2.5D Common-Offset Inversion of Mobil North Sea AVO Data Set

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ABSTRACT

This short report deals with the application of TRIP 2.5D Common-offset inversion algorithm on a field data set from the North Viking Graben in the North Sea. This data set was donated to TRIP by Mobil Exploration and Producing Technical Center, a sponsor of TRIP, to evaluate our inversion code.

We show: a) inversion of each offset gives a "true amplitude"depth map of the subsurface, b) post-inversion stack produces a clearer image by reducing the noise in the data and c) common-image gathers (coherency pannels from different offset inversion) near a well indicate flat events with different amplitude. The offset dependent depth map might be used in the AVO analysis of reflection seismic data.

1. INTRODUCTION

The Rice Inversion Project has developed an asymptotic linearized 2.5D common-shot and common-offset inversion code in which the traveltime and amplitude factors are computed using a high order essentially nonoscillatory (ENO) finite difference schemes. This short report describes the application of the code (common-offset) in the analysis of a seismic line from the North Viking Graben in the North Sea.

The inversion formula for common-offset 2.5D data, we have implemented is given by

$$\begin{aligned} m_{est}(\xi, x, z) \quad \sim \quad & \frac{(-\Delta)^{1/2}}{4\pi^2} \int dx_r \int_0^t dt \; S_{2.5D}^{-1}(t) \\ . \quad & |\partial\psi_s/\partial x_s + \partial\psi_r/\partial x_r| \cos(\theta/2)(x_s, x, x_r) \\ . \quad & \left. \frac{\sqrt{1/\tau_{s,yy} + 1/\tau_{r,yy}}}{a_{ip}(x_s, z) a_{ip}(x_r, z)} v^2(x, z) Data_{2.5D}(x_r, t) \right|_{t=\tau_s+\tau_r} . \end{aligned} \tag{1}$$

m_{est} is an estimation of the log-step in $p-$wave velocity, Δ is the Helmholtz operator satisfying

$$(-\Delta)^{-1/2} w(\mathbf{x}) \equiv \int |\mathbf{k}|^{-1} w(\mathbf{k}) e^{i\mathbf{k}\cdot\mathbf{x}} d\mathbf{k}, \tag{2}$$

$$S_{2.5D}(t) \equiv 2t_+^{-1/2} * \frac{\partial S_{3D}}{\partial t}, \tag{3}$$

S_{3D} is the source wavelet, $*$ is the convolutional operator, ψ_s and ψ_r are the angles the incident and reflected rays at the specular point make with the normal to the surface, and $\theta(x_s, x, x_r)$ is the angle between the incident and reflected rays at the output point, Figure (1), $v(x, z)$ is the background velocity in the medium and $Data_{2.5D}(x_r, t)$ is the input data, that is assumed to be collected in a line along the dip of a 2.5D medium.

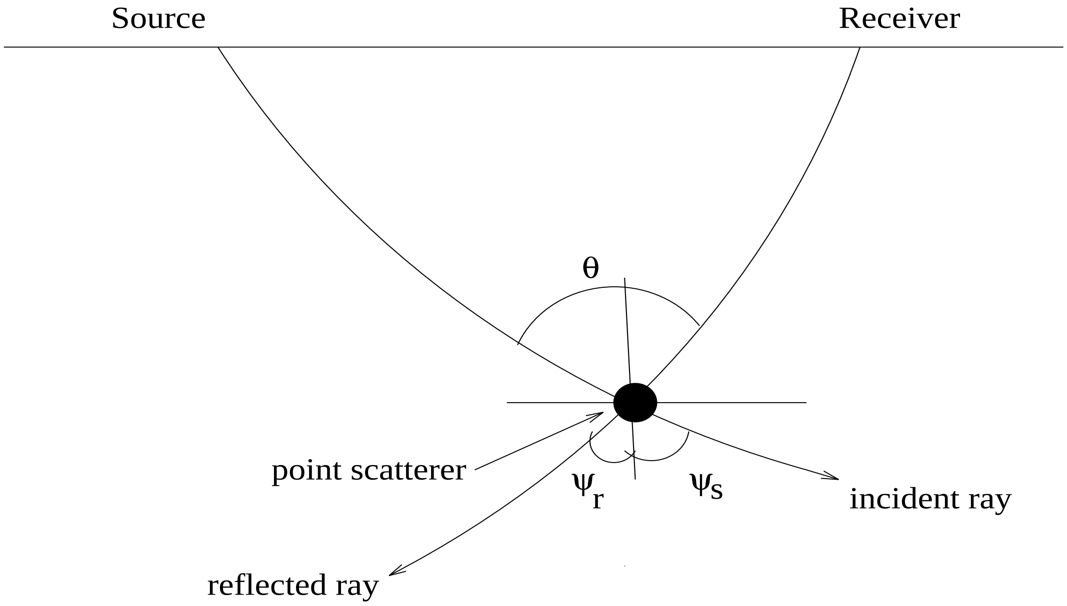

FIG. 1. Diagram to show the angles at the specular point.

τ_s and τ_r are the traveltime from the source and the receiver to a point scatterer in the subsurface, whereas $a_{ip}(x_s, z)$ $a_{ip}(x_r, z)$ are the corresponding inplane amplitudes. $\tau_{s,yy}$ and $\tau_{r,yy}$ are the y-components of the traveltime Laplacian.

Computation of the traveltimes, inplane component of the amplitudes, the variation of the angles ψ_s and ψ_r with respect to the source and receiver position, (mixed-derivative of the traveltimes), and y-component of the traveltime Laplacian is described in Symes et. al., (1994), Araya and Symes (1996a,1996b).

In Araya and Symes (1996a,1996b), we have shown that this inversion formula is quite accurate, in the sense that forward modeling using the inversion of the data as input come quite close to fiting it.

The 2.5D common-offset inversion algorithm pseudo-code block is described in Araya and Symes (1996b). This is repeated here for completeness:

For each offset {

deconvolve the source

get source coordinates

compute τ, $\tau_{s,yy}$, $a_{ip}(x_s, z)$, p_1, p_3, $\partial\psi_s/\partial\xi$

interpolate τ, $\tau_{s,yy}$, $a_{ip}(x_s, z)$, p_1, p_3, $\partial\psi_s/\partial\xi$

get receiver coordinates

compute τ, $\tau_{r,yy}$, $a_{ip}(x_r, z)$, p_1, p_3, $\partial\psi_r/\partial\xi$

interpolate τ, $\tau_{r,yy}$, $a_{ip}(x_r, z)$, p_1, p_3, $\partial\psi_r/\partial\xi$

compute θ

compute contribution of trace to image

}

Apply the Helmholtz operator.

We will describe the regional geological setting of the area, processing of the seismic line and show our results.

2. REVIEW: REGIONAL GEOLOGY AND TECTONICS OF THE AREA

According to Keys and Foster, the geological history may be summarized as follows: the North Viking Graben evolved as a result of late Permian to Triassic rifting. The trend is north-northeast. Jurassic to early Cretaceous extensional episodes accompaned by sedimentation lead to Cretaceous and Tertiary basin fill. At the base of the Cretaceous Figure (2) is an unconformity. Jurassic syn-rift sediments are unconformably overlain by Cretaceous and Tertiary basin fill. The Paleocene series is undisturbed by rifting and dips

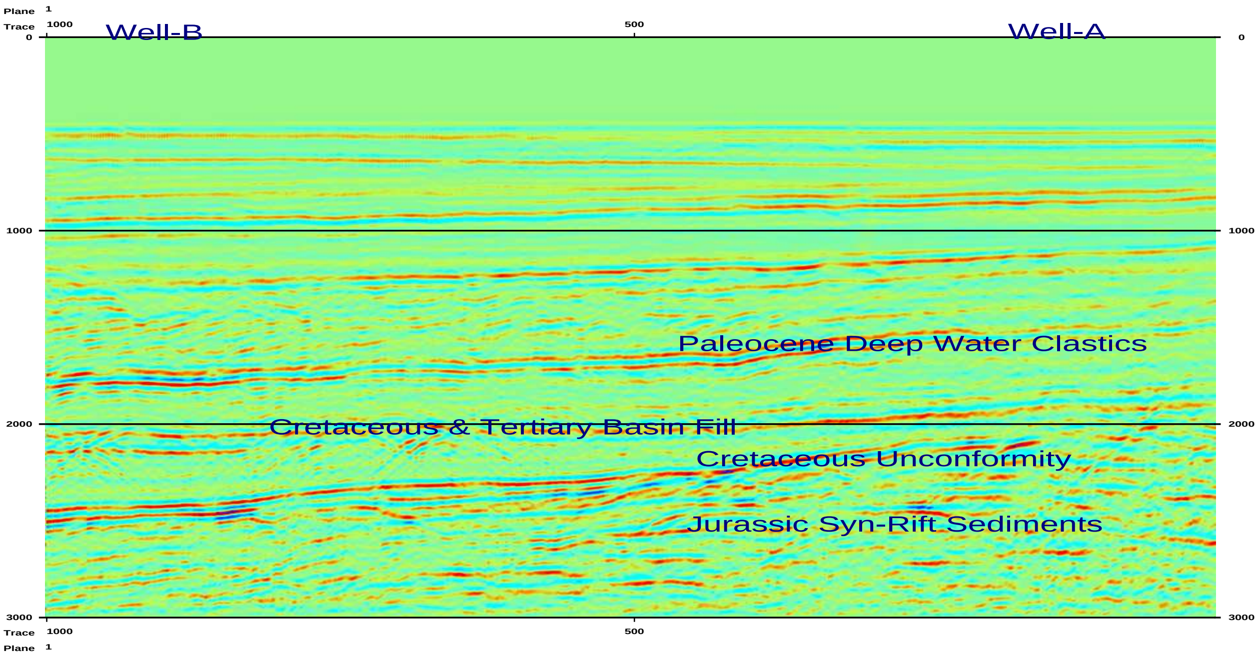

FIG. 2. CMP stack of The North Sea Data using ProMAX© 2D.

gently into the basin.

The primary and second reservoir in this area are Jurassic clastics sediments that range from fluvial to deltaic and shallow marine and Paleocene deep water clastics respectively.

Jurassic traps are mostly fault bounded structures with some stratigraphic truncation of the Base of the Cretaceous Unconformity, where as the Paleocene traps are depositionally mounded structures or stratigraphic pinchouts.

3. THE SEISMIC DATA SET

The seismic data set consists of 1011 shots from a 25km 275m long line. The shot point number ranges from 101 to 1012 with 11 shots i.e., shot 180, 181, 188, 189, 190, 549, 550 551, 859, 860 and 861 missing. Each shot has 120 channels. The shot and receiver intervals are both 25m. The near and far offsets are 262m and 3237m respectively. The source and cable depth is 6m and 10m respectively.

4. PRE-INVERSION PROCESSING

ProMAX© 2D was used in the preinversion processes. These included: sorting into common-offset, removal of receiver ghost and source signature, componsation for intrinsic attenuation and infill of missing traces.

5. 2.5D COMMON-OFFSET INVERSION

We inverted 52 offsets from the entire line. These offsets range from 262m to 1637m. Four offsets i.e., 1237m, 1212m, 937m and 412m were missing from the data. In Figures (3) and (4) we show the input and inverted data from an offset of 287m respectively. Note that the faults in the Jurassic syn-rift sediments are clearly seen incontrast to the CMP stack in Figure (2). Figure (5) shows input data from an offset of 962m. Note that the data has been muted above 1000 milliseconds at Mobil. The inversion of this data is shown in Figure (6). In Figure (7) and (8), we show the input and inversion output from an offset of 1637m., we can clearly see the images where the input data was not muted.

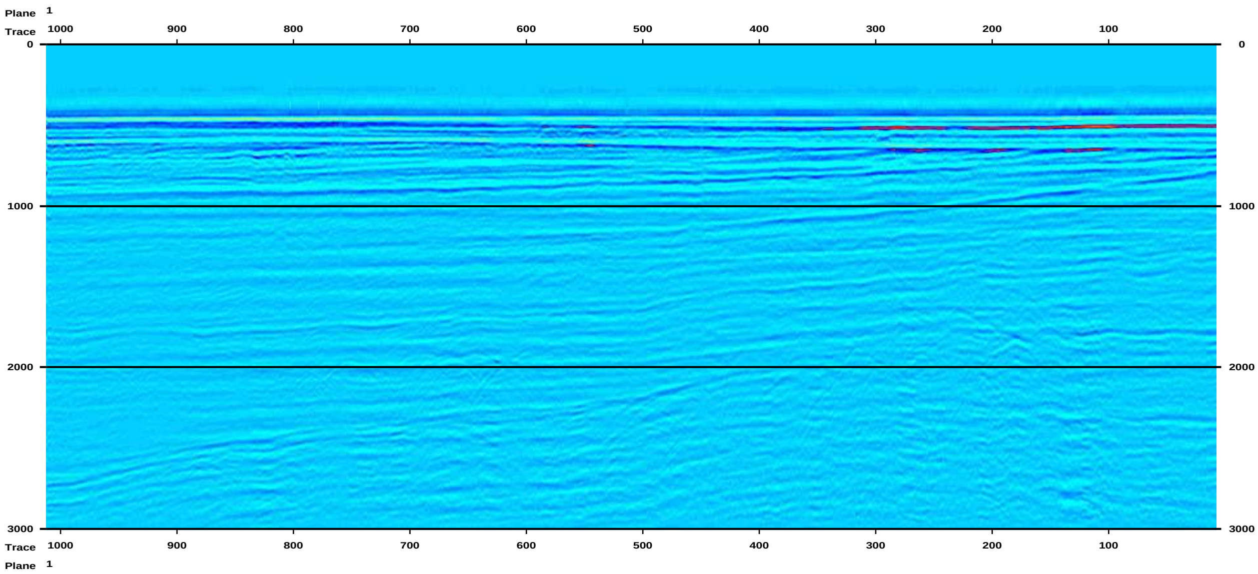

FIG. 3. Common-offset data, offset=287m.

Post-inversion stack of 52 different offsets produced an excellent image by reducing the noise due to multiples as can be seen in Figure (9). In Figure (10), we show common-image gathers from several offsets. This is a test to see if our inversion produces data that can used in AVO analysis. We were motivated to do this by our colleague Dr. Richard Baumel at Conoco Inc. We can see the variation in the amplitude, while the events are flat.

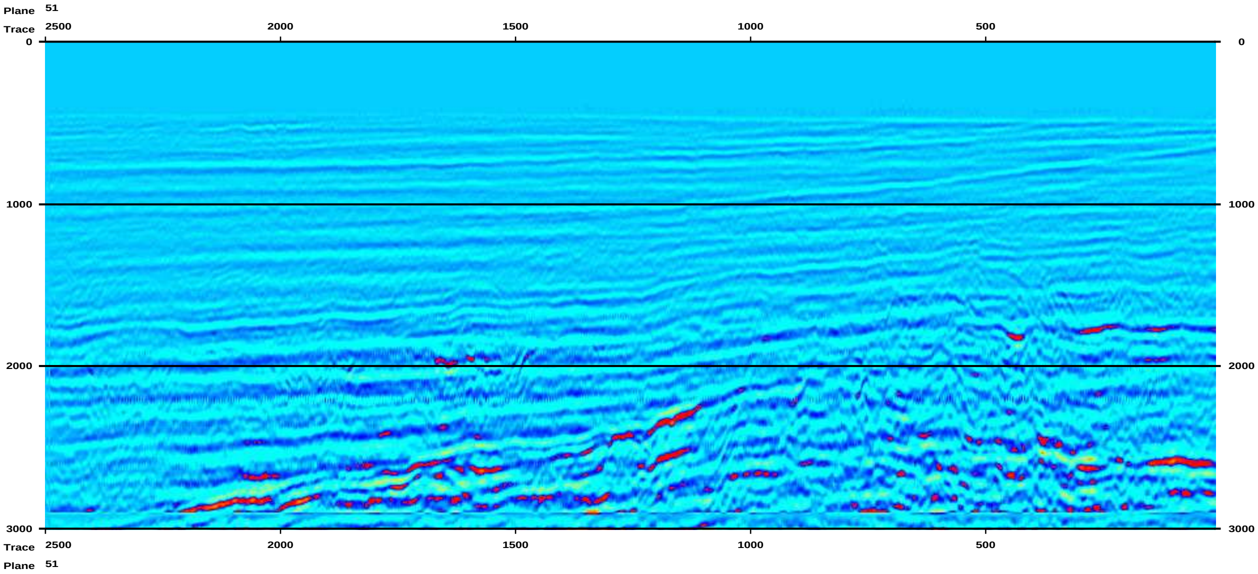

FIG. 4. 2.5D Common-offset inversion, offset=287m.

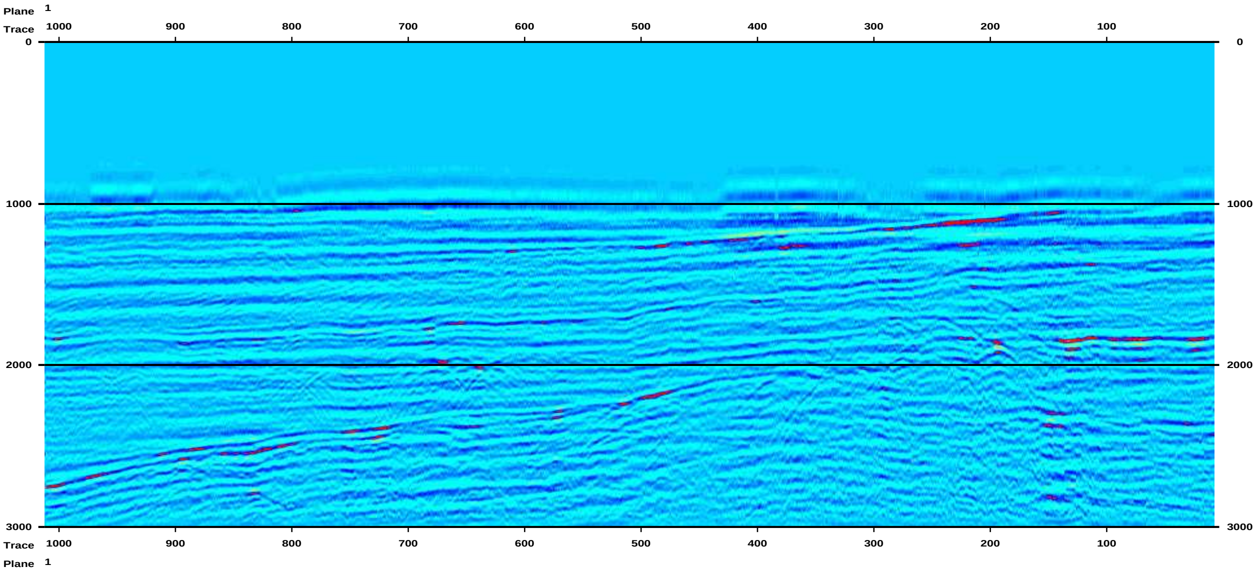

FIG. 5. Common-offset data, offset=962m.

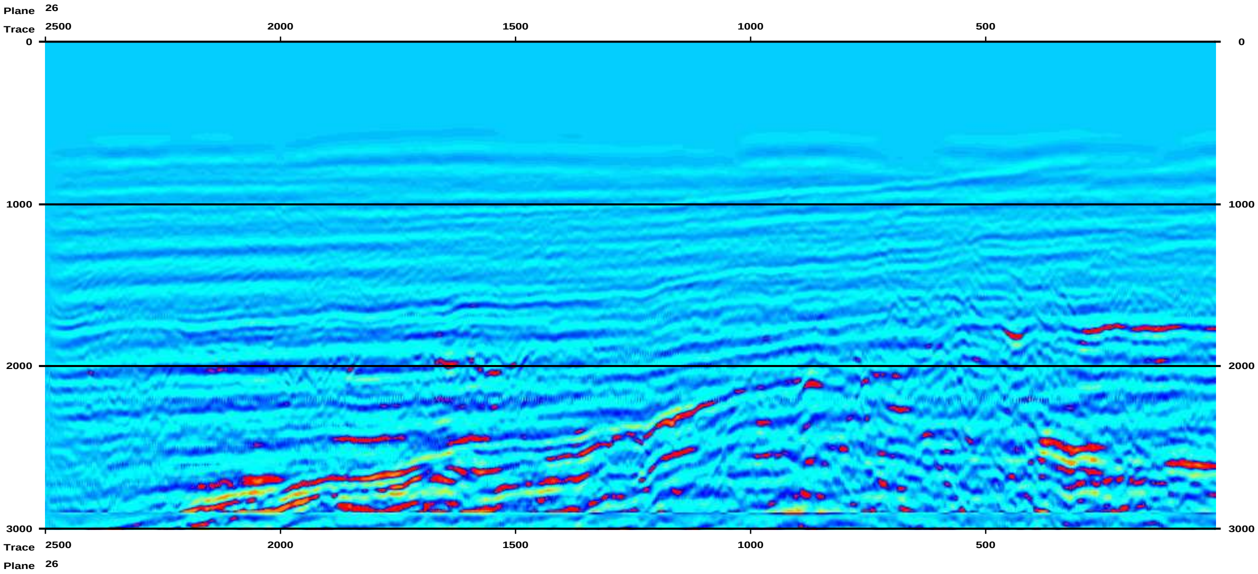

FIG. 6. 2.5D Common-offset inversion, offset=962m.

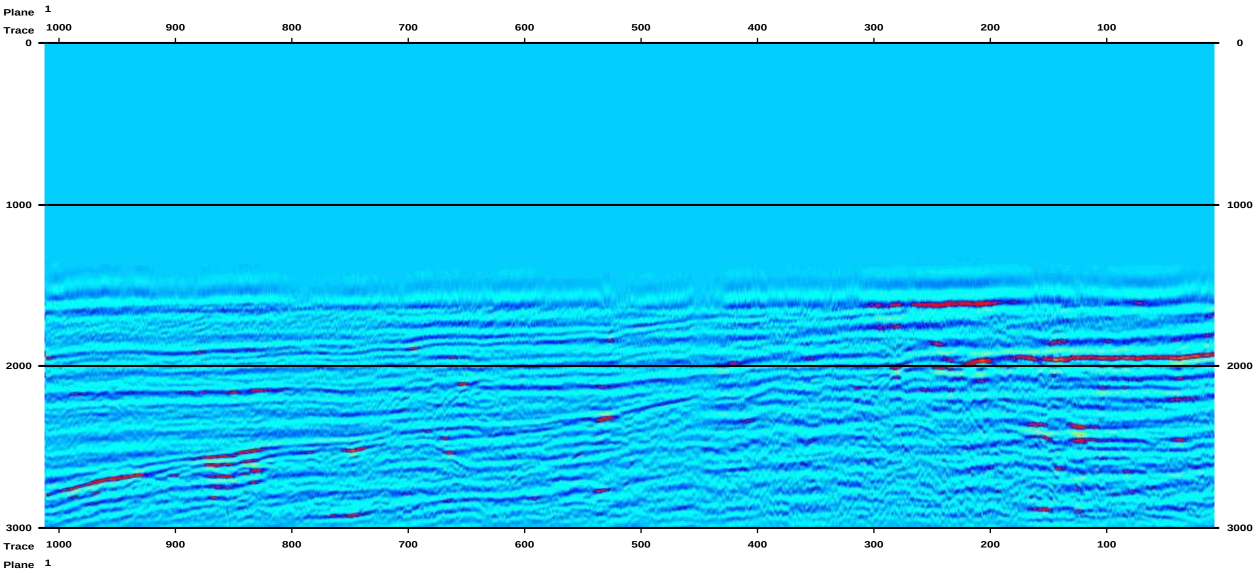

FIG. 7. Common-offset data, offset=1637m.

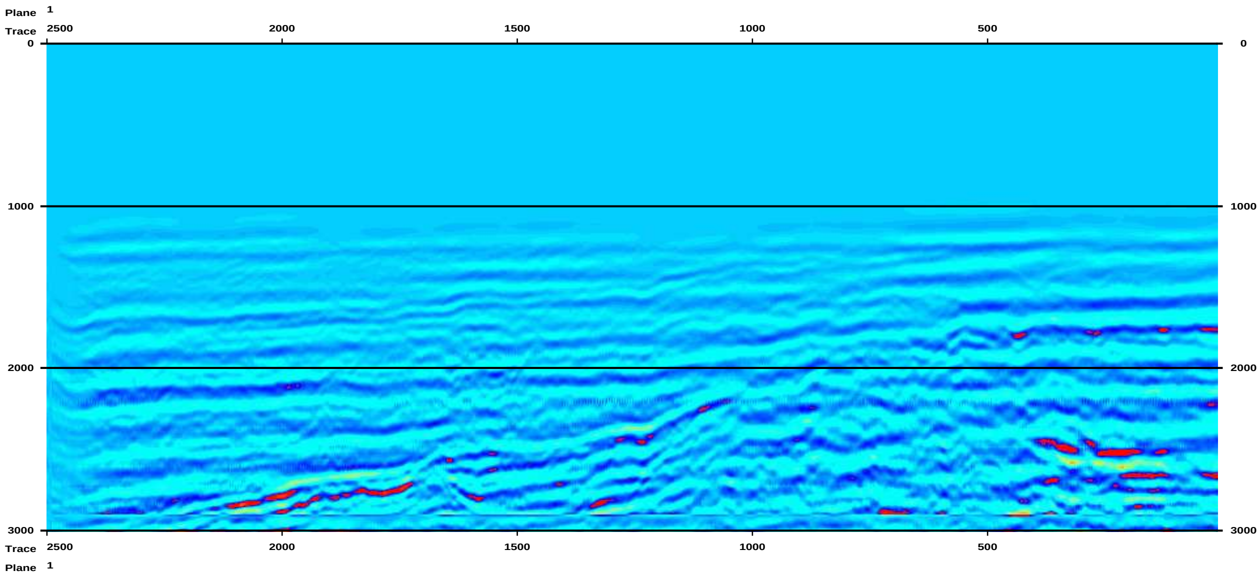

FIG. 8. 2.5D Common-offset inversion, offset=1637m.

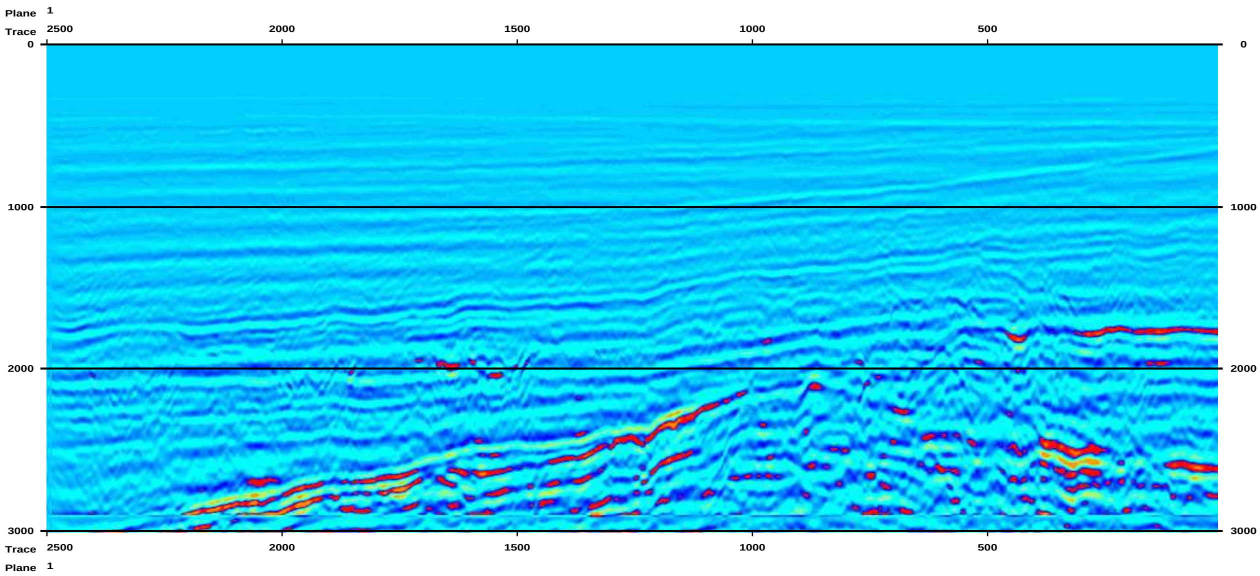

FIG. 9. Post 2.5D Common-offset inversion stack.

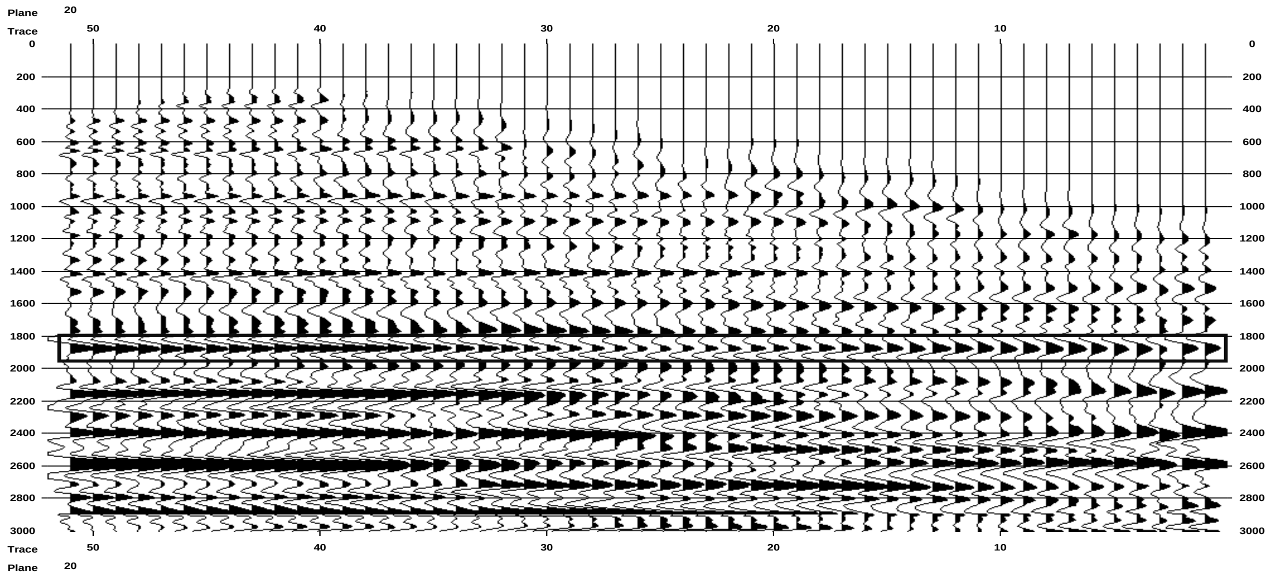

FIG. 10. Coherency panels for 2.5D Common-offset inversion

6. EFFICIENCY

We tested our inversion code for performance. The time required to invert 3 seconds of data from a single offset with 1011 shots on an IBM RS-6000 Model 370 was 4:00 hours. The most expensive part of the algorithm is the traveltime and amplitude computation. To reduce this cost, we designed traveltime cache and trace blocking as descibed below.

6.1. TRAVELTIME CACHE

Traveltimes and amplitudes cost are hierarchical: it is cheap to interpolate from coarse grid in core to fine grid, more expensive to read coarse grid array from disk and even most expensive to compute array from scratch. To reduce the computational cost, we 1) allocate a buffer to hold coarse grid arrays in core (user defined size), 2) maintain table with source (or receiver) location, offset into buffer, age, disk file name (if written to disk), 3) store arrays in buffer on computation, 4) when buffer is full, write oldest array to disk and 5) when table is requested, look first in buffer (lookup table), if not there look to disk, if not on disk then compute from scratch.

In the examples we have shown, saving the traveltime the time required for 6 offsets was 6:46 hours instead of 24:00 hours (without saving the traveltime).

6.2. TRACE BLOCKING

In reflection seismic data aquisition, sources and receivers often share positions in space (regular and commensurable sampling). Therefore we can amortize cost of table creation by handling a number of traces at once ("blocking"). Since most of the tables used by neighboring groups of traces are shared, the effect is to divide traveltime and amplitude access cost by number of blocks. For this experiment, blocking (and saving the traveltimes and amplitudes) reduced the computational cost to 5:45 hours.

7. CONCLUSIONS

We have shown that our inversion code produces a good time to depth conversion of field data efficiently. We have also seen some information on AVO analysis, though our program is adapted for acoustic medium. To do realistic inversion for reflectivity, our program needs to be adapted to invert $P \rightarrow P$ reflections for elastic parameters and include attenuation factors. This may help in rational AVO analysis for Hydrocarbon saturation, determination of lithology at reservoir scale and controlled amplitude display.

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