From data to discovery: Exploring East Java's subsurface with the Facies Map Browser

David Little[1]* presents datasets matched and merged into a single interpretable volume, called 2D^cubed^, that is used to gain a regional overview enabling structural framework and consistent regional interpretation calibrated to 86 exploration and appraisal wells.

Indonesia is emerging as a key region for frontier and Infrastructure-Led Exploration (ILX). To support exploration efforts, TGS has completed a comprehensive regional study that integrates publicly available data with the latest seismic and well information. This integration enables the creation of high-resolution, calibrated facies maps across key petroleum system intervals, helping to identify play potential and assess prospectivity in underexplored parts of the basin. The results are delivered through an interactive online platform known as the Facies Map Browser (FMB).

Indonesia has a well organised national data repository where vintage data can be accessed. The country has a large volume of 2D data but this varies widely in vintage and quality. TGS matched and merged the available datasets into a single interpretable volume. We called this transformation a 2D^{cubed} and use this 3D volume to gain a regional overview. This was the study baseline that enabled structural framework and consistent regional interpretation that was calibrated to 86 exploration and appraisal wells.

Detailed well interpretation, including sequence, chronostratigraphic, and lithostratigraphic picks, as well as gross depositional environment (GDE) and facies, are part of the study. With inputs derived from cutting descriptions, core data, well correlations, seismic facies interpretations, and biostratigraphic reports. Specific attention was paid to the lithological interpretation, particularly the variation and gradation within the dominant carbonates of the region, feeding into the wider depositional model, building upon the hydrocarbon story that already exists.

Maps derived from the latest seismic data enable the generation of regional GDE maps that delineate the geological evolution and sedimentary history of the region, providing insights into the petroleum system at key intervals, but also have multiple applications for Carbon Capture Storage (CCS) site screening, through overburden and potential aquifer distribution mapping.

The FMB helps users to high-grade areas for prospectivity and also includes a block in the 2024 bid round, with the Kojo block in the Makassar Strait that was awarded to Bumi Armada and will likely include areas in future rounds. New seismic data continues to be acquired throughout this study area and is being used as an interpretation QC. This work suggests that there is still plenty of potential for conventional exploration as well as for CCS applications within this region.

Introducing the big idea

Exploration in the East Java Sea began in the 19th century, with the first commercial oil production recorded around 1887. While early activity laid the groundwork, substantial progress has been made in recent decades, particularly in exploring Cenozoic petroleum systems. These efforts primarily target structural traps commonly linked to carbonate build-ups.

This FMB study harnesses the latest seismic data alongside a detailed sequence stratigraphic analysis of 86 exploration and appraisal wells. By integrating these datasets, it enhances our understanding of the basin's tectonic and depositional history.

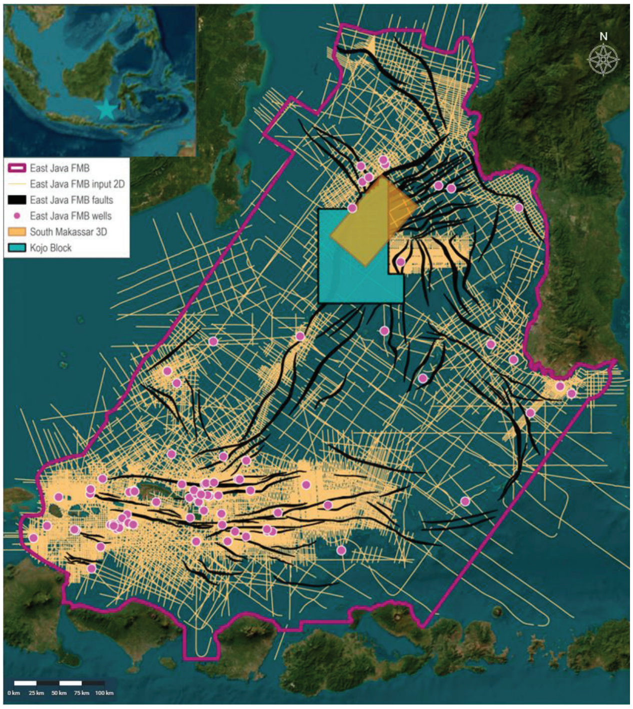

Figure 1 East Java Sea FMB Project Area including Project Wells and input 2D data (yellow lines) for the 2D^{cube}, the Kojo block (teal polygon) and the South Makassar 3D (gold polygon).

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This refined perspective supports more accurate play fairway evaluations, identifies potential future exploration hotspots, and provides critical input for early stage carbon capture and storage (CCS) screening workflows.

The regional backdrop

The East Java Sea is located between the islands of Java, Kalimantan, and Sulawesi is part of the tectonically dynamic Southeast Asian region. It sits on the eastern edge of the Sunda Shelf, shaped by the interactions between the Eurasian, Indo-Australian, and Pacific tectonic plates. These plate movements have influenced the basin's evolution from early rifting through to complex deformation and subsidence phases.

The basin's geological history is marked by multiple tectonic episodes. Initial rifting during the Late Jurassic to Early Cretaceous periods, laying the structural framework of the region. Major basin development occurred during the Paleogene (Eocene–Oligocene) as back-arc extension formed deep grabens and half-grabens. This was followed by Miocene compressional events, which caused inversion of earlier extensional structures, forming numerous fault-bounded traps that are favourable for hydrocarbon accumulation.

From data to discovery

This study can be broken out into 2 separate phases that run in tandem across the project cycle that ultimately ends with a fully integrated product.

2D^{cubed} is a method of guiding interpolation of 2D seismic data along 3D geological horizons, generated from 2D dip fields and layer models. This allows distances of kilometres to be bridged, something that would otherwise not be possible with conventional interpolation techniques.

The input data must be a grid of intersecting 2D lines. These are subjected to a post-stack demigration. This ultimately results in the creation of a volume that can have a full 3D post-stack migration applied to it, correctly positioning events that would not be possible to position in a 2D sense.

The input data must be matched as closely as possible in terms of amplitude, time and spectral character (Whiteside et al., 2013). This is a two-pass process. First, global adjustments are made. These can be line or survey specific. Secondly, windowed adjustments to time and overall amplitude are made at each intersection to make the individual horizons tie. This demigrated input data must be matched so that the geological horizons can be tracked between 2D lines, forming a continuous network of horizons that can be used as the framework for the 3D layer model.

The 3D geological time model is used to guide the seismic interpolation. 2D input amplitudes from around the 3D output point (x,y,t) are drawn together along the 3D layers to form a gather. This gather is then processed to form the output sample (Whiteside et al., 2013).

3D post-stack migration is the final step in 2D^{cubed} generation. A 3D velocity field is generated from the available 2D migration velocities. The 3D migration gives the 2D^{cubed} a distinct advantage over other interpretation tools in that, although other geological horizon generators may be able to estimate the position of horizons in 3D space, they cannot correct for out of plane events present in 2D data.

With a final 2D^{cubed} output delivering a regionally consistent volume a seismic interpretation was applied for the whole project area in order to capture all the mega-sequence intervals relevant to the petroleum systems, with a primary focus on the Late Miocene to Early Eocene.

This interpretation formed the structural framework and key control for tying project wells consistently to the regional volume.

As part of the FMB project, a subset of strategically selected wells underwent a comprehensive subsurface analysis. (Figure 1)

This included detailed sequence stratigraphy, chronostratigraphic and lithostratigraphic tops picking, and the characterisation of gross depositional environments (GDEs) and associated facies.

Lithological modelling was completed using an integrated dataset comprising cuttings descriptions, core analysis, data derived from biostratigraphic reports, and petrophysical log responses. This multi-disciplinary approach enabled robust lithological classification and highlighted heterogeneities within the basin.

Special emphasis was placed on interpreting the carbonate lithologies, which dominate much of the region's stratigraphic record. Carbonate classification followed the foundational scheme of Dunham (1962), later refined by Embry and Klovan (1971), where carbonates are categorised according to depositional texture — specifically the balance between mud-supported and grain-supported structures — and their inferred depositional environment. This framework allowed for a more nuanced interpretation of carbonate facies and their spatial distribution within the basin.

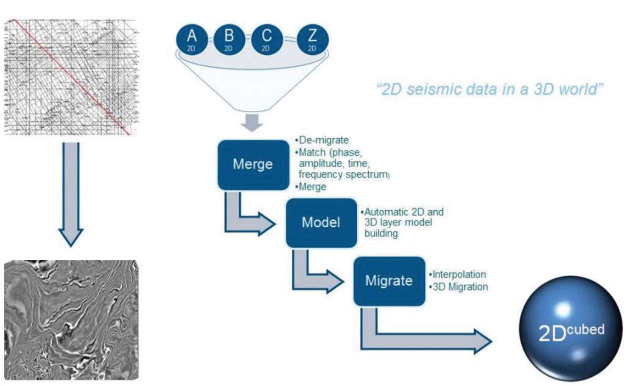

Figure 2 2D^{cubed} Process diagram.

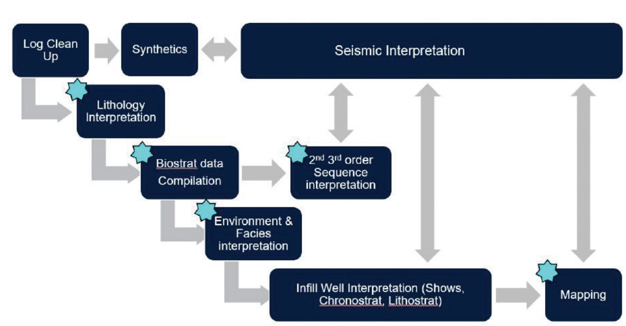

Figure 3 FMB project workflow.

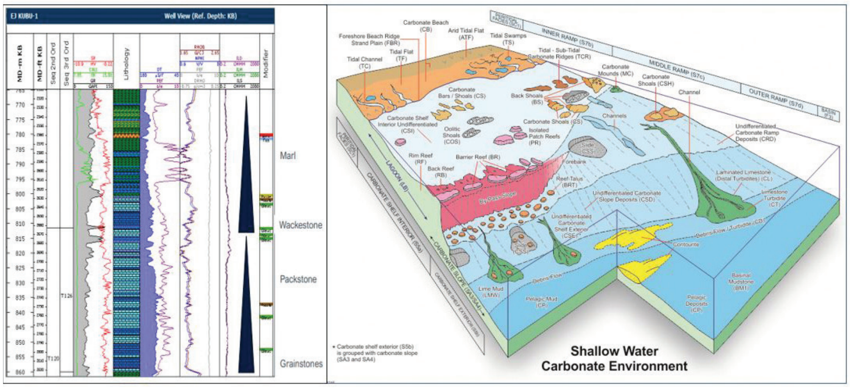

Figure 4 Example lithological interpretation from the study and associated Carbonate Depositional Model.

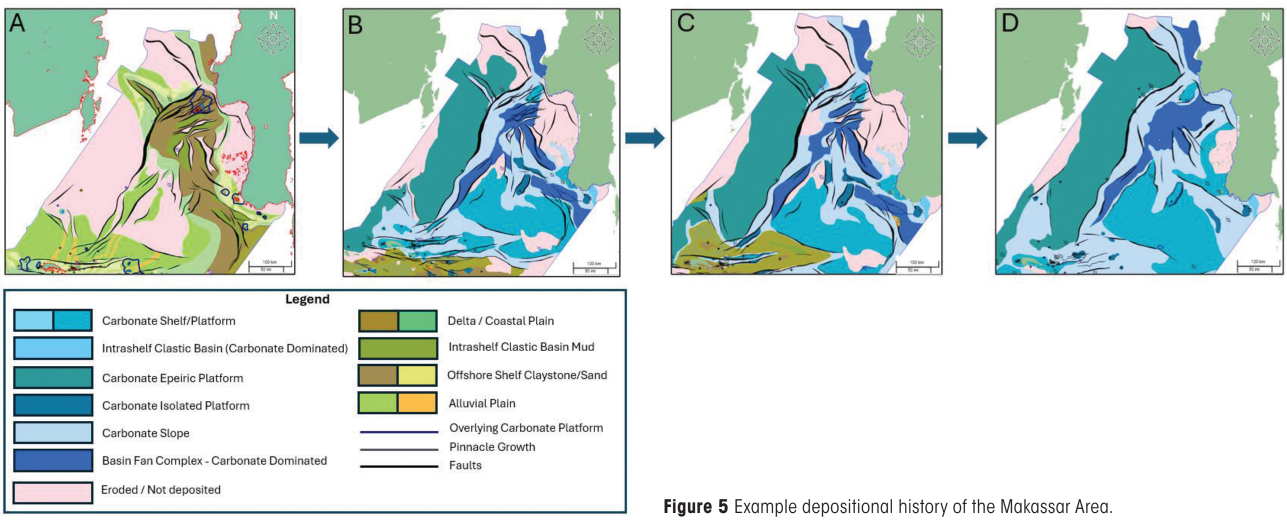

Figure 5 Example depositional history of the Makassar Area.

Lithological interpretation at a sequence stratigraphic level of detail (3rd and 4th Order) permitted the identification of GDE specific facies, which, when combined with 2Dcubed seismic interpretation, enabled the mapping of these facies away from well control into more underexplored frontier areas of the basin.

Key stratigraphic intervals from the Late Miocene to the Early Eocene were prioritised for mapping, as they represent the more prolific petroleum plays within the region.

The objective was to delineate potential source rocks, seal intervals, and reservoir-quality units, thereby enhancing the regional hydrocarbon prospectivity model and refining the play-based exploration framework.

With a fully integrated dataset, merging high-quality regional 2Dcubed seismic with consistent, sequence-based stratigraphic interpretations across 86 exploration and appraisal wells, the FMB reveals valuable insights into the basin's geological evolution.

For example, sediment input pathways during the Bartonian to Ypresian interval were interpreted, shedding light on clastic dispersal mechanisms and carbonate platform development. Additionally, the FMB helps to refine the timing and nature of major carbonate generation phases, offering a clearer picture of the region's stratigraphic architecture and petroleum system evolution.

A subset of the facies maps created for this study is presented. The earliest map (Figure 5A) comprises of alluvial, lacustrine and fluvio-deltaic sediments that were deposited during the Early Eocene rifting. Rapid sedimentation rates and increasing water depths within the half-graben and graben depocentres indicated rapid extension during or immediately prior to deposition. Observed tilted fault blocks formed structural highs and led to the development of carbonates in the Mid-Late Eocene as marine conditions prevailed (Figure 5B and 5C).

Platform and pinnacle reef type carbonate development continued into the Oligocene, especially in the east of the basin as bathymetry continued to decrease. The deposition of deep marine sediments came after a hiatus marking the end of the rift phase and high subsidence (Figure 5D).

Understanding the depositional regime as well as the timing of events provides a lot of the parameters required for prospecting in a region.

The Kojo block shown in (Figure 1) was one of six blocks that were awarded in 2024. It is centrally located over the study area, and tying into a regionally consistent interpretation allows observations to be made on the big picture (Figure 6 and Figure 7).

Interpretation at the mega-sequence level offers a broad regional perspective and serves as a key input for understanding the structural controls within the project area. Figure 6 is an example northwest-southeast seismic line extending from the Paternoster High, through the South Makassar Basin, and into the Salayar Basin to the east.

In the geo-seismic section (Figure 6), platform carbonate plays are evident at the base of the Miocene, highlighting

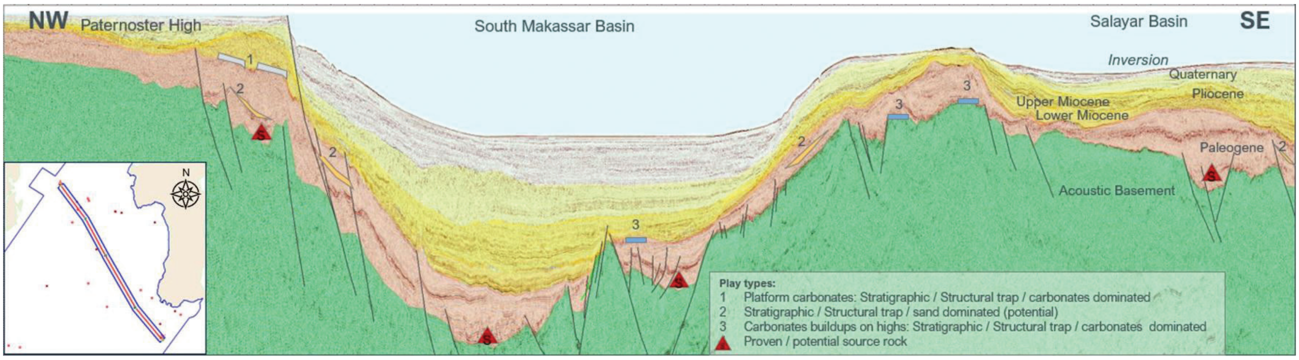

Figure 6 Geo-seismic section through the South Makassar Basin demonstrating interpretation and play types.

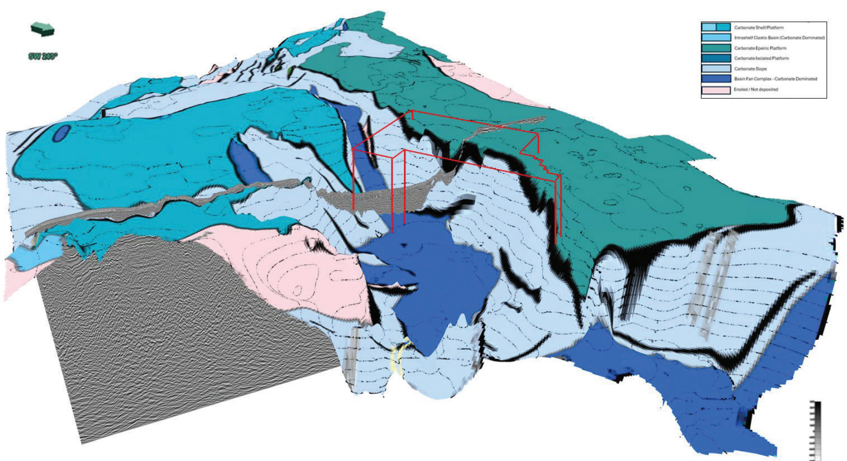

Figure 7 3D view example depositional facies map draped over 2D^{cubed} seismic (Red polygon projecting the Kojo block).

potential reservoir targets. Near the shelf edge, during the Eocene to Oligocene periods, there is evidence of combination traps involving both stratigraphic and structural elements. As the section progresses eastward, carbonate buildup plays become more prominent over structural highs. Additionally, the presence of possible Eocene-aged coaly shale packages as possible source rock could be preserved within the depocentres, suggesting favourable conditions for hydrocarbon generation and entrapment.

Indonesia is positioning itself as a regional leader in carbon capture and storage (CCS), leveraging its energy expertise, skilled workforce, and infrastructure to support emissions reduction across the Asia Pacific.

In a significant policy shift, the Indonesian government recently issued a presidential regulation enabling CCS operators to allocate a portion of their storage capacity for CO_2 from neighbouring countries. Building on this momentum, Indonesia and Singapore signed a Letter of Intent (LOI) earlier this year to explore cross-border CCS collaboration.

ExxonMobil is partnering with Indonesia's state-owned energy company, Pertamina, to evaluate the development of a major CCS hub. The proposed site, located beneath the Java Sea, is estimated to hold up to three gigatons of CO_2, potentially making it the largest storage facility in Southeast Asia.

Through strategic initiatives like these, Indonesia is actively advancing its role in enabling a lower-carbon future for the region and establishing itself as a key hub for both domestic and regional CCS efforts.

Building on the outputs from this FMB study, we begin to explore how these results can inform early-stage regional carbon capture and storage (CCS) screening — not only within the East Java Basin, but in any comparable sedimentary basin.

The foundational datasets and interpretations generated through this FMB work offer broad applicability for identifying and evaluating potential CCS sites.

Effective CCS site screening relies on several key geological parameters. Central among them is the ability to clearly define potential aquifers, understand their spatial extent, and character-

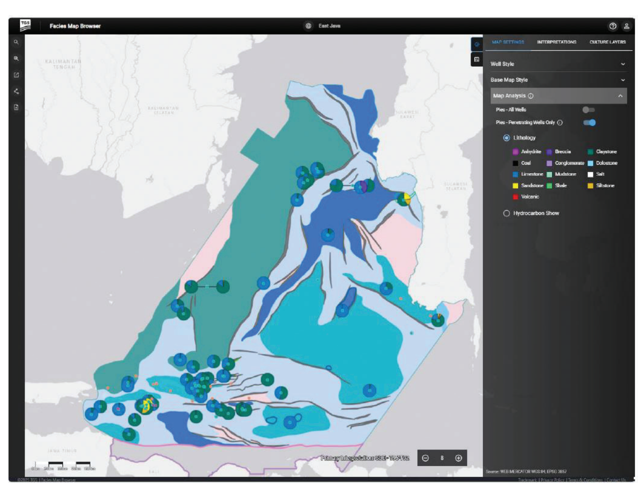

Figure 8 Facies map with gross lithology pies (for the mapped interval) displayed over well spot locations.

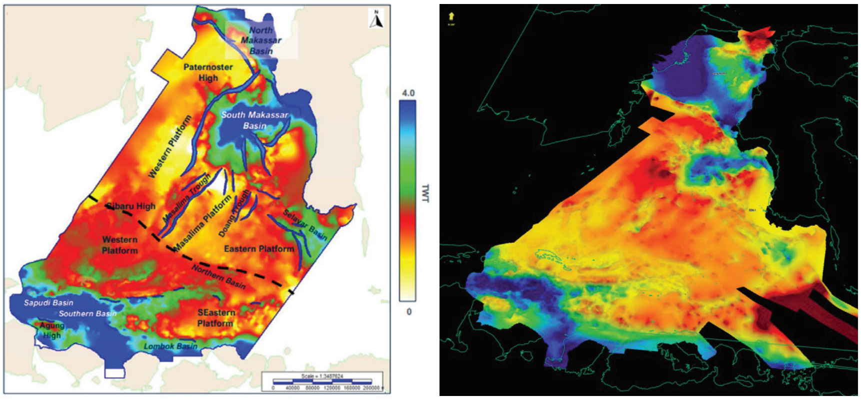

Figure 9 Cenozoic Isochron (seabed down to top Cretaceous) grid for the study highlighting potential depocentres for CCS aquifers and extended continuous 2D^{cubed} volume into the Kutei Basin.

ise variability in thickness. Equally important is the quantification of total overburden, as well as an assessment of internal geomorphological features and the integrity of sealing intervals that can act as caprocks.

Facies mapping within the study has enabled the delineation of potential aquifer zones. Lithological variations across these aquifers can be visualised using lithology pie charts plotted spatially on maps, helping to assess heterogeneity and connectivity at a regional scale (Figure 8). Seismic interpretation further contributes by identifying zones where aquifers are buried beneath a minimum of 800 m of overburden — considered a necessary threshold for long-term CO_2 containment.

Additionally, well data provides direct observations confirming aquifer intervals exceeding 50 m in thickness, along with insight into both the lithology and depositional facies of the overburden and potential sealing units.

Many of these essential inputs — facies distributions, thickness maps (Figure 9), overburden characteristics, and lithological profile — are already available as part of this FMB study. When integrated, these layers of information can be synthesised into a preliminary common risk map, supporting high- and low-grading of areas based on CCS suitability.

While this represents a strong foundation for early-stage screening, further refinement can be achieved through more advanced workflows. These include containment analysis, petrophysical and rock physics evaluation of both aquifer and seal units, detailed volumetric assessments of aquifers, and expanded sedimentological studies to better understand reservoir quality and caprock effectiveness.

Nonetheless, as a first-pass tool for regional CCS screening, this study provides a comprehensive and scalable framework for identifying viable storage sites, laying the groundwork for more detailed site-specific assessments in the future.

Key findings and the future for East Java

This integrated study of the East Java region has advanced the understanding of the area's geological evolution and sedimentary history. By combining stratigraphic interpretation, structural analysis, and seismic integration, the study offers valuable insights into the development of the petroleum system across key stratigraphic intervals.

Combining data and interpretation into cohesive, user-friendly interpretation tools, such as FMB, allows rapid analysis and geological prediction. This integrated approach accelerates the identification of high-quality reservoirs and source rock potential across large underexplored regions, significantly streamlining exploration decisions and collaborative analysis.

Importantly, the results of this study align with a resurgence of industry interest, as evidenced by recent a bid round block within the study area. This renewed attention underscores the exploration potential and relevance of the East Java Basin in the current energy landscape.

Beyond hydrocarbon exploration, the FMB provides critical datasets for evaluating the region's suitability for carbon capture and storage (CCS). Detailed mapping of overburden characteristics and potential aquifer distributions forms a solid foundation for initial CCS screening and feasibility assessments.

Looking ahead, the value of this work can be further enhanced by incorporating additional and more recent seismic datasets, such as the 6552 km West Sulawesi 2D survey and the South Makassar 3D volume (Figure 1).

In summary, the strategic use of advanced subsurface data is fundamental to the continued success of exploration efforts in the Asia Pacific region. The integration of modern seismic acquisition, advanced data processing techniques, and comprehensive interpretation platforms greatly improves geological insight and exploration outcomes, underscoring the critical importance of data-driven methodologies in discovering new oil and gas reserves.

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