Identification and Prediction of the High Heterogeneous Channel Sand in Southern Turgay Basin*

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Abstract

With the development of high quality 3D seismic exploration in Southern Turgay Basin, the exploration targets are being shifted from the structural traps to stratigraphic traps. As for one of the most important reservoir, the identification and prediction of the high heterogeneous channel-sands is the key to enhance drilling success rate and reduce the investment risk. The multi-geophysical methods and integrated studies of geology and geophysics have been applied to determine the distributed area of the channel-sands in Southern Turgay Basin of Kazakhstan.

The channel-sands are widely distributed from Upper Jurassic to Cretaceous. The channel-sands in the mature explored Cretaceous strata are meandering or braided river bars. On well-logging, the SP curve of the channel sand presents the block - shape and positive cycle with bell – shape with high porosity and permeability, and lower self-potential, gamma ray and density; Whereas in seismic profiles, channel sands presented the 'bright spot' with the low frequency, high amplitude and short reflection. No obvious rules of 'bright spot' can be found in the seismic profiles. The multi-geophysical methods, such as strata slice, 3D visualization and spectral decomposition, etc., have been applied to identify more than 50 pieces of channel-sands with the cutting and overlying each other vertically and horizontally.

As for the relatively lower explored Upper Jurassic strata, the channel-sands developed in submerged distributary channel, branching mouth bars of deltaic system or fan deltaic system. On well-logging, channel sand presents the middle porosity and permeability, and lower self-potential, gamma ray and density; Low-frequency and varied amplitude presents in seismic profiles. The area distribution of the deltaic or fan deltaic can be determined by sequence stratigraphy and the distribution of the channel-sands in different cycles vertically can be identified by chronostratigraphic interpretation in wheeler domain. Several cases suggested that the integration of strata slice, chronostratigraphic interpretation in wheeler domain, 3D visualization and spectral decomposition is an effective method to identify the high heterogeneous channel-sand, which has been confirmed by drilling results.

Introduction

Channel sand is important reservoir in Southern Turgay Basin and has typical characters on geology, seismic section and well logging. To find the deposition regular of channel sand, methods of strata slice, chronostratigraphic interpretation in wheeler domain, 3D visualization and

spectral decomposition were used to identification and prediction it. Different method has different effect and shows their typical advantage. In this article, we integrate geology and geophysics methods to find channel sand in Jurassic and Cretaceous in Southern Turgay Basin.

Sedimentary Characteristics of Channel Sand

As one of the most important reservoir types in Southern Turgay Basin, channel sand is widely distributed in Upper Jurassic system and Cretaceous system, which mainly refers to marginal bank of meandering river and river island of braided river. In Middle Jurassic system, it mainly refers to underwater distributary channel sand and point bar of delta or fan delta front subfacies. Akshabulak (J3ak) of Upper Jurassic system in Southern Turgay Basin is deposition of lake basin in atrophic phase, which is mainly deposition of fluvial facies, with lithology referring to interbed siltstone and mudstone-bearing fine sandstone of with unequal thickness. Single channel sand body has small scale with strong non-uniformity and uncertainty in spatial distribution. Fluvial facies mainly develops in upper part of J3ak, mainly involving deposition of meandering river; and some river islands, marginal banks and other microfacies can be identified according to seismic attribute and drilling data, Lower Cretaceous in Southern Turgay Basin refers to the fluvial facies deposition of lake basin entering depression phase, which is a set of conglomerate and siltstone-bearing fine-grained conglomerate blended in red brown mudstone; as Cretaceous channel is classified into straight river, meandering river and braided river, different tectonic positions have large variances in types of channel sand body.

Karaganshy (J2kr) and Doshan (J2ds) of Jurassic system in Southern Turgay Basin are deposition of lake basin expansion period, mainly involving fan delta in short axis direction and deltaic deposit in long axis direction of the basin. Their main reservoirs are subaqueous distributary channel sand and point bar of delta or fan delta front subfacies, with lithology of sandstone and siltstone.

Seismogeological Characteristics of Channel Sand

Logging research indicates that channel sand shows the characteristics of box curve and positive cycle with bell-shaped. In the profile of vertical flow direction, the sand body has a semi-lenticular shape of flat top and convex bottom. The channel sand body in the area is characterized by high porosity, high permeability, low natural potential, low natural gamma and low density. Due to small scale and thin thickness are less than seismic resolution, the channel sand body owns the "bright spot" seismic response characteristics of "low frequency, high amplitude and short axis shape" (Figure 1), with the "bright spot" reflection characteristics of channel sand verified by forward model (Figure 2). The channel sand in Southern Turgay Basin is the typical type of mud covering sand, whose top and bottom formations are mudstone, and top and bottom reflection coefficients are nearly equal, with opposite polarity. Such "bright spot" reflection characteristics have no obvious distribution rules but great position changes in profile, which makes it difficult to directly judge the trend, scale and spatial distribution of channel; therefore, during research, it is required to find out the position of main channel and then seek the corresponding sand body according to channel types of various depositional environments.

Methodology and Application for Channel Prediction

According to depositional setting characteristics of formation, we use the idea of sequence stratigraphy to divide the research segment into many phases through stratal slicing technology, and then apply seismic attribute analysis, visual carving, spectral decomposition slice and other

technologies to research the plane and spatial distribution rules of channels in various phases, and perform qualitative or quantitative description.

Strata Slice

Strata slicing technology can approximately reflect isochronous deposition characteristics inside formation, with specific steps of making strata slice as follows: (1) Select isochronous seismic event as the top and bottom marker bed. During actual research process, select the reflecting layers of two isochronous interfaces completely covering objective interval generally ([Figure 3](#)). (2) Build stratigraphic model in time domain. Perform linear interpolation between marker beds according to the contact relations like parallel, baselap or toplap to build a stratigraphic model close to authentic stratigraphic unit. Interpolation shall follow the principle that the time window of each single layer shall be more than half of wavelength ([Figure 3](#)). (3) Build strata slice body. In stratigraphic time model, extract seismic attributes like reflection amplitude, reflected energy, coherence cube or curvature body from each strata slice of original 3D seismic body. Therefore, according to the seismic body, all strata slices represent the seismic response from geological plane in stratigraphic model in time domain (Zeng et. al., 1998; Zeng and Hentz, 2004).

In Southern Turgay Basin, we selected the reflection axis of two unconformity interfaces J3ak and J3km as an isochronous reference seismic event. It can be seen from strata slice analysis that J3ak channel develops in many phases from deep to shallow, with scale becoming larger, distribution migrating from north to south of work area, and mainly belonging to meandering river deposition. Seen from the plane, the channel has a stripped distribution with high amplitude, as well as multi-phase channel-superimposed continuous distribution in some areas.

Chronostratigraphic Interpretation

Our main idea is to apply theories such as high-resolution sequence stratigraphy, seismic stratigraphy and sedimentology to divide high-resolution sequence stratigraphic as well as prediction of sedimentary facies and reservoir. We integrated technical means like stratigraphic sequence division, waveform analysis, auto tracking of single layer, Wheeler domain (chronostratigraphic domain) conversion, seismic multi-attribute extraction and comprehensive analysis to find out the sequence interface development and spatial distribution of channel sand characteristics in whole work area.

The steps for Wheeler domain interpretation are: (1) Post-stack seismic processing: Apply structurally-oriented filtered technology to filter noise and improve the quality of seismic data; then obtain the data containing information about dip angle / azimuth angle after processing, thus for auto tracking of single layer; (2) Auto tracking of internal structural layers of sedimentary deposits, which provides data basis for establishing sedimentary rhythm body; (3) Converting seismic event to Wheeler domain, which can realize conversion from seismic profile to geological profile, then identify sequence interface, normal or inverse cycle, system tract, etc., thus further sequence stratigraphy analysis can carry out; (4) Sedimentary facies and microfacies interpretation: Extract time slice from Wheeler domain to perform analysis and interpretation of sedimentary facies and sedimentary microfacies on important single layers.

According to the results of regional sedimentary facies research, the stratigraphic sequence is divided in this area. Sequence Sb2 is fluvial deposition and Sequence Sa1 is delta deposition (Figure 4). Extracting energy attribute from single layers of Sequence Sb2 can help to clearly identify channel, flood plain, flood fan and other sedimentary subfacies (Figure 5). Channel deposit shows typical linear strong energy characteristics on planar graph, while flood plain is characterized by low energy, but flood fan is also characterized by high energy, distributed in small fans and developed at both sides of main channel, which can further identify the sand bank formed by river island, marginal bank and other sedimentary microfacies; such microfacies have higher energy and develops in the center of channel or the convex bank of channel bend. Sequence Sa1 is of delta deposit (Figure 6) and the deposition in underwater distributary channel and estuary dam of delta can be identified from seismic attribute of single layer.

3D Visualization

3d visualization involves three steps in detail. (1) Browse 3D data cube of study area and predict the distribution rules of channel. It can be seen from browse and analysis that many sets of abnormal reflection of channel sand exist in research area, and multi-period channels from shallow to deep are developed there, which become smaller and migrate from north to south in the study area. (2) Use sub-particle separation technology to perform channel carving. Through control over color, saturation and illumination, select proper time window along marker bed, and strip off all channel sand bodies for delicately carving the spatial distribution of all sand bodies. (3) Use amplitude or geological body thickness picking to perform quantitative prediction of channel sand. Then, apply visualization tool to pick up seismic amplitude to describe channel sand with quantitative prediction. During exploration and development stage, well proposal can be suggested after using such method to improve drilling success rate, and thus providing basis for development program design and demonstration (Ran et. al., 2004).

Visualization of J3ak data in the study area shows that the abnormal large amplitude reflection characteristics of channel are obvious (Red-green refers to strong amplitude in Figure 7) and superimposed with each other. Through visualization on seismic data cube, attribute separation and sub-particle carving, it can delicately describe the spatial distribution rules of channels and confirm the sand body of 24 channels, and make clear that the sand body has an area of 26.6km^2. KK45, KK63 and KK79, the three wells drilled on channel have all obtained industrial oil flow and the predicted thickness of main channel is perfectly consistent with the actual drilling result, only having a thickness error of 1-3m.

Spectral Decomposition

Spectral decomposition technology refers to a processing technology that transforms seismic data from time domain into frequency domain to obtain amplitude spectrum and phase spectrum-tuning cube through short time window Discrete Fourier Transform (DFT). Amplitude tuning cube is mainly used to estimate the thickness of thin bed, which can improve the resolution ratio of thin bed to formation with less than a quarter-wave length. The specific steps are: (1) Use DFT to generate full-band tuning data cube; (2) Browse frequency slice in combination with regional sedimentary characteristics to analyze sedimentation type and identify the structure and mode of geologic body during deposition, to predict the distribution of channel. (3) Use frequency body to predict thickness of sand body according to Rayleigh criterion.

In WB area of Southern Turgay Basin, Cretaceous Mii (Figure 3, lower part of K1) is a set of glutenite reservoir of fluvial facies, with top and bottom surrounding rock of brownish red and grayish-green mudstone, showing "bright spot" reflection on seismic profile. On spectral slices, strong amplitude of Cretaceous Mⅱ is stripped (Figure 8), which shows fluvial facies characteristics and is of straight river with low bend, indicating that this area lies in the upstream of river with flat topography and the river were lying in low-lying areas between two mountains. In Figure 8a, red-yellow-green stands for the thick sand corresponding to strong amplitude, while bluish violet is weak amplitude, indicating thinning of sand. Several frequency slices used have predicted that Mii developed 12 rivers with an area of 35.7km^2. Then apply Rayleigh criterion to perform quantitative prediction (Xu et. al., 2006) on Mii reservoir thickness (Figure 8b and 8c, and Table 1). The error between predicted sand thickness and drilled thickness is minor (about 0-3m), the predicted thickness of well WB9 (Figure 8b) is identical with that of drilling; the predicted thickness of WB2 and WB3 wells bears an error of 1m with drilling; for WB24, the error is 3m.

Conclusions

After making clear the structure and depositional setting of sedimentary deposits, the position and distribution rules of channel sand can be determined more accurately. After objective analysis on the quality of seismic data, specific technology used for post-stack processing can ensure more reliable prediction result. Spectral decomposition technology can better carve the distribution of channel and boundary characteristics of sand, which provides an effective way to conduct quantitative prediction on thickness of thin sand under the condition of no wells. The development of reservoir identification and prediction technology from time domain to frequency domain and then to chronostratigraphic domain has greatly improved the capability of solving complex geological problem.

Acknowledgements

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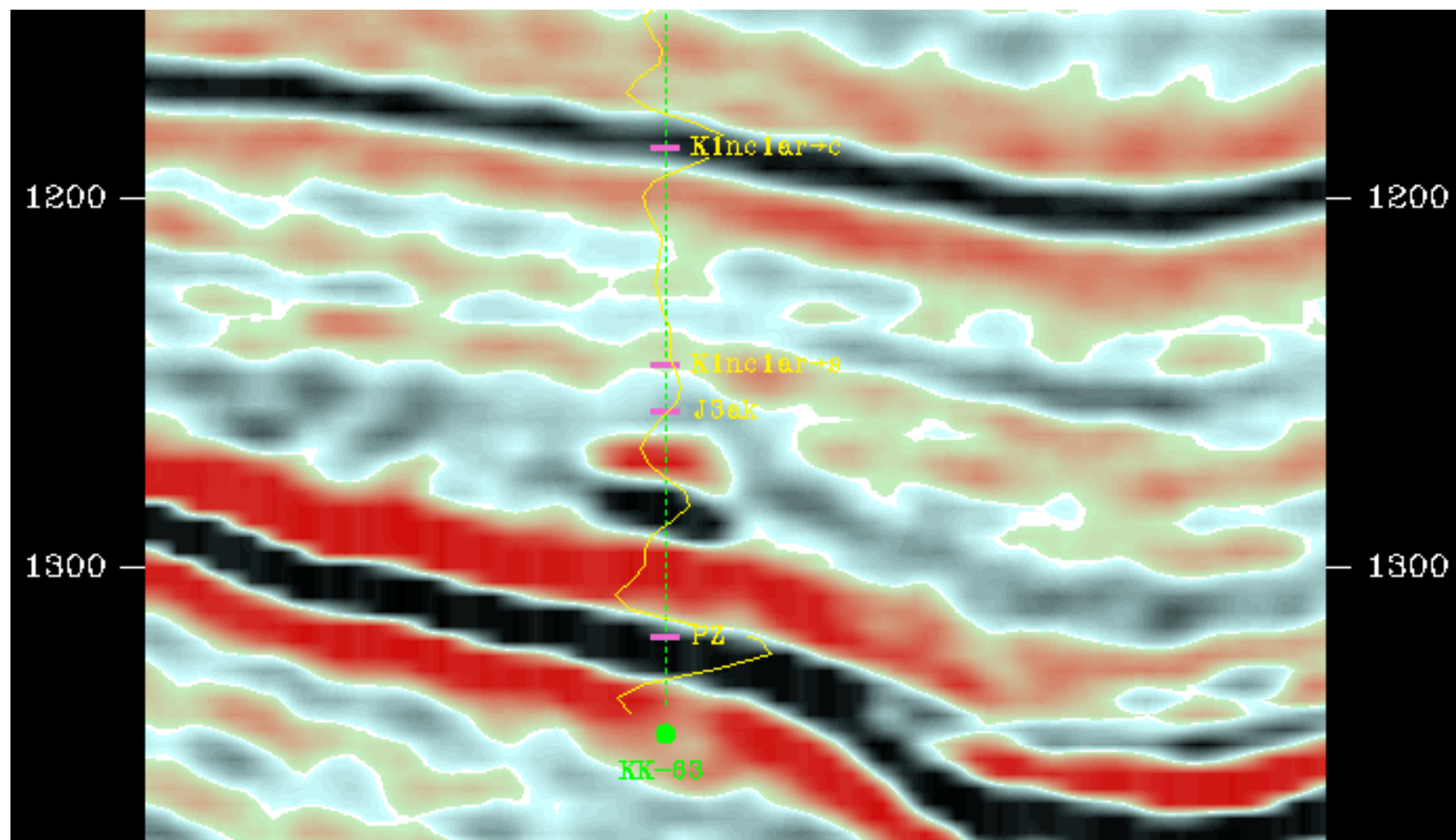
Figure 1. 'Bright spot' of channel sand showing on the seismic section has highlight reflection energy.
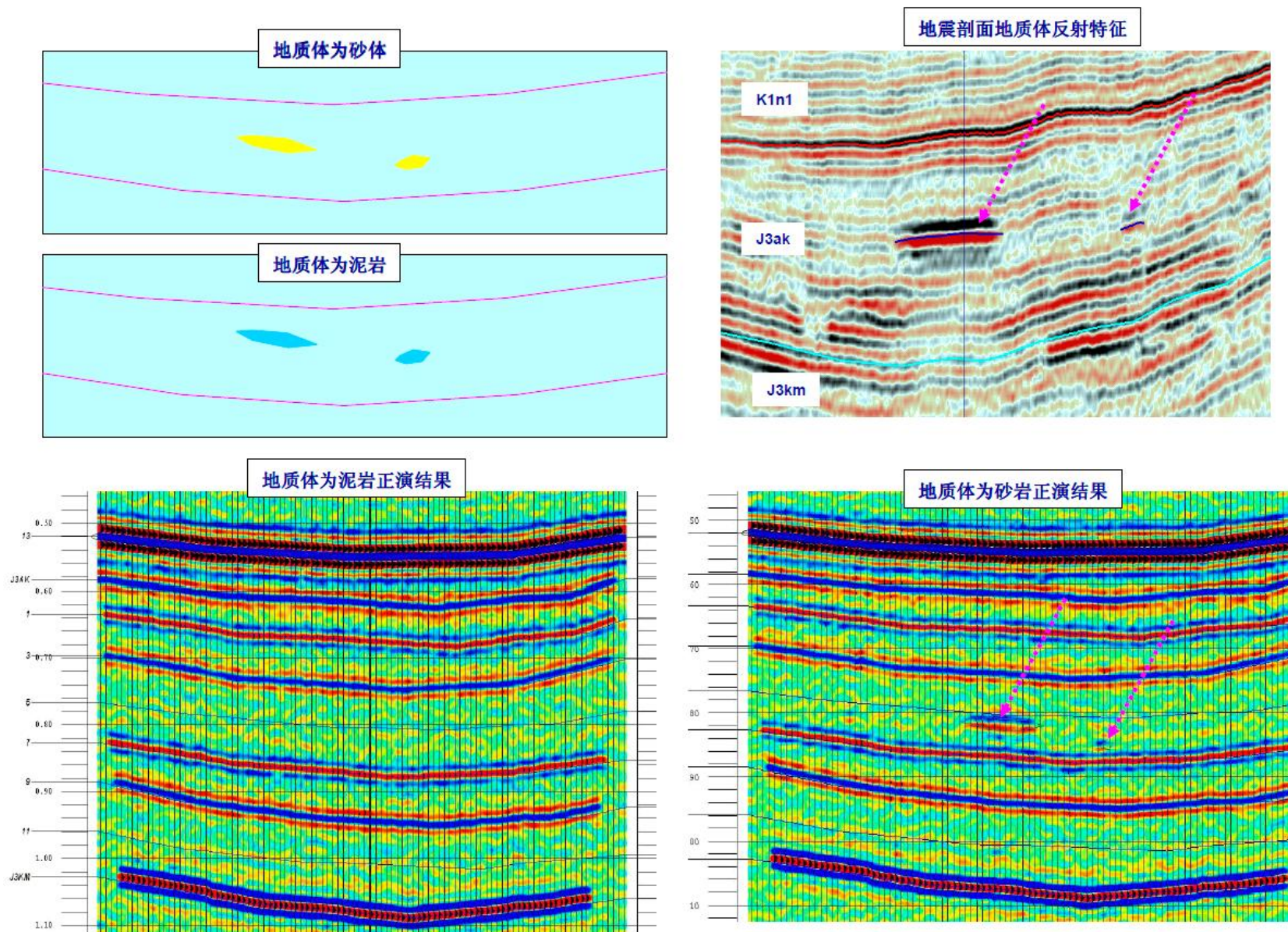
Figure 2. Forward models with different lens property are showing different results. In research area, sand lens body in J3ak strata has typical reflection character like bright spot and this kind of characteristic were used to find new channel sand.
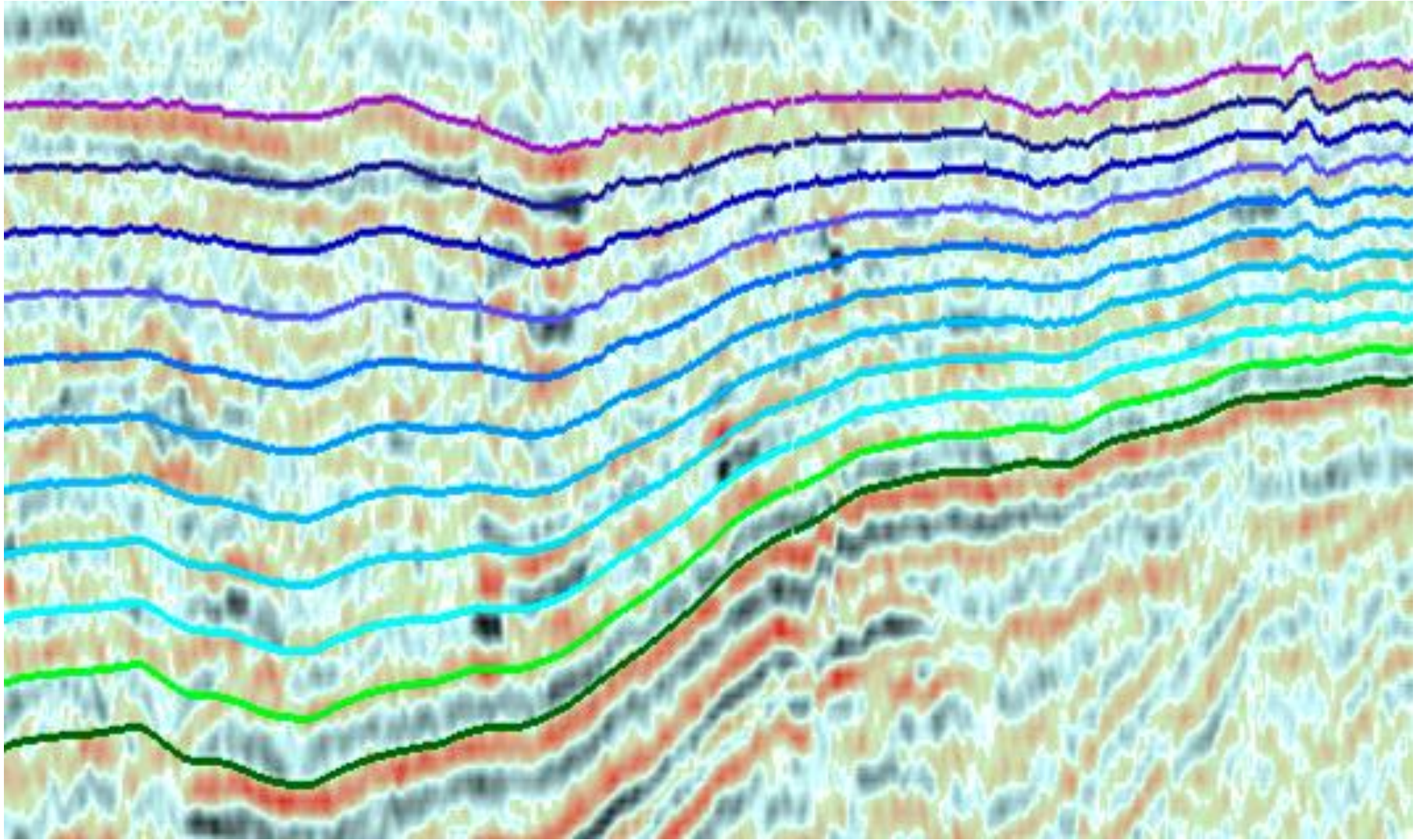
Figure 3. Achieving strata slice from seismic volume. Choose two horizons to control the slice window. In this area, J3ak as top isochronal horizon and J3km as bottom isochronal horizon were choose.
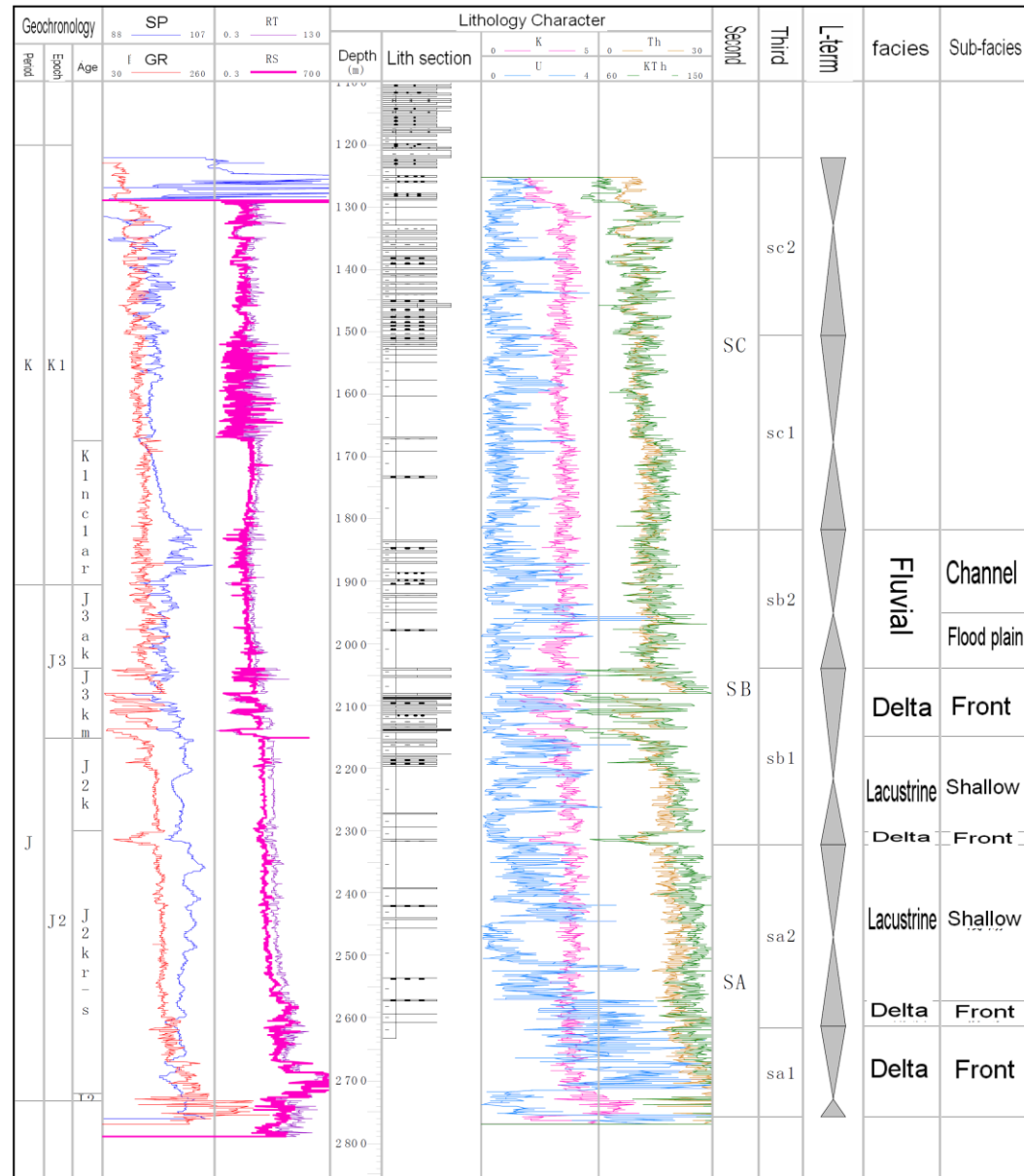
Figure 4. Sequence and Sediment Columnar Section for research area according to Well analysis.
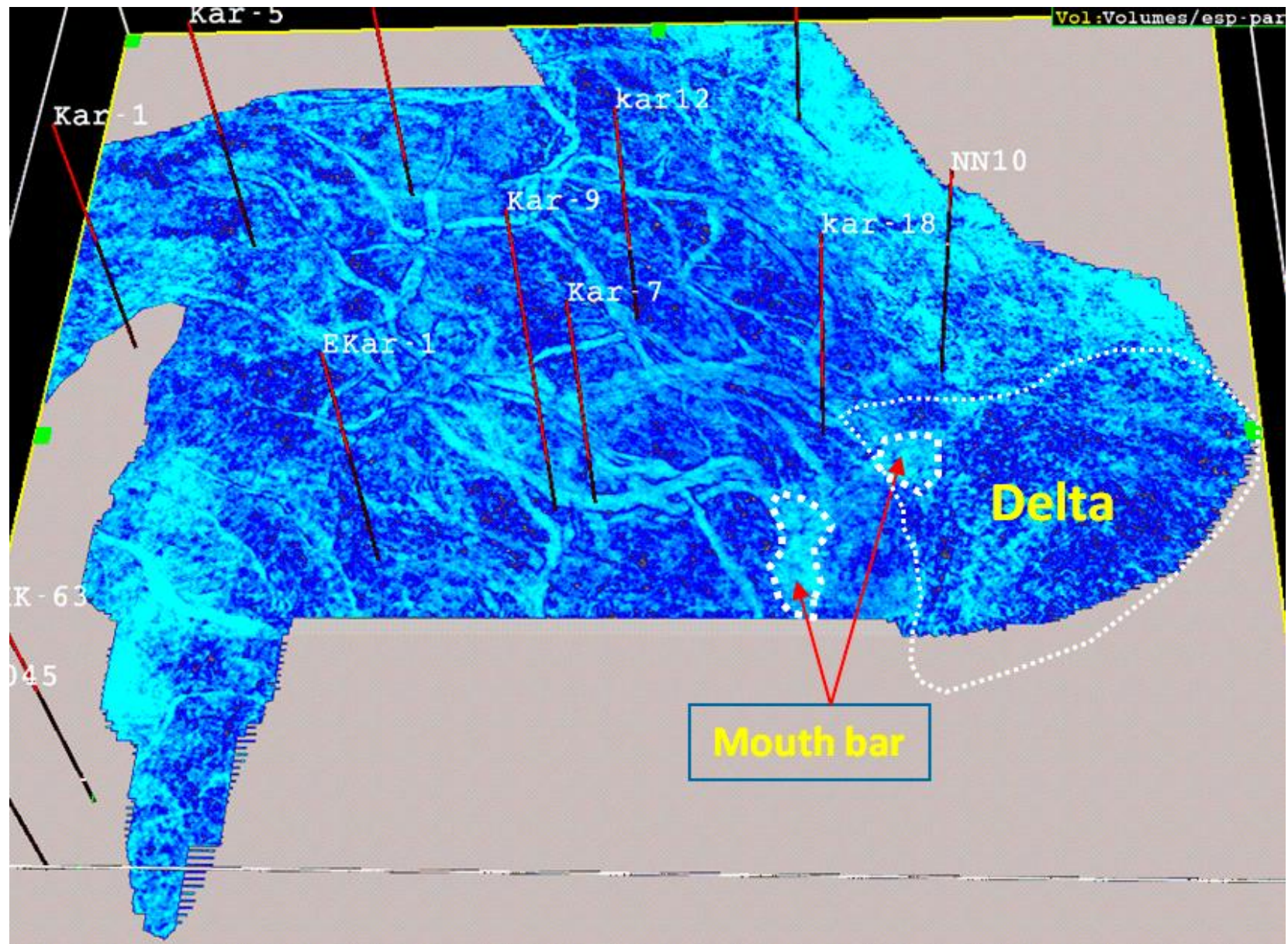
Figure 5. Energy attribute from single layer of sb2 sequence. Linear figure showing on is channel.
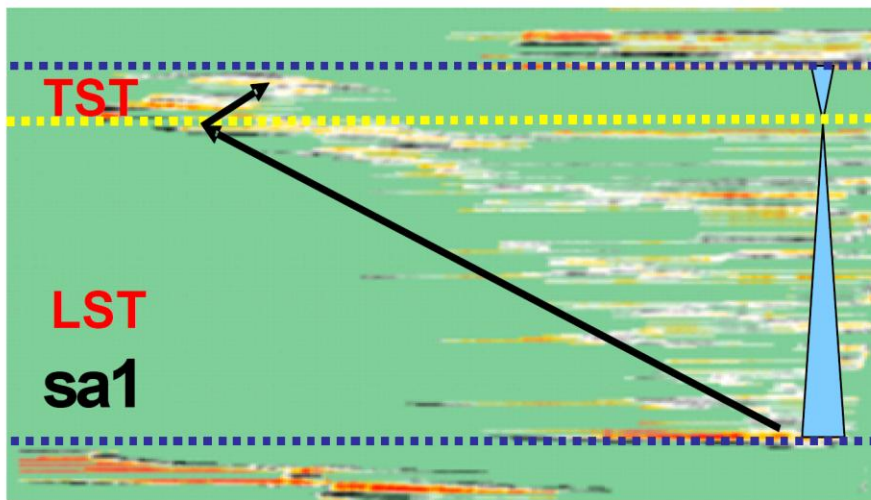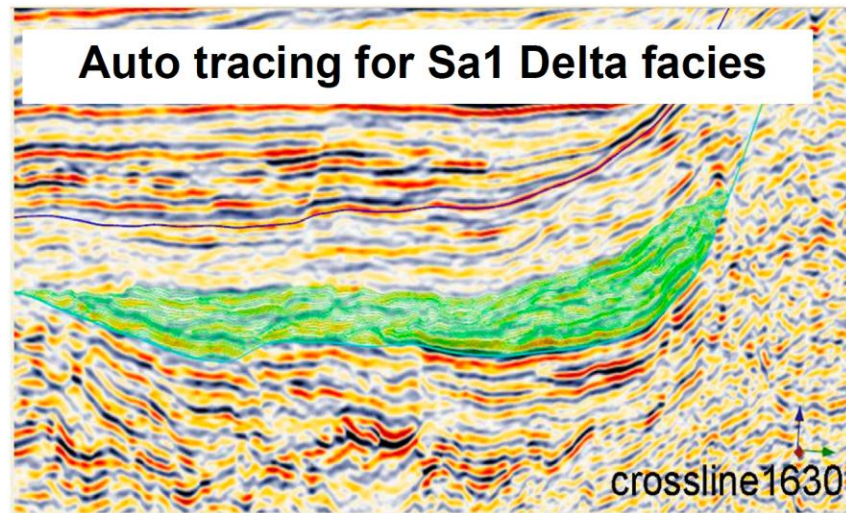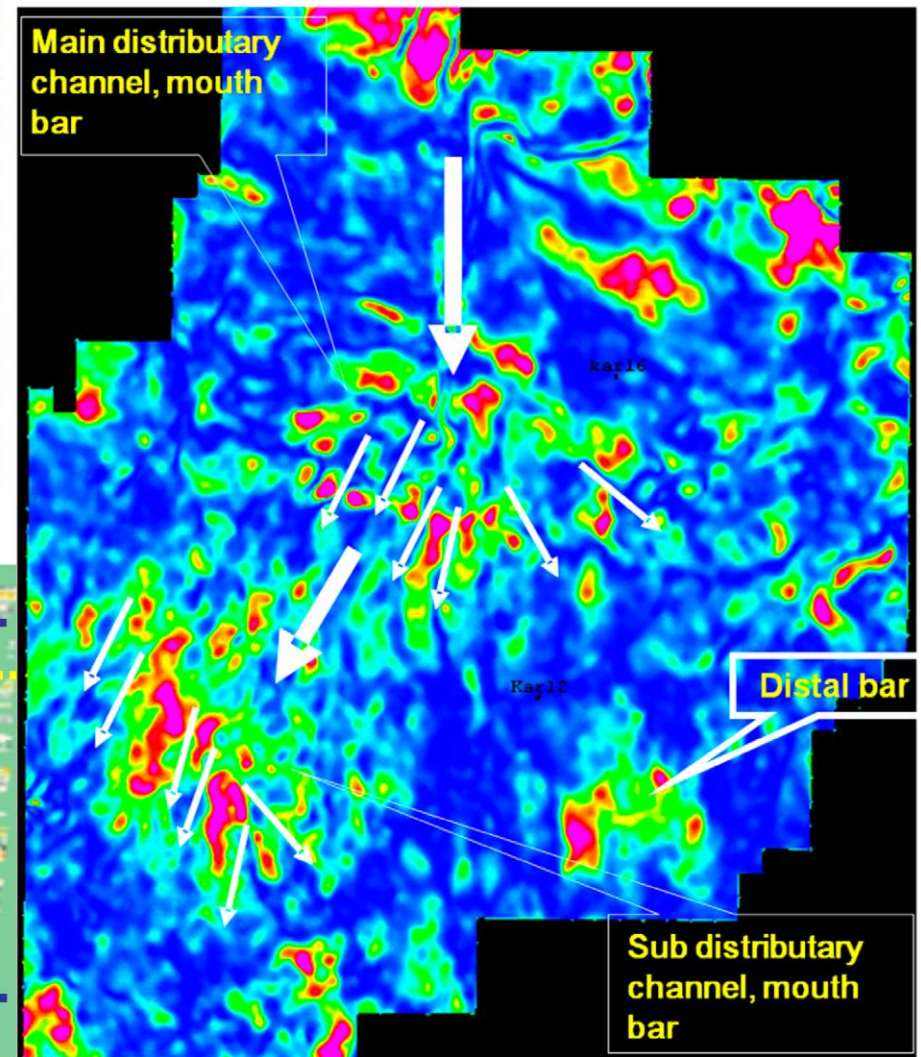
Figure 6. Chronostratigraphic method used to recognize the facies and sand distribution character in southern Turgay basin. During with wheeler domain interpretation, more details of the inner characters of sequence sa1 can be identified.
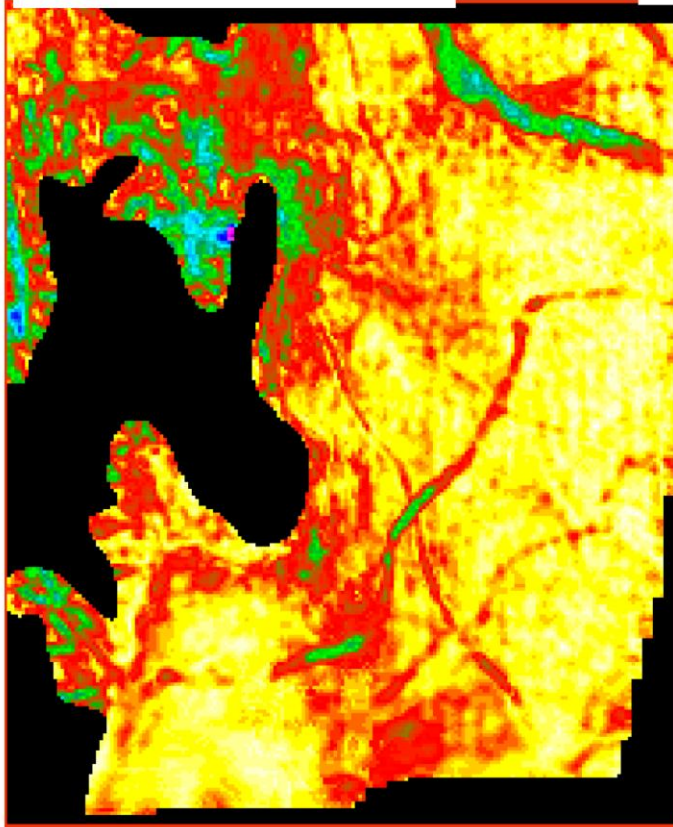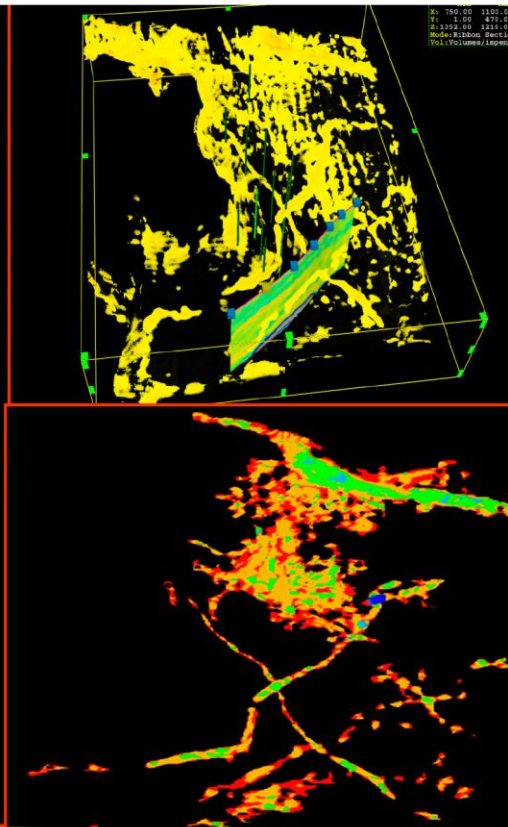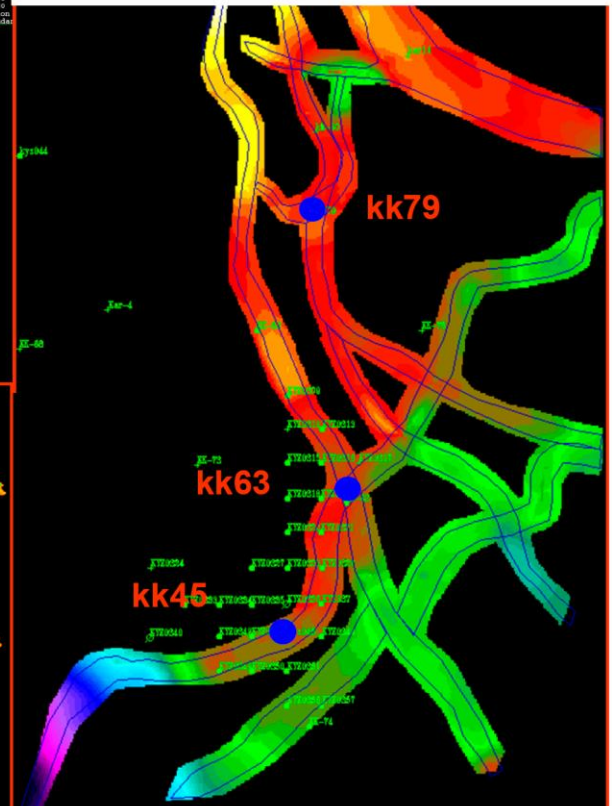
Figure 7. A. Showing reorganization of sand channel by sensitive attribute. B. Using 3D visualization method to carving them. C. Identify the channel's area and main channel's wide approximately.
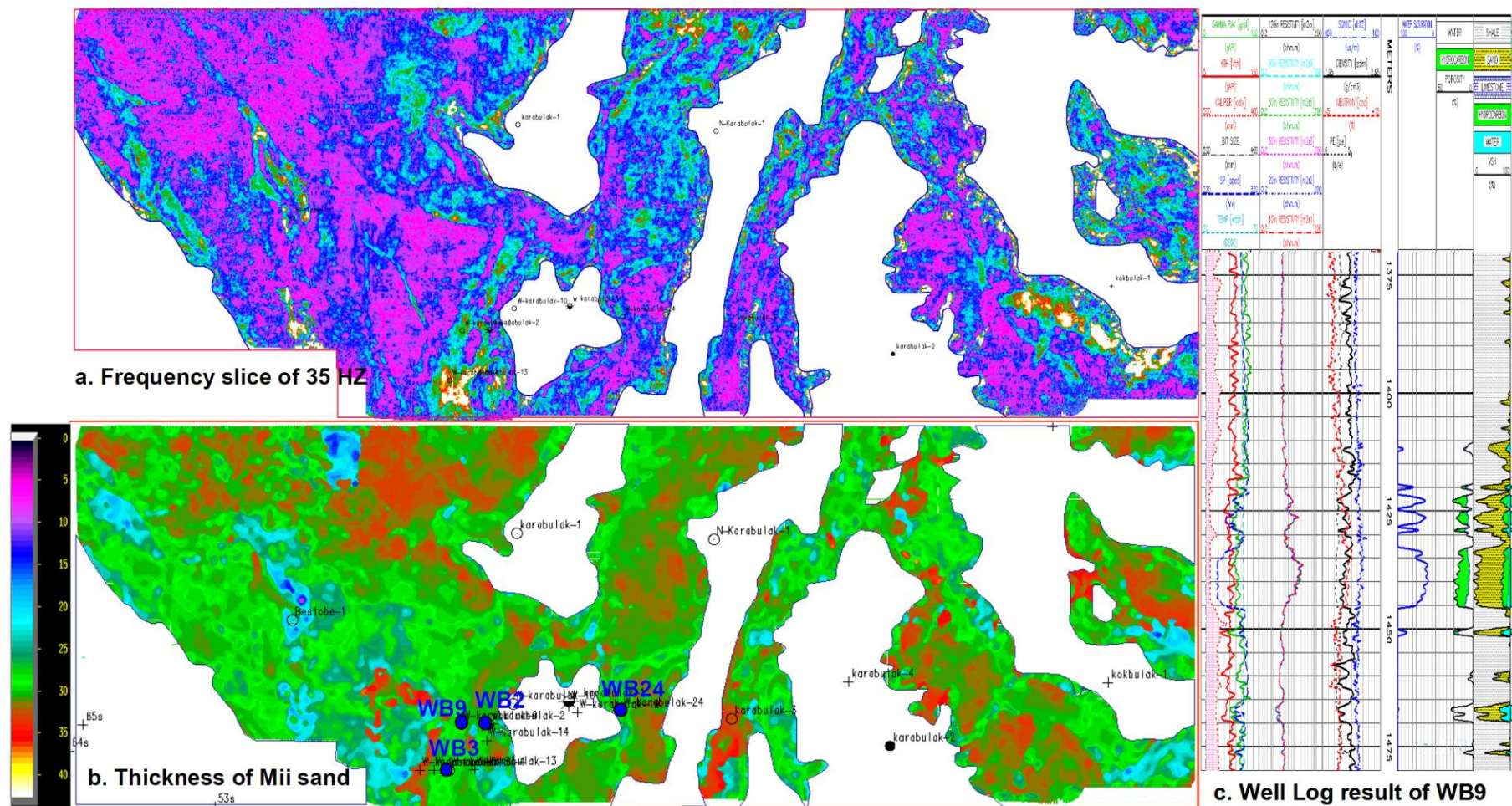
Figure 8. A. Frequency slice of 35HZ at WB area is showing detail shape and boundary of channel. B. Thickness of Mii sand is derived from frequency slice with Rayleigh criterion. The color bar shows that different color instead of different thickness. C. Well log interpretation result for WB9 show the drilled thickness of Mii sand.

Well Name	Drilled Thickness(m)	Predict Thickness(m)	Error(m)
WB2	28	29	1
WB3	28	29	1
WB9	29	29	0
WB24	13	16	3

Table 1. Thickness compare between drilled and predict for example wells in WB area.