Seismic Modeling as a tool for designing 3D seismic surveys

Analena Mileo Camara de Oliveira, Bernardo Radefeld Meireles, Diego Chagas Garcia and Roberto Dittz Chaves, all from PETROBRAS, Brazil

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Abstract

It is well known to the geophysical community that the use of seismic modeling is an important tool for survey design. However, operational restrictions and cost together with a tight time schedule for the design of 3D projects restricts the amount of different parameters and geometries that can be tested for a particular area. Ray tracing over 3D geologic models has been applied by the oil industry for some time to decide what parameters should be applied to a given survey. These parameters include, for example, sail line direction, streamer separation and length. These studies are also important for the development of new techniques, in which is possible to evaluate the contribution of long offsets and azimuths. In this work, the area under study is characterized by the presence of a thick allochthonous salt body, and our aim was to assess different survey parameters and geometries so the subsalt layers of interest can be well illuminated. Two software's running in different platforms were used to assess the appropriate survey design and it will be shown that they could effectively contribute for parameter evaluation.

Introduction

The purpose of a survey design is to find a set of parameters that will give the best result given certain operational restrictions. In conventional 3D projects, the designer is limited to a few choices concerning the main parameters to be used. Examples are the decision of the maximum offset and sail line direction. The former can be very important to seismic illumination studies involving deep objectives, and which can be accomplished using long enough streamers or techniques where more than one vessel are used. In this case it is possible to obtain offsets up to 16 km. The sail line direction is also important as this parameter can be set to fit the best trade off between geologic interest and operational cost.

The necessity to have a good illumination of geologic layers in sub-salt and pre-salt layers represents a big challenge to PETROBRAS and other companies. One way to deal with this question is to use geometries in which a large spectrum of azimuths is obtained. Particularly, the use of wide-azimuth (WAZ) and multi-azimuth (MAZ) are examples to deal with this kind of problem that involves obtaining a good image just bellow layers of high velocity. However, there is a high economic impact associated to these techniques, which is reflected not only by cost but also operational problems. In this scenario it is extremely important to assess the need either of the conventional or non-conventional 3D surveys.

The Model

The choice of an optimized design came after a construction of a 3D geologic model. The area under study contains a very complex geology characterized by allochthonous salt. Conventional seismic has shown limitations to image subsalt horizons where it is not possible to obtain a good continuity and resolution. **Figure 1** shows a seismic section of this geologic reality, the purple area represent the salt. The surfaces used in the model were obtained from a xyz file and converted to trimesh surfaces using the software GOCAD. One difficult step of the illumination study is to make sure the surface can be correctly load into the specific software, any problem or inconsistency in the model can jeopardize the quality of the study. Two velocity fields were used to build two alternative scenarios for geologic model. One was the velocity field used by the processors, varying both horizontally and vertically, and the other was a velocity cube defined manually with constant velocities within each layer or block. In **figure 2 and 3** it is possible to see sections of these two different velocities models.

Ray-trace Modeling

For the ray-trace methodology it was used two different commercial software's that has been widely used by the oil industry. The first is NORSAR running in a UNIX platform and the other is MESA loaded in WINDOWS. These two programs have different capabilities and purposes. In the UNIX platform the ray trace is done using wave fronts and a big volume of data. And it is also possible to use a velocity cube varying both vertically and horizontally. To reach a reasonable computational time we used a cluster with parallel computing capacity. In this work a cluster with 32 nodes were used. The other program is more commonly used to draw different geometries with exclusion zones and to do simple analysis as CMP fold calculation. However, this software also includes a package that contains ray-trace capabilities. The ray-trace methodology used in this case needs less computational resources and the velocity field can be set constant by block or layer. The velocity is build as a discrete set of cross-sections that are subsequently interpolated to obtain a continuous velocity field over the 3D area. The physical parameters for each layer of these discrete velocities were manually entered to represent the best possible geologic model. This program is the ideal solution for a tight time schedule modeling.

The main difference between these two programs is that the first one should be used when you need results where every little nuances of the geologic model are important and time is not a strong limitation for the survey design. The second solution is much more portable and you do not need powerful computational resources to get an answer, although the accuracy of the answer will be affected as you need to respect the trade-off between time machine and accuracy. In this work a comparison will be made between the results obtained by these two different tools, for at least one geometry.

Survey Parameters

The acquisition parameters used can be divided in three categories: i) two conventional 3Ds with streamers lengths of 5.7 and 8 km; ii) one long offset survey using two vessels, a source boat displaced 8 km from a cable boat towing 8 km streamers, in this case it is possible to obtain offsets of 16 km (**figure 4**); iii) a survey containing a broad range of azimuths, similar to wide-azimuth surveys, as it is possible to see in **figure 5**. Table 1 gives a set of parameters that illustrate what was used. Note that in this context long-offset means the use of two boats.

Parameter/Survey	Old	New	Long offset
Survey type	3D	3D	3D Long offset
Number of ships	1	1	2 (1 source sh.)
Source	2	2	4 (2 per ship)
Shot interval (m)	25	25	50 (per source)
Streamer length	5700 m	8000 m	8km (16 km max. offset)
Streamer number	6	8	8
Streamer separation	100 m	100 m	100 m
Group interval (m)	12.5	12.5	12.5
Record time (s)	8	8	8
Fold	57	80	120
Survey direction	E-W	E-W	E-W

Table1 – Survey parameters used for modeling, wide azimuth was not included here. Only the survey titled as old was simulated by the two software’s.

Illumination maps

The illumination results are displayed in maps or tridimensional graphics. NORSAR generates a hit-map indicating the number of rays that hits a chosen horizon, “hot” colors indicates more hits indicating that these areas have a better illumination. Areas represented by “cold” colors are less illuminated. MESA generates similar maps calibrated to the CRP fold (common reflection point), low or zero values represents survey parameters that are inadequate. **Figures 6 and 7** shows the illumination maps generated by both software’s, where the Old parameters were used. The horizon chosen for study was just bellow the allochtonous salt.

Comparing figures 6 and 7 it is possible to assess the differences between the results obtained by the two software’s. Looking at the figures it is clear that the details are different from one another; however the areas with poor coverage coincide. The map showed in **figure 7** is more uniform and some of the low coverage areas are in accordance with the results of figure 6. However it is possible to conclude that both maps indicates that the coverage is relatively poor and other geometries should be considered before a final decision about the parameters and geometry can be made.

The other designs designated as New, Long Offset and Wide Azimuth resulted in the figures 8, 9 and 10. These geometries were generated using only the UNIX application as we judged that all nuances of the geologic model would be of interest to assess the difference between the designs. From the results showed in these figures it is reasonable to say that designs using long offsets and a broader distribution of azimuths can be the only way to get a high data quality for geologies involving subsalts areas.

Conclusions

Modeling showed that a conventional seismic acquisition, even with an offset of 8 km, did not improve the illumination quality of deep objectives located bellow thick layers of evaporites. The extra long offsets, like the dual-boat modeled, can fill holes that are not covered with usual multi-streamer 3D seismic. It is also clear that the wide azimuth design could enhance even more the coverage quality of the long and conventional surveys. However, the trade-off between data quality and cost it’s an issue to be evaluated in the case of wide-azimuths techniques.

Illumination mapping by 3D ray-tracing is an important tool to optimize the choice of a possible set of survey parameters. As per the results of this work the WAZ acquisition design provided the best overall illumination albeit portions of the target weren’t so improved. However other illumination studies made by us pointed that in many cases simply larger offsets can illuminate hidden targets without the need of expensive WAZ techniques. To decide between conventional and “exotic” geometries a 3D ray-trace modeling is a very important tool to take the right decision, otherwise it would be a shot in the dark.

Concerning the choice of application for seismic modeling, it is clear that more refined algorithms can give better images and more complete answers, but the computational cost is very high, where a cluster is needed to give a final result in reasonable time. However, less sophisticated algorithms can perform faster, although less accurate and generating coarser images. Also these programs are good for the generation of different geometries that can be exported to more complex programs that will perform a more realistic ray-tracing.

Seismic modeling can expend a lot of time to give the desired answers, and become necessary to specialize people in the tools they will need. The most important step is to build a geologic model that describes with good accuracy the reality. To sum up, modeling requires a multidisciplinary team including both geophysicists and geologists, so the model can truly represent the problem at hand, and also to guarantee that different formats could be shared between different software's and run smooth.

Examples

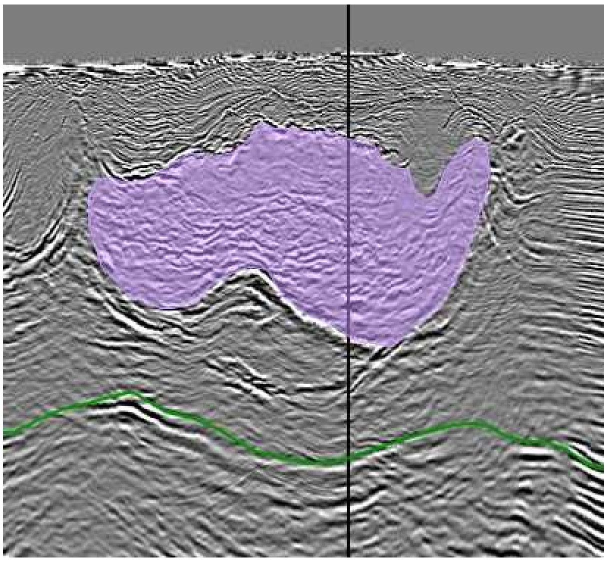

Figure 1 – 2D seismic section showing allochtonous salt and a possible objective just bellow the evaporites.

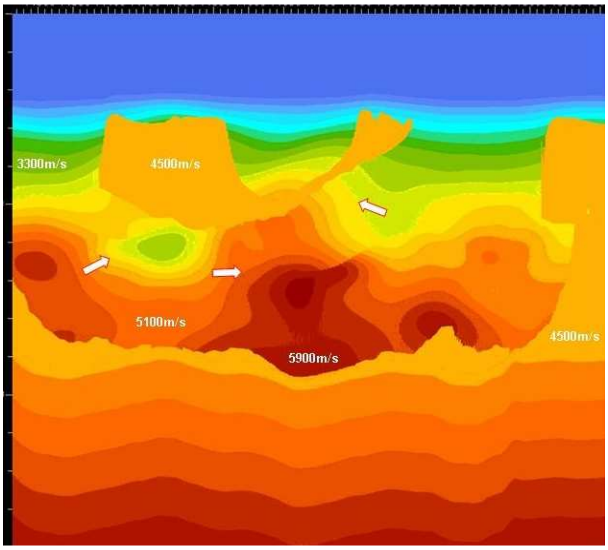

Figure 2 – Cross-section of velocity cube varying horizontally and vertically.

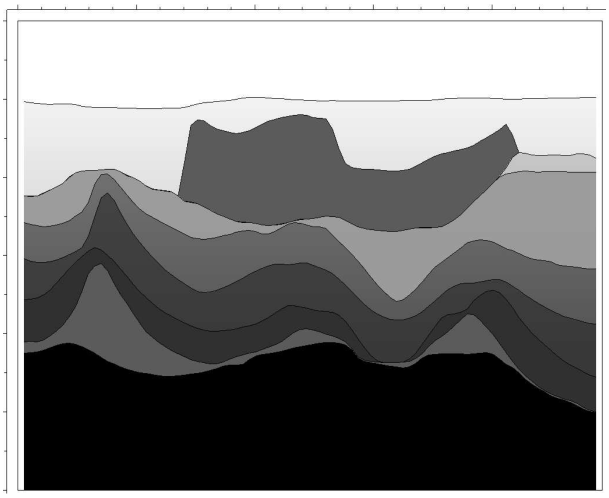

Figure 3 – Cross section of a velocity field showing velocities fixed by block or layer.

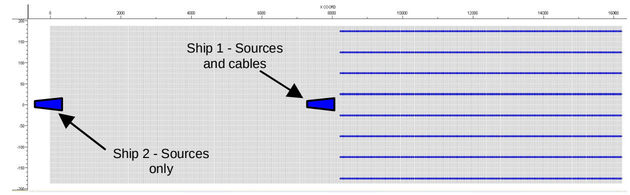

Figure 4- Long offset seismic survey with 2 boats (16 km).

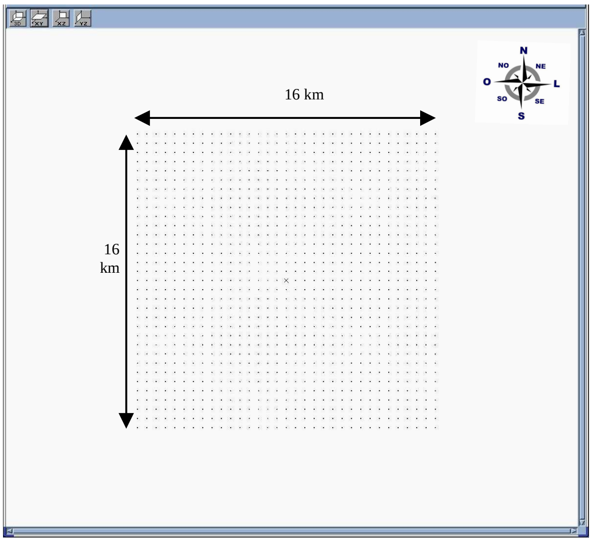

Figure 5 – Wide azimuth survey geometry.

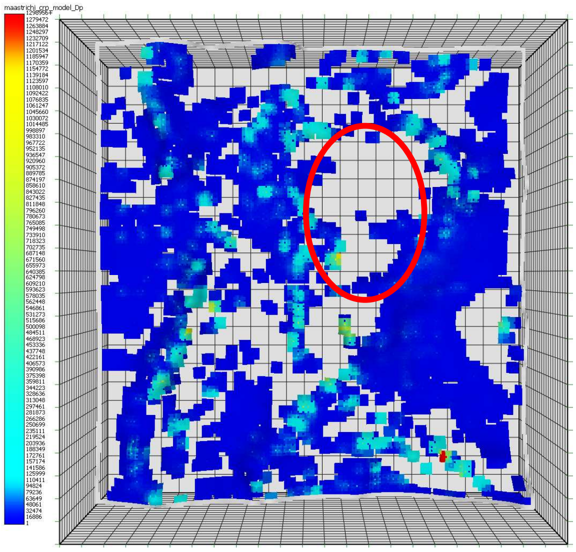

Figure 6 – CRP Fold Map resulted from MESA, which corresponds to the objective horizon just below the evaporites. Blank areas correspond to zero fold.

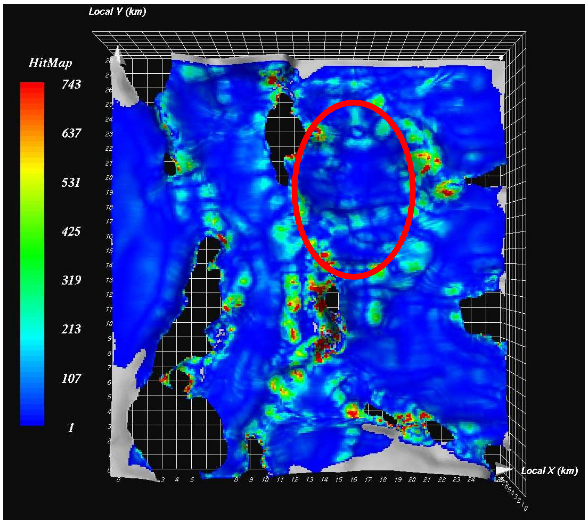

Figure 7 – Hit-map corresponding to the same horizon and parameters used to obtained figure 6. This result and others from figure 8 to 10 were achieved with NORSAR. The blue indicates a deficiency in illumination and the gray areas to no coverage at all.

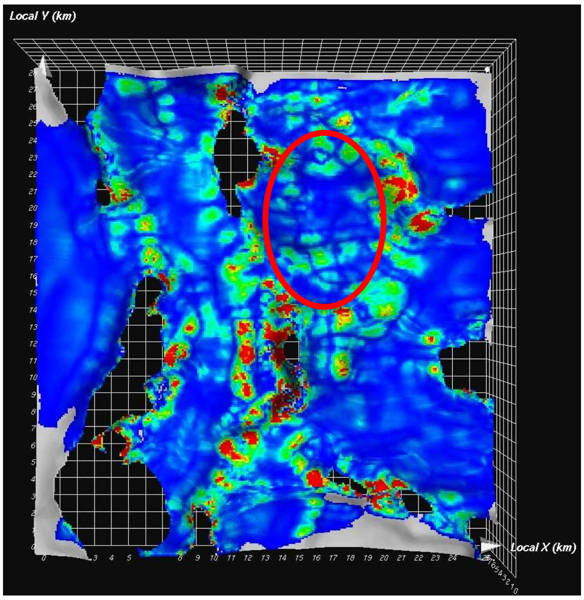

Figure 8 - Hit – map using the same horizon from the previous geometries and referring to the parameter titled as New, which differs from the Old parameters just by streamer length (8 km). Looking at the area inside the ellipse (all figures) it is possible to see the coverage was a little bit better than the previous ones.

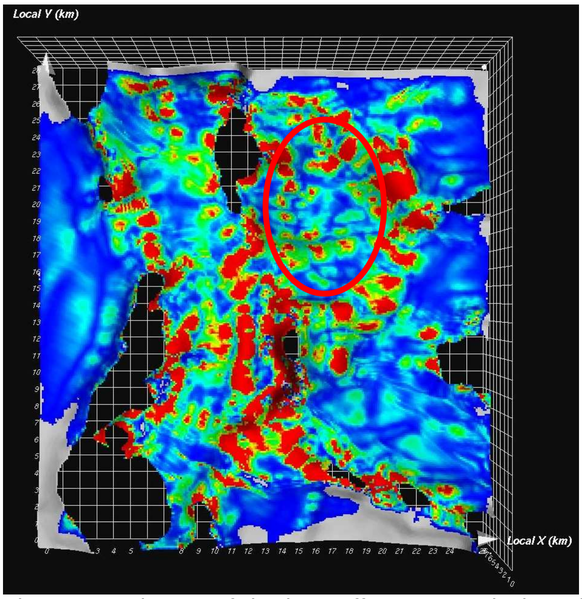

Figure 9 – Hit-map of the long offset survey design with offsets up to 16 km. There is an overall increase of coverage and the area concealed by the ellipse had a significant increase in number of hits.

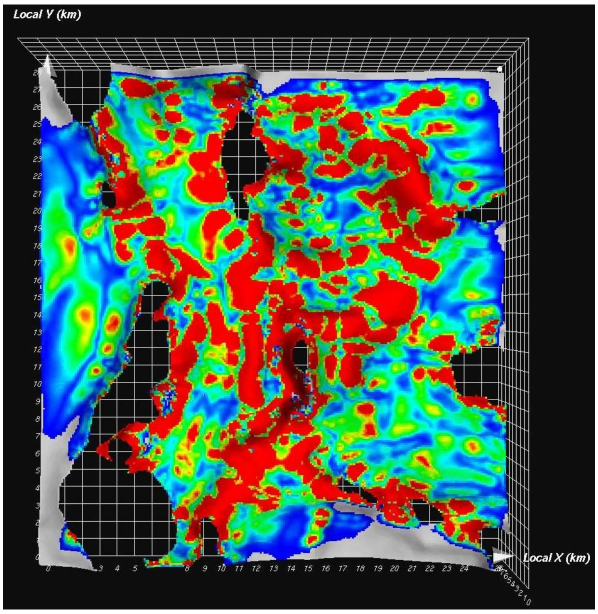

Figure 10 – The Best result is obtained with a wide-azimuth geometry (figure 5). In this case the survey can use multiple vessels.

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