CARBONATE RESERVOIR CHARACTERIZATION AND ITS USE ON RESERVOIR MODELING : A case study of Senoro Field

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This paper was selected for presentation by a JFES program committee following review of an abstract submitted by the author(s).

ABSTRACT

The Mantawa and Minahaki carbonate sequence is the main hydrocarbon bearing reservoir of Senoro Gas Field, Senoro-Toili Block, Central Sulawesi. Carbonate reservoir of Mantawa Formation commonly recognized as pinnacle reef build up type which were growth in the structural high areas. On the other hand, Minahaki limestone is platform carbonate type which dominantly characterized by mud supported facies. In such reservoir, heterogeneity and reservoir distribution is the prime challenge in characterizing the reservoir. This paper describes the reservoir characterization study that focuses on rock type classification and its use on reservoir modeling. In preliminary process, conventional core and well-logs were integrated to obtain reliable information of depositional model, lithofacies, diagenetic history and reservoir rock type. Since cored interval is limited, the interpretation at cored interval was subsequently propagated to un-cored wells using electrofacies approach. Multivariate analysis was applied in order to determine the log type that corresponds with certain facies. It is indicated that sonic, neutron, VGR and secondary porosity index has a good relationship with facies description. Applying these approaches, reservoir rock type was identified and yields three rock type classes representing good, medium and poor quality. Rock type identification result was then up-scaled and co-simulated with AI attribute as secondary parameter. The final rock type distribution was utilized to guide porosity and permeability distribution.

TEXT

This study contains summary of reservoir characterization study at Senoro Gas Field, Senoro-Toili Block, Sulawesi Island (**Figure 1**).

This field was discovered by drilling Senoro-1 wildcat well in April 1999 and it was tested 13.7 MMSCFD of gas, with 2% CO_2 and 600 ppm H_2S. Since then, 5 (five) successful delineation wells have been drilled and tested in the Senoro structure in year 2000, 2001, 2005, 2007 and 2009, i.e SNR-2/2ST, SNR-3, SNR-4, SNR-5 and SNR-6 wells.

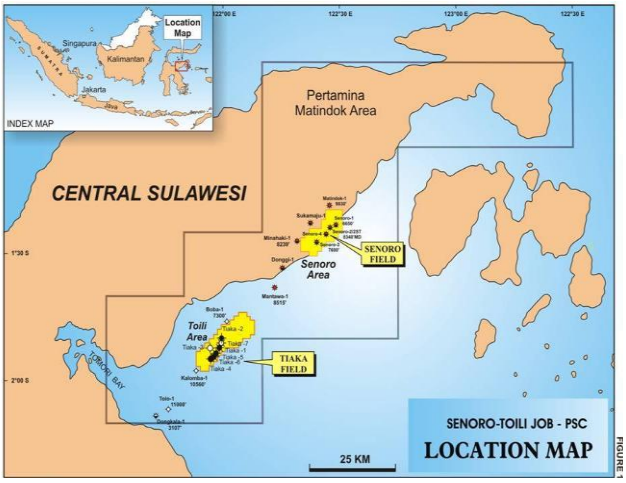

Figure 1. Senoro-Toili Block, Sulawesi Island

The Minahaki Formation represents the main reservoir target in the Senoro field and adjacent area of northern Tomori. It consists of platform facies carbonates (formerly referred to as the Upper Platform Limestone) and the reefal facies carbonate build-ups at the top, namely Mantawa Member. The Mantawa Reef Member at the top of Minahaki Formation generally provides excellent reservoirs in Senoro Field. **Figure 2** showing the depth structure map of Senoro field.

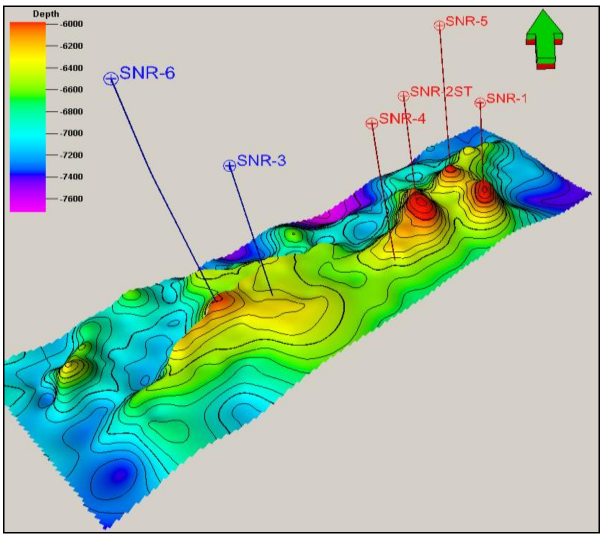

Figure 2. Depth structure map of Senoro field

The purpose of the study was to formulate a reliable geologic model of producing formations in Senoro field (Mentawa and Minahaki) based on available seismic data, well logs, core data and well tests. Petrophysical analysis and reservoir characterization combined with the geologic model was described to study the degree of reservoir heterogeneity at several scales, develop numerical techniques to predict facies and property distribution. The final reservoir distribution will be used to determine the optimum number, type and locations of producing wells and their drilling schedule for various development scenarios.

Geologically, Senoro-Toili Block is located in a tectonically complex area at the eastern arm of Sulawesi, formed by a collision process between Banggai-Sula micro-continent and East Sulawesi Ophiolite Belt.

The Banggai-Sula micro-continent was originally a part of the major Australia-New Guinea Continental Plate, which itself had been formed during the Mesozoic break-up of Gondwanaland. Following the break-up, the Banggai-Sula micro-continent drifted westerly directed by the South Sula-Sorong Fault. As the micro-continent continued its westward drift, a really extensive Miocene carbonate shelf with localized reef growth was developed along the micro-continent margin.

During the Late Miocene - Early Pliocene time, the Banggai-Sula micro-continental shelf collided with the East Sulawesi Ophiolite Belt resulted in folding, thrusting and imbricating structures of micro-continent shelf section, coinciding with the uplift of abducted East Sulawesi Ophiolites.

In the Pliocene – Pleistocene period, following over-thrusting and uplifting of eastern Sulawesi, as a result, an easterly-directed deposition of post-tectonic flysch and molasse sediments occurred in the thrust front basin. The Micro-continental shelf sediments were buried deeply, allowing the maturity of the Miocene source rock sections.

The stratigraphy of eastern Sulawesi is related to two distinct depositional time periods. The first representing a continental margin rift/drift sequence of Banggai-Sula deposition prior to the collision, and the second representing a foreland basin flysh-molasse sequences, deposited in front of an easterly-migrating thrust front after collision had occurred. A generalized stratigraphic diagram of the Tomori-Banggai Basin is presented in **Figure 3**.

A total 33 lines of 2-D seismic data (PSDM) with several vintages and six wells were used to define structural configuration of the entire Senoro field.

Two major reservoir types were identified based on seismic, log and core observations. Based on geometry of body recognized from seismic data, limestone in Senoro can be generalized into 2 types, namely build-up type and platform type. The platform type recognized as Minahaki Formation, which is widely developed in all areas. Meanwhile, the build-up type limestone (Mentawa) only developed in the northern part of Senoro Field. **Figure 4** showing the carbonate development across Senoro and adjacent fields (Minahaki and Cendanapura).

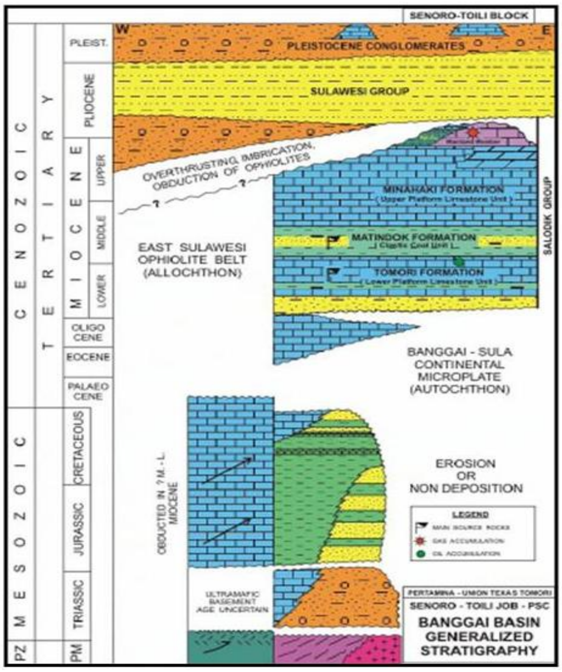

Figure 3. Stratigraphic column of Senoro-Toili Block

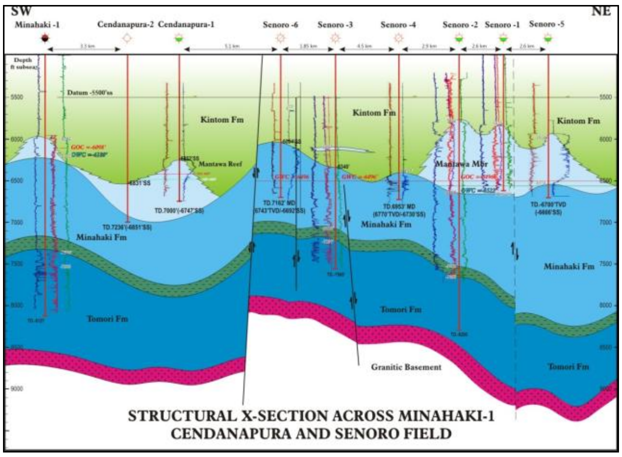

Figure 4. Structural cross section across Minahaki-1, Cendanapura and Senoro Field

Reservoir characterization was conducted to get a better understanding of the detail caracteristics of Senoro carbonate reservoir. An integrated analysis of wireline logs interpretation and detailed core description were (routine core and SCAL reports) taken from Senoro-2, Senoro-3, Senoro-4, Senoro-5 and Senoro-6. General reservoir characterization workflow is shown in **Figure 5**.

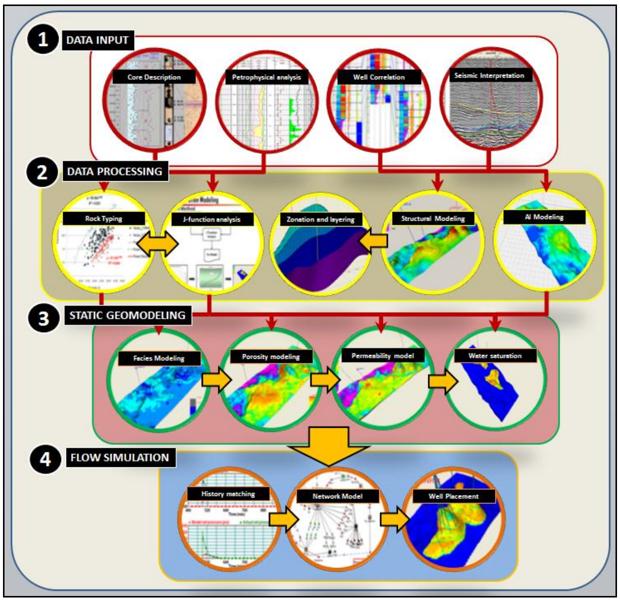

Figure 5. General reservoir characterization and simulation

Standard well logging such as gamma ray, density, neutron, sonic and resistivity logs have been run in entire wells. It was analysed to determine reservoir properties by applying the results of petrophysical parameters from core. A carbonate reservoir which composed by pure carbonates minerals commonly having low gamma-ray logs characters. The gamma-ray curve would tend to increase if associate with radioactive mineral content such as Uranium, which commonly rich with organic shale or organic carbon materials. For an example, as presented by the Senoro-05 and Senoro-06 wells, frequently at a certain depth the gamma-ray log curve increase drastically caused by the presence of shale or organic carbon streaks or breaks of dark color **(Figure 6)**. after validated by conventional core analysis. The common value of gamma-ray log curve for Senoro field, which represented by Senoro-1, Senoro-2 and Senoro-5 well for the northern area and Senoro-3 and Senoro-6 well for the southern area, ranges from (15 – 73) API and (23 – 55) API each for Senoro-5 and Senoro-6 well respectively.

The carbonate reservoir is composed predominantly by calcite mineral, and if associated with dolomite in number that quite significant would have high grain density value which ranges between (2.7 - 2.9) gr/cc. Whereas, the bulk density of carbonate rock itself will be vary depending on the contribution of porosity, permeability and fluid content. An increase in porosity or permeability value will certainly increase in reservoir quality, and at normal condition would commonly followed by decrease in bulk density.

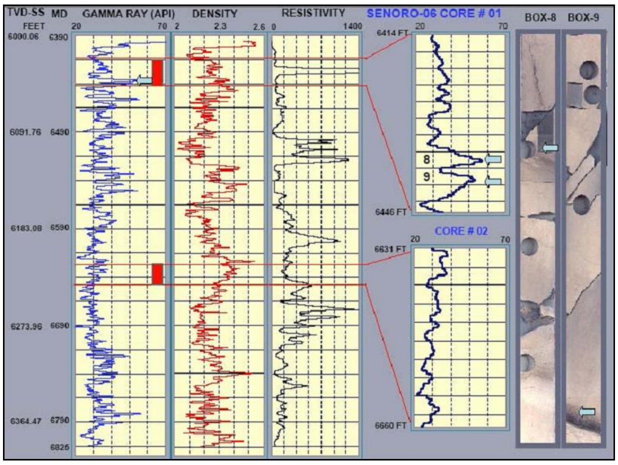

Figure 6. Gamma ray respons affected by organic shale and organic carbon streaks (core #1&2 of Senoro 6)

The Senoro-05 in conjuntion with Senoro-1 and Senoro-2 wells which represent the northern area, mostly illustrate the grainstone-packestone with abundant vuggy facies, and commonly reflected as reef build-up association (Mentawa Member). In other side, the Senoro-03 and Senoro-06 well, which represent the southern area showing no indication of reefal facies. Conversely, the whole cored of Senoro-3 and Senoro-6 wells has reflected a mud-supported bioclastic mudstone-wackestone and few packstone and grainstone facies with abundant chalky, which is interpreted as carbonate platforms of Minahaki formation. It is consistent with the depth interval of Senoro-06 well, which in general deeper than Senoro-05 well in the northern area. Based on detail conventional core analysis, it is interpreted that the carbonate reservoir in Senoro field has ever exposed previously to sub-aerial (Vadose zone). It is closely related to the regional sea level drop which occured during Miocene – Pliocene period. This event has a consequences towards the similarity of diagenetic events at both northern and southern area of Senoro structure. This similarity in diagenetic events can be best detected by using detailed conventional core analysis. In fact, such a similarity has also been represented on conventional core analysis where taken from Matindok, Donggi and Sukamaju fields, the adjacent area of Senoro field.

The process of re-crystallization of carbonate mud matrix and selective bioclasts as main diagenetic event, would altered carbonate rock become chalky, as clearly seen on the whole analyzed core. Further, the regional exposure of carbonate rock, as mentioned above, would prompt to the occurrence of dissolution process on carbonate body. This process of dissolution can be clearly seen especially in reefal facies which generally composed from original aragonitic minerals such as: coral, red algae, mollusks debris, ostracods and other marine biota. The reservoir qualities are slightly difference between northern and southern area of Senoro structure. A detailed discussion about reservoir qualities of Senoro field would be described in this section forward.

In the northern area, the carbonate reefal build-up of Mentawa Member has evolved significantly to a better reservoir quality caused by at least two diagenetic events. Firstly, the re-crystallization process of carbonate mud matrix will create micro-crystallin porosity in significant ways and also high distribution of secondary macro-porosity. The distributions of secondary macro-porosity such as moldic, vuggular and honeycomb porosities in conjunction with micro-crystalline porosity, almost throughout carbonate sequence, have been interpreted as main parameters that controlled significantly improvement on carbonate reservoir quality. The value of porosity and permeability which have been determined from routine core laboratory measurements have a ranging number from 22.42 - 39.57% and 5.04 - 180 mD respectively.

On the other hand, the reservoir quality improvement in the southern area of Senoro structure is not similar to the northern area. The carbonate rocks in the southern area of Senoro structure (Minahaki Formation) were dominated by carbonate mud matrix (mud supported fabric) and planthonic globegerinids foraminifera. It will probably causing the porosity type in this area were predominantly by micro-intercrystalline porosity which formed within micro-crystal calcite and micro-dolomite and commonly have less than 8 micron in diameter size. The macro secondary moldic and vuggular porosities were only developed in restricted interval. The porosity commonly has low value, rely on petrography analysis; approximately 8.00% in average with the highest value is 13.5%.

The next challenging work was to use lithology characteristics from core description as a reference to classify facies, which reflects the lithology and diagenetic characteristics. The classification result indicate that Senoro field can be divided into 6 general facies, namely mudstone to wackestone, packstone, grainstone, abundant vuggy limestone, limestone abundant biomoldic and limestone abundant chalky. Subsequently, facies was simplified into 3 classes based on linear porosity-permeability cross plot i.e good (represented by grainstone and limestone abundant vuggy), medium (represented by packstone and wackestone with abundant biomoldic), and poor (represented by mudstone-wackestone with abundant chalky). The porosity vs. permeability cross-plot for each facies is formulated in **Figure 7.**

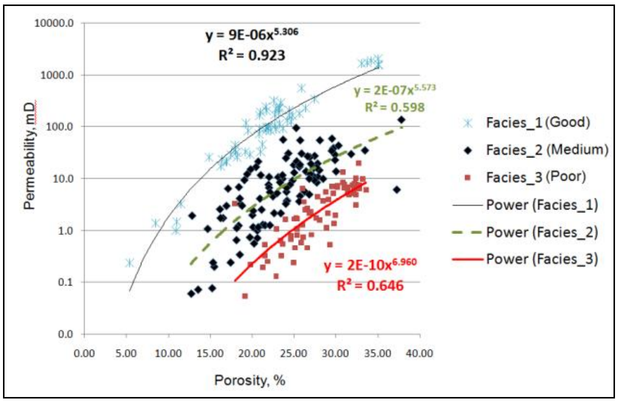

Figure 7. The porosity vs. Permeability cross-plot for each facies (rock type)

Further, callibration between core-well logs was made to propagate the defined facies at un-cored intervals (electrofacies). Hence, multivariate statistical analysis was applied to determine the probability log that corresponds to particular facies. This analysis was selected as a tool because it has the capability to delineate complex relationships between facies and log data, and it allows more than two variables to be analysed at the same time.

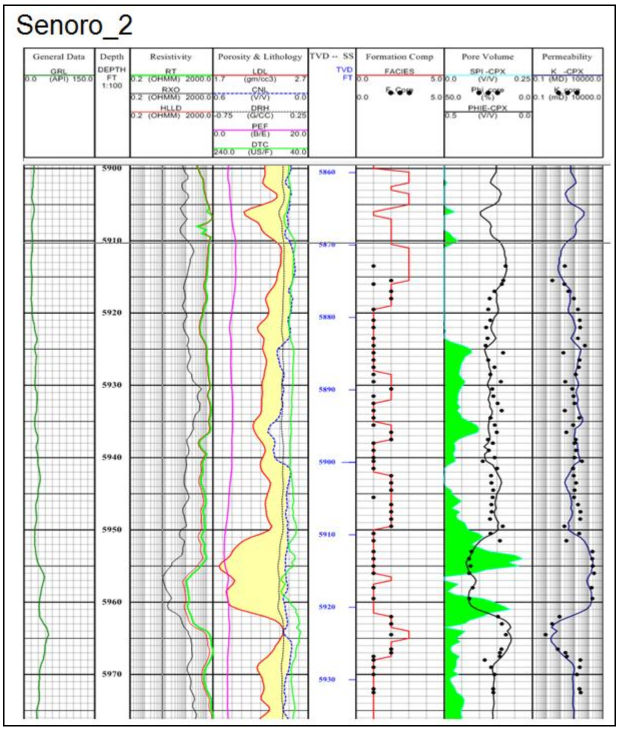

Figure 8. Comparison between core derived facies data and facies prediction result

Applying this approach, 4 logs were likely justified for e-facies propagation i.e DT sonic, neutron, VGR and secondary porosity index (SPI). VGR is the clay content acquired from the calculation of the gamma ray log, in this study VGR was used to normalize the gamma ray log. SPI on the other hand, is the discrepancy of sonic derived porosity and density-neutron derived porosity, which in turn reflecting abundant vuggy facies. In this study, the multivariate algorithm was gave good prediction accuracy. **Figure 8** shows the comparison between core derived facied and facies prediction results. After facies description (rock type) has been successfully predicted, integration of all available information about the reservoir was developed to obtain a better understanding of the reservoir. Starting with the structural and geological modeling, estimation of reservoir petrophysical properties using geostatistical tools, reserve calculation and finally, analyzing the uncertainty.

Structural modeling was conducted to define the geometry of the hydrocarbon-bearing formation by combining seismic and well data. In this process, faults, seismic horizons and geological data were integrated (Bahar A, 2007). Senoro field has 2 major faults with trending relatively NE-SW direction. Those faults are connected to each other and separate Senoro field from adjacent Cendanapura field, which is located in the SW of Senoro area. Grid block resolution and trend was defined based on minimum well distance and fault direction respectively. In Senoro, 100 x 100 m grid size was selected with NW-SW direction. Five horizons were interpreted based on seismic and detail well correlation. Accordingly, Mentawa reef was devided into three horizons (Upper, middle and lower zone), whereas Minahaki consist of 2 horizons.

Following the structural modeling, facies and porosity model were then distributed based on geostatistical approach. Sequence Indicator Simulation and Sequential Gaussian Simulation with trend were used for distributing facies and porosity, respectively. AI impedance map was incorporated as secondary input (collocated co-krigging), since correlation coefficient showing a good agreement (-0.8).

Permeability Modeling was formulated for various rock type based on porosity-permeability transforms. Whereas water saturation distribution was calculated from capillary-gravity equilibrium using the J-functions and irreducible water saturation transform defined from core data and transition zone analysis.
The final process of static reservoir modeling was volume calculation and uncertainty analysis.
Original gas in place value (OGIP) was calculated using base case values and functions for all parameters. Afterwads, sensitivity of OGIP value to variations in key parameters (defined in the base case) was done by defining low and high limits for each parameter. After carefully assessed the static geomodel, fine grid geologic model was subsequently up-scaled into bigger grid size for further dynamic flow simulation process.

ACKNOWLEDGEMENT

The Author wish to thank the managements of JOB Pertamina-Medco E&P Tomori Sulawesi, Medco Exploration & Production Indonesia and BP MIGAS for their permission to publish this paper.

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