APPLICATION OF FULL-WAVE FORWARD MODELING FOR SEISMIC EXPLORATION FEASIBILITY STUDIES

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Summary (All headings should be Arial 12pt bold)

This article provides a technique to use full-wave forward modeling to validate seismic survey designs as well as to project a potential seismic data processing flow based on the obtained modeling results. Some examples on the use of this technique are presented for different seismic-geological conditions modeled with the full wave forward modeling package Tesseral.

Method

Seismic survey geometries, their configuration, parameters, receiver and source line placement in relation to the target object, play a very decisive role in the exploration of hydrocarbon deposits or exploration of new promising oil and gas areas.

Full-wave seismic modeling, the theoretical foundations of which are considered in [1], makes it possible to obtain seismic data that are almost identical to those that will be observed during field seismic surveys when using the same geometry as in modeling. Given sufficient a priori information about the morphology of the shallow geological section, the compressional and shear waves propagation velocities, as well as the rocks density, synthetic seismograms obtained by full-wave modeling will contain all types of useful waves and interference waves (reflected, refracted, diffracted, converted, multiple, surface, etc.), which can be expected during real field observations.This makes it possible to make a case in advance not only for the survey design, but also for an effective sequence of data processing procedures data to identify the target reflections among the background interference waves and, thus, successfully solve the geological task in a more efficient and timely manner.

Full-wave seismic modeling has proven itself in seismic survey design, in particular, when prospecting for oil and gas deposits in stock zones [2], when modeling the effect of mining on the seismic wave field [3], and when solving problems of engineering seismic exploration [4] , etc., in recent years, it has also been increasingly used to substantiate survey designs in complex seismic geological conditions.

In this article, we use full-wave seismic modeling for the justification and planning of seismic survey designs in various seismic geological conditions, in particular, the Dnieper-Donetsk basin and the Cis-Carpathian trough. Tesseral 2-D software package (Calgary, Canada) was used for the full-wave modeling and processing of synthetic seismograms.

Full Wave Modelling Technique

Preliminary full-wave modeling of the seismic data for a specific object of study allows the contractor for data acquisition, processing and interpretation to convincingly show the customer that the geological task can be successfully solved using the proposed survey design and the sequence of processing procedures selected as a result of testing on synthetic data. In some cases, when the area under study has a fairly simple tectonic structure, it is sufficient to use only post-stack time migration to obtain the final data processing products. Pre-stack time migration may be necessary for objects with a more complex structure. Finally, it may be necessary to use pre-stack depth migration for complex structures with steeply deeping reflecting boundaries and strong lateral velocity changes. Thus, full-wave modeling allows, prior to the start of the field work, to justify to the customer not only the data acquisition methodology, but also an appropriate seismic processing flow for the observed data, and, thus, to make an estimate in advance of the total cost of work, taking into account the complexity of the object under study.

The justification of a given survey design for the study of a specific exploration area or oil and gas field can be carried out in the Tesseral package [5] in the following order:

1- Depth-velocity model – it can be created in several ways:
   a. From a geological section, for example: "Atlas of oil and gas fields of Ukraine" [6];
   b. From an existing geo-seismic section;
   c. From a migrated seismic section in depth scale;
   d. From logging data (acoustic and density logs);
   e. From VSP data with stratigraphic column.
2- Survey Design parameters - are selected experimentally:
   a. Receiver and Source distance;
   b. Length and type of the receiver spread (Single-ended, split, Static, etc.);
   c. Placement of the receiving profile relative to the target structures;
   d. Signal acquisition parameters (Sample rate, record length);
   e. Geophone grouping parameters
3- Select Modelling Parameters:
   a. Type of wave equation (scalar, acoustic, elastic, elastic anisotropic (anisotropy parameters required), viscoelastic (Quality factor for individual layers required).
   b. Type of source;
   c. Signal type (single, symmetrical, double, Ricker pulse, Pusiriev pulse or user defined);
   d. Maximum signal frequency;
   e. Wave field snapshots - visualization Parameters;
   f. Multiple waves - with/without mode;
   g. SV waves source;
   h. Set up to three fracture orientation systems (fracture information required);
   i. Set the Matrix and fluid parameters and the porosity coefficient (reservoir properties required)
4- Generate synthetic data.
5- The depth velocity model is transformed into a velocity distribution grid.

6- The velocity grid is transformed into a set of V(t0) curves with a given step.
7- Generate a CDP time section.
8- Perform post-stack time migration on the CDP time section.
9- Perform pre-stack time migration on the synthetic seismograms.
10- Perform pre-stack depth migration on the synthetic seismograms.
11- The results of the pre-stack depth migration are transformed into a depth scale.

The obtained results are analyzed at each stage of the processing data. The acquisition (item 2) and the modeling (item 3) parameters can be changed if required. After that, the generation of synthetic seismograms (item 4) and their data processing (item 5-11) are repeated until a satisfactory result is obtained. In some cases, when unsatisfactory results are obtained after modelling and processing of the synthetic data, it may be necessary to change the model itself, therefore, the modelling process should be repeated from the very beginning (paragraph 1).

Let us consider some examples of using full-wave modeling to substantiate a survey design, as well as a data processing flow for various seismic geological conditions.

Results

Survey design for foothills

Due to the complex surface condition in the study area (foothill topography with elevation changes of 400 m., forests, mature hydrographic system) doubts naturally arose about the possibility of obtaining useful seismic data

Based on the foregoing, a preliminary justification of the acquisition parameters was carried out. The following parameters were chosen for modeling:

- Receiver line length: 7200m
- Receiver distance: 35m, source distance:70m
- Total Amount of sources along the profile: 103
- Type of receiving spread: static
- Maximum signal frequency: 45Hz
- Record length: 5sec, sample rate: 2ms

A fixed receiver spread (the array of active receivers does not move along the receiving line) was used based on the availability of many years of world experience in seismic surveys for similar conditions, in particular, in the foothills of the Canadian Rocky Mountains (Rocky Mountain Foothills) [7], as well as way to increase the recording fold.

Fig. 1 shows an oil field model, and in fig. 2 – shows the CDP time section obtained as a result of processing the corresponding synthetic seismograms, the velocity field was obtained directly from the model. As can be seen from Figure 2, even with “ideal” velocity data, the resulting CDP time section has little resemblance with the original model. Obviously, it is rather difficult to achieve even such a result when performing the velocity analysis on CDP gathers during processing.

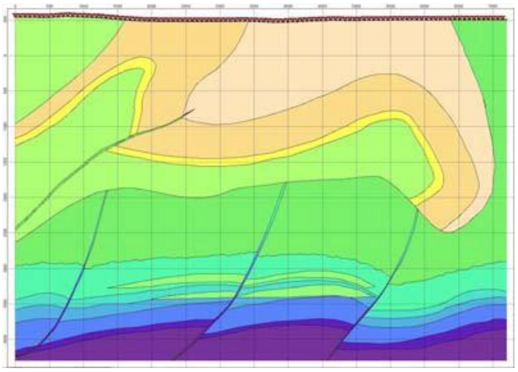

Fig. 1 shows an oil field model

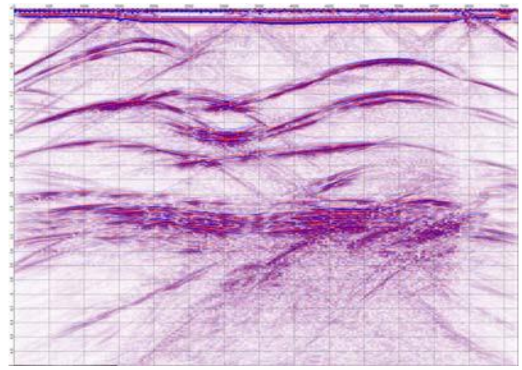

Fig. 2 – shows the CDP time

Figures 3 and 4 show the results of time and depth pre-stack migration in depth scale overlaid on the model.

It should be noted that under the conditions of fractured, steeply dipping reflectors, the depth pre-stack migration (Fig. 4) has a very tangible advantage over the time migration (Fig. 3), especially for the deep horizons near the deposits (depth 3100-3500 m).

Naturally, the lateral parts of the structure remained “unilluminated” due to the limited size of the survey design, especially since these parts of the structure are not of search interest.

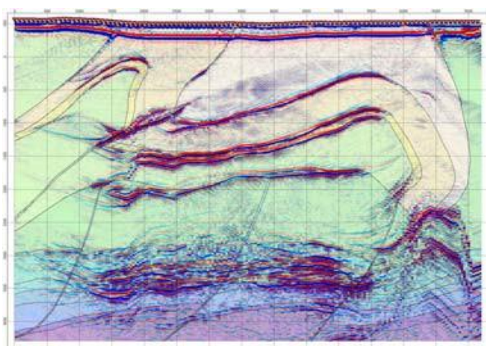

Fig. 3 Pre-stack Time Migration Result

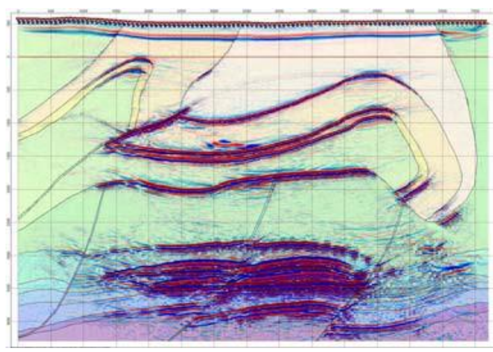

Fig. 4 Pre-stack Depth Migration Result

We can draw the following conclusion after analyzing the modeling results:

1- The proposed acquisition survey makes it possible, in general, to solve the structural problem.
2- To achieve an acceptable result, the data processing flow should include pre-stack depth migration.

Seismic Survey Design for steeply deeping reflectors conditions

For this object, the task was set to build a model with steep layers together with tectonic faults, in particular, a deep thrust (fig. 5). It was clear in advance that the limited size of the survey would not allow obtaining a satisfactory image of the steep reflective boundaries at the left side of the study area. To verify this, a modeling with the initial model was performed. The modeling results were demonstrated to the customer, after which it was agreed to expand the area by 2 km to the left and increase the depth of the model.

The following acquisition parameters were used for modeling:

- Receiver line length 4200 m (preliminary), 6200 m. (final) taking into account the expansion;
- Receiver spread type – static;
- Receiver distance: 20m, source distance:40m
- Total Amount of sources along the profile: 103
- Maximum signal frequency: 35Hz
- Record length: 4sec, sample rate: 2ms

Fig. 6 shows a snapshot of the elastic wave field propagation overlaying the model.

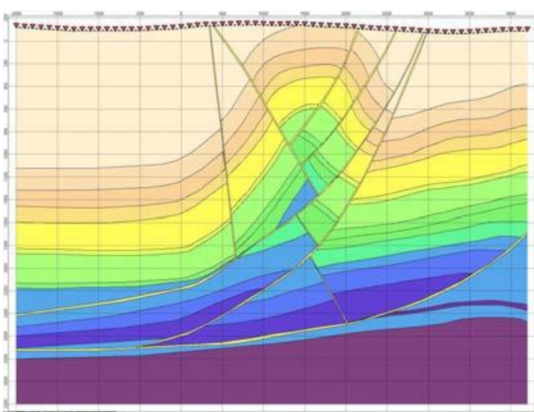

Fig. 5 Extended depth velocity model of A complex structure

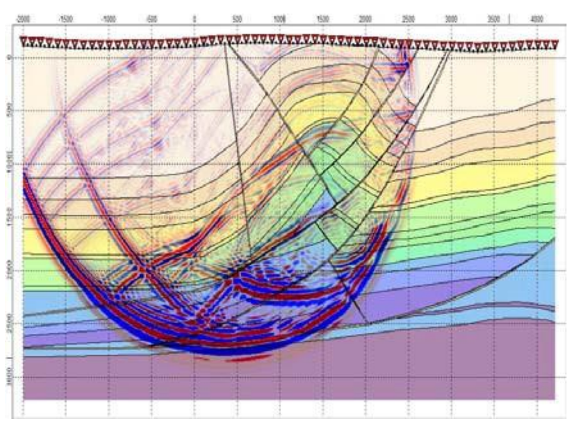

Fig. 6 Snapshot of the elastic wave field propagation overlaying the model.

Fig. 7 shows one of the synthetic seismograms obtained with the above acquisition and modeling parameters, as well as the time CDP section, from which it can be inferred about the complexity of the structure under study.

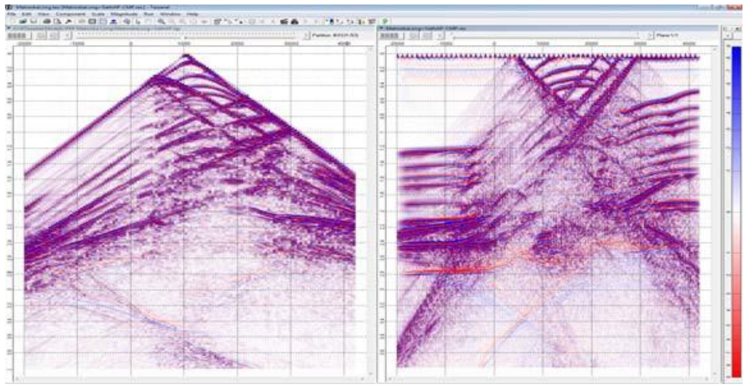

Fig. 7 A synthetic seismogram (left) and the CDP time section(right)

Fig. 8 shows the results of pre-stack depth migration in depth scale before (left) and after (right) an area expansion of 2 km to the left.

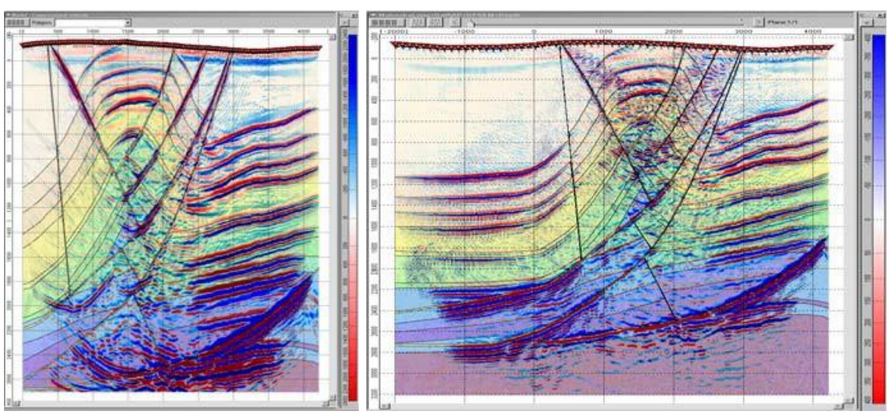

Fig. 8 Results of pre-stack depth migration in depth scale before and after a 2km expansion to the left and an increased in depth

Based on the obtained modeling results, we can draw conclusions that are similar in principle to the previous model.

Seismic Survey Design for Salt Dome tectonics

The object of research here is a pre-salt overhangs (the so-called “cut-off” at the level of reflecting horizons IVv and IVg) in the Lower Permian deposits

Due to the limited size of the research area, the question naturally arose about the possibility of “illumination” of the target reflector using the proposed acquisition design. The following parameters were used for modeling:

- Receiver line length 8800 m;
- Receiver spread type – static;
- Receiver distance: 50m, source distance:100m
- Total Amount of sources along the profile: 88
- Maximum signal frequency: 30Hz
- Record length: 6sec, sample rate: 2ms

Here, again, the static receiver spread was chosen due to the small size of the study area and in order to increase the recording fold

Fig. 9 shows a simplified model of a salt stock flank and the result of pre-stack depth migration of the corresponding synthetic seismograms overlayed on the model. As it can be seen, by using this survey design, the Lower Permian “cut-off” is displayed quite reliably in the wave field.

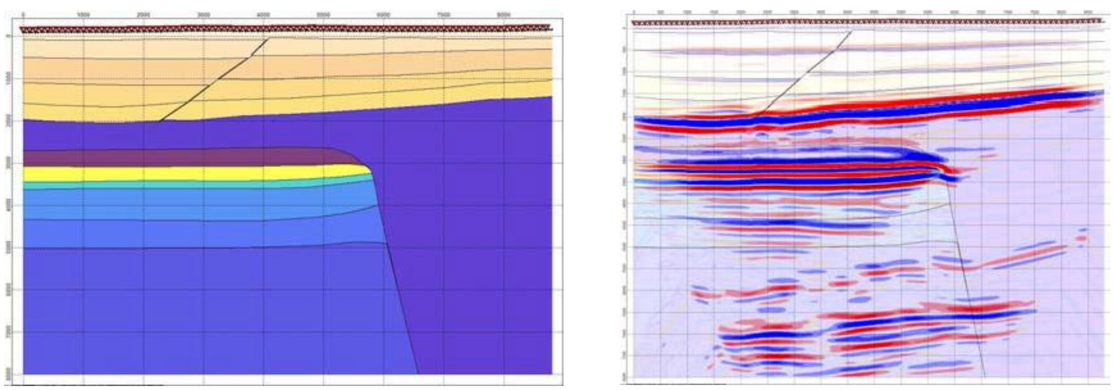

Fig. 9 Salt stock flank model and the results of pre-stack depth migration. Depth

Seismic Survey Design in simple structures

For this object, the task included detailing the geological structure of the area, tracing faults and delineating the lens-shaped gas deposit (Fig. 10 about 1600m deep). The physical parameters of the reservoir were based on a 10% porosity. The following parameters were used in the acquisition geometry and data modeling:

- Receiver line length 6000 m;
- Receiver spread type – split spread;
- Receiver distance: 30m, source distance:60m
- Total Amount of sources along the profile: 88
- Maximum signal frequency: 30Hz
- Record length: 5sec, sample rate: 2ms

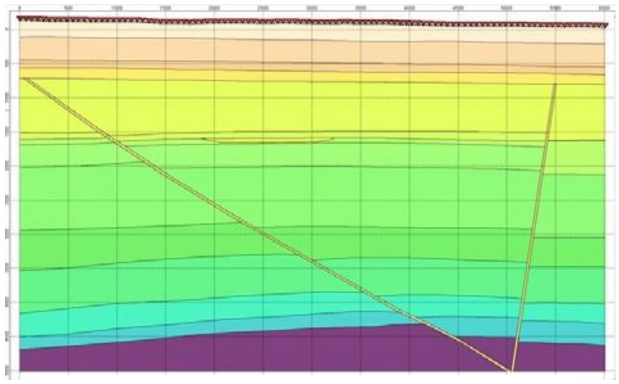

Fig. 10 Simple geological model.

Fig. 11 shows a CDP time section (left) and the corresponding post-stack migration result (right). It can be seen that the target object (central part of the section around 1400 ms.) looks quite contrasting in the form of a “bright spot”. The plane of the gently sloping tectonic fault is clearly traced in both figures. The stronger disruptor manifest itself only in the form of a small but quite clear discontinuities of the events.

The results of time and depth pre-stack migrations practically do not provide an increase in information, so their implementation in this area can be managed based on cost savings and reduction of data processing time. Based on the results, we can conclude that the geological task can be successfully completed using even a short data processing flow.

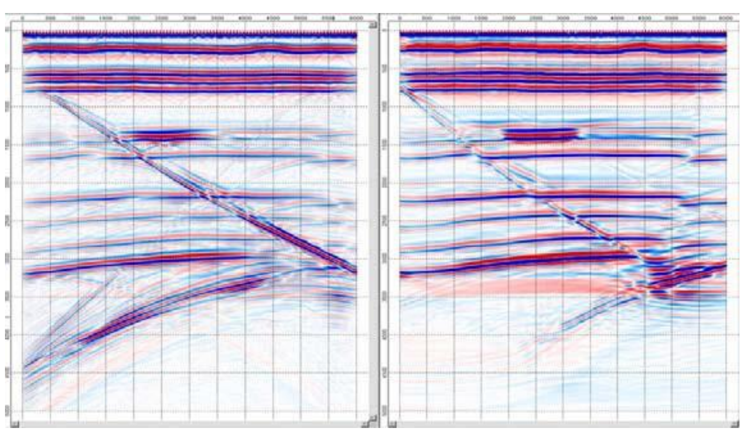

Fig. 11 Time CDP stacked section (left) and the corresponding post-stack time migration result (right).

Conclusions

Full wave seismic modeling makes it possible not only to substantiate the proposed survey design for complex geological structures, but also to project a sequence of processing procedures to be applied on the acquired data records from the object under study.

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