Biogenic Gas Exploration and Development in Bentu PSC, Central Sumatra Basin, Indonesia*

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Abstract

Biogenic gas has become an economic target of exploration and exploitation, due to the high demand for gas. Its geological occurrence is easily interpreted; it is significantly widespread and shallow; gas is of good quality of gas with >98% content of CH_4, low S and CO_2 content. Production tests from this block resulted in a production rate peak of 50 MMscfd at Segat field. This article presents a summary of geology, geochemistry and geophysical aspects in order to assess biogenic gas accumulation in Bentu Block.

Biogenic gas origins were shown by carbon isotope analysis to be of $\delta^{13}C$ CH_4 value -62 to -66 ‰. The main gas-bearing reservoir is a 7-25 foot thick sand layer over the upper Miocene to Pliocene Binio Formation, at a depth of 600-2000 feet below sea level. The Binio Formation was deposited in a coastal environment that reflects the onset of marine regression. The gas is trapped along a NW-SE anticlinal system, related to a reverse fault.

Seismically, existing data clearly exhibits strong amplitude anomalies or a –bright spot" as a Direct Hydrocarbon Indicator. Furthermore, advanced geophysical analysis, AVO, seismic attribute and LMR methods, were carried out to confirm gas presence. The result of this analysis has been helpful to distinguish between coal and gas-bearing reservoirs, where coal revealed a similar appearance in the seismic data. Seismic data were also important in delineating lateral gas distribution and exploring prospects and leads in Bentu Block.

Biogenic gas characteristically occurs at a shallow depth and in high quality, which makes this gas economically attractive for production. Bentu area, as one of the proven and potential biogenic gas targets, provides a typical setting for integration of geological, geochemical and also geophysical features to assess gas accumulation.

Introduction

Bentu PSC is located in the South Bengkalis Trough, Central Sumatra Basin. This block is operated by Kalila Bentu Ltd (a subsidiary of Energi Mega Persada, Tbk) (Figure 1). Previously, operators of this block were looking for oil in a deep target whilst shallow gas was considered as a drilling hazard. Nowadays, gas has become the economic target, due to its high demand and attractive price. Therefore, Kalila Bentu Ltd is studying shallow gas intensively to achieve a better understanding of gas accumulation in Bentu PSC.

Shallow gas in Bentu PSC is trapped within the upper Miocene to lower Pliocene Binio Formation as the main target of exploration and exploitation on this block. The primary gas reservoirs are thin sand layers in the Binio Formation (Lower Petani) at 600-2500 feet below sea level. The uppermost sands are from 7 to 25 feet thick, and commercial flow rates of biogenic gas have been proven.

In the Bentu PSC, there are five proven anticlinal biogenic gas structures: Bentu Field, Seng Field, Segat Field and Terusan Field. All fields in Bentu are associated with a NW-SE anticlinal structural trend. These anticlinal structures are related to NW-SE-trending reverse faults, which are parallel to the regional structure in the Central Sumatra Basin.

Using integrated geology, geochemistry, geophysics and reservoir data of producible biogenic gas has led to the identification and general assessment of biogenic gas characteristics and occurrences in Kalila Bentu PSC.

Regional Geology

Bentu PSC area is geologically situated in the Sumatran back-arc basin. The blocks are approximately 30 km NW of the Barisan Mountains. A series of eight NW-SE-trending anticlines traverse through the blocks, but only 2 major anticlinal structures pass through the location of the field. These are Bentu-Penar trend and Minas-Lago trend. Bentu-Penar anticlinal trend passes through Bentu, Seng and Segat fields, while Minas-Lago Trend goes through Terusan (Figure 2).

The structural history of the Central Sumatra Basin can be summarized in five episodes, as follows:

1. A Late Jurassic - Cretaceous orogeny when Paleozoic and Mesozoic strata were metamorphosed by extensive igneous activity and erosion, associated with significant intrusions of granite batholiths.
2. Extension during the Paleocene, producing a series of northerly and northwesterly trending horst-graben systems and dispersed normal faults.
3. Middle Oligocene uplift and erosion of the earlier rift graben complexes associated with minor magmatism.
4. Middle Miocene initiation of uplift of the Barisan Mountains with an associated increase in volcanism.
5. A widespread, northeast-southwest-oriented, Plio-Pleistocene compressional event that had a significant impact on the present-day structure of the basin, as outlined on the map of structural elements. Major uplift of the Barisan Mountains occurred in association with major right-lateral wrenching and formation of a series of northwesterly trending anticlines and thrust faults. Faults active during this compressional event show considerable dip-slip and, in places, some strike-slip movement associated with the reactivation, reversal and propagation of the pre-existing, Graben-bounding, normal faults.

During the fifth phase, folding and faulting of the primary traps of many oil and gas fields of Central Sumatra were formed; these include all fields in Bentu PSC area.

Reservoir Geology

The Binio Formation is the main target, as a proven biogenic gas reservoir in the Kalila Bentu PSC. It is a late Miocene- early Pliocene-aged sequence of claystones and minor sandstones in a formation that is part of the Petani Group. Binio Formation was deposited on top of Telisa Formation. The sediments of Binio Formation were deposited in a variable-tide dominated coast characterized by flaser, lenticular ripples, wavy and herringbone sedimentary structures. Binio Formation is conformably overlain by Korinci Formation, a monotonous regressive sequence of late Pliocene-aged composed of claystones, siltstones, sandstones and minor coal. These sediments were deposited in a continental (dominantly fluvial) environment (Figure 3). The sediments of both formations were derived from the northeast (Sunda Shield), with significant input from the rising Barisan Mountains to the southwest.

Binio Formation is predominantly composed of claystone, interbedded with several relatively thin sandstones. Claystone is the dominant lithology on this formation. The claystone is described as medium grey to light grey, soft to firm, rarely medium hard in the middle part, sub-blocky to blocky, generally non-calcareous, with traces of pyrite and glauconite in places. Sand is dominant in the upperpart of the Binio Formation, and the bottom part is dominantly comprosed of claystone. Sandstones in Binio Formation are described as white, loose to unconsolidated, medium to coarse, subangular to subrounded, poorly to moderated sorted, with traces of pyrite and slightly calcareous. Reservoir sand in Binio Formation is present in Segat-3 well as a litho-type for reservoirs on Binio Formation (Figure 4). All of this sand is biogenic gas reservoir sand, and no GWC (gas-water contact) has been identified from any wells in Bentu Blocks: all hydrocarbon contacts are described as gas down to (GDT).

The Segat-3 cores were obtained at 323 to 341 meters. These conventional cores were recovered of B2A sand. Coarsening-upward, cross and parallel lamination, ripple, wavy and herringbone and common scours are present in this sand, which is intepreted as a sequence of tidal mud flat, mixed flats and tidal sand flat of the tide-dominated coast. The lack of bioturbation and root cast on this sand reflects its rapid deposition (Figure 5).

Geochemistry

Biogenic gas is commonly formed at shallow depths and low temperatures (less then 75^{o}C) by anaerobic bacterial decomposition of sedimentary organic matter and thus is unrelated to the processes of oil formation. Biogenic gas is generally very dry (> 95% methane), contains less than 0.2% ethane (Schoell, 1983) and isotopically light, with the δ^{13}C values typically less than –60‰ (Katz, 1995).

Compositional gas analysis in Binio formation from Bentu-2, Seng-1 and Segat-2 wells in the Bentu Block shows methane content of 97 - 99 mole %, no H_2S and < 1 mole % CO_2 (Table 1) with δ^{13}C CH_4 value of - 67 to -64 ‰ (Table 2). Based on methane content and Plotted δ^{13}C CH_4 with C^{2+} on Schoell gas genetic diagrams (1983), the gas trapped in all fields in both blocks is classified as biogenic gas (Figure 7).

Source rock richness, types of kerogen and maturity analysis have been analyzed from cuttings and sidewall core (SWC) samples from Telisa and Binio formations. The organic carbon content (TOC) for Binio Formation is mainly poor to fair, ranging from 0.12 to 1.07% by weight, with an average of 0.38 % by weight. However, organic carbon content for Telisa Formation indicates poor to good, ranging from

0.21% to 1.4% by weight, with an average 0.94% by weight (Table 3). From cutting samples in Terusan and Segat fields, the kerogen type of Binio and Telisa shales suggests Type III to mixture Type III-II kerogen. Such kerogens have source potential for gas and a little oil when they reach maturity. The maturity parameter reveals that all samples are immature to just mature. Rice and Claypool (1981) suggest that for commercial biogenic gas accumulations a minimum of-0.5 wt.% TOC is needed to generate biogenic gas. Based on that, the source rock of biogenic gas presence in Bentu block likely came from Telisa Formation, due to the richness of its TOC content. Several samples with TOC > 0.5% in Binio Formation have source-rock potential.

A near-surface geochemical survey which applies a headspace sampling technique has been carried out in Desabaru area as a lead play in Bentu Block. A set of samples have been collected from this area. The result reveals that, from seventeen analyzed samples, only one sample gives a reliable result of its carbon stable isotope. The methane gas contained in the sample is most probably derived from a biogenic origin due to the value of $\delta^{13}C$ CH_4 is – 66 ‰. The survey shows that there are potential resources of biogenic gas in Bentu Block.

Reservoir Properties

The log and conventional core laboratory analysis of Binio sandstone in Segat field indicates that the average porosity for reservoirs in B2A sand intervals ranges from 25-40% while permeability ranges from 70-2000 md (Figure 4). The high results of porosity and permeability measurements are due to the undercompacted nature of the sedimentation. This evidence is seen in a thin section, where the grains have not rotated to an optimal packing configuration; the evidence also is represented by the grain contact type, which indicates point to planar contact (Figure 6). This type of grain contact allows for greater porosity - also permeability, due to its open pore-throat system.

A gas-bearing reservoir can be easily recognized from wireline log responses. High values of deep resistivity, lower density and neutron response, and also slowness of transit time (Sonic) are the excellent signs which identify a gas-bearing reservoir (Figure 4). Crossover of density vs. neutron porosity is often used to determine the boundary of the gas. A gas-bearing reservoir yields a lower response of density and neutron and also creates an excellent crossover, caused by the compressibility of the gas. This wireline response has been confirmed with DSTs in Seng-1, Segat-2, Segat-3 and Segat-4.

The high quality of sand and gas mobility within the reservoir resulted in excellent gas test and production results. From Segat-3 well DST test on B2A, B3A, B4a, B5A and B6Eq, the gas rate ranged from 3 to 14.5 MMscfd at 64/64 choke size and reservoir pressure was from 338-457 psig (Figure 4).

From gas component analysis, gas produced has a very high content of CH_4 (Methane) at 97-98% percent, and low of H_2S (hydrogen sulfide) content of <0.1 ppm, with CO_2 (carbon dioxide) below 0.45%. No content of C_2-C_7 is detected from gas analysis, reflecting the dryness of gas from biogenic origins (Table 2). This characteristic, as explained above, makes this gas economical for production, due to the simplicity of the gas exploitation method and surface facilities design.

Geophysical Aspects

The Bentu PSC is covered by 2D seismic data acquired in 1979, 1980, 1984, 1992, and 1998. Because the exploration wells targeted the deeper Tualang-Lakat Formation, seismic acquisition parameters were not optimized for shallow gas. At that time, shallow gas was considered a drilling hazard, not a resource, due to a lack of gas markets. Fortunately, this 2D seismic data still revealed bright-spots in the shallow Binio and Korinci formations (Figures 8 and 9).

In relatively soft sand, the presence of gas and/or light oil will increase the compressibility of the rock dramatically: the velocity will drop accordingly and the amplitude will decrease to a negative ―bright spot” anomaly. A gas-filled sand may be transparent, causing a so-called dim spot, i.e., a very weak reflector. It is very important before interpreting seismic data to find out what change in amplitude is expected for different pore fluids, and whether hydrocarbons will cause a relative dimming or brightening compared to brine saturation (Avseth, 2005). It was hoped bright-spot amplitude anomalies would be reliable direct hydrocarbon indicators for gas reservoirs in this area.

However, the Mangan-1 bright spot proved to be associated with coal. Terusan-1, B6eq bright spot did not encounter any oil or gas shows, but it could be associated with thin stacked reservoirs, due to tuning effects (Figure 8).

To determine whether each bright spot anomaly was associated with gas, the bright spots were overlaid on the depth structure map. If the bright spot anomaly conformed to the depth map, then it was likely associated with gas. Fortunately, in this area, control was available in the form of a proven gas field (Seng) and a proven water field (Mangan) (Figures 10 and 11).

In Seng the bright-spot anomaly extent conforms to the depth structure map (Figure 10), probably representing gas accumulation. In Mangan the bright spot anomaly extent does not conform to the depth structure map (Figure 11); the bright spot anomaly probably does not represent gas.

Amplitude variations with offset (AVO) form the comparison of seismic amplitude changes to the offset of traces from the source. AVO have been used for over a quarter of a century in the hunt for gas and oil. Given the high sensitivity of AVO analysis, any gas, if present, will explain the class of the sandstone reservoir. The result can also support the study of the DHI ―Bright Spot”.

Amplitude versus offset (AVO) interpretation is facilitated by cross-plotting the AVO intercept (A) and gradient (B). Rutherford and Williams (1989) derived the classification scheme for AVO anomalies, with further modifications by Ross and Kinman (1995) and Castagna (1997).

AVO modeling in synthetic of Seng-1 shows a negative intercept and gradient for top gas. This is the type of AVO class III anomaly. AVO modeling in synthetic of Mangan-1 shows a negative intercept and positive gradient for coal (Figure 12).

The AVO analysis methods are applied to confirm the high-amplitude response in the tested structure located at the Seng-Mangan field. An attempt has been made to assess the amplitude response of these sandstones on seismic line at the Seng-Mangan well. The bright spot is located on the crest of the structure. The evaluation includes amplitude versus offset (AVO) gather analyses in this pre- stack time migration (PSTM) seismic line 475-80 (Seng well). The result indicates that the amplitude is class III low-impedance sandstone with a negative intercept (Rp) and negative gradient (G). The same work process has been performed in seismic line 474-80, which crosses Mangan-1 well (Figure 12).

AVO analysis of CDP gathers in Seng and AI inversion shows a response of AVO class III. This result was confirmed by well logs and DST's.

Conclusion

Gas in Kalila Bentu is classified as biogenic gas based on gas isotope lightness, high content of CH_4 (dry gas), and low C_2-C_7 content in its composition. The gas was most probably generated from shale intervals in Telisa Formation and Binio Formation, based on organic carbon content. All source rock samples are immature / just mature. Hydrocarbons were produced from microbial activity during anaerobic sedimentation conditions. Binio Formation was deposited in rapid sedimentation conditions. It is reflected by restricted sand between shales, undercompacted sand and lack of bioturbation and root casts in the sediment. The presence of gas can easily be recognized from a bright-spot anomaly on the seismic, and it has been confirmed with AVO analysis to distinguish between gas presence and coal. This biogenic gas has been confirmed by flowing tests and production.

The characteristic of biogenic gas that occurs at shallow depths, easily recognized from geology and geophysical interpretation, is of high quality and relatively large volume, and gas can be economically produced. Bentu area, as one of the proven and potential biogenic gas source areas, provides a typical example of integrated geology, geochemistry, geophysical and reservoir study to assess gas accumulation.

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Component (%)	Well Name	Seng-1			Segat-2			Bentu-2		
	Reservoir Name	B-3A	B-3A	B-6A	B-2A	B-2A	B-5A	B-5A	B-5A	B-5A *RFT
H2S (in ppm)	Hydrogen Sulfide	0	0	0	0	0	0	0	0	0
CO2	Carbon Dioxide	0.43	0	0.34	0	0.13	0.24	0.4	0.38	0.53
N2	Nitrogen	1.9	0.98	0.8	2.14	1.82	0.74	0.95	0.77	1.19
C1	Methane	97.24	98.62	98.42	97.75	97.9	98.76	98.15	98.43	97.33
C2	Ethane	0.25	0.29	0.31	0.1	0.15	0.2	0.26	0.21	0.5
C3	Propane	0.12	0.08	0.1	0.01	0	0.05	0.13	0.1	0.22
i-C4	Iso-Butane	0.01	0.02	0.02	0	0	0.01	0.05	0.04	0.08
n-C4	n-Butane	0.03	0.01	0.01	0	0	0	0.03	0.03	0.06
i-C5	Iso-Pentane	0.01	0	0	0	0	0	0.02	0.03	0.06
n-C5	n-Pentane	0.01	0	0	0	0	0	0.01	0.01	0.02
C6	Hexanes	0	0	0	0	0	0	0	0	0.01
C7+	Heptanes Plus	0	0	0	0	0	0	0	0	0
Specific Gravity (air=1.000)		0.5693	0.561	0.5635	0.563	0.5635	0.5609	0.566	0.565	0.572
Gross Heating Value, BTU		991	1,006.00	1,003.00	992	991	1,002.00	1,003.00	1,007.00	1,008.00
per cu-ft dry gas at 14.65 psia and 60degF										

Table 1. Gas composition from Seng-1, Segat-2 and Bentu-2 shows high content of Methane (CH_4 >97%) and low content of C_2-C_7, CO_2 AND H_2S. Dominant presence of CH_4 resulted in a high gross heating value (>990 BTU). Specific gravity also indicates the lightness of Gas (<0.6 SG) due to the high content of methane.

Composition	Segat-3 (DST)
	$\delta^{13}C$ (‰)
C_1	-67.00
C_2	n/a
C_3	n/a
iC_4	n/a
C_4	n/a
CO_2	n/a

Table 2. Carbon isotopic compositions of Segat-3 gas samples show $\delta^{13}C$ value ranging from -62.78 TO -67.00 ‰, indicating biogenic gas origins ($\delta^{13}C$ below -60 ‰).

No	Well Name	Field	Sample Type	Sample Depth (FtSS)	Formation	TOC (%)	Mean Ro (%)
1	Segat-2	Segat	SWC	965	Binio	0,17	n/a
2	Segat-2	Segat	SWC	1171	Binio	0,14	n/a
3	Segat-2	Segat	SWC	1293	Binio	0,14	n/a
4	Segat-2	Segat	SWC	1381	Binio	0,3	n/a
5	Segat-2	Segat	SWC	1656	Binio	0,12	n/a
6	Terusan-1	Terusan	Unwashed Cuttings	3181	Telisa	1	0,39
7	Terusan-1	Terusan	Unwashed Cuttings	3340	Telisa	1,01	0,44
8	Terusan-1	Terusan	Unwashed Cuttings	3470	Telisa	1,1	0,45
9	Terusan-1	Terusan	Unwashed Cuttings	3550	Telisa	1,14	0,47
10	Terusan-1	Terusan	Unwashed Cuttings	3590	Telisa	1,23	0,46
11	Segat-2	Segat	SWC	3612	Telisa	0,63	0,41
12	Terusan-1	Terusan	Unwashed Cuttings	3690	Telisa	0,82	0,49

Table 3. Source rock analysis from selected wells sorted by depth present TOC and Ro values for Binio and Telisa formations. Binio Formation mostly reveals TOC <0.5%. Dominantly Telisa shales show TOC >0.5%. Vitrinite reflectance (Ro) dominantly indicates immature to just mature for Telesia Formation.

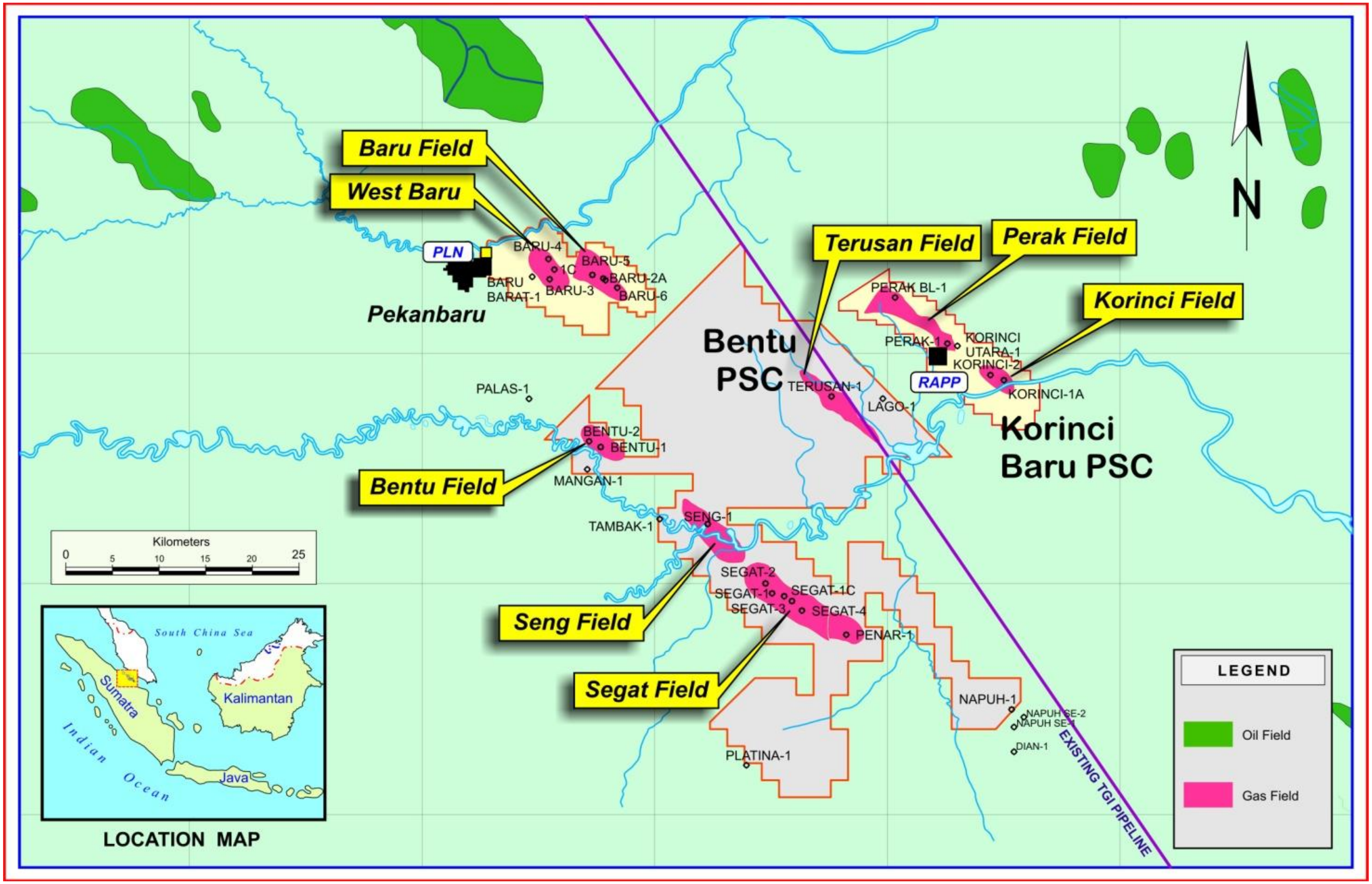

Figure 1. Location map of Bentu and Korinci Baru PSC.

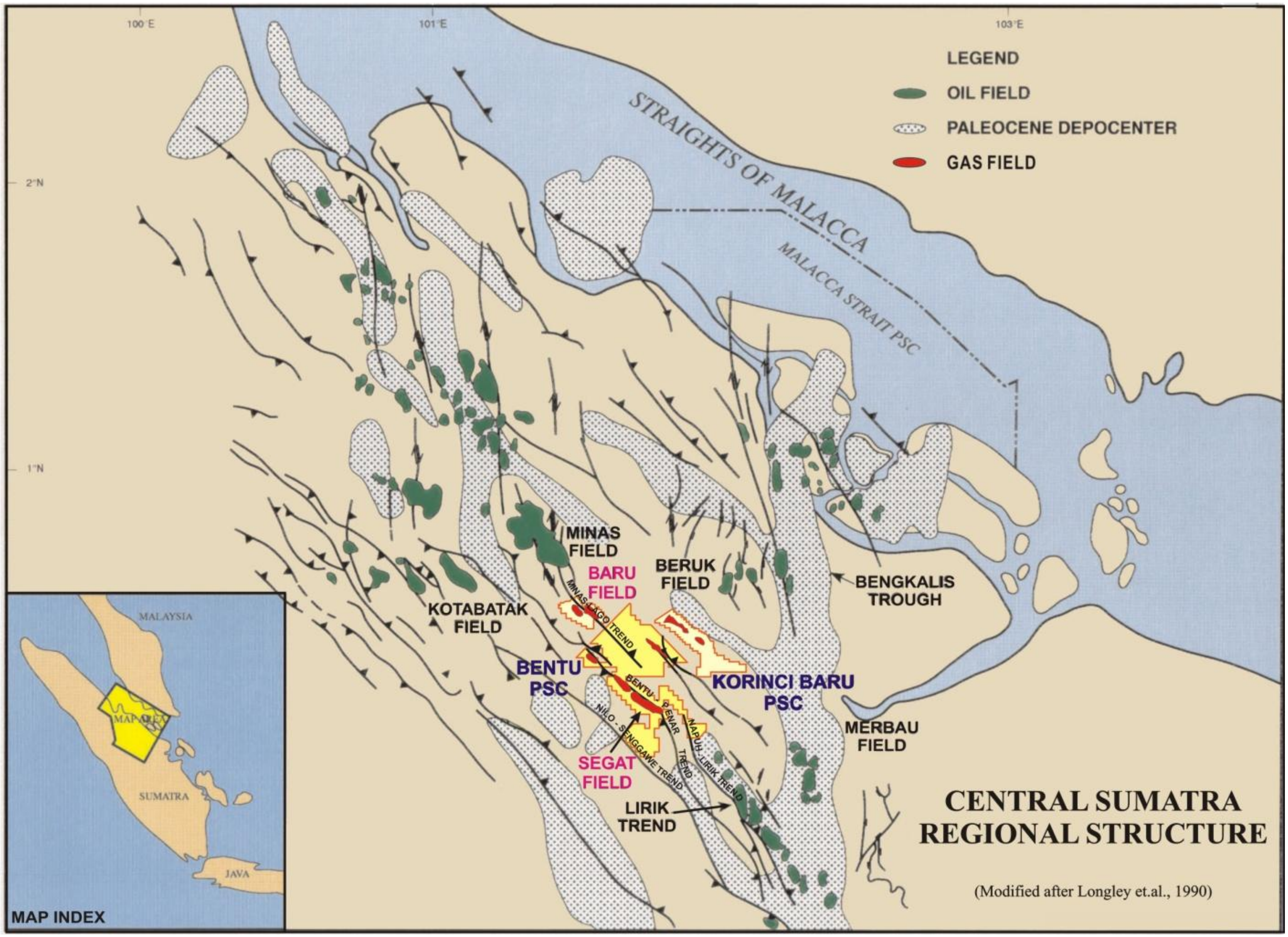

Figure 2. Regional structure of Central Sumatra Basin (modified after Longley et al., 1990).

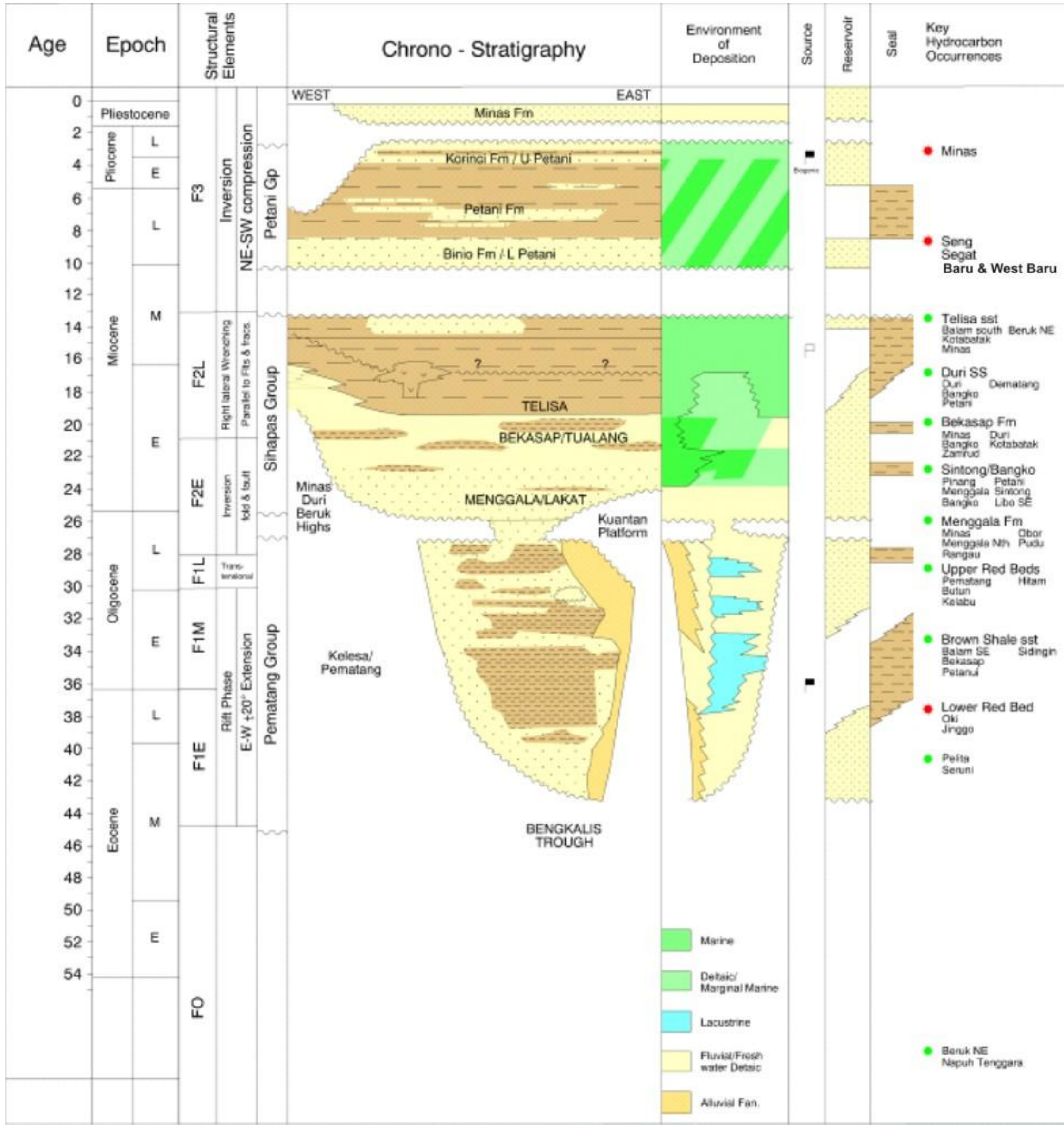

Figure 3. Regional stratigraphy of Central Sumatra Basin.

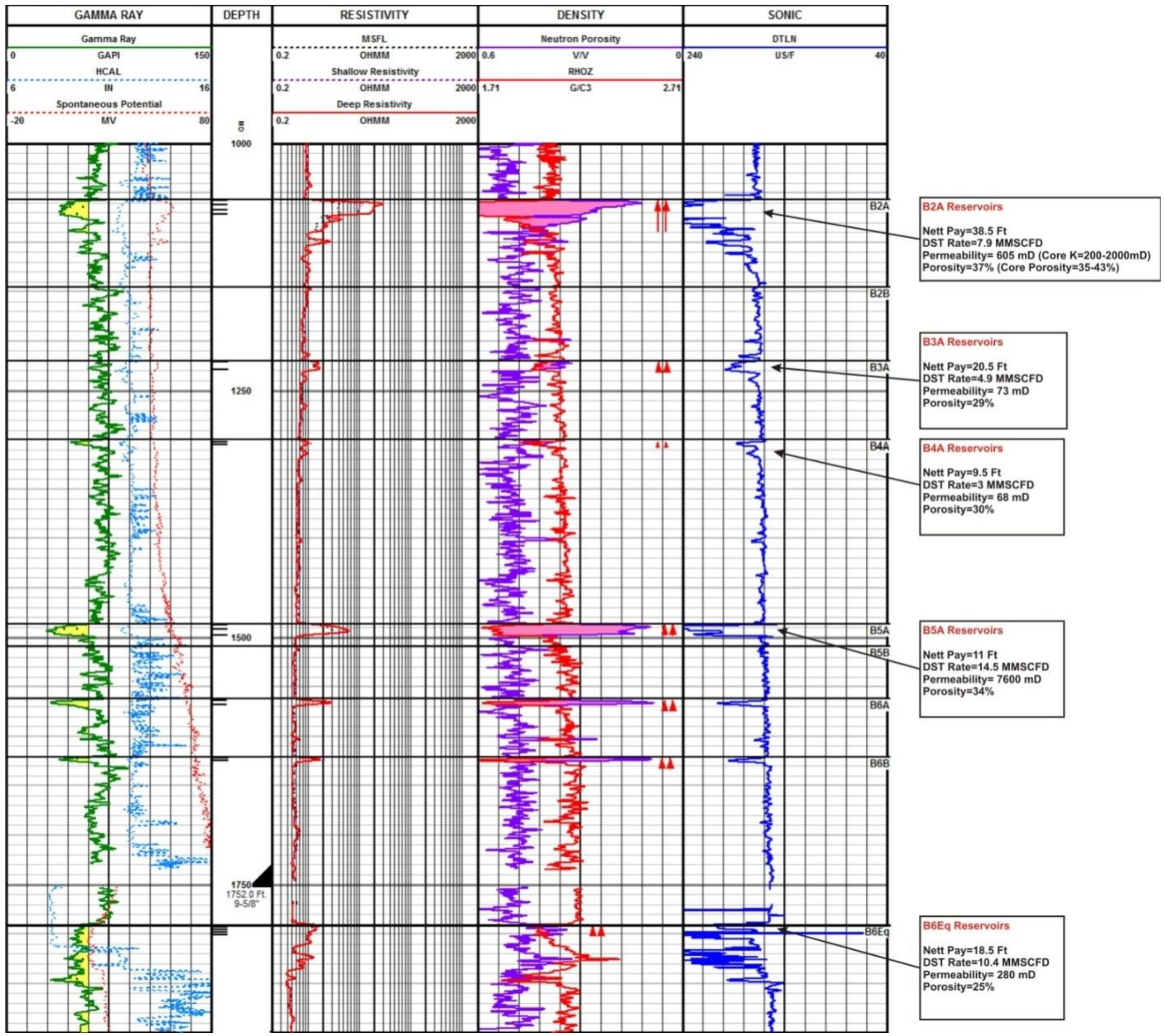

Figure 4. Well-log data and DST results from Segat-3 well for DST tested interval in Binio Formation. Excellent corelation between log responses with gas presence confirmed by DST test.

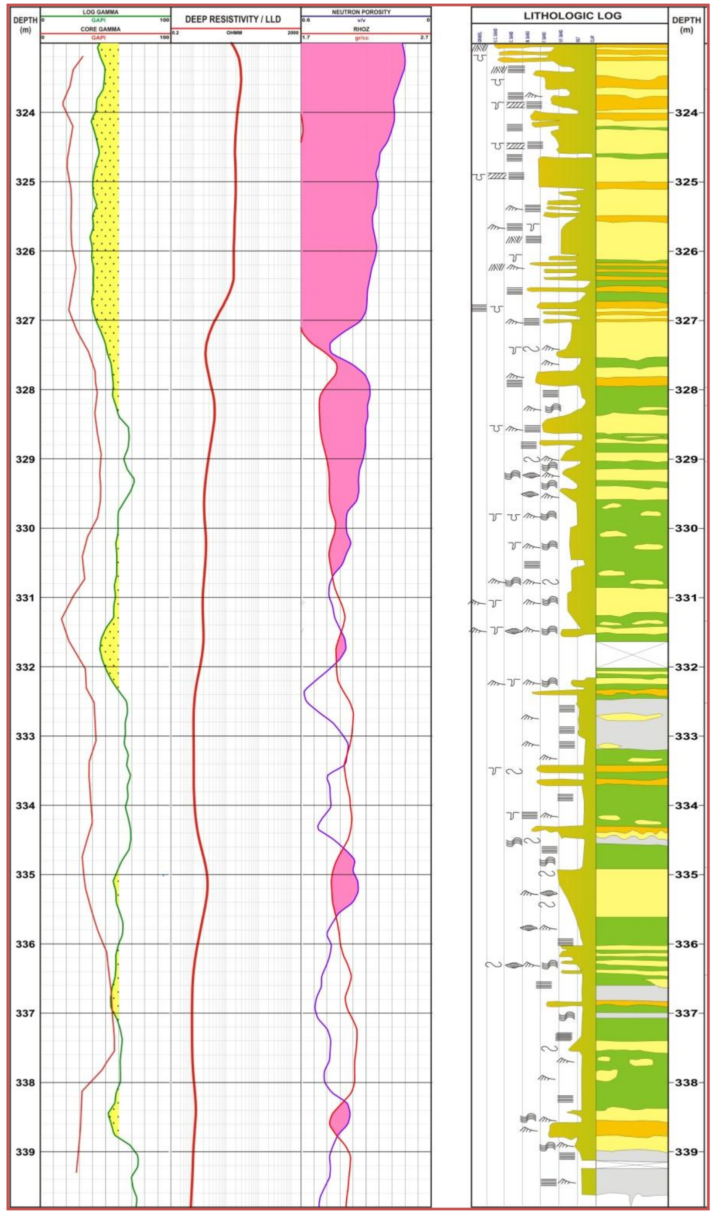

Figure 5. Conventional core analysis of Segat-3 well from 323-341 meters, showing a good corelation between wireline log response with sand presence from a conventional core. The depositional environment shows a sequence of tidal mud flats, mixed flats and tidal sand flats of a tide-dominated coast.

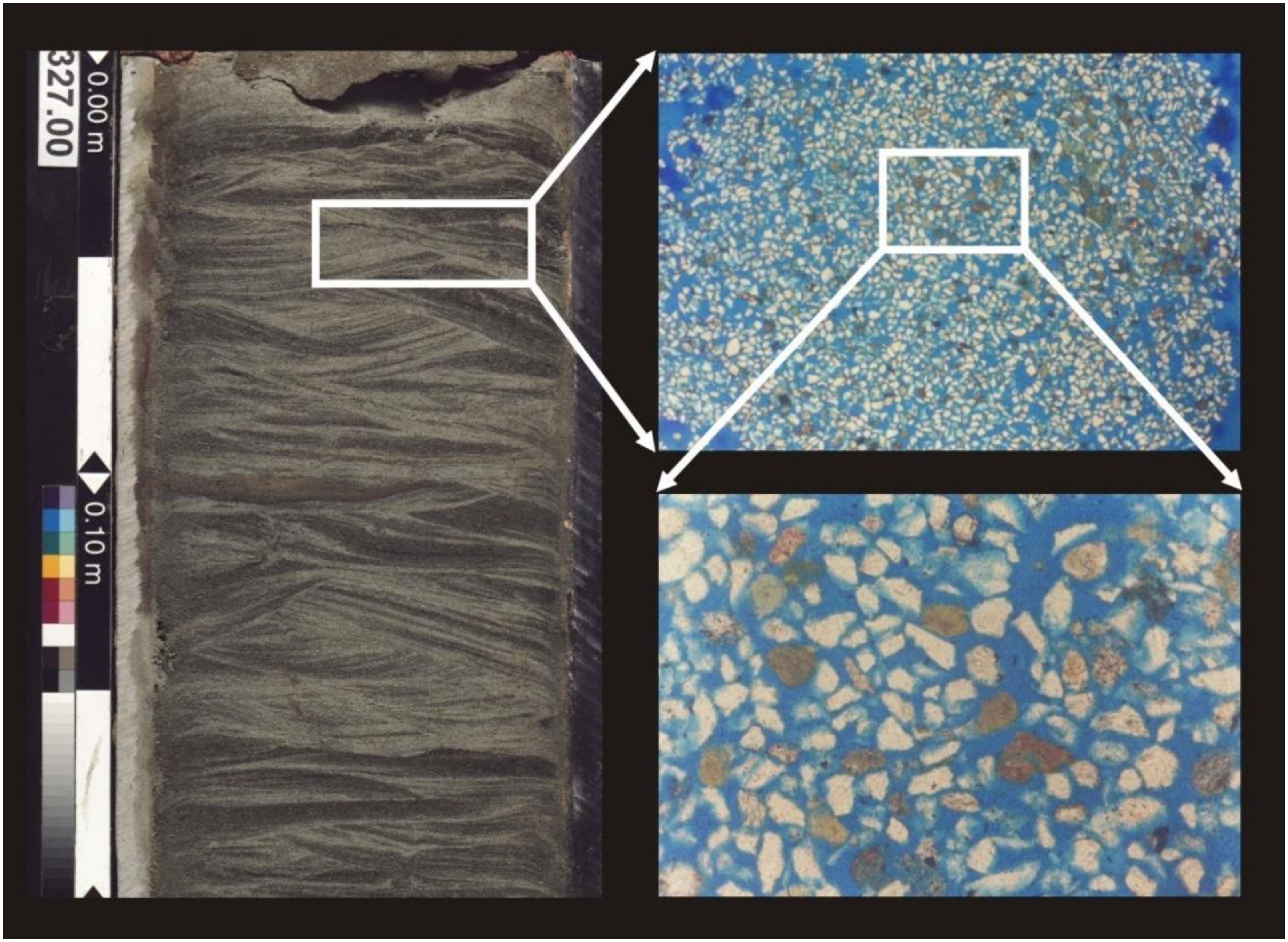

Figure 6. B2A sand reservoir core photos and photomicrograph from Segat-3 well, depth 327.00 to 327.02 meters showing cross lamination and parallel lamination. Photomicrograph from thin section showing that sand is composed of very fine- to fine-grained well sorted quartzarenites. Undercompacted condition is reflected by point to point contacts between grains. The porosity is noted by the blue color in the thin section.

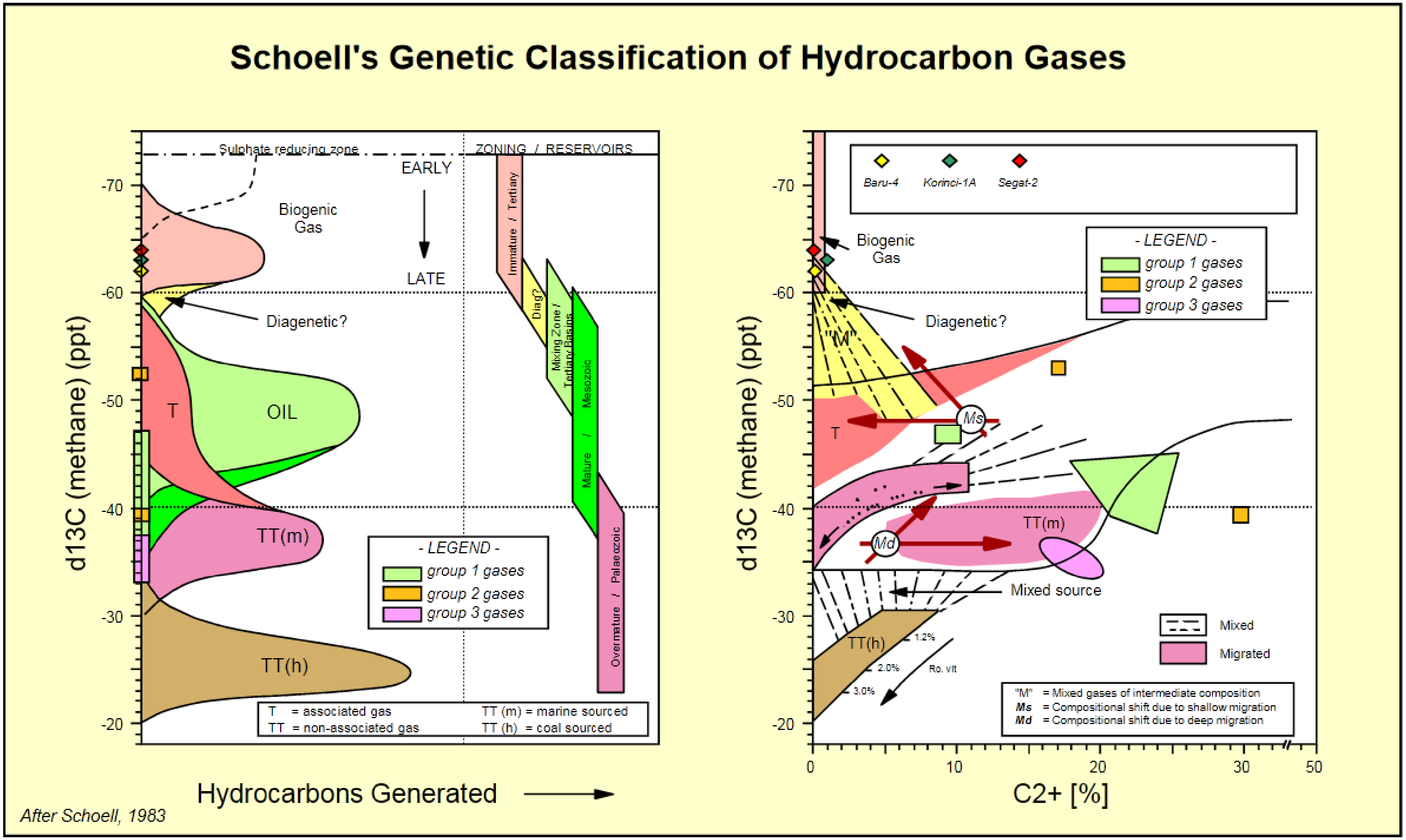

Figure 7. Schoell diagrams classified gas samples from Segat-2 well as biogenic gas, based on gas isotope composition.

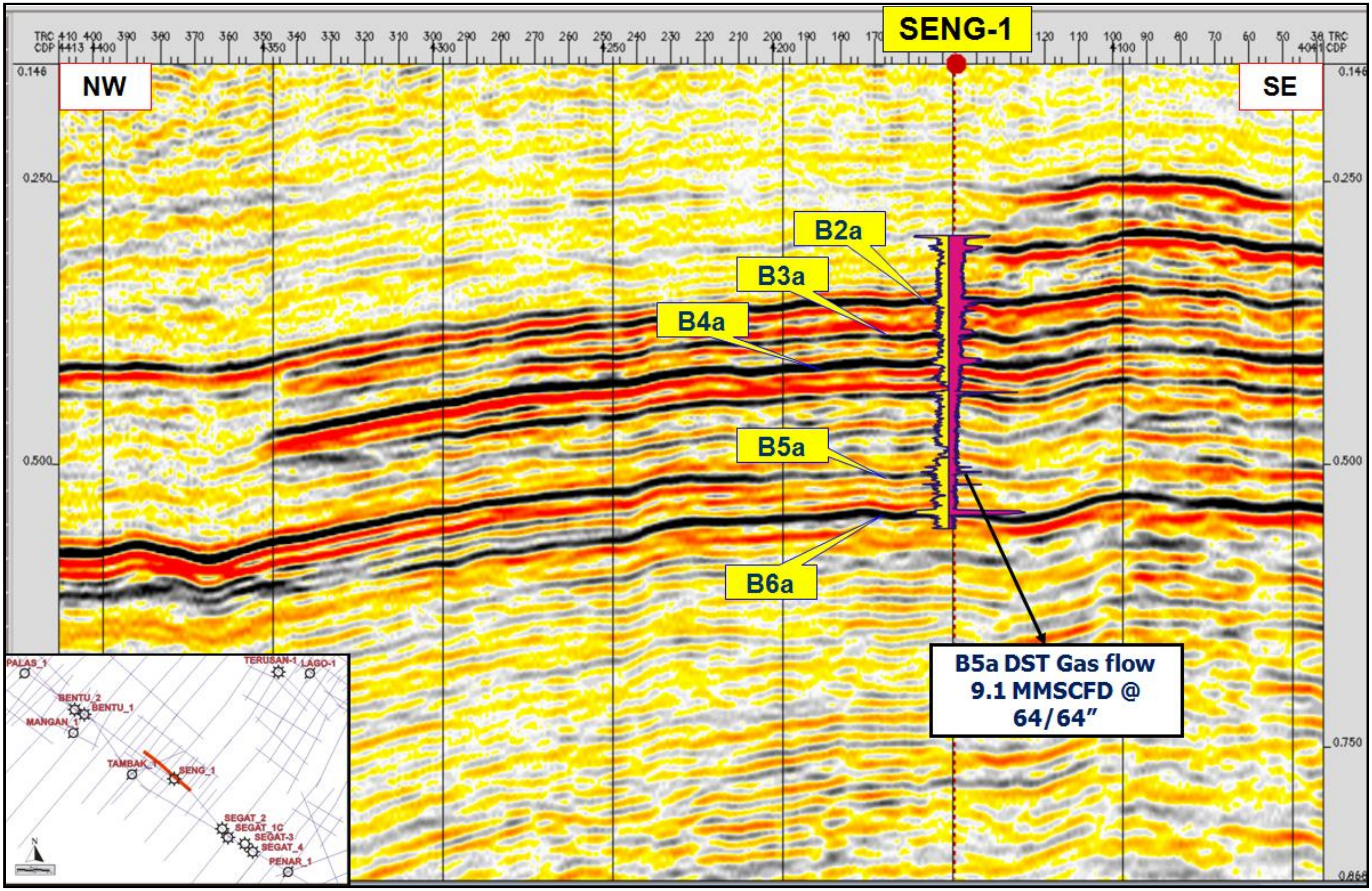

Figure 8. 2D seismic line through the Seng-1 well shows bright-spots from 250-600 ms.

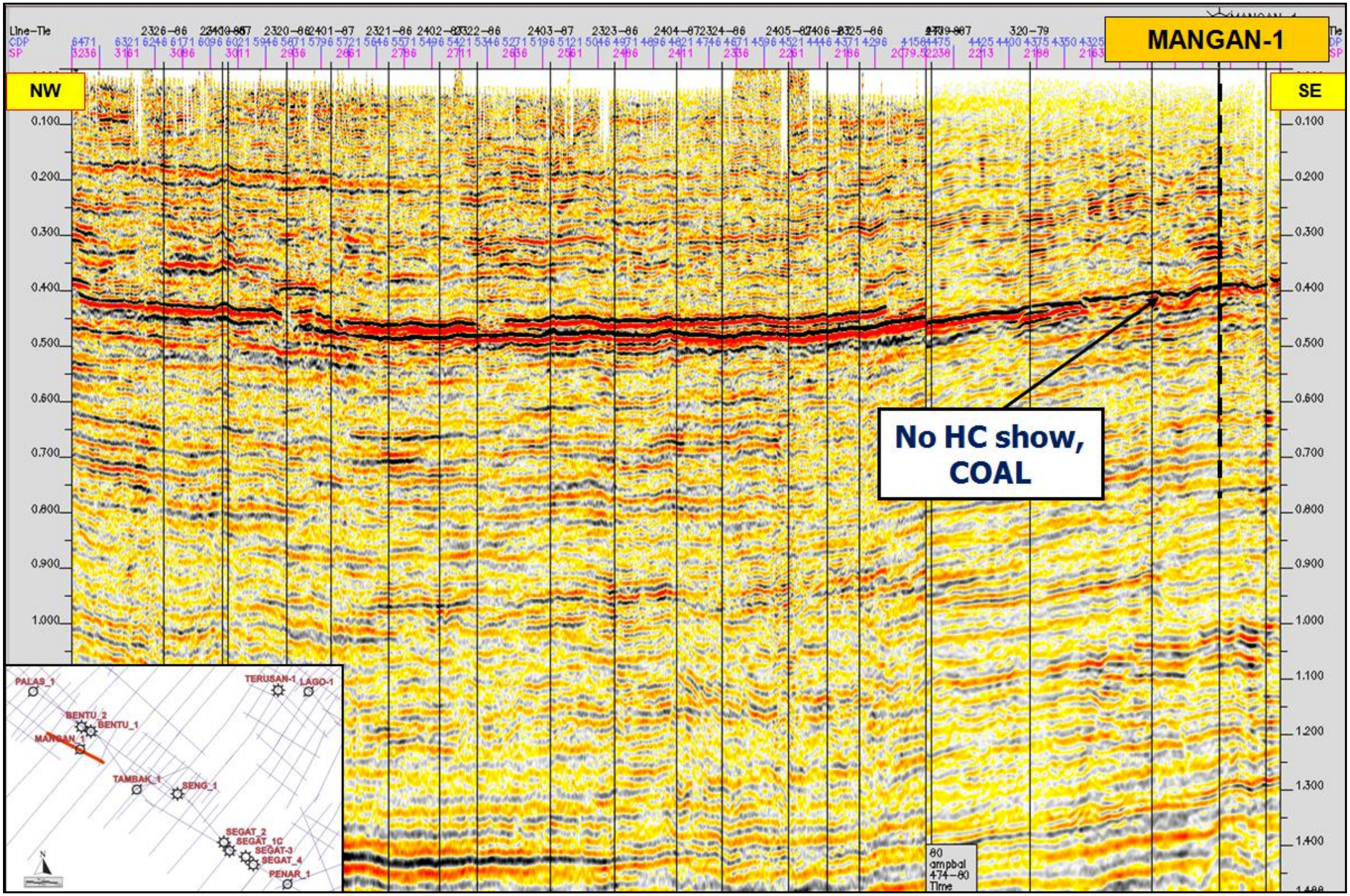

Figure 9. 2D seismic line crossing the Mangan-1 well showing bright-spots at 250-600 ms.

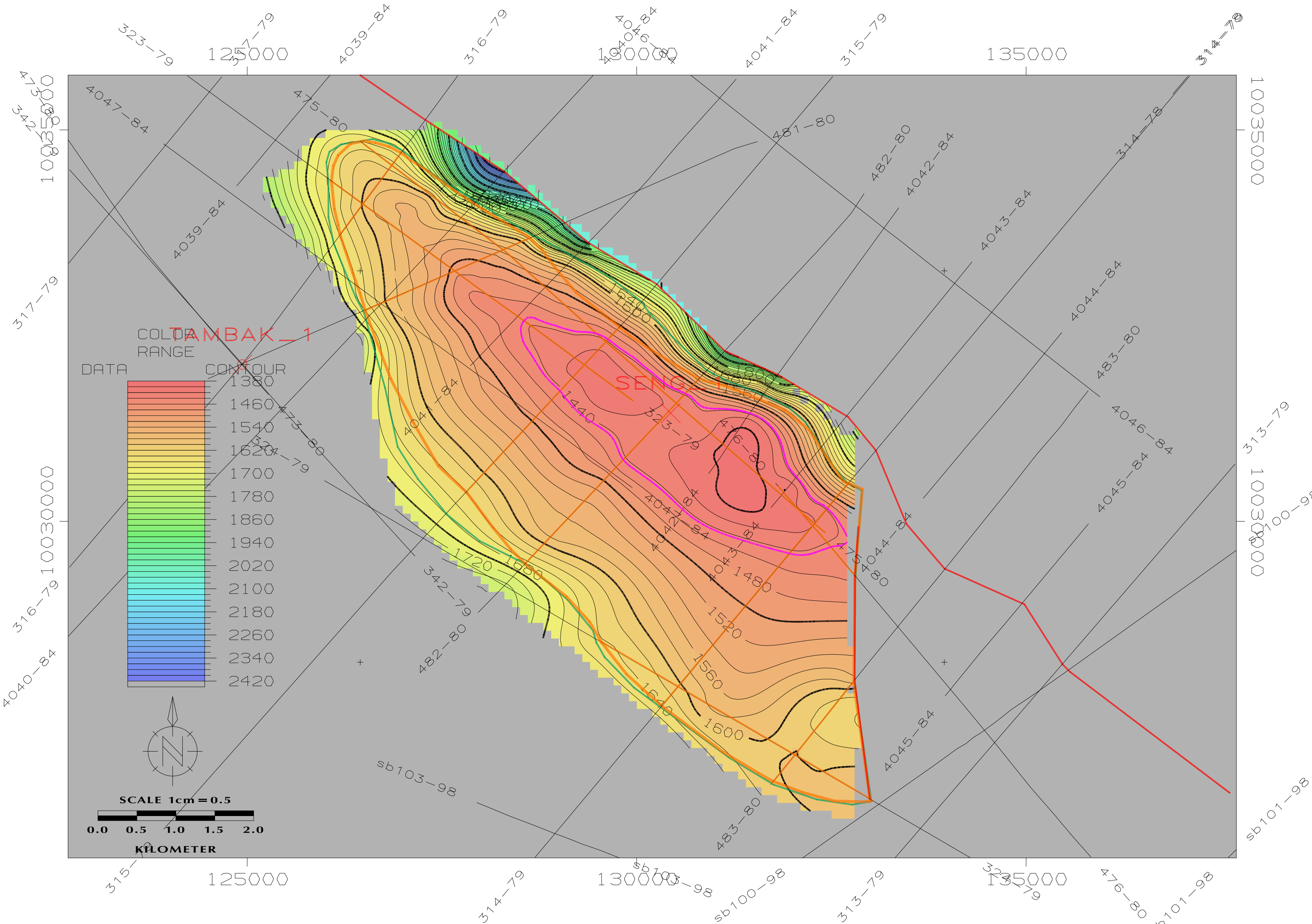

Figure 10. Depth structure map of B2A sand at Seng field. Amplitude anomaly extent conforms to the structure map; therefore, the anomaly likely represents gas.

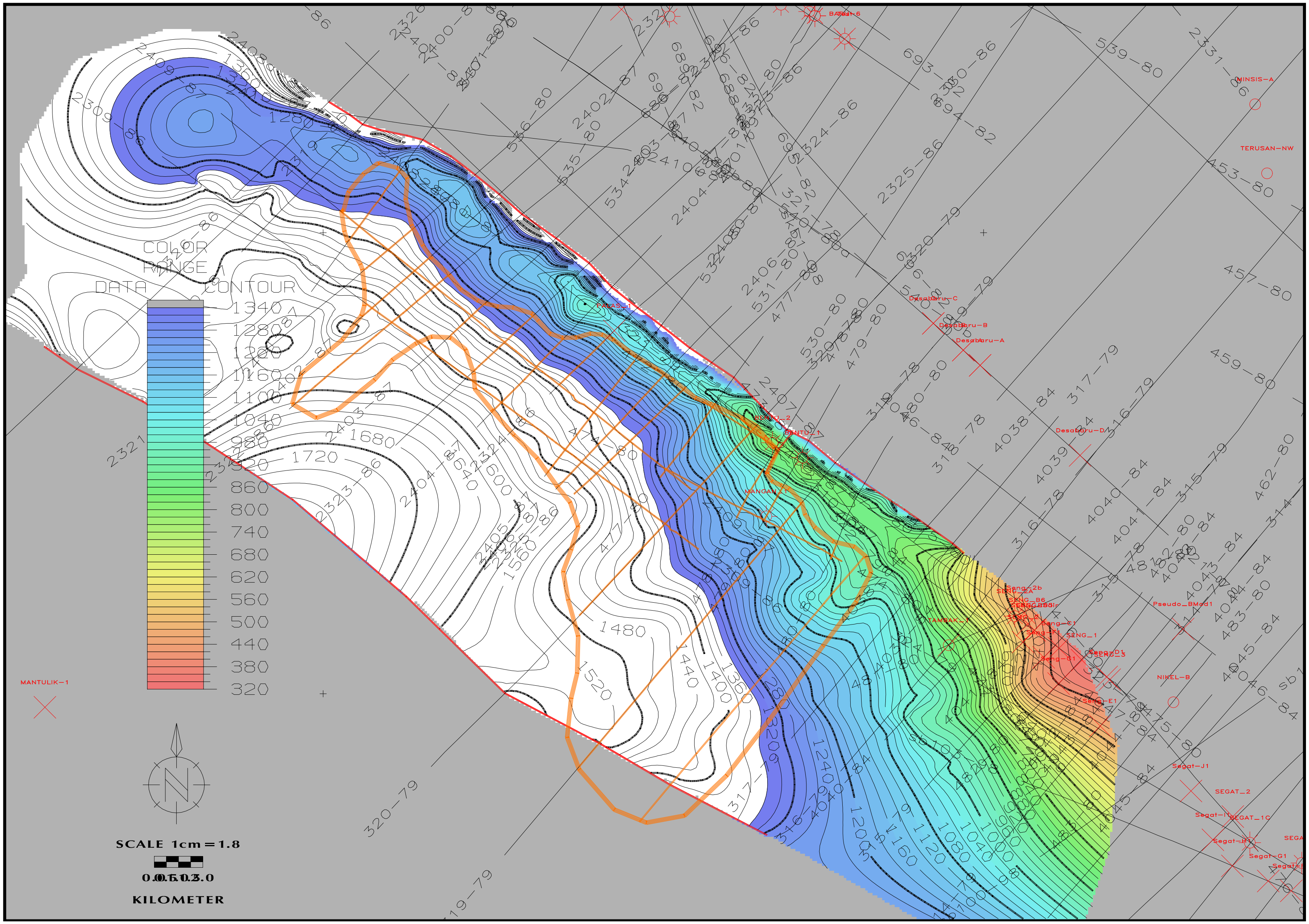

Figure 11. Mangan field amplitude anomaly extent does not conform to the structure map; therefore, the anomaly likely does not represent gas.

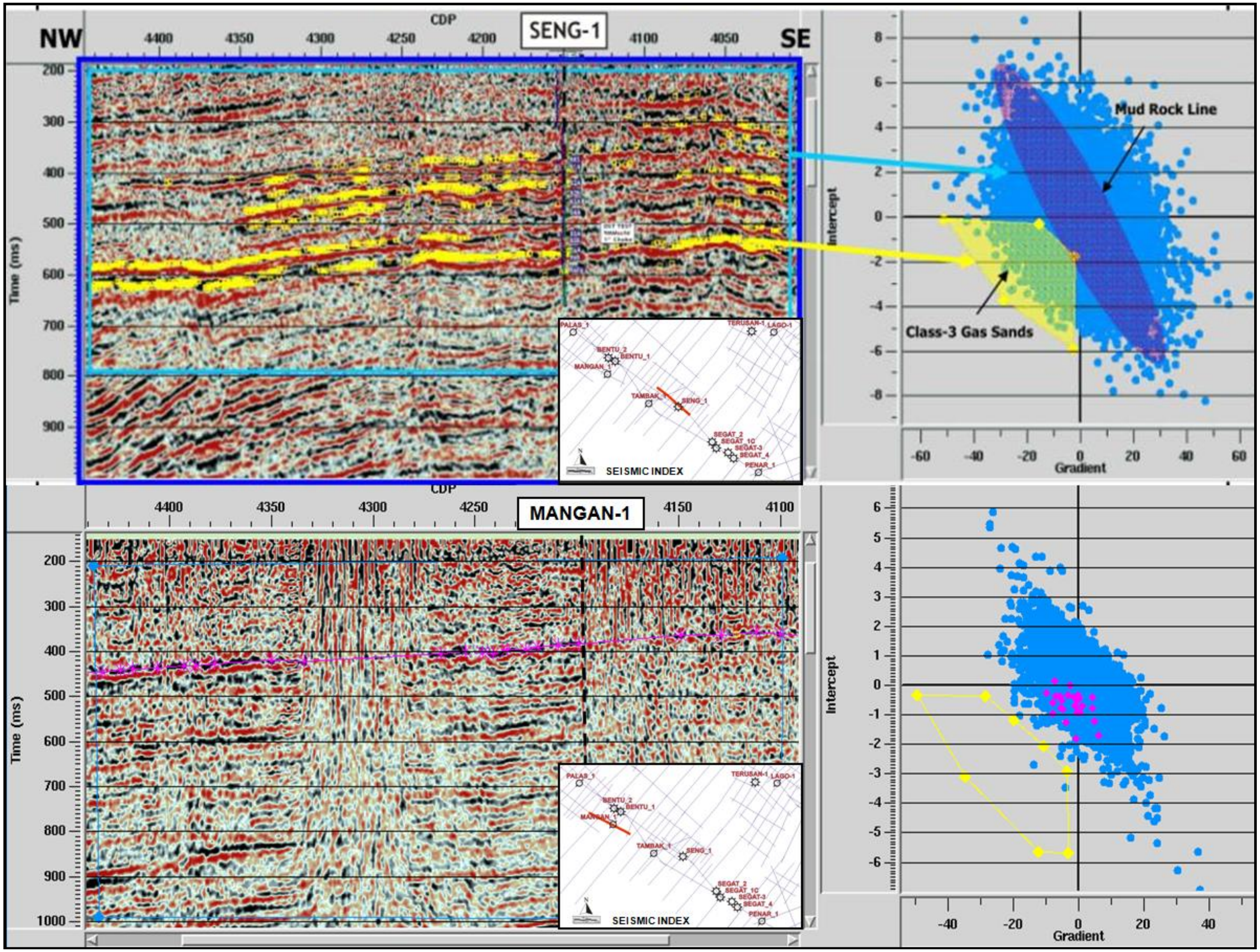

Figure 12. AVO plots along seismic lines through Seng-1 and Mangan-1; gas at Seng-1 well is class-3 gas sand while AVO plots from Mangan-1 well shows coal classes.