Data Rejuvenation of Vintage 2002 Streamer Data Using Modern Reprocessing and High-Frequency FWI for Enhanced Imaging in the Shale Diapir Province, Offshore Equatorial Guinea

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ABSTRACT

Utilizing modern processing and imaging technologies such as Full Waveform Inversion (FWI) on legacy data can provide new fresh insights to the subsurface in a mature basin. Here we show a case study that applies modern processing techniques such as demultiple and deghosting, together with high frequency FWI up to 40 Hz to vintage 2002 streamer data, to image shale diapirs and complex fault imaging within the distal Niger Delta Basin, offshore Equatorial Guinea.

The vintage 2002 survey was acquired in a shallow water environment with seafloor depth varying between 50 to 100 m. The shot spacing was 25 m flip-flop, over six streamers with maximum 4800 m streamer length.

There are two primary plays in this area; the shallow marine to upper slope Qua Iboe reservoirs and the more deeply buried lower slope to base of slope Isongo reservoirs primarily within structural traps and charged by the Akata source shales. The Isongo reservoirs are buried in some areas beneath 4 km of complex overburden and are not illuminated by diving wave energy, only reflection energy. Localized gas bodies present in the survey area create dim zones associated with Q-absorption. These geo-bodies were compensated for by building a 3D Q model and imaging using Q Kirchhoff Pre-Stack Depth Migration (Q-KPSDM).

Modern demultiple and deghosting workflows were utilized in this reprocessing work, producing improved imaging via reduced multiple energy contamination and broader frequency content in the data. Due to the strong multiple energy reverberating underneath the gas anomalies, additional iterative Surface Related Multiple Elimination (SRME) and targeted near offset demultiple workflow were employed to reduce the residual multiple energy.

For the low frequency FWI updates, we employed an elastic DM-FWI engine (Liu *et al*., 2024), using the hydrophone data, to update the pressure-wave velocity (Vp) model. The initial shear-wave velocity (Vs) and density were estimated using available well shear logs. These parameters were subsequently updated during the inversion based on changes in the Vp model. The FWI objective function is based on Dynamic matching (Mao *et al*., 2020), which maximizes the local windowed cross-correlation between observed and modelled data. The inversion was performed in frequency stages up to 40 Hz, with the lower frequency updates utilizing predominantly the diving wave energy to update the first 1500 m of the model, before switching to the full wavefield to obtain deeper updates. For frequency updates over 15 Hz the demultiple shot gathers were used.

For the final frequency updates, multi-parameter FWI (MP-FWI) was deployed to simultaneously invert for velocity and reflectivity (LS-RTM). This is possible due to the unique aspect of the inversion which is the separation of the low and high wave number of the components of the gradient, enabling the sensitivity kernels to update the velocity and the vector reflectivity, respectively (Yang *et al*., 2021).Throughout the lifetime of the project, well information was used as guide to validate the velocity model building stages.

The final velocity model captures long to short wavelength, geologically consistent velocity variations from shallow overburden to deep reservoir targets. Small and shallow localized gas bodies can be observed in the high-resolution model.

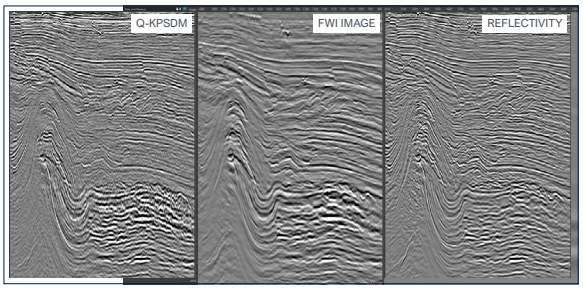
Due to the data-driven iterative nature of the FWI process, the resulting FWI image, which is a derivative of velocity model, inherently benefits from a high signal-to-noise ratio, revealing conformable geological structures suitable for structural interpretation framework that are less subject to illumination variations.

Q Kirchhoff Pre-Stack Depth Migration (Q-KPSDM) was run with the regularized offset classes able to compensate for amplitude absorption caused by localized gas anomalies and provides a balanced, broadband image.

The MP-FWI reflectivity cube, akin to a non-linear least-squares data domain reverse time migration (LS-RTM) image, delivers consistent amplitude fidelity and enhanced reflector continuity throughout the section particularly around subtle dipping structures, making it a robust product for both structural and stratigraphic interpretation.

Figure 1 presents the comparison between Raw Q-KPSDM (left), FWI Image (middle) and reflectivity (right).

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The final results demonstrate clear improvements with better multiple energy reduction, improved imaging of shale thrust and geologically constrained velocity model. This project has demonstrated that there is still appreciable value to be extracted from vintage seismic surveys through modern imaging technologies. This refreshed seismic dataset will enable the operator to refine uncertainty estimates for discovered volumes and derisk the considerable prospective portfolio.