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EVALUATING THE FEASIBILITY OF CO_2 STORAGE THROUGH A GEOMECHANICAL APPROACH: A CASE STUDY OF THE TALANG AKAR FORMATION, CRESTAL AREA OF ASRI BASIN, LUF WELL

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ABSTRACT
Asri Basin is one of Indonesia's sedimentary basins, and it is the carbon dioxide storage target in Carbon Capture Storage (CCS) technology. A study of carbon dioxide storage containers must be carried out based on geological aspects, namely geological and rock conditions. This research aims to identify reservoir feasibility values in the Asri Basin, such as pore pressure and fracture pressure, along with other factors affecting reservoir stability, in order to minimize leakage during the carbon dioxide injection process. The identification process in this research uses quantitative and qualitative studies based on well data. Eaton's method was used to estimate the research well pore pressure and fracture pressure in the research wells. The research well is located in the crestal area of the Asri Basin and has a pore pressure with a normal pressure trend. The fracture pressure value gets smaller in the depth range of the Talang Akar Formation. There is a process of diagenesis of the clay mineral smectite into illite, which begins to be found at a depth of 3000 - 3500 ftTVDSS. The developed stress regime is a normal stress regime with the vertical stress value as the largest. The injection process in the Asri Basin can be carried out in the Talang Akar Formation with several five storage intervals at a depth of 3560 - 4130 ftTVDSS.
Keywords : Fracture Pressure, Geological Carbon Storage, Mineral Diagenesis, Pore Pressure, Stress Regime

ABSTRAK
Cekungan Asri merupakan salah satu cekungan sedimen di Indonesia yang menjadi target penyimpanan karbon dioksida dalam teknologi Carbon Capture Storage (CCS). Kajian mengenai wadah penyimpanan tersebut harus dilakukan berdasarkan aspek geologi, yaitu kondisi geologi dan batuan. Penelitian ini bertujuan untuk mengidentifikasi nilai kelayakan penyimpanan pada Cekungan Asri, seperti tekanan pori dan tekanan rekah, beserta faktor lainnya guna meminimalisasi kebocoran pada proses injeksi karbon dioksida. Proses identifikasi dalam penelitian ini menggunakan studi kuantitatif dan kualitatif berdasarkan data pengeboran sumur. Metode Eaton digunakan dalam mengestimasi tekanan pori dan tekanan rekah sumur penelitian. Sumur penelitian terletak di daerah tinggian Cekungan Asri dan memiliki tekanan pori dengan tren tekanan normal. Nilai tekanan rekah semakin kecil pada kisaran kedalaman Formasi Talang Akar. Terdapat proses diagenesis mineral smektit menjadi illit yang dijumpai pada kedalaman 3000-3500ftTVDSS. Rezim tegasan yang berkembang adalah rezim tegasan sesar normal dengan nilai tegasan vertikal paling besar. Proses injeksi pada Cekungan Asri dapat dilakukan pada Formasi Talang Akar dengan beberapa interval penyimpan pada kedalaman 3560-4130 ftTVDSS.
Kata Kunci : Tekanan pori, Tekanan Rekah, Diagenesis Mineral, Rezim Tegasan, Geological Carbon Storage

INTRODUCTION
Indonesia is one of the countries developing a new technology called CCS (*Carbon Capture Storage*). The injection of carbon dioxide enhances oil and gas production in a basin or serves positive energy resource. This marginal field of the CCS Project is currently being attempted in the Asri Basin, one of Indonesia's sediment basins that has been producing oil and gas since 1980.

The Asri Basin is located in the Sunda Arc region (Nurfaidah et al., 2023). It has a thick reservoir layer, that is being considered for carbon dioxide injection. In the planning process of this injection, several feasibility studies are conducted to determine the suitability of a reservoir for carbon dioxide storage. Geology is one of the key aspects of the feasibility study, from the geological conditions to the rock mechanics aspects, various assessments are carried out to evaluate reservoir quality. Pore pressure, fracture pressure, and stress regime are utilized to assess the reservoir. Besides, an identification of mineral diagenesis is employed to determine the appropriate storage interval of carbon dioxide. This feasibility study is part of the subsurface integrity studies aimed at minimizing the potential carbon dioxide leakage in the Talang Akar Formation.

LITERATUR REVIEW

Geology of Research Area

Asri Basin is one of the tertiary basins that is formed from the convergent process between the India-Australia Plate and the Sunda Micro Plate (Ralanarko et al., 2020). This basin has a 300 km^2 area, with the north boundary is the Sunda Shelf, the south boundary is West Java Basin, the east boundary is Biliton Basin, and the west boundary is Lampung Plateau. (**Figure 1**)

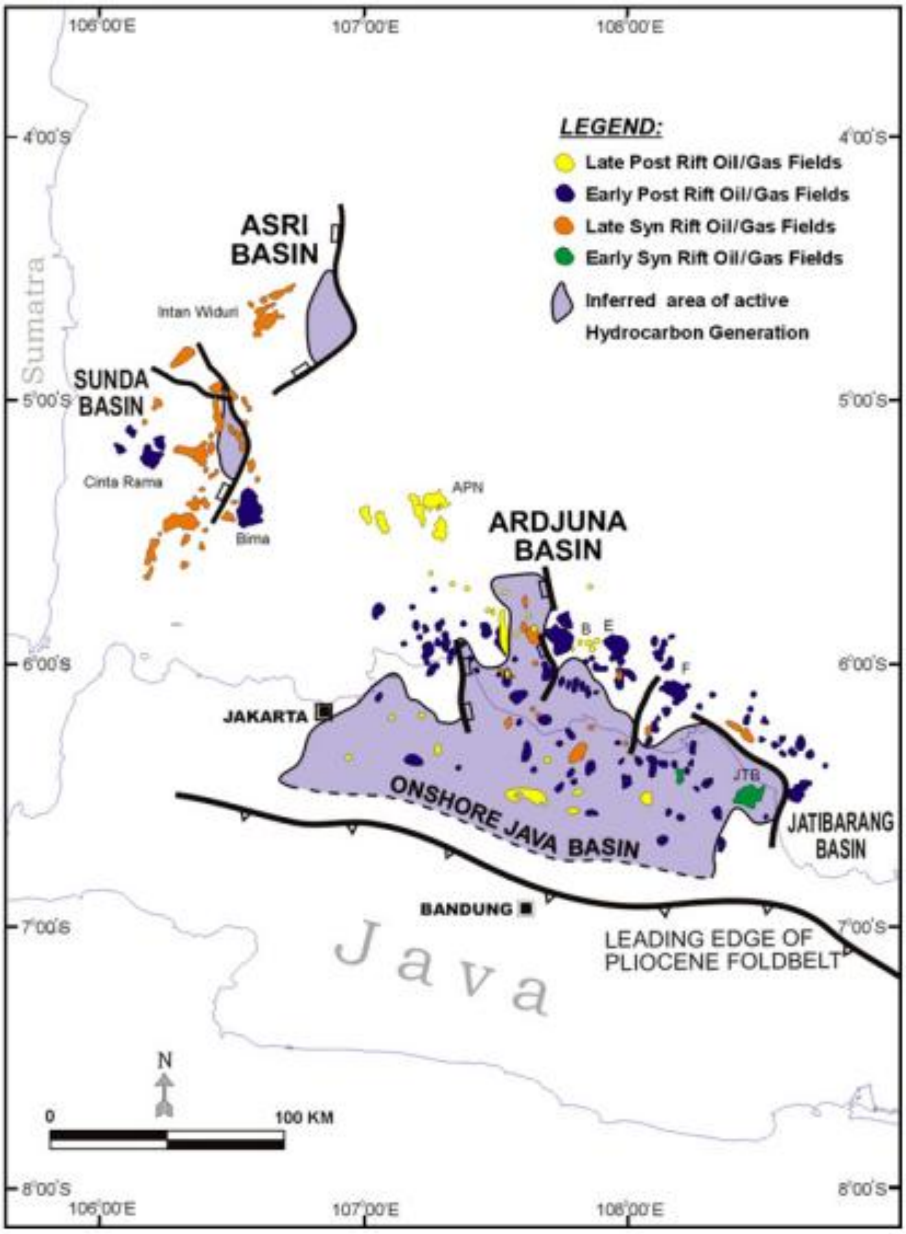

Figure 1. Sunda-Asri Basin Location Map by Doust (2008) in Sukanto et al. (1998)

The formed of Asri Basin is divided into four main tectonostratigraphy systems. There are four phases: pre-rift, syn-rift, post-rift, and syn-orogeny (Ralanarko et al., 2020). (**Figure 2**)

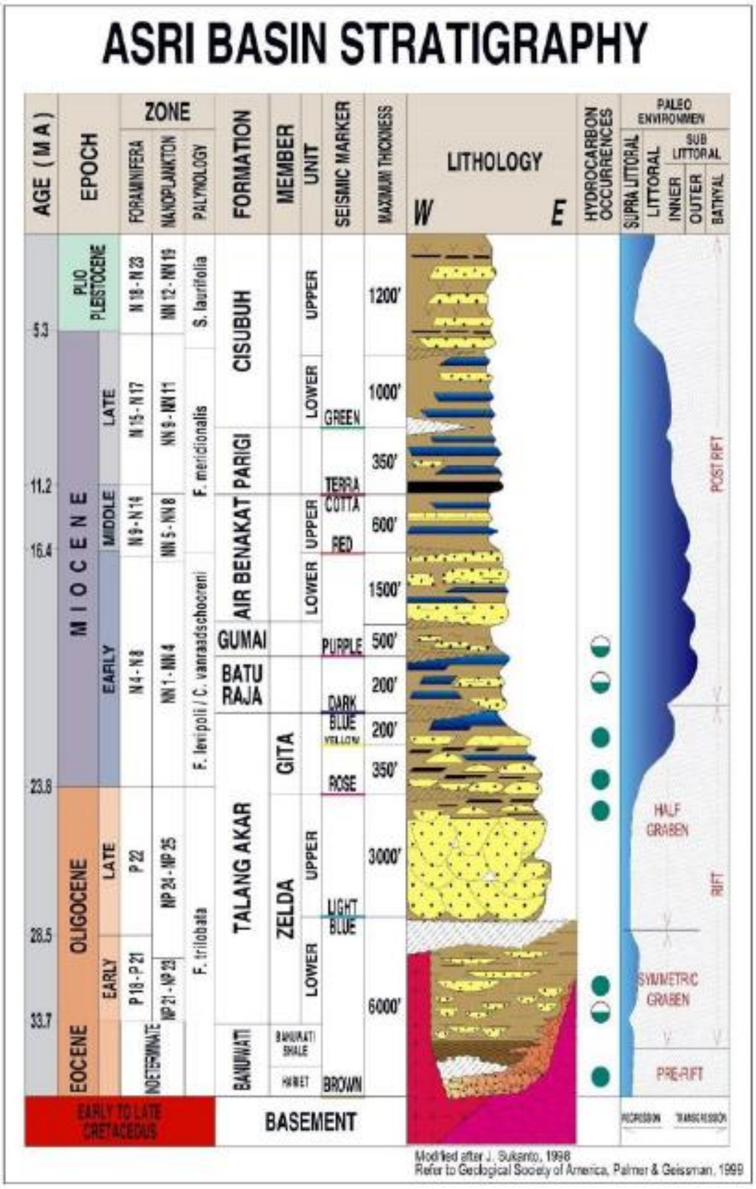

Figure 2. Stratigraphy of The Asri Basin by Sukanto et al., (1987) in Ralanarko et al. (2020)

1. Pre-rift phase, is marked by the movement of the India Plate to the Eurasia Plate (subduction process). The Jatibarang volcanic product takes a place in a southwest-northeast direction, which is the same as the movement of the plate. This volcanic product has a rock basement with granite/granodiorite and metamorphic rock such as quartzite.
2. Syn-rift phase, is marked by the push movement of the Sunda Shelf, which moves along with the Hindia-Australia oceanic Plate, causing an increase in sediment supply in a few directions. The sediment deposition during this period is in the Banuwati Formation in fluvial to lacustrine deposition with sandstone and conglomerate in the lower interval bed and shale in the upper bed. Furthermore, Talang Akar formation is divided into two members, Gita and Zelda. Zelda member has fluvial depositional lithology, shale, mudstone (lower Zelda), and sandstone with shale (Middle and Upper Zelda).
3. Post-rift phase, marks the end of the fault movement and the formed of Gita Member. There is coal with a thin bed in Gita Member. Then, a tide phenomenon caused Baturaja Formation to form with sedimentary carbonate materials. Afterwards, the sea level increased until Asri Basin completely started to drown, and Gumai Formation, Air Benakat Formation, and Parigi Formation were present.

4. Syn-orogeny phase, marked by compressional and fault movement, causes an intrusive process. The Cisubuh Formation contains shale and tuff.

Carbon Capture Storage (CCS)

Renewable energy with a climate change mitigation concept that uses geology and chemical aspects is called Carbon Capture Storage (CCS). This technology is usually developed in the oil and gas industry, especially in Enhanced Oil Recovery (EOR) systems or as a positive potential energy with carbon dioxide injection. The carbon dioxide capture is taken from the emissions of power plants. This process is called pre-combustion capture. The carbon dioxide gas is injected into the subsurface reservoir until it reaches "supercritical" phase. This phase is a state of carbon dioxide heated and pressurized above its critical temperature and pressure (Mortezaei et al., 2018). Carbon dioxide exhibited liquid and gas properties, making it a versatile solvent and working fluid.

Based on de Coninck & Benson (2014), a appropriate carbon dioxide injection reservoir has a high porosity and permeability quality, a depth colum reaching more than 800 meters in the subsurface, and an impermeable seal to trap the carbon dioxide and minimize the leaking potential.

RESEARCH METHOD

This research employs both qualitative and quantitative methods. It utilizes secondary data, specifically well-drilling data, which is divided into two types of data collected during drilling (RFT, DST, LOT) and data reports (well logs, final drilling report, and mud weight).

Pore Pressure Analysis

This identification process uses well logs, mud weight, RFT, DST, and the final drilling report. They are calculated using the Microsoft Excel software and then converted into a 1D pressure diagram. To identify the pressure, this research applied the Eaton Method (1975) in Ramdhan (2022). Pressure by the weight of the fluid column (Hydrostatic Pressure) and loading by the total weight of the rocks and fluids above (Vertical Stress) are written as follows.

Hydrostatic Pressure (Ramdhan, 2022)

$$P_h = \rho_f \cdot g \cdot h \ldots (1)$$

Information :

P_h = Hydrostatic Pressure (pa)

ρ_f = Specific Gravity of Fluid (kg/m)

g = Gravity (9.81 m/s^2)

h = Column Height (m)

Vertical Stress (Ramdhan, 2022)

$$\sigma v = \rho_b \cdot g \cdot z \ldots (2)$$

Information :

σv = Overbuden stress (psi)

ρ_b = Density of Sedimentary Rock (gr/cc)

g = Gravity (9.81 m/s^2)

z = Thickness of Sedimentary Rock Layers (ft)

This research uses Sonic Log and Normal Compaction Trend (NCT) to estimate pore pressure. Eaton assessed that the pore pressure value is directly proportional to the data deflection in the Normal Compaction Trend (NCT). Based on the Eaton Method (1975) in Ramdhan (2022), the NCT and Pore Pressure formula is written as follows.

Normal Compaction Trend (NCT)

$$\Delta t_n = ae^{-bz} + \Delta t_m \ldots (3)$$

Information :

Δtn = Normal Compaction Trend

[a] = Coefficient of Regression Results

[e] = Exponential

Δtm = Transit Time Matrix Value

Pore Pressure

$$P = \sigma v - (\sigma v - P_n) \left(\frac{\Delta tn}{\Delta t}\right)^n \text{ for sonic curve} \ldots (4)$$

Information :

P = Pore Pressure

σv = Vertical Stress

P_n = Hydrostatic Pressure

Δtn = Transit Time in Normal Direction

Δt = Transit Time is Read

The constant value (n) in the empirical formula of pore pressure is filled in with the suitability of the sonic log value with pore pressure value, along with the suitability to the geological conditions of each research area (Ramdhan, 2022). The process of adjusting the constant value is called "Cheatn With Eaton".

Fracture Pressure Analysis

Fracture pressure is the pressure that a rock formation can withstand until it reaches the point of failure (Ramdhan, 2022). A few parameters, such as vertical stress, formation pressure, and rock conditions, influence fracture pressure. Furthermore, the rock condition is identified by the elasticity properties against deformation through the Poisson Ratio and Young's Modulus parameters. The Poisson ratio measures the ratio of lateral stress to axial shortening, while Young's Modulus measures the deformation resistance of uniaxial stress. The Poisson Ratio formula is written based on Wang & Wang (2015) with DT (Compression) sonic log data and DT (Shear) sonic log to determine the values of Vp and Vs (Goodman, 1989) in Feng (2017).

V_p = 1/DTCO* 10^6 * 0,3048… (5)
V_s = 1/DTSM* 10^6* 0,3048… (6)
V_{dyn} = $\frac{1}{2}\ x\ \frac{Vp(Vp)-2\,(Vs(Vs))}{(Vp(Vp))-(Vs(Vs))}$ … (7)

Information :
V_{dyn} = Dynamic Poisson Ratio
Vp = Compressional Velocity
Vs = Shear Velocity

The dynamic poisson ratio value is assumed to be the static poisson ratio value because, until now, no correlation has been available as a reference in converting the value (Wang & Wang, 2015). Young's Modulus is calculated based on the Lacy equation (1997) in Zoback & Kohli (2019) as follows.

$$E_{dyn} = \left(\frac{(RHOB*Vs(Vs))*((3*(Vp(Vp))-(4*(Vs(Vs)))}{(Vp(Vp))-(Vs(Vs))}\right)*10^9 \ldots(8)$$

$$E_{sta} = 0{,}7 * E_{dyn} \ldots(9)$$

Information :
E_{dyn} = Dynamic Young's Modulus
E_{sta} = Static Young's Modulus
RHOB = Rock Density
Vp = Compressional Velocity
Vs = Shear Velocity

This elasticity parameter value becomes a constant for identifying fracture pressure with the Eaton Method. The empirical formula is as follows.

$$\text{Fracture Pressure} = (\sigma v - P) * \left(\frac{V}{1-v}\right) + P \ldots (10)$$

Information :
σv = Vertical Stress (psi)
P = Pore Pressure(psi)
V = Poisson ratio *(unitless)*

Stress Regime Analysis

Two main stresses control the stress regime: Maximum Horizontal Stress (SH_{max}) and Minimum Horizontal Stress (Sh_{min}). Blanton and Olson (1999) in Zoback & Kohli (2019) calculate the stress value based on the rock's elasticity value (poroelastic). The equation is written as follows.

$$Sh_{min} = \frac{v}{1-v}\sigma v + \frac{1-2v}{1-v}\alpha Pp + \frac{vE}{1-v(v)}\varepsilon\, min \ldots(11)$$

$$SH_{max} = \frac{v}{1-v}\sigma v + \frac{1-2v}{1-v}\alpha Pp + \frac{vE}{1-v(v)}\varepsilon\, max \ldots(12)$$

Information :
Sh_{min} = Minimum horizontal stress (psi)
Sh_{max} = Maximum horizontal stress (psi)
v = Poisson Ratio
σv = Vertical Stress
α = Biot Coefficient
Pp = Pore Pressure
E = Young's Modulus
$\varepsilon\, min$ = Minimum horizontal strain
$\varepsilon\, max$ = Maximum horizontal strain

Pore Pressure Formation Mechanism Analysis

The factors that cause a pore pressure are divided into two main mechanisms: loading mechanism and unloading mechanism (Dasgupta et al., 2020).

Loading Mechanism

Imbalance of the compaction process by the compaction process with a vertical or horizontal direction (loading) that occurs in a short duration so that the fluid is trapped and cannot escape. This phenomenon is called undercompation.

Unloading Mechanism

Other than loading factor, the process mechanism includes of hydrocarbon formation, clay mineral diagenesis, and the increase in tempereature. This research discusses the diagenesis of smectite clay minerals into illite, the process between smectite minerals and potassium ions creating additional fluid volume. This phenomenon can increase pore pressure in the presence of trapped fluid. In identifying this mechanism, Dutta (2002) in Ramdhan (2022) and Katahara (2006) in Qin & Han (2016) presents a cross plot between sonic logs and density logs that have a linear relationship, then added smectite lines (eodiagenesis, early stage of diagenesis—the chemical, physical, and biological changes that occur to sediments shortly after deposition and during shallow burial, but before deeper compaction and cementation processes dominate.) and illite lines (telodiagenesis, final stage of diagenesis—the process that alters sediments after their initial deposition, during and after lithification, but before metamorphism).

RESULTS AND DISCUSSION

This research uses an oil and gas procustion well, the LUF well, located in the Crestal Area of Asri Basin. LUF well has been producing oil and gas since 1988. Its geometry is vertical well and located below the sea level.The LUF well is located in Asri Basin with coordinates Latitude 04° 39′ 18.916″ S and Longitude 106° 39′ 05.435″ E. This well has a depth of 3629 ftTVDSS. This well is produced starting form Air Benakat Formation, located at the top formation to the basement rock layer (Jatibarang Volcanic Product).

Pore Pressure

Based on gamma-ray log, in the LUF well has a cut-off value of vshale of 0.5 by Larionov Method by Kamayou et al. (2021) (kama.

Pore pressure calculations are done on shale lithology because seismic velocity only works in shale. In other lithologies such as sandstone and carbonate rocks, velocity is not only a function of effective stress but also porosity in that lithologies are complex and these lithologies has a stress-insensitive material (rigid characteristic) (Ramdhan, 2022). The pore pressure measurement estimation results based on the Eaton Method in the LUF well show a normal pressure trend. The empirical equation constant value is 0.4 based on pore pressure calculation with sonic logs. Then, the exponential value in the Normal Compaction Trend is $228.5302726e^{-0.0002009x}$.

The range value of pore pressure in the LUF well is 341,07 – 1983,35 psi/ft, with an average value of 1112,44 psi/ft. This value is not much different from the value of hydrostatic pressure of 1131,21 psi/ft. The hydrostatic pressure value in the LUF well is calculated using the water gradient value in the research area, which is 0,433 psi/ft. The pore pressure data is calibrated with direct measurement data, namely RFT. RFT (Repeat Formation Test) was conducted 10 times with good-quality measurements, indicated by red triangle mark on the 1D pressure diagram. The direct measurement also shows the same pressure trend: normal pressure. This aligns with the pore pressure calculation based on the Eaton Method in the LUF well. (**Figure 3**).

Fracture Pressure

The fracture pressure in LUF well calculated by two elasticity rock parameters, Poisson's ratio and Young's modulus. The average Poisson ratio value is 0,4 ranging around 0,19 – 0,49. Afterwards, the average static Young's modulus value is 4,09 GPa and the dynamic Young's modulus value is 5,89 GPa. Overall, the average value of fracture pressure in LUF well based on the Eaton Method is 1776,76 psi/ft. This trend shows a smaller value in the Talang Akar Formation. Furthermore, this value is calibrated with LOT (Leak Off Test) data at a depth of 1648 ftTVDSS, with an error value of 2,29%. This number indicates that the value of fracture pressure is align closely with LOT measurements. (**Table 1.**)

Stress Regime

Based on Poroelastic (Blanton and Olson, 1999) in the LUF well, the average value of (Sh_{min}) is 1859,84 psi/ft and (SH_{max}) is 1896,31 psi/ft. In the 1D pressure diagram, both values have a smaller trend than the vertical stress, marked by a purple (SH_{max}) and brown (Sh_{min}) trend. (Figure 3). Based on stress regime classification by Anderson (1951), these values are a normal fault stress regime with vertical stress as the largest stress system (Sh_{min} < SH_{max} < *Vertical Stress*).

Pore Pressure Formation Mechanism

The analysis of the mechanism of pore pressure formation in this research identified one cause, known as clay mineral diagenesis (Dutta, 2002) in Ramdhan (2022). The cross-plot shows that, upon entering the process of mineral diagenesis, half of the data have undergone diagenesis into illite clay minerals. This is evident based on the cross-plot data of sonic logs and density logs, indicating that the diagenesis of these minerals has been in the ongoing diagenesis phase, marked by data that crosses the illite line (telodiagenesis). The diagenesis process begins at a depth of 3000 – 3500 ftTVDSS, which is located right at the Talang Akar Formation. (**Figure 4**).

Storage Interval of Carbon Dioxide

Based on the pore pressure estimation measurement result data, the LUF well exhibits a pressure trend indicating normal pressure. This normal pressure is measured from the top to the bottom of the formation rocks in the LUF well. Several factors influence normal pressure conditions, such as the proper loading process, which allows the fluid in the sediment layer to escape normally from the pore space of the rock (Ramdhan, 2022). Subsequently, this condition is used as one of the considerations in assessing and estimating the storage interval, especially in determining reservoir depth intervals.

The second assessment parameter is fracture pressure. The fracture pressure conditions in the Talang Akar Formation show a trend towards decreasing values. This decrease occurs due to various factors, ranging from rock conditions to tectonic development in the research area. The average values of Poisson's ratio and dynamic Young's modulus in the Talang Akar formation are 0.33 and 11.82 GPa (**Figure 5**). Based on the classification of Young's modulus and Poisson's ratio value ranges, these values fall within the shale lithology category (Molina et al., 2017). Additionally, the elastic properties also align with the interpretation of gamma ray logs data, indicating that the shale layer's thickness in the Talang Akar Formation is quite substantial.

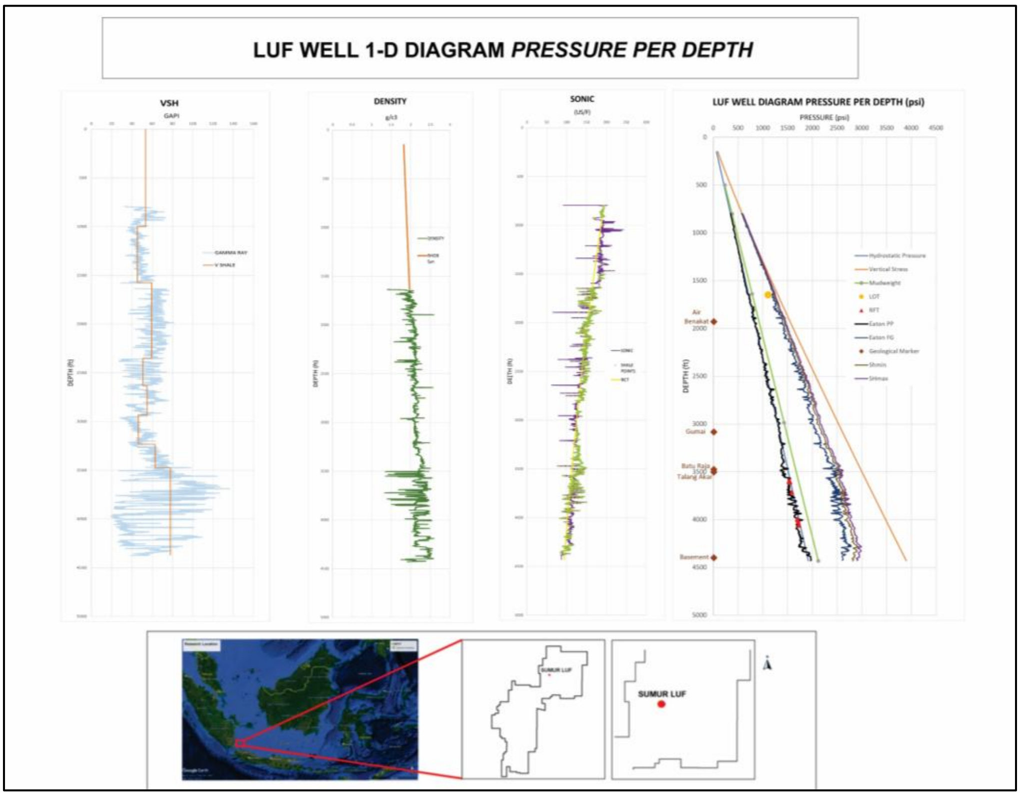

Figure 3. LUF Well 1-D Pressure Diagram

Table 1. The Result of Fracture Pressure Error Against LOT Data (Leak Off Test)

Depth (Ft)	Hydrostatic Pressure (Psi)	Vertical Stress (Psi)	Fracture Pressure (Psi/ft)	Mudweight (Psi)	LOT (Psi)	Error (%)
1648	713.58	1305.10	1130.88	783.619	1105.47	2.29

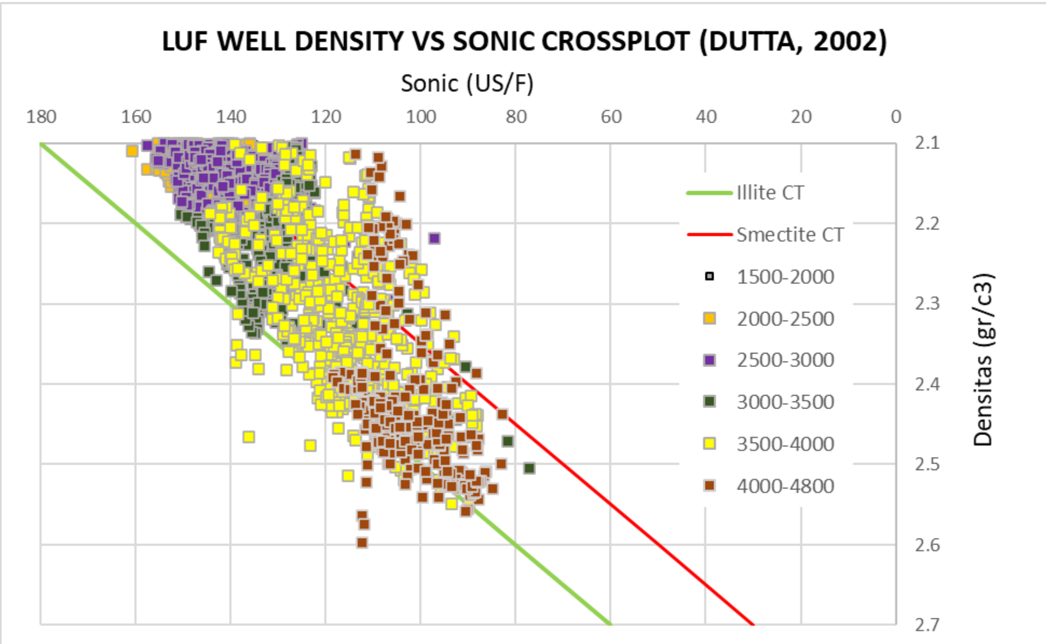

Figure 4. LUF Well Sonic and Density Logs Cross-Plot shows a diagenesis mineral smectite to illite

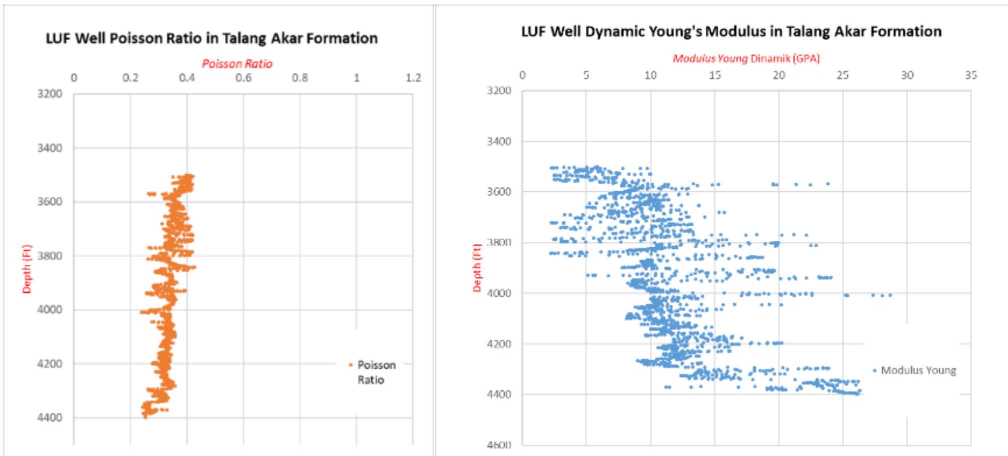

Figure 5. LUF Well Distribution of Poisson Ratio and Dynamic Young's Modulus Values in Talang Akar Formation

In addition, the cause of the decreasing fracture pressure value is also influenced by the tectonic development in the Asri Basin. The research well has a stress regime in the form of a vertical normal fault (Sh_{min} < SH_{max} < *Vertical Stress*). According to Ralanarko et al. (2023), the Asri Basin has two main systems, one of which is a tensile normal fault that develops along with the formation and filling of the basin. In another statement, Ralanarko et al. (2020) considered that the convergent process when the Asri Basin was formed was influenced by the presence of a strike-slip fault. The research well is located in the crestal area of the basin, which has the potential to be exposed to maximum horizontal stress along with quite significant vertical stress. This deformation activity can affect the mechanical conditions of the rock due to the compressional and extensional forces.

Furthermore, other factors are present in the identification results based on the sonic and density log cross-plot. In the research well, most of the clay mineral content has entered the diagenesis process into illite. This is shown in the trend of the cross-plot data, some of which have undergone diagenesis to pass the illite line (telodiagenesis). The mineral diagenesis starts from a depth of 3000 – 3500 ftTVDSS, which is the sedimentation range of the Talang Akar Formation (**Figure 4**).

This phenomenon of mineral diagenesis is also related to the fracture pressure conditions in the research well. With illite formation, the fluid volume conditions will increase due to the chemical process between smectite clay minerals and potassium ions. Illite clay minerals have very fine grains, so their specific surface area will be larger. Illite has a specific area of 40 – 100 m^2/kg (Hillel, 2004). This larger area can potentially close the gaps in rock porosity and secondary porosity in the rock formation. This phenomenon can affect the value of rock fracture pressure, which will increase because the porosity where the fluid moves is closed by the presence of clay minerals, whose area is getting larger, causing increased pressure. Along with the deformation force that occurs, if the fluid volume increases and the force applied to the rock increases, this can bring the rock to the peak point of deformation (fractures and failure). This is what affects the fracture pressure value in the Talang Akar Formations, which is increasingly close to the pore pressure trend.

This research study identifies feasible depths based on reservoir studies that have been assessed, both by rock geomechanics approach and geological interpretation of the research area. Based on the studies that have been conducted, there are five storage intervals that can be used as targets for carbon dioxide storage. The intervals are selected based on geological conditions, the thickness of the reservoir rock, and the quality of the seal rock layer in the Talang Akar Formation. This formation has a sandstone reservoir with fluvial depositional. which is considered productive because it has good porosity and permeability (Burhannudinnur et al., 2023). (**Figure 6**)

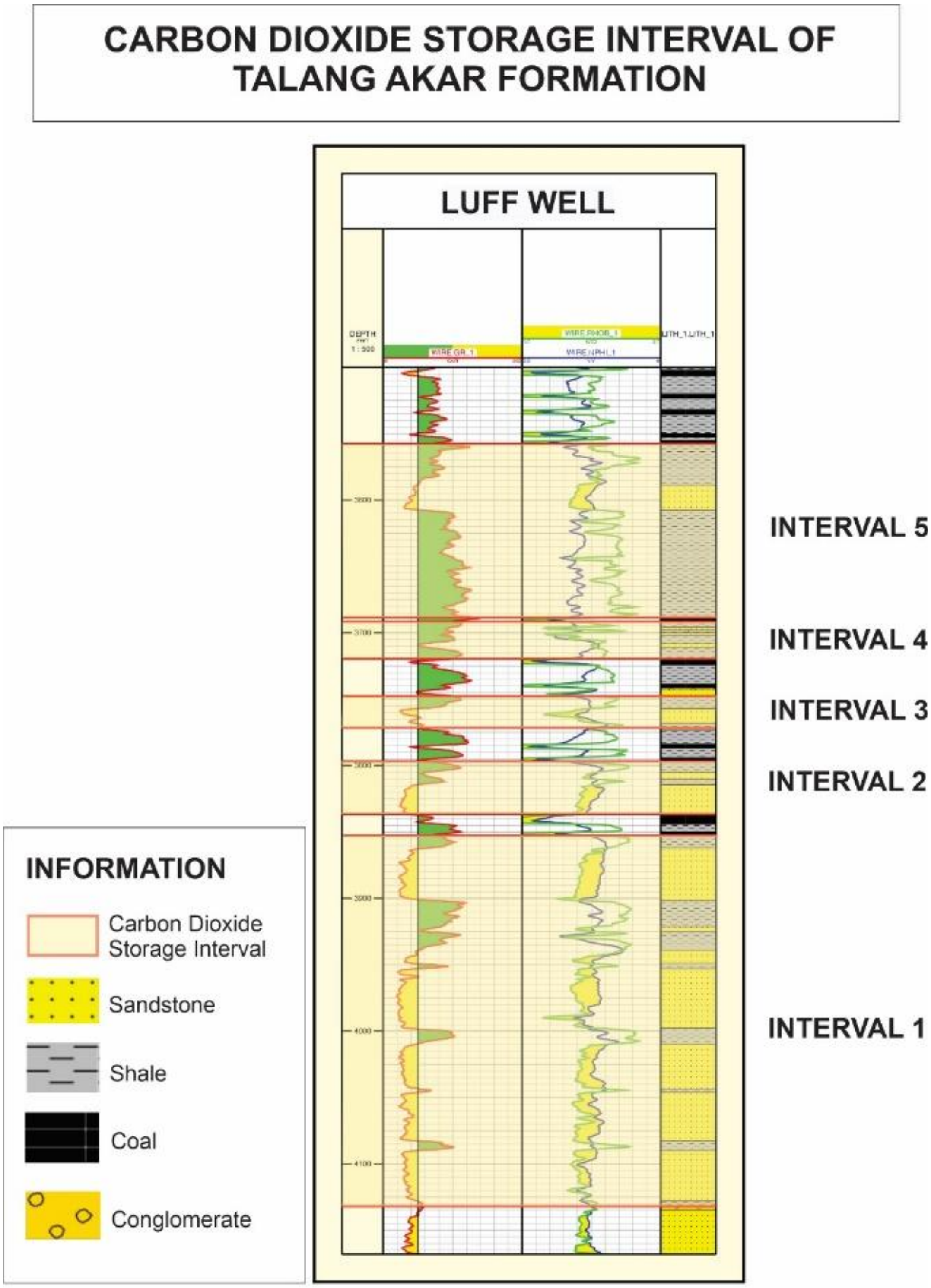

Figure 6. LUF Well Carbon Dioxide Storage Interval of Talang Akar Formation

The entire storage interval starts from a depth of 3560 ftTVDSS. The five intervals have different storage capacity column potentials, such as Interval 1 reaching 275ft depth column, Interval 2 reaching 38ft depth column, Interval 3 reaching 23ft depth column, Interval 4 reaching 27ft depth column, and Interval 5 reaching 130ft depth column. Based on the total storage potentials, carbon dioxide injection can be carried out with a total storage interval of 493ft depth column with a range of 3560 ftTVDSS – 4130 ftTVDSS or 1085.08 – 1258.82 meters below the surface.

According to the classification of a appropriate reservoir by de Coninck & Benson (2014) in Carbon Capture Storage, the depth of storage interval in the Talang Akar Formation starts from 1085.08 meters below the surface, aligning with the injection depth requirements,

which is more than 800 meters below. Thereafter, Talang Akar has a normal pressure trend, and the sealing layer has a thick layer to withstand the movement of carbon dioxide. However, the volume of carbon dioxide injection needs to be reconsidered due to the considerable root of fracture pressure, the presence of mineral diagenesis factors, and the geological structures in the Asri Basin.

CONCLUSIONS

Based on the analysis and identification of pore pressure and fracture pressure in the research area, the LUF well has a normal pressure trend from the top formation to the bedrock with an average of 1112.44 psi/ft. However, in the fracture pressure trend of the pressure decreases and it is close to the pore pressure trend in the depth range of Talang Akar Formation. The average fracture pressure result is 1776.76 psi/ft with an average Poisson Ratio value of 0.33 and a dynamic Young's modulus of 11.82 GPa in Talang Akar Formation.

The research well shows a diagenesis of smectite to illite starting from a depth of 3000 – 3500 ftTVDSS, precisely in the depth range of the Talang Akar Formation. The stress regime in the LUF well is a normal fault regime. It is estimated that the condition of clay mineral diagenesis, along with the development of geological structures, affects the fracture pressure in the Talang Akar Formation.

Based on the feasibility study by the rock geomechanics approach as subsurface integrity in the Talang Akar Formation, it has been concluded that five feasible carbon dioxide storage intervals can be carried out in the research area. Carbon dioxide injection in the CCS technology system can be carried out with a depth range of 3560 ftTVDSS – 4130 ftTVDSS in Talang Akar Formation with sandstone lithology as a reservoir and shale as a cap rock or trapped systems of carbon dioxide.

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