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Parigi Carbonate Reservoir for Underground Gas Storage in West Java, Indonesia

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Abstract - This paper focuses on the characteristics and distribution of shallow reservoir carbonate in an underground gas storage. This study was done on Parigi carbonate as a significant reservoir carbonate in West Java Basin. The carbonate is abundant, and it occurs at shallow depths 800 to 1000 m below sea level. This formation broadly spreads out in onshore and offshore West Java areas as platform and build-up carbonates. The development of build-up carbonates is mostly in a low relief offshore. They well-developed onshore where the build-up exhibits coral reef frameworks, high relief, reaching over 450 m in thickness. The carbonate outcrop in Palimanan, western Cirebon which has been studied is grouped into four types of lithofacies. The preservation condition of this carbonate reservoir is important, for the storage capacity can inject a big gas volume. The porosity and permeability parameters are the most influential factor in reservoir evaluation. The parameters for gas storage in this field are within the range of the existing field parameters in Europe and America.

Keywords: Parigi, gas, carbonate, reservoir, porosity, permeability

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Introduction

Background

A depleted gas reservoir as underground gas storage is economical and effective for gas storage strategy, which means it continuously in safety role and supply of gas. Underground gas storage systems have been applied in Europe, Australia, the US, and China (Dussaud,1988; Evans and Chadwick, 2009), but not in Indonesia. This study is an effort to introduce the underground gas storage to be applied in depleted oil and gas fields in Indonesia. This is an early stage of underground gas storage feasibility. Thus, designing, evaluating, and operating gas storages need to be continued to discuss until a project can be implemented in a depleted field in Indonesia. Carbonate rock is a good reservoir for underground gas storage. Parigi carbonate, deposited about 800 to 1100 m below sea level, is a candidate for this study, because it has been proven as an oil and gas reservoir in a few fields in the West Java Basin areas (Sudarmono *et al.*, 2003). Several elements that characterize storage reservoirs such as porosity, permeability, body shape, type of caprock, size of the volumetric, and depth location of the reservoir will be discussed in this paper.

Feature of Parigi Carbonate

The studied field is situated about 180 km SE of Jakarta, in the Jatibarang Subbasin. It is one of several sedimentary subbasins in West Java Basin, controlled by N-S host and graben structures that were reactivated during the Pliocene (Ryacudu and Bachtiar *et al*., 1999). The northern part of West Java Basin is bounded by the Sunda Platform, southern part by Bogor Trough, eastern part by Karimun Java Arch, and the western part by Seribu Platform (Figure 1) (Noble *et al*. 1997). The Parigi build-ups were deposited in a shallow marine platform setting during inactive regional tectonics. Moreover, the development of Parigi build-ups is on the paleo-highs which are not necessarily associated with basement paleo-structural features. Offshore, the development of carbonate build-up is mostly in a low relief. It well developed onshore where the build-up exhibits coral reef frameworks, high relief, reaching over 450 m in thickness. The outcrop of this carbonate occurring in Palimanan, West Cirebon has been studied and it is grouped into four types of lithofacies (Jambak *et al*., 2015).

Methods and Materials

The main method of this study is to compare the main parameters of the Parigi carbonate reservoir with the existing underground gas storage in European countries, Australia, and in The United State. A depleted field in Jatibarang was selected for this study. Subsurface data such as seismic cube and well logs were used for analyzing the reservoir characteristic. The average static pressure is between 1,170 - 1,330 psi, and the historical pressure data of this field was obtained from the measurement of static pressure data conducted at various wells and measurement times.

Underground Gas Storage in Overseas

The use of underground gas storage has been done in many developed countries in American Continent (The United States, Canada, and Argentina) and European countries such as Austria, Belgium, The Netherlands, Croatia, Czech, France, Germany, Hungary, Poland, Romania, Russia, Spain, and The United Kingdom. In the Asian/Australian continents, they are Azerbaijan,

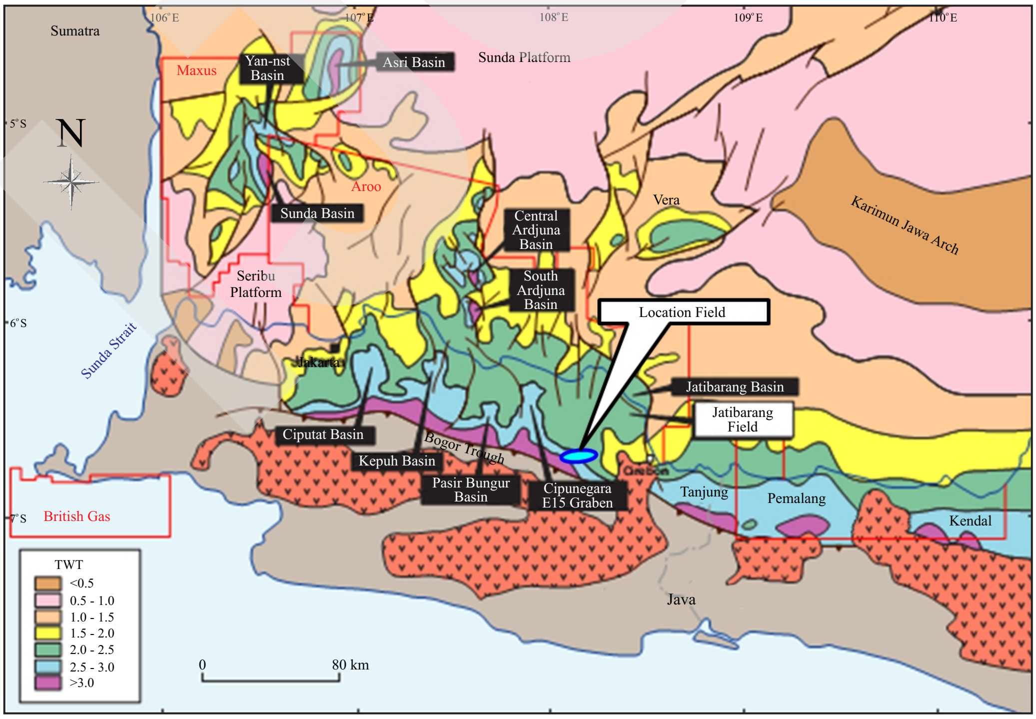

Figure 1. Regional setting of West Java Basin and location of the studied area . (Nable *et al*., 1997).

Uzbekistan, Australia, Iran, China, Japan, and Korea (Dussaud, 1988).

In Australia, the underground gas storage is at the Mondarra field in Perth, western Australia. This gas can flow directly (free flow) or be taken using a compressor as much as 150 TJ/day or 6.25 TJ/hour. The gas flows through several necessary processes and procedures before being distributed to consumers (APA.com.au, 2013). To anticipate peak market demand (winter) and emergency gas reserves, Denmark gas companies provide underground gas storage at the Torup salt dome located in northern Denmark (Hjuler *et al*., 2016).

Gas Storage in Aquifer Layer in France

France uses two salt caves and eleven aquifers for underground gas storage, operated by a France company. In France, gas storage is necessary for stabilizing the gas supply with market demand. Therefore, they put a surplus of summer gas into the storage, and channel it during the winter season (Dussaud, 1988). Depleted oil and gas fields for natural gas re-storage has been used extensively in The United States for the past sixty years. In France, the procedure has only been used since 1956 using aquifer techniques to store gas due to the lack of availability of oil and gas fields.

An underground storage in an aquifer layer is an artificial reproduction of a natural gas field created by removing some of the water from the aquifer reservoir by injecting the gas. To use this type of storage, it is necessary to study tectonics and geological structures in the reservoir rock by observing its porosity and permeability and the layer cover above it (caprock). A lot of time and effort was put into finding the reservoir and researching its feasibility as a place to store natural gas. It takes about 5 years from the beginning of the prospect location survey up to the first gas injecting. Table 1 shows the number of underground gas storage in France since 1956.

Results and Discussions

Parigi Carbonate Reservoir Evaluation

The challenges of evaluating carbonate reservoirs are more varied. Therefore, various reservoir parameters need to be identified and marked before the results are properly tested. The history of its formation must be understood, then matched, and modeled. Procedures for identifying and characterizing by petrophysical means will be useful to help solve some of the major challenges faced in the exploration and production of carbonate reservoirs. Geophysical methods will

Table 1. Subsurface Gas Storage in France

Underground gas storage operated by Gaz de France (as of January 1, 1989)							
Underground storage	Type	Beginning of operations	Thickness of overburden (above reservoir)	Ultimate reservoir capacity million m³ (n)	Compress or rating (kW)	Number of output wells	Number of observation wells
Beynes Suptrieur (Yvelines)	Aquifer	1956	405	475	9700	14	14
St. Illers (Yvelines)	Aquifer	1956	470	1260	23800	28	16
Chemery (Loir et Cher)	Aquifer	1965	1120	6000	29900	55	20
Tersanne (Drome)	Salt Cavety	1970	1400	425	6500	11	-
Cerville - Velaine (M.et-Moselle)	Aquifer	1970	470	1375	18700	36	16
Beynes Profond (Yvelines)	Aquifer	1975	740	800	3300	24	11
Gourmay-sur-Aronde (Olse)	Aquifer	1976	750	3100	11600	40	15
Etres (Ain)	Salt Cavety	1979	1400	1000	5600	6	-
St-Clair-sur-Epte (Val-d'Oise)	Aquifer	1979	742	600	5100	9	17
Soing-en-Sologne (Loir-et-Cher)	Aquifer	1981	1135	700	7200	8	16
Izaute (Gers)	Aquifer	1981	487	3000	7200	16	9
Germigry-sous-Coulombs (seine-et-Marne)	Aquifer	1982	892	2200	7200	16	22

help analyze the facies of carbonate deposition. Parigi carbonate forms excellent reservoirs owing to the presence of high porosity (average 30%) and permeability (up to 2 darcies). The wide-spread distribution of build-ups in offshore and onshore West Java Basin is an important factor to analyze the carbonate facies of high-quality carbonate reservoirs in this area.

The result of the onshore Parigi carbonate outcrop study northeast of the field area by Jambak *et al*. (2015) is analog to the Parigi carbonate reservoir in the studied area. The Randegan and Palimanan are located about 30 km to the east of this studied area. The four Parigi carbonate lithofacies in Randegan and Palimanan are interpreted from top to bottom as follows: 1) Mudstone-wackestone Facies, 2) Wackestone-packstone Facies, 3) Packstone-grainstone Facies, and 4) Mudstone-wackestone in the bottom part. In this study, the environment of deposition, facies, and diagenetic processes are studied using Well logs and 3D-seismic analyses. Porosity logs and density logs are to understand the porous zones in the Parigi build-up.

Well Log Evaluation

The analysis of a few well data was done by using GR, RHOB, and Facies logs. GR log detects the shale content of sedimentary rock formations. The sandstones and carbonates normally exhibit low radioactivity response, while the clays and shales show higher response in the API unit. The RHOB log is to measure *in-situ* bulk formation density in g/cm^3 and is defined as the overall density of the rock. The Carbonate Facies log indicates wackestone-packstone in the bottom and upper part of the Parigi build-up. The middle part is dominated by packstone which is an abundance of moldic type porosity (resulting from the preferential solution of certain grain types and leaving recognizable grain outlines).

Those logs analyses produced five different bed boundaries, such as Top Parigi (Parigi Zone-A), Parigi Zone-B, Parigi Zone-C, Parigi Zone-D, and Bottom Parigi as shown in Figure 2. The gas-oil contact and oil-water contact are well identified in the upper part of carbonate build-up. These tops are applied in seismic facies analysis. The Parigi carbonate boundaries (top and bottom) can be differentiated clearly from the GR log and lithology change. The carbonate facies log is not well interpreted due to very limited data from cores in the whole Parigi carbonate section, such as lack of fossil data, and all the sections based on Dunham classification (1962) are classified as packstone and wackestone lithofacies only. The

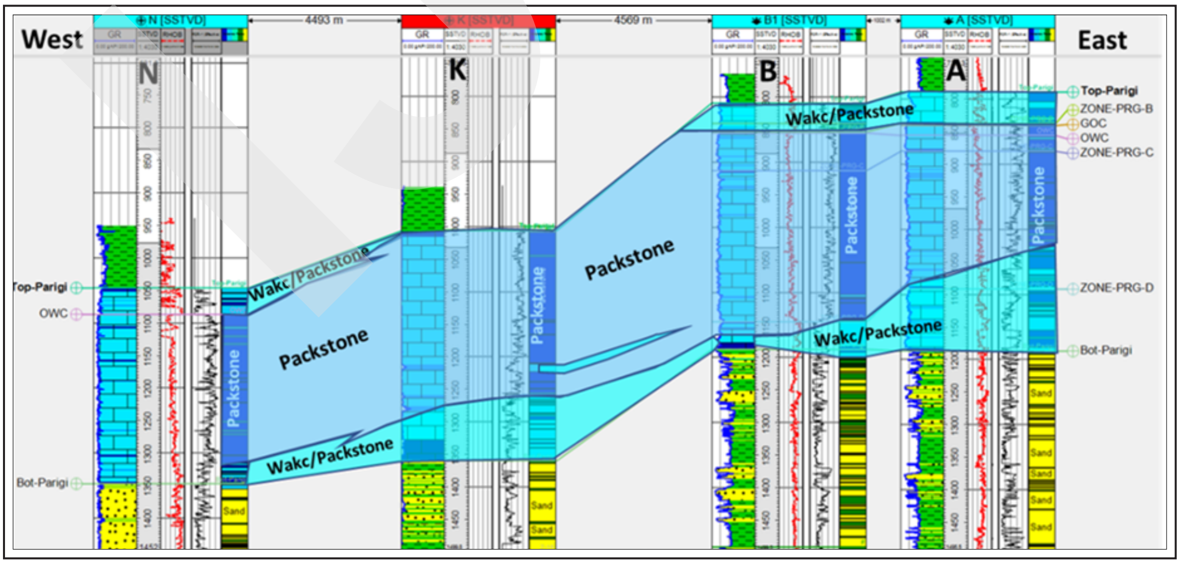

Figure 2. Indicator of top and bottom Parigi carbonates from drilling and wireline logs. The upper and the bottom part of Parigi carbonates indicate wackestone-packstone facies with good porosity and permeability indications. The middle part is dominated by packstone with moldic type porosity.

outcrop study of Parigi carbonate in Palimanan identifies four lithofacies for the whole carbonate section, and these facies analog to subsurface Parigi carbonate in this field.

The lithofacies sequence is correlating to the Parigi carbonate outcrop in Randegan and Palimanan area. The upper part of build-up is the best for underground gas storage.

Seismic Facies Analysis and Results

Four wells with varied data set, including wireline, mud logs, and completions reports, are used in the study to establish regional correlations of five litho-stratigraphic surfaces (Top Parigi, Top Parigi-B, Top Parigi-C, Top Parigi-D, and Bottom Parigi). The 3D seismic data is incorporated in the workflow to aid the interpretation of the relative position of depositional environments.

The 3D seismic coverage in the study area is used to define overall build-up geometry and identify the potential reservoir closure for underground gas storage. The seismic facies boundaries of Parigi carbonate sequences are interpreted based on the log evaluations and characteristics of seismic reflections such as mounded, parallel, clinoform, progradation, etc. (Sukmono, 2010), shown in Figure 3. The geometry of Parigi carbonate is a product of shaping the depositional surface, changing base level, and accumulating sediment. Based on the seismic characteristic and distribution of Parigi carbonate, the surfaces can be divided as Parigi Zone-A (upper part), Parigi Zone-B (upper part), Parigi Zone-C (middle part), and Parigi Zone-D (bottom pat) for seismic facies interpretation of the carbonate zones (Figure 3).

The Parigi carbonate lithofacies study in the Palimanan outcrop is correlated to the subsurface Parigi carbonate in the study area. The analogue from top to bottom as follows: 1) Outcrop mudstone-wackestone facies=seismic Parigi Zone-A (wackestone-packstone), 2) Outcrop wackestone-packstone facies=seismic Parigi Zone-B (wackestone-packstone), 3) Outcrop packstone-grainstone facies=seismic Parigi Zone-C (packstone), and 4) Outcrop mudstone-wackestone facies=seismic Parigi zone D (wackestone-packstone) in the bottom part. The oil-water contact, and oil gas contact are well identified in

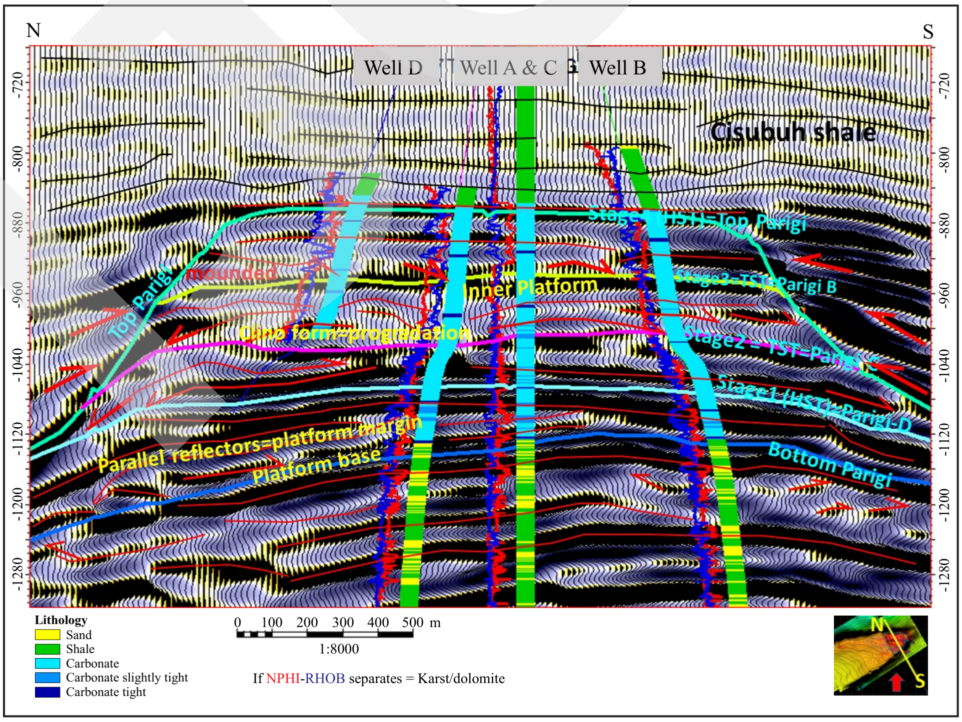

Figure 3. Reflection configuration of Parigi carbonate indicates platform margin facies, progradation clinoform, inner platform, parallel, and mound.

the upper part of carbonate build-up by flat spot within Zona-A and Zone-B at about -950 m.

Zone-A is characterized by mounded facies and dominated by wackestone and packstone facies. The facies identification is also carried out by the distribution of FMI (Formation Micro Imager) data log from well and core data as well. This facies zone is estimated as the best reservoir zone for gas storage within the Parigi carbonate layer in this depleted field.

Seismic Attribute Analysis and Results

A seismic attribute extraction is done to know the reservoir characteristic. The RMS amplitude attribute is used to interpret the lateral distribution of the Parigi carbonate in the studied area. Interpretive analysis is to evaluate reservoirs using the RMS amplitude attribute by the assumption of the small size of the amplitude value which is often called *bright spot*.

The brighter the bright spot (the amplitude contrast) the better the porous reservoir or hydrocarbon prospect indication in that location, because the higher the bright spot indicates the large porosity, small density, and possible hydrocarbon. In this study, the RMS attribute was sliced at time 1,156 ms (carbonate Zone-C) which is a reservoir interest zone. The red colour shows a large contrast value of amplitude, while yellow and blue colours indicate a low amplitude (Figure 4). The north build-up is evaluated for underground gas storage.

RMS amplitude is one of the seismic attribute methods in geophysical interpretation used to determine the distribution of reservoirs on the target horizon. Generating these attributes can make it easier to analyze seismic data horizontally. In this study, the attributes generating RMS amplitude of effective porosity and density spreading on the target horizon are used to identify the carbonate build-up horizontal distribution.

The results of the porosity model that has been obtained based on the dissemination of modeling property, is then continued with the creation of a permeability model. The method is performed by using the equation cross plot result of permeability-porosity of the core data. Figure 5 shows cross plots (equation) between permeability and porosity of core data.

The cross plots in the figure show strong positive correlations between permeability (independent variable) vs Porosity (dependent variable) in the same direction. This means that the increase in the value of porosity will be followed by an increase in the value of permeability. In packstone facies with a density of < 2.2 g/cc, R^2=0.8252, and r=0.91 the regression lines are separated by the regression lines of the packstone facies whose density > 2.2g/cc, R^2 = 0.6514, and r = 0.81. In wackestone facies with a density of <2.5g/cc, R^2 =0.8796, and r = 0.94 the regression lines are separated by the regression lines of wackestone facies that are >2.5g/cc, R^2 = 0.7858, and r = 0.88.

The values R^2 and r of the scatter plot diagram appear to correspond to a straight line (regression), so it is said that there is a linear relationship between permeability and porosity. The values of R^2, which are close to the value of 1, indicate the more valid the result of the porosity-permeability cross plot equation.

Four surfaces (horizons) have been identified in the north build-up of the Parigi carbonate

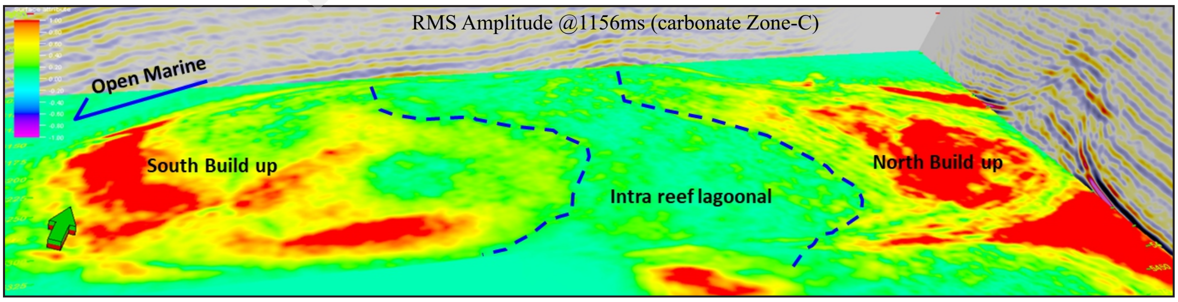

Figure 4. Application of RMS amplitude attribute on time slice at 1,156 millisecond of Parigi carbonate Zone-C.

zone from a seismic section (Figure 3). Two seismic attributes of porosity and density have been generated to identify the vertical distribution of porosity and density in Parigi carbonate (Figure 6). The porosity and density values in Parigi carbonate are divided in two types. The upper part (Parigi Zone-A) is relatively more porous (high porosity value 0.24 frac - 0.30 frac) and less dense 2.2gr/cc (density section) with a permeability of 1 -100 mD. The lower part is relatively tighter (0.10 frac – 0.15 frac) and denser 2.5gr/cc (density section). The north build-up is the best reservoir in Parigi carbonate that has a good porosity (porous zone), less dense with good permeability for gas flow.

Density and porosity evaluation from seismic extraction determine two zones in the Parigi carbonate that is upper zone which is porous/less dense zone and the lower zone which is tight /denser. The upper zone is the high capacity of reservoir for underground gas storage requirements, and demands high-matrix permeability, good porosity, and good vertical and lateral reservoir continuity. The upper zone is a reef build-up that was developed on the platform limestone (lower zone).

The porosity and density seismic attribute section shows that the growth of the build-up sequence was periodically interrupted by marine transgression and regression (yellow density). The RMS amplitude identifies this Parigi carbonate build-up expanded better at the area platform within the inner-middle neritic area. Regionally, the Parigi carbonate is overlain by onlapping the Cisubuh Formation shale (Figure 6). It is interpreted that the open marine was relatively opened to the south. Figure 7 shows the paleogeography of the Cisubuh Formation regionally acts as a seal for reservoir Parigi carbonate in West Java Basin.

Sealing Evaluation

The Cisubuh Formation is dominated by shales with minor intercalations of sandstone, conglomerates, and calcareous streaks. Based on the dating through fossil analysis of Cisubuh Formation, it is thought to form at Late Miocene (N17) in the deposition of regression pattern with the thickness of this formation reaching 946 m. The wells information in the studied area indicates that the average thickness of Cisubuh shale ranges from 200 - 400 m with shale density varying from 2.0 - 2.21 g/cm^3. The shales are the main seal for sealing hydrocarbons in the Parigi carbonate reservoirs. The Cisubuh Formation contains an abundance of foraminifera such as *Globigerinoides ruber and Rotalia,* and fossils *Mollusk.* This formation is believed to be deposited in a shallow marine.

Total Volumetric of Parigi Reservoir at North Build-up

A technical review of the geophysical, geological, and reservoir aspects of the Parigi build-up

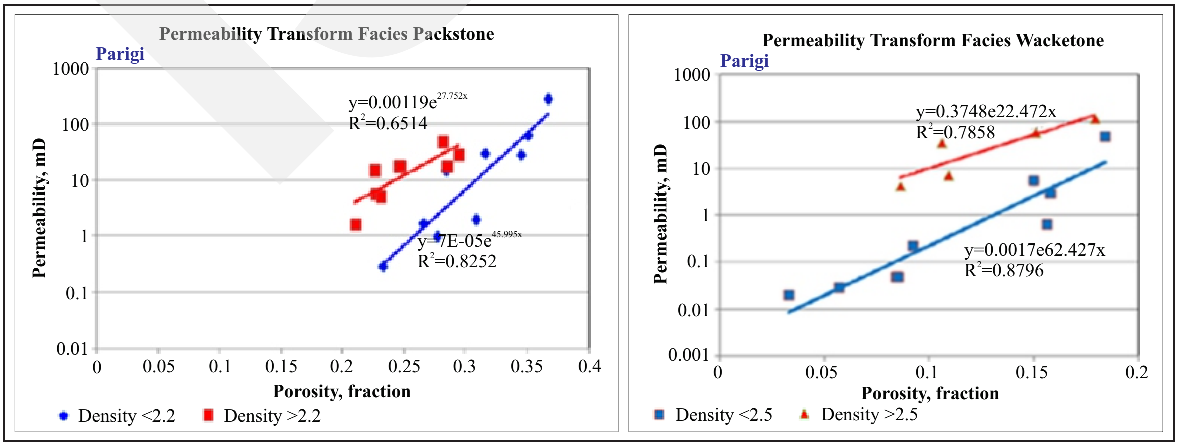

Figure 5. Cross plot permeability and porosity of packstone (left) and wackstone (right) facies on Parigi carbonate in the studied area.

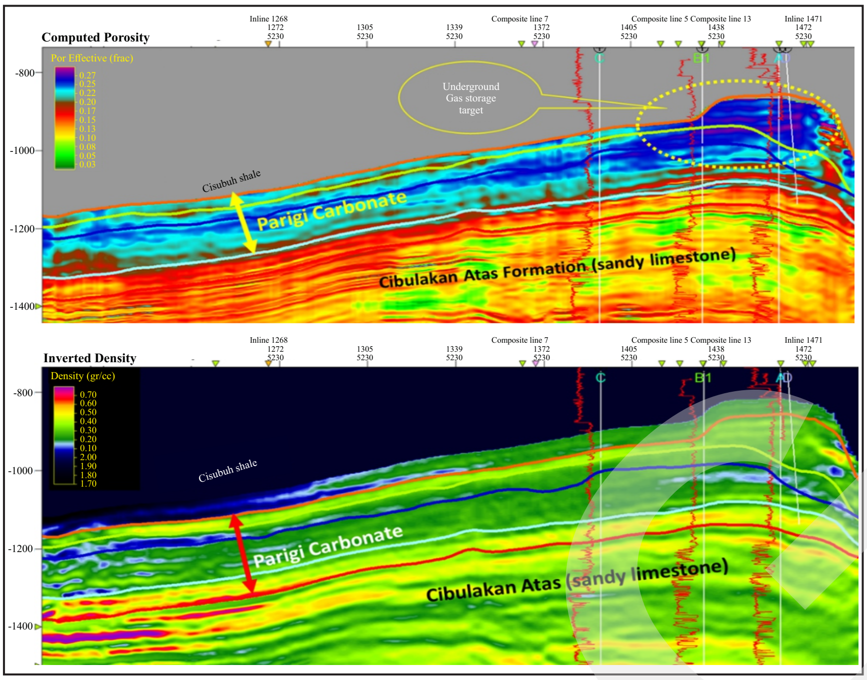

Figure 6. The seismic attribute of Parigi carbonate indicates high porosity (upper figure) and less density (lower figure) within the upper part of the build-up carbonate.

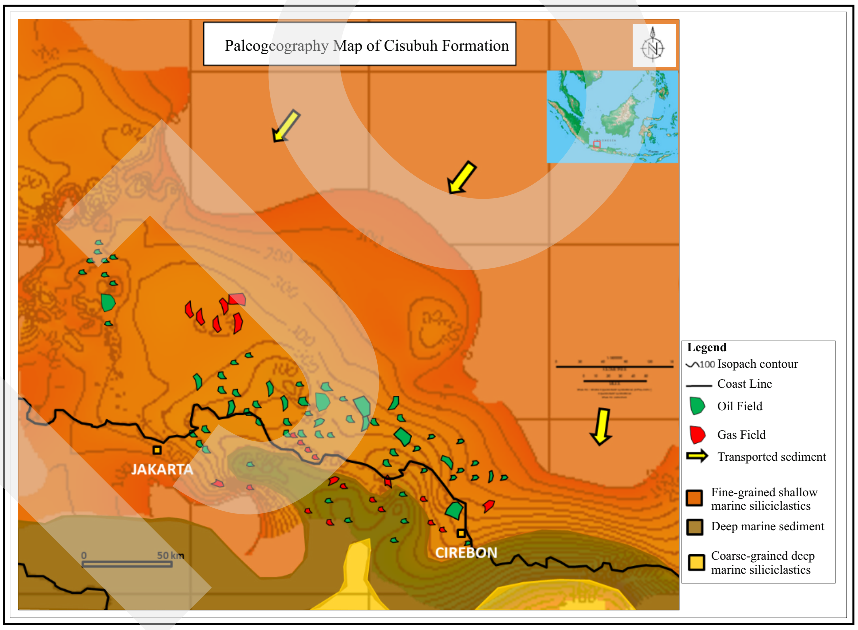

Figure 7. Cisubuh depositional setting offshore and onshore of West Java Basin. The sediment is transported from Sundaland in the north to the basin in the south.

structure results in a total volumetric of Original Oil in Place (OOIP) estimated at 66.13 MMstb and Initial Gas in Place (IGIP) of 53,209 MMscf (53.2 Bcf). This is based on fine model calculation, where the Bulk volume = 254.,332E+6m^3; Net Volume = 247,032E+6m^3; Pore Volume = 53,471E+6m^3; HCPV oil = 15,829E+m^3; HCPV gas = 8,372E+m^3; NP = 9.71 MMSTB; GP = 13,674 MMscf(13.7Bcf); RF oil = 14.68%, and RF gas = 25.70%. Based on a decline curve analysis (DCA), estimated reserves in 2017 were 153,000 barrels of oil and 12.6 Bcf of gas. The oil and gas production in this field is estimated to be stopped by 2025 due to uneconomic production costs.

Parigi Reservoir Underground Gas Storage Assessment

After depleting oil and gas production in 2014, the underground gas storage capacity of the Parigi carbonate build-up reservoir, including “cushion” natural gas (remaining gas) used to provide pressure in the reservoir, is approximately 12.7 Bcf. During this time, the reservoir pressure has dropped by some 160 psi below its initial value (1,330 psi) and in 2017 = 1,170 psi. The reservoir pressure trend indicates that this field is subjected to a combination drive reservoir. The carbonate build-up is buried about 800 m below sea level, overlain by thick shale that looks feasible for underground gas storage (Figure 8).

Table 2 shows a comparison of underground gas storage parameters in European countries, America, and Parigi carbonate in the studied field. The reservoir carbonate parameters in the field studied are within the range of feasible gas storage parameters of the existing field in those two foreign countries. Most lithology of the gas storages in Europe and America is composed of Pre-Tertiary rocks (>55 Mya) whilst in this field, it comprises Tertiary carbonate (<55Mya).

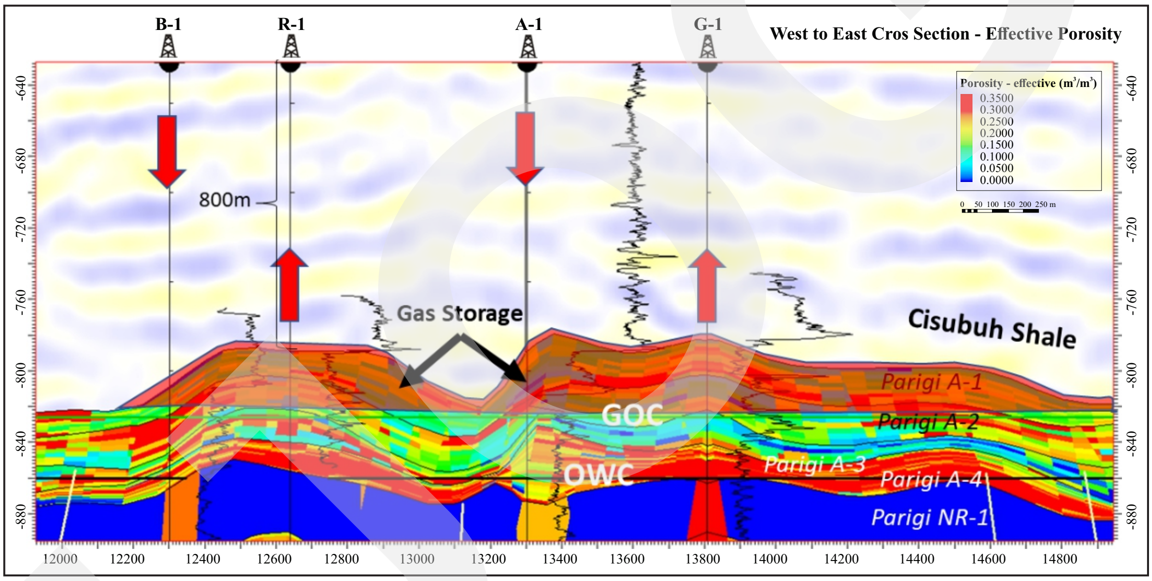

Figure 8. Shallow Parigi carbonate is feasible for underground gas storage in a depleted field in onshore West Java. B-1 and A-1 wells are injection wells. R-1 and G-1 wells are the production wells.

Table 2. Main Parameters of Subsurface Gas Storage in Europe, America, and Studied Field

Main Parameter	Depleted Europe Field	Depleted America Field	Depleted Studied Field
Total volume (Bcf)	59	26 - 55	53.2 (IGIP)
Working gas capacity	35	13 - 28	19 (5 active wells)
Storage pressure (psi)	1,247 - 1,957.5	4,99 - 4,335	1,170 - 1,330
Number of wells	26	23 - 38	28
Gas cushion (%)	45	51	~50%
SW (%)	<45	<45	>45%
Porosity (%)	10%-30%	15%-23%	24% - 30%
Permeability (mD)	1mD - 800mD	1mD - 200mD	1mD - 320mD
Depth of reservoir (m)	650 - 1300	1400 - 2862	800
Reservoir thickness (m)	4.5 - 100	3 - 150	80

Conclusion

The Parigi carbonate has been buried in a depth of about 800 m below the ground surface. Based on seismic interpretation, this carbonate build-up is approximately 4,100 m wide and 13,000 m long, with the best estimate thickness is 80 m. Assuming an effective carbonate build-up reservoir of 25% from the whole build-up in the NE part, the effective closure area is approximately 4,75 km^2.

The overlying cap rock of Cisubuh Formation is claystone estimated to be > 200 m thick, distributed widely in West Java Basin. The bottom part of Parigi carbonate is tight limestone probably has low permeability, seismically classified as parallel seismic reflection known as platform carbonate

With an effective carbonate reservoir of 25% (top build-up), an underground gas storage pressure of 1,170 psi, a build-up area capacity of 1,173 acre (4,75 km^2), and an effective thickness of 80 m, the estimated gas storage capacity is approximately 53.2 Bscf.

The Parigi carbonate reservoir parameters in this field are within the range of the existing field parameters in Europe and America. This large-scale underground gas storage is capable to support the gas distribution in the dynamic gas market in West Java Province.

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