New Insights into the Tertiary Petroleum Systems of the East Java Sea and Southern Makassar Strait, Indonesia

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Abstract

Modern broadband seismic data provides new insight into the Eocene-Miocene syn- to early post-rift sections of the East Java Sea (North Madura) and South Makassar Basin. Previous subsurface imaging suffered from shallow imaging obstacles and “hard” Eocene-Miocene carbonates, which render the interpretation of basement and overlying early syn-rift sections difficult. Thickness and distribution of these syn-sift sections differ significantly when comparing the North Madura area and the South Makassar Basin. Late syn- and early post-rift carbonate development also differs significantly in that a carbonate inter-reef blanket interrupted by pinnacle reef formation on top of a syn-rift section is present in North Madura. This contrasts with carbonate sections including bioherms that are controlled by the geometry of the underlying basement substrate and which occurs over extensive parts of the western South Makassar Basin. Early syn-rift including source rocks appear limited, requiring petroleum charge generation and migration form the central South Makassar Basin.

Introduction

Modern broadband seismic data acquired over 2582 km2 and 4049 km2 over off the coast of Madura Island and the western margin of the South Makassar Basin (Figure 1), respectively, provide new insights about deeper basin structure and stratigraphy. Subsurface imaging in both areas suffered from image deterioration due to shallower features but also from the high impedance contract of Paleogene carbonates which cover older syn-rift sections and basement. The new data image the carbonates and underlying stratigraphy as well as the basement, thus allowing characterization of reservoir sections and traps in relation to deeper structure. The East Java Sea/North Madura area has a successful exploration history that comprises a number of discoveries and fields, while the South Makassar Basin due to its distal location off the South Sulawesi coast and large water depths (averaging 2000 m) largely remains a frontier area.

Structural-Stratigraphic Setting

Both E Java and S Makassar share a comparable Paleogene tectonic history and stratigraphic succession with an Eocene onset of extension, development of a syn-rift sequence that is topped by carbonate deposition representing late rift-transition and post-rift phases. Figure 2 provides an overview over the lithostratigraphy and structural position of the study areas, which both cover transitional areas from platforms to deeper basinal settings. Late Eocene to Miocene carbonates are primary exploration targets. However, the older syn-rift clastic section in the E Java Sea (Ngimbang Fm.) is also a proven petroleum play. Carbonate buildups are the major carbonate reservoir facies in East Java. In contrast eroded Barai Fm. carbonates re-deposited in slope debris fans along the western flank of the South Makassar Basin have been proven reservoir in the Ruby field (Pireno et al., 2009). Basement potential was also proven by the Pangkat-1 well (for summary see Pireno and Darussalam, 2010)

Results

Modern seismic data provide a consistent image of the deep subsurface below the Eocene -Oligocene carbonates and allow inferences on deep structure and syn-rift development in relation to carbonate deposition. Thicker syn-rift sections on the western margin of the South Makassar Basin are limited to the eastern extension of the Pangkat Graben and basin center areas and are much reduced or non-existent

on an extensive basement high in the south of the survey area (Figure 3). This limits the chance of occurrence of syn-rift lacustrine and terrestrial coal source rock suggested to be the main petroleum system drivers in the Makassar Strait region (Argakoesoemah, 2017). However, seismic data also suggest that a carbonates platform developed directly over exposed basement (Figure 3). Basement structure and morphology strongly influenced carbonate development as illustrated in the example section in Figure 3, giving rise to various local carbonate facies developments such as bioherms and debris aprons along basement fault that may have reservoir potential. High impedance parallel internal reflector configuration is replaced by thicker and more transparent sections at fault scarps and around local basement highs. The carbonate platform edge can be mapped throughout the survey area and transition to slope and basin setting is recognizable (see seismic section in Figure 3). Internal reflector configuration from parallel to chaotic can suggest that carbonate debris was shed from the platform margin down slope into the incipient South Makassar basin center. Carbonate development appears to extend along the basin margin outside the survey area to the south.

The North Madura area is characterized by a number of large pinnacle reefs structures which have been successfully tested (e.g. Kujung I Fm. in well JS-14-A1). Some carbonate buildups are associated with faults extending from the basement across the syn-rift section but the apparent regional alignment along the inverted syn-rift section in E-W direction as illustrated in Figure 4 is more striking. Smaller buildups located between larger pinnacle reef structures and particularly off trend to the north are recognizable in seismic sections (Figure 5) and on coherency horizon slices, which allows detailed carbonate paleo-depositional environment interpretation.

Although not as prominent, the South Makassar platform carbonate evolution terminates with local bioherm development over the southern basement high. Figure 5 compares these bioherms with the pinnacle reefs of North Madura. While in South Makassar the bioherms rest on top of mostly parallel bedded reflectors there is a clear carbonate top and base tied to well data and recognizable throughout North Madura. The pinnacle reef containing carbonate section tops a predominately clastic syn-rift sequence. Internal buildup structure is parallel bedded to transparent, with a significantly higher internal impedance contrast in the South Makassar bioherms. Subsequent deposition and drowning of the reefs in North Madura is characterized by termination of overburden reflectors against the reef structures, while significant draping is recognizable in South Makassar. The former shows no sign of carbonate erosion or development of allochthonous carbonate facies in slope aprons or debris flows in the survey area.

Conclusions

Syn- and early post-rift section and carbonate development over North Madura and the western margin of the South Makassar Basin show significant differences in seismic expression and distribution. However, the syn-rift sequence in South Makassar also terminates with carbonate development that appears to include local growth of bioherms. Basement structure and paleo-morphology significantly determine the carbonate section development and allow for varied reservoir facies, whereas pinnacle reefs appear to be the major reservoir option in the North Madura area. Here, carbonate facies appear to be largely controlled by the syn-rift inversion, whereby pinnacle reef development aligns with orientation of the basin inversion. A significant part of the western South Makassar Basin margin was a basement high lacking syn-rift half grabens limiting the extent of source rock prone syn-rift section. Petroleum charge for reservoirs and traps need to extend from the Pangkat Graben extension area or the South Makassar Basin center (Courel et. al., 2011). Syn-rift sections that could contain source rocks however, are present over most of the North Madura area.

References

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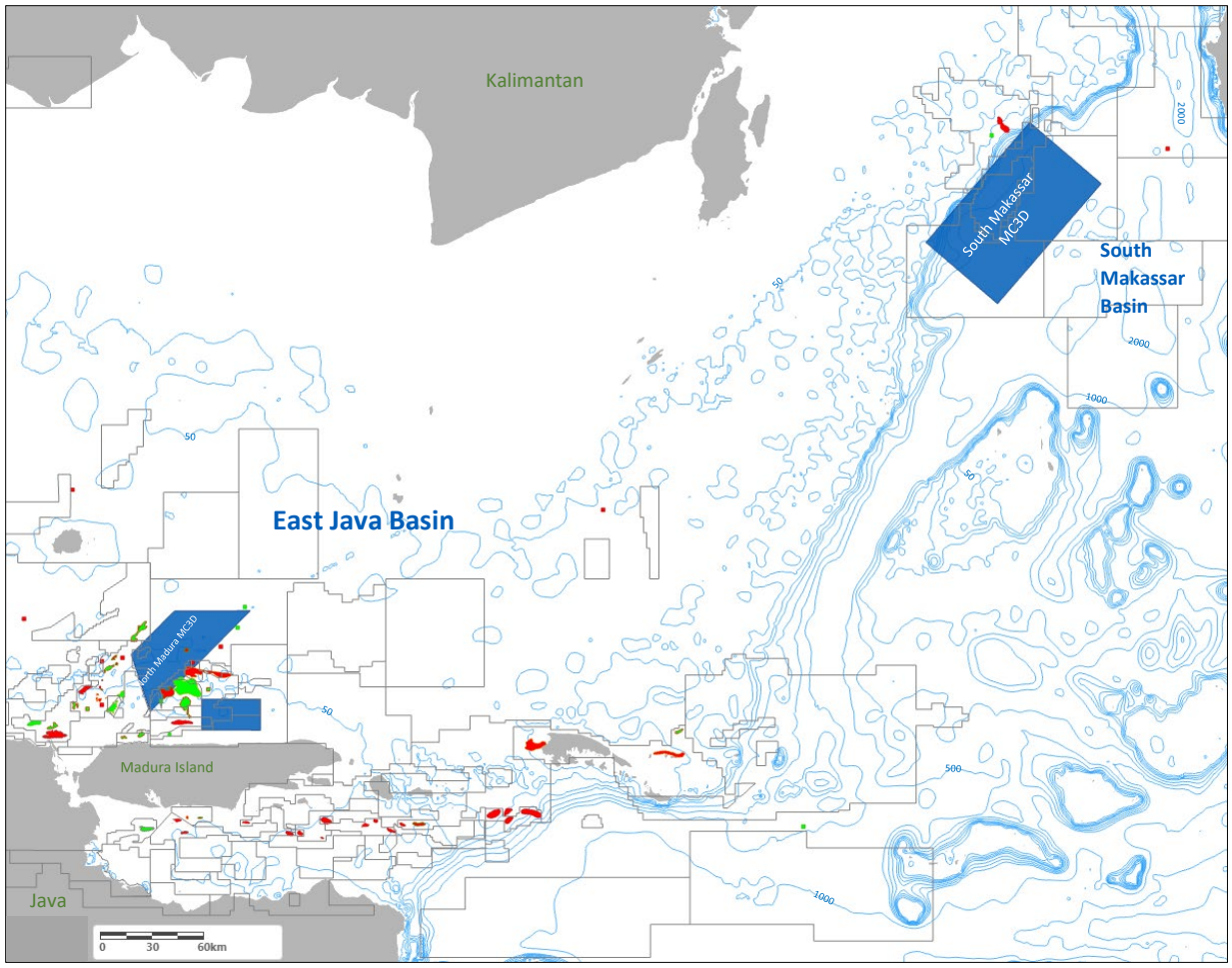

Figure 1. Study area overview, blue polygons: SMC3D survey locations, blue contours: bathymetry in m, green and red: oil and gas fields (IHS, 2022)

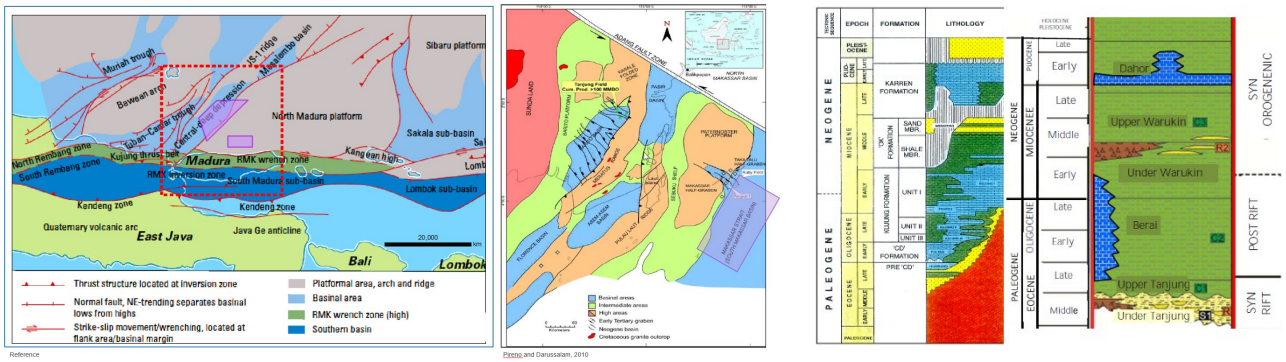

Figure 2: Overview over structural setting and simplified stratigraphy of the East Java and South Makassar study areas. Survey locations are highlighted by purple polygons.

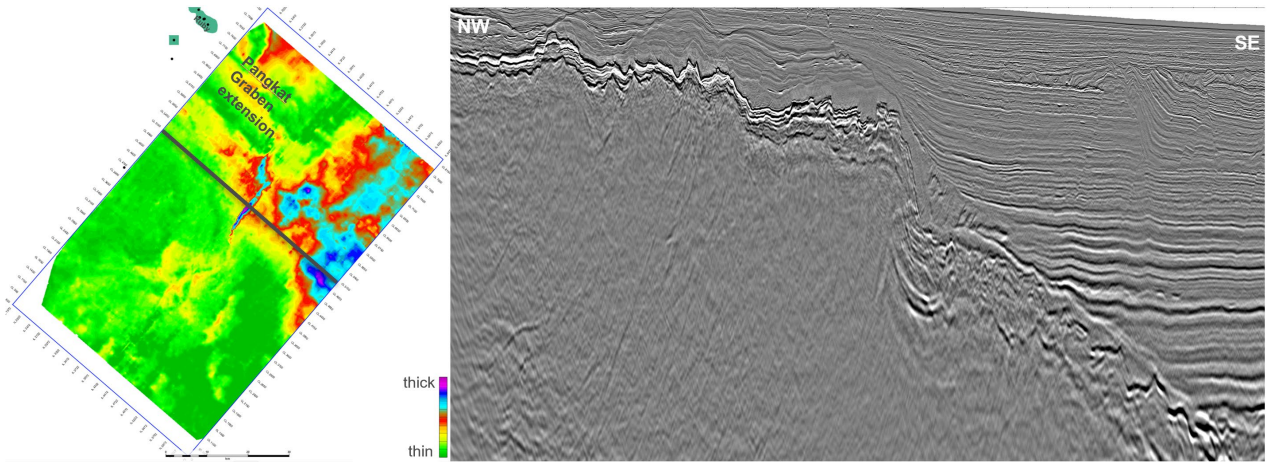

Figure 3. Top basement to top Berai carbonate isochrone over the South Makassar survey area (left, black dots outside map are well surface locations) and section exemplifying platform development on top of basement as well as transition to slope and basinal setting (right, approximate line location marked on isochrone map on the left).

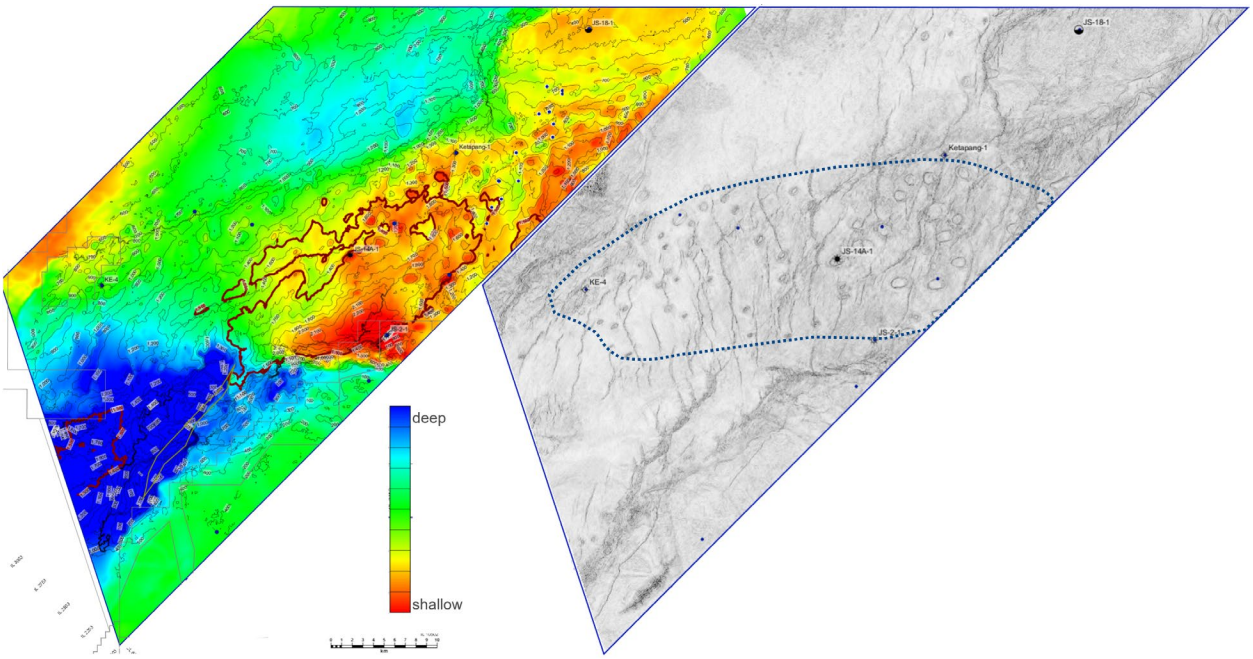

Figure 4: Left: depth structure (color) of top Kujung Formation with isochrone contours of the top basement-top Kujung section overlain in the North Madura survey. The thickest parts of the section are enclosed in the highlighted contour. Right: Coherency attribute on top Kujung Formation horizon, same survey area as left map, dashed line encloses area of significant pinnacle reef development (circular features on coherency attribute map).

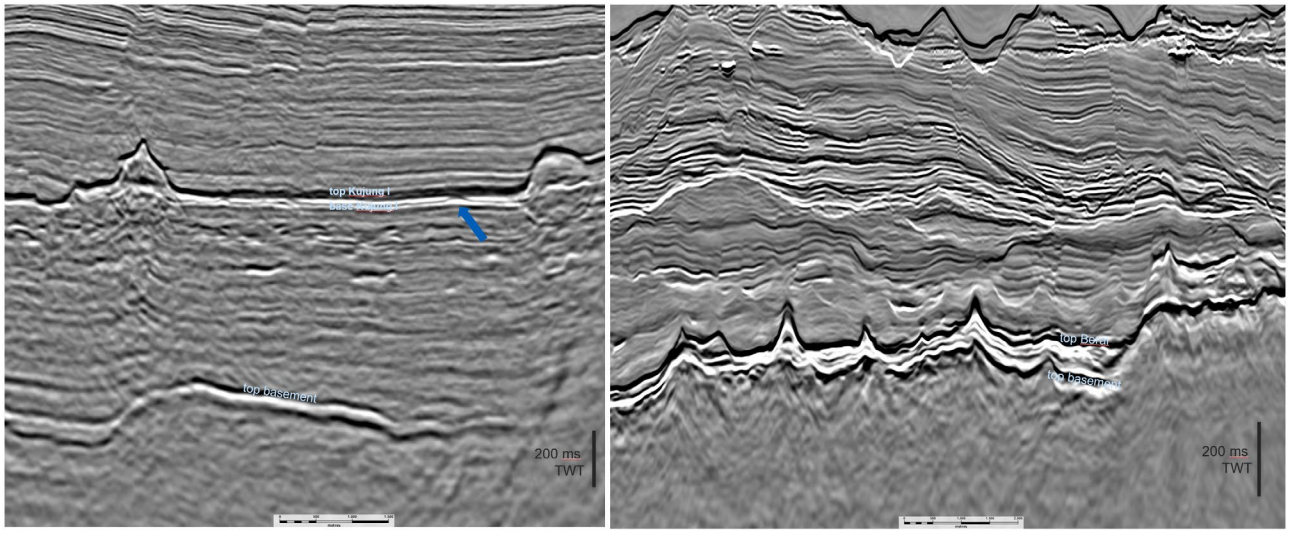

Figure 5. Full stack amplitude time section (black= hard response, negative reflection coefficient) of Eocene-Miocene carbonate buildup structures in North Madura (left) and the South Makassar Basin (right). Blue arrow on left panel points to smaller bioherm structures in the inter-reef facies in the Kujung I (left panel, top and base horizon correlation from nearby wells). Vertical bars indicate 200m TWT vertical scale.