APPLICATION OF MODELLING FOR 2D SEISMIC EVALUATION DESIGN WITHIN TRUST BELT OF NORTHERN CUBA

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ABSTRACT

The Area of study is one of the perspective areas, arranged in the north-east of a province Matanzas in Republic of Cuba. The territory is within fold-and-trust belt of Northern Cuba. This is a region of complicated geological structure, which scatters the seismic energy. Near surface high impedance carbonates and volcanic units screen out the seismic energy from penetrating into the surface. Seismic data acquired within this area are characterized by poor seismic image. Improving illumination of target horizons is challenge problem at the current stage of exploration. Definition optimum parameters of seismic data acquisition design is one of the way for improving seismic imaging within the Area of study. For this purpose a geological model was created along the seismic line crossing the Area of study and synthetic seismograms were computed. The synthetic seismograms were processed. Time and depth migrations before stack were applied. Conventional velocity analysis did not allow to recover velocity model with accuracy requirement. It is shown the importance of building accurate velocity model for stack and migration for improving seismic image in the region of complicated geological settings like the fold-and-trust belt of Northern Cuba.
It has been proven, that long offset acquisition and travel-time tomography (reflections/refractions) are the successful strategy of exploration within the fold-and-trust belt (Dell' Aversana et al. 2000, Dell' Aversana et al. 2001). The tomographic models allow to reconstruct the velocity model with accuracy requirement. Large offsets (up to 20 km), 12.5 m distance between three component geophones are recommended for shooting test line. An iterative and interactive tomographic inversion of refraction/reflection arrivals is recommended to be applied for the processing of acquired seismic data for reconstruction an accurate velocity/interface model and improving seismic image.

INTRODUCTION

The JSC "ZARUBEZHNEFT" plans to develop activities in partnership with the Cuban state oil company "Cubapetroleo" (CUPET) in conduction geological and prospecting operations. The company considers a number of perspective license Blocks in territory of Cuba for exploration and development of oil-fields with use of experience of the company and modern process engineering of prospecting and development. The Area of study is one of the perspective areas, arranged in the north-east of a province Matanzas. Oil field Majaguillar is adjoining in the west-north of the Area of study. The produced territory is within the fold-and-trust belt of Northern Cuba.

This Area, adjoining land and sea shelf areas are covered by network of seismic lines. In phase since 1985 on 2007 around 1200 km seismic lines have been completed by "CUPET", «TOTAL», «CNW», «OFD», «PEBERCO» and «SHERRITT». The seismic stack sections received in this territory in different years are characterized by a low S/N ratio, poor seismic imaging despite of upgrading method of acquisition, application of high-end receiver system and recording equipment. Seismic interpretation in fold-and-thrust belts is typically difficult and strongly model-driven because of

problems in imaging. Adjusting of a design of seismic acquisition system and processing are important ways for improving seismic imaging for interpretation.

METHODS

For the purpose of Seismic Evaluation Design (SED) a geological model was created along the sub-meridional seismic line crossing some wells in the Area of studies. Synthetic seismograms were computed and processed. The synthetic line was named Test line 1.

The following stages were performed:

1. Reprocessing of historical seismic lines and borehole data.
2. Interpretation of all available seismic, borehole and geological data.
3. Generation of an a priori depth-velocity model. This model probably does not adequately coincide with the actual subsurface medium because the amount of available geological and geophysical data is not enough. Some crucial velocity variations, that may impact on obtaining a seismic image in the area under investigation were included.
4. Computing synthetic seismograms for depth-velocity model.
5. Processing synthetic data, analyzing the possibility of getting an adequate-quality seismic image with various parameters of field acquisition system.
6. Identification of the problem, making a conclusion.

The information of two types was used for two-dimensional an Earth model description: high-accuracy information from exploration wells and less accurate, but widely distributed seismic information in the inter-well space. The first information type makes it possible to obtain reliable estimations of physical properties of the section in individual points, i.e. to create one-dimensional models. The second information type is used for interpolation and infill two-dimensional model.

The two-dimensional an Earth model along seismic line was generated on the basis of well data and data of adjacent geological sections across the line. Four wells were used: San Anton 1, Angelina 100, Majaguillar 1. Majaguillar Este 1. The results of velocity analysis of seismic data received at reprocessing did not allow to get reliable kinematic model. The final velocity model was constructed by the method of averaging of migration velocities and constructing a maximally simplified homogeneous-layered geological model. Such model is presented as a series of thin homogeneous layers (Fig.1). It was assumed that acoustic heterogeneity within a layer is insignificant as compared to acoustic heterogeneity of adjoining layers associated with changes in matrix lithology or type of saturation.

For adjusting the computer program the second model was taken from data of previous investigations in the adjacent Varadero area on the basis of a seismic-geological section. The synthetic profile was name Test line 2. Length of this simulated particular seismic line was approximately 12 km. The depth-velocity model is shown in Figure 2. Synthetic seismograms were computed and processed. This model is an extremely complex case for seismic prospecting, because velocities have a huge lateral variability, the central part of the section is complicated by steeply dipping short-extent interfaces characterized by a very large velocity contrast.

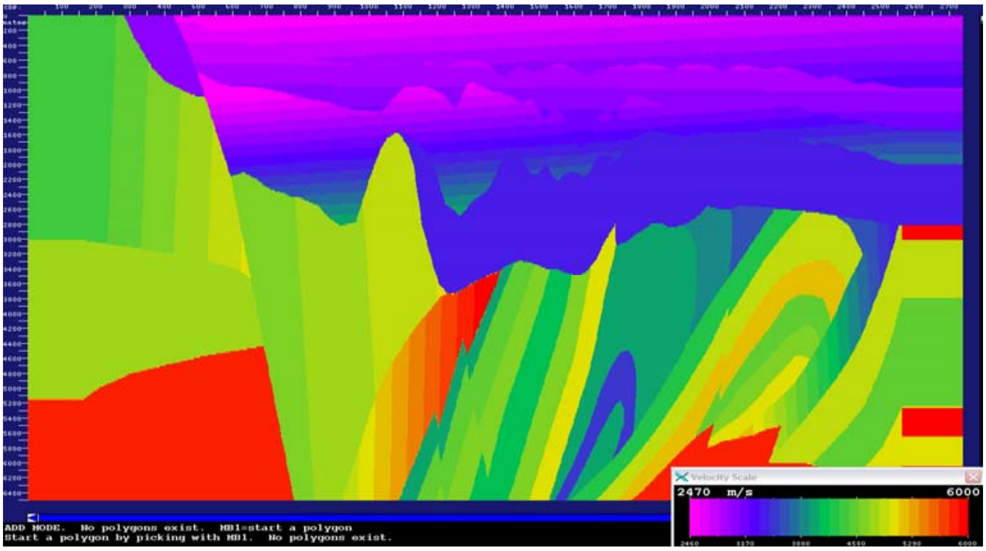

Figura 1,- The predicted depth-velocity model along Test line 1 (Area of study)

Computing of synthetic SP gathers was performed in the acoustic model of earth using the finite difference method (Mooney,1983). This method can be applied to geological models of considerable complexity including models with two dimensional velocity variations. Modeling did not include simulation of noise signals registered at the field seismic recordings (surface wave, other coherent noise generated in the upper part of the section, random noise). The numerical experiment has been performed for getting an answer to the following questions:

- Is it possible the adequate recovery of seismic image of the subsurface medium with an unknown velocity model and with restoration of velocity model through solving the travel-time problem?
- What is the maximum possible Receiver Station (RS) and Shot Point (SP) interval for adequate recovery of seismic image of subsurface medium in case known depth-velocity mode?

Following has been performed:

1. Computation of synthetic seismograms with SP and RS interval 10 m. Maximum offset is 20 000 m.
2. Processing of synthetic seismograms.
3. Analysis of results, conclusions.

Processing of SP gathers has involved generation of CMP stacked section, migration of stacked section, pre-stack depth migration (PSDM). At first, PSDM procedures were performed with the known velocity model. The depth-velocity model was recomputed to V^{RMS}. Stacking was made using the obtained V^{RMS}. Then, post-stack depth migration, and pre-stack depth migration were performed. Steps were made for three options of SP and RS intervals: 10 m, 20 m and 50 m. Comparison of obtained migrated images was used for getting the answer about sufficient images with a known velocity model. This is idealized case in absence of noises and with a known depth-velocity model. The PSDM stack with 50 m interval for SP and RS and accurate velocity model is shown on Figure 3.

Further, velocity analysis of V^{RMS} was performed using conventional processing tools. Some attempts were made to recover the velocity model through solving the travel-time problem. For this purpose the same method was used, which had been used in processing of the real field data. The restored depth-velocity model was used for PSDM. The PSDM stack with 50 m interval for SP and RS and recovered

velocity model is shown on Figure 4. The results of the same processing sequence for the second model from Varadero are shown on Figure 5 and Figure 6.

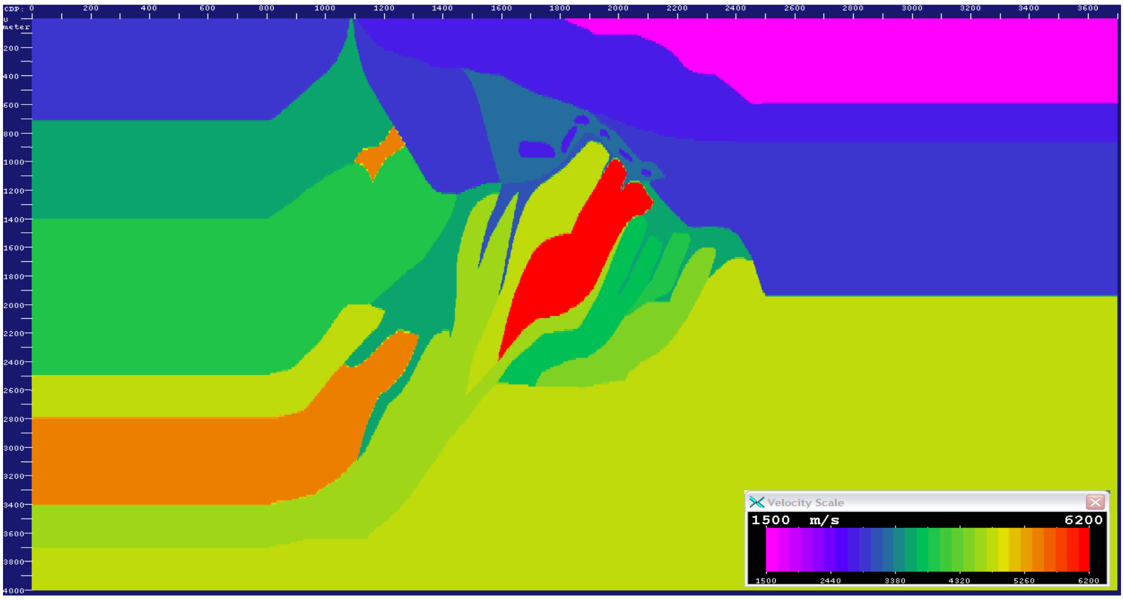

Figura 2.- The depth-velocity model along the Test line 2 (Zone Varadero)

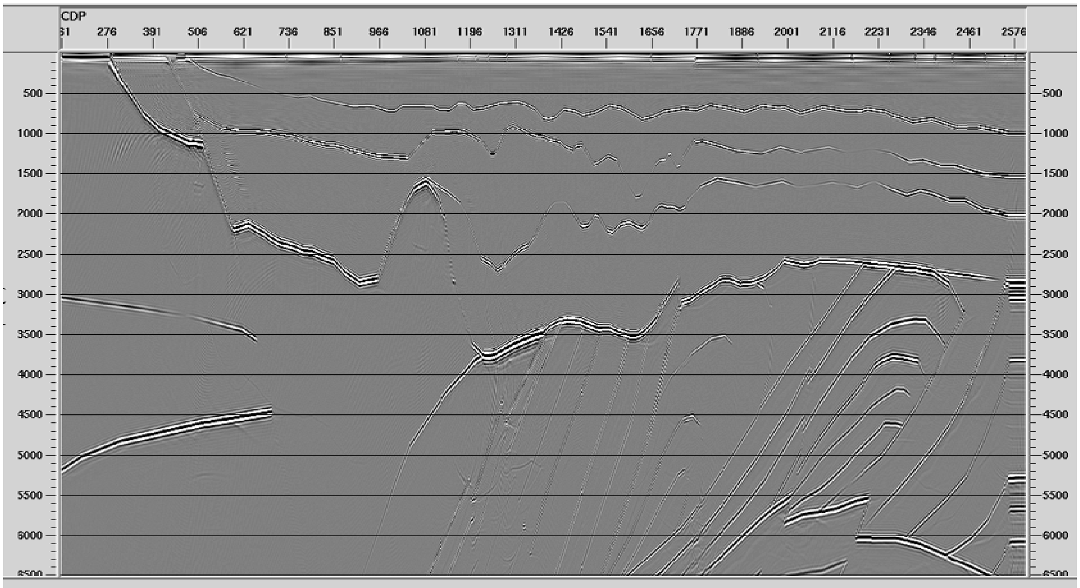

Figura 3.- PSDM stack with the accurate depth-velocity model (Test line 1).

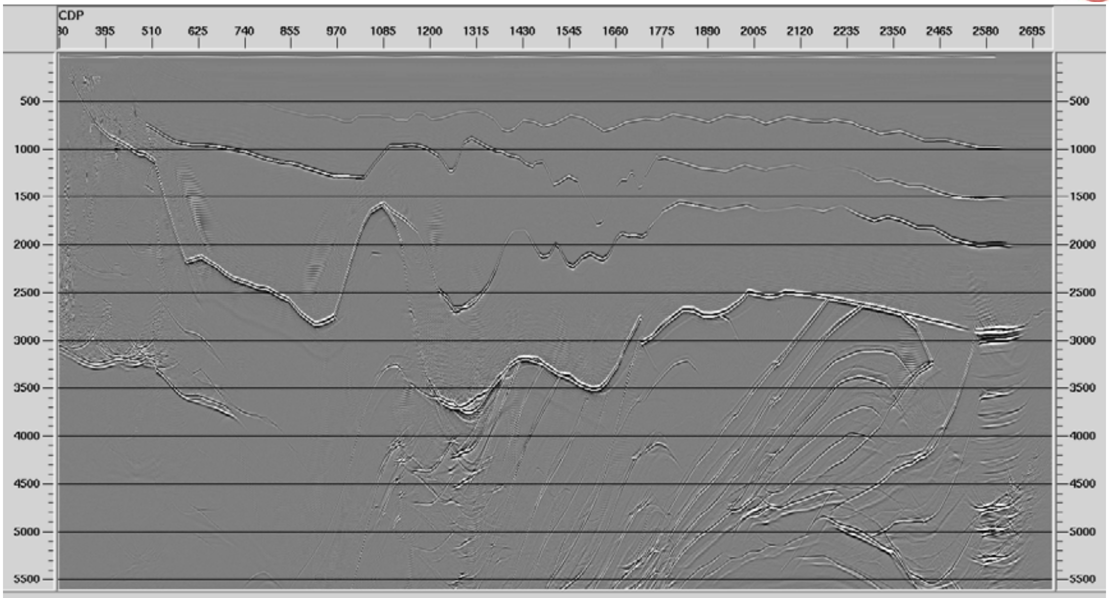

Fig. 4.- PSDM stack with the recovered depth-velocity model (Test line 1).

RESULTS AND DISCUSSION

Figure 3 and Figure 4 show results of PSDM with using the accurate and recovered velocity models for Test line 1. Pre-stack migrated image has no appreciable artefacts. Variations in amplitude of reflections from upper horizons reflect variations in acoustic contrast of the boundary in the model. Presented images in this section were obtained with 50 m interval for SP and RS. Results of processing synthetic seismograms with spacing interval 10 m and 20 m has insignificant visible differences in comparing to 50 m interval and they are not presented.

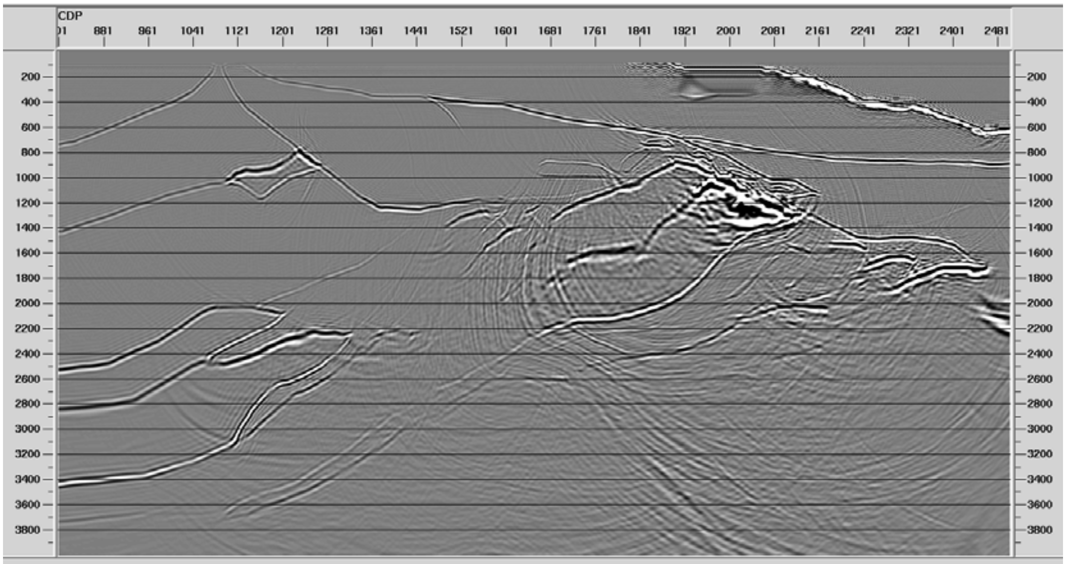

Fig. 5.- PSDM stack with the accurate depth-velocity model (Test line 2).

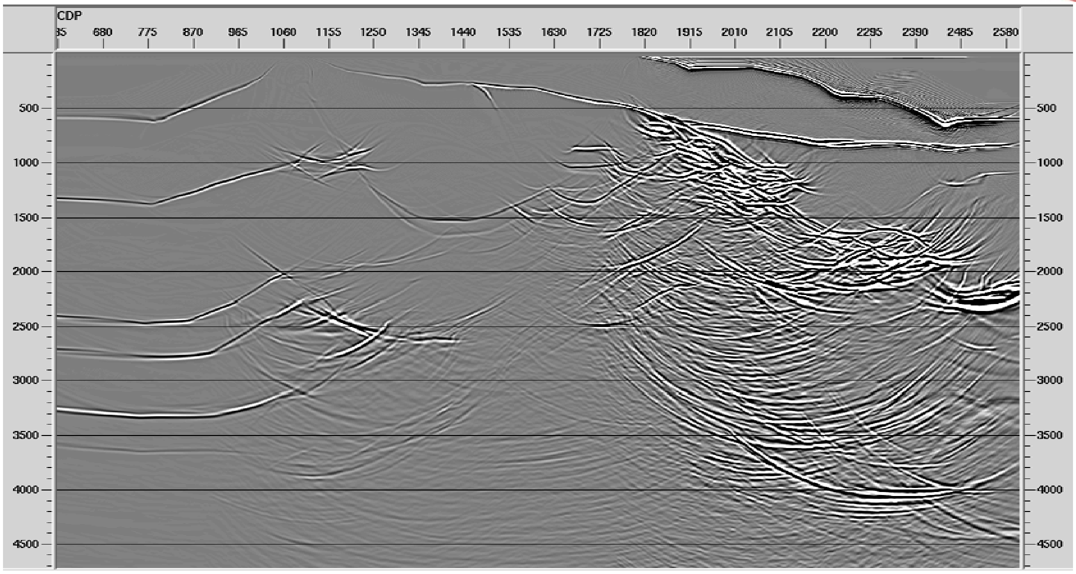

Fig. 6.- PSDM stack with the recovered depth-velocity model (Test line 2).

The numerical experiment performed on this model does not reproduce the problems with seismic images observed in the field data. The reason for this might be: either used a priori depth-velocity model does not reflect real changes of velocities in the section or quality of seismic image obtained from real data is catastrophically affected by some factors that were not included in the numerical experiment. Such factors may be as follows:

1. Three-dimensional effects resulting in the fact that reflected waves observed in real data contain a complex interference pattern of various out-of-the-plane reflections.
2. Complex structure of the upper part of the section has made significant absorption of useful reflections in the upper part of the section.
3. Masking of real data with a strong coherent and random noises.

Analysis of field seismic data of previous years provides evidence against hypothesis 3. While field data in fact are considerably complicated with coherent and random noises, it is quite possible to identify reflected waves with high probability. Hypothesis 2 looks unlikely too, because horizons in the middle part of the section are well identifiable on seismic lines of previous years. The velocity anomalies in the upper part of the section could be found during reprocessing, but evidence of such situation were not met.

Hypothesis 1 is corroborated by analysis of perpendicular lines in the area under investigation, which does not make it possible to detect any definitive direction of dip of reflecting planes. A possibility can be also considered that the target horizons contain no extended reflecting features and look like a set of chaotic local contrasting bodies. In such case, an image obtained as a result of field seismic surveys will also correspond to the observed pattern.

The results of reprocessing and reinterpretation of seismic data of previous years, as well as two conducted numerical experiments allow to make following conclusions:

- extremely complex variation of acoustic properties of medium in the middle part of the section and three-dimensional structure of subsurface medium are resulted as impossibility to obtain an adequate seismic image from 2D seismic data;

- the zone of target reflections contains dip reflecting planes and is characterized by chaotic variation of acoustic properties.

As a result of the undertaken research effort, it is possible to assume that the reason of bad seismic imaging is not in poor quality of 2D field seismic observations conducted previously.

The PSDM stack for synthetic seismograms with accurate velocity model (Figure 5) has adequate seismic imaging of the two dimensional geological model. The effort to recover properly velocity model using conventional velocity analysis was unsuccessful in this particular case (Figure 6).

Nevertheless, it is possible to make some recommendations for performing experimental 2D surveys, which will make it possible to obtain a better signal-to-noise ratio and provide additional information for further studies and possibly obtain an interpretable seismic image.

CONCLUSIONS

On the basis of the results of modelling, the following conclusions can be formulated:

- It is possible to improve a seismic image in the region of complicated geological settings like the fold-and-trust belt of Northern Cuba using an accurate velocity model.
- The SP and RS interval equal 50 m and large offset up to 10000 m are sufficient for the adequate recovery of seismic image of subsurface medium in case of known depth-velocity model. Nevertheless, RS spacing equal 12.5 m will provide more effectively elimination of noise on real data.
- The effective depth-velocity model obtained as the result of processing synthetic seismograms does not provide acceptable accuracy for depth migration. Recovery of accurate velocity model for stack and migration is the foreground task for development of seismic data acquisition technique and processing sequence.
- The long offset acquisition and travel-time tomography (reflections/refractions) are the proved successful strategy of exploration within the fold-and-trust belt. The tomographic models allow to reconstruct the velocity model with accuracy requirement.
- It is recommended to complete experimental line in the Trust belt of Northern Cuba with "Global Offset" seismic (up to 10000 m offset) using a single three component geophones with 12.5 m interval between receiver stations. An iterative and interactive tomographic inversion of refraction/reflection arrivals should be applied for the processing of acquired seismic data and reconstruction an accurate velocity/interface model.

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