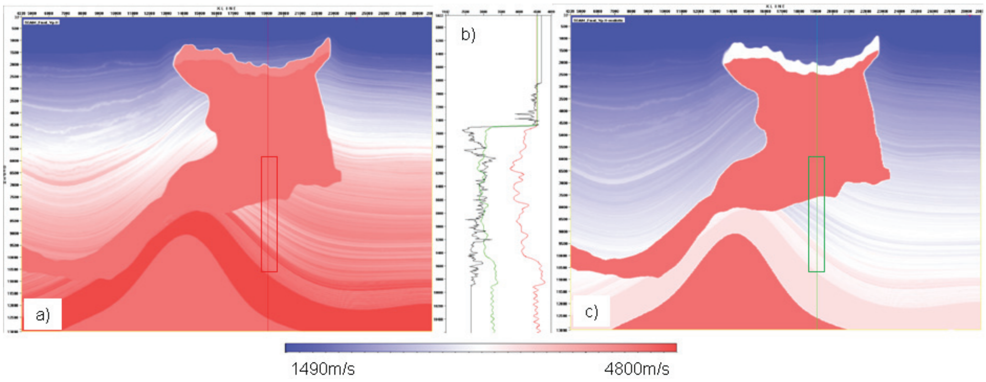

Figure 1: *Velocity model used for forward modeling and migration. The model is modified SEG SEAM model. a) Original SEAM velocity model, b) velocity profiles through SEAM original model (red line), SEAM modified model (blue line) and checkshot velocity from GB-873 well (black line) and c) Modified SEAM velocity model.*

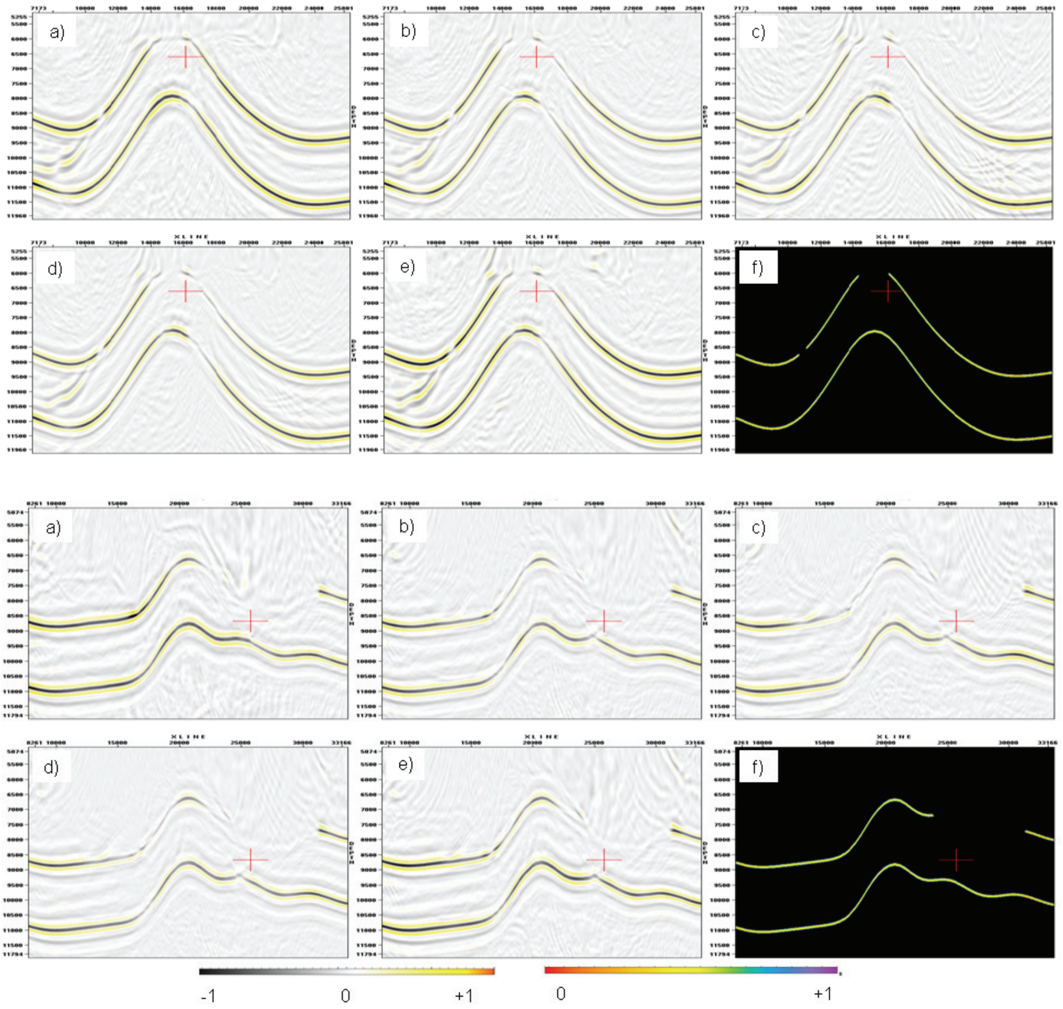

Figure 2: *RTM illumination stacks and reflectivity model for one in-line and one cross-line section. a) Long offset WAZ N-S acquisition simulation , b) Baseline WAZ N-S acquisition simulation, c) Baseline WAZ W-E acquisition simulation, d) Dual WAZ simulation, e) Double-wide WAZ simulation and e) Reflectivity model used for forward modeling. Note that the image of the deeper horizon is more continues and stronger amplitude on long offset stack then on any other stack.*

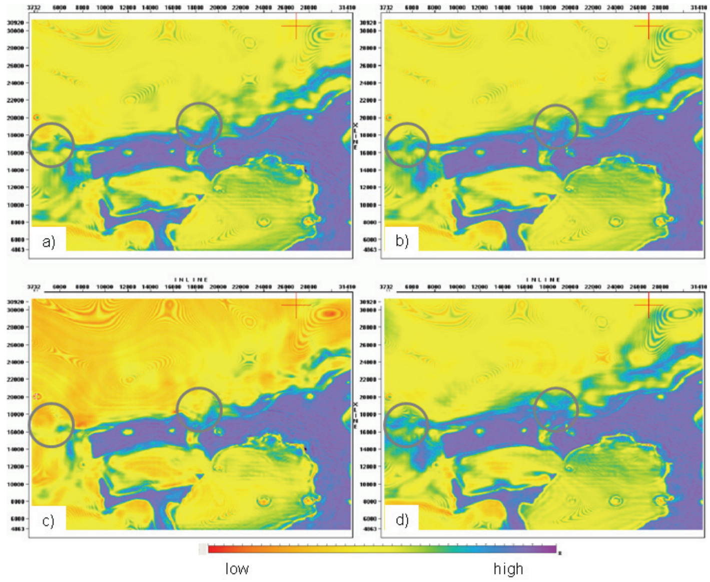

Figure 3: *Amplitude maps extracted along the shallow horizon from RTM illumination stacks. a) Baseline WAZ W-E acquisition simulation, b) Baseline WAZ N-S acquisition simulation, c) Long offset WAZ N-S acquisition simulation and d) Dual WAZ acquisition simulation.*

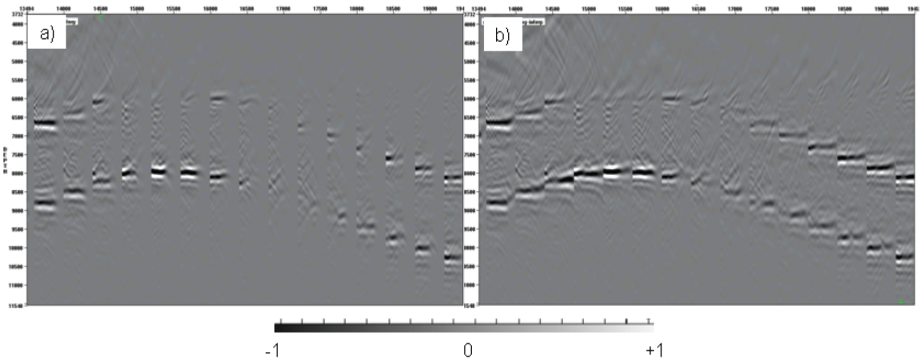

Figure 4: *RTM illumination 2D angle gathers. a) Baseline WAZ N-S acquisition simulation and b) Long offset WAZ N-S acquisition simulation. Note the angle extent of the events.*

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