The Success Application of Weighted Stack AVO Attribute for Feature Imaging in Horst Trend Area, Arthit Field, Thailand*

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Abstract

"Alpha" is the first development platform in the South Arthit Field, located in the Horst Trend Area (HTA) of the North Malay Basin. The reservoirs of interest are stacked gas-bearing sandstones accumulated in Formation 2 (FM2), varying from units 2E (shallow) to 2A (deep). The main discovery was interpreted as a 4-way dip structural closure in the shallow units and a nose trap in the deeper unit. The other two smaller prospects were situated in a different fault blocks. Based on two drilled wells within the same closure, sandstone reservoirs in FM2 contained hydrocarbon and were deposited in a fluvial depositional environment. However, planning new well locations in order to target channel sand was still uncertain. This is due to the fact that seismic amplitude attributes extracted from the conventional 3D seismic data, such as RMS amplitude and coherency, could not provide sufficient lithology information to perform geo-body identification. For these reasons, a technique using Weighted Stack AVO (WSAVO) attribute was selected to support mapping of shallow targets, and uncertainties related to identifying sand reservoir bodies were significantly reduced. The resulting sand maps were used as a guide for optimized well planning for the Alpha platform.

The WSAVO attribute cube was generated in order to separate possible sandstone interfaces from other lithology interfaces by using intercept and gradient properties derived from seismic data. Prior to generating the WSAVO attribute, stochastic modeling was carried out for all possible lithology interfaces in the Intercept–Gradient domain, using geophysical log data such as P-wave, S-wave, and density. The result from the stochastic modeling showed that separating top sandstone interfaces from other lithology interfaces could be achieved. After that, a weighted-stack function was derived and applied to intercept and gradient attributes calculated from the angle stacks. Positive values in the WSAVO attribute cube represented top sandstone interfaces, while negative values represented all other interfaces. The WSAVO attribute was extracted along an interpreted horizon of interest to image channel-like features and possible sand bodies. Thus, both sand bodies from WSAVO attribute maps and channel sand orientations from well correlations were integrated and used as a guide for well targeting.

Sixteen wells were drilled from the Alpha platform. Most of them encountered sands, indicated by the positive amplitudes observed by the WSAVO attribute, and showed good results with 45 to 100 meters of pay. A few wells encountered only 15 to 25 meters of pay, and this also corresponded to the values extracted from the WSAVO attribute, showing less positive values.

The result of this study shows that the WSAVO attribute was an effective tool that can be used to identify sand bodies and for optimized planning of development wells along the HTA. In summary, the WSAVO technique was recommended for future exploration and development activities to increase the productivity and to reduce number of wells over the field.

Introduction

The Arthit Field is located in the northwestern margin of the North Malay Basin, Gulf of Thailand as shown in Figure 1. The basin was developed during extensional tectonic rifting in Tertiary time. The structures were formed by strike-slip fault systems and developed asymmetric half grabens along Northwest-Southeast (NW-SE) and North-South (N-S) striking fault segment orientations. The basin was filled with non-marine to marginal marine sediments since at least the Oligocene age. The Arthit concession was divided into ten structural trends that are believed to be a factor controlling the petroleum play fairway elements.

The stratigraphy of the Arthit Field can be divided into four formations (Figure 2). Formation 0 (FM0) represent the Late Eocene to Late Oligocene period, and consists of alluvial and lacustrine sediments deposited during the syn-rift period. Formation 1 (FM1) represents the Late Oligocene to Early Miocene period, and consists principally of an alluvial outwash plain deposited as an unconformity on top of Formation 0. Formation 2 (FM2), ranging from Early to Mid-Miocene is an unconformity overlying Formation 1. Formation 2 consists of overall complex fluvial reservoirs that grade southwards to lacustrine. Formation 3, it is the topmost recording of marine deposit since Pliocene to Recent. However, this study is focusing on Unit 2E and Unit 2D, which are mainly composed of fluvial successions.

The Alpha platform aimed to encounter gas-bearing sands in Formation 2 from units 2E to 2A. The main target (HTA-A) was located to the west of the platform (see Figure 3), and was a 4-way dip structural closure at the shallow targets (i.e., units 2E, 2D, 2C, and 2B) and a nose trap at the deeper target (i.e., unit 2A). Two smaller prospects were located in a different fault block to the east of the platform. Two exploration wells, AE1 and AE2, had discovered gas accumulations in the HTA-A segment, having FM2 as the main gas-bearing formation. Geophysical data interpretation was critical for the South Arthit Field developments to confirm the presence of gas-bearing sands in FM2. However, seismic interpretation was challenging since extracted seismic attributes like RMS amplitude and coherency could not provide enough information to delineate channel sands or other reservoir bodies. In an attempt to resolve these challenges a rock physics study was initiated. This study showed that by using a combination of intercept and gradient stacked attribute cubes, the top sand units could be identified from all other interfaces. The new attribute was referred to as a Weighted Stack AVO cube (WSAVO). The WSAVO cube was used a key tool when mapping sand bodies in the area. This approach reduced the uncertainties when mapping the reservoir bodies, and was used to guide the appropriate well planning for the area surrounding the platform.

Methodology

The WSAVO attribute was generated in order to classify the seismic interfaces related to the top sand and separate these from all other interfaces. The attribute was calculated by using rock physics analysis and AVO modeling results, derived during the quantitative interpretation feasibility analysis. The results showed that intercept and gradient attributes at the top sandstone were different from the ones related to other interfaces. Thus, these differences could possibly be used for fluid and lithology identification. A linear relationship was derived to distinguish the top sandstone interfaces from others, and was applied to the AVO attribute cubes. Calculating the weighted stack attribute comprised of phase I; a quantitative interpretation feasibility study, and phase II; weighted stack AVO cube generation as described below.

Quantitative Interpretation (QI) Feasibility Study

The analysis of phase I included fluid replacement modeling, AVO classification, cross-plot analysis, and lithology detection. This was carried out using well data from well AE4 that had the required set of measured log data (Vp, Vs, and density). After completion of dry rock calculation, two fluid types, which were 85% gas and 100% brine saturation, were substituted using the Gassmann equation to generate new sets of logs for the analysis. Five reservoirs were analyzed in this study, which were unit 2D, 2C, 2B, 2A, and FM 1. A good acoustic impedance contrast was observed between gas and brine sandstone in the shallow reservoir section (unit 2D). At increasing depth (FM 1) the acoustic impedance contrast between gas and brine sand was considerably reduced, as shown in Figure 4. It was concluded that the ability to identify gas sands from wet sands was decreasing as a function of increasing reservoir depth.

Generally, AVO classes in the area of study were class II and class IIp for brine and gas bearing reservoirs respectively (Rutherford and Williams, 1989). The AVO modeling accounted for all likely combinations of lithology interfaces in the area to ensure the classification would be valid for identifying the top of sandstone reservoirs in the Arthit Field. The AVO classification of the modeled results was analyzed in an Intercept–Gradient cross plot. In this case, interfaces of interest for lithology detection were shale-sand and coal-sand interfaces, since these represented the main drilling targets. The concept of lithology detection was determined by the best WSAVO function to separate any interface associated with top sandstone from other interfaces as shown in Figure 5.

WSAVO Cube Generation

Appropriately processed 3D seismic angle stack data (near, mid, far) were used as input data to derive intercept and gradient attributes. These attribute cubes were then used to calculate the WSAVO cube by applying the function derived earlier. Positive amplitudes in the WSAVO cube represented the top of sandstone interfaces, while negative amplitudes represented other interfaces. A simplified schematic of the workflow is shown in Figure 6 below.

Surface Attributes Extraction

Both WSAVO and more conventional RMS amplitude attributes were tested when mapping reservoir bodies. A volume attribute was calculated by summing the positive samples within a selected window of the WSAVO cube. Using the same time window, a RMS amplitude attribute was extracted from the full offset stack data. This combination of seismic attributes and a priori information about the direction of sand deposition from log correlation, were used to optimize development well targeting for the Alpha platform. Furthermore, this methodology provided improved confidence in terms of identifying the reservoirs and to classify the trapping styles. The workflow for surface attribute extraction is shown in Figure 7 below.

Result and Discussion

The Alpha platform comprised of sixteen (16) development wells to produce hydrocarbons from three separate segments (HTA-A, HTA-B, and HTA-C). The main area (HTA-A), a four-way dip closure, was developed with thirteen wells. The remaining wells targeted two smaller prospects (HTA-B and HTA-C). All the wells were drilled into stacked gas reservoirs, from unit 2E to 2A. The main pay was found in unit 2D and 2B, with approximately 55 and 25 percent of net pay respectively.

RMS Amplitude and WSAVO Attributes Comparison

Four stacked reservoirs located from unit 2E to 2D were selected when testing the WSAVO and RMS amplitude attributes. Channel sand bodies in unit 2C, 2D, and 2B could neither be observed in WSAVO or RMS attributes, due to the nature of the normal compaction trends of sand and shale in this area, reducing the seismic contrasts with increasing depth. In addition, the seismic quality with depth was also degrading, possibly influenced by lack of far angle data, lower resolution, and lower signal to noise ratio.

The shallowest reservoir interval to be drilled was situated in unit 2E. Both WSAVO and RMS amplitude attributes were generated along Horizon A using the same window length (30 ms), as shown in Figure 8. Three wells (B, F, and K) penetrated the bright RMS amplitudes and strong positive amplitudes on WSAVO, and all three found gas bearing reservoirs. The reliability of the WSAVO attribute was further confirmed at well (L), the negative WSAVO attribute had correctly anticipated the outcome, as no gas sand was found at this level.

The second attribute extraction interval was performed in the upper part of unit 2D. This unit contained most of the pay along the HTA. RMS amplitude and WSAVO attributes were extracted along the Horizon C within a 30 ms window, covering sand 12-20 and 12-30 as shown in Figure 9. Channel features were hardly defined on the RMS amplitude map. However, the channel features could be identified using the WSAVO attribute map. In general, the channel orientation was in an E-W direction towards the HTA-A prospect. At this level, all wells that penetrated into the positive amplitude on the WSAVO attribute found gas sand, while two wells drilled onto the negative amplitude found no sand, as predicted.

The third surface attribute was extracted along the Horizon C-3, using a 40 ms window as shown in Figure 10. The WSAVO attribute map showed channel-like features with positive amplitude in a NE-SW direction, which was difficult to identify from the RMS amplitude attribute map. Most of the wells drilled through the positive amplitude on the WSAVO attribute found gas reservoir at this level. The exception was well J, which still found reservoir despite being drilled on negative WSAVO attribute amplitude. This might be an effect caused by poor seismic data due to attenuation by the shallow channel above this reservoir.

The deepest surface attribute was generated along the Horizon D, which was located at the lower part of unit 2D (Figure 11). The channel sands could be recognized as positive amplitudes on the WSAVO attribute map. The channel direction was mainly in NNW-SSE but some channels were oriented in a NW- SE direction.

According to the overall evaluation after drilling 16 wells, the WSAVO attribute successfully predicted sandstone reservoirs with more than 90 percent accuracy.

Net Sand/Net Pay Predictability of WSAVO Attribute

According to the results from 16 recently drilled wells, penetrating various reservoir zones, more than 80 percent of the positive amplitudes observed in the WSAVO attribute predicted sand correctly (see Figure 12). WSAVO volume attributes extracted along the Horizon A and Horizon D showed predictability of net pay and net sand percentage of 82 and 93 respectively. On the other hand, the positive amplitude extracted from the WSAVO attribute cube along Horizon C and Horizon C-3 showed 100 percent predictability related with net sand and 87 and 93 percent predictability related with net pay.

Channel Sand Modeling from Well Correlation

The result of log interpretation and well correlation were important information to confirm the channels and their indicated depositional direction from the WSAVO attribute. Sand deposition models from well correlation within four layers were overlain the WSAVO attribute maps, as shown in Figure 13. The uppermost interval was Horizon A, covering sand 09-90 in unit 2E, as shown Figure 13a. This sand was interpreted as a delta sand deposition based on log characteristics from 11 wells. The Horizon C interval included sand layers 12-20 and 12-30, located in the upper part of unit 2D, as illustrated in Figure 13b. These sandstones were interpreted as stacked fluvial channels deposited in a NW-SE direction, and consistent with the positive amplitude anomaly observed in the WSAVO attribute map. The sand layer 13-30 was located within the Horizon C-3 WSAVO attribute window. These stacked channels were mainly deposited in a NNW-SSE direction, with some channels also deposited in a NE-SW direction. This conformed to the channel features observed in the WSAVO attribute map, as shown in Figure 13c. In lower unit 2D, sands 13-70 and 13-80 were combined by using a volume attribute extraction along Horizon D, as shown in Figure 13d. Log interpretation suggested that these sands were channelized sands along at least two directions. One of the two could be a channel belt deposited in a NE-SW direction, while the others were deposited in a NNW-SSE or even N-S direction.

Conclusions and Recommendations

The results after drilling 16 development wells indicated that the WSAVO attribute was an effective tool that can be used to identify sand bodies, and to help guiding correct locations for development wells in the HTA. The methodology was especially successful at the shallowest targets (Unit 2E, 2D, and 2C). The application of this seismic attribute helped reducing uncertainties in terms of reservoir presence, and results from the wells at the Alpha platform confirmed this statement. Therefore, the WSAVO attribute was recommended when planning future exploration and development wells, as this approach can increase the success ratio of the project. However, the extracted WSAVO attribute in the South Arthit Field was not deemed suitable when evaluating the deeper targets due to increasing pore stiffness and maximum offset limitations of the 3D seismic dataset.

Reference Cited

Rutherford, S.R., and R.H. Williams, 1989, Amplitude-Versus-Offset Variations in Gas Sand: Geophysics, v. 54, p. 680-688.

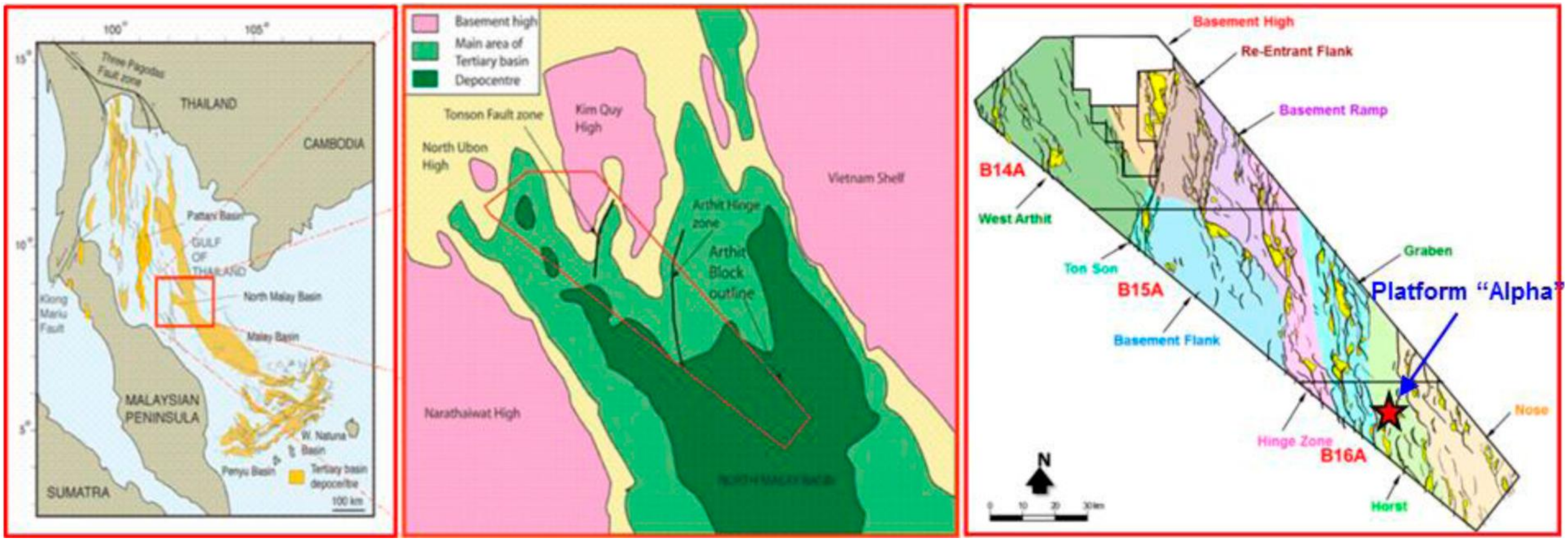

Figure 1. Location map, regional structural map and structural trends map for Arthit field. The location of the Alpha platform is indicated by the star.

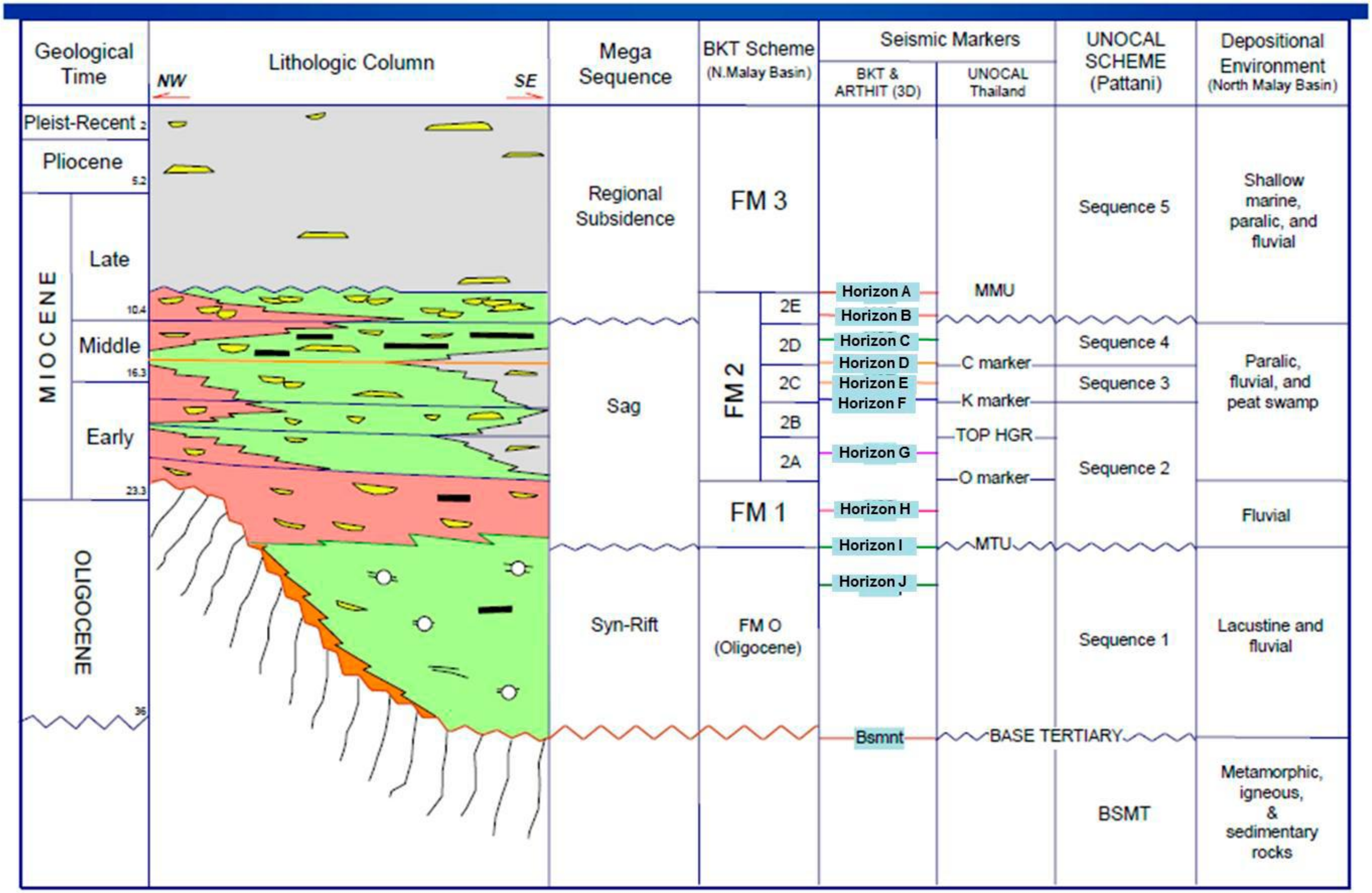

Figure 2. Stratigraphic column of the North Malay Basin.

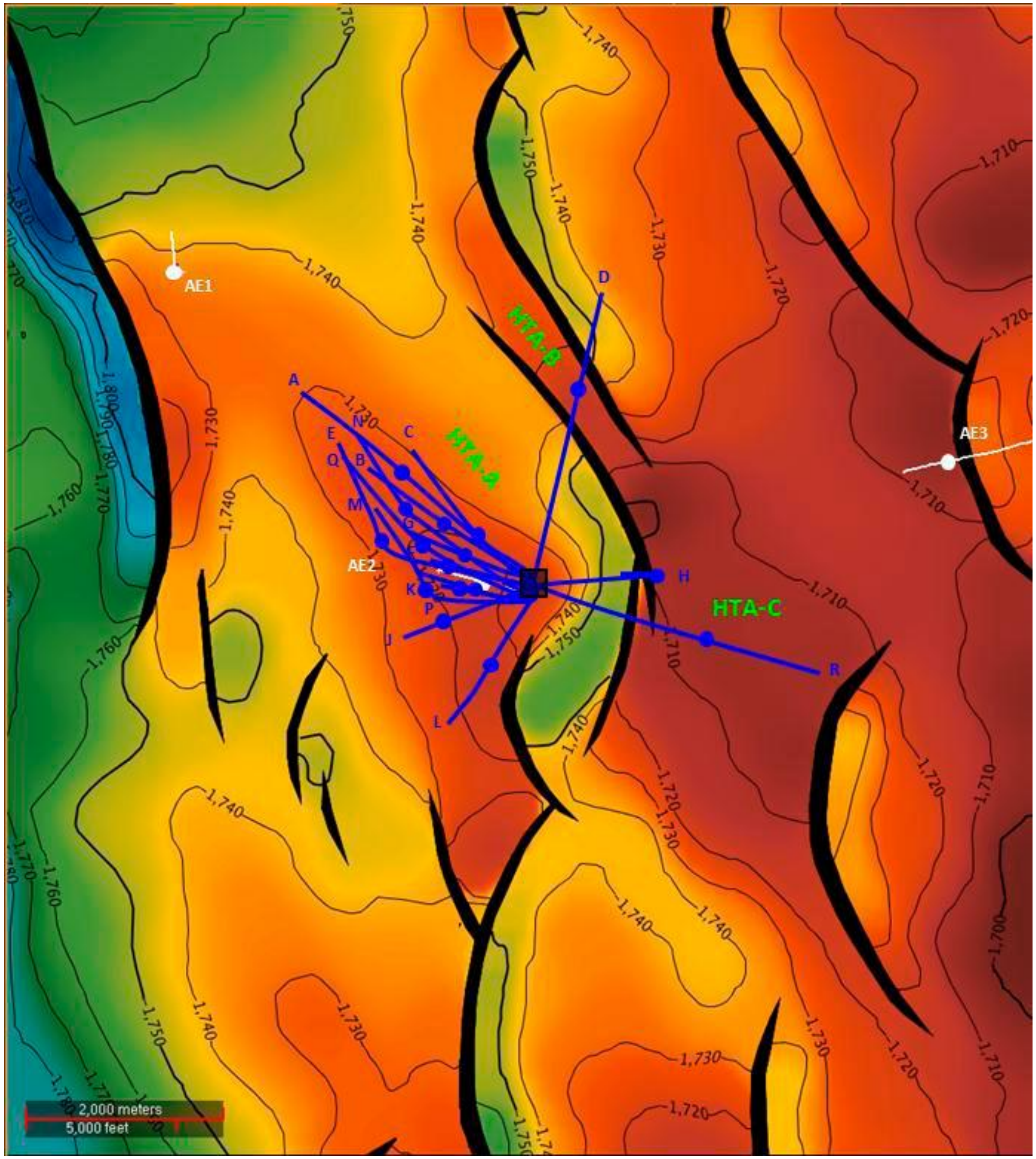

Figure 3. Platform “Alpha” with 16 wells overlaid onto the Horizon C depth structural map.

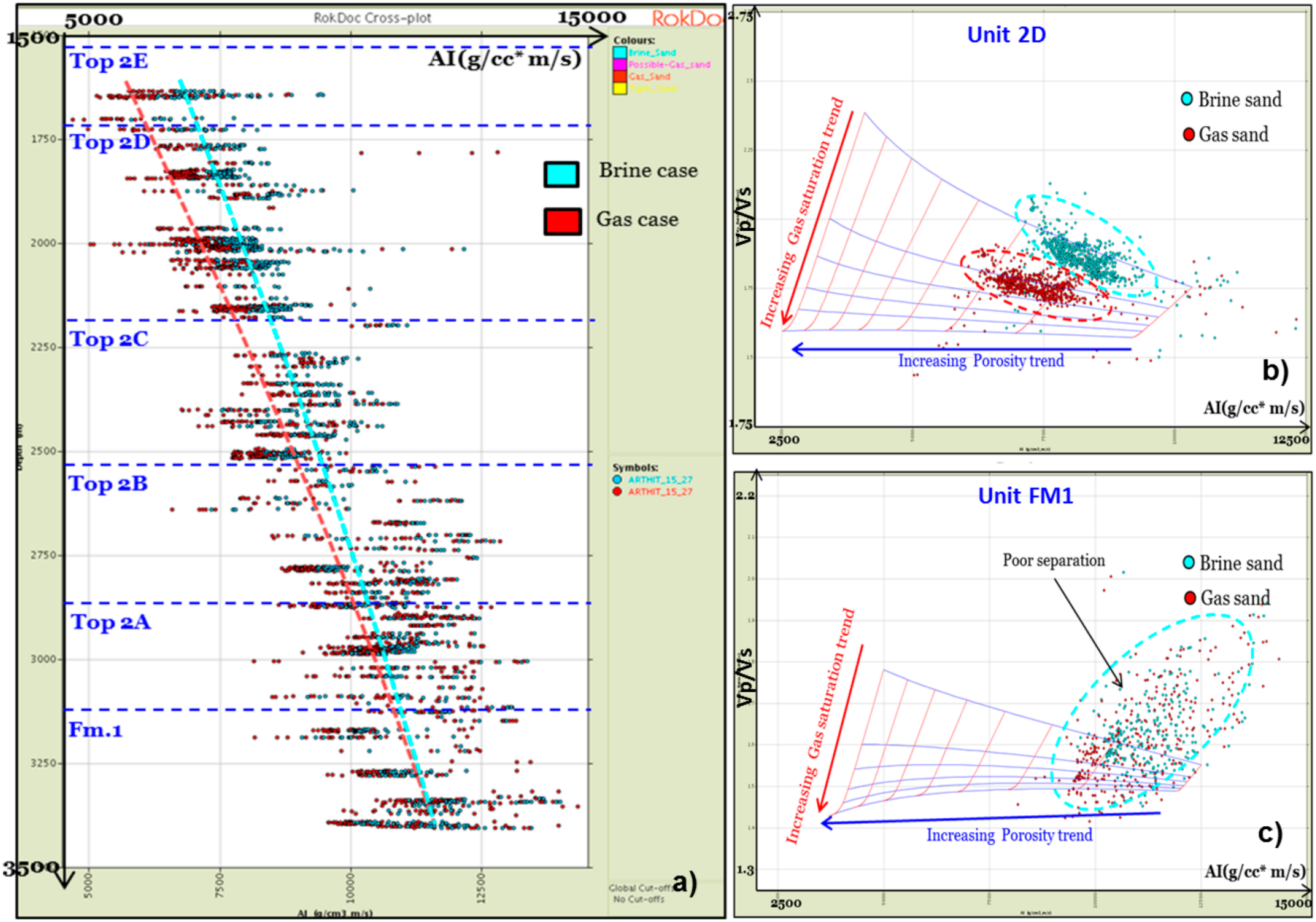

Figure 4. Resulting cross-plots after Fluid Replacement Modeling (FRM) at log scale. The red and blue dots represent gas and brine respectively. a) With increasing depth of burial from unit 2E to unit FM1, identifying types of pore fluid were increasingly challenging (see superposed trend lines). b) A clear separation between gas and brine sandstone is shown in unit 2D. c) Due to increased pore stiffness resulting from decreasing porosity of the deeper sandstones in unit FM1, separating gas sands from brine sands were no longer deemed possible.

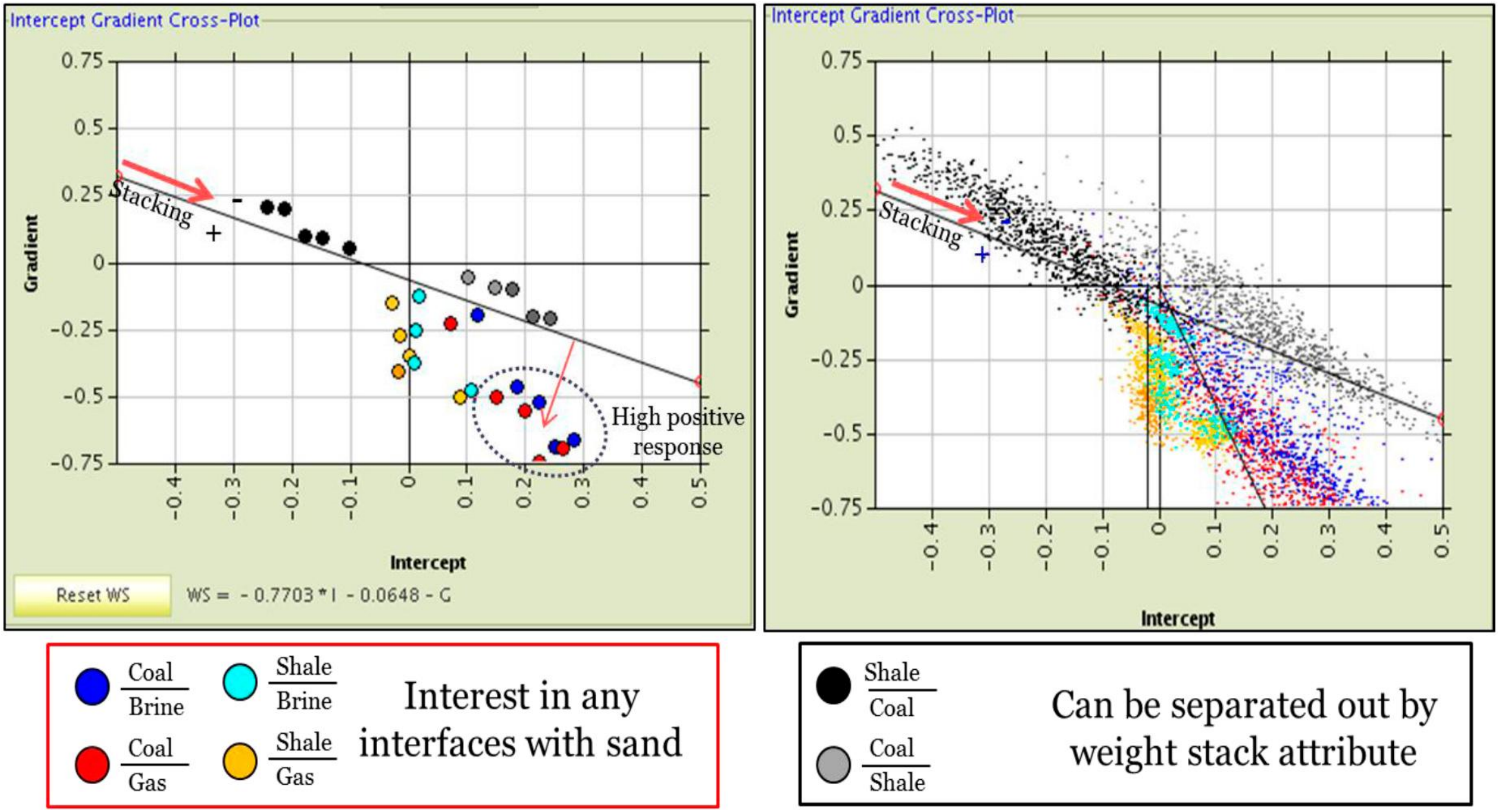

Figure 5. Single interface modeling (left) were conducted for all possible interfaces in the area. Black and grey circles were separated from others using a WSAVO function, (-0.7703xIntercept – Gradient – 0.0648). A Monte Carlo simulation (right) was conducted to verify the statistical accuracy of the WSAVO function.

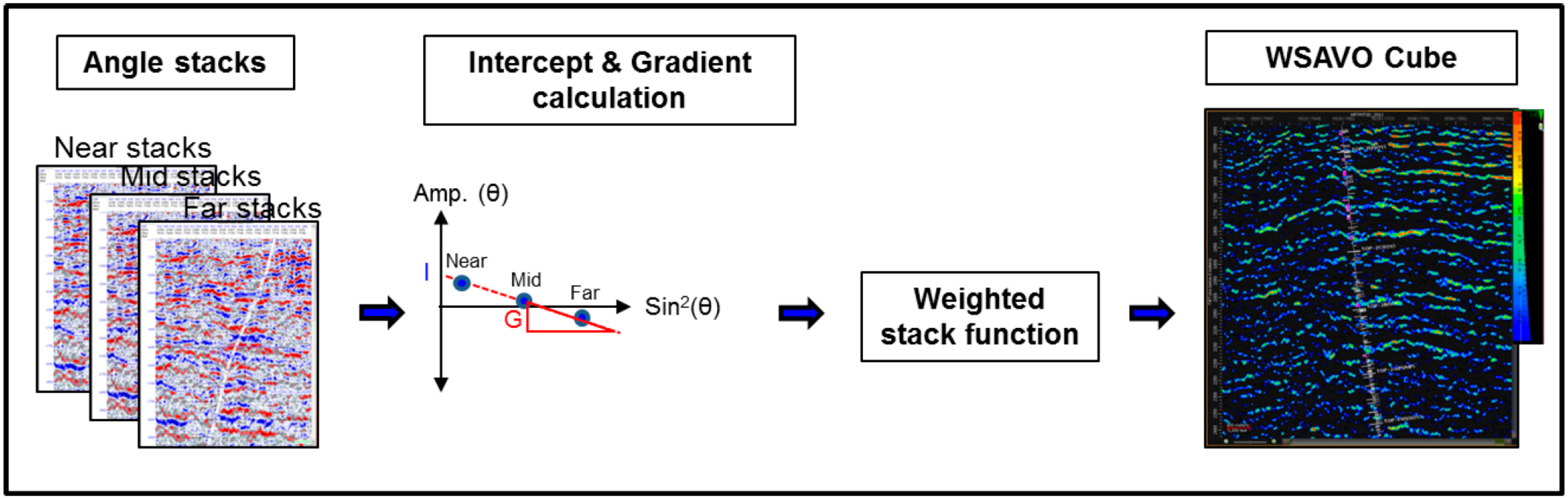

Figure 6. A simplified diagram showing the workflow applied to derive the WSAVO cube.

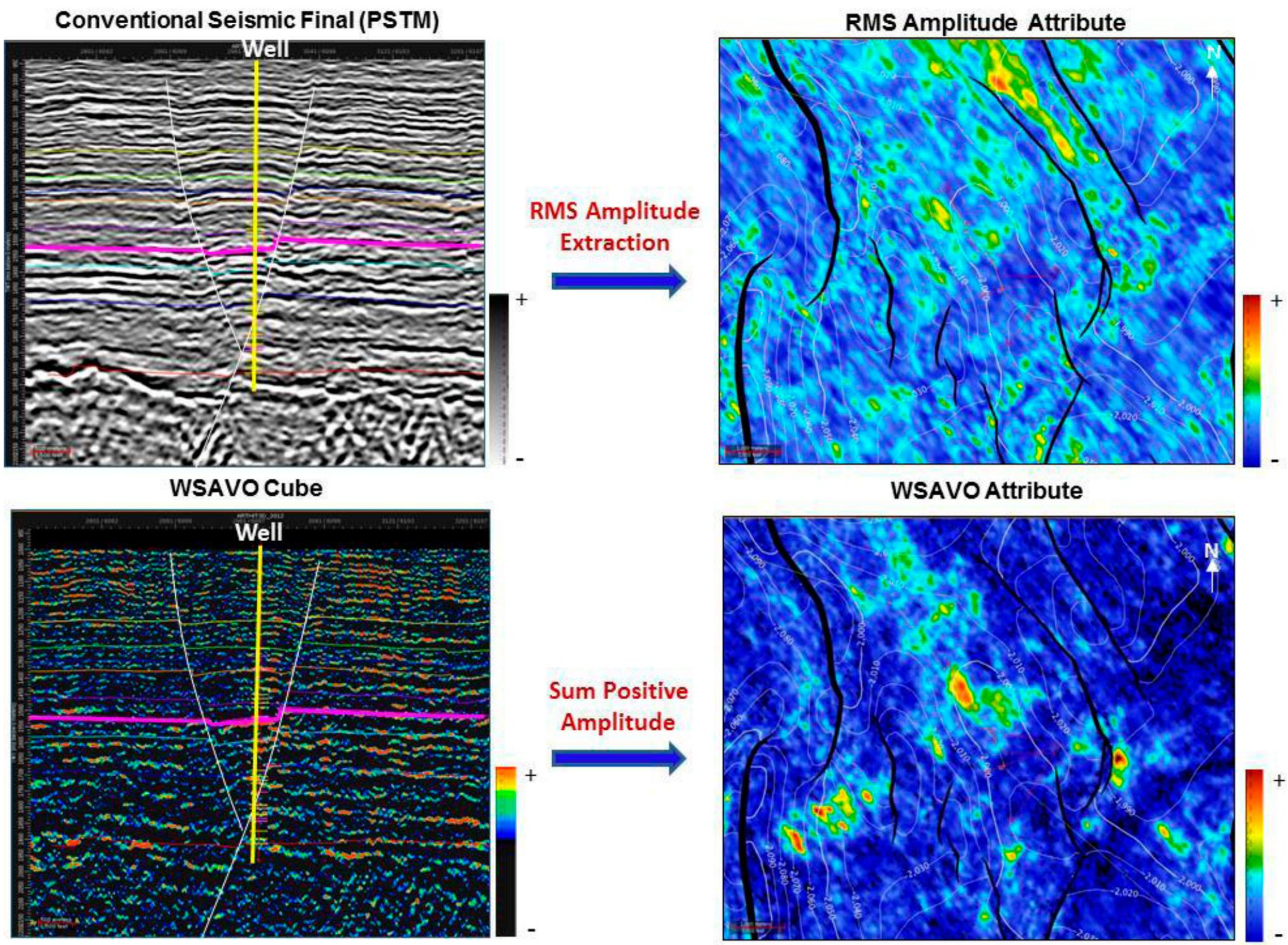

Figure 7. Workflow for surface attributes generation; RMS amplitude and WSAVO attributes.

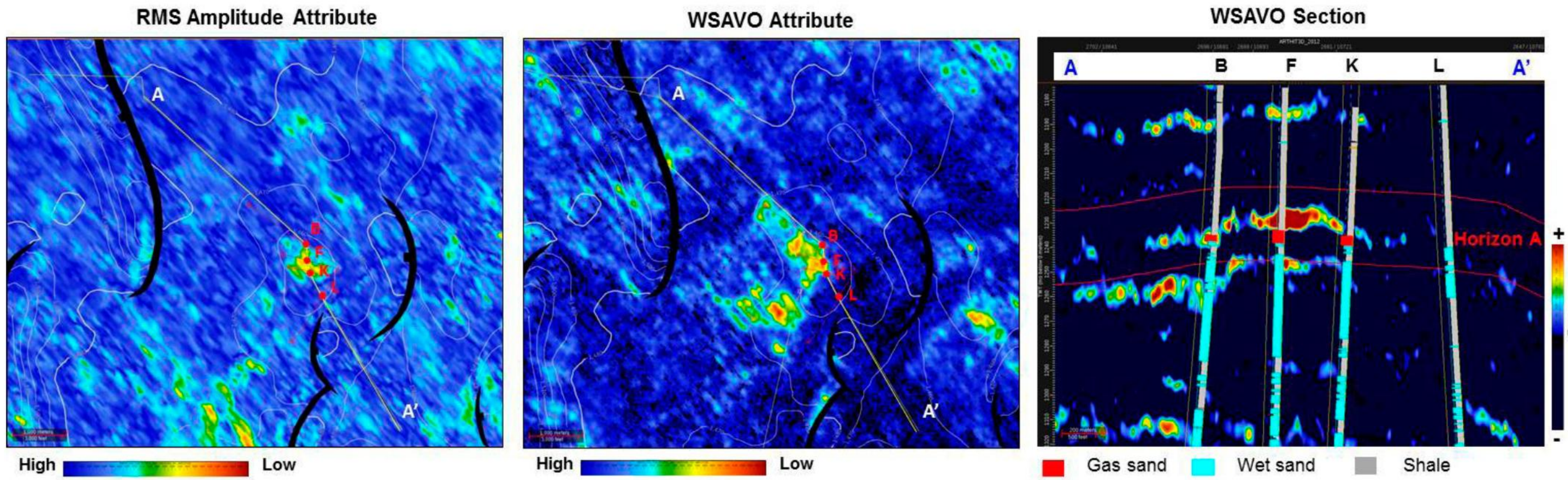

Figure 8. RMS amplitude attribute map (left), WSAVO attribute map (middle) extracted along Horizon A using a 30 ms window covering the 09-90 sand interval (right).

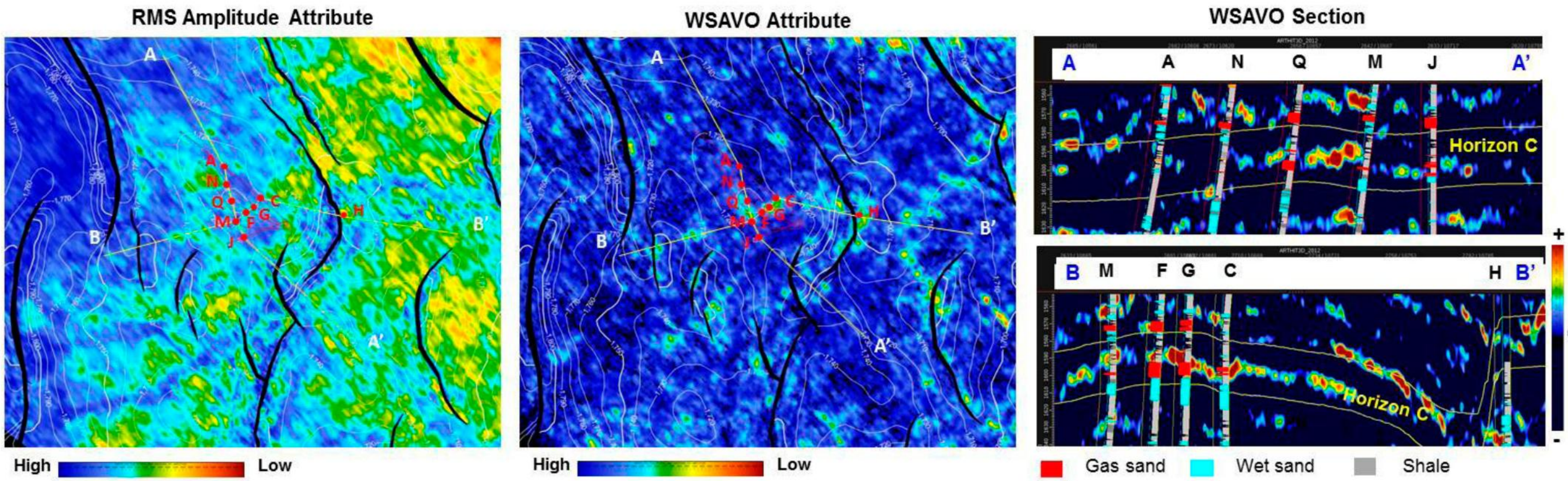

Figure 9. RMS amplitude attribute (left) and weight stack AVO attribute (middle) which extracted along Horizon C with window 30 ms covering sand 12-20 and 12-30 (right).

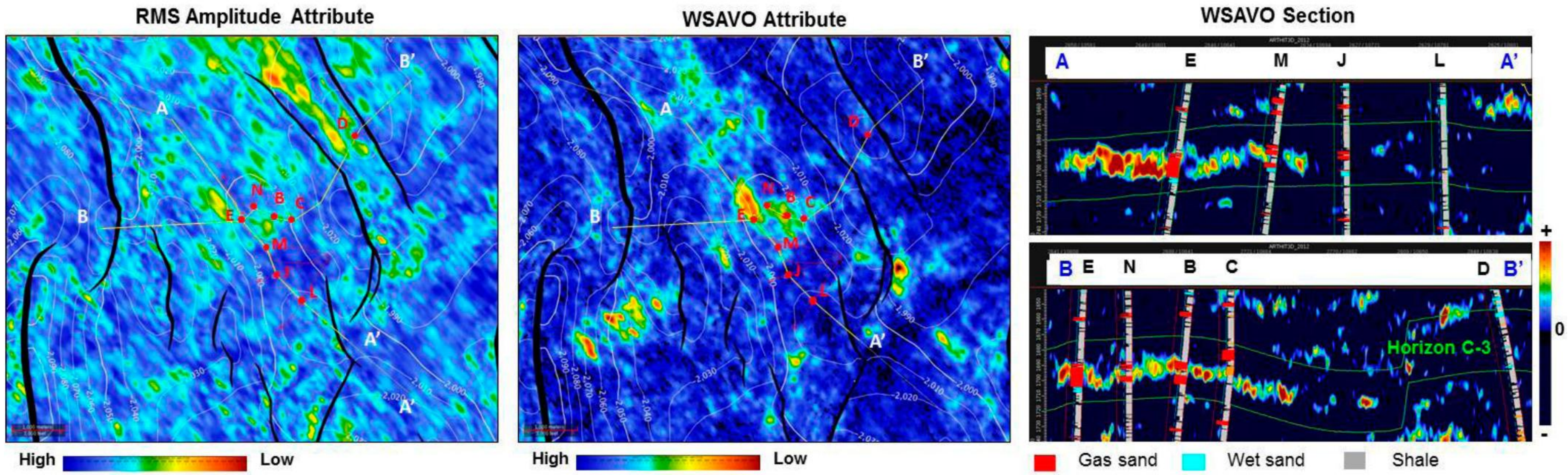

Figure 10. RMS amplitude attribute (left) and weight stack AVO attribute (middle) which extracted along Horizon C-3 with window 40 ms covering sand 13-25 and 13-30 (right).

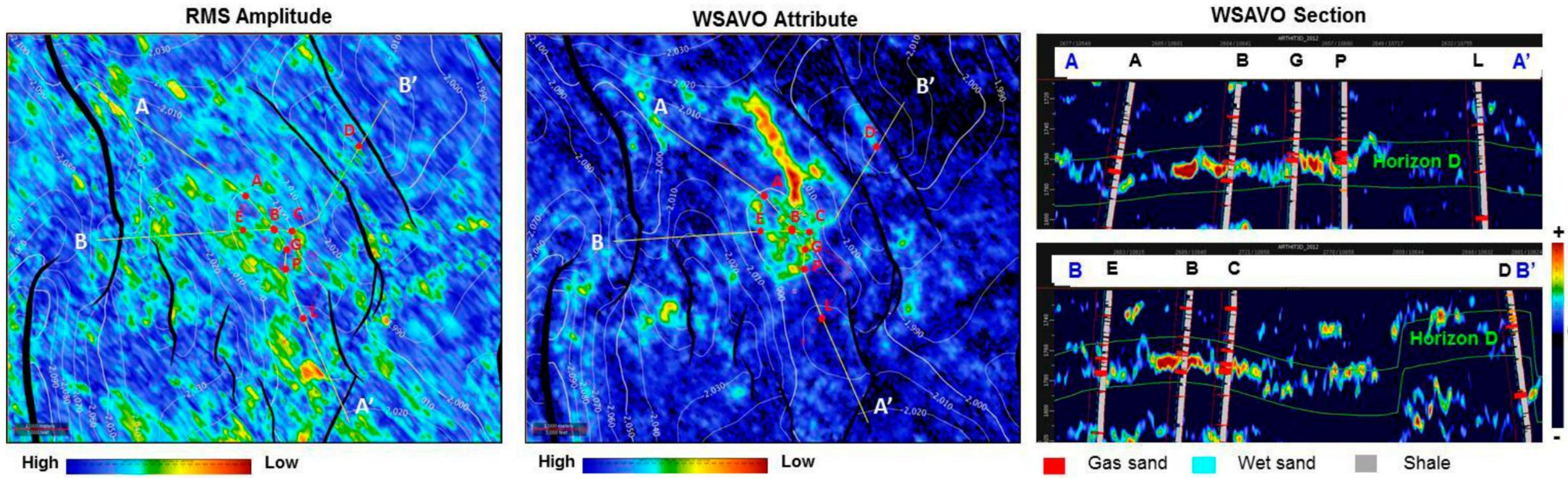

Figure 11. RMS amplitude attribute (left) and weight stack AVO attribute (middle) which extracted along Horizon D with window 30 ms covering sand 13-70 and 13-80 (right).

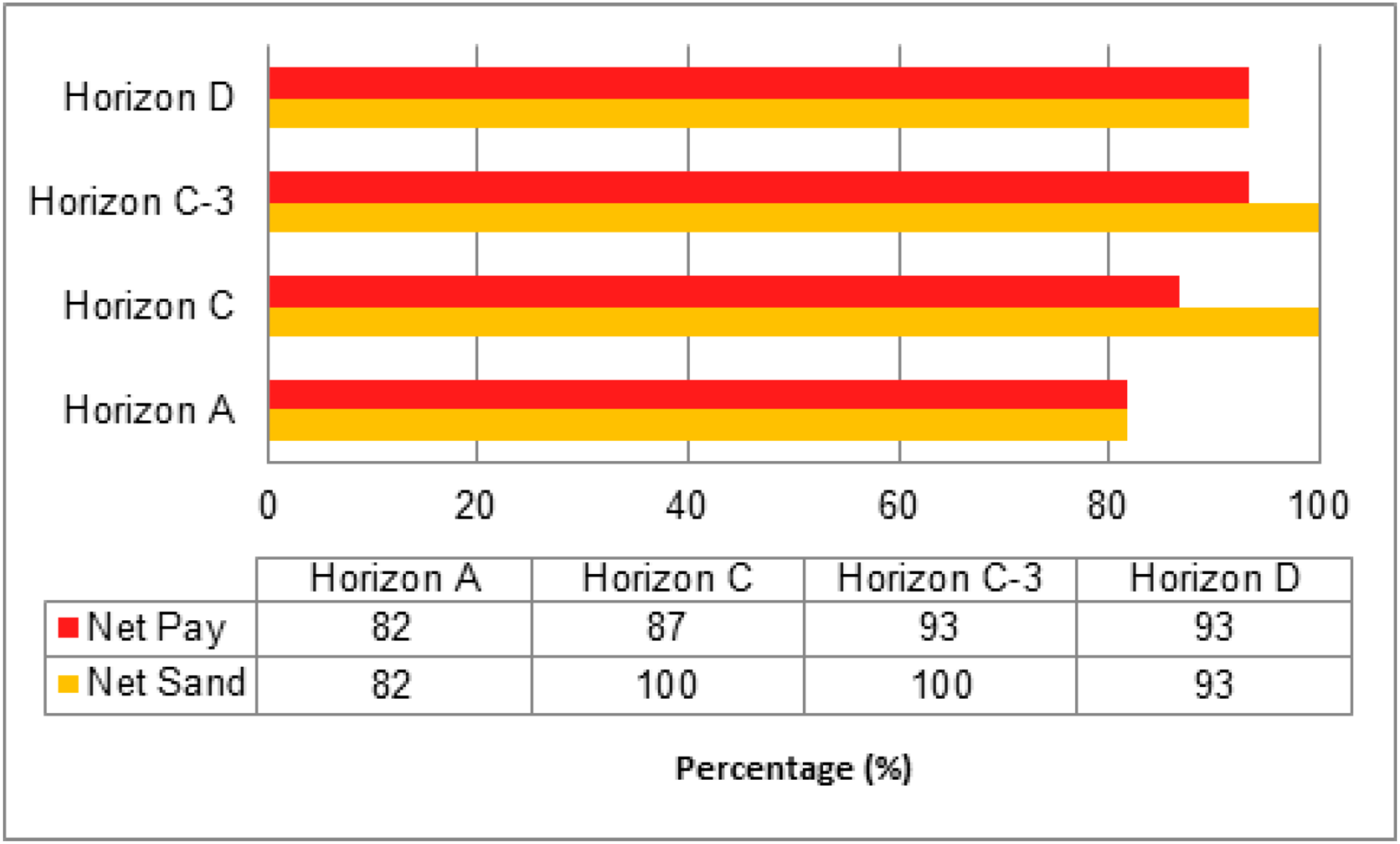

Figure 12. Bar chart illustrating sand predictability of WSAVO attributes within four different intervals. The red bars represent detectability of net pay within each interval, while net sand is represented by yellow bars.

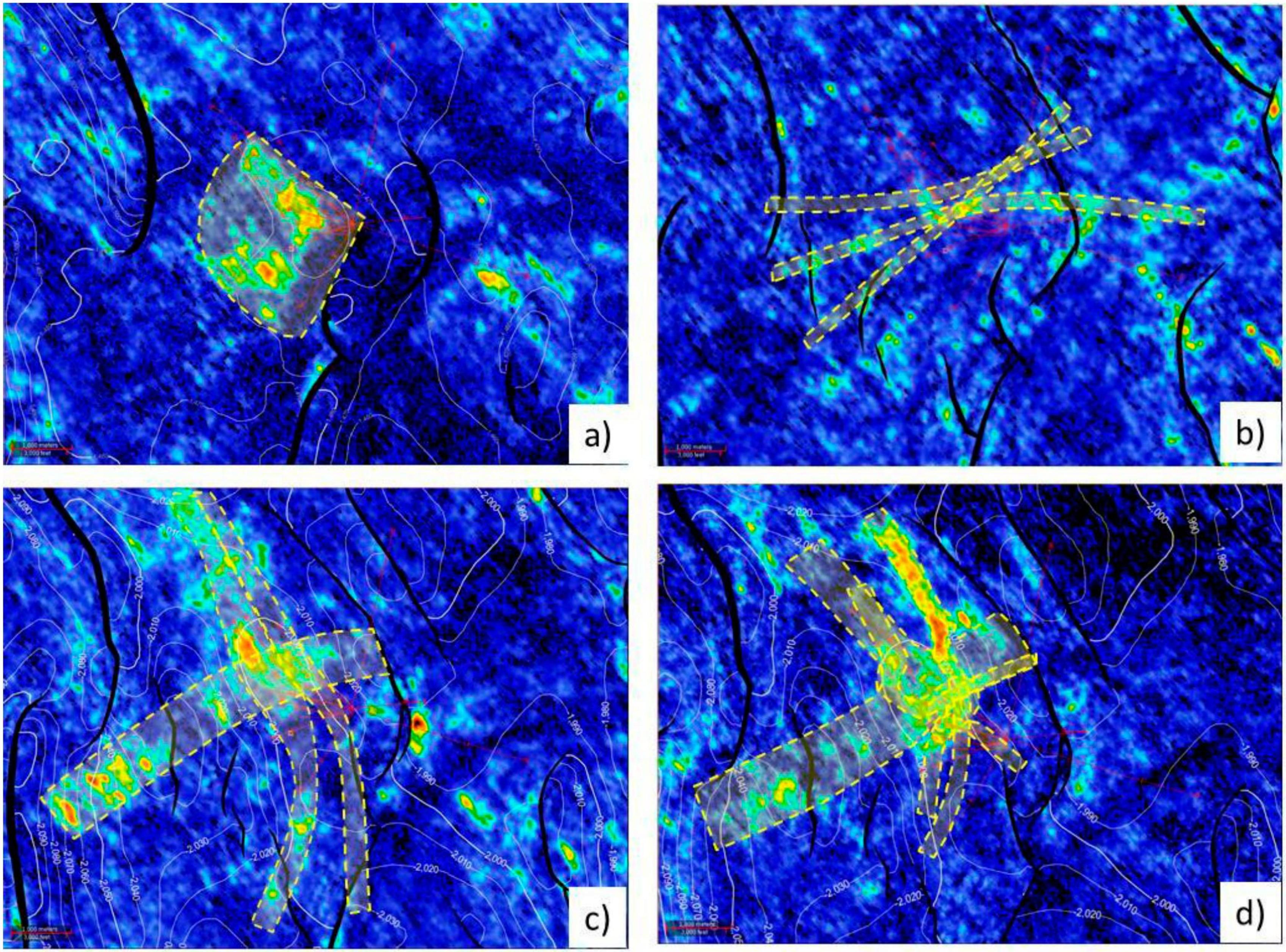

Figure 13. WSAVO attribute maps overlain by sand models from well log correlations. a) Model of sand 09-90 in unit 2E overlain on Horizon A. b) Channel sand model of sand 12-30 in upper unit 2D overlain on Horizon. c) Channel sand model of sand 130-30 in middle unit 2D overlain on Horizon C-3. d) Channel sand model of sand 13-70 and 13-80 in lower unit 2D overlain on Horizon D.