

# EA The Heist of the Ngimbang “Vault” of the Madura Strait\*

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## Abstract

Currently recognized for its multiple shallow biogenic gas fields, the Madura Strait is also the habitat of a deep thermogenic petroleum system of likely greater value. Deeply buried and unprobed in the Strait, the Ngimbang “vault” possess, however, the essential elements leading to the generation of hydrocarbons and their effective containment. Surprisingly, direct evidence of the activation of the Ngimbang source can be identified 5 km upward within the biogenic gas accumulations.

The Madura Strait constitutes the easternmost expression of the East Java Basin, one of the Cenozoic inverted-back arc basins of western Indonesia. While those basins are relative analogs to each other and predictable in terms of thermogenic systems, the Madura Strait stands out with the predominance of an active biogenic system (Satyana and Puwaningsih, 2003). The area is associated with the repeated discoveries and successful developments of shallow dry and isotopically depleted gas accumulations from the Plio-Pleistocene Mundu Formation. Those accumulations are typically found at c.1Km burial depth, and can be grouped spatially into three clusters aligned along a distinctive East-West trend: Western Madura Strait, Central Madura Strait and Eastern Madura Strait ([Figure 1](#)).

## Geology

The presence of shallow biogenic targets in a part of the basin unaffected by the Late Neogene inversion and where traditional Eocene to Early Miocene plays have remained deeply buried, resulted in selective exploration of the area. Nonetheless, direct evidence of thermogenic activity exist just northeast, in the Kangean area, where massive structural inversion has occurred. There, the organic-rich facies of the Middle Eocene Ngimbang Formation are interpreted to source the thermogenic accumulations of the immediately overlying Ngimbang reservoirs ([Figure 1](#)). Across the Madura Strait, where only a handful of well penetrations exist in the Ngimbang Complex, Early Miocene Kujung discoveries westward (Widjonarko, 1990), and recent migration models eastward linking the Strait to the Kangean area (Bianchi et al., 2018), suggest that the Ngimbang source is also present over part of the Madura Strait. The southernmost extension of Ngimbang source facies is expected to reach at least the East-West limit defined by the shallow biogenic gas accumulations ([Figure 1](#)).

During most of the Neogene, the Madura Strait was subject to a substantial sediment deposition which led to the burial of the Ngimbang Complex to great depth (estimated burial depth > 6 km). Thermal alteration modeling demonstrates that the Ngimbang is virtually mature over the entire Madura Strait. Where inferred present, the Ngimbang source facies are predicted to be part of a narrow, East-West oriented gas window, running from onshore East Java to Eastern Madura Strait, in which three well-defined dry gas kitchens can be confidently defined ([Figure 1](#)). Interestingly, those dry gas kitchens show close spatial correlation with the three clusters of biogenic accumulations. The shale-dominated overburden of the Ngimbang Complex has been previously shown by pore pressure modeling as developing huge overpressure conditions across the Madura Strait (Bianchi et al., 2015), with also the presence of a net pressure reversal within the Ngimbang Complex itself (Vear and McGregor, 1996; Bianchi et al., 2018). In such setting and once the containment was ensured, the Ngimbang Complex acted as a vault in which thermal alteration of the source facies and its hydrocarbon products could have progressed undisrupted.

### Geochemistry

Although the Mundu gases are isotopically depleted, their detailed isotopic characterization show that they result in fact from a mixture of gases. This is exemplified by their abnormal enrichment of  $\delta^{13}\text{C}_2$  compared to  $\delta^{13}\text{C}_1$  (typically 20-50‰) in comparison with the Kangean Ngimbang gas (<10 ‰). This enrichment is irreconcilable with a co-genetic relationship between  $\text{C}_1$  and  $\text{C}_2$ , suggesting varying degrees of mixing of methane of different origins (Bianchi, 2019). With evidences supporting both presence and dry gas maturity of the Ngimbang source directly below the Mundu gas accumulations, the possible contamination from Ngimbang methane is addressed by developing a mixing diagram between the Mundu gas from the Eastern Madura cluster and the Ngimbang gas of the Kangean area ([Figure 2A](#)). The diagram uses  $\text{C}_2/\text{C}_1$  as a function of the  $\delta^{13}\text{C}_1$  (denominator of the  $\delta^{13}\text{C}$  ratio representing 99% of the whole methane analyte) and the mixing trend is therefore represented by the line defined between the two end members. All relevant measurements obtained from the Mundu gas of Western and Central Madura Strait plot on this mixing trend, supporting the underlying presence and activation of the Ngimbang source, and a heist of the Ngimbang vault at those locations.

### Conclusions

The post-mature geochemical signature of the Ngimbang gas indicates the extreme confinement conditions of the Ngimbang vault, but also that the heist has occurred rather late in the geological history of the Madura Strait. With the contamination of the Mundu gas recognized in both Western and Central Madura Strait, this also implies that a common mechanism affecting the two areas has been in play. From seismic, it is noticeable that the Mundu gas accumulations typically occur along deep-rooted faults re-activated during the Late Neogene inversion. A breach of the long-confined Ngimbang Complex during the Late Neogene by fault reactivation, and the use of those faults as migration pathways to the Mundu reservoirs some 5 km upward, appears then the most likely scenario in light of the direct and indirect evidence available. The associated plumbing system involves a large panel of plays to be present in the Madura Strait, within and in the vicinity of the Ngimbang complex ([Figure 2B](#)).

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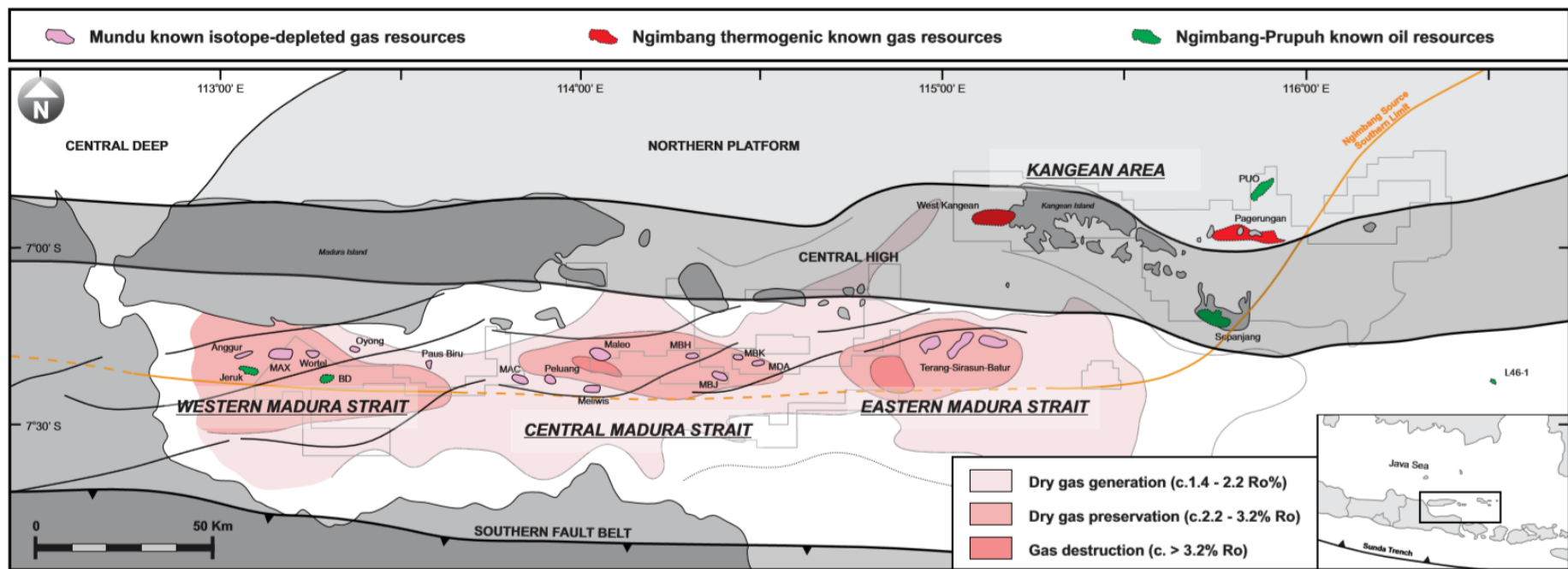


Figure 1. Reconstruction of the thermal alteration reached by the Ngimbang of the Madura Strait. The inferred southern extension of the Ngimbang source is indicated with the orange colored line (modified from Bianchi, 2019).

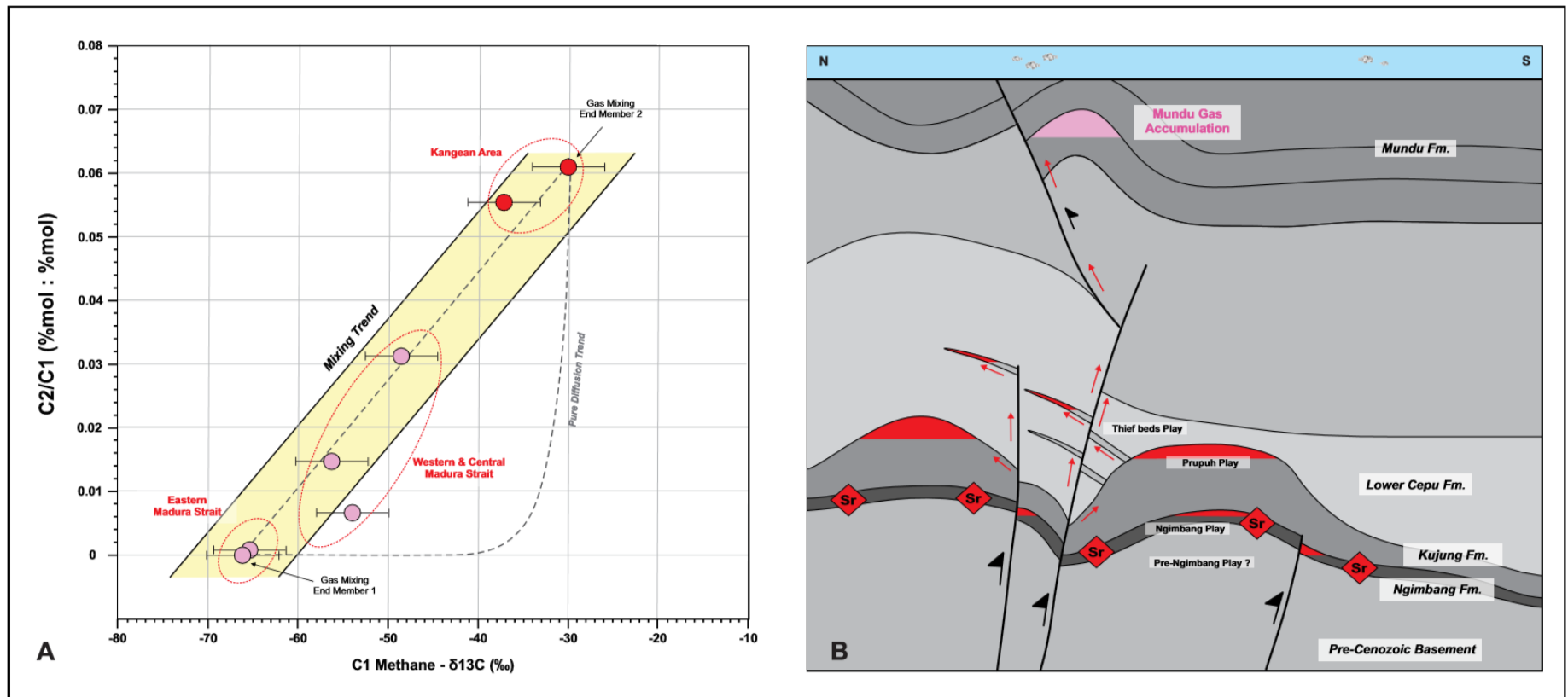


Figure 2. (A) Isotopic evidence of Ngimbang gas presence in the Mundu gas accumulations of Western and Central Madura Strait; (B) Conceptual model of secondary migration from the Ngimbang source and associated plays (modified from Bianchi, 2019).