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Controlling Factor in Pliocene Carbonate Reservoir Quality as Key to Evaluate Play Chances: Case Study from Mundu Carbonate from South Madura Strait - East Java Basin*

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Abstract

The Mundu carbonate of East Java Basin is a prolific oil and gas reservoir target. As a very successful play, Mundu carbonate associated with 18 discovered structures and seven dry holes. These carbonate reservoirs consist of more than 85 % foraminifera bioclast, and worth 3.5 Trillion Cubic Feet of Gas. The Mundu reservoirs is unusual compared to other carbonate reservoirs across offshore East Java due to total porosities which average above 40% and are often associated with very excellent permeability. However, factors controlling the reservoir properties remain debatable.

Introduction

To understand the diagenetic history and surficial process responsible to the quality of Mundu reservoir (Figure 1), a comprehensive study was conducted using more than 1008 core plug data along with sedimentology descriptions, XRD, SEM, stable isotopes and petrography analysis. Based on the meso to micro observation of core and petrographic studies there are five distinct carbonate facies in Mundu (following Ashton Embry and Klovan, 1971). The facies are namely; 1). Foraminifera grainstone, 2). Foraminifera packstone, 3). Foraminifera wackestone, 4). Foraminifera mudstone, and 5). Argillaceous foraminifera wacke-packstone facies. Bioturbation / trail facies dominated by skolithos and zoophycos facies. *Skolithos* facies are typically *Glossifungites*, *Thalassinoides*, *Palaeophycus*, *Teinichnus* whilst *Zoophycos* dominated by *Zoophycos* bioturbation facies.

Discussion

Lime muds are the predominant material found in the matrix with only minor amounts of detrital clay observed. In the interval where detrital clays matrices found, the facies tend to be associated with argillaceous wackestone or even claystone. Both matrix types appear as interstitial fillings within the rocks texture. The appearance of convincing deeper water foraminifera in Mundu always accompanied by the common to abundant appearances of shallow water calcareous larger benthic forams, mangrove associated pollen and spores, and shallow water *Rotaliids*/ *Milliolids*. In addition, sequential Strontium analysis from whole rock powder indicated 5.1 - 5.8-.ma age that is much older than Mundu defined by previous publications.

The range of $\delta^{18}O_{PDB}$ values from three wells with Mundu core is -17 ‰ to 0.3 ‰, and the range of $\delta^{13}C_{PDB}$ values is -13 ‰ to 1.3 ‰ (Figure 2A). The $\delta^{18}O_{PDB}$ values from MEL are slightly more extensive compared to OY well. More positive $\delta^{18}O_{PDB}$ values may reflect slightly colder seawater for the benthics found in Mundu from OY-2, while MEL showing more pervasive cementation at the base of Mundu. The $\delta^{13}C_{PDB}$ values in all wells indicating organic influence. This set of stable isotope values overlap with published foraminifera isotope values of globigerinids living in surface waters of modern Indonesia Sea (Mohtadi et al., 2002) (Figure 2B). It indicates no significant change of seawater temperature where tropical globigerinids of the Mundu lived in Pliocene to the present day ocean water. Overlap of stable isotope values between modern and Pliocene population's shows that foraminiferal tests in the Mundu reservoirs have experienced little or no diagenetic alteration since initial deposition on the Pliocene time seafloor. It also implies that the presence of overburden sediment, which can exceed 800 m atop the Mundu Formation and the associated loading stresses have exerted little or no influence to the diagenetic evolution of the fluids in the reservoir. This implies an early emplacement of hydrocarbon that may have shut down further fluid evolution.

Figure 2C compares relevant Miocene stable isotope values from East-Java Kujung carbonate to those from OY and MEL field. The isotopes from Kujung site indicate unique karstification characteristic. We can see clearly, the Mundu Formation in OY field shows no such burial-karst diagenetic overprint. Classifying the Mundu reservoir based upon facies (Figure 3A), sedimentary structure (Figure 3B), matrix cement (Figure 3C) and degree of bioturbation (Figure 3D) has allowed us to illustrate how each of these influence the reservoir quality and to determine which environment of deposition is likely to produce the best quality reservoir. In addition, clay components also control the reservoir property.

Mundu reservoir porosity is typically supported by matrix porosity and grain-to-grain porosity. The best reservoirs have total porosity between 45%-60% volume with permeability ranging from 100 milli-Darcy to over 4000 milli-Darcy. In this case, the best zones have less lime mud matrix filling and less clay association. Within this condition, the space between grains is still well preserved and only minor cementation occurs within the forams chambers. Mechanical process such winnowing and sea bottom current also keep the clay particles away from the clean reservoir. The bottom sea geometry during Pliocene enabled such internal waves flow emplaced plankton and foraminifera as an internalites deposit on the Pliocene shelf and shoreface.

The plots on Figure 3A illustrate that the best reservoir connectivity found in cross-bedded grainstone and glauconitic sandstone dominated facies. These types of rocks usually have a lower intensity of bioturbation and less lime mud matrix constituents, resulting in one of the cleanest reservoirs found within the Mundu strata. The bioturbated packstone is also a relatively clean facies where the bioturbation process has resulted in an improvement of reservoir quality. However, - this is not as great as expected due to the clogged porosity seen under microscopic observation. Lesser reservoir quality found associated with an increase of the interstitial clay fillings and the collapse of forams chambers due to the bioturbation mull over activity.

A third class of facies is the muddier limestone usually found at the base of the Mundu sedimentary cycle. Low energy and the dissipation of winnowing process have caused poor matrix sortation. Whereby clay and mud matrix have mixed and generate dirty grain sedimentation. The bioturbation in this zone is only associated with a low energy ichnofossil. Core scale observation shows intensely disturbed sedimentary structures with strong appearance of suspension sedimentary settling dynamics given the floating nature of the forams grains in the finer lime matrix.

The poorest quality facies are generally located near the base of the reservoir, which occur due to the nature of strata succession. Further, this package of tight strata also found as the topmost succession, creating a permeability barrier immediately above the cleanest reservoir, and often interpreted as a fining upward succession from core and log observations.

Conclusions

The studied Mundu carbonate gives a unique contrast when compared to the older Oligocene-Miocene carbonate from the surrounding area, especially when correlated with diagenesis and its impact on reservoir quality. Typically older carbonates from the surrounding area inevitably rely on secondary porosity such molds and vugs as its reservoir properties foundation. Contrast with the older Tertiary carbonates, the Mundu limestone reservoir diagenesis stalls when it passes the burial stage. There is clearly evidenced from cores where no pore types can be found to be associated with; karstification, cavern process, and macro-meso dissolution. Most of reservoir properties in Mundu are mainly the product of active surficial processes during the sediment emplacement where it mainly re-arranged through the marine cementation and mature burial stage.

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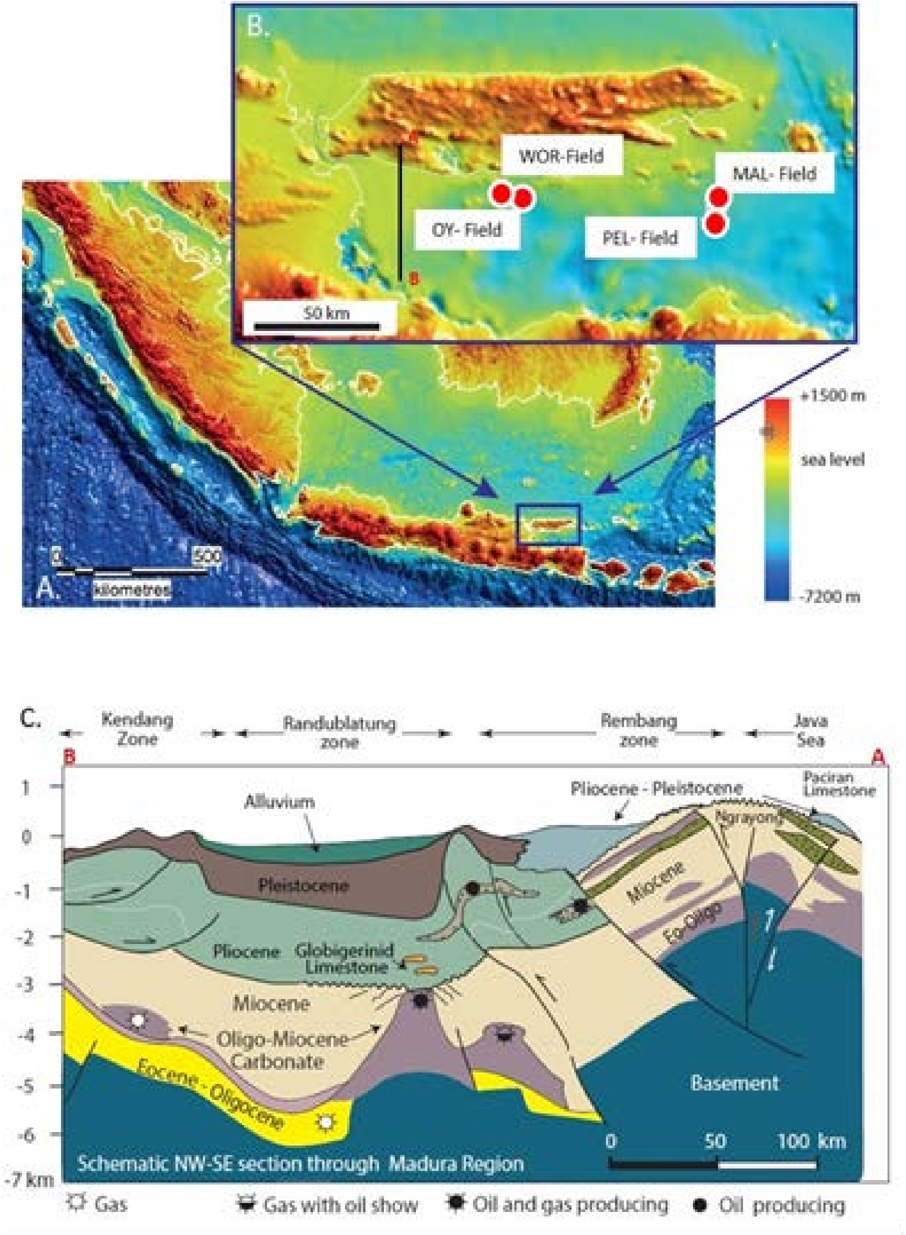

Figure 1. A) Map showing location of East Java Basin. B) Madura Strait location showing the location of studied field area. C) Idealized geological cross section across the studied area showing the Pliocene Globigerina Limestone Mundu.

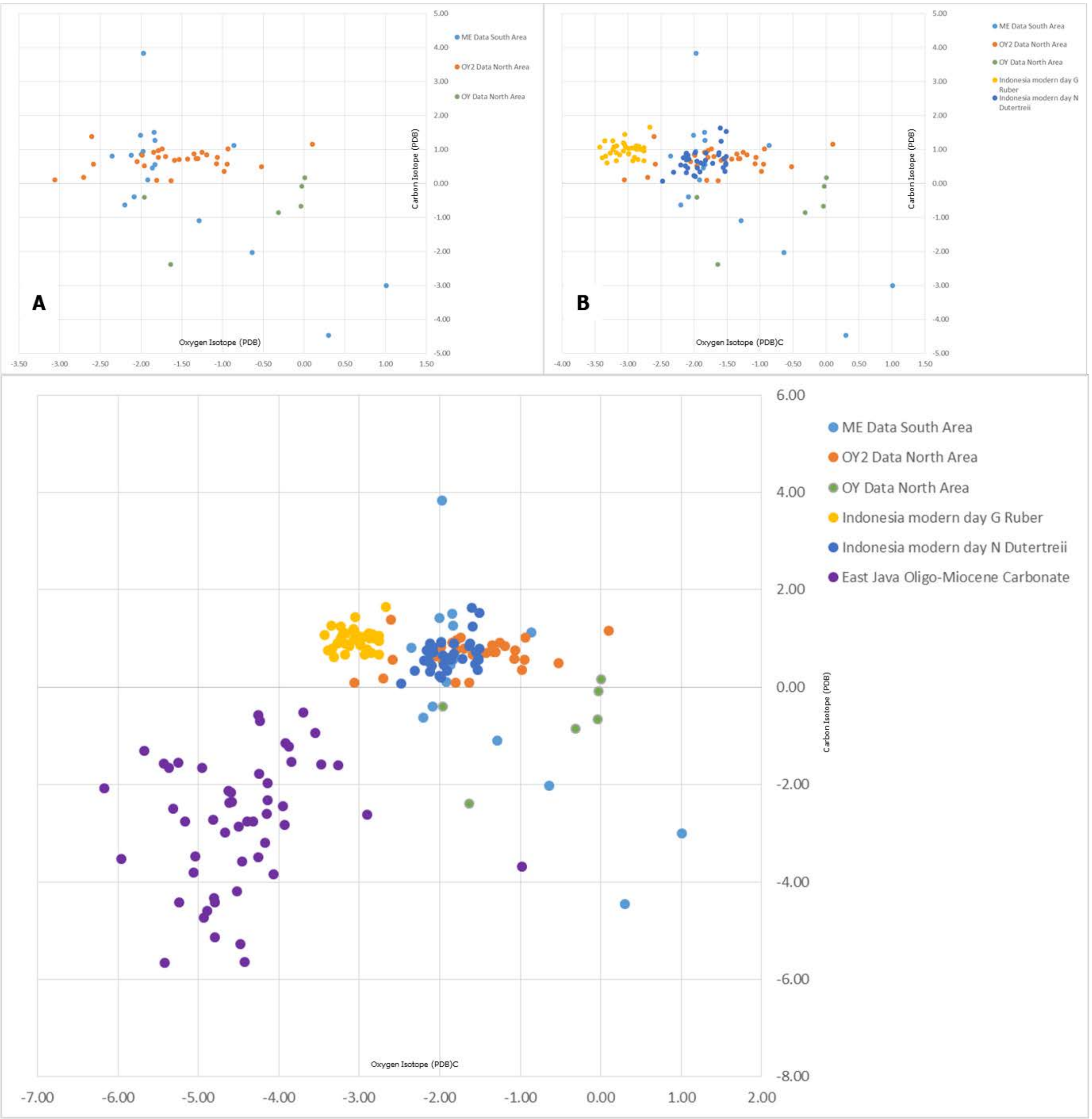

Figure 2. A) Stable isotopes from OY and MEL fields. B) Stable isotopes from OY field's forams compared with the cold water and warm water Globigerina from Mohtadi et al, 2002. C) Comparison of Mundu stable isotopes with Miocene carbonate from Kujung (Hehakaya, 2017).

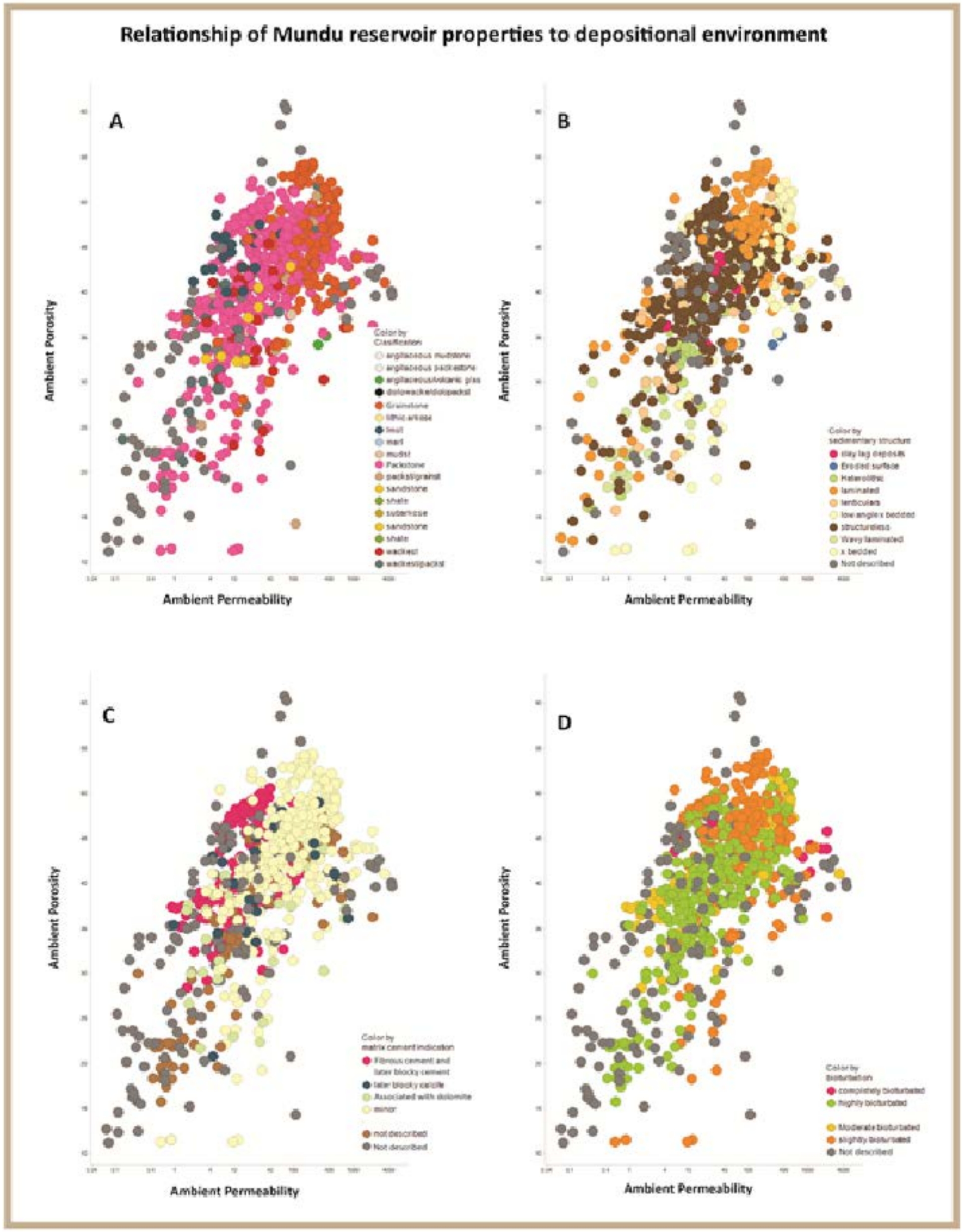

Figure 3. Compilation of reservoir property and quality relation from nine fields around Sampang and Madura area within the context of; A) Lithology Facies. B) Sedimentary structures reflecting surficial process. C) Diagenesis and cementation. D) Degree of bioturbation.