Scientific Contributions Oil & Gas, Vol. 49. No. 2, June: 297 - 317

SCIENTIFIC CONTRIBUTIONS OIL AND GAS

Testing Center for Oil and Gas
LEMIGAS

Journal Homepage:http://journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

Integrating DT Sonic and RMS Velocity as Dual Indicators for Overpressure and Fluid Screening in the Lower Seurula Formation of the Rayeu Field, North Sumatra Basin

Pramuditya Dwi Permana, Dasapta Erwin Irawan, and Agus Mochamad Ramdhan

Institut Teknologi Bandung,
Ganesha Street No.10, Lb. Siliwangi, Kecamatan Coblong, Bandung City, Jawa Barat 40132, Indonesia

Corresponding author: Pramuditya Dwi Permana (pramuditya.permana@gmail.com)

Manuscript received: February 17th, 2026; Revised: March 26th, 2026
Approved: May 01th, 2026; Available online: June 15th, 2026; Published: June 15th, 2026.

ABSTRACT - Velocity anomalies are widely used as indicators of Overpressure and hydrocarbon presence in clastic sedimentary basins. However, seismic and sonic velocity responses are inherently non-unique because similar anomalies may result from unloading Overpressure, lithological variation, or fluid-related effects. This ambiguity becomes significant within the Lower Seurula Formation of the Rayeu field, North Sumatra Basin, where several wells exhibit varying production performance despite comparable velocity responses. This study proposes an integrated interpretation framework combining residual DT sonic (ΔDT) and residual RMS velocity (ΔVRMS) as dual indicators for Overpressure and fluid screening. The workflow integrates well log analysis, seismic-derived RMS velocity, interval velocity evaluation, clay transformation interpretation, and Fluid Replacement Modeling (FRM). Results indicate that the Lower Seurula Formation is dominated by unloading-related Overpressure, supported by persistent DT sonic deviation, interval velocity reversal, and evidence of smectite-illite transformation. FRM analysis demonstrates that gas saturation significantly reduces P-wave velocity and may generate responses similar to Overpressure anomalies. Wells exhibiting elevated ΔDT and strongly negative ΔVRMS responses generally correspond to better production performance. These findings demonstrate that integrating residual DT sonic and residual RMS velocity reduces interpretation ambiguity between unloading-related Overpressure and hydrocarbon-related fluid effects. The proposed workflow provides a practical approach for early-stage fluid screening and Overpressure evaluation in clastic sedimentary basins.

Keywords : overpressure, DT sonic, RMS velocity, Lower Seurula, fluid screening, unloading

How to cite this article:

Pramuditya Dwi Permana, Dasapta Erwin Irawan, and Agus Mochamad Ramdhan, 2026, Integrating DT Sonic and RMS Velocity as Dual Indicators for Overpressure and Fluid Screening in the Lower Seurula Formation of the Rayeu Field, North Sumatra Basin, Scientific Contributions Oil and Gas, 49 (2) pp. 297 - 317. DOI org/10.29017/scog.v49i2.2108.

INTRODUCTION

The North Sumatra Basin is one of the major hydrocarbon-producing basins in Indonesia and has been explored for decades due to its significant petroleum potential (Hall 2012; Doust & Noble 2008). Despite extensive exploration and appraisal activities, abnormal pore pressure remains an important subsurface challenge because it influences drilling safety, reservoir evaluation, and hydrocarbon prediction, particularly within deeply buried shale-dominated intervals.

Overpressure in sedimentary basins is commonly associated with disequilibrium compaction or undercompaction, where pore fluids are unable to escape during rapid sedimentation (Dickinson 1953). Under loading conditions, increasing effective stress generally produces progressive velocity increase and porosity reduction with depth. However, several studies have shown that Overpressure may also be generated by unloading mechanisms such as hydrocarbon generation, fluid expansion, and clay mineral transformation (Bowers 1995; Swarbrick & Osborne 1998). Unlike loading mechanisms, unloading processes may generate anomalously low velocity responses without significant porosity increase.

One of the commonly discussed unloading mechanisms is the smectite-illite transformation, which releases bound water during clay diagenesis and potentially contributes to secondary Overpressure generation (Burst 1969; Bruce 1984). In shale-dominated systems, this mechanism may preserve anomalously high sonic transit time responses even below the normal compaction trend. Velocity anomalies derived from sonic logs or seismic velocity data are inherently non-unique because similar responses may originate from Overpressure, lithological variation, or hydrocarbon saturation. Consequently, interpretation based on a single velocity indicator may lead to uncertainty, particularly in clastic basins where multiple geological processes coexist.

Within the Rayeu field, several wells penetrating the Lower Seurula Formation exhibit similar velocity anomalies but different production performance, suggesting that velocity response alone may not uniquely represent Overpressure conditions. This ambiguity complicates subsurface interpretation and early-stage reservoir screening. This study aims to evaluate the dominant Overpressure generation mechanism within the Lower Seurula Formation of the Rayeu field through integrated analysis of DT sonic, RMS velocity, interval velocity behavior, clay transformation evidence, and fluid replacement modeling (FRM). The study further proposes the integration of residual DT sonic (ΔDT) and residual RMS velocity (ΔVRMS) as dual indicators to improve interpretation reliability and fluid screening in clastic systems.

Geological Setting

Regional Geological Framework

The North Sumatra Basin is a major back-arc basin located along the western margin of Sundaland. Basin development was initiated during Paleogene extensional tectonics, forming a series of north-south-oriented grabens controlled by pre-existing basement structures (Davies 1984; Barber et al., 2005). Subsequent post-rift subsidence enabled the accumulation of thick Paleogene-Neogene sedimentary successions dominated by clastic deposition.

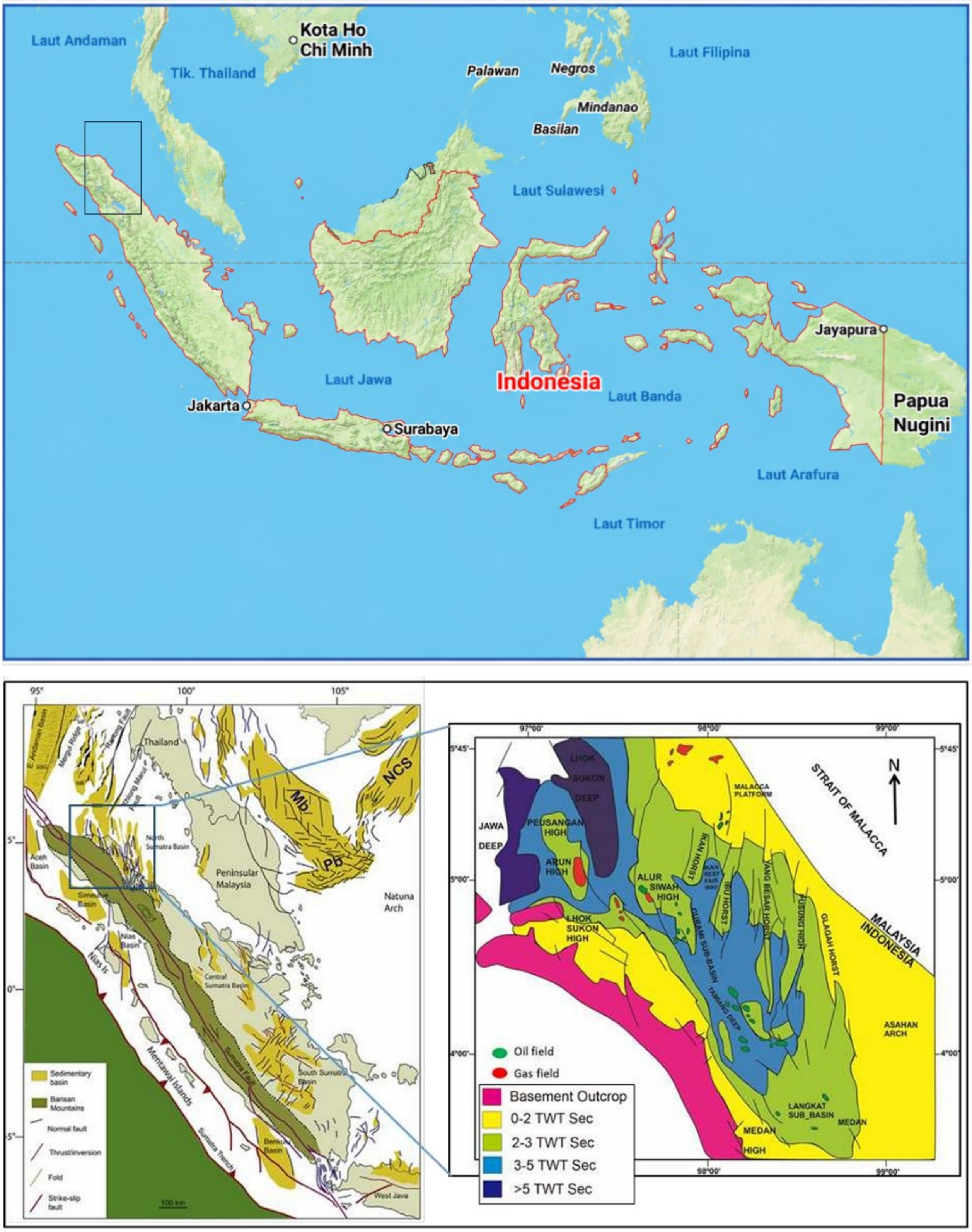

Figure 1. Regional structural framework of the North Sumatra Basin showing major basement highs and graben orientation (modified after Pubellier & Morley 2013; Anderson et al., 1993).

The tectonic evolution of the basin was strongly influenced by oblique subduction of the Indo-Australian Plate beneath Sundaland, followed by Miocene inversion and strike-slip reactivation. Rapid sedimentation and the development of thick shale intervals contributed to widespread abnormal pore pressure conditions within several depocenters of the basin.

Stratigraphic Framework

The basin stratigraphy consists of pre-Tertiary basement overlain by Paleogene syn-rift and Neogene post-rift sedimentary sequences. Regionally, thick marine shale intervals of the Baong Formation act as important source rock and regional seal components within the petroleum system (Buck & McCulloh 1994). The North Sumatra Basin contains a proven petroleum system characterized by mature shale source rocks, thick regional seals, and sandstone reservoirs within Neogene successions. Hydrocarbon generation and fluid migration within shale-dominated intervals are considered potential contributors to unloading-related Overpressure development in the study area. The Lower Seurula Formation belongs to the Neogene post-rift succession and consists predominantly of interbedded sandstone and shale deposited within shallow marine to deltaic environments. Thick shale intervals combined with rapid sedimentation contribute to abnormal pore pressure development within the formation.

Rayeu Field and Lower Seurula Formation

The study area is located within the Rayeu field, which lies within the mature hydrocarbon province of the North Sumatra Basin. Exploration and appraisal activities within the Rayeu area have resulted in multiple drilled wells that provide the subsurface data used in this study.

Production performance within the Rayeu field varies significantly among wells despite the presence of relatively comparable seismic and sonic velocity anomalies. Several wells penetrating the Lower Seurula Formation demonstrate distinct reservoir behavior ranging from non-commercial gas indication and high water saturation to strong gas-condensate production. Wells such as Piada-1 and Rayeu CA exhibit productive hydrocarbon flow from the Lower Seurula interval, while Piada B-1 shows strong gas indication without a sustained production response. East Arun A-1 is characterized by significant water production despite gas presence, whereas NLS A-1 demonstrates relatively cleaner gas-bearing reservoir behavior. The strongest production performance is observed in Rayeu CA, which represents the main productive intervals within the study area.

These production variations indicate that velocity anomalies alone may not sufficiently explain reservoir productivity and fluid distribution within the Lower Seurula Formation. Similar seismic and sonic responses may originate from different geological mechanisms, including unloading -related Overpressure, lithological variation, and hydrocarbon saturation effects. Consequently, a more comprehensive and integrated evaluation approach is required to distinguish the dominant controls on velocity behavior and improve fluid screening reliability within the Rayeu field.

METHODOLOGY

Available datasets used in this study include well logs, seismic-derived RMS velocity, XRD mineralogical data, and production test information from wells penetrating the Lower Seurula Formation within the Rayeu field. These datasets represent fundamental data types commonly available in exploration and development fields, making the proposed workflow practical and transferable for areas with limited data availability. Data quality control and interval correlation were conducted prior to interpretation to ensure consistency between well-scale and seismic-scale observations.

This study integrates DT sonic analysis, seismic -derived RMS velocity evaluation, interval velocity interpretation, clay transformation analysis, and fluid replacement modeling (FRM) to investigate Overpressure mechanisms and fluid-related seismic responses within the study interval (Eaton, 1975; Bowers, 1995; Gassmann, 1951). The workflow was designed to evaluate the dominant Overpressure generation mechanism and to assess whether integration of residual DT sonic (ΔDT) and residual RMS velocity (ΔVRMS) can improve

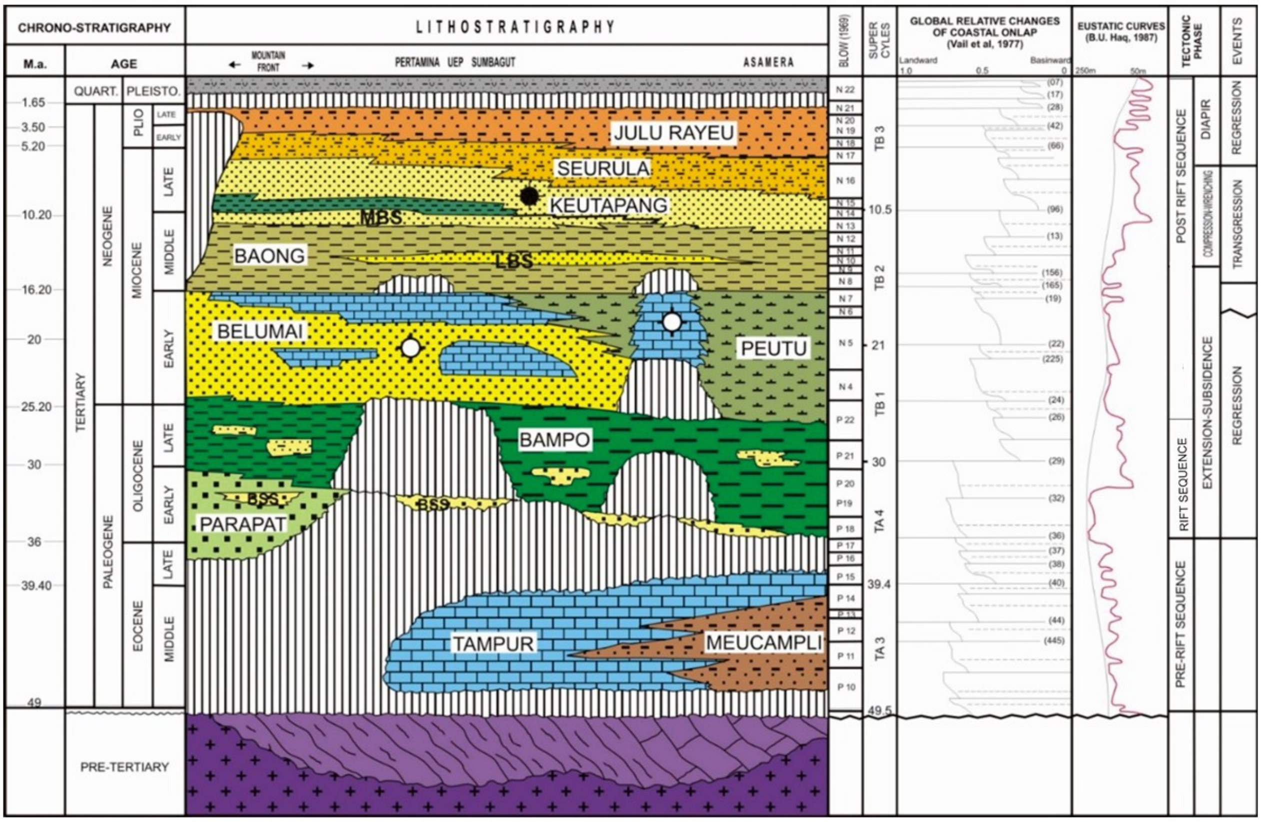

Figure 2. Regional lithostratigraphy of the North Sumatra Basin from Early Eocene to present day (modified after Ryacudu et al., 1992).

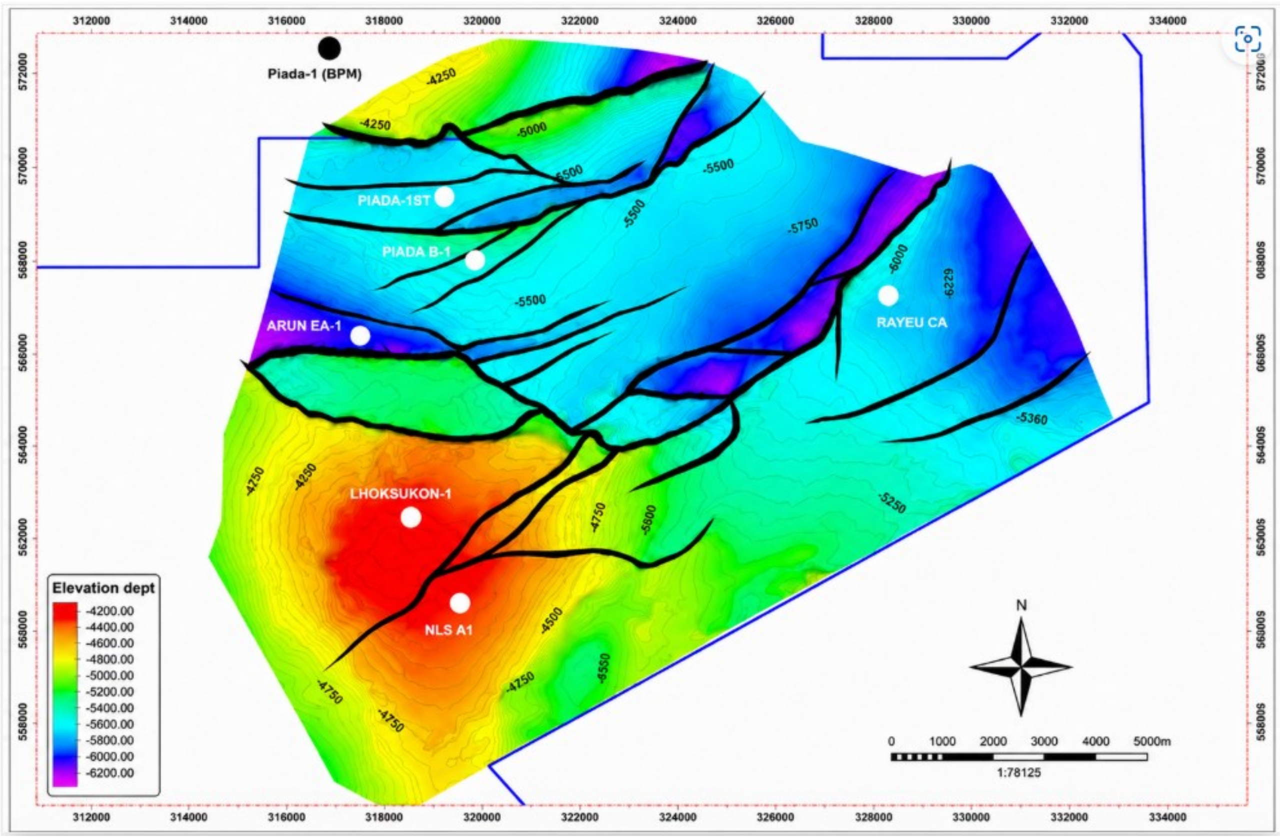

Figure 3. Structural depth map of the Rayeu field showing major fault distribution, structural compartments, and analyzed wells within the Lower Seurula Formation.

discrimination between unloading-related Overpressure and hydrocarbon-related fluid effects. (Bowers 1995; Swarbrick & Osborne 1998). Residual comparison between DT sonic and RMS velocity was subsequently applied to assess interpretation consistency among wells exhibiting different production performance. Due to data availability limitations within the study area, seismic velocity evaluation was primarily conducted using RMS velocity data. Interval velocity was subsequently derived through Dix conversion to support the interpretation of Overpressure-generating mechanisms.

In this study, interval velocity analysis was used mainly for qualitative validation because the derived results are highly sensitive to noise amplification and local instability. Therefore, RMS velocity was retained as the primary parameter for regional interpretation since it represents the original seismic velocity response and provides more stable regional trends. The DT trend was established using a shale baseline defined by gamma ray cut-off values greater than 80 API, representing intervals dominated by clay-rich lithologies. In contrast, the VRMS trend was derived from a linear regression equation ($Y = 1.7543x - 1.7$), providing a regional compaction reference for seismic velocity. These baseline trends were subsequently used to calculate residual DT (ΔDT) and residual RMS velocity (ΔVRMS) for anomaly screening.

RESULT & DISCUSSION

DT Sonic Response

DT sonic analysis within the Lower Seurula Formation shows persistent deviation from the normal compaction trend (NCT) in several wells. Under normal loading conditions, sonic transit time generally decreases progressively with burial depth due to increasing effective stress and porosity reduction. However, the analyzed wells exhibit flattening and locally increasing DT responses below the expected compaction trend, indicating the presence of abnormal pressure development. The persistence of elevated DT responses without significant porosity rebound is interpreted to be consistent with unloading-related Overpressure

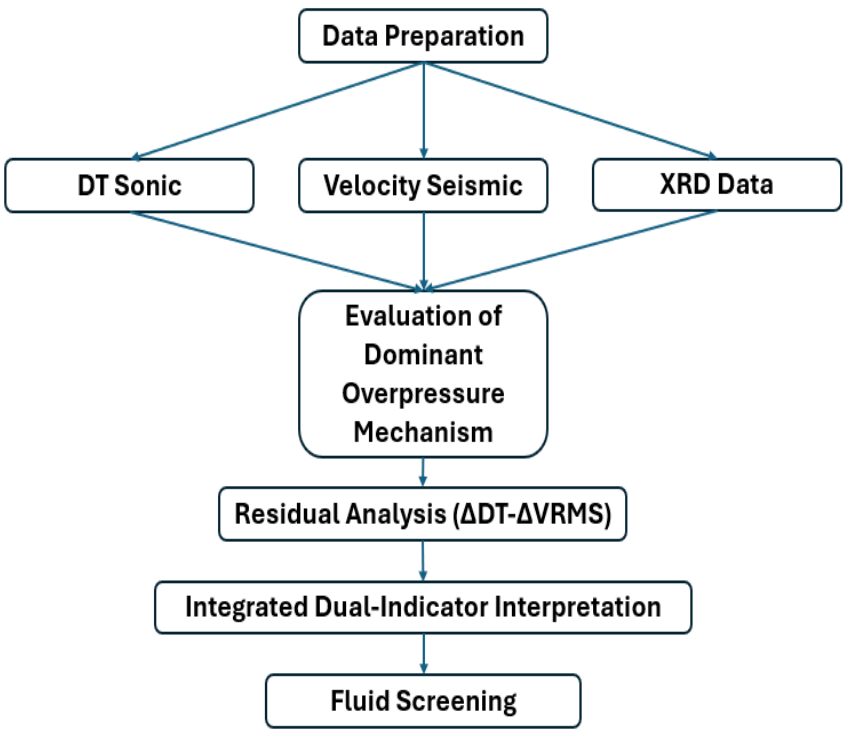

Figure 4. Integrated workflow for Overpressure evaluation and fluid screening within the Lower Seurula Formation of the Rayeu field.

mechanisms rather than disequilibrium compaction alone. This behavior is consistently observed across all analyzed wells within the study area. Rayeu CA was selected as the representative well because it exhibits the strongest production performance and the clearest DT anomaly response.

Seismic Velocity Behavior

Seismic velocity evaluation within the Lower Seurula Formation was primarily conducted using RMS velocity data due to data availability limitations within the study area. RMS velocity was selected as the primary parameter for regional interpretation because it represents the original seismic-derived velocity response and provides smoother regional trends. Unlike DT sonic data, which represents localized well-scale responses, RMS velocity reflects cumulative seismic velocity behavior over broader subsurface intervals and therefore provides more representative regional-scale characterization within the study area. This regional behavior allows RMS velocity anomalies to capture larger-scale pressure distribution and fluid-related seismic responses beyond individual well observations.

Consequently, residual RMS velocity was considered important for evaluating the regional continuity of velocity anomalies within the Lower Seurula Formation. To evaluate the dominant Overpressure-generating mechanism, interval velocity was subsequently derived from RMS velocity through Dix conversion (Dix, 1955). According to Bowers (1995), unloading-related Overpressure mechanisms are commonly characterized by interval velocity reversal or decreasing velocity trends with depth, in contrast to normal loading behavior, where velocity progressively increases with burial depth.

Mineralogical Evidence

XRD mineralogical analysis within the Lower Seurula Formation indicates progressive reduction of smectite content with increasing burial depth, accompanied by persistent illite dominance within shale intervals. Smectite minerals are still observed within shallower intervals around 6380–6425 ft, whereas deeper intervals below approximately

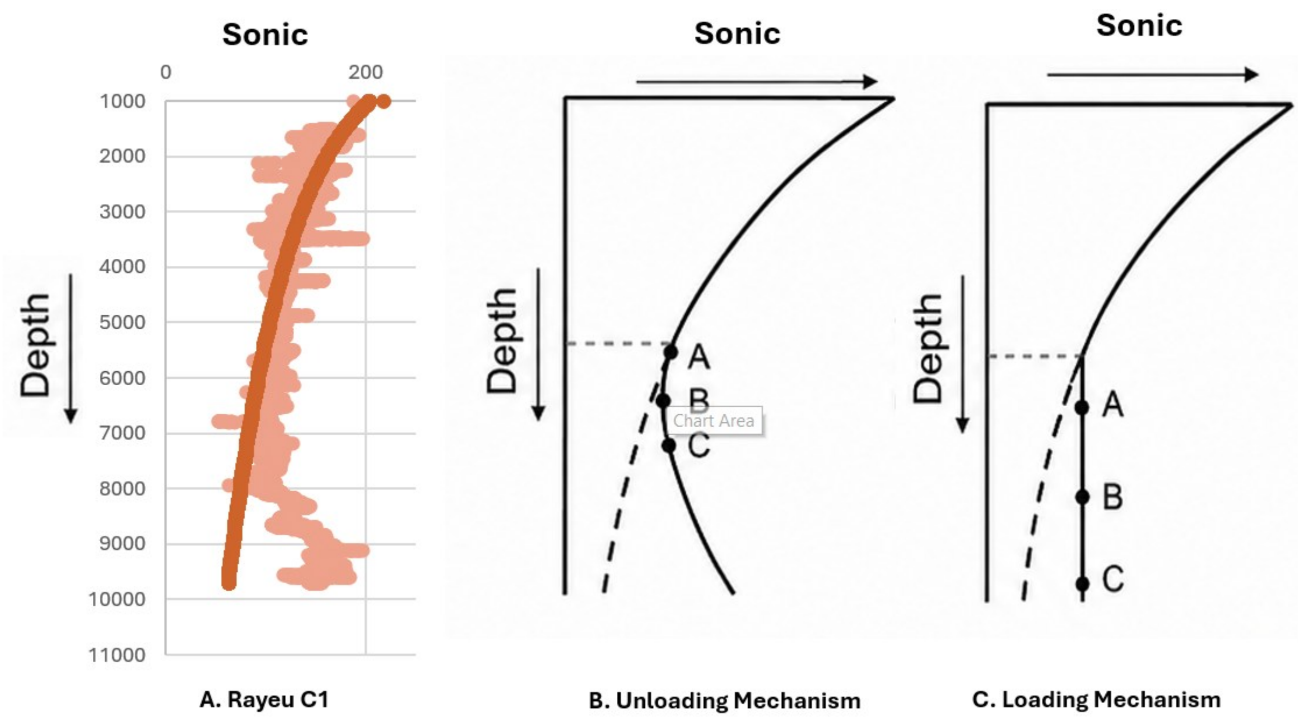

Figure 5. Representative DT sonic responses within the Lower Seurula Formation. Panel A shows actual DT sonic data from Rayeu CA, while Panels B and C illustrate conceptual unloading and loading responses adapted from Ramdhan et al. (2011). The observed DT behavior in Rayeu CA is more consistent with unloading-related Overpressure.

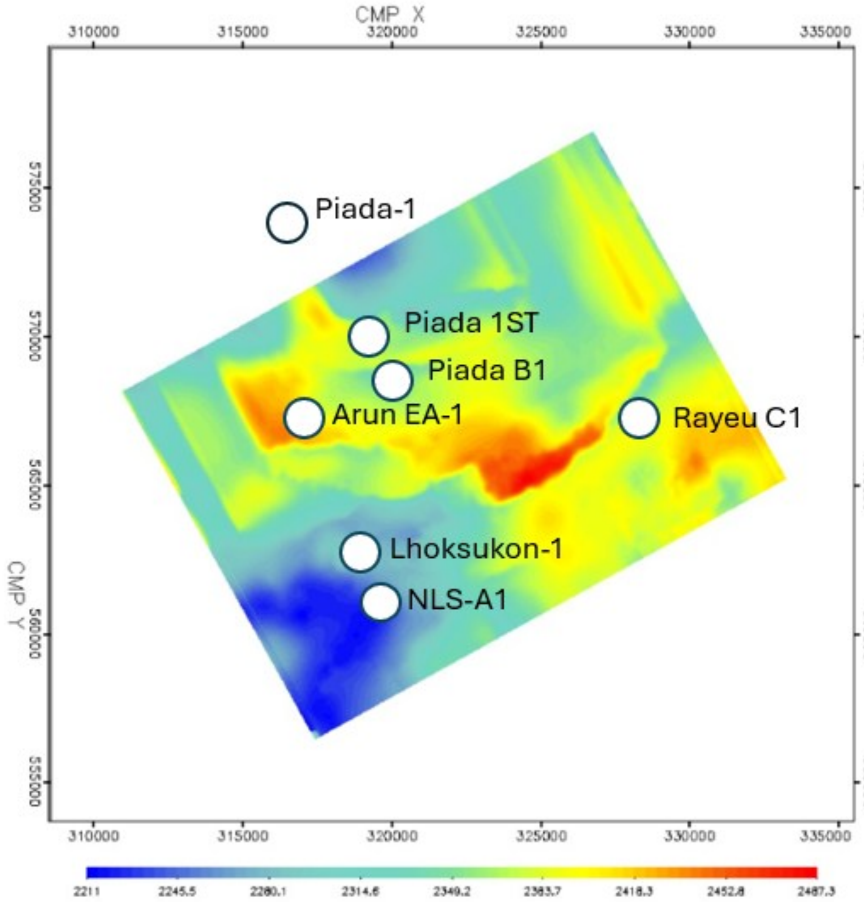

Figure 6. RMS velocity distribution within the Lower Seurula Formation showing regional seismic velocity behavior and analyzed wells in the Rayeu field.

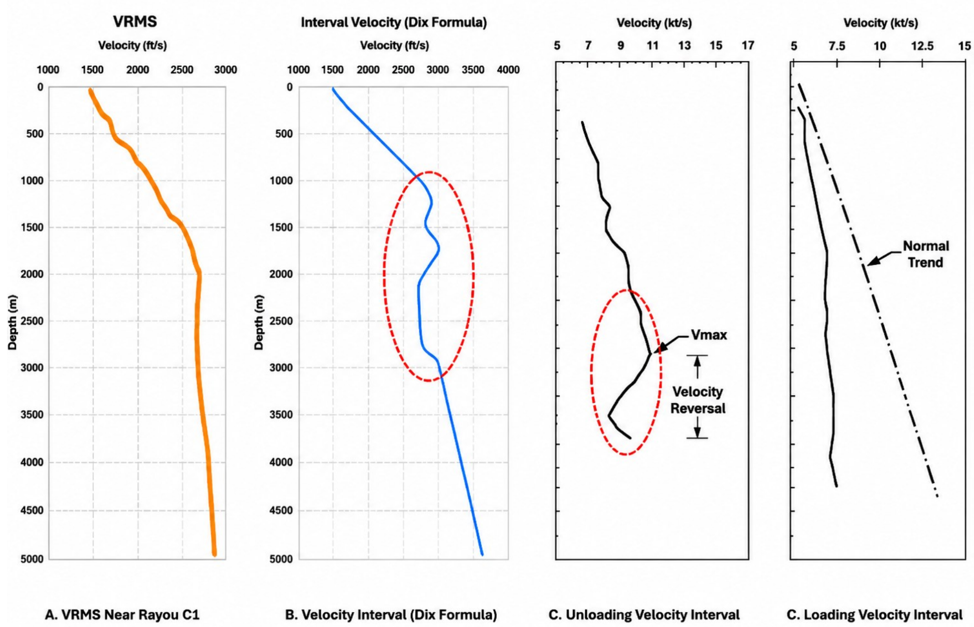

Figure 7. Illustration of seismic velocity behavior within the study area. Panel A shows the RMS velocity near Rayeu CA, while Panel B represents the interval velocity derived using the Dix conversion. Panels C and D illustrate unloading and normal loading interval velocity responses based on Bowers (1995). The observed interval velocity behavior within the Lower Seurula Formation is consistent with unloading-related Overpressure.

6465 ft show near-complete disappearance of smectite content. This mineralogical trend is interpreted to reflect smectite–illite transformation associated with burial diagenesis and bound-water release. According to Burst (1969) and Bruce (1984), this clay transformation process may contribute to secondary Overpressure generation through dehydration-related fluid expansion mechanisms. The observed mineralogical behavior, therefore, supports the interpretation that unloading -related processes contribute significantly to abnormal pressure development within the Lower Seurula Formation.

Residual DT Sonic

Residual DT sonic (ΔDT) analysis was conducted to evaluate the relationship between sonic velocity anomaly and reservoir productivity within the Lower Seurula Formation. A total of eight wells were evaluated in this study, although only several wells possess both DT sonic and production flow test data suitable for direct quantitative comparison. Positive ΔDT responses are consistently observed across the analyzed wells, indicating persistent deviation from the normal compaction trend associated with abnormal pressure development. Representative DT sonic responses from Rayeu CA, NLS A-1, and East Arun A-1 are shown in Figure 9-11.

Among these wells, Rayeu CA exhibits the strongest residual DT anomaly of 18.6 µs/ft and also records the highest production rate of 8.11 MMSCFD within the 6475-6495 ft test intervals. NLS A-1 shows residual DT anomaly around 8.8 µs/ft with production rate approximately 1.26 MMSCFD from the 4300–4320 ft interval, whereas East Arun A-1 exhibits residual DT anomaly around 10.5 µs/ft with production rate 1.1 MMSCFD within the 6550–6930 ft interval. Although the individual well displays provide insight into local sonic behavior, direct comparison between wells is difficult because each figure covers different depth ranges.

Therefore, the productive intervals were subsequently displayed using a consistent zoomed window corresponding to the DST-tested zones to facilitate comparison of DT responses within

No.	Depth *feet*	Clay Minerals %			
		Smectite	Illite	Kaolinite	Chlorite
1	6380.75	3	7	7	10
2	6386.70	2	5	5	9
3	6391.20	2	4	4	8
4	6394.55	2	3	3	9
5	6414.05	2	3	5	8
6	6420.60	2	5	5	9
7	6424.35	2	3	4	9
8	6425.70	1	2	4	7
9	6428.20	-	4	2	7
10	6431.20	-	4	2	8
11	6434.15	-	5	3	9
12	6436.10	-	2	3	8
13	6437.20	-	4	3	6
14	6592.40	-	4	3	8
15	6594.20	-	2	2	7
16	6595.30	-	2	3	7

Depth *feet*	Clay Minerals %			
	Smectite	Illite	Kaolinite	Chlorite
6465.40	-	3	2	2
6467.50	-	5	4	8
6481.50	-	3	1	6
6486.00	-	4	2	4
6492.00	-	3	3	7
6509.00	-	3	4	7
6514.00	-	2	2	7
6524.00	-	3	4	8
6526.00	-	4	4	8

Depth *feet*	Clay Minerals %			
	Smectite	Illite	Kaolinite	Chlorite
6602.00	-	3	4	7
6603.85	-	4	3	8
6605.30	-	3	3	8
6610.10	-	3	1	2
6610.60	-	3	3	8
6614.10	-	3	2	4
6616.20	-	2	2	7
6619.90	-	2	4	6

Figure 8. XRD mineralogical composition within the Lower Seurula Formation showing progressive reduction of smectite content and increasing illite dominance with burial depth, interpreted as evidence of smectite–illite transformation associated with unloading-related Overpressure mechanisms.

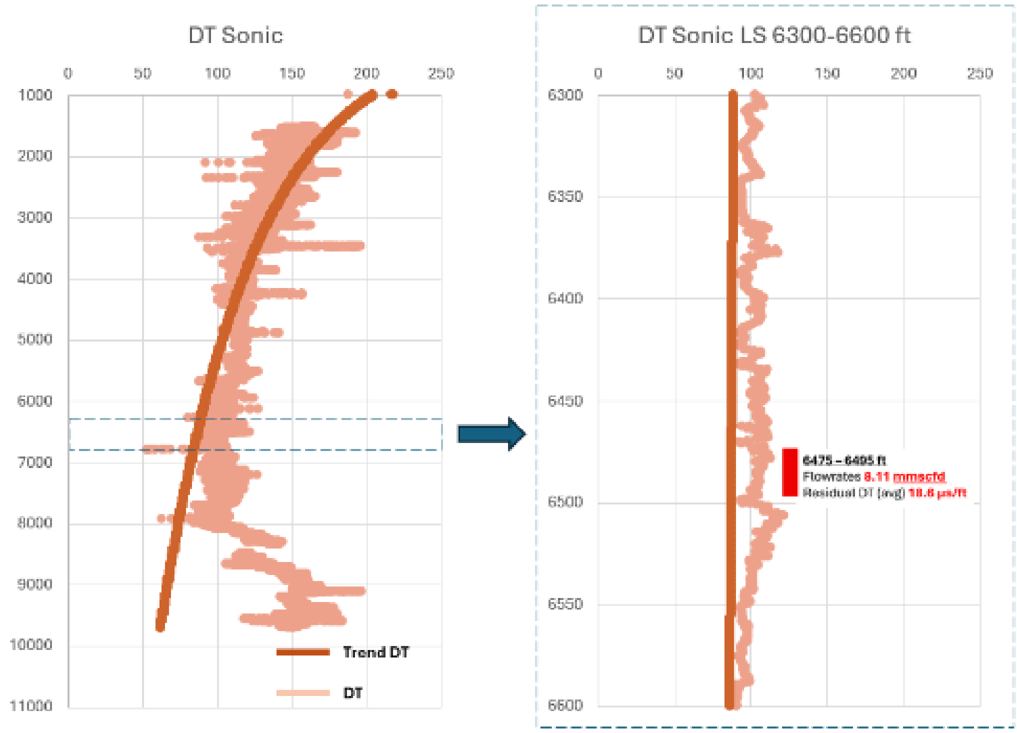

Figure 9. DT sonic response from the Rayeu C-1A well. The left panel shows the full DT sonic display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 6475–6495 ft interval, recording flow rates of 8.11 MMSCFD with an average residual DT value of 18.6 μs/ft.

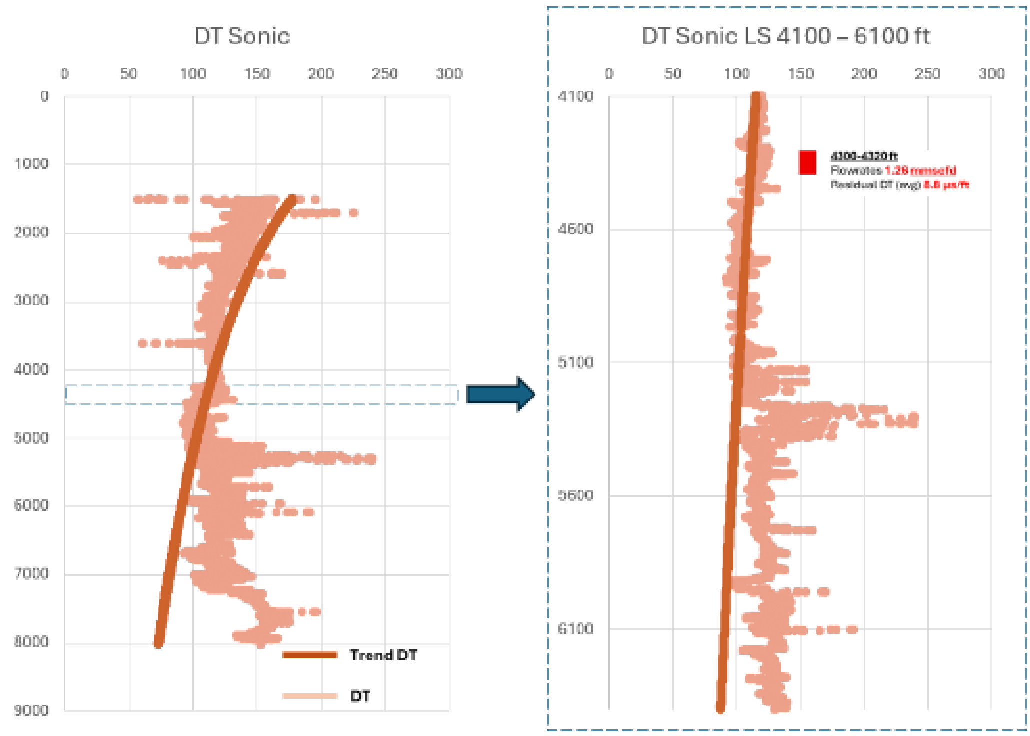

Figure 10. DT sonic response from the NLS A-1 well. The left panel shows the full DT sonic display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 4300–4320 ft interval, recording flow rates of 1.26 MMSCFD with an average residual DT value of 8.8 μs/ft.

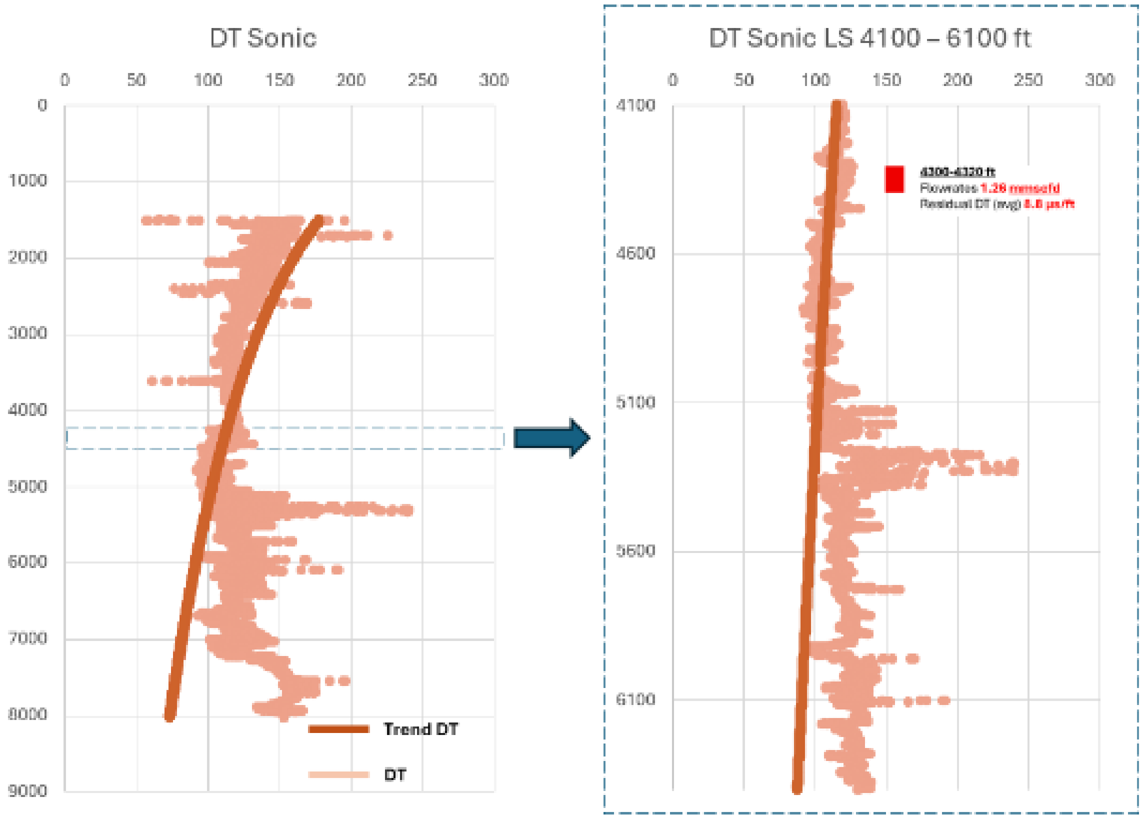

Figure 11. DT sonic response from the East Arun A-1 well. The left panel shows the full DT sonic display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 6550–6930 ft interval, recording flow rates of 1.1 MMSCFD with an average residual DT value of 10.5 μs/ft.

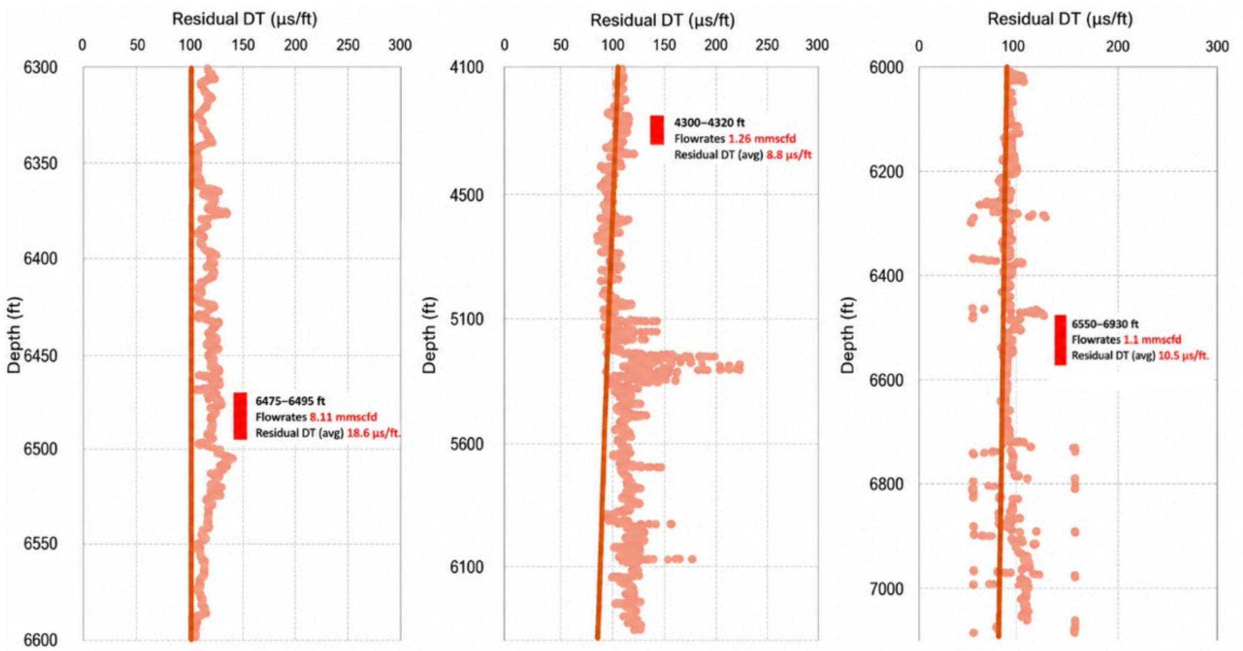

Figure 12. The side-by-side comparison indicates that Rayeu CA (Left) exhibits the strongest DT deviation within the tested interval, whereas NLS A-1 (Middle) and East Arun A-1 (Right) show comparatively weaker responses. These observations suggest variable velocity behavior within the Lower Seurula Formation despite similar regional geological settings.

equivalent stratigraphic intervals. The comparison demonstrates that wells with stronger residual DT anomalies generally correspond to better production performance within the study area. Additional wells further demonstrate variability in reservoir response. Piada-1ST shows hydrocarbon indication, whereas Piada B-1 exhibits gas bubble indication without sustained flow response. Piada-1 recorded production exceeding 8 MMSCFD but lacks available DT sonic data for residual analysis, while the Lhoksukon well demonstrates hydrocarbon flow without corresponding DT sonic information.

Table 1. Summary of residual DT sonic and production response within the Lower Seurula Formation.

No	Well	Residual DT	Flow	Remarks
1	Rayeu CA	18,6	8,11	Flow
2	NLS A-1	8,8	1,26	Flow
3	ARUN EA-1	10,5	1,1	Flow
4	PIADA 1ST	12,2	not available	HC Indication
5	LHOKS UKON-1	No DT	2,12	Flow
6	PIADA-1	No DT	8	Flow
7	PIADA B-1	No DT	not available	Bubble

Crossplot analysis between residual DT sonic and production flow rate demonstrates a strong positive correlation ($R^2 \approx 0.97$), indicating that higher ΔDT anomalies are generally associated with improved reservoir deliverability, as shown in Figure 11. This relationship suggests that residual DT sonic may serve as an effective indicator for identifying productive intervals within the Lower Seurula Formation.

The observed relationship is consistent with the unloading framework proposed by Bowers (1995), where velocity anomalies may develop due to fluid expansion mechanisms such as hydrocarbon generation, clay diagenesis, and gas charging. Under unloading conditions, velocity behavior deviates from the normal compaction trend despite continued burial, producing elevated DT responses associated with the reduction of effective stress.

Nevertheless, the observed velocity anomalies remain inherently non-unique because elevated ΔDT responses may still be influenced by both unloading-related Overpressure mechanisms and hydrocarbon-related velocity effects. Consequently, DT sonic alone remains insufficient for definitive fluid discrimination, highlighting the necessity for integrated interpretation with additional seismic velocity indicators.

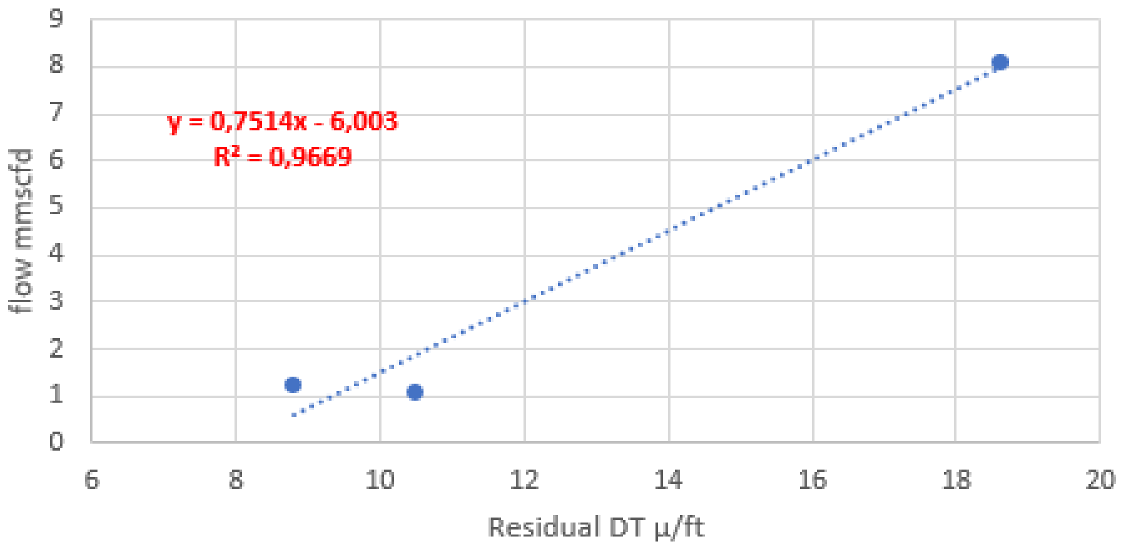

Figure 13. Crossplot between residual DT sonic and production flow rate showing strong positive correlation within the Lower Seurula Formation of the Rayeu field.

Residual RMS Velocity

Fluid replacement modeling (FRM) based on Gassmann fluid substitution principles demonstrates that gas saturation significantly reduces P-wave velocity within reservoir intervals (Gassmann 1951; Smith et al., 2003). Similar observations were also reported by Prabaningrum et al. (2019), where gas-charged reservoirs exhibit lower seismic velocity responses compared to brine-saturated conditions. This behavior indicates that seismic velocity reduction within the Lower Seurula Formation may be closely associated with hydrocarbon-related fluid effects. Residual RMS velocity (ΔVRMS) analysis was subsequently conducted to evaluate regional seismic velocity behavior within the Lower Seurula Formation and its relationship to reservoir productivity. Compared to DT sonic responses, RMS velocity provides broader regional coverage and represents the original seismic-derived velocity response used throughout the study area.

Wells exhibiting lower ΔVRMS values generally correspond to stronger hydrocarbon productivity. Rayeu CA shows the strongest negative ΔVRMS anomaly of -50.1 m/s and also records the highest production rate of 8.11 MMSCFD within the study area. NLS A-1 exhibits ΔVRMS anomaly around -28.2 with production

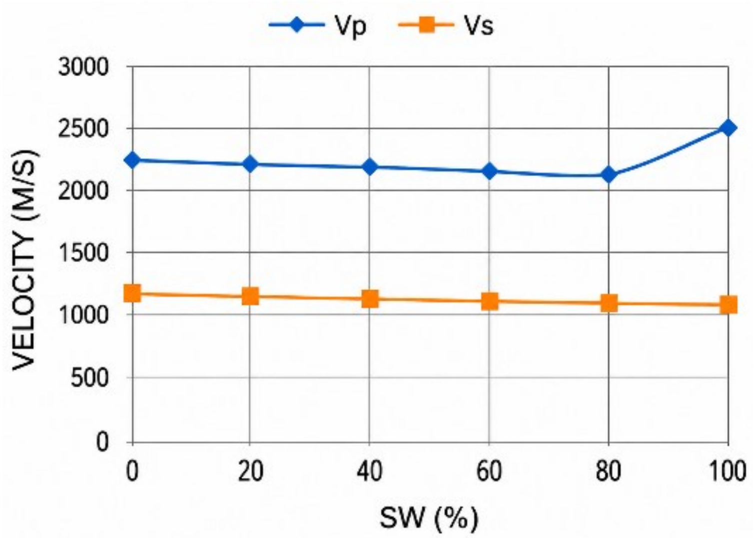

Figure 14. Velocity (y-axis) and water saturation (x-axis) relation in gas case (Prabaningrum et al., 2019)

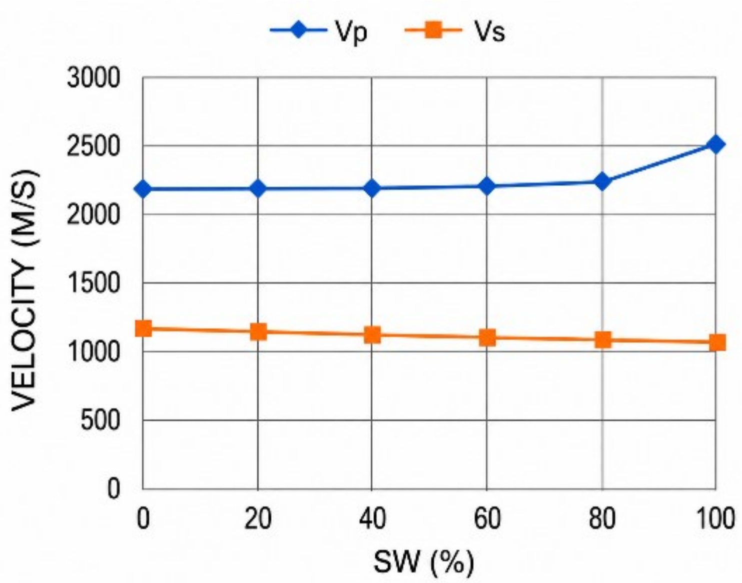

Figure 15. Velocity (y-axis) and Water Saturation (x-axis) relation in oil case (Prabaningrum et al., 2019)

Scientific Contributions Oil & Gas, Vol. 49. No. 2, June 2026: 297 - 317

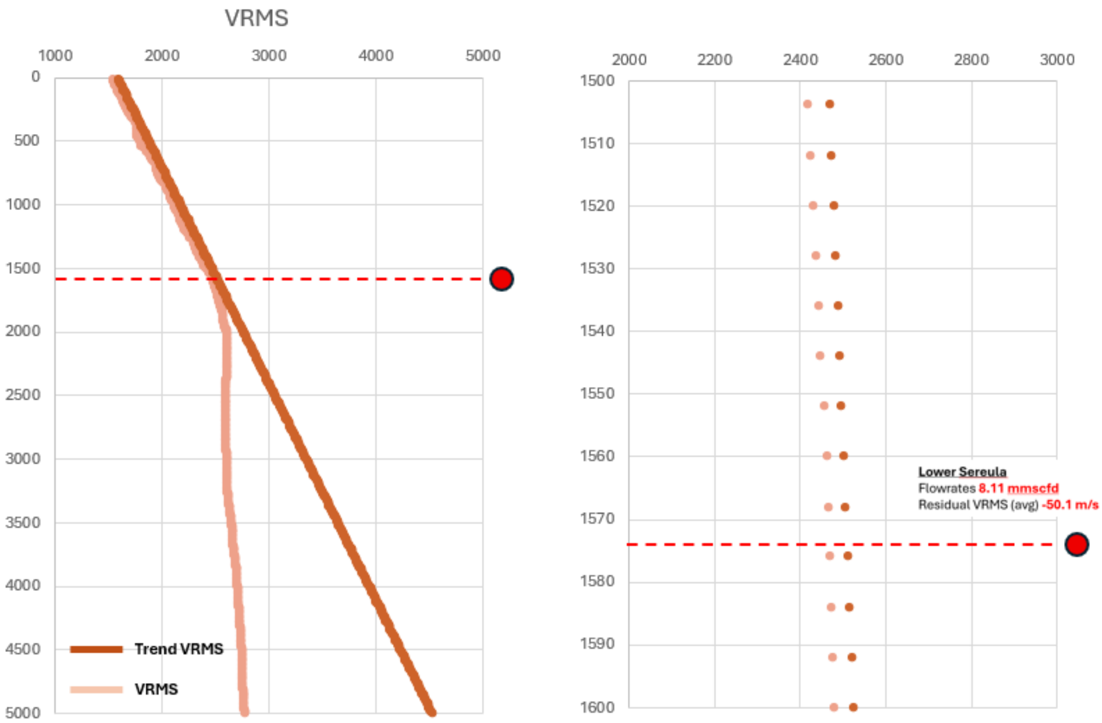

Figure 16. Velocity RMS response from the Rayeu C-1A well. The left panel shows the full Velocity RMS display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 1574 ms interval, recording flow rates of 8.11 MMSCFD with an average residual VRMS value of -50 m/s.

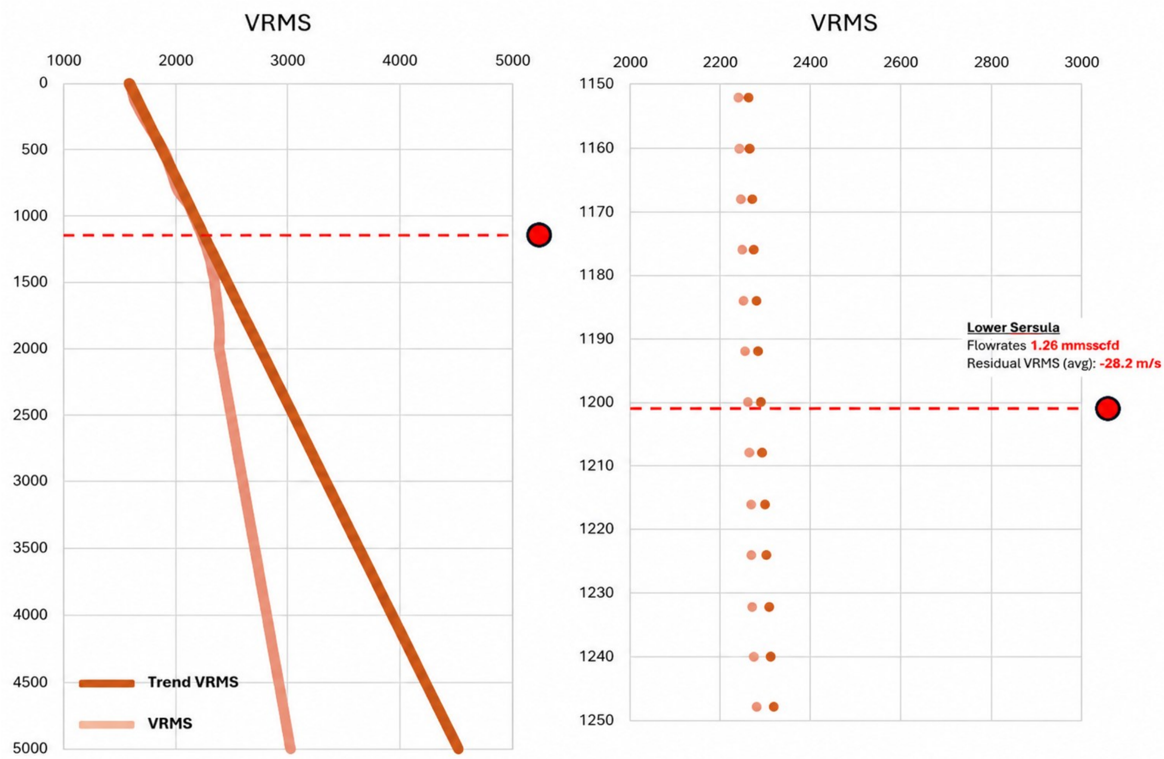

Figure 17. Velocity RMS response from the NLS A-1 well. The left panel shows the full Velocity RMS display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 1202 ms interval, recording flow rates of 1.25 MMSCFD with an average residual VRMS value of -28.2 m/s.

rate 1.26 MMSCFD, while East Arun A-1 shows ΔVRMS anomaly around -20.7 with production rate 1.1 MMSCFD. Lhoksukon-1 also demonstrates a relatively low ΔVRMS response of -12.4 associated with a hydrocarbon flow of 2.12 MMSCFD.

Similar to the DT analysis, RMS velocity responses were displayed using a consistent interval to facilitate direct comparison between wells. This approach highlights relative differences in regional seismic velocity behavior and their potential relationship to production performance. Additional wells further demonstrate variability in seismic velocity response within the Lower Seurula Formation. Piada-1ST exhibits ΔVRMS anomaly around -16.1 associated with a hydrocarbon indication, whereas Piada B-1 shows a relatively strong ΔVRMS anomaly around -33.1 despite only exhibiting a bubbling gas response without sustained production flow. Piada-1 recorded hydrocarbon flow exceeding 8 MMSCFD but lacks available RMS velocity data for residual analysis.

Table 2. Summary of residual RMS velocity and production response within the Lower Seurula Formation.

No	Well	Residual DT	Flow	Remarks
1	Rayeu CA	-50,1	8,11	Flow
2	NLS A-1	-28,2	1,26	Flow
3	LHOKSUKON-1	-12,4	2,12	Flow
4	ARUN EA-1	-20,7	1,1	Flow
5	PIADA 1ST	-16,7	not available	HC indication
6	PIADA B-1	-33,1	not available	Bubbling gas
7	PIADA-1	No Vrms	8	Flow

Crossplot analysis between residual RMS velocity and production flow rate demonstrates a strong inverse correlation ($R^2 \approx 0.75$), where decreasing ΔVRMS values generally correspond to increasing reservoir productivity. This relationship indicates that stronger negative RMS velocity anomalies are commonly associated with improved hydrocarbon deliverability within the Lower Seurula Formation.

As illustrated in Figure 7, interval velocity derived through Dix conversion was used primarily for qualitative validation of unloading-related Overpressure mechanisms rather than for quantitative regional interpretation. Although interval velocity reversal represents an important indicator of unloading behavior according to Bowers (1995), the derived interval velocity response is highly sensitive to noise amplification and local instability. Consequently, RMS velocity was retained as the primary seismic parameter because it preserves the original seismic-derived velocity trend and provides more stable regional behavior across the study area.

Nevertheless, low RMS velocity responses within the study area may be influenced by both unloading-related Overpressure mechanisms and hydrocarbon-related fluid effects. Consequently, residual RMS velocity alone may not be sufficient for definitive reservoir discrimination. The integration of residual DT sonic and residual RMS velocity, therefore, provides a more reliable approach for reducing interpretation ambiguity and improving fluid screening within the study area.

Integrated Dual-Indicator Interpretation

Velocity anomalies within the Lower Seurula Formation are influenced by the combined effects of unloading-related Overpressure and hydrocarbon -related fluid responses. Consequently, interpretation based on a single velocity parameter alone may lead to ambiguity in distinguishing pressure-related anomalies from fluid-related effects. Residual DT sonic primarily represents localized well-scale responses associated with effective stress reduction, whereas residual RMS velocity reflects broader regional seismic velocity behavior. The integration of both parameters, therefore, provides a more reliable framework for evaluating anomaly consistency between local and regional responses within the study area.

Quadrant A represents normal compaction conditions where both ΔDT and ΔVRMS remain within normal trends, indicating the absence of significant pressure or fluid-related anomalies. Quadrant B represents pressure-dominated systems characterized by elevated ΔDT responses without a strong regional seismic anomaly, suggesting localized unloading-related Overpressure effects. Quadrant C represents localized anomalies potentially associated with lithological variation or fluid effects without significant regional pressure influence. Meanwhile, Quadrant D represents intervals characterized by both elevated ΔDT and

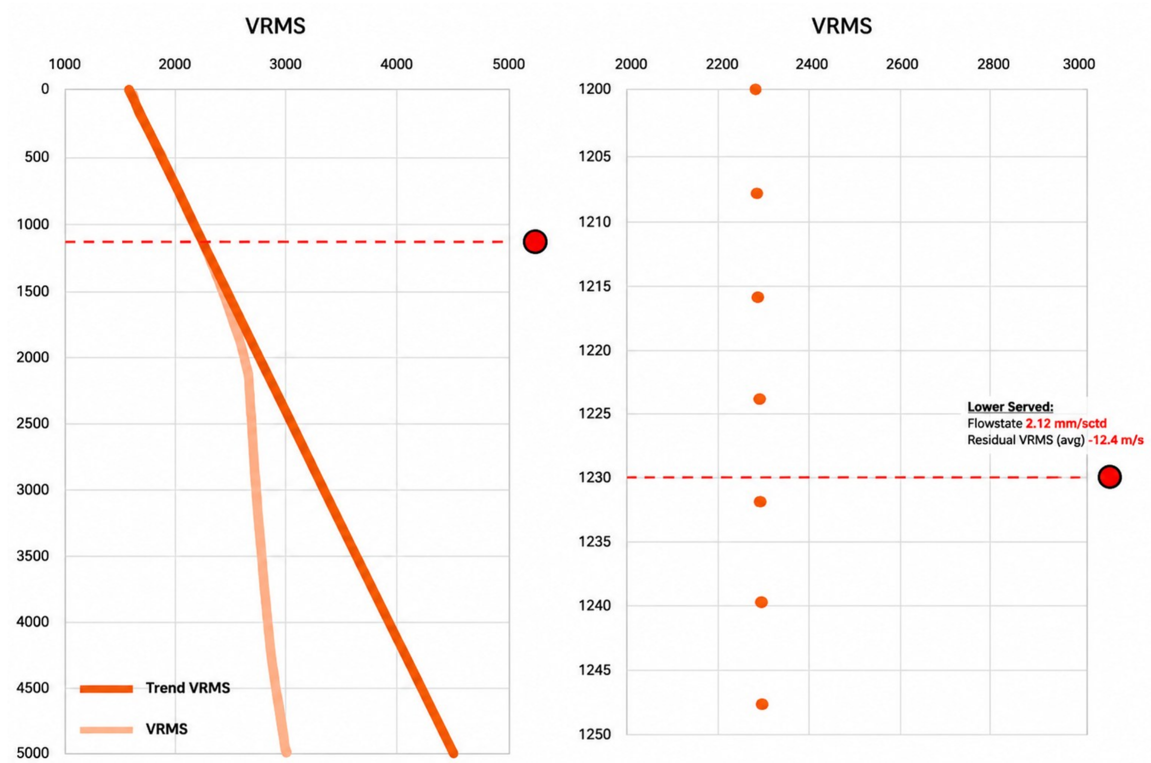

Figure 18. Velocity RMS response from the Lhoksukon-1 well. The left panel shows the full Velocity RMS display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 1230 ms interval, recording flow rates of 2.12 MMSCFD with an average residual VRMS value of -12.4 m/s.

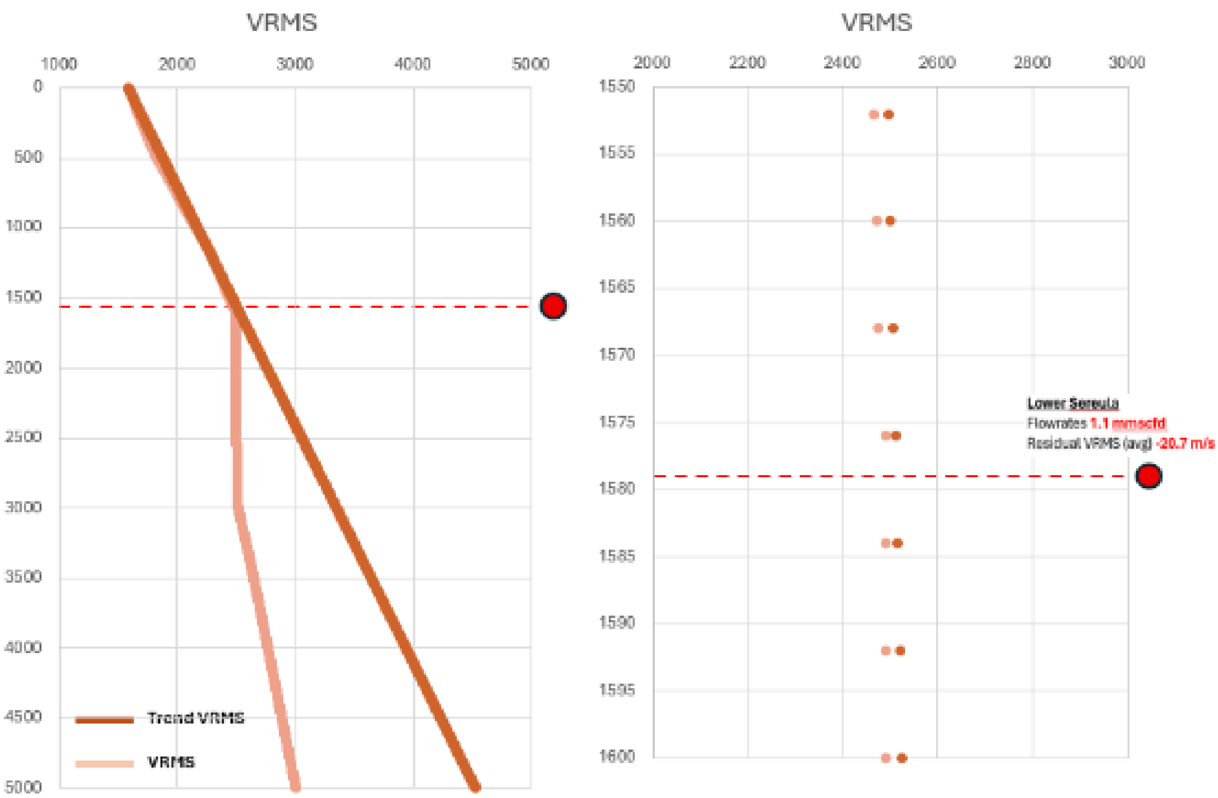

Figure 19. Velocity RMS response from the Arun EA-1 well. The left panel shows the full Velocity RMS display, while the right panel presents a zoomed interval view within the Lower Seurula Formation. DST was conducted within the 1579 ms interval, recording flow rates of 1.1 MMSCFD with an average residual VRMS value of -20.7 m/s.

strongly negative ΔVRMS responses, interpreted as zones influenced by combined Overpressure and hydrocarbon-related velocity reduction. This quadrant represents the most prospective hydrocarbon-bearing domain within the study area. The proposed framework was subsequently applied to wells with available residual DT and residual RMS velocity data.

CONCLUSION

Integrated analysis of DT sonic, RMS velocity, interval velocity behavior, mineralogical interpretation, and Fluid Replacement Modeling (FRM) indicates that Overpressure within the Lower Seurula Formation is predominantly controlled by unloading-related mechanisms. Persistent DT sonic deviation from the normal compaction trend, interval velocity reversal derived from Dix conversion, and evidence of smectite–illite transformation consistently support unloading -related Overpressure generation within the study area. Residual DT sonic analysis demonstrates positive correlation with production performance, where wells exhibiting higher ΔDT responses generally correspond to better reservoir deliverability. However, elevated DT anomalies do not always represent productive hydrocarbon accumulation, indicating that residual DT sonic alone mainly serves as an indicator of potential reservoir deliverability rather than a definitive fluid indicator.

Residual RMS velocity analysis captures broader regional seismic velocity behavior and shows inverse correlation with production performance, where stronger negative ΔVRMS responses generally correspond to improved hydrocarbon productivity. Nevertheless, RMS velocity represents an averaged regional seismic response and remains insufficient for independently distinguishing pressure-related effects, lithological variation, and hydrocarbon influence. FRM analysis further demonstrates that gas saturation significantly reduces seismic velocity and may generate responses similar to unloading-related Overpressure anomalies. This observation confirms that velocity anomalies within the Lower Seurula Formation are influenced by the combined effects of Overpressure and hydrocarbon-related fluid behavior, resulting in interpretation ambiguity when only a single velocity parameter is used.

The proposed dual-indicator framework integrating residual DT sonic and residual RMS velocity provides a more robust and physically consistent interpretation approach for reducing ambiguity between local and regional velocity responses. Wells characterized by simultaneously

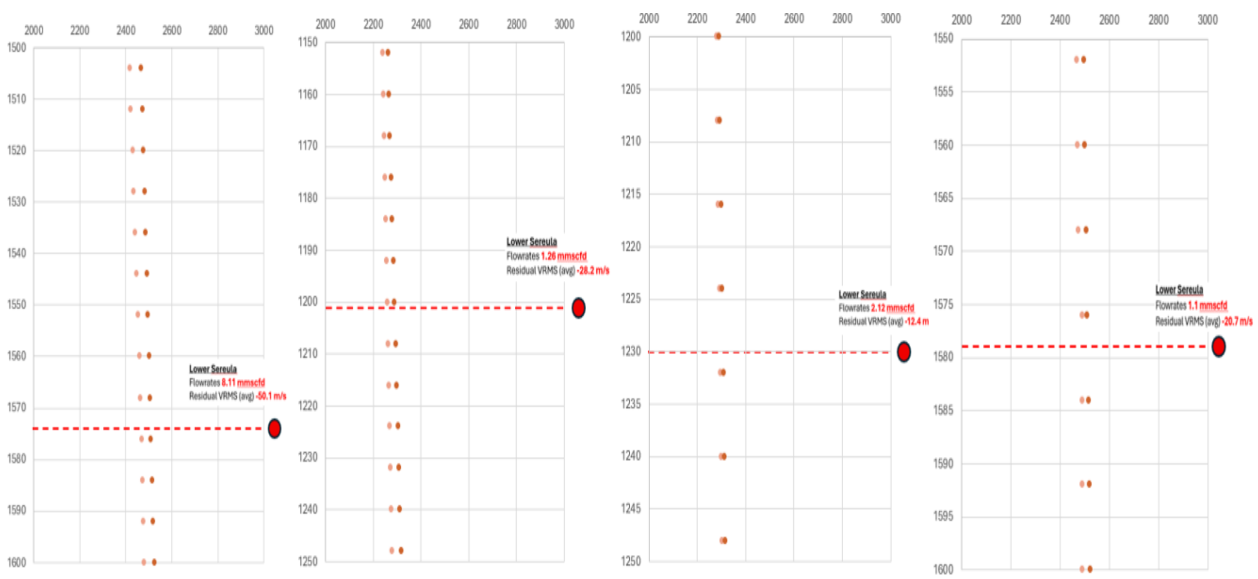

Figure 20. The side-by-side comparison indicates that Rayeu CA (Left) exhibits the strongest RMS deviation within the tested interval, whereas NLS A-1 (Middle-Left), Lhoksukon-1 (Middle-Right), and East Arun A-1 (Right) show comparatively weaker responses. These observations suggest variable velocity behavior within the Lower Seurula Formation despite similar regional geological settings.

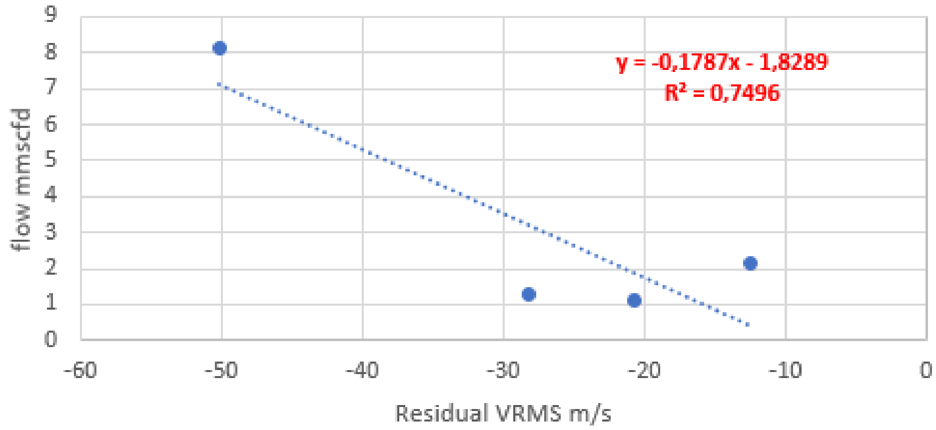

Figure 21. Crossplot between residual Velocity RMS and production flow rate showing strong inverse correlation within the Lower Seurula Formation of the Rayeu field.

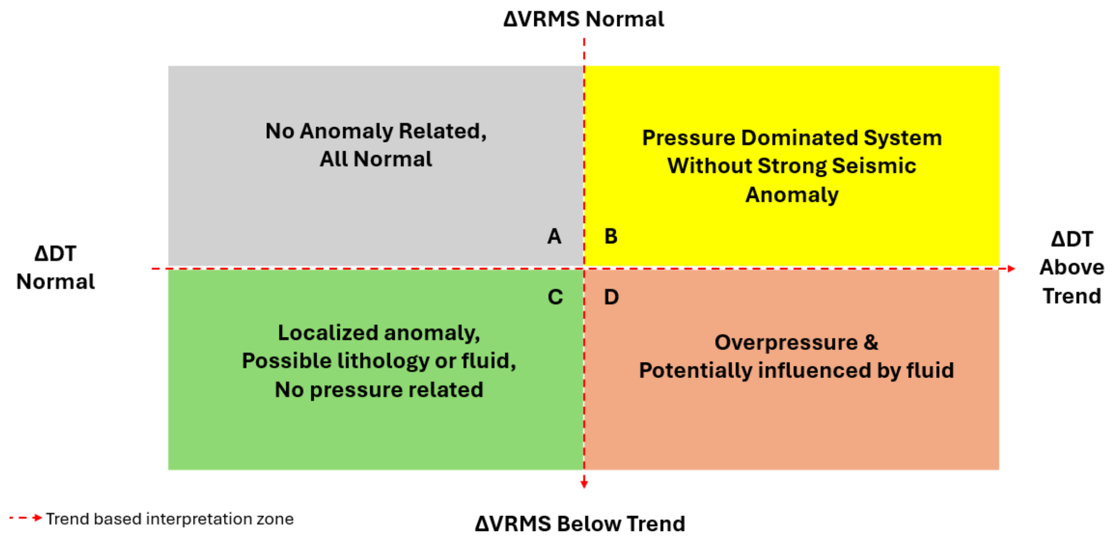

Figure 22. Proposed dual-indicator interpretation framework integrating residual DT sonic and residual RMS Velocity within the Lower Seurula Formation.

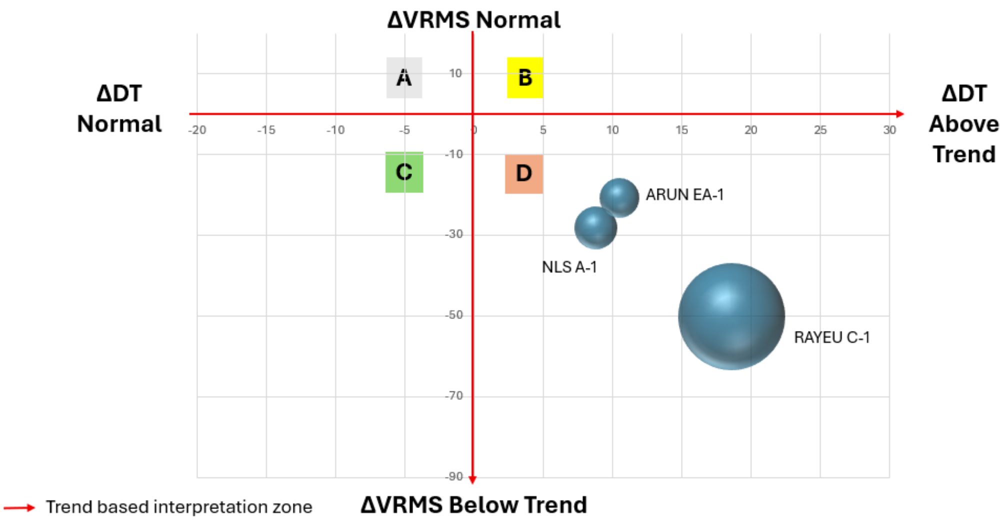

Figure 23. Integrated crossplot of residual DT sonic and residual RMS velocity within the proposed dual-indicator interpretation framework. All three analyzed wells with available residual DT and residual RMS data are clustered within Quadrant D.

elevated ΔDT and strongly negative ΔVRMS responses generally correspond to better reservoir productivity within the study area.

The proposed workflow offers a practical and transferable approach for early-stage fluid screening and Overpressure evaluation within clastic basins, particularly in exploration settings characterized by limited well control and reliance on seismic-derived RMS velocity data.

ACKNOWLEDGEMENT

The authors would like to express sincere gratitude to Institut Teknologi Bandung (ITB) for academic support throughout this study. The authors also thank PT Pema Global Energi for permission, technical support, and valuable discussions related to the Lower Seurula Formation of the Rayeu field. Appreciation is further extended to colleagues and technical teams involved in data preparation, interpretation, and completion of this research and paper preparation.

DECLARATIONS

Author contribution

P.D Permana: Conceptualization, methodology, data curation, formal analysis, investigation, visualization, and writing – original draft. D.E Irawan: Supervision, methodology review, scientific discussion, and writing – review & editing. A.M. Ramdhan: Supervision, methodology review, scientific discussion, and writing – review & editing.

Funding statement

This research was conducted as part of the author's Master's Program at Institut Teknologi Bandung (ITB). No specific external funding was received for this study. Data access, technical support, and permission to publish were provided by PT Pema Global Energi.

Competing interest

The authors declare no competing interests related to this work.

The use of AI or AI-assisted technologies

The authors used ChatGPT to assist with language refinement and manuscript editing. All scientific interpretations, analyses, conclusions, and final content were reviewed and approved by the authors, who take full responsibility for the content of this publication.

GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbol	Definition	Unit
ΔDT	Residual sonic transit time relative to the established DT trend	μs/ft
ΔVRMS	Residual RMS velocity relative to the regional RMS velocity trend	m/s
DT	Compressional sonic transit time measured from well logs	μs/ft
VRMS	Root Mean Square seismic velocity derived from stacking velocity analysis	m/s
Vint	Interval velocity calculated between seismic horizons	m/s
GR	Gamma Ray Log used for lithology identification and shale selection	API
FRM	Fluid Replacement	

	Modeling based on Gassman fluid substitution theory	-
XRD	X-Ray Diffraction analysis for mineralogical characterization	%
NCT	Normal Compaction Trend representing expected compaction behavior	-
Overpressure	Pore pressure exceeding normal hydrostatic pressure	psi
Loading	Overpressure generated by rapid sedimentation and incomplete dewatering	-
Unloading	Overpressure generated without significant porosity reduction, commonly associated with diagenesis or fluid expansion	
Smectite–Illite Transformation	Clay mineral conversion associated with diagenesis and fluid release	%
Fluid Screening	Identification of intervals potentially influenced by hydrocarbon fluids	-

REFERENCES

Barber, A. J., Crow, M. J., & Milsom, J. S. (2005). Sumatra: Geology, resources and tectonic evolution. Geological Society Memoir 31.

Bowers, G. L. (1995). Pore pressure estimation from velocity data: Accounting for overpressure mechanisms besides undercompaction. SPE Drilling & Completion, 10(2), 89–95.

Bruce, C. H. (1984). Smectite dehydration—Its relation to structural development and hydrocarbon accumulation in Tertiary basins. AAPG Bulletin, 68(6), 673–683.

Buck, S. P., & McCulloh, T. H. (1994). Bampo-Peutu petroleum system, North Sumatra, Indonesia. AAPG Memoir 60, 625–637.

Burst, J. F. (1969). Diagenesis of Gulf Coast clayey sediments and its possible relation to petroleum migration. AAPG Bulletin, 53(1), 73–93.

Davies, P. R. (1984). Tertiary structural evolution and related hydrocarbon occurrences, North Sumatra Basin. In Proceedings of the 13th Indonesian Petroleum Association Annual Convention (pp. 19–49).

Dickinson, G. (1953). Geological aspects of abnormal reservoir pressures in Gulf Coast Louisiana. AAPG Bulletin, 37(2), 410–432.

Dix, C. H. (1955). Seismic velocities from surface measurements. Geophysics, 20(1), 68–86.

Doust, H., & Noble, R. A. (2008). Petroleum systems of Indonesia. Marine and Petroleum Geology, 25(2), 103–129.

Eaton, B. A. (1975). The equation for geopressure prediction from well logs. Paper presented at the SPE Annual Fall Technical Conference and Exhibition, Dallas, Texas. SPE-5544-MS.

Gassmann, F. (1951). Elastic waves through a packing of spheres. Geophysics, 16(4), 673–685.

Hall, R. (2012) Late Jurassic–Cenozoic reconstructions of South East Asia and the SW Pacific. Journal of Asian Earth Sciences, 54, 32 –56.

Hutchison, C. S. (2014). Tectonic evolution of Southeast Asia. Bulletin of the Geological

Society of Malaysia, 60, 1–18.

Meckel, L. D. (2012). Exploring a 19th century basin in the 21st century: Seeing the North Sumatra Basin with new eyes. In Proceedings AAPG International Conference and Exhibition.

Prabaningrum, R. S., Dezulfakar, H., Linzai, N., Syaifuddin, F., & Utama, W. (2019). Utilizing S -wave and P-wave to find the presence of hydrocarbon using FRM and joint PP & PS seismic inversion. In Proceedings Joint Convention Semarang 2019, HAGI-IAGI-IAFMI-IATMI.

Ramdhan, A. M., & Goulty, N. R. (2011). Overpressure and mudrock compaction in the Lower Kutai Basin, Indonesia: A radical reappraisal. Marine and Petroleum Geology, 28 (7), 1443–1459.

Ryacudu, R., Djaafar, R., & Gutomo, A. (1992). Wrench faulting and its implication for hydrocarbon accumulation in the Kuala Simpang area – North Sumatra Basin. In Proceedings of the 21st Indonesian Petroleum Association Annual Convention (pp. 93–116).

Sjahbuddin, E., & Djaafar, R. (1993). Hydrocarbon source rock characteristics and the implications for hydrocarbon maturation in the North Sumatra Basin. In Proceedings of the 22nd Indonesian Petroleum Association Annual Convention (pp. 509–531).

Smith, T. M., Sondergeld, C. H., & Rai, C. S. (2003). Gassmann fluid substitutions: A tutorial. Geophysics, 68(2), 430–440.

Swarbrick, R. E., & Osborne, M. J. (1998). Mechanisms that generate abnormal pressures: An overview. In B. E. Law, G. F. Ulmishek, & V. I. Slavin (Eds.), Abnormal pressures in hydrocarbon environments (AAPG Memoir 70, pp. 13–34).

Tampubolon, R. A., Ozza, T., Arifin, M. T., Hidayatillah, A. S., Prasetio, A., & Furqan, T. (2017). A review of regional geology of the North Sumatra Basin and its Paleogene petroleum system. Berita Sedimentologi, 37, 23–29.

Tribuana, I. Y., Mulyadi, U., Ramdhan, A. M., & Rustam, A. H. (2016). Pore pressure estimation in hard unloading-overpressure zone using single compaction equation, case study: Lower Kutai Basin. *Scientific Contributions Oil and Gas (SCOG)*, 39(2). https://doi.org/10.29017/SCOG.39.2.105.

Utama, H. W., Wicaksono, B. A. S., & Adhitya, B. (2025). Analysis of pore pressure and overpressure formation mechanism using open hole log data of Jambi Sub Basin, South Sumatra Basin. *Lembaran Publikasi Minyak dan Gas Bumi (LPMGB)*, 59(1). https://doi.org/10.29017/LPMGB.59.1.1757.