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Evaluating Linear Moveout Effectiveness in Detecting 3-D Seismic Survey Geometry Errors in Chad Basin, Nigeria

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ABSTRACT

Accurate geometry is critical for the integrity of three-dimensional seismic surveys for hydrocarbons, particularly in structurally complex basins such as the Chad Basin, Nigeria. This study evaluates the effectiveness of linear moveout (LMO) analysis as a diagnostic tool for detecting and correcting geometry errors during 3-D seismic survey for hydrocarbon in the Chad Basin of Nigeria. Pre-stack seismic gathers from a recent survey were subjected to systematic LMO workflow analysis that included resampling of raw field data at 4ms sample rate, screen quality control followed by database geometry assignment to field data trace headers. LMO corrections was then applied using velocities representative of the near-surface and shallow subsurface formations. The corrected gathers were examined for residual linear trends, abnormal event alignments, and discontinuities indicative of geometry inconsistencies. Diagnosis showed that properly positioned source-receiver configurations produced coherent seismic events that flattened consistently after LMO corrections. In contrast, gathers affected by geometry errors displayed persistent linear trends, events misalignments, and irregular offset-dependent distortions even after LMO application. These observed anomalies clustered along acquisition lines segments of flooded terrain where flood level covered the receiver stations, suggesting localized position inaccuracies due to wrong receiver line deployment. The study concludes that Linear Moveout analysis is a reliable approach for early detection of 3-D seismic geometry errors and that integrating it into quality control workflow reduces geometry errors significantly prior to migration thus improving both stacking coherence and subsurface imaging fidelity.

Keywords:
Linear Moveout Analysis,
Geometry Error,
3-D Seismic,
Chad Basin.

INTRODUCTION

High- quality three-dimensional (3-D) seismic surveys are fundamental for accurate subsurface imaging, which is essential for hydrocarbon exploration, structural interpretation, and reservoir characterization. However, the geometry of seismic acquisition (i.e. the precise positions of sources and receivers, offsets, azimuths, binning geometry, and survey layout) must be well controlled. Geometry errors, particularly in 3-D land surveys, distort the alignment of reflection events across traces, reduce stack coherency and degrade the effectiveness of stacking processes used to enhance seismic signal continuity (Yilmaz, 2001; Sheriff & Geldart 1995). Inaccurate acquisition geometry and missing traces can also generate false seismic events and artifacts that contaminate stacked and migrated sections (Trad et al., 2002). Such artifacts may appear as smeared reflections which can obscure real geological structures thus leading to incorrect interpretation of faults and stratigraphic boundaries (Calvert, 2004).

In the Nigerian sector of the Chad Basin, despite its promising structural and stratigraphic features, exploration has been hampered by uncertainties in imaging and subsurface interpretation (Obaje et al., 2006; Omosanya et al., 2011; Nwankwo et al., 2012; Suleiman et al., 2017). To date, there is limited published work analyzing how acquisition geometry errors can affect seismic data quality in the Chad Basin, and how diagnostic tools such as linear moveout (LMO) analysis can aid in detecting and mitigating these errors. This lack of basin-specific studies creates a methodological gap in understanding how acquisition geometry uncertainties may influence seismic data quality and interpretation in this frontier basin.

This article is intended to evaluate how Linear Moveout (LMO) analysis can enhance detection of acquisition geometry errors in 3-D seismic surveys, using a case study from the Chad Basin, Nigeria. Specifically, the study diagnosed geometry errors (wrongly located receiver/sources, irregular offsets, azimuthal distribution problems) via LMO residuals. It also quantified the impact of detected geometry errors on seismic data quality. In addition, this article proposes a workflow that integrates LMO diagnostic steps into quality assurance/control (QA/QC) during and after acquisition in the Chad Basin context.

In preprocessing QC for 3-D land seismic data, the importance of adhering to design specifications, analyzing noise properties, normal moveout, and offsets cannot be overemphasized (Raef, 2009). This study showed that geometry (including offsets and receiver/source layouts) plays a crucial role in producing clean data for further processing. Under more controlled geological environments, studies have used Monte Carlo simulations to assess how geometry errors affect seismic refraction velocity models, showing that depth estimates are particularly sensitive to certain types of wrong positioning or offset errors. In Chad Basin, structural styles, stratigraphic architecture, and fault propagation using seismic reflection have been interpreted (Okpikoro & Olorunniwo, 2010). These provide excellent information on basin structure, faults, sedimentary units, and tectonic history. Little is published on how geometry errors detection influences downstream processing results (stack coherency, migration accuracy) in this basin.

The contributions of this study include empirical diagnostics, impact quantification and workflow proposal. The use of Linear Moveout analysis on real 3-D seismic data from the Chad Basin to detect geometry errors (wrong position of receivers) is demonstrated. This study also quantified how detected geometry errors affect data quality metrics (binning irregularity, offset distribution and potential migration artifacts) in this specific geological setting. A practical QA/QC workflow incorporating LMO diagnostics that can be applied during acquisition and in early preprocessing stages to prevent or correct geometry errors were proposed. Through this case study, insights into the nature and magnitude of acquisition geometry errors in the Chad Basin, contributing to knowledge that may help reduce exploration risk and improve imaging in similar frontier basins were provided.

Area of Study and its Geology

The Nigerian sector of the Chad Basin occupies the northeastern corner of Nigeria. Geographically, the basins lies between latitude 10°30′ N and 14°00′N and longitudes 8°00′E and 15°00′E, forming the southwestern segment of the greater Chad Basin that extends into Chad, Niger, Cameroon, and the Central African Republic (Mohammed et. 2018). To the north, the Nigerian Chad Basin merges with the Termit Trough and the Tenere Basin in Niger Republic. The eastern boundary is defined by the Cameroon structural high and the Mandara Mountains, which separate it from the Benue Trough and the Logone-Birni Basin. The western margin is demarcated by Fika and Kerri-Kerri Formations transitional zones adjoining the Gombe and Gongola Basins, while the southern is marked approximately by the Dikwa and Bama ridges, beyond which the Biu Plateau rises (Shettima et al., 2011). From geomorphological standpoint, the basin's boundaries reflect both tectonic and depositional controls.

MATERIALS AND METHODS

This study utilized a land-based 3-D Seismic waves generated using an array of four vibroseis per source position. In some points where vibroseis access was impossible, explosive source (dynamites and detonators) were employed and the seismograms were recorded on tape. The acquisition design consists of orthogonal source and receiver lines with 400m source lines interval and 200m receiver lines interval while the source points and receiver station intervals remained 50m respectively. The survey was acquired using Sercel SN 428XL recording system, with 1440 channels being recorded per source point. The seismogram was recorded at a 2ms sample rate and 8.0 seconds record length on tape but record length was 6.0 seconds on paper for visual QC checks. The recorded data in SEG-D format was converted to SEG-Y format with full metadata (coordinates, elevation, and azimuth, offset) for each trace.

Prior to linear moveout and geometry error analysis, standard preprocessing steps were applied to the raw data. They included trace editing - removal of dead, clipped and noisy channels based on signal-to-noise ratio threshold (Sun et al., 2018); amplitude corrections – gain adjustments, AGC (automatic gain control) or other amplitude scaling; elevation and static corrections – correction for variation in receiver and source elevation; near-surface weathered layer statics (Al-Hajeri, Al-Saad, & Al-Dulaijan, 2009) and time synchronization – verifying shot timing and receiver timing.

The Linear Moveout methodology involved subjecting pre-stack seismic gathers obtained from seismic records of the above described 3-D acquisition survey design to systematic LMO workflow analysis. This LMO workflow included resampling of raw field data at 4ms sample rate, screen quality control followed by database geometry assignment to the field data trace headers. LMO corrections were then applied using velocities representative of the near-surface and shallow subsurface formations. The corrected gathers were examined for residual linear trends, abnormal event alignments, and discontinuities indicative of geometry inconsistencies. Diagnostic comparisons were performed between corrected and uncorrected gathers, and anomalous patterns were mapped across the survey grid to identify possible spatial clustering of geometry errors. Properly positioned source-receiver configurations produce coherent seismic events that flatten consistently after LMO correction while gathers having geometry errors display misalignments, and irregular offset-dependent distortions. LMO assumes that for small offsets and relatively flat near-surface layers, reflection or arrival times should shift approximately linearly with offset (before hyperbolic corrections). Deviations from linear behavior in the early portion of offset/time data can indicate wrong positioning, timing errors, or coordinate error assignment (Mu et al., 2025).

Once seismogram records with geometry errors were identified via LMO residuals, the spatial distribution of the wrongly positioned traces/sources are mapped. The designed survey layout is compared with the recorded to identify deviations (such as offset from planned receiver positions and incorrect source location). Analysis of how these geometry errors affect data quality metrics is carried out. Stack coherency and common midpoint binning quality could also be carried out. In practice, however, once the geometry errors are detected early and only a few numbers of shot records are involved, corrections were effected and the affected seismic shots records are cancelled and retaken in their correct positions. In this case study, some portions of three receiver lines out of the six receiver lines in the spread were wrongly deployed by the laying crew who could not recognize the surveyed receiver lines due to flooding that covered the surveyed receiver position pegs.

RESULTS AND DISCUSSION

Figure 1 below presents the 3-D orthogonal acquisition geometry, highlighting sections where the receiver lines were incorrectly deployed. Figure 2a presents a display of the LMO errors showing LMO effectiveness in geometry error detection while figure 2b represents shot records with good LMO displays. To show the effect of LMO error on offset distribution and binning, the offset distribution plot as designed (figure 3a and figure 4a) verses offset distribution due geometry errors (figure 3b and figure 4b) were plotted. It is obvious from the comparison of the planned versus acquired fold distributions that the incorrect receiver deployment negatively affected the fold distribution.

Portions of receiver lines incorrectly deployed

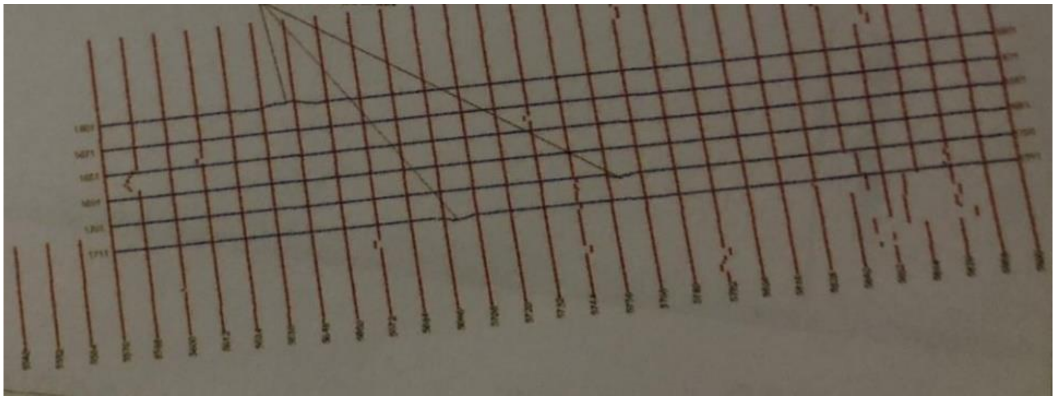

Figure 1: Showing 3-D Orthogonal Geometry with Portions of Incorrect Receiver Line Deployment Indicated

Figure 2a: Showing LMO Errors due to Incorrect Receiver Stations Deployment on the Recorded Seismic Receiver Lines

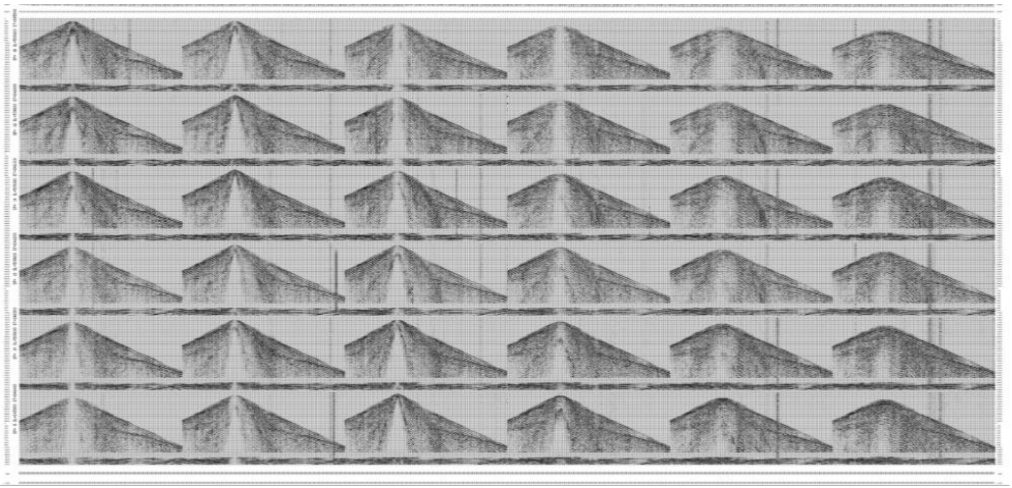

Figure 2b: Showing LMO Displays of Correctly Positioned Receiver Stations and shot point Records

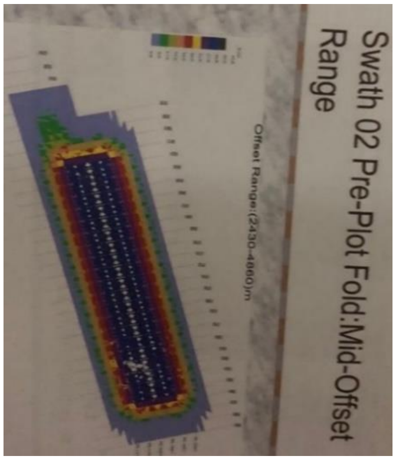

Figure 3a: Pre-plot (Mid-offset Range) Fold

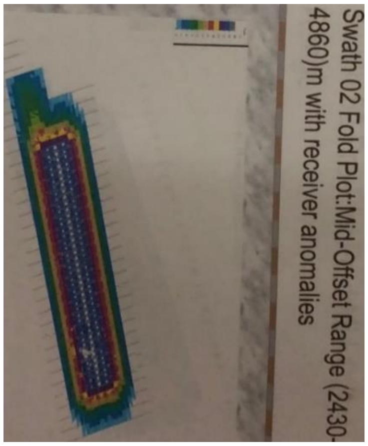

Figure 3b: Post-plot (Mid-Offset Range)

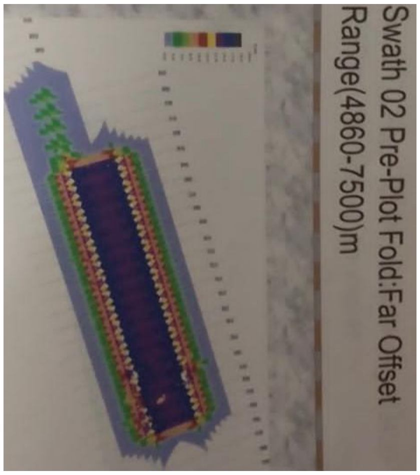

Figure 4a: Pre-plot (Far-offset) Fold

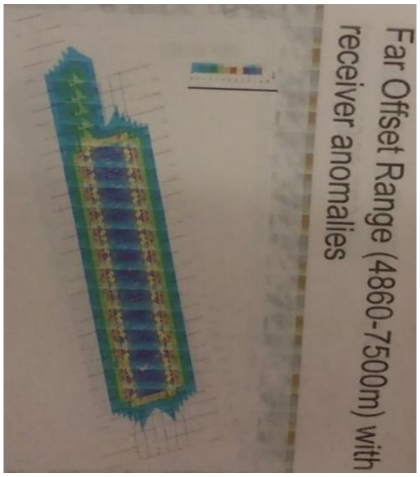

Figure 4b: Post-plot (far-offset) fold

It is important to note that the post-plot folds represent the acquired with receiver anomalies while the pre-plot represent the planned.

Discussion

The Linear Moveout (LMO) analysis applied in this study proved highly effective for diagnosing subtle geometry inconsistencies within the 3-D seismic acquisition geometry of the Chad Basin. The diagnostic approach allowed rapid identification of abnormal residuals in the LMO domain, which corresponded spatially with known sections of the receiver lines that traversed flooded terrain. In these areas, the receiver laying crews were unable to see the surveyed receiver pegs because floodwaters had covered the ground markings. Consequently, several receivers were deployed off-line or at incorrect intervals, resulting in irregular offsets, azimuth distortions, and degraded binning regularity.

LMO residuals in these zones displayed systematic deviations from expected linear trends, confirming that even small wrong positioning in flooded terrain can have a measurable effect on the travel-time behavior of direct and reflected arrivals. These findings are consistent with the sensitivity of LMO residuals to spatial positioning errors (Mu et al., 2025) and the offset-dependent distortions (Pace et al., 2024). Moreover, deterioration in stack coherency along the affected receiver lines underscores the importance of accurate source-receiver geometry (Al-Hajeri, Al-Saad, and Al-Dulaijan, 2009). Acquisition parameters such as offset distribution, bin size, and fold coverage play a critical role in determining the effectiveness of moveout corrections in aligning seismic events across offsets and in improving data coherency during data processing (Onwubuariri et al., 2023). Another noteworthy observation was that geometry errors introduced in the flooded zones propagated into the common midpoint (CMP) domain, generating inconsistent fold coverage and subtle migration artifacts. These wrongly positioned traces were corrected such that both the stack amplitude continuity and reflection coherence were not adversely affected. This shows that early LMO-based QC is an effective means of preventing the compounding of errors during processing. This aligns with the conclusion that accurate statistics and geometry verification before migration greatly enhances imaging fidelity (Sun et al., 2018).

In addition, the LMO analysis in this study highlighted how environmental and logistical conditions – such as seasonal flooding – can be a major non-technical source of acquisition error in frontier basins like the Chad Basin. The flooding did not only disrupted visibility of receiver pegs but also made ground-based GPS verification challenging. Such conditions emphasize the need for adaptive acquisition strategies that incorporate real-time LMO QC to monitor geometry integrity as field operations proceed. Overall, the discussion reinforces that LMO diagnostics are not merely theoretical quality indicators but practical field-level tools for detecting and mitigating geometry errors arising from both technical and environmental constraints.

CONCLUSIONS

This study demonstrates that Linear Moveout (LMO) analysis is a powerful diagnostic tool for detecting geometry errors in 3-D seismic surveys, especially under difficult field conditions. In the Chad Basin case study, LMO residuals effectively pinpointed sections of receiver lines that were wrongly deployed due to flooding, where receiver-line deployment crews could not visually locate surveyed receiver pegs while deploying. The analysis confirmed that these geometry errors led to distortions in offset and azimuth distributions. By applying LMO analysis and corrections, the wrongly deployed receiver sections were identified and corrections effected. This significantly improved data consistency, fold uniformity, and image fidelity. Therefore, integrating LMO-based diagnostics into the quality assurance (QA/QC) workflow enhances survey reliability, reduces re-acquisition costs, and ensures higher confidence in subsurface imaging results. This study also contributes to regional exploration practice by documenting the specific impacts of environmental challenges – such as flooding – on 3-D seismic geometry integrity in the Chad Basin, providing a framework that can be adapted for similar terrain-limited basins across sub-Saharan Africa and beyond.

RECOMMENDATIONS

It is recommended to integrate real-time LMO QC during acquisition, employ GPS-based dynamic positioning system, seasonal planning of acquisition campaigns, automate geometry verification using AI-Assisted LMO Tools.

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