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*Full Length Research Paper*

# Imaging complex structure in seismic reflection data using prestack depth migration: case study of Olua area of the Niger Delta, Nigeria

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**Estimate of seismic velocity from seismic reflection data in prestack depth migration can be formulated as a general inverse problem. The current state of the art solution to this nonlinear problem is reflection tomography. The technique consists of minimizing the nonlinear least–squares function measuring the mismatch between the traveltimes picked from the seismic data and those calculated by ray tracing through the model. This technique was applied to 3D seismic reflection data acquired from Olua area of the Niger Delta, Nigeria. An improved image of the fault plane in the subsurface was obtained.**

**Keywords:** Prestack, Migration, Tomography, Velocity model, Complex structure.

## INTRODUCTION

The process of converting seismic field data into a meaningful seismic section involves a lot of steps of data manipulations. The overall objective of seismic data processing is to obtain a geologically sound seismic section that reliably represents a cross section of the earth, describes the lithologic facies and probably detects a hydrocarbon accumulation. Unfortunately, there is no unique processing sequence or flow chart that can be applied to every seismic data acquired from any part of the world. Every basin has its own geological settings, rock properties, sedimentary environment, etc. Therefore each area must be treated as a unique case.

A critical stage in all seismic data processing flow is the migration process. Seismic migration is necessary to overcome the limitations of geophysical methods imposed by areas of complex geology, such as faulted sequence, salt intrusions and folding. This process of moving seismic event (either in space or time) to the actual location of occurrence in the subsurface rather than the location at the surface where it was recorded creates a more accurate and detailed image of the subsurface.

Depth migration is especially applied in areas of complex subsurface structures and having lateral velocity variations or steeply dipping reflections (Gadallah, 1994). Correct imaging of complex structures using prestack depth migration (PSDM) have been successfully obtained by Bradford et al, 2006; Adler et al, 2008; Alerini et al, 2009 and Etgen et al, 2009. The technique requires building a nearly correct velocity model to produce a correct structural image and to focus stratigraphic details. So using migration to estimate velocity model (which is needed for migration) presents a nonlinear problem. The current state of the art solution to this nonlinear velocity or imaging problem is seismic reflection tomography. Stork (1992) presented a method of reflection tomography in postmigration domain. Seismic tomographic migration uses a succession of migration iterations in combination with optimization routine to build and refine the velocity model.

In this study, we focus on the use of reflection tomography applied to 3D seismic data acquired from Olua area of the Niger Delta, Nigeria. Our objective is to obtain high resolution seismic image of the complex faulted sequence in the

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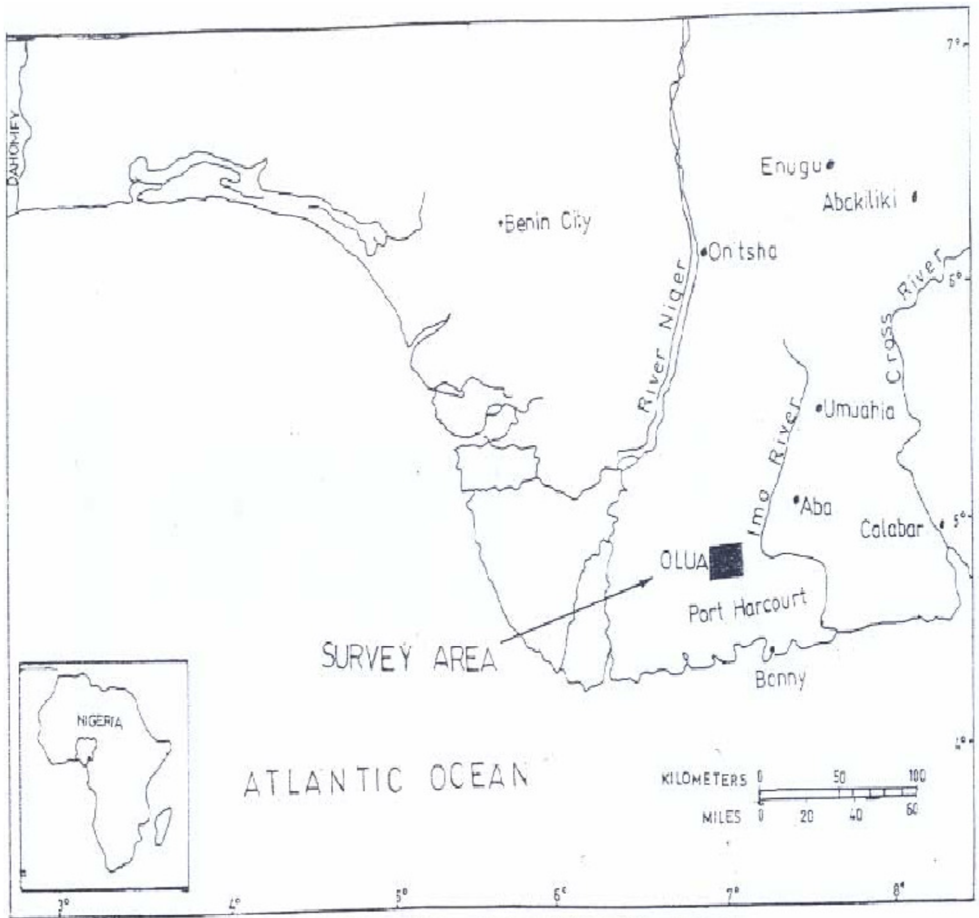


FIG.1 APPROXIMATE LOCATION OF THE STUDY AREA

seismic reflection data using PSDM.

## Geology and petroleum geology of the study area

Olua is a community in Rivers State, southeastern part of the Niger Delta sedimentary basin of Nigeria (Fig. 1). The area lies between latitude $4^0$ $22^I$N and $4^0$ $26^I$N and longitude $6^0$ $37^I$E and $6^0$ $43^I$N (Fig. 2).

The Niger Delta basin is dated as Cenozoic in age and is situated on continental margin of the Gulf of Guinea in equatorial West Africa. The northern edge of the delta is demarcated by the Cretaceous Abakaliki anticline, extending further to the southeast as the Afikpo syncline and Calabar flank. To the northeast of the Niger Delta, is the structurally defined Benue hinge line, while the sediments of Okitipupa ridge mark the western boundary of the delta.

The geology of the Niger Delta is now fairly well documented (Short and Stauble, 1967; Murat, 1972; Reyment, 1965; Merki, 1972). The Niger Delta is a major geological feature of significant petroleum exploration and exploitation in Nigeria (Whiteman, 1982). It ranks amongst the world's most prolific petroleum producing Tertiary deltas that together account for about 5% of the world's oil and gas reserves (Ayoola, 1983). It accounts for the entire hydrocarbons produced in Nigeria today. The source rock of the hydrocarbons is believed to be from the mature Eocene to Miocene shales of the Akata and Agbada Formations, usually trapped in faulted rollover anticlines associated with growth faults. The Akata Formation consists mainly of marine shales while the Agbada Formation represents a deltaic facies.

## Data acquisition

Seismic reflection survey was carried out at Olua area, employing the Common Depth Point (CDP) profiling. The energy source was the dynamite. When the shot was fired, the reflection signals were received by the array of geophones 2.5m, apart. There were 10 geophones per

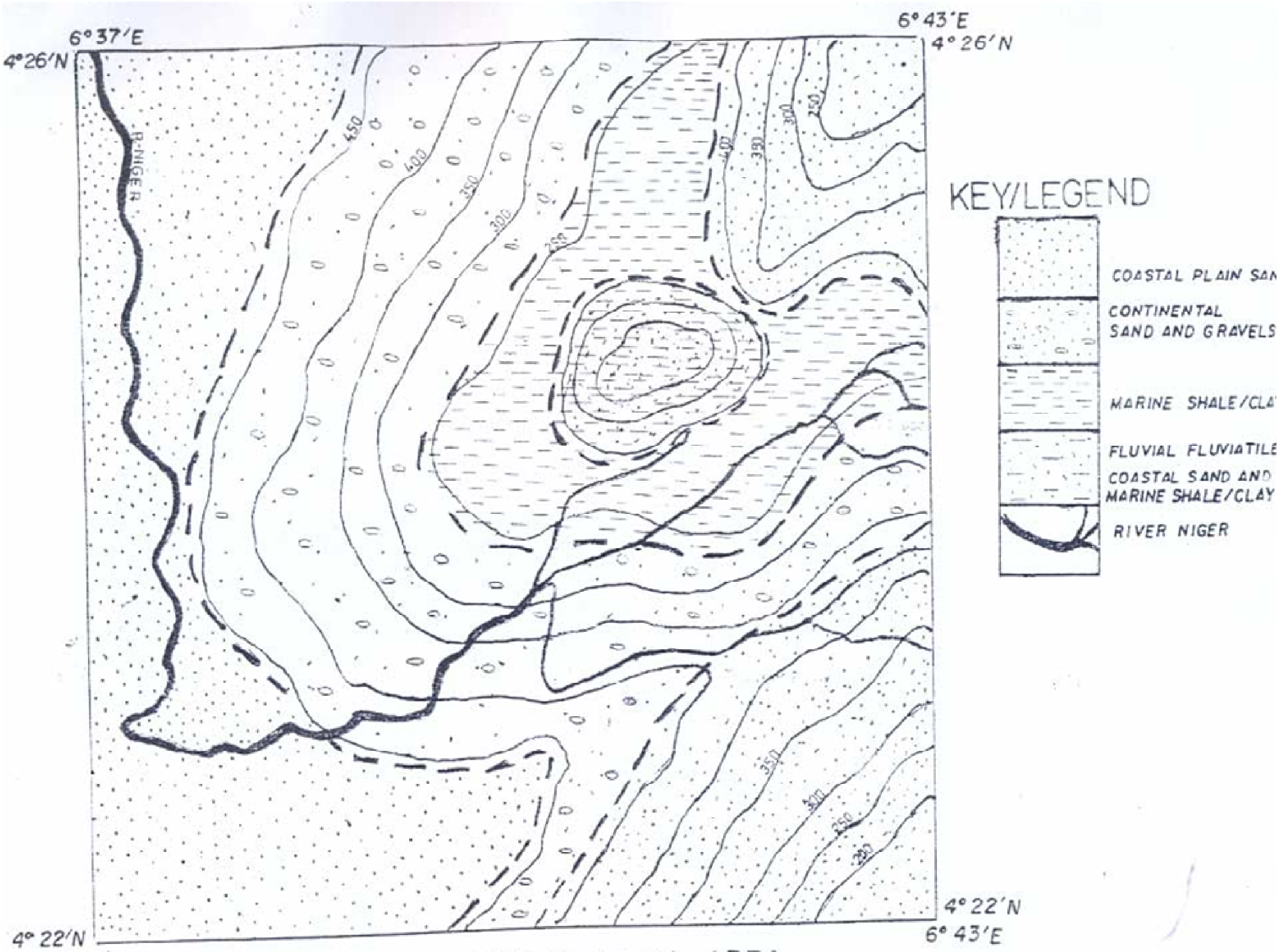


FIG. 2 GEOLOGICAL MAP OF OLUA AREA

**Table 1.** Data Acquisition Parameters

| **Recording instrument** | **Sercel 338B 48 channels** |
|---|---|
| Format | SEG B |
| Sampling rate | 2ms |
| Source | Dynamite |
| Shot depth | 35-50m |
| Shot interval | 50m |
| Receiver array | 10Hz single geophones |
| Receiver spacing | 2.5m |

group. Other data acquisition parameters are as shown in Table 1.

## Data processing by tomographic migration

This approach was implemented on the geological model shown in Fig. 3, which shows the interval velocities of the layers.

Before migration, field data was preliminary processed to remove some traces which represent unsorted multiplexed data and turn them into demultiplexed traces. Preprocessing for migration also included time-varying band–pass filtering, F-K filtering and muting the first–

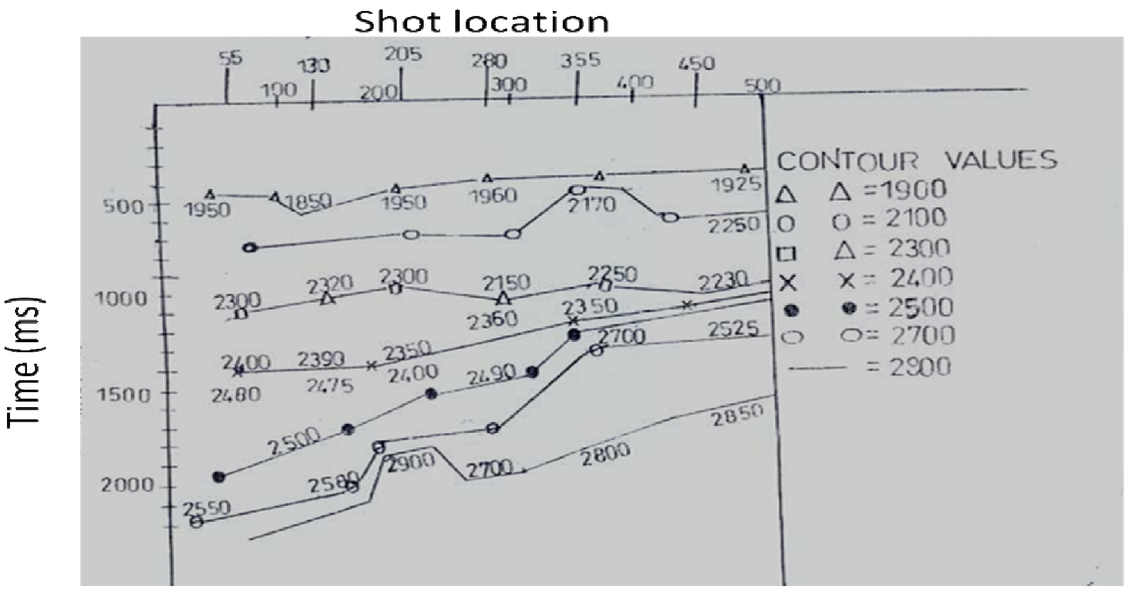


**Fig. 3.** Interval velocity model of a seismic profile from Olua area

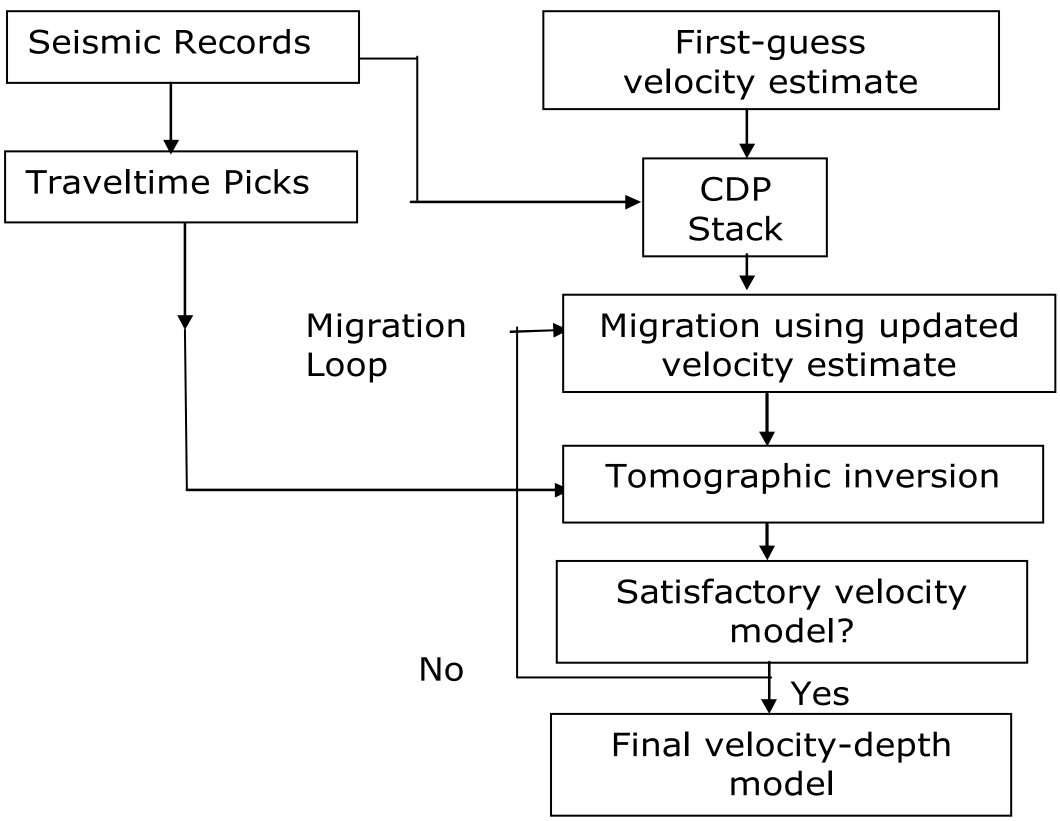


**Fig. 4.** Iterative tomographic migration (after Bording et al, 1987)

arrival trace. NMO/DMO corrections as well as elevation static corrections were applied to the traces within the CDP gathers.

The flow chart for tomographic migration adapted after Bording et al (1987), is illustrated in Fig. 4. The input to the process consists of travel time picks of the seismic

**Fig.5 Stacked section**

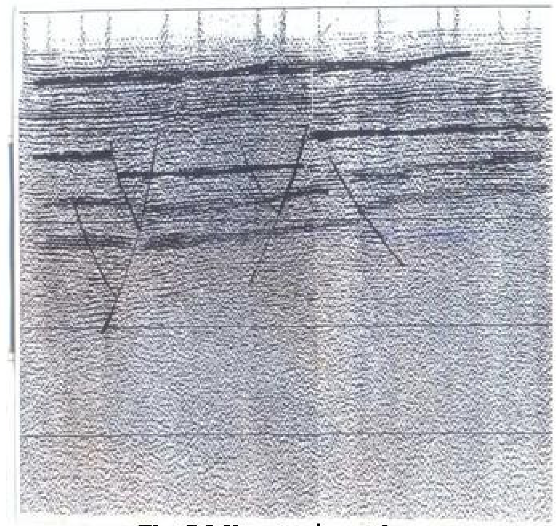

**Fig.6 Migrated section**

reflection events on the unstacked seismic data and a first–guess velocity model. The first-guess velocity model is used to compute the travel time by tracing rays through the model (raytrace modeling).

Following the picking of the travel times from the seismic data and the computation of the travel times by raytracing (Aki and Richards, 1980), tomographic inversion was applied by solving the travel time equation:

$\Delta T = D. \Delta S$

Where $\Delta T$ is the difference between the traveltime picked from the seismic data and that estimated by raytracing through the model.

D is an n x m matrix containing the ray distances.

n is the number of ray paths.

m is the number of slowness cells.

A least–squares slowness solution obtained was used to refine and update the original slowness model in order to minimize the deviation between the travel time picked from the data and that estimated by raytracing. This iteration process was repeated until an optimum solution was obtained when no variation in $\Delta S$ occurs.

The final velocity–depth model was then used for the final depth migration to obtain the improved image of the subsurface structure. Fig. 5 shows the seismic time section obtained from one of the seismic profiles taken in the study area while Fig. 6 shows the improved seismic section obtained after tomographic migration of the same data.

## DISCUSSION

A comparison between the stacked image of Fig. 5 with the migrated image of Fig. 6 shows that PSDM produces a much clearer image of the subsurface structure. The difference in image quality is particularly more evident around the fault plane.

Diffractions from the top of the fault plane at the centre of the migrated image are collapsed to a point after migration. This resulted in a better resolution in the migrated image which will help the interpreter to more accurately delineate the fault pattern.

## CONCLUSION

Migration process is performed in order to move reflectors to their proper positions so that the record section matches the earth model. The most critical stage in the processing stream of PSDM is the velocity model estimation. Reflection tomography has become a preferred method of solving this nonlinear velocity or imaging problem. This method when applied to a 3D seismic reflection data acquired from Olua area of the Niger Delta resulted in a better resolution in the image of the fault plane in the subsurface.

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