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A Comparison between Model Base Hardconstrain, Band-limited, and Sparse-Spike Seismic Inversion: New Insights for CBM Reservoir Modelling on Muara Enim Formation, South Sumatra

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Abstract. Coal Bed Methane (CBM) as a newly developed resource in Indonesia is one of the alternatives to relieve Indonesia's dependencies on conventional energies. Coal resource of Muara Enim Formation is known as one of the prolific reservoirs in South Sumatra Basin. Seismic inversion and well analysis are done to determine the coal seam characteristics of Muara Enim Formation. This research uses three inversion methods, which are: model base hard-constrain, bandlimited, and sparse-spike inversion. Each type of seismic inversion has its own advantages to display the coal seam and its characteristic. Interpretation result from the analysis data shows that the Muara Enim coal seam has 20 (API) gamma ray value, 1 (gr/cc) – 1.4 (gr/cc) from density log, and low AI cutoff value range between 5000-6400 (m/s)*(g/cc). The distribution of coal seam is laterally thinning northwest to southeast. Coal seam is seen biasedly on model base hard constraint inversion and discontinued on band-limited inversion which isn't similar to the geological model. The appropriate AI inversion is sparse spike inversion which has 0.884757 value from cross plot inversion as the best correlation value among the chosen inversion methods. Sparse Spike inversion its self-has high amplitude as a proper tool to identify coal seam continuity which commonly appears as a thin layer. Cross-sectional sparse spike inversion shows that there are possible new boreholes in CDP 3662-3722, CDP 3586-3622, and CDP 4004-4148 which is seen in seismic data as a thick coal seam.

1. Introduction

Coal Bed Methane (CBM) as a newly developed resource in Indonesia is one of the alternatives to relieve Indonesia's dependencies on conventional energies. Indonesia has approximately 453.3 Trillion Cubic Feet (TCF) of CBM reserve that covers 11 basins over Sumatra, Java, Borneo, and Celebes. The biggest resource is in the South Sumatra Basin (183 TCF or 40.37% of national resources), followed by the Barito Basin and Kutai Basin. (Hasyim, 2010).

Coal-Bed Methane (CBM), or *Coal Seam Gas* (CGS), or *Coal-Mine Methane* (CMM) is an unconventional resource of natural methane gas which founded in coal deposits or coal seams (coal-bed). Subsurface explorations on coal seams are definitely identified by well-logging data. But the presence of coal seams on conventional seismic data may not easily determine. By practicing seismic inversion we could achieve the coal seam distribution known from its low impedance value. Various inversion methods are available in the industry and each will characterize the data differently. This research was purposed to emphasize which inversion that most suites on a CBM field.

2. Geological Setting and Stratigraphy of South Sumatra Basin

The South Sumatra basin was formed by three major tectonic phases: 1) extension during late Paleocene to early Miocene forming north-trending grabens that were filled with Eocene to early Miocene deposits; 2) relative quiescence with late normal faulting from early Miocene to early Pliocene; and 3) basement-involved compression, basin inversion, and reversal of normal faults in the Pliocene to Recent forming the anticlines that are the major traps in the area (Pulunggono, 1986). South Sumatra Basin is prolific reservoirs which contain oil, gas, and coal bed methane reserves. The stratigraphy of South Sumatra Basin has been massively discussed by the petroleum expertise or geoscientist since last decades. According Ginger, 2005, the stratigraphy is given as follow (Fig 1).

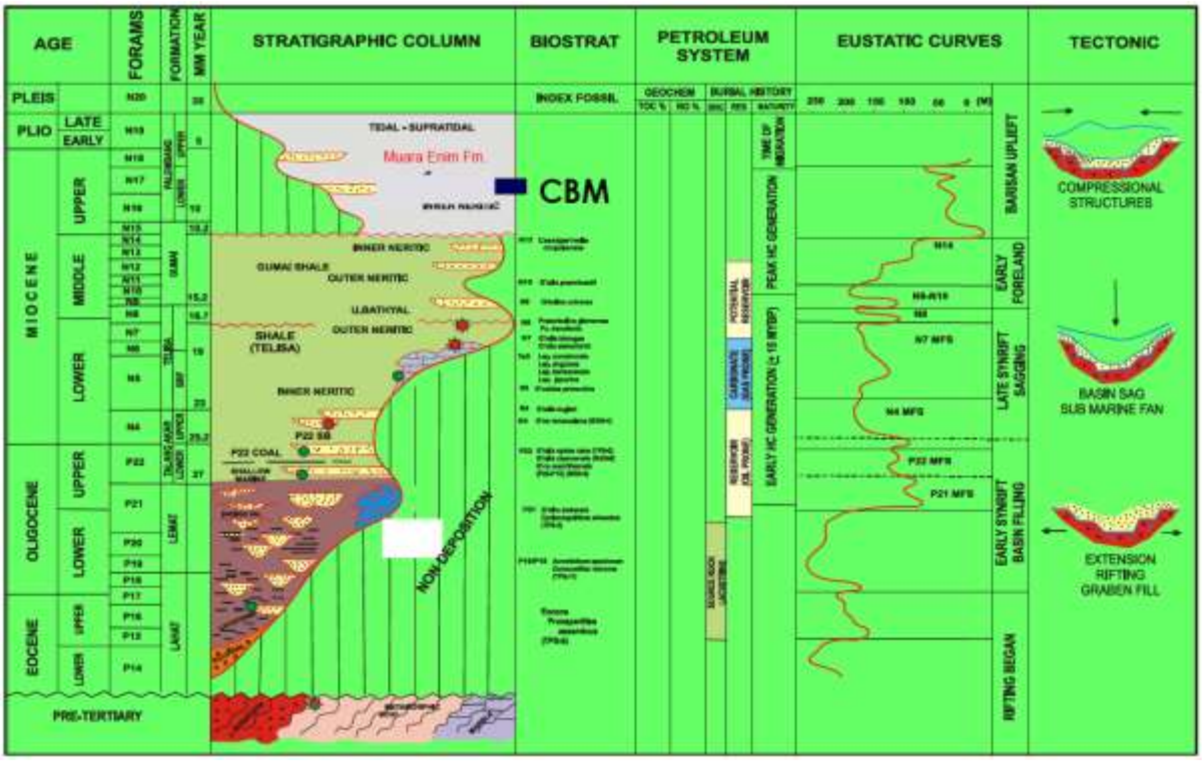

Fig 1. Stratigraphy of South Sumatra Basin (Ginger, 2005)

South Sumatra Basin is distinguished to three group of rocks, which are pre-tertiary rocks, tertiary rocks, and Quaternary rocks. Pre-tertiary rocks act as a basin floor which appears in igneous, metamorphic, and sedimentary rocks. During the middle to late Cretaceous, the pre-tertiary rocks intensively had had folding and faulting and being intruded by igneous rocks since the orogenesis of middle Mesozoic (De Coster, 1974). Tertiary rocks consist of Lahat Formation, Talang Akar Formation, Baturaja Formation, Gumai Formation which is deposited during transgressive phase in Early Eocene to Middle Miocene (Telisa Group) and Air Benakat Formation, Muara Enim Formation, and Kasai Formation which is deposited during regressive phase in Middle Miocene to Pliocene (De Coster, 1974). Quaternary rocks consist of the decomposition of igneous, sedimentary, and metamorphic rocks in which appear as alluvial deposits. The alluvial deposits have various thickness and deposited spreads along the river as a meander both in the middle and the edge of the river.

The presence of coal seam exists in Muara Enim Formation and distinguishes as coal bearing formation which is being our target (Fig 2). Muara Enim Formation represents the last phase of tertiary regression which comfortably overlain above Air Benakat Formation in shallow marine, delta plain, paluda, and non-marine. The thickness of Muara Enim Formation is 500 to 1000 m, consists of sandstone, claystone, siltstone, and coal. Coal seam of Muara Enim Formation appears as a lignite which is deposited during Late Miocene to Early Pliocene.

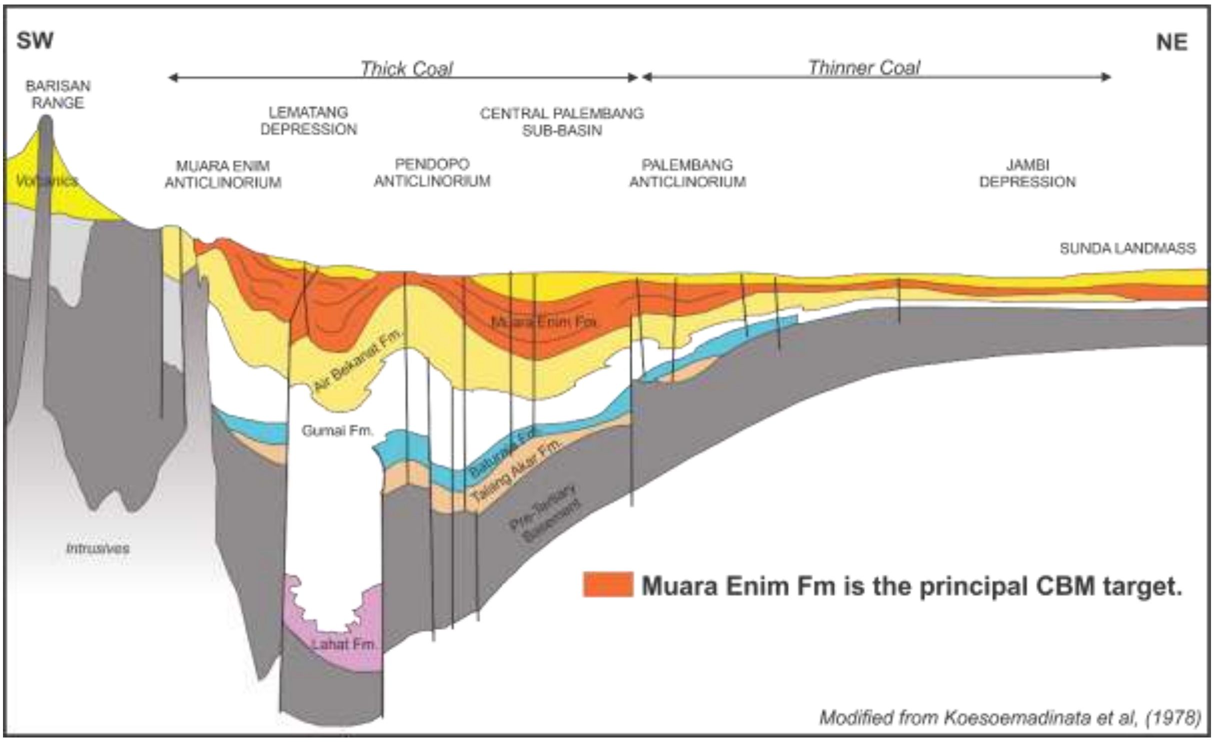

Fig 2. Muara Enim Formation as a CBM prone formation in South Sumatra Basin (Koesoemandinata, 1978)

3. Method

According to Sukmono, 2000, Seismic Inversion is a sub-surface modeling process which requires seismic and well data input as a control. There are few types of post-stack inversions which are model base, bandlimited, and sparse-spike inversion. Model Based Inversion generally adopts GLI method (Generalized Linear Inversion), a process to provide a seismic model (impedance) which eventually compared with seismic data and iteratively repeated until obtaining lowest error count. Model Based Inversion is divided into two types, which are Model-Based Soft-Constrain and Hard-Constrain. Soft-Constrain Inversion doesn't set any absolute bounds on how far the impedance can move from the initial guess, while Hard-Constraint Inversion imposes fixed boundaries on the calculated impedance. Band-Limited inversion is a modification of discrete recursive inversion. This inversion purposed to re-obtain low frequencies which are lost in the process of recursive inversion. Low frequencies are achieved from low-filtered well-log data. Band-Limited inversion provides simple Acoustic Impedance section. Nevertheless, band-limited are depended on the acoustic impedance of the first layer, lacked with lateral resolution and noisy data are also being inverted. Sparse Spike Inversion basically seeks minimal series of high-value reflection coefficient. This value directly impacts the appearance geological event such as unconformity, lithology boundaries, etc. Iteratively, sparse spike inversion applies additional reflectors which are dimmed on each iteration. Iteration process will be halted if RC model represents seismic data. RC obtain from such process of deconvolution. Sparse Spike also able to provide higher resolution model by the increasing of bandwidth reflectivity and less dependent on initial model (Hampson and Russel, 2005).

On this paper, the authors only rely the linear programming which relies on sparseness, frequency, windows length, impedance output option, and time range. Linear programming is a recursive inversion with a sparse spike assumption. If high-resolution deconvolution is applied then it will be assumed as the real value of reflectivity (Hampson and Russel, 2005). This average of reflectivity value will lose low-frequency component. The absence of low frequency will be replaced by the frequencies of the geological model (Oldensburg, 1983).

4. Pre-Inversion Analysis

The pre-inversion analysis is one of the important step before determining the proper inversion to display the coal seam layer beneath the surface. The initial model is made based on log data and seismic horizons. The impedance value is obtained from two wells to aim the interpolation pattern of impedance value (Fig 3). Based on this initial model we could able to determine a quick-look of a probable final inversion. The initial model expressed a distribution of low impedance coal from SW-NE.

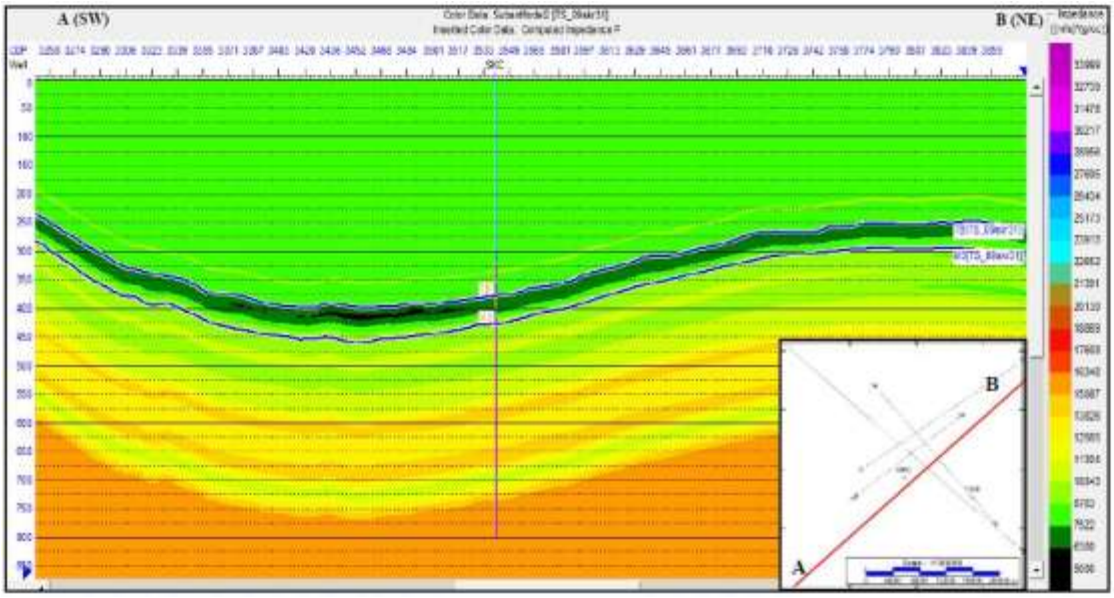

Fig 3. Pre-Inversion initial model on determined seismic section.

Based on those three inversions, it will be chosen the best inversion depending on the highest correlation value on the cross plot analysis and the inversion which is able to display the best coal seam. All the inversions add 40ms both the top and the bottom horizon. The Model Based Inversion shows that hard constraint is better than soft-constraint inversion based on the number of iteration (Table 1) and error comparison graphic (Fig 4).

Table 1. Iteration and error ratio of Hard-Constrains and Soft-Constrains

Hard-Constrain

Iteration/Error	Constrain (%)										
	0	5	10	15	20	25	30	35	40	45	50
5	1785	1089	1160	1214	1310	1359	1359	1359	1359	1359	1359
10	1780	1118	1249	1273	1352	1411	1420	1420	1420	1420	1420
15	1806	1221	1296	1383	1417	1473	1495	1553	1465	1465	1465
20	1817	1395	1352	1393	1450	1421	1514	1553	1553	1553	1553

Soft-Constrain

Iteration/Error	Constrain (%)										
	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
5	2778	2570	2118	2024	1956	1502	1463	1463	1399	1367	1338
10	3038	2374	2174	2037	1948	1489	1489	1451	1390	1364	1337
15	3965	2375	2191	2064	1541	1492	1492	1455	1392	1364	1339
20	4045	2743	2216	1616	1549	1499	1499	1460	1394	1367	1342

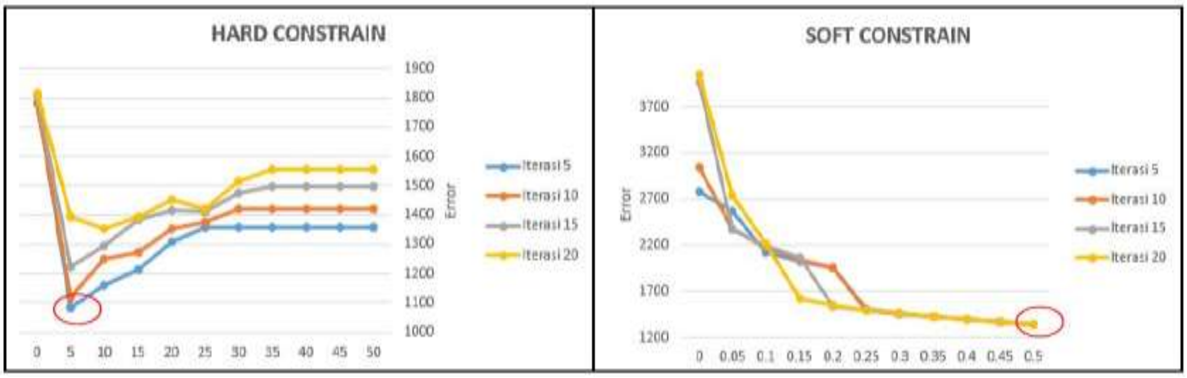

Fig 4. Error comparison chart of Hard-Constraint and Soft-Constraint.

In Bandlimited Inversion, the author only applied the constraint high cut frequency that appears on the frequency 65 Hz and the lowest error (fig 5). In Sparse Spike, Inversion was obtained error value based on sparseness and frequency, from the graphic shows that sparseness at 10 and frequency at 65 Hz has the lowest error (fig 6). Based on the error analysis previously and the inversion cross plot of each method, the model based hard constraint appears as the best inversion. Crossplot inversion is done based on trial and error for each type of inversion in which the highest correlation belongs to spars spike inversion (a= 0.884757). It shows the result of the correlation between inversion trace and seismic data (fig 7). Among Model Base Hardconstrain, Bandlimited, and Sparse Spike Seismic Inversion, the best inversion to display the continuity of coal seam is Sparse Spike Inversion.

Bandlimited

f	40	45	50	55	60	65	70	75
Error	1635	1476	1476	3252	3252	1219	1219	1219

Sparse-Spike

f	Sparseness									
	5	10	15	20	25	30	35	40	45	50
55	540	579	616	635	619	748	676	692	657	741
60	514	560	535	535	566	544	606	606	671	672
65	482	445	523	523	494	570	578	547	576	617

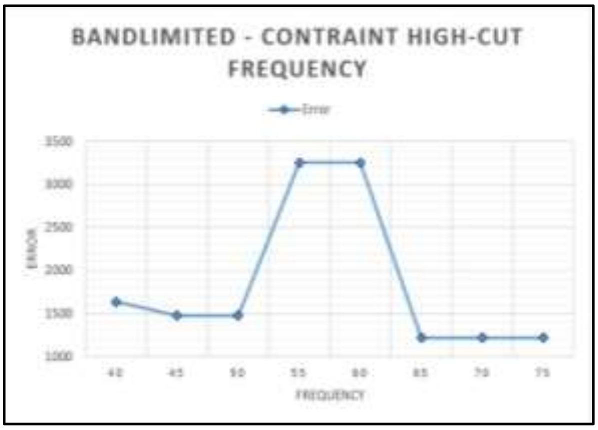

Fig 5. Bandlimited High-Cut Frequency Error Ratio

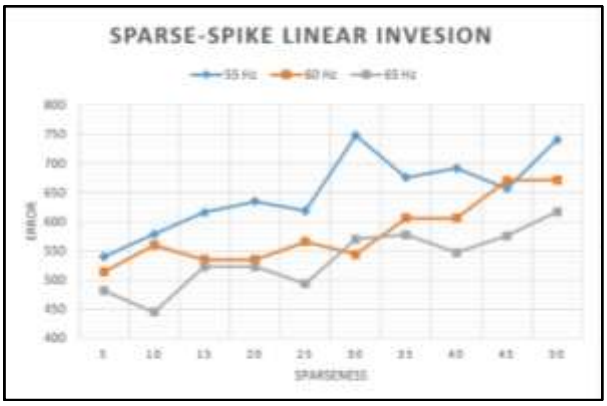

Fig 6. Sparse-Spike Linear Inversion Error Ratio

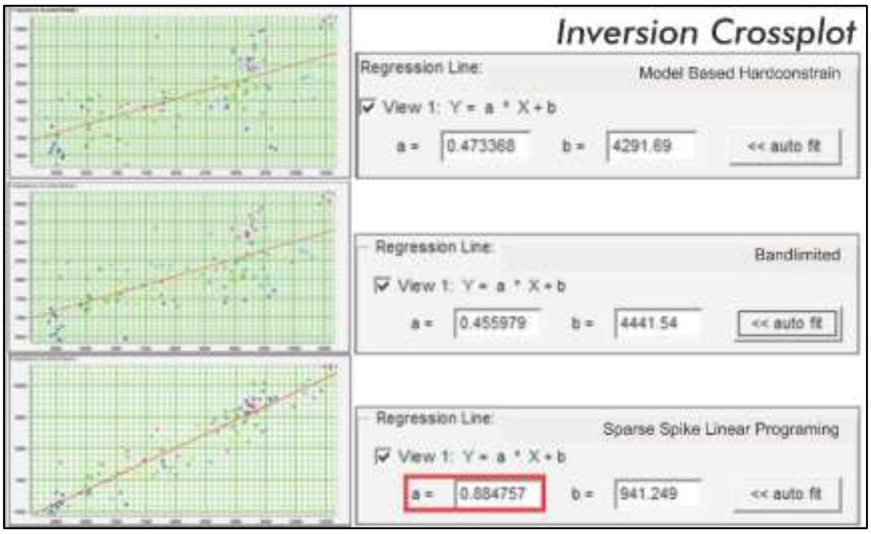

Fig 7. Inversion cross-plot comparison that concludes Sparse-Spike has the highest correlation value among others

5. Result and Discussion

Reservoir, cap rock, and source rock of coal bed methane are the coal seam its self. Our main interest is located at Muara Enim Formation as coal bearing formation. Coal has specific properties, which low gamma ray, low density, and low p-wave as appear in cross-plot analysis to recognize the cut off value between coal and other lithologies such as sand and shale (Fig 8 & 9). Based on the analysis data the Muara Enim Coal Seam has 20 (API) gamma ray value, 1 (gr/cc) – 1.4 (gr/cc) from density log, and low AI cutoff value range between 5000-6400 (m/s)*(g/cc). Based on Sparse Spike Inversion, the coal seam is quite thick based on SKC-well and it shows its continuity among the others (Fig. 10, 11, & 12). The horizon slice at Top Coal (Fig 10) shows that the coal seam is thinning from northwest to southeast.

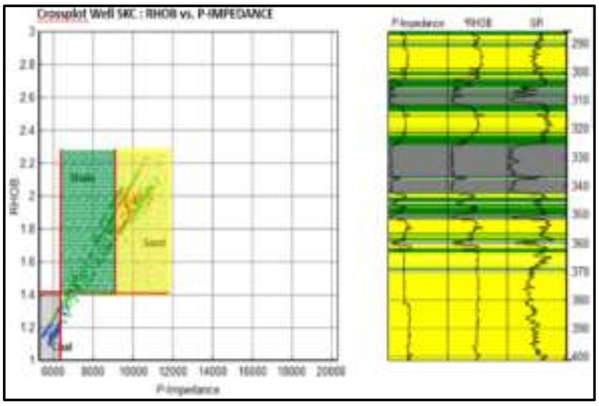

Fig 8. Well SKC

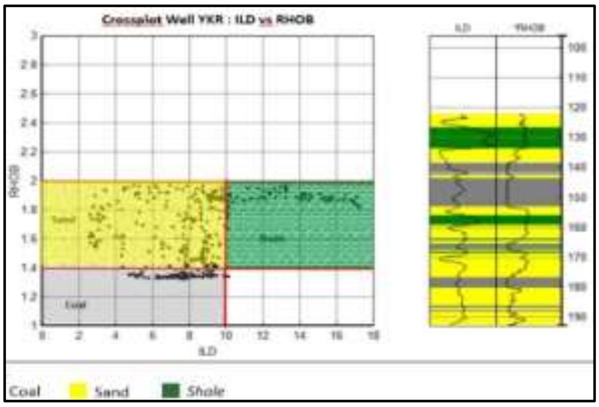

Fig 9. Well YKR

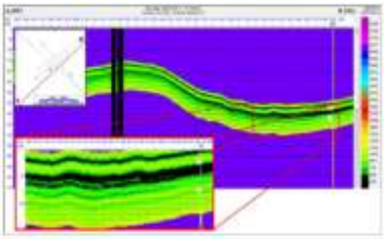

Fig 10. Sparse-Spike

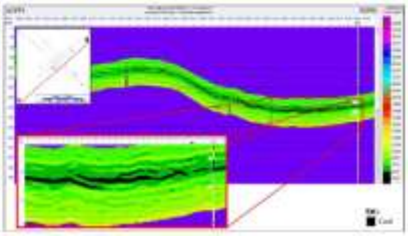

Fig 11. Bandlimited

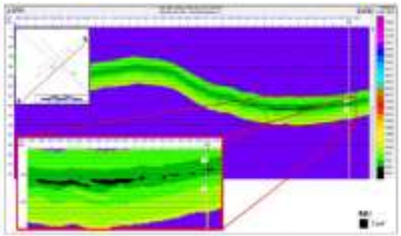

Fig 12. Modelbased

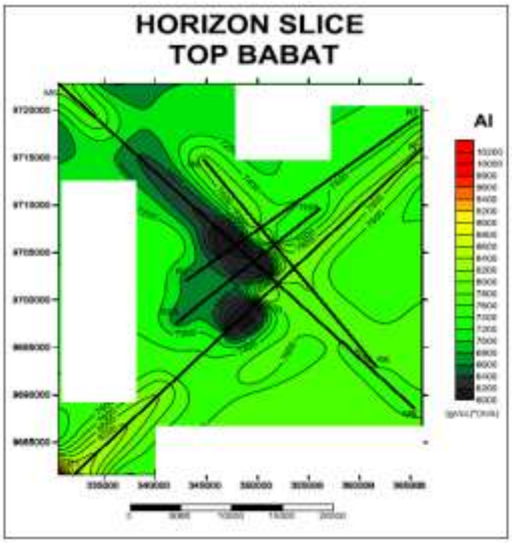

Fig 13. Top Coal overlaid with Base map

Theoretically, Sparse Spike Inversion has high amplitude to do the inversion, and the coal in the research area is lignite to bituminous which has low density and Vp. Hence, the impedance contrast will give giant peak as high amplitude Further drillings are purposed by identifying coal seams on the inverted seismic trace, preferred due lack of well data to do well correlation. Based on "Rule of Thumb" which regulate CBM to only exploit coal seams located over than 300m below the surface. Other criteria for consideration are structures which occurred on the coal. CBM drilling targets anticline flanks or plain seams. Structures consequently impact coal characteristics. Anticline seam will develop fast dewatering causing cleat shrinkage which diminishes pore permeability and syncline seam will lead over-emphasized water production. Most likely thick seams is an ideal target. Based on considered parameters, drilling planning will be purposed at CDP 3586-3622 (fig 14), CDP 4004 – 4148 (fig 15), and CDP 3661 – 3722 (fig 16.)

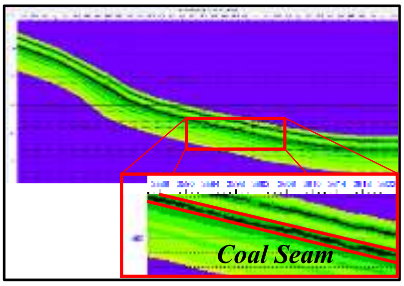

Fig 14. CDP 3586 – 3622

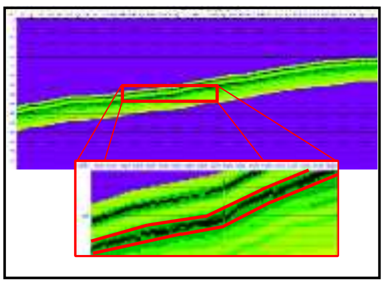

Fig 15. CDP 4004 – 4148

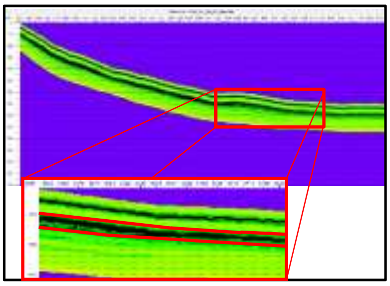

Fig 16. CDP 3661 – 3722

6. Conclusion

Each seismic inversion will express coal seams differently. Sparse-Spike is considerably the most proper seismic inversion to display thick coal seams within its wide distribution area. Therefore, dark areas on top coal horizon map results are considered as coal thickness. Lateral coal distribution is gradually thinning from NW to SE. Moreover, anticline identified formed from SW to NE trapping two seams. Consequently, a number of three purposed wells are adequate to cover this field's future production.

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