Revealing the Haushi interval with a pre-migration demultiple solution in the south of Oman

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Summary

Multiple contamination in seismic data from the south of the Sultanate of Oman is challenging due to the combined presence of short-period surface and internal multiples generated in the upper section. We present an innovative workflow to attenuate multiples in the pre-migration pre-stack domain based on a dataset from the south of the Sultanate of Oman. The workflow involved least-squares multiple imaging to obtain a reliable reflectivity of multiple generators in the near surface. The reflectivity was input to a one-way wave-equation multiple prediction method, modelling both surface and interbed multiples as several separate multiple models. The use of a primary model, obtained by an iterative process, in the simultaneous adaptive subtraction was fundamental to better tackle the multiple energy and mitigate the risk of damaging primary events. The demultiple flow revealed the geology of the Haushi interval, enabling a clear interpretation of the main events. High-definition imaging of reflectors like the Ghadir Manqil allowed better understanding of the deep basin architecture. In addition, tomographic velocity updates took advantage from data with reduced multiple content.

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Introduction

Multiple contamination in seismic data from the south of the Sultanate of Oman is known to be a significant obstacle for oil and gas exploration in the area (Sambell et al., 2010). The near-surface geology in the area consists of alternating fast layers (carbonates and anhydrites) and slow layers (clastic), which are responsible for the generation of energetic multiples that cover deeper weak primary events. Processing of wide-azimuth data with carefully designed demultiple flows has enabled imaging the deep geology of the south of Oman (Retailleau et al., 2014). Recently, post-imaging and post-stack demultiple results have provided a significant improvement to solve this multiple challenge (Al-Obaidani et al., 2023). During our case study in the Sultanate of Oman, we will present an innovative pre-migration, pre-stack demultiple sequence to remove both surface and internal multiples using primary protection. The resulting seismic image has unlocked exploration barriers in this specific area.

Exploration in Block 55 (Figure 1) started in 1973, with Shell developing their activities in this area since October 2019. In 2022, a densely sampled blended seismic acquisition of 1001 sqkm was planned. The acquisition employed 30,000 nodes and 480 vibrators in a carpet shooting geometry (75 m by 100 m node grid with 25 m by 25 m shot spacing) (Figure 1). At that time, seven exploration wells had been drilled, but no commercial discovery had been made. This motivated the seismic processing of this new data to produce a better image that could ease interpretation of the Haushi reservoirs (Gharif and Al Khlata), as well as the Ara carbonates, Buah and Khufai units. One of the main challenges was multiple contamination, which was particularly dominant in the Haushi interval and prevented consistent geological interpretation, as illustrated on the Reverse Time Migration (RTM) stack in Figure 2a.

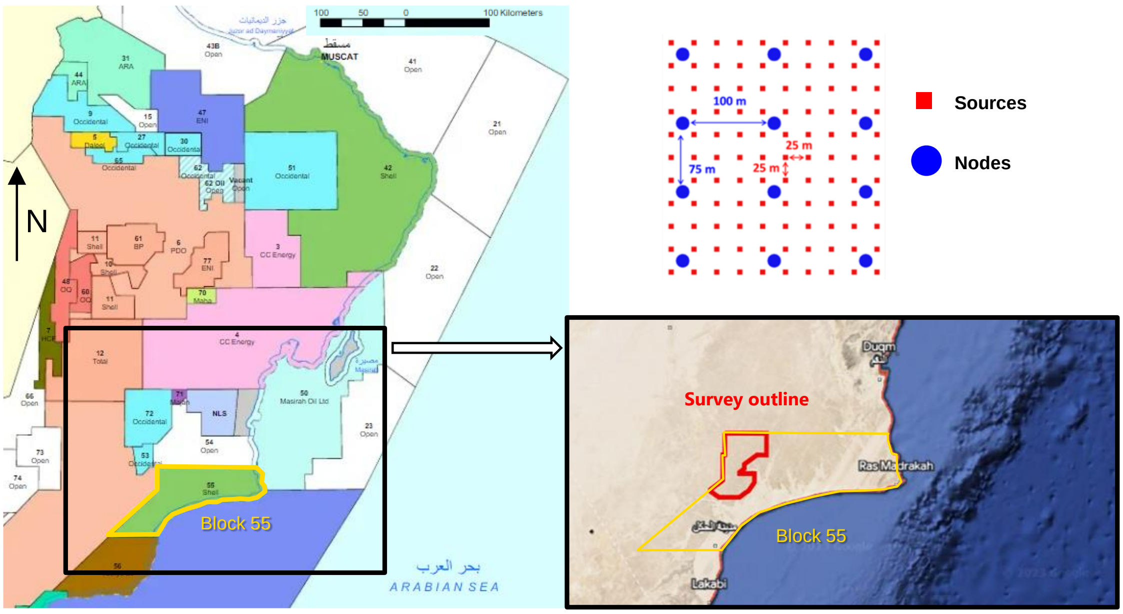

***Figure 1** Location map of Block 55 (left), the survey within the block (bottom right), and the acquisition layout (top right).*

Method

Our advanced demultiple flow involved an iterative approach using several multiple and primary models that were jointly subtracted from the denoised data. First, we built a detailed reflectivity of the near surface for accurate multiple model generation. The reflectivity was derived using the periodicity of the recorded surface multiples with a least-squares multiple imaging scheme (Poole et al., 2022). Then, surface and internal multiples were modelled using a one-way wave-equation propagation method with the obtained near-surface reflectivity and the denoised pre-stack data (Pica and Delmas, 2008; Pica, 2014). To compensate for amplitude and phase mismatches between the multiple models and seismic data, a simultaneous joint adaptive subtraction in the complex wavelet domain was performed on pre-stack, pre-migrated 3D receiver gathers (Sablon et al., 2016). Our final joint adaptive subtraction was guided by a primary model computed from a migration/demigration loop (Toubiana et al., 2022). This process maximized subtraction effectiveness without compromising primary energy preservation.

Results

One of the critical success factors of the study was to deliver migrated products that were good enough to allow the technical team to start the prospect maturation process and identify drill-ready candidates. Least-squares multiple imaging produced a reliable reflectivity of the near surface down to 800 m depth. Using this reflectivity, free-surface multiples were modelled (Figure 3b), and adaptively subtracted them from the input data (Figure 3a) and assessed in the image domain with a 50 Hz RTM over the whole area (Figure 2b).

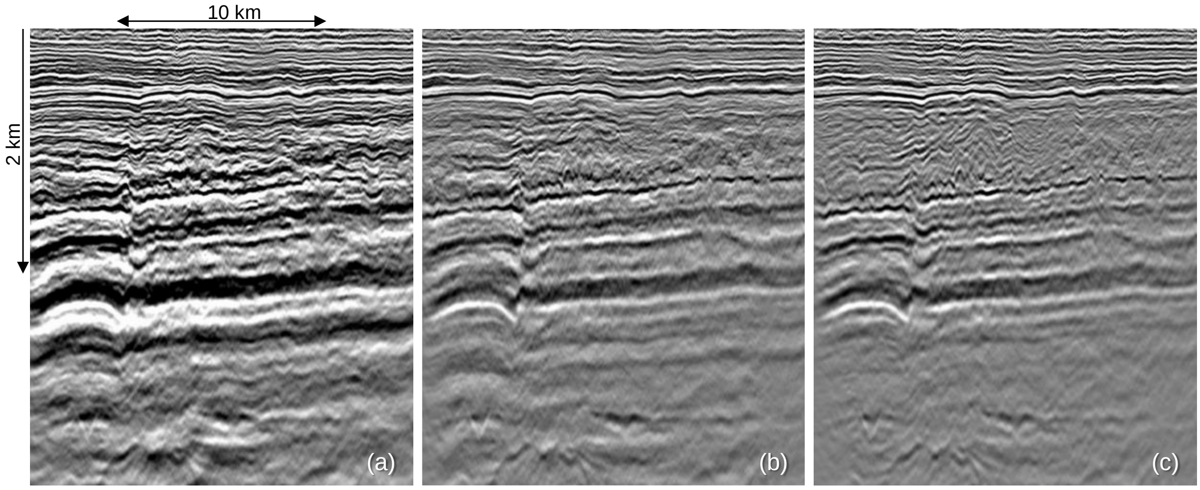

Figure 2 *RTM stack in depth before demultiple (a); after subtraction of free-surface multiples only (b); after joint subtraction of surface and internal multiples using primary protection (c).*

Five months after the project started, the interpretation team used this fast-track volume to mature the prospect and better understand the risks and the range of potential volume outcomes. At this stage, the near-surface velocity was the result of updates obtained by Multi-Wave Inversion (MWI) (Bardainne, 2018) and Full-Waveform Inversion (FWI) (Messud and Sedova, 2019). Analysing the velocity field led us to identify the main shallow impedance contrasts responsible for generating internal multiples, associated to horizons which had average depths of 200 m, 450 m, and 700 m. Using corresponding intervals of the reflectivity, three internal multiple models were generated (one of them is illustrated in Figure 3c) and then subtracted from the data.

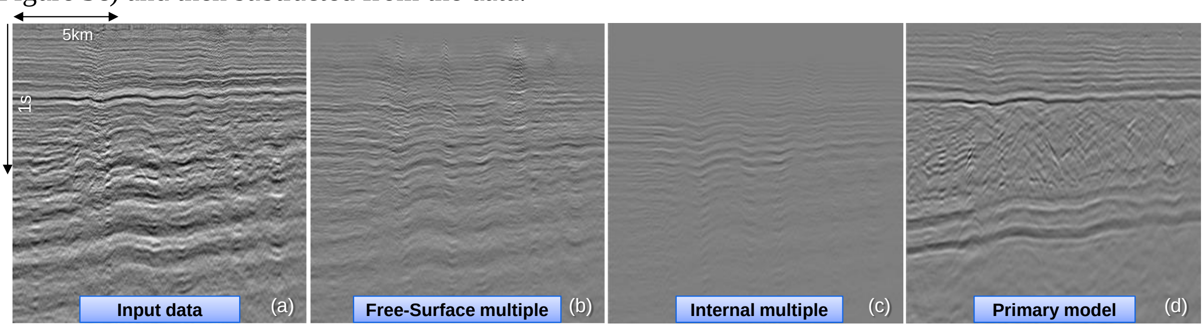

Figure 3 *Pre-migration stacks: input data before demultiple (a), free-surface multiple model (b), one of the internal multiple model (c) and the primary model (d).*

At this point, an off-line flow was designed for primary model generation. The flow included harsh surface and internal multiple subtraction, followed by depth migration and stack resulting in a multiple-free image over the whole section. This multiple-free image was de-migrated to produce a pre-stack, pre-migration primary model. The stack of the primary model is illustrated in Figure 3d. The primary model was key to preserving primary energy without compromising multiple removal in the final simultaneous joint subtraction of all models (Figure 2c). The approach involved a joint adaptive subtraction of surface-related multiple, three internal multiples, and the primary model from the data. The adapted primary model was added to the adaptive subtraction result, commonly called residual, to obtain the data after demultiple. This technique reduced the risk of attenuated geological events, especially at the Haushi interval, where primaries were weak and complex. As illustrated in Figure 4, the use of primary model in the simultaneous subtraction (Figure 4b) outperformed the off-line flow used to generate the primary model (Figure 4a).

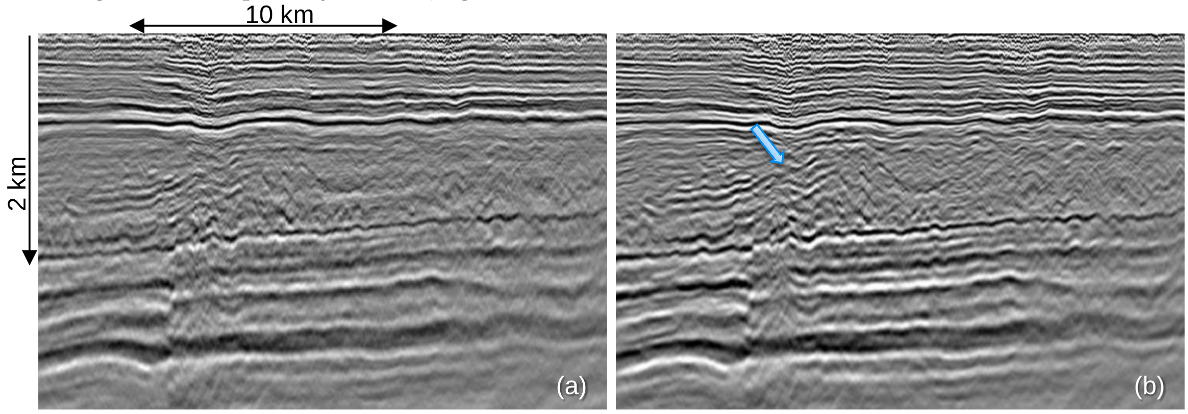

Figure 4 *RTM stack in depth after simultaneous adaptive subtraction without primary protection (a) and with primary protection (b).*

The flow resulted in pre-migration, pre-stack data with significantly reduced multiple energy (Figure 5) revealing weak amplitude primaries (highlighted by the green arrows). The resulting final image of the project enabled clear interpretation of the main events and revealed the geology of the Haushi interval (Figure 6).

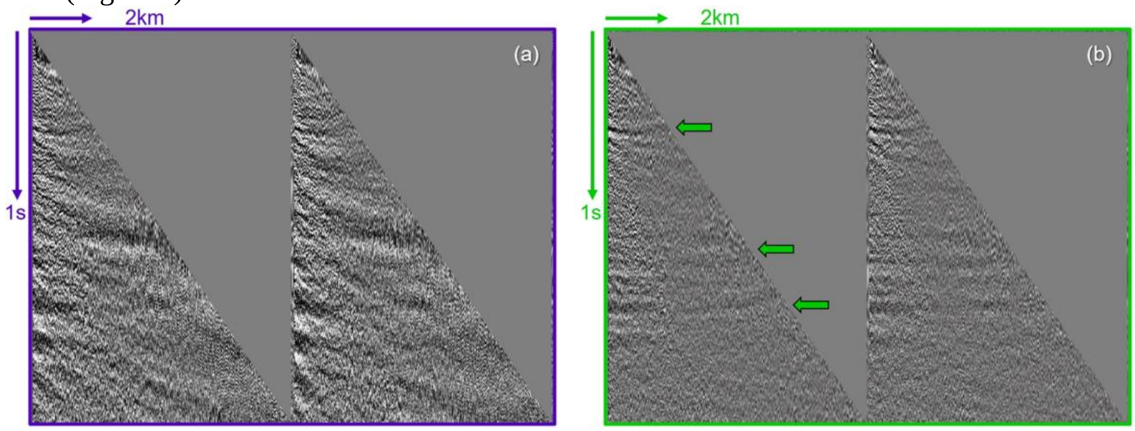

Figure 5 *Pre-migration gathers before (a) and after (b) the proposed demultiple flow, revealing weak amplitude primary energy.*

Conclusions

Effective pre-stack, pre-migration demultiple was made possible by generating accurate surface and internal multiple models using a near-surface reflectivity from least-squares multiple imaging. A primary model generated using demigration enabled the simultaneous adaptive subtraction of multiple models without compromising either multiple removal or geological event preservation, which was the trade-off faced in previous workflows applied in similar processing projects. An additional benefit included the possibility to incorporate data with reduced multiple content into tomographic velocity updates. Data going into the velocity model building flow did not need harsh demultiple preconditioning, and migration of multiple models was not required. The demultiple flow applied to this case study allowed the production of images that helped the exploration team to mature this underexplored area with more confidence. In addition, the new seismic volumes helped the team to better understand the deep basin architecture, and reflectors like the Ghadir Manqil which were imaged for the first time with this level of definition (section below Buah in Figure 6).

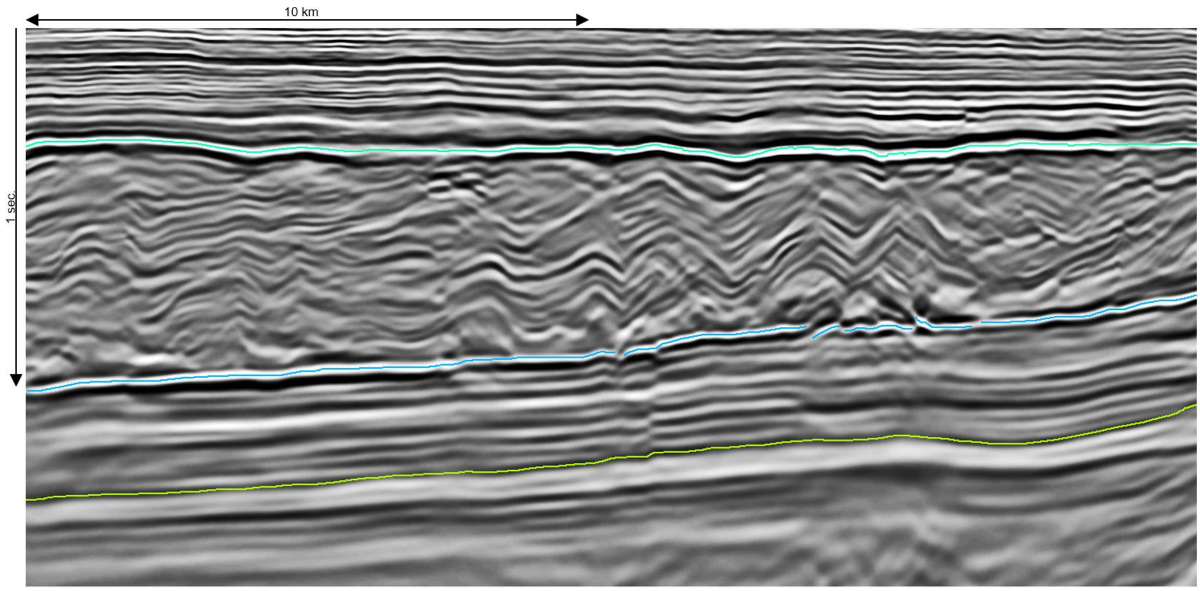

Figure 6 *Interpretation of the final seismic data enabled by the pre-stack demultiple flow (followed by strong denoise) showing the Haushi interval between the Nahr Umr (upper light green) and the Buah (in blue), and the Ghadir Manquil formation (lower olive green).*

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