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RESERVOIR CHARACTERIZATION USING SCALED QP AND QS AT POSEIDON FIELD, BROWSE BASIN

KARAKTERISASI RESERVOIR MENGGUNAKAN QP DAN QS YANG DISKALAKAN DI LAPANGAN POSEIDON, CEKUNGAN BROWSE

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Abstract. Reservoir characterization is a critical component of hydrocarbon exploration and development. Seismic wave attenuation, which is closely linked to the physical properties of rocks, has emerged as an effective tool for this purpose. The Scaled Qp and Qs (SQp and SQs) methods represent advanced attenuation-based technique capable of discriminating lithology and fluid content through analysis of P-wave and S-wave attenuation. This study applies SQp and SQs attributes to characterize lithology and fluid distribution within the Plover Formation of the Poseidon Field, using 3D partial angle stack seismic data and well logs from three wells: Kronos-1, Poseidon-1, and Poseidon-2. Crossplot analysis indicate that low SQp values (0.02–0.2) are associated with sandstone, whereas higher SQp values (0.2–0.7) correspond to shale. In terms of fluid discrimination, high SQs values (0.55–0.7) identify gas-bearing zones, while lower SQs values (0.4–0.55) indicate brine-saturated interval. SQp and SQs volumes derived from simultaneous inversion reveal that gas-saturated sandstone reservoirs — characterized by low SQp and high SQs — are distributed along a southwest to northeast trend, consistent with the location of all three wells. These results demonstrate that SQp and SQs attributes effectively distinguish reservoir from non-reservoir lithology and delineate hydrocarbon-bearing zones, providing a reliable attenuation-based workflow for reservoir characterization in similar geological settings.

Abstrak. *Karakterisasi reservoir merupakan komponen penting dalam eksplorasi dan pengembangan hidrokarbon. Atenuasi gelombang seismik, yang terkait erat dengan sifat fisik batuan, telah muncul sebagai alat yang efektif untuk tujuan ini. Metode Scaled Qp dan Qs (SQp dan SQs) mewakili teknik berbasis atenuasi tingkat lanjut yang mampu membedakan litologi dan kandungan fluida* *melalui analisis atenuasi gelombang P dan gelombang S. Studi ini menerapkan atribut SQp dan SQs untuk mengkarakterisasi litologi dan distribusi fluida dalam Formasi Plover di Lapangan Poseidon, menggunakan data seismik tumpukan sudut parsial 3D dan log sumur dari tiga sumur: Kronos-1, Poseidon-1, dan Poseidon-2. Analisis crossplot menunjukkan bahwa nilai SQp rendah (0,02–0,2) dikaitkan dengan batupasir, sedangkan nilai SQp yang lebih tinggi (0,2–0,7) sesuai dengan serpih. Dalam hal diskriminasi fluida, nilai SQs tinggi (0,55–0,7) mengidentifikasi zona yang mengandung gas, sedangkan nilai SQs yang lebih rendah (0,4–0,55) menunjukkan interval jenuh air garam. Volume SQp dan SQs yang diperoleh dari inversi simultan mengungkapkan bahwa reservoir batupasir jenuh gas — yang dicirikan oleh SQp rendah dan SQs tinggi — tersebar di sepanjang tren barat daya hingga timur laut, konsisten dengan lokasi ketiga sumur tersebut. Hasil ini menunjukkan bahwa atribut SQp dan SQs secara efektif membedakan litologi reservoir dari non-reservoir dan membatasi zona yang mengandung hidrokarbon, menyediakan alur kerja berbasis atenuasi yang andal untuk karakterisasi reservoir dalam pengaturan geologi yang serupa.*

1. INTRODUCTION

Reservoir characterization is a critical component of hydrocarbon exploration and development. In this process, reservoir properties are predicted and mapped across the study area. The key physical properties typically evaluated include lithology, porosity, and fluid type. These properties are extrapolated from well data throughout the study area using seismic-derived attributes.

A widely used approach in reservoir characterization is seismic inversion, both pre-stack and post-stack, which generates volumes of acoustic impedance, shear impedance, Vp/Vs ratio, and elastic impedance (Russell, 1988). For example, acoustic impedance volumes have been used to estimate porosity distribution in Bonaparte Basin (Lestari et al., 2023), while Vp/Vs, lambda-rho and mu-rho volumes have been applied to identify gas distribution in the Penobscot Field (Juventa & Fatkhan, 2021).

Another commonly technique is seismic multi-attribute analysis, which employs statistical methods that integrate multiple seismic attributes to predict reservoir properties (Hampson et al., 2001). This approach has been used to estimate gamma-ray, porosity, and density distribution in fields within the Barito and Bonaparte Basins (Febridon et al., 2020; Pratama et al., 2020).

Despite their widespread use, conventional reservoir characterization methods such as seismic inversion and multi-attribute analysis have several limitations. These approaches primarily rely on elastic properties derived from amplitude information and are sensitive to noise, tuning effects, and overburden complexity. Moreover, they often struggle to independently and simultaneously resolve lithology and fluid content which is essential for accurate reservoir evaluation. This limitation indicate the need for supporting approach that provide greater sensitivity to both rock type and fluid saturation.

Seismic wave attenuation offers such an alternative perspective. Attenuation refers to the loss of wave energy as it propagates, resulting in a reduction in amplitude (Al-Sadi, 1980). The energy loss is quantify by the quality factor (Q). The important of Q attributes was demonstrated by Ogiesoba (2016), who showed that Q volume derive from seismic data can be used to identify brittle zones and hydrocarbon sweet spots in the Austin Chalk and Eagle Ford Shale, South Texas. Similarly, Singleton (2008) demonstrated that seismic attenuation can serve as an additional tool in prospect evaluation for hydrocarbon detection, alongside simultaneous impedance inversion method.

To address the limitation of conventional method, this study applies the Scaled Qp (SQp) and Scaled Qs (SQs) attenuation attributes, which offer distinct and independent sensitivity to lithology and fluid content, respectively. SQp estimates P-wave (compressional) attenuation, which is primarily related to lithology, while SQs represents S-wave (shear) attenuation, offering additional insight into fluid type (Hermana et al., 2017). Previous studies have demonstrated the effectiveness of these attributes in differentiating lithology and fluid content. The SQp attribute produces a response similar to the gamma-ray log, whereas the SQs attribute shows behaviour comparable to resistivity (Hermana et al., 2020). Hermana et al. (2018) conducted a series of test to evaluate the performance of SQp and SQs attributes, including log data crossplot analysis followed by the application of simultaneous inversion. El-Badaji and Hermana (2021) compared the SQp and SQs attributes with Amplitude Versus Offset (AVO) analysis, and showed that these attributes can identify hydrocarbon distribution. In an offshore Malaysian field, SQp values were observed to be low in sand-dominated channels and high in mud-dominated region (Lew et al., 2018). Another study in offshore Sarawak demonstrated that modeled resistivity under varying gas saturation conditions was consistent with SQs anomalies pattern (Salleh et al., 2021). In the North East Java Basin, gas-saturated sandstone reservoir were characterized by low SQp values (0-0.5) and high SQs values (0.6-0.7) (Sadat et al., 2021). Additionally, a study in the Kutai Basin incorporated SQp and SQs alongside elastic properties such as Poisson ratio and Lamda-Mu-Rho for gas detection (Safira et al., 2022).

In the Poseidon Field, prior work by Sihotang and Herawati (2021) utilized Lambda–Mu–Rho parameters derived from simultaneous inversion to investigate lithology and fluid distribution. Their results indicated that gas-saturated sandstone is characterized by Lambda-Rho value below 50 GPa·g/cc and a Lambda/Mu less than 0.8, with spatial distribution trending from northeast to southwest. While this study provided a valuable framework, it relied on elastic impedance-based inversion and did not incorporate attenuation-based analysis, leaving the independent lithology–fluid discrimination potential of the Plover Formation underexplored. This study addresses that gap by applying SQp and SQs attenuation attributes to the Plover Formation sandstone reservoir at Poseidon Field. This work represents the first application of the SQp and SQs framework in this field and provides an attenuation-based approach for characterizing lithology and gas distribution.

2. LITERATURE REVIEW

2.1. Scaled Qp (SQp) and Scaled Qs (SQs)

The SQp and SQs methods are based on seismic attenuation theory. The amount of wave attenuation is quantified by the quality factor (Q), which indicates how strongly a medium attenuates a wave. A high Q value corresponds to low attenuation. The quality factor is defined as:

$$Q = \frac{2\pi E}{\Delta E} \quad (1)$$

where Q is the quality factor, E is the seismic wave energy, and ΔE is the energy loss per cycle. In general, higher Q values are associated with denser rock and higher impedance. Conversely, increasing porosity tends to reduce Q. The Vp/Vs also affects Q value. Lithology plays an important role: higher shale content reduces attenuation, resulting in higher Q values. Additionally, the presence of water- particularly bound water in shale -can increase Q. Therefore, attenuation analysis provide valuable information for identifying lithology types and fluid conditions in rocks (Zhang & Stewart, 2008).

Attenuation in fluid-filled rocks occurs because the presence of fluid causes the rock to behave as a viscoelastic material, allowing heat transfer and leads to attenuation (Mavko et al., 2009). The Qp and Qs are estimated based on differences between elastic modulus at high- and low-frequency conditions. These differences are influenced by changes in anisotropic stiffness, which are related to crack density and can be approximated using Hudson's crack theory (Dvorkin & Mavko, 2006)

Hermana et al. (2016) modified the Qp and Qs formulation and introduced scaled attenuation attributes, SQp and SQs as follows:

$$SQp = \frac{5}{6\rho} \frac{\left(\left(\frac{Vp}{Vs}\right)^2 - 2\right)^2}{\left(\left(\frac{Vp}{Vs}\right)^2 - 1\right)} \quad (2)$$

$$SQs = \frac{10}{3\rho} \frac{\left(\left(\frac{Vp}{Vs}\right)^2\right)}{\left(3\left(\frac{Vp}{Vs}\right)^2 - 2\right)} \quad (3)$$

where ρ is density and Vp/Vs is the ratio of P-wave and S-wave velocities. The density and Vp/Vs volumes were derived from seismic data through simultaneous inversion.

2.2. Simultaneous Inversion

Simultaneous inversion is a technique used to estimate P-impedance (Zp), S-impedance (Zs), density, and Vp/Vs from pre-stack seismic data at different incident angles. This method is based on the assumptions that seismic reflectivity varies with incident angle, as described by the Aki-Richards approximation- a simplified form of the Zoeppritz equation and later modified by Fatti et al. (1994). The inversion process requires several inputs including seismic gathers or partial-angle stacks, low-frequency models, and wavelets. From these inputs, Zp and Zs can be estimated using linear relationships (Hampson et al., 2005).

$$ln(Z_S) = k\, ln(Zp) + kc + \Delta L_S \quad (4)$$

$$ln(\rho) = k\, ln(Zp) + mc + \Delta L_D \quad (5)$$

where k and m are the gradients of the relationship between Zp-Zs and Zp-ρ, respectively; kc and mc are the corresponding intercepts; and ΔLs and ΔL_D represents deviations from linear trends.

3. RESEARCH METHOD

3.1. Geological Setting

The Poseidon Field is located in the Browse Basin, northwest Australia, at water depths of approximately 250 m. The basin comprised a stratigraphic succession from the Mesozoic to the Cenozoic, dominated by sandstones, carbonates, and shales, formed under extensional tectonic regimes.

The Browse Basin experienced multiple tectonic phases, including extension, thermal subsidence, and inversion (Struckmeyer et al., 1998). During the Triassic–Jurassic period, fluvio-deltaic to shallow marine sediments were deposited, forming the Plover Formation, which serves as the primary reservoir. This formation consists predominantly of sandstone interbedded with claystone and minor volcanic rocks. The petroleum system is characterized by the Plover Formation acting as both source and reservoir rocks, sealed by the clay-rich Vulcan Formation. Structural trapping is mainly controlled by horsts and associated fault systems.

3.2. Seismic and Well Data

The seismic dataset used in this study consists of 3D Full Stack data with an angle range of 6–42°, as well as 3D Partial Angle Stack data, including Near (6–18°), Mid (18–30°), and Far (30–42°) stacks. All seismic volumes are recorded with reverse polarity with a sampling rate of 4 msec (ConocoPhillips, 2012). The dataset spans inline numbers 2351-3221 and crossline numbers 1486- 2710, with inline spacing of 18.75 m and cross-line spacing of 12.5 m. The study area covers approximately 2.5 km² and includes three wells: Kronos-1, Poseidon-1, and Poseidon-2. The well data consist of Gamma Ray, Resistivity, Neutron Porosity, Density, P-wave and S-wave logs, as well as formation marker. Both seismic data and well data were taken from the Terranubis website and the National Offshore Petroleum Information Management System (NOPIMS), Australia. Error! Reference source not found. presents the base map of the study area while **Figure 2** shows representative of seismic section for the full (a), near (b), mid (c), and far (d) stack data.

The research location is in Panggung Village, Pelaihari Subdistrict, Tanah Laut Regency, South Kalimantan Province. A regional geological map of the research area is shown in **Figure 1**.

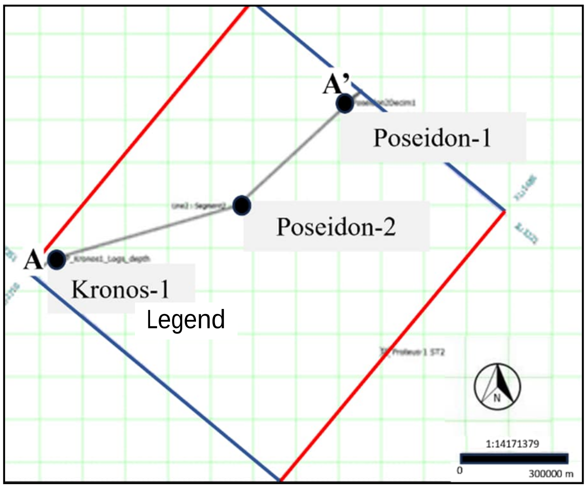

Figure 1. Base Map of Study Area.

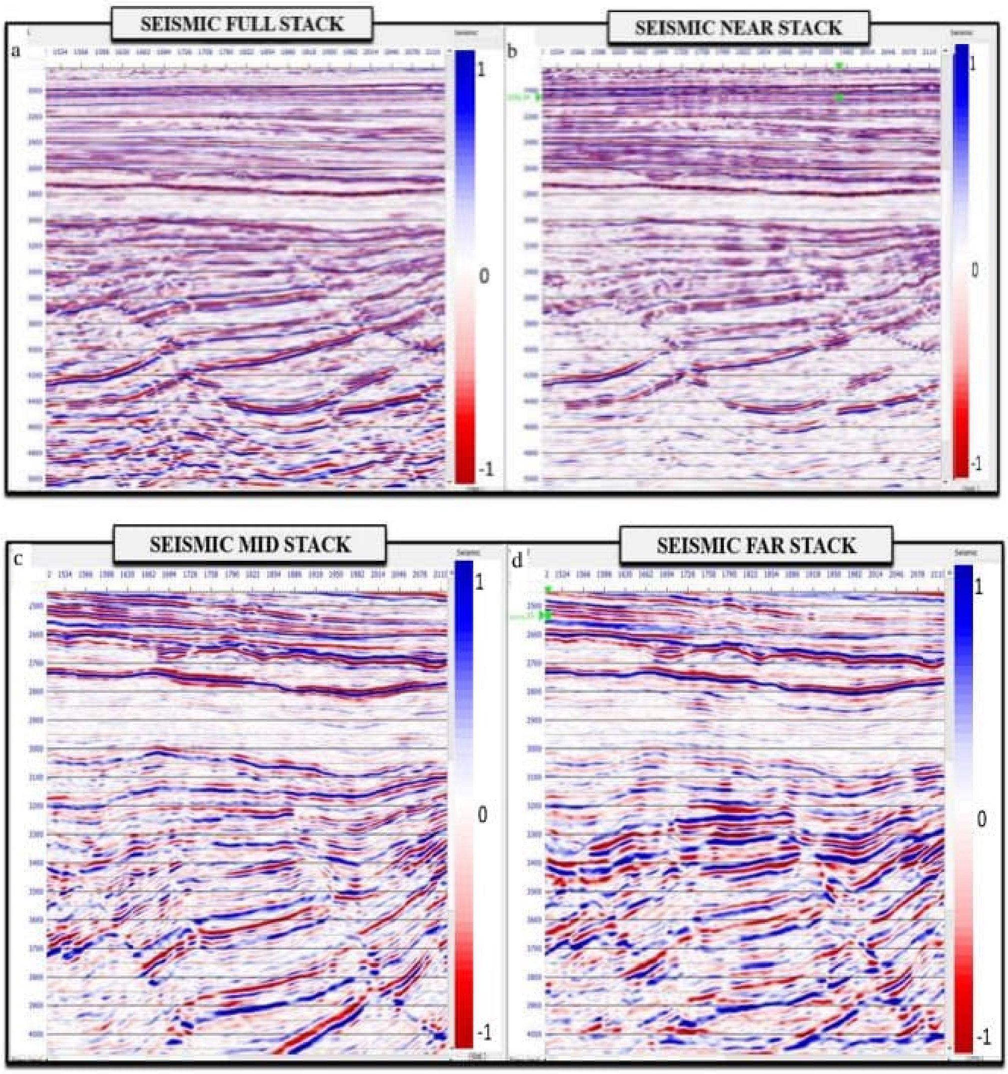

Figure 2. Seismic data for Full Stack (a), Near Stack (b), Mid Stack (c), and Far Stack (d).

3.3. Flowchart

The workflow consists of well log analysis, including the calculation of shale volume, total porosity, and water saturation. The SQp and SQs logs are also derived using Equations 2 and 3, followed by crossplot to identify lithology and fluid distribution. A wavelet is extracted from both full stack and partial angle stacks for well-to-seismic tie and inversion process.

The low-frequency model is built using well logs, extracted wavelet, and horizons. Simultaneous inversion is then applied to generate P-impedance, S-impedance, density, and Vp/Vs volumes. Based on these results, SQp and SQs volumes are derived. Horizon slicing is carried out to observe and interpret lithology and fluid distribution within the Plover Formation.

4. RESULT AND DISCUSSION

4.1. Well Log Analysis

Error! Reference source not found.**3** shows the well log analysis from the Kronos-1 well, highlighting the sandstone interval of the Plover Formation at depths between 4950–5050 m. The gamma ray log (<40 gAPI) and low shale volume (<0.4 V/V) indicate a sandstone lithology. High resistivity values and low water saturation (0.2–0.5) suggest the presence of hydrocarbons. A density-neutron crossover confirms gas saturation, which is also supported by a low Vp/Vs ratio. The total porosity ranges from 10–15%. Attenuation attributes provide additional support for this interpretation, where low SQp (0–0.2) corresponding to sandstone lithology, and high SQs (0.55–0.6) are associated with gas-bearing reservoirs.

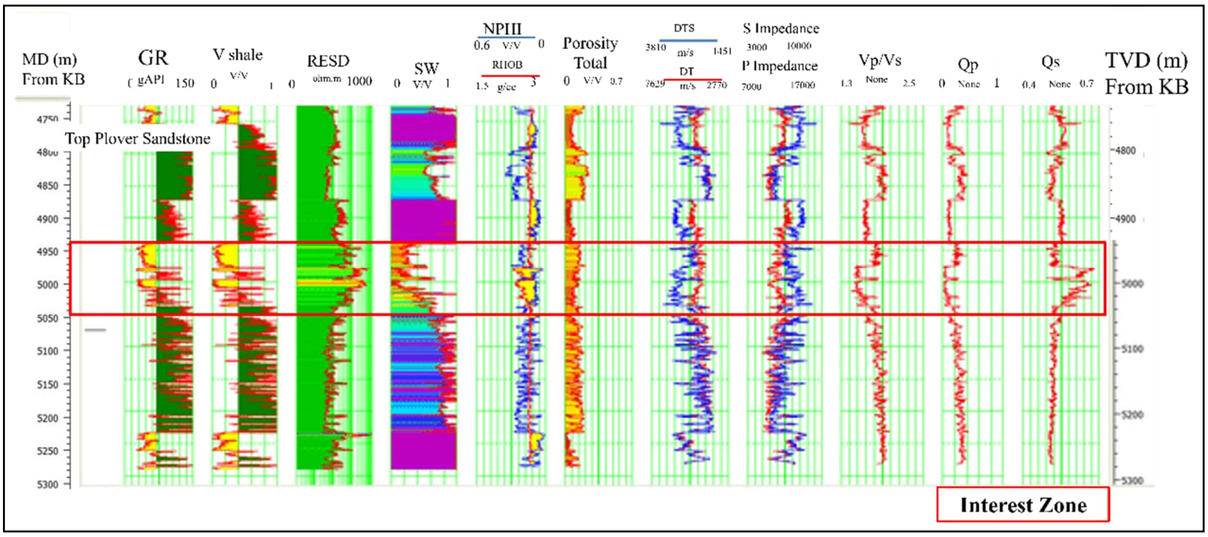

Figure 3. Well Log Analysis of Kronos-1.

4.2. Horizon Interpretation and Time Structure Map

Two horizons were interpreted: the base of the Plover interval characterized by volcanic lithology, and the base of the Plover sandstone. The top of the Plover Sandstone reservoir is located at approximately 3200 msec and lies beneath the base of the Plover Volcanic, as shown in **Figure 4**. **Figure 5** shows the time-structure maps of the base Plover Sandstone horizon. The Kronos-1, Poseidon 1, and Poseidon 2 wells are situated on a structural high and are associated with three-way fault dependents structures.

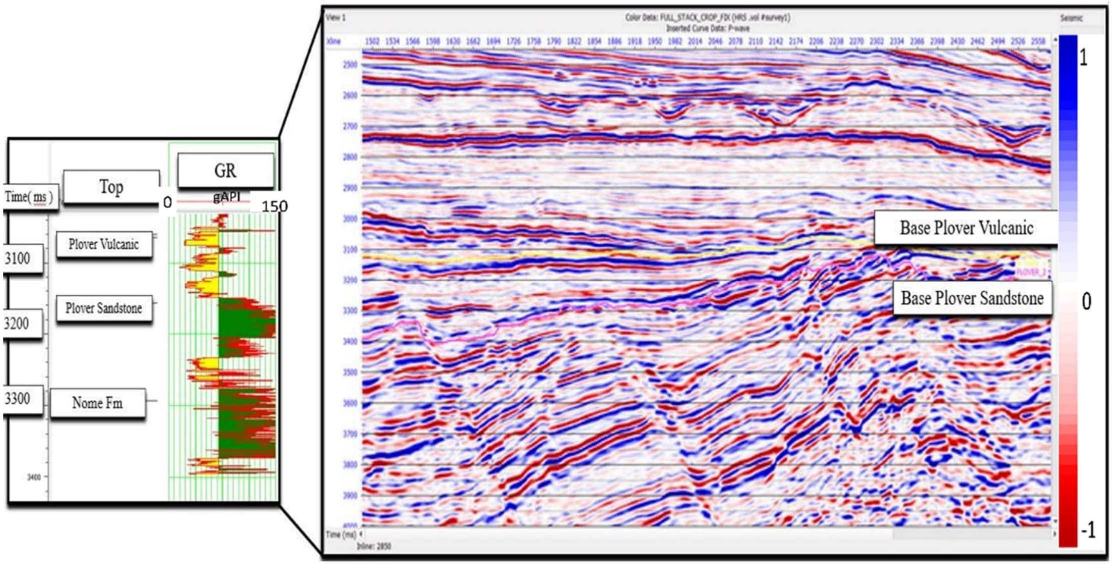

Figure 4. Seismic line and example of GR log for Plover interval.

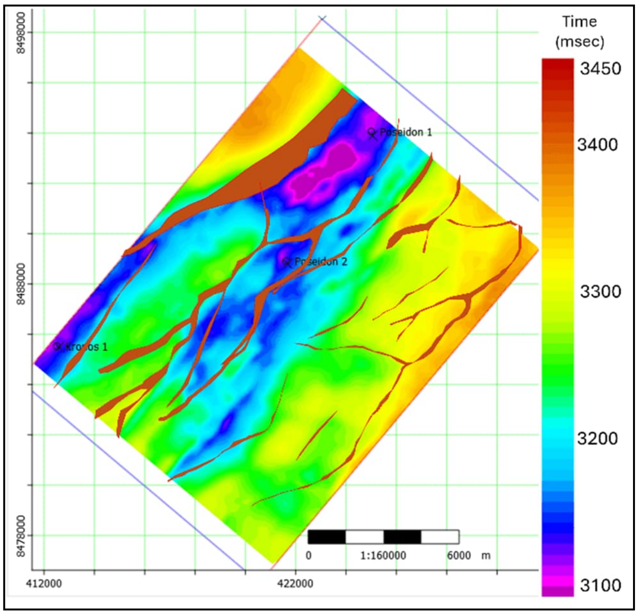

Figure 5. Base Plover Sandstone Time Structure Map.

4.3. P-impedance versus Vp/Vs Crossplot

The crossplot of P-impedance vs. Vp/Vs, with the gamma-ray (GR) log used as the color-bar in **Figure 6**, indicates that the Vp/Vs parameter can effectively distinguish sandstone (low gamma ray) from shale (high gamma ray) lithologies. In contrast, P-impedance alone shows limited capability in differentiating lithology. Sandstone interval generally shows lower Vp/Vs values (< 1.7). However, some intervals with low gamma ray value also display relatively high Vp/Vs, indicating ambiguity in lithology classification. Therefore, additional parameters are required to improve lithology discrimination.

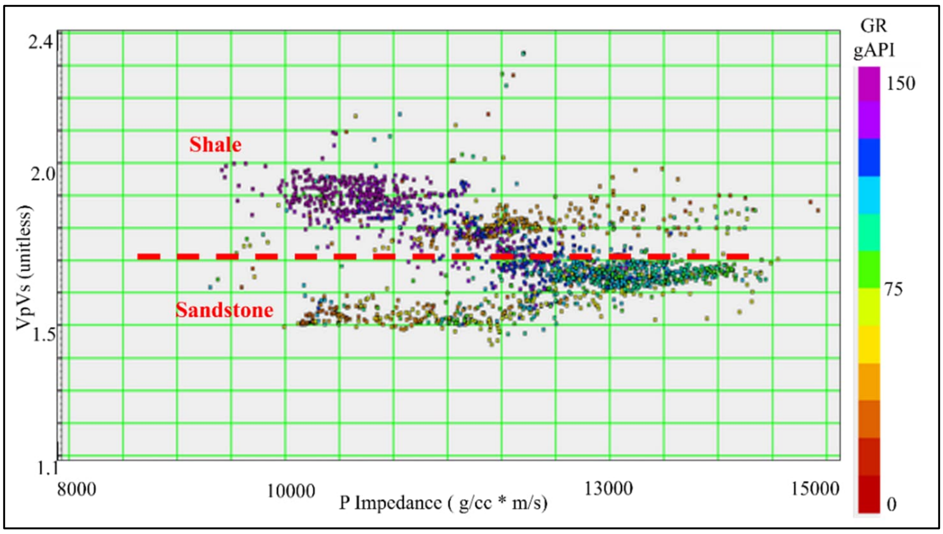

Figure 6. P-impedance – Vp/Vs crossplot with GR data as color bar.

4.4. Crossplot SQp vs. SQs

Error! Reference source not found. shows the SQp-SQs crossplot from three wells, with shale volume (Vsh) as the color-bar, to evaluate lithology separation. The results demonstrate that the SQp attribute provides clearer separation between sandstone and shale in the Plover Formation compared to the Vp/Vs parameter. Shale zones (Vsh > 40%) are characterized by high SQp values (0.20–0.55), whereas sandstone zones (Vsh < 40%) show low SQp values (0–0.15).

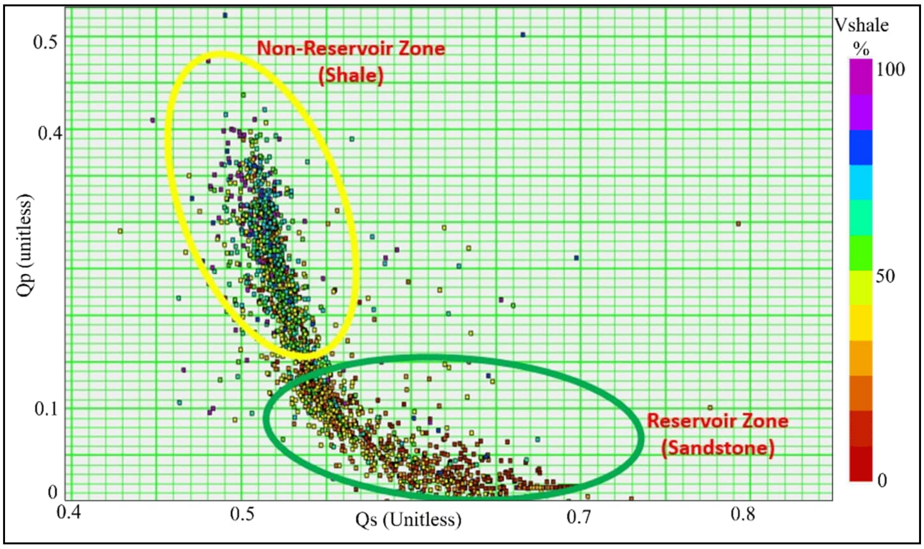

Figure 7. SQp - SQs crossplot with Vshale as color bar for lithology identification.

The SQp-SQs crossplot with water saturation (Sw) as a color-bar, as displayed in **Figure 8**, demonstrated strong sensitivity for identifying gas-bearing zones. Gas reservoirs (Sw < 0.5) are characterized by relatively high SQs values, ranging from 0.6 to 0.7, whereas non hydrocarbon zone (Sw = 0.9 -1) shows lower SQs values, typically between 0.4 and 0.55.

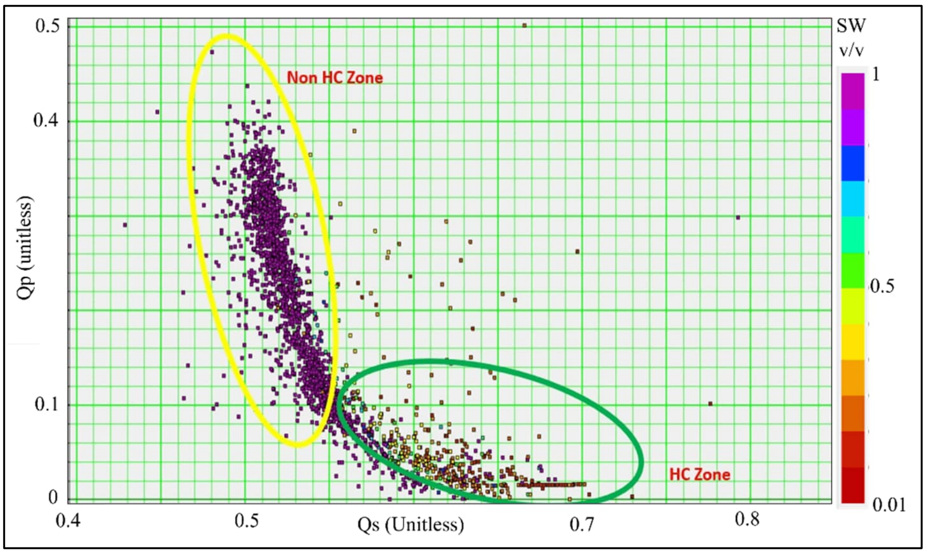

Figure 8. SQp - SQs crossplot with Sw as color bar for identification of hydrocarbon zone.

4.5. Inversion Result

4.5.1. Vp/Vs

Figure 9 shows the Vp/Vs inversion results along a section crossing Kronos-1, Poseidon-1, and Poseidon-2 wells. The results indicate relatively low Vp/Vs ratios (1.5–1.75) below the base of the Plover Volcanic. These low ratios are interpreted as gas-saturated sandstones, as the presence of gas reduces P-wave velocity and lowers the Vp/Vs value. In contrast, higher Vp/vs values are more likely associated with shale or brine-filled rocks. At the three well locations, the Vp/Vs and density results derived from simultaneous inversion show error ranging from 5–11% when compared with well log data within the Plover interval. These error levels are considered acceptable for proceeding to next process. Since the calculation of SQp and SQs depends on Vp/Vs and density, the resulting SQp and SQs volumes are expected to inherit a comparable level of uncertainty.

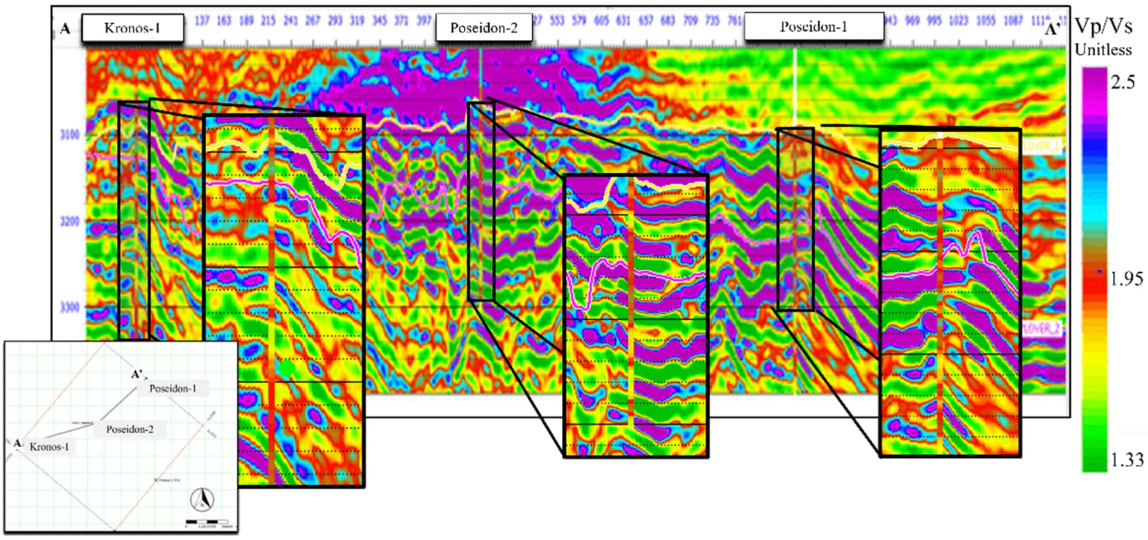

Figure 9. Vp/Vs inversion result passing through all three wells.

4.5.2. SQp and SQs

The SQp volume shown in Error! Reference source not found. highlights the target zone within the Plover Formation, located at approximately 3100–3200 ms (equivalent to a depth of about 4500–5000 m). This interval is characterized by which exhibits low SQp values ranging from 0.04 to 0.2. Such low values are associated with lithologic conditions in which seismic wave energy undergoes stronger attenuation, as typically observed in the reservoir sandstone. In contrast, non-reservoir lithologies such as shale generally have higher SQp values due to lower attenuation, influenced by shale-bound water and a more compact structure. Therefore, the SQp attribute is effective in distinguishing sandstone reservoirs from shale-dominated intervals.

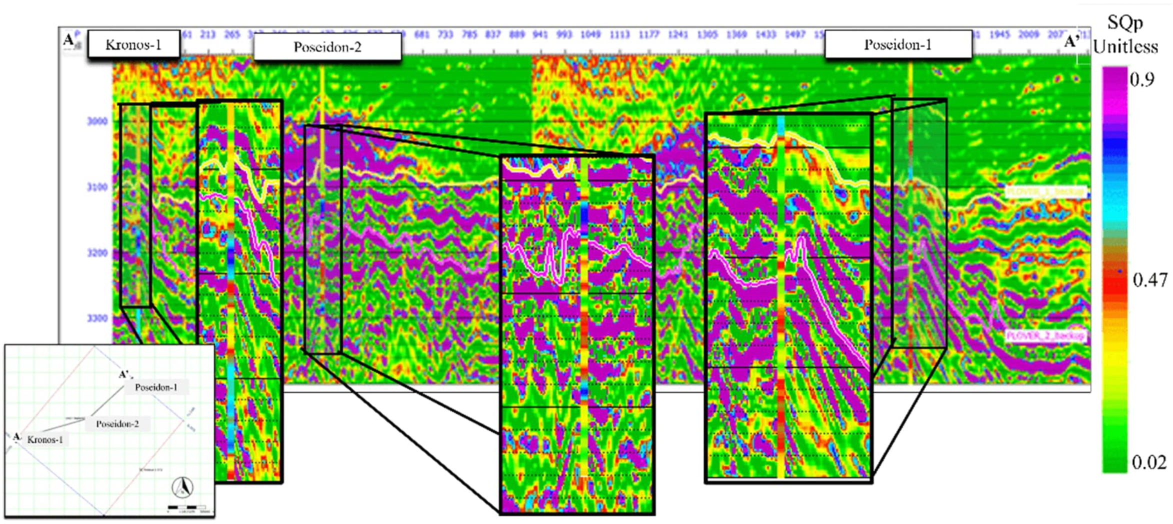

Figure 10. SQp section passing through all three wells.

Figure 11 shows the SQs section across the three wells, showing the target zone within the Plover Formation at 3100–3200 ms (approximately 4500–5000 m depth). In this interval, SQs values range from 0.5 to 0.7, indicating strong S-wave sensitivity to elastic contrast. This response is commonly associated with fluid variations, where gas generates higher elastic contrast than brine, resulting in higher SQs values. In contrast, lower SQs values are typically observed in brine-saturated zones, as brine has more uniform physical properties and does not significantly affect the rock's shear modulus, leading to weaker S-wave attenuation. The SQs results at the Poseidon-2 well are less reliable than those at the Kronos-1 and Poseidon-1 wells. This is due to higher inversion errors in density and Vp/Vs at Poseidon-2, which reach approximately 11%, exceeding the errors observed at the other wells.

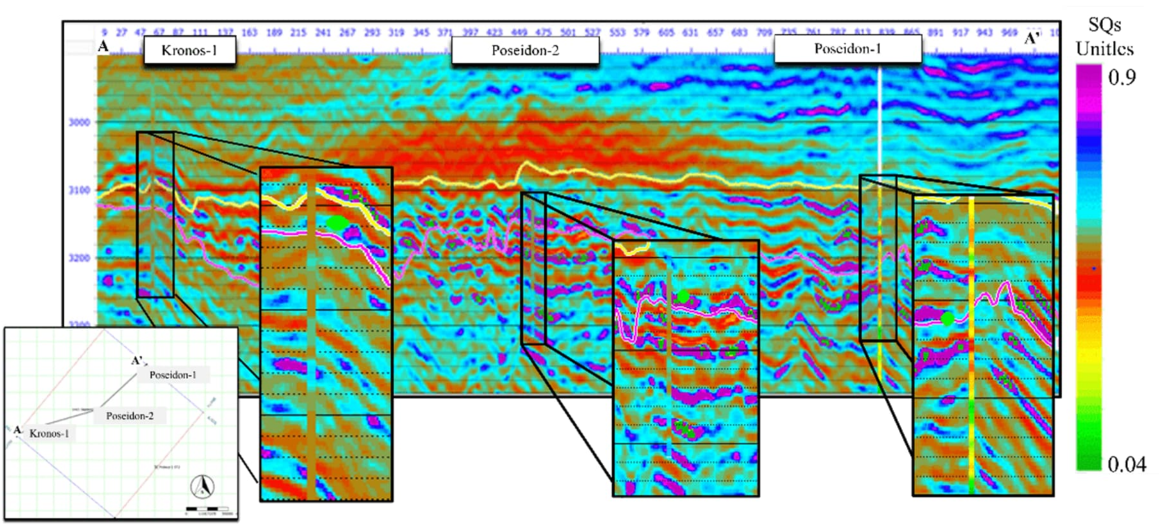

Figure 11. SQs section passing through all three wells.

4.6. Slice Map

4.6.1. Vp/Vs Slice Map

Figure 122 shows a Vp/Vs slice between the base of the Plover Volcanic (+10 ms) and the base of the Plover Sandstone, illustrating the distribution of gas-saturated zones. The map indicates low Vp/Vs values, ranging from 1.3 to 1.7, at the Kronos-1, Poseidon-1, and Poseidon-2 wells. These low values are interpreted as gas-saturated reservoir zones. Spatially, the low Vp/Vs trend extends from the southwest toward the northeast.

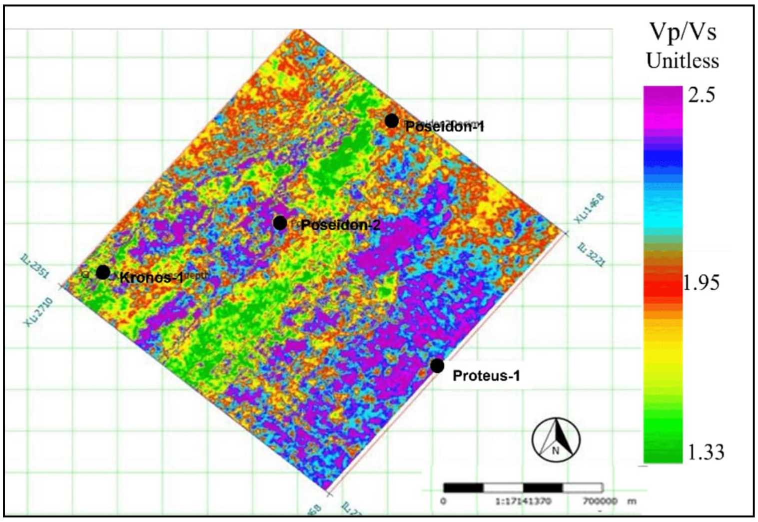

Figure 12. Vp/Vs slice map.

4.6.2. SQp and SQs Slice Map

Figure 13 shows SQp slice within the same interval. All three wells-Kronos-1, Poseidon-1, and Poseidon-2 - exhibit low SQp values ranging from 0.02 to 0.2. These low values are characteristic of sandstone lithology. The presence of pore space in sandstone enhances seismic wave attenuation, resulting in reduced SQp values. The distribution of low SQp values is predominantly oriented from southwest to northeast, as highlighted by the black line in the figure.

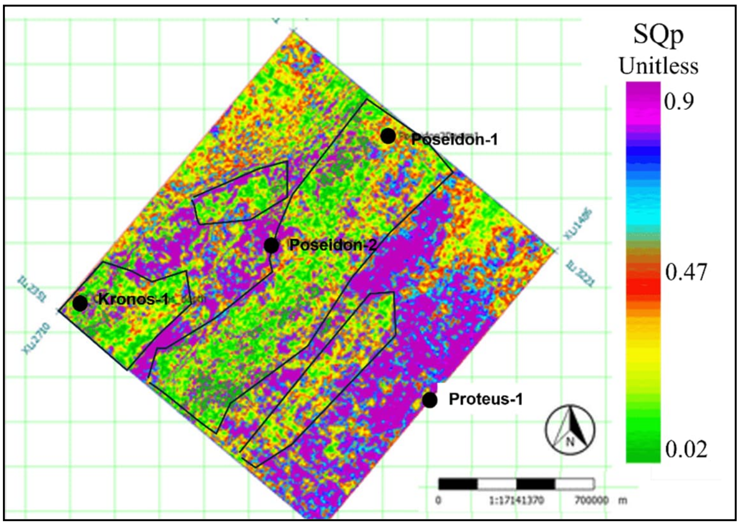

Figure 13. SQp slice map.

Figure 14 shows the corresponding SQs slice. High SQs values (0.5- 0.7) are observed across all three wells and occur in the same region as the low SQp anomalies. These values also distributed along a southwest-northeast trend, as highlighted by the black line. High SQs values in this interval are interpreted as a response to gas-saturated sandstone.

The southwest–northeast trend of gas-bearing sandstone distribution is consistent with previous finding in the Poseidon Field based on Lambda–Mu–Rho analysis (Sihotang & Herawati, 2021).

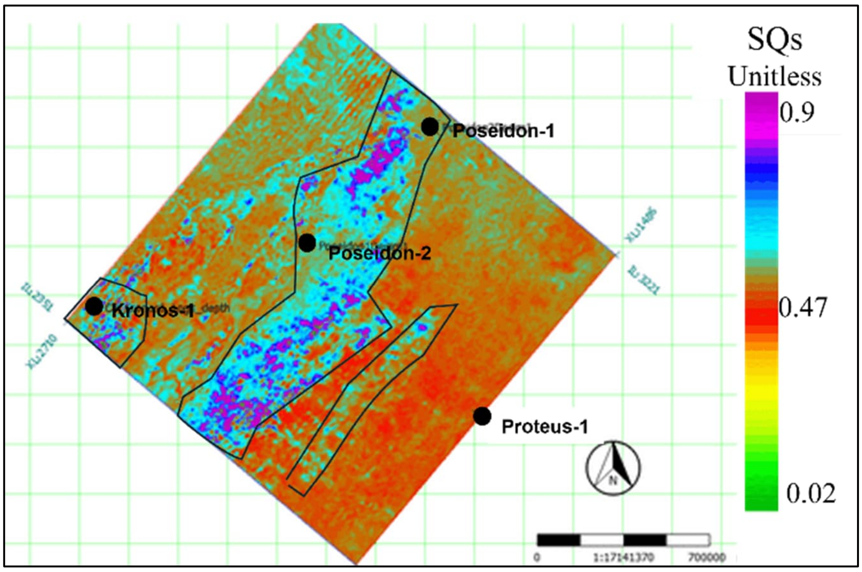

Figure 14. SQs slice map.

5. CONCLUSION

Based on this study, the SQp and SQs attributes are effective in distinguishing hydrocarbon-bearing sandstone reservoirs from brine-saturated shale within the Plover Formation. Crossplot analysis indicates that sandstone reservoirs are characterized by lower SQp values (0.01–0.2) and higher SQs values (0.55–0.7), whereas shale intervals exhibit higher SQp values (0.2–0.5) and lower SQs (0.4–0.55). Attributes slicing further reveals that gas-bearing reservoirs, defined by with low SQp and high SQs values, are distributed along a southwest-northeast trend. In contrast, non-reservoir zones, characterized by higher SQp values (0.3–0.9), are predominantly located in the southern part of the study area. These results demonstrate that the integration SQp and SQs attributes provides an effective approach for mapping lithology and identifying gas-saturated zones in the Plover Formation.

The defined SQp and SQs value ranges can serve as practical screening criteria in hydrocarbon exploration workflows within the Plover Formation. Moreover, the southwest-northeast distribution trend identified from attribute slicing offers a useful spatial framework for guiding future prospect delineation. Overall, the SQp and SQs attributes contribute valuable insights into lithology and fluid distribution, which are critical in hydrocarbon exploration. Nevertheless, the applicability of SQs and SQp attributes to other field with different lithology and fluid conditions requires further investigation to assess the broader robustness of this approach.

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