Affordably making the invisible unmissable

Neil Hodgson[1]*, Karyna Rodriguez[1], Helen Debenham[1] and Lauren Found[1] demonstrate how reprocessing vintage data can bring new prospectivity to basins in Oman and East Coast India

Reprocessing the geology

At midnight, a man stands under a streetlight staring at the ground, looking for his car keys. 'Did you drop them here?' asks a stranger to which he replies 'I don't know, but it's the only place with any light'. In exploration for oil and gas, seismic is your light source. Access to more vintage seismic data switches on more street lights which helps the search yet it is reprocessing these data that makes those lights brighter. Whilst just re-looking at what our predecessors looked at isn't going to change the story, reprocessing these data will reveal a new order of information – both in the detail and depth that the imaging extends to. This is just what the explorer needs; new information that is an antidote to uncertainty.

The most material advances in the exploration toolbox for the last 40 years have been the inexorable improvements in seismic processing techniques, giving better data, quicker and cheaper. Such advances in seismic technology not only throw more spotlights on the ground but its cost effectiveness vs new acquisition simply allows you to switch on daylight, understanding new geological stories painted on a broader canvas in exquisite detail. Reprocessing the available data, or, better accessing the reprocessed data that is available through a multi-client company, is rarely a waste of precious time, as Daniel Boorstin (1984) and maybe Stephen Hawking (2001) have both put it; 'The greatest enemy of knowledge is not ignorance, it is the illusion of knowledge.

Global Seismic Reprocessing

Ahead of new acquisition getting a new story has to come from the 'affordable solution' play book and where old datasets already exist – these may well be able to supply the light at the right price if they are reprocessed.

As techniques in processing evolve quickly, 'vintage data' that can be vastly improved includes most seismic last processed more than seven years ago. Seismic processing improvements that have almost ubiquitous efficacy are of broadly two types; the first getting rid of noise that should not be there and the second putting the remaining signal in the right place. Techniques involving removing artefacts from the data include source and streamer de-ghosting, multiple removal such as Surface Related Multiple Elimination (SRME), and improved noise removal techniques (Radon etc). Putting data in the right place includes using new ways to migrate data either via better migration algorithms or by deriving and utilising a better velocity field for the algorithms to work with. Such techniques like Full Waveform Inversion that were once frontier cutting edge research tools (ie expensive and slow) are now almost a standard procedure, run fast and cost effectively, yet they are also constantly evolving and improved imaging results.

To that end Searcher constantly seeks to be the engine of change globally by collecting vintage datasets under agreement with host-governments and reprocess these data with our partners to image geology never imaged before. We use this data to reveal new oil and gas stories, which we share with investors (oil and gas explorers) to allow them to identify new opportunities.

Turning on the lights offshore Oman

There has been very little exploration offshore Oman's NE coast – sometimes called the Sea of Oman or the Sohar Basin, where only three offshore wells have been drilled (Hodgson et al., 2022). The quality of the available seismic dataset plays a big part in this, as even the two earliest wells in the offshore (drilled in the late 1960s early 1970s (BM-A1, BM-B1)) found clastic reservoirs, with oil and gas shows and as recent geochemistry has demonstrated, oil prone source rocks of Late Cretaceous age. As you can imagine from that time the seismic used to locate the wells is pretty shocking to modern explorers and one has to salute the courage of earlier generations in their embracing of uncertainty. A later well drilled just onshore Oman (Barka-1) found oil-stained Eocene Nummulites, proving the working hydrocarbon system, and many studies have located repeating natural oil slicks/seeps using satellite data in the basin. However, the vintage dataset offshore had poor resolution of the complex structuring in the basin, and almost not imaging of the pre-Tertiary. Almost 40 years separates the first exploration from the last well drilled in the basin (EP-A1, 2010). The well was drilled on a small 3D dataset in the far north of the basin, distal from sediment entry points. The 3D images constrained the exciting structuring offshore, yet this well found, perhaps unsurprisingly, no reservoir.

In 2022 Searcher reprocessed 4200 km of 1999 vintage 2D data located closer to coarse quartz clastic sediment entry points, with our partners DUG, taking the raw data through a modern processing sequence that removed artefacts and noise, and then used an iterative Kirchhoff algorithm to obtain a new velocity profile and Pre-Stack Depth Migrate the data to accurately place

[1] Searcher
* Corresponding author, E-mail: n.hodgson@searcherseismic.com
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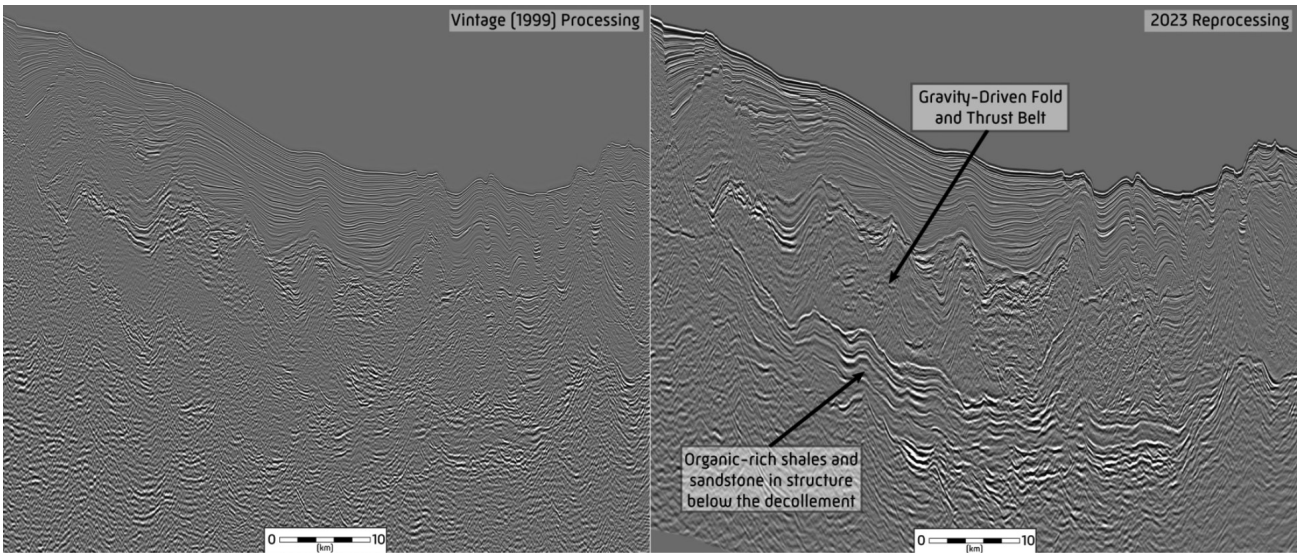

Figure 1 Comparison of Offshore Oman Vintage (1999) processing (LHS) with 2023 PSDM reprocessing (RHS).

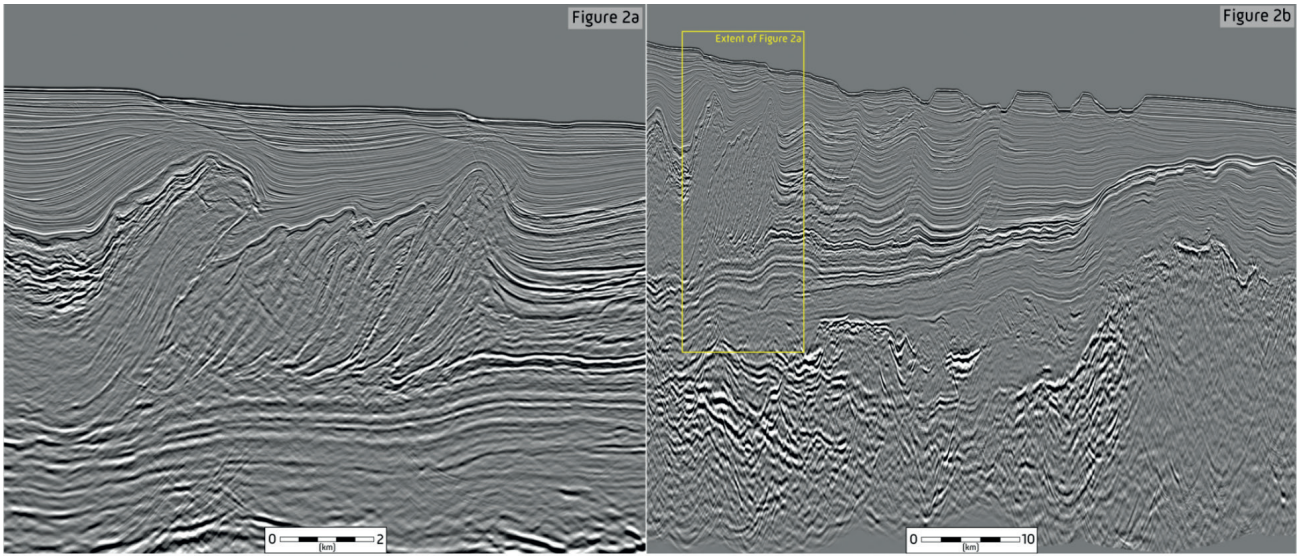

Figure 2a and 2b. 2a Zoom into the detail of the Gravity-Driven Fold and Thrust Belt as imaged on reprocessed PSDM data. 2b. Zoom in to the new Cretaceous or Jurassic basins imaged in deeper water again on reprocessed PSDM data.

signal from whence it came. Figure 1 shows a comparison of vintage data with reprocessed data. Reprocessed data has far less noise and multiple energy in it – this has been removed by de-ghosting and SRME techniques. The fidelity of the data is improved as the frequency spectrum of the data is now much wider, with lower frequency and much wider high-frequency signal present. This quality of the data has been called 'broadband' in the past, a term that is almost redundant as all reprocessed data is like this now. When migrated using the correct (geologically consistent) velocity profile steeply dipping data is imaged correctly, and reflectors below this irregular steeply dipping section are also enhanced.

Although a crisper, cleaner image is useful, the key to this exercise is what extra geological information the data now brings to the interpreter. Of course, the individual thrust slices are now well imaged (Figure 2a), and were they to provide prospective targets (such as we see in the Orange Basin of Namibia), one could map these in a way impossible on the vintage version. Bright events above, beyond and within the gravity-driven fold and thrust belt here can also be analysed on flattened gathers for Amplitude vs Offset responses where shallow gas and oil targets in clastic reservoirs have strong type III anomalies.

However, the prize lies below the gravity-driven fold and thrust belt, where organic mudstones of Late Cretaceous to Early Tertiary age lie beneath the decollement. Actually, maturation of the organic material in these mudstones reducing viscosity and allowing horizontal shear may indeed be the cause of the decollement as the clastic wedge of the Sohar basin tilted into the Makran subduction zone in the east.

Amplitudes vary a lot in this sub-decollement section. Some of these might represent clastics pouring into the basin soon after the emplacement of the Oman Ophiolite to the west where wadis rapidly cut through the fractured ophiolite to erode basement granites. Such quartz-rich sediments are well represented in the Late Cretaceous and Early Tertiary sections onshore (ref Andy Racey 2023 Report available through Searcher).

What the reprocessed data also tells us that the vintage data could not, is that the decollement surface **is** not regular and that structures can now be mapped on the slope in modest water depth today (see Figure 1). Such prospects where source reservoir and structure are entwined are very prospective.

Out in deeper water – an older basin, perhaps a Jurassic continental fragment from a lost Tethyan Sea is now imaged with potential for clastics and carbonates, and new source rock systems (Figure 2b). This area should have just been oceanic crust. However, what appears to be syn-rift is now imaged on reprocessed data suggesting an exotic terrain may be present. Because exploration of such geology within the Tethyan margin of the Persian Gulf to the north has been so rewarding, one is hard pressed to discount the presence source – reservoir pairs being imaged only on the reprocessed data from this basin. Such revelatory imaging is part of what is bringing this area into the spotlight again, where a forthcoming licensing round presents a new generation of explorers with the tools to better understand this area than ever before.

An additional light source Offshore East Coast India

An ongoing licensing round also underlies the 10,000 km of 2D data that Searcher and partner Shearwater reprocessed offshore SE India in 2022. This margin is partly magma poor, partly transform, and partly magma rich, but is only lightly explored outside the Krishna Godavari Basin (Hodgson et al, 2022). Although almost unexplored in deep water, a few brave wells have been drilled, including some of the deepest water wells ever drilled by man.

The geology in deepwater reflects an interplay of a complex passive margin with several sediment input points along its margin, dominated by lateral drowning by sediments coming from the mighty Ganges in the north. Shallow clastic biogenic gas accumulations in the northeast have been discovered but the deeper geology remains largely untouched. Geologic plate reconstructions suggest that the deep basin on this margin could have a basal Early Cretaceous (Aptian) source rock, deposited in a narrow, restricted basin between India and Antarctica. This situation is not unlike the early opening of the Atlantic, where a narrow Early Cretaceous basin, with an active spreading centre allowed anoxic Aptian source rock to be deposited, later to provide the source for the Venus, Graff and La Rona plays of Namibia. In frontier settings hunting and high-grading source rock is key to success. Whilst sediment entry points, and crucially from that sediment, provenance can be deduced on vintage data, and surfaces can be mapped on 2D cubed data (de migrated vintage 2D that is remigrated into 3D datasets), hunting source rock requires access to flattened gathers, and that requires full reprocessing to achieve.

Searcher's SE India regional lines reprocessed by Shearwater in India in 2023 come from two vintages. Firstly, an IndiaSpan dataset acquired in 2006, and secondly the East Coast 2D dataset acquired in 1995. These vintage datasets are spectacular when reprocessed (see Figure 3). The de-ghosting of the Ganges sourced Late Tertiary channel-levee systems allows the mapping in fantastic detail of the development of basin floor channel levee systems, the levee failure and beltway channel migrations (Figure 4a). These systems can be very cryptic on the vintage data but stand out gloriously in reprocessed data. The Searcher reprocessed data set is a complement to existing datasets to be used in combination with the vintage 2D and patches of vintage 3D and 2D cubed data in the basin, where the detail revealed by the reprocessed data, and the AVO analysis possible with properly flattened gathers can be combined with regional surfaces to evaluate and constrain the structuration and onlap of the sedimentary system in this immense deep-water basin.

However, the power of fully reprocessed data is not limited to sedimentology or structure, but this data excels in AVO studies of lithology, particularly organic content, and in direct hydrocarbon detection. Positive Type 2/3 AVO anomalies within the fringing talus slopes of the 85° Ridge (Figure 4b) are tantalising yet – more so are the flattened gathers over the Aptian unit at the base of slope along this margin which display a positive Type IV AVO response which suggests the presence of an organic-rich mudstone. Yet

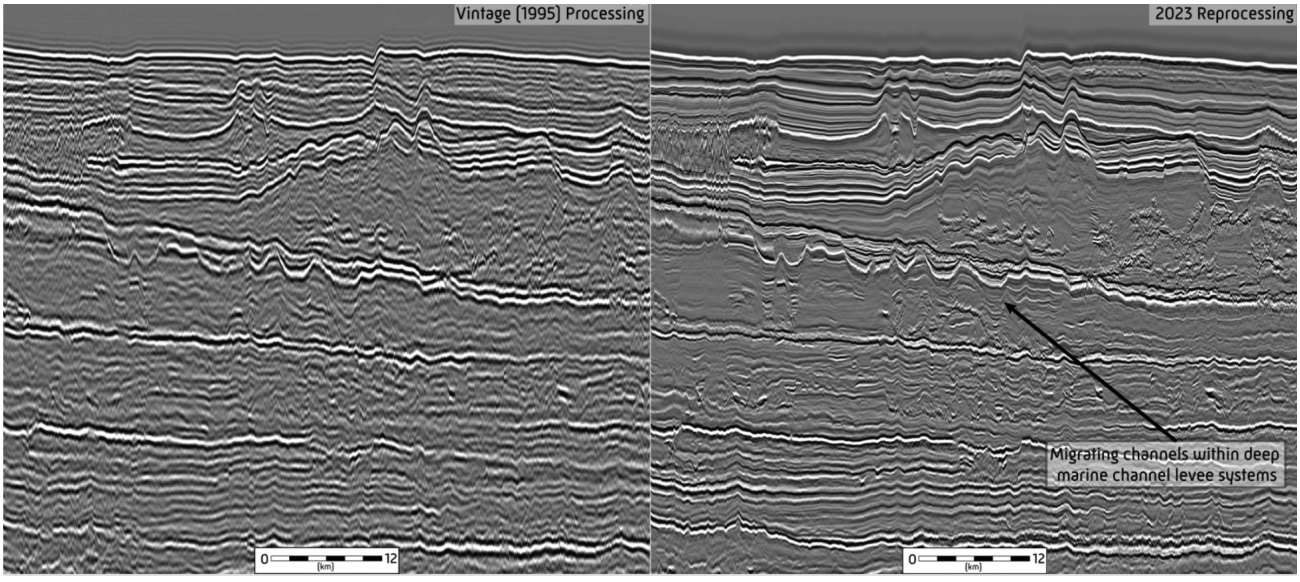

Figure 3 Offshore SE India Vintage (1995) processing (LHS) and 2023 reprocessing through PSTM (RHS).

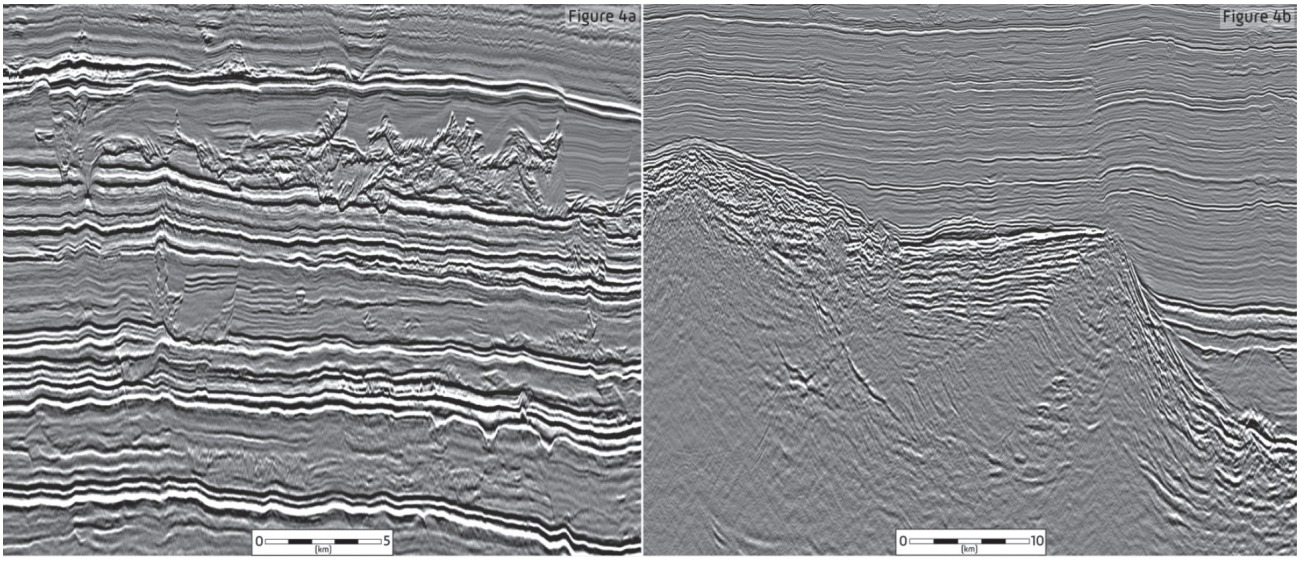

Figure 4a and 4b. 4a. Zoom into the detail of the Levee-constrained channel beltway on reprocessed PSTM data. Compare to Figure 3 vintage data. 4b. Zoom in to the prograding carbonate shelf edge on the 85° Ridge on reprocessed PSDM data.

this basin also has another secret; out beyond the shelf far offset stacks in the Early Tertiary (Paleocene) are dimmed significantly compared to near offsets. The response is not AVO Type IV, it is Type II and therefore could be a series of stacked sand reservoirs which have been charged with hydrocarbon from a source rock potentially below this package. The AVO Type II response could be due to a low acoustic impedance contrast between the sands and the shales overlying them such that the dimming in the far angle could be the response of hydrocarbon charge. Fluid substitution modelling is being undertaken to investigate this hitherto unreported feature, widespread over the basin and present over many of the open blocks in the current licensing round.

The identification of the Early Tertiary plays and their relation to sediment entry systems from quartz-rich hinterlands to the shelf or the lateral Ganges-related sediments, is only possible within the new framework of reprocessed data adding a new dimension to exploration on this most prospective and as yet unexplored margin.

Reprocessing vintage data is given a new life, yielding new information

In both Oman and SE India the combination of these reprocessed data into the evaluations of 2023/24 licensing round blocks is proving to be an essential aid to the explorers evaluating these blocks. These are the right data available at the right price to increase confidence in analysis and facilitate stronger and more aggressive bidding. As L. Frank Baum said that 'No thief, however skillful, can rob one of knowledge. Which is why knowledge is the best and safest treasure to acquire'. Reprocessed vintage seismic can allow explorers to re-image, re-process and re-understand the geology, finding brave new worlds and reducing uncertainty in their interpretations of them and increasing confidence in their analytical conclusions at a cost that matches the maturity of the investment. This principle can be applied world-wide (Hodgson and Rodriguez, 2022) to the reprocessing of vintage data which affordably brings such strong light to the search for new ideas and new insight. It can turn night into day, and make the hitherto invisible into the henceforth unmissable.

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