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Stratigraphic characterization of a fluvial reservoir using seismic attributes and spectral decomposition: An example from the Northern Malay Basin

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Abstract

The addition of new reserves from mature basins such as Malay basin requires a stratigraphic approach that encompasses locating subtle stratigraphic traps and improving the reservoir characterization of the producing fields to deliver more production. Seismic attributes controlled by well information and aided by many interpretation and visualization tools can provide a lot of geological and stratigraphic information from a 3D seismic volume. In this study, a number of seismic attributes that has a demonstrated ability to delineate stratigraphic elements and lithological variations have been applied to investigate the stratigraphic architecture and sand distribution of an Upper Miocene reservoir in an undeveloped field, Northern Malay Basin. The interpretation of the attributes (i.e. spectral decomposition, coherence, RMS amplitude, and sweetness) along with the fluvial geomorphology analysis indicated that the reservoir interval is a meandering fluvial system. Fluvial depositional elements that include channels, point bar, scroll bar, and crevasse play have been interpreted. The Sweetness attribute highlighted high amplitude anomalies related to the sand-prone depositional features. These anomalies interpreted as hydrocarbon sweet spots.

Keywords: *seismic attributes; spectral decomposition; reservoir characterization; fluvial reservoirs.*

1. Introduction

The Northern Malay Basin is a prolific gas region. Most of the fields are non-associate gas fields. The coal and coaly shale gas-prone is the main source rock in the area. The main producing strata are of Middle Miocene to Lower Pliocene age, namely E, D, and B stratigraphic groups. These sequences are characterized by thinly-bedded sand reservoirs along with a remarkable occurrence of coal in group E [1].

In the past, the interpretation of the subsurface was largely controlled by the existing geological models. This was due mainly to the limited resolution and quality of the data. The continuous development of the 3D seismic data quality in the Malay Basin made it possible to obtain robust interpretation for the subsurface. The seismically-driven geological interpretation considerably impacted the hydrocarbon exploration and production in the area. It is possible now, by using many interpretation methods and visualization techniques to understand the reservoir compartmentalization and external geometry, predict the sedimentary facies and pore-fill, and image the depositional evolution of a reservoir.

The area under investigation is an undeveloped gas field, located in the Northern Malay Basin. It is a faulted anticline, has gas discoveries in several reservoir intervals along with minor oil in group E. reservoir heterogeneity due to the stratigraphic complexity is the main challenge in this field, in addition, the presence of coal layers in group E, that interferes seismic signal and affects lithology and hydrocarbon prediction.

This study examined the depositional architecture and facies distribution of B100 reservoir of an undeveloped field, Northern Malay Basin. It is an Upper Miocene reservoir interpreted to be deposited in a fluvial environment.

A number of seismic attributes that has a demonstrated ability to delineate stratigraphic elements and lithological variations have been applied. The analysed attributes (i.e. spectral decomposition, coherence, RMS amplitude, and sweetness) showed that the reservoir is a complex meander fluvial system and the gas charge is mainly associated with the sand-prone fluvial facies such as point bar, channel-fill, and crevasse splay.

2. Geological setting

The Malay, offshore Malaysia, is a northwest-trending rift basin, developed by extensional tectonic along a shear zone during the early Tertiary (Figure1). This tectonics is believed to be related to the collision of the Indian plate with the Eurasian plate [2]. After the rift phase, the basin underwent a thermal sagging followed by a structural inversion. This structural inversion has created a series of anticlinal traps and half-grabens [1]. The Northern Malay Basin encompasses three structural trends, centre, west and east flanks. The centre is characterized by thick Tertiary section and steeply dipping basement faults, whereas the flanks are relatively gently dipping towards the centre, with a few major normal faults and half-grabens [3].

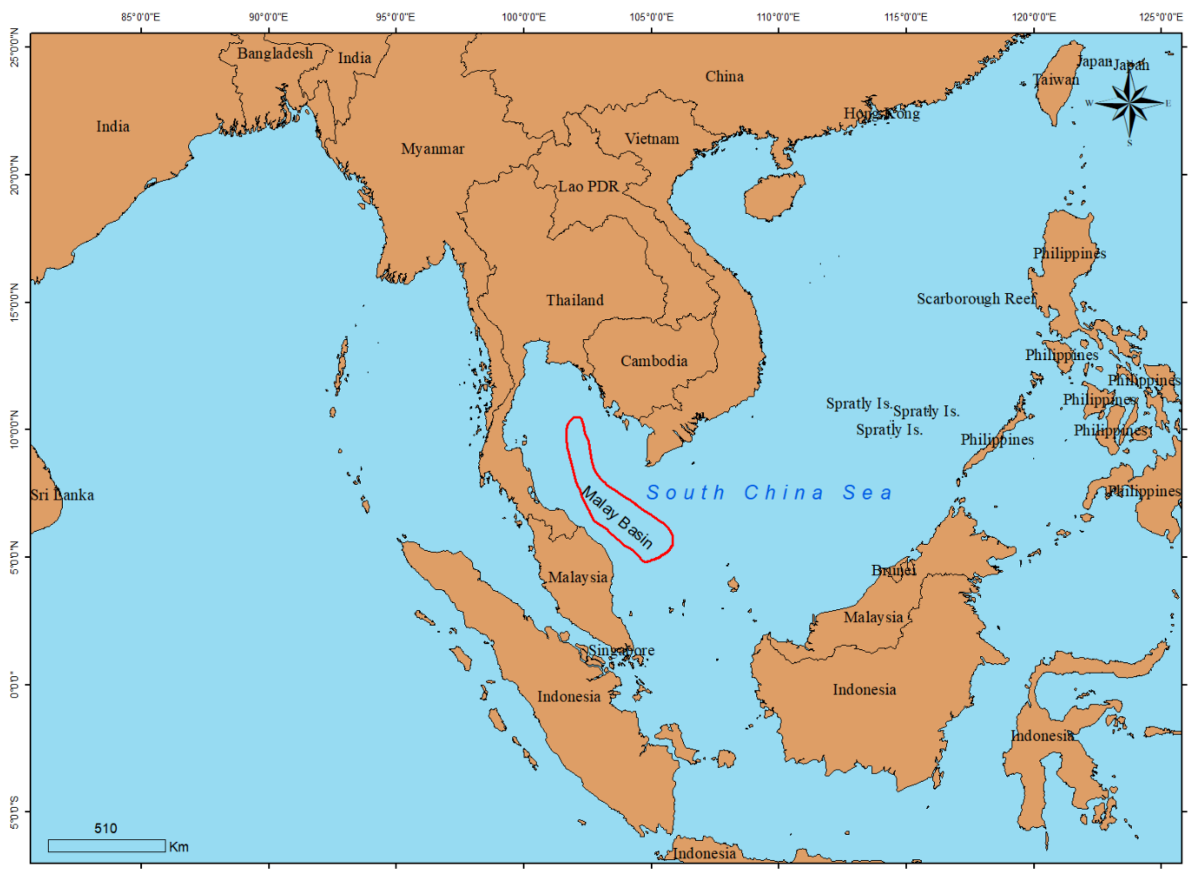


Figure 1. The location map of the Malay Basin. It is located offshore the peninsular Malaysia in the South China Sea

The field under investigation is located in the central structural domain, namely Cakerawala-Bujang trend (Figure2). The stratigraphy of the basin is from Oligocene to Recent. Based on seismic stratigraphy and biostratigraphy, the stratigraphic scheme of the basin is divided alphabetically, the older M to the younger A [4] (Figure3).

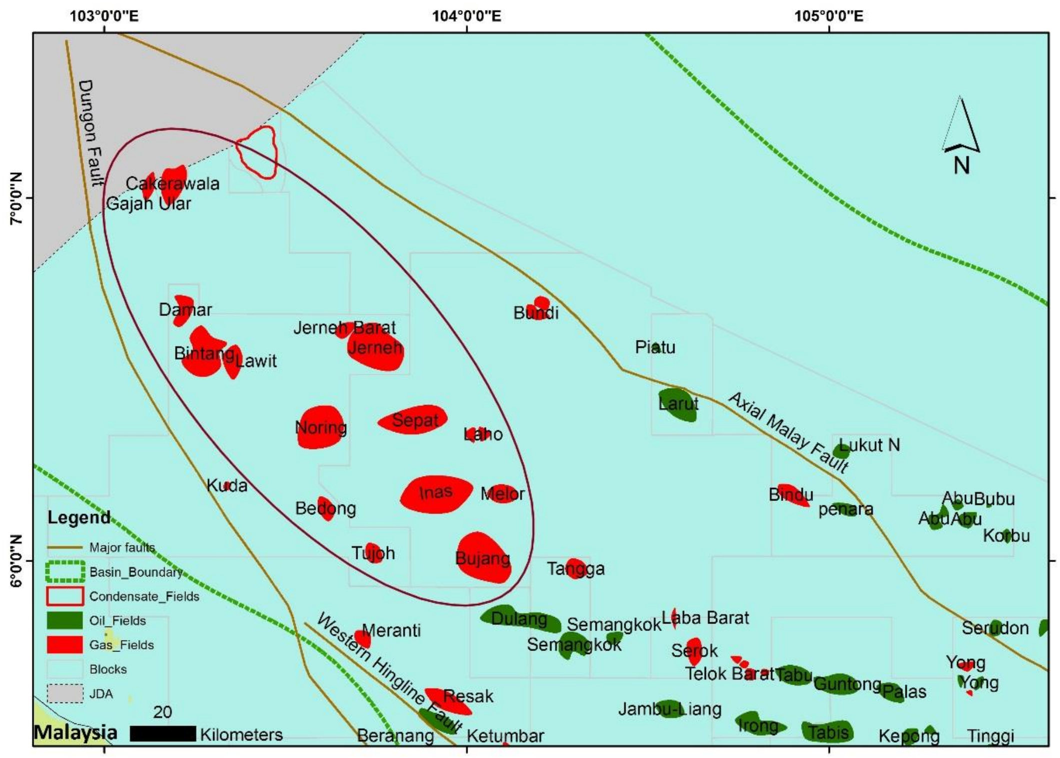


Figure 2. Location map of the Northern Malay basin. The field under study is located in the basin central part, namely Bujang-Cakerawala trend (dashed oval). After Madon et. al. [8]

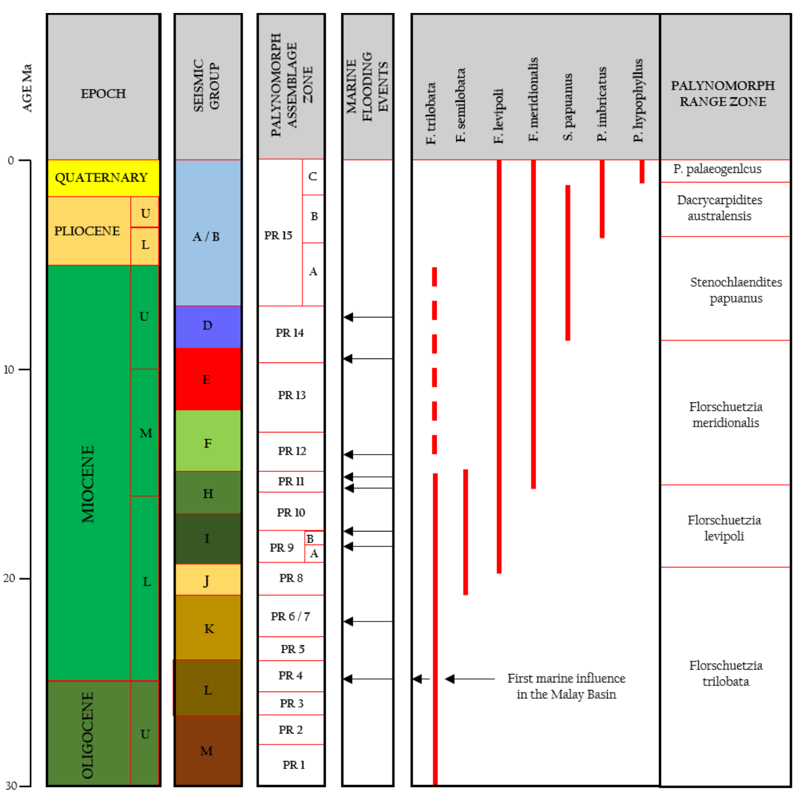
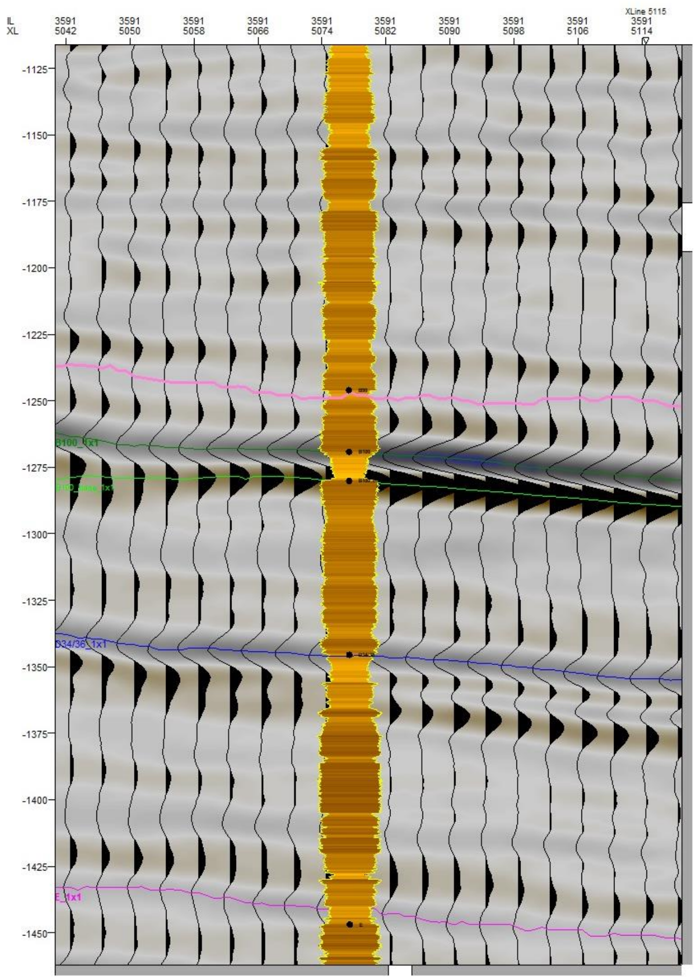


Figure 3. Stratigraphic scheme of the Malay Basin. The seismic groups correlated to the main palynomorphs assemblage zones (PR). The marine flooding events are also indicated. After Madon et. al. [8]

The petroleum system elements of the Northern Malay Basin include a mature and effective source rock (coal and carbonaceous shale) of group H and I that provide the hydrocarbon charge to reservoirs in E, D, and B groups. The hydrocarbon in the Northern Malay Basin is mainly gas, being trapped in the stratigraphically shallower units, E, D, and B. this is possibly due to the regional overpressure seal in the below group F. These reservoir sequences are interpreted to be deposited in continental, coastal, and shallow marine environments [1].

3. Methodology



A full-stack 3D seismic cube covering 400 km^2 and eight wells have been utilized in this study. The B100 reservoir ranges in two-way time between 1150 and 1600 ms. The top of the reservoir was picked on a strong trough that has been tied to the well-defined stacked gas sand characterized by a sharp base on gamma-ray (Figure 4). The horizon was auto-tracked and interpolated into continuous surface for attribute extraction (Figure 5).

Figure 4. The top of the reservoir is tied to a well-defined gamma ray fining-upward parasequence at Well-8

←

3.1. Seismic attributes generation

This study integrates many seismic attributes that have a proven capability to delineate stratigraphic features and lithological variations. Coherence, RMS amplitude, and sweetness were generated and analysed in this study.

Coherence or variance attribute is a post-stack seismic attribute that measures the similarity between seismic waveform in a specified interval [5]. The coherency of a 3D seismic cube is done by computing local waveform similarity in different directions. The geological discontinuities such as faults, fractures, and stratigraphic boundaries are characterized by low coherence. The quality of the generated coherence map is largely affected by signal-to-noise ratio, static and stacking velocity errors [6]. Coherence attribute map was used to highlight channels edges and map the morphological variations.

RMS amplitude attribute calculates the root mean square (RMS) of single-trace samples T[i], over a user-specified vertical window with a length of n samples, for each sample in an input trace [5]. Sweetness attribute is the ratio between response amplitude and RMS response frequency. Strong amplitude anomalies of sweetness attribute are interpreted as good quality reservoir spots whereas clay rich areas are characterized by low amplitude [5]. RMS amplitude, reflection strength and sweetness attributes have a popular application as reservoir quality and fluid indicator and for channels detection in the Malay Basin. Gas-prone channel sand usually has strong anomalies, whereas the floodplain and the mud-filled channels have weaker response [7].

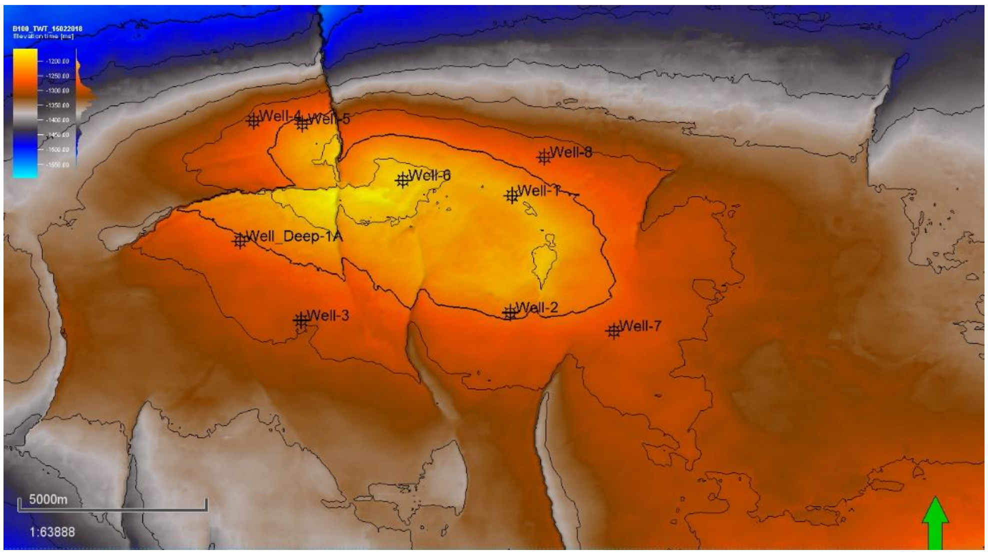


Figure 5. Time structure map of top B100 reservoir, showing an anticlinal structure crossed by numerous faults

3.2. Spectral decomposition and colour blending

Spectral decomposition is an efficient geophysical method for seismic geomorphology and reservoir characterization. It is a time-frequency analysis aims to break down the seismic trace into band-limited frequencies to highlight specific geological features [8]. The methodology followed for spectral decomposition includes extracting a sub-seismic volume (500 ms) for the zone of interest from the whole survey, Frequency selection is a crucial step in spectral decomposition. In order to get the best RGB color combination for imaging different geological variations, the frequencies of the red, green, and blue bands must be tuned and optimized. Frequency selection was performed interactively over the zone of interest and discrete frequencies of 25, 35, and 45 Hz were chosen for red, green, and blue channels respectively (Figure 6).

3.3. Iso-proportional slicing

Iso-proportional slicing also known as stratal slicing is an imaging tool that employed to generate attribute maps between two reference horizons [9]. Stratal slice is aimed to overcome the limitations of the time and horizon slices when the strata are not sheet-like or flat-lying. This method linearly samples the seismic attribute between two reference horizons in an equally-spaced interval to generate seismic attribute maps on phantom surfaces [10]. Four slices were extracted from all the generated attribute volumes to delineate channel bodies and their associated depositional features, predict lithology, and to carry out morphometric measurements of the channel width, depth, and sinuosity (Figure7).

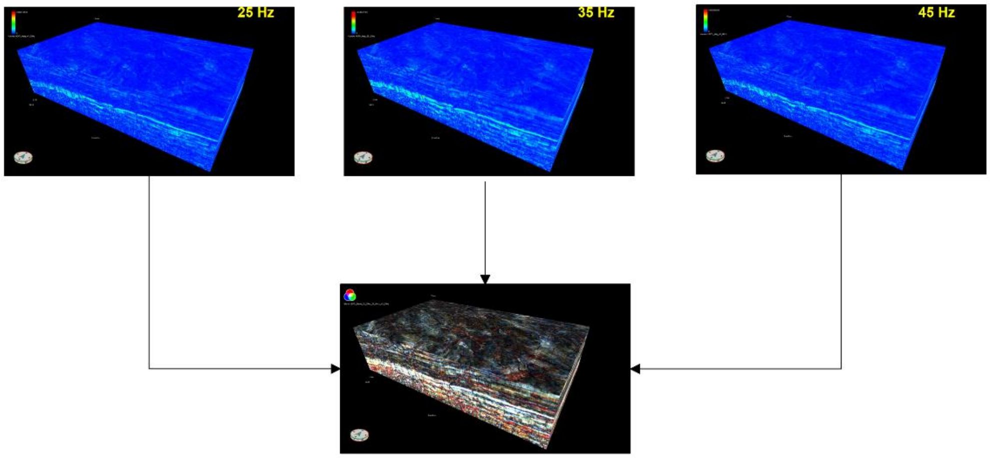


Figure 6. Spectral decomposition of a 500ms sub-volume at discrete frequencies of 25, 35, and 45 Hz. These volumes were combined together into an RGB color blended volume

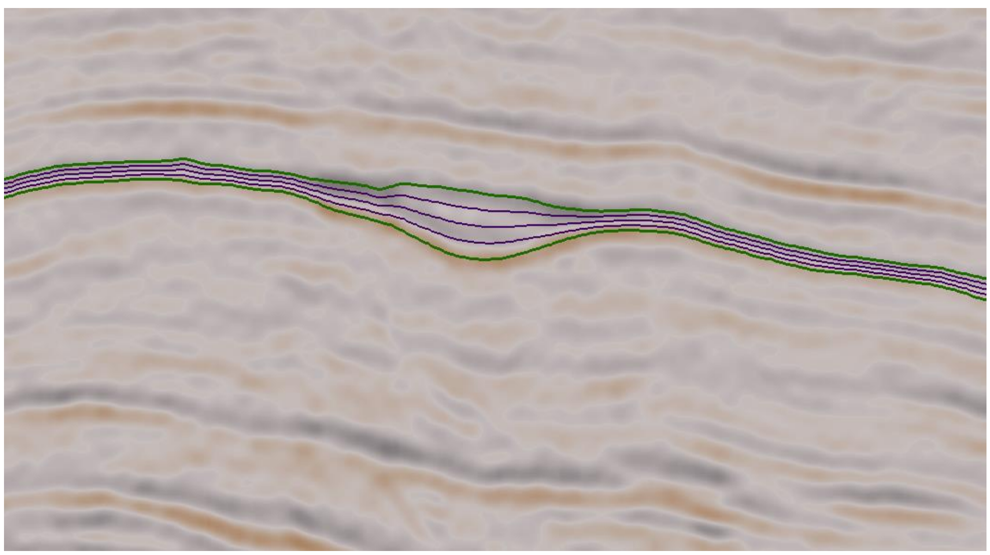


Figure 7. Stratal slicing process. It is a linear sampling of the seismic attributes between two reference horizons in an equally-spaced interval to generate seismic attribute maps on phantom surfaces

4. Results and discussion

Many details about B100 reservoir external geometry and the internal architecture have been obtained by the generated seismic attribute maps. On the basis of seismic geomorphology and well information, many features that related to the meander system were highlighted and different facies and geometries were interpreted. These maps showed that the reservoir interval is occupied by meander channel system. Stratal slicing is a very useful interpretation and visualization tool that aimed to provide a more precise representation of the stratigraphic elements and the depositional history interpretation. Four slices have been generated through B100 reservoir interval to study the stratigraphic evolution and channels development. The observed fluvial features include meandering channel, meander belt, meander scrolls, low sinuosity channel, point bar, abandoned channel, crevasse splay and so on Figure 8

A typical meander system is clearly visible in the RGB blended map. A large meander belt is present in the SE part of the area with meander radius about 500m. Meander scrolls are clearly visible within this belt indicating a lateral channel migration through time. The low amplitude response of the channel-fill is most probably due to the presence of mud, nevertheless, meander scrolls and point bar have a higher amplitude response indicating deposition of sand. Small incised tributary channels that feed the major meander belt are also observed. A meander loop exposure in the north-central part, containing 3 to 4 adjacent point bars was highlighted on the map. Isolated scattered point bars in the central part of the area can be seen as well. Floodplain crevasse splays are observed in the central part of the area. They are common in numerous fluvial environments and characterized by thin sand layers as confirmed by wells.

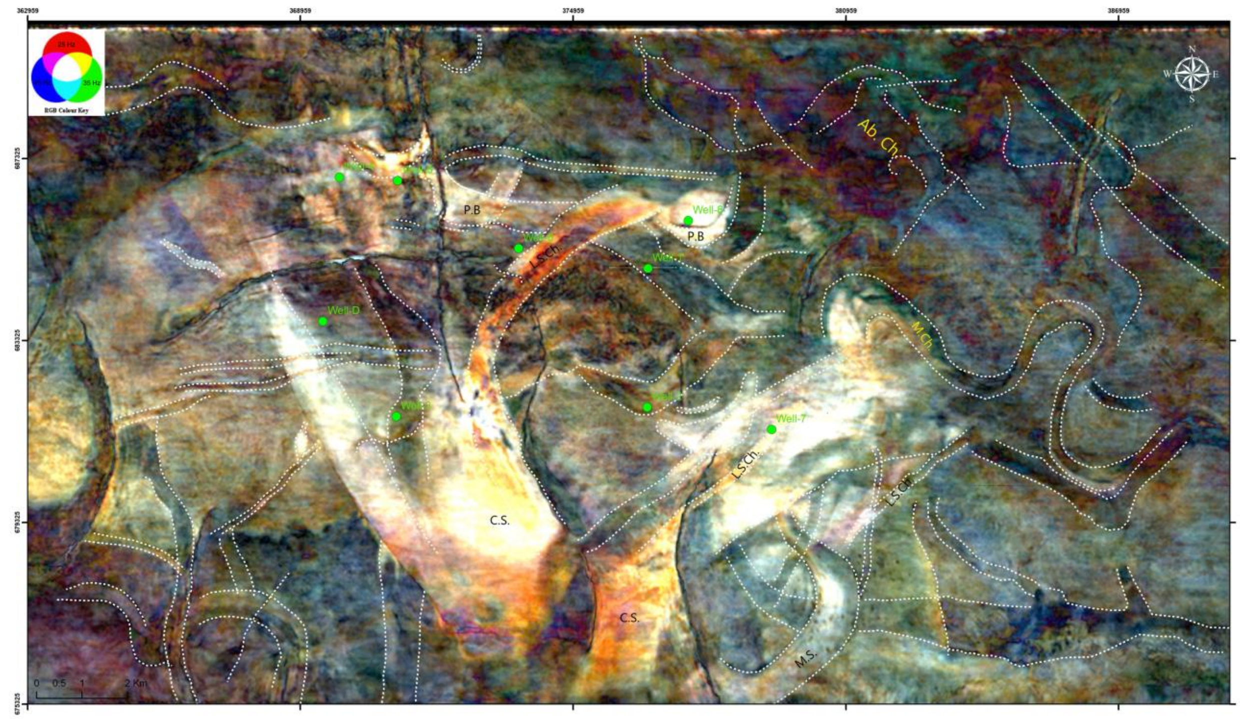


Figure 8. Stratal slice map of B100 reservoir on an RGB color composite volume. Frequencies of 25, 35, and 45 Hz were selected and blended into an RGB colour composite volume to image the zone of interest. The interpreted fluvial depositional elements include: ((M.Ch=meandering channel, L.S.Ch.=low sinuosity channel, P.B.=point bar, C.S.= crevasse splay, M.S.= meander scrolls, Ab.Ch.= abandoned channel)

The RMS amplitude and sweetness attributes were utilized to detect the sand distribution that related to channels and its depositional elements. Several high-amplitude anomalies over B100 reservoir interval were highlighted. The well data confirmed that these amplitude anomalies might be related to gas-charged sand bodies Figure 9. The attribute maps also showed that the sand distribution and hydrocarbon occurrence are very patchy due to the stratigraphic nature of the meander system. Most of the drilled wells were not in optimum locations to this hydrocarbon target. Mud-filled channels showed very weak amplitude response.

5. Conclusion

Seismic geomorphology has proven to be a very powerful interpretation tool. The produced highly detailed attribute maps with the aid of stratal slicing and visualization tools were capable to map and delineate B100 reservoir architecture. The generated attribute maps revealed that the B100 reservoir interval is predominantly occupied by a fluvial meandering-rivers system. RMS amplitude and sweetness attributes controlled by well information were used to highlight the reservoir sweet spots where good sand and probably hydrocarbon occur. This analysis showed that the drilled wells were not in the optimum location to test the hydrocarbon in this interval. The result of this study must significantly improve our knowledge and understanding and help to predict reservoir quality and lead to an accurate wellbore placement in the future.

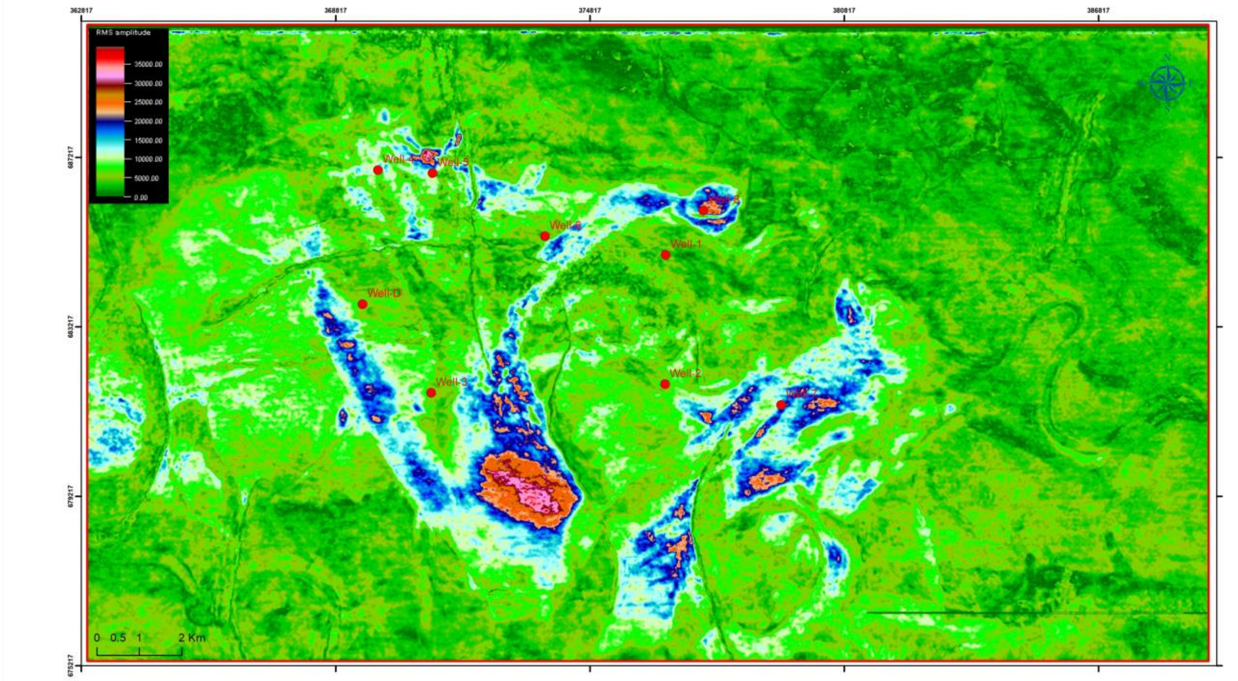


Figure 9. Sweetness attribute map of B100 reservoir, showing high amplitude anomalies and patchy distribution related to the sand-prone facies

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