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THE EVOLUTION OF CHANNEL SYSTEM IN THE NORTHEAST MALAY BASIN, TERENGGANU OFFSHORE

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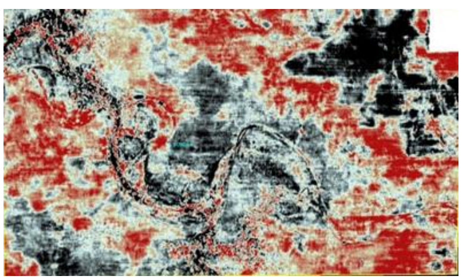
Graphical abstract



Abstract

This study aims to evaluate the evolution of the channel system in the Pleistocene-Recent succession in the northeast Malay Basin based on channel morphologies. The variable types of channel morphologies were determined from seven seismic time slices of study area. The fluvial channel became wider and low-sinuous when the sea-level rise. Meanwhile, the fluvial channel became narrower and high-sinuous when sea levels decreased. The point bars are seen in the meandering curve of the high-sinuosity channel. This occurred because of the sea-level decrease and more sediment being deposited in the study area. The point bars morphology do not appear in the transgressive event. An oxbow lake appeared in the 525 ms seismic time slice and is labelled as the oldest channel system. The channel morphologies then changed, and the oxbow lake does not appear in the younger system channel (Recent). The channel morphology changes have been proven to be affected by global sea-level changes.

Keywords: Evolution channel system, sea-level changes, channel morphologies, Pleistocene-Recent succession, northeast Malay Basin

Abstrak.

Kajian ini bertujuan untuk mengkaji evolusi sistem sungai berusia Pleistosen hingga Resen di timur laut Lembangan Melayu berdasarkan kepelbagaian morfologi sungai. Kepelbagaian jenis morfologi sungai ditentukan dengan melakukan analisis terhadap tujuh keratan masa seismos kawasan kajian. Alur sungai telah berubah menjadi lebar dan berkeliukan rendah ketika paras air laut meningkat manakala alur sungai menjadi semakin sempit dan berkeliukan tinggi apabila paras air laut menurun. Beting pasir kelihatan pada lekuk dalam alur sungai berkeliukan tinggi. Hal ini demikian disebabkan oleh paras air laut menurun dan mengakibatkan sedimen terenap di kawasan tersebut. Morfologi beting pasir akan mula tidak kelihatan disebabkan proses transgresi air laut. Terdapat juga morfologi tasik ladam yang kelihatan pada keratan masa seismos 525 ms yang dilabelkan sebagai sistem sungai yang berusia paling tua (Pleistosen). Manakala morfologi sungai berubah dan tasik ladam sudah tidak kelihatan pada sistem sungai yang berusia lebih muda (Resen). Hal ini dapat membuktikan bahawa jenis morfologi berubah disebabkan oleh perubahan paras air laut global.

Kata kunci: Evolusi sistem sungai; perubahan paras air laut; morfologi sungai; turutan Pleistosen-Resen; timurlaut Lembangan Melayu

1.0 INTRODUCTION

Channel systems have complex erosional and sediment production histories resulting from both external and internal influences throughout geological time. The external variables that most significantly affect the fluvial system are tectonic, eustatic and climatic and the internal variables are geomorphic. The responses of the fluvial system to changes in these controls are complex, involving both erosion and deposition. Global sea levels have risen and fallen many times in response to growth and falling-off during the Pleistocene-Recent succession. The channel pattern changes during the transgression and regression event. The channel pattern is divided by the type of sediment loaded. Rivers are divided into sediment production, transfer, and depositional zones, providing a process-based view of sediment movement through river networks over geological time [1].

River classifications such as straight, meandering, or braided have been developed for channel patterns [1]. [2] and [3] observed that for a given discharge, braided channels occur more often in steeper slopes than meandering rivers. Both studies recognized a continuum of channel pattern. Additionally, [3] proposed a threshold between meandering and braided rivers, providing a means for predicting changes in channel pattern as a function of altered discharge or channel slope. [4] developed a GIS model for predicting channel patterns as a function of slope and discharge, demonstrating that unstable and laterally migrating channels (i.e., braided and meandering patterns) have correspondingly younger and more dynamic floodplain surfaces than stable, straight channels. Changes in meandering rivers naturally exhibit complex behavior, and considerate the river dynamics can be challenging in environments also matter to cumulative human impacts [5].

The arrangement of channel and overbank deposits in a fluvial succession is commonly referred to as the architecture of the beds. The architecture is described in terms of shape and size of the sand or gravel beds deposited in channels. The 3-D characterization of fluvial system allows the differentiation of sand-prone point-bar deposits and mud-prone abandonment channel facies [6]. The majority of rivers have been impacted to some degree by anthropogenic activity, and most of the world's large river systems have been extensively modified to harness resources, improve navigation, and control flooding [7].

As natural recorders of depositional conditions, river deltas are sensitive to global environmental changes, including those caused by climate change and human activities [8]. Work by [9] approached a river network by dividing into channel heads and tributary junctions. Consequently, links are numbered according to their position in the network. Not all channels of a given order behave similarly. For example, differences may occur in terms of reach-scale morphology and the associated processes in first-order channels that depend on basin topography (i.e., channel slope and confinement) and physiography (the supply of water and sediment to the channel). First-order channels in mountain basins may greatly differ from those of plateaus, coastal plains, or glacial lowlands [10].

Fluvial channel systems have complex erosional and sediment-production histories throughout geological time. The morphological character of a river changes when the character of the sediment transported from the source area changes. The character of sedimentary deposits reflects the geology, morphology and erosional history of the source area as well as the type of river transporting the sediment [1]. However, there is still lack of study that interpreted the river systems morphology, particularly coastal plain, using time slice technique in the study area. This study aims to investigate the presence of Pleistocene influences on modern channel systems in the study area with the 3-D time slices technique and to analyze the evolution of channel systems throughout geologic time.

2.0 METHODOLOGY

2.1 Geological Setting

The study area is located in the northeast Malay Basin (Figure 1). The northeastern part of the basin is filled with alluvial, lacustrine and fluvial sediments from the Oligocene to the early Lower Miocene. The coastal fluvial marine area increased to inner neritic from late Lower Miocene to the present, but became a narrow seaway from northeast to southwest flank [11]. This type of non-marine sediment filled was originally supplied by Gulf of Thailand from Mekong River from the Oligocene to the Pliocene [12]. The Malay Basin is a Tertiary basin in Sunda Shelf and one of the major hydrocarbon provinces in Southeast Asia. The northern part of Malay Basin is mainly gas-producing, while the southern part is oil-producing. This basin is separated from the Pattani Basin, including Narathiwat High in the north and the Penyu Basin in the south, by the Tenggol Arch that extends southeast to the West Natuna Basin in Indonesia. The Malay Basin is 200 km wide and 500 km long with a total area of approximately 83 000 km^2. Generally, the Malay Basin was developed starting in Middle Miocene, resulting from the Asia and India plate collision formed by extrusion of crustal slabs SE Asia. The Malay Basin consists mainly of NW-SE trending wrench faults and results from the opening of the South China Sea through seafloor spreading. The northeast Malay Basin has a major gas reserve. This includes the Malaysia-Thailand Joint Development Area, Vietnam-Malaysia Commercial Agreement, and the deepest part of the Malay Basin. The basement is mainly Cretaceous granites elongated to the Con Son Swell bounded by a fault direction from South to North. The structural is less steep and more structured in the northeast flank, marked by a number of half-grabens [13].

2.2 Data Interpretation

The data used in this study covers 3-D seismic reflection data with a total area range of 623 km^2. The bin spacings of inline and crossline for these surveys are 25 m and 12.5 m, respectively. The vertical length used in this study ranges from 0 ms to 600 ms. The velocity information from the well data was used to convert the depth and thickness in milliseconds two-way time into meters. Both vertical and horizontal resolutions of seismic data are limited, and this imposes limits on what geologically significant features can actually be recognized on seismic data. Vertical resolution is determined by the seismic source signal and the way it is filtered by the earth. For example, the signature of a typical marine air-gun array has frequencies in the range 8-150Hz; the upper frequency limit will be reduced as the seismic signal propagates through the earth, perhaps to about 50Hz at a TWT of 2s. Based on [14], with a seismic frequency wave of 40Hz and seismic velocity of about 1750 m/s the vertical and horizontal resolution is approximately 10.94m. This 3-D seismic data interpretation approach enables viewing time-slices along horizontal integration and provides detailed map views of fluvial depositional elements. In this approach, the seismic data is sliced into two-way time starting from 5 ms until 525 ms. Types of features that are quantified in this study include fluvial style, channel direction, point bar, sinuosity and channel width. The meandering channels are river channels of varying sinuosity and appear to be the most common fluvial styles in this seismic data set. Straight channel which is quite few over their entire lengths. The whole river system occurred in a big incised valley, including all river deposits such as point bar. Seven time slices were made and interpreted from the images traced from the seismic time slices. The seismic time slices used are as follows: 525 ms s, 450 ms, 310 ms, 220 ms, 150 ms, 110 ms, and 15 ms. The dimension of every time-slice is 35.6 km long and 17.5 km width, and the age of this sequence is Pleistocene to Recent (1.5 Mya). In some cases, the channel architecture appeared on more than one time slice. The evolution of the channel system along the Pleistocene-Recent was analyzed by presenting the differentiation of the channel pattern appeared on the seismic time slice.

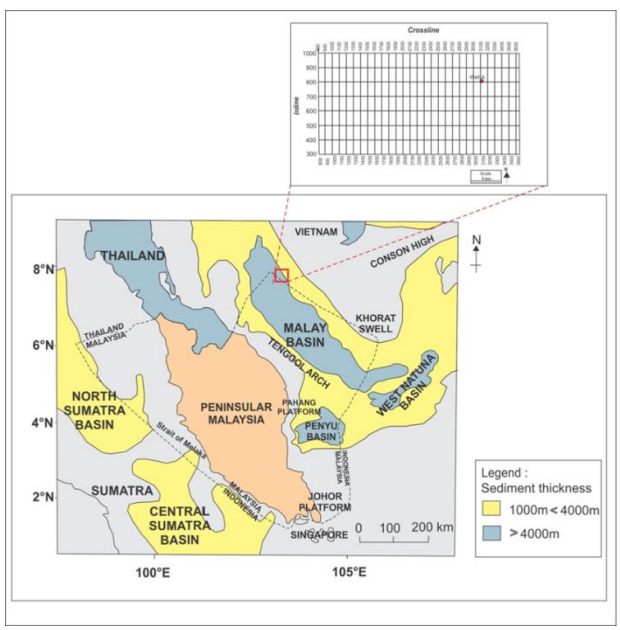


Figure 1 The map is showing the study area in red box located in northeast Malay Basin, offshore Terengganu

3.0 RESULTS AND DISCUSSION

3.1 Evolution of Channel System

The variable types of river morphology were obtained from seismic time slices ranging from 5 ms to 525 ms two-way time. The seismic time slice is known as the seismic sections and may be seen from the plan-view or horizontally. The amplitude attribute was used in this study. The evolution of channel system from the Pleistocene to the Recent age was investigated by visualizing the difference in shapes and geometry of the channel. Seven time slices were picked from the oldest channel system represented by Figure 2(i) until the youngest channel system represented by Figure 2(vii). The two-way times chosen to represent the time slices range from 525 ms for the oldest channel to 15 ms as the youngest one.

The width and length of each time slice is approximately 35.6 km x 17.5 km.

Figure 2(i) shows the oldest channel system sliced at 525 ms in the study area, highlighting a major river in the western area and a high-sinuosity meandering smaller river with some dendritic tributaries, as well as point bars corresponding to an anastomosing river pattern. The major river dimensions are about 600 m width and about 40 km length, while the dimension of the small meandering river is about 400 m width and about 14 km length. Two point bars were detected near the river meander with dimensions of 6 X 2 km and 4 X 1 km for lengths and widths, respectively. Based on these point bars position which indicate lines of deepest channel and lateral accretion channel, the river is interpreted as flowing from southeast to northwest. An oxbow lake of around 6 X 3 km dimension is observed in the southern part of the meander nose. Some dendritic tributaries are observed mostly in the western part of the study area and a few in the eastern part. The length of these dendritic tributaries ranges from 0.5 to 1.5 km. [15] interpreted the meandering rivers as carrying suspended load or a mixture of suspended load and bed load. The size and geometry of the river changed, becoming more sinuous with the formation of point bars when the sea-level rise. On the other hand, the rivers became thinner with the global sea-level decrease. The sediments started to deposit towards the downstream when the river flow is at its lowest rate due to the rise of sea-level.

Figure 2(ii), which was developed at time slice 450 ms, is quite similar to the older river pattern sliced at 525 ms. The major river is still not much changed, while the oxbow lake has disappeared. Many more dendritic tributaries are observed in the time slice. The small rise in sea-level caused some flooding to the area and hence covering the oxbow lake as well as to form more dendritic tributaries. The shape of the anastomosing rivers has slightly changed compared to the older one, as the channels became narrower. The anastomosing channel dimension is about 380 m width and about 18 km length consisting of several channel bars within the channel. The major river became wider in the western part and the dimension is about 2.7 km width and 12 km length. The anastomosing river is generally narrower and relatively highly sinuosity in this younger channel system.

Figure 2(iii) shows a time slice taken at 310 ms, indicating that more dendritic tributaries developed in the eastern part of study area. The measured length of dendritic tributaries ranges from 300 m to 1.2 km. These dendritic tributaries originated from the major river. An additional point bar is observed in the inner bend of the southern river and the dimension of this point bar is about 9 X 1 km length and width. A new meandering channel developed towards the east of the major river with dimensions of about 11 X 0.2 km length and width. An interesting feature found in this time slice is the appearance of two abandoned channels, indicated by dashed lines. The length and width of the river is approximately 0.9 X 13 km.

Figure 2(iv) shows the retraced diagram of the seismic time slice developed at 220 ms, depicting more dense rivers in the eastern part of the floodplain. These rivers can be classified as dendritic tributaries, anastomosing, meandering, straight, and a few abandoned rivers overlain by the major river in the middle of the study area. The length of dendritic tributaries ranges from 400 m to 2.5 km, while the length and width of abandoned channel is about 16 X 1.2 km. A point bar is also observed in the most southern part of the straight river with a size of about 5 X 1 km length and width. Cross-channel bars are located in the river meanders on the northeast of study area. The sizes of these bars are approximately 4 X 2 km length and width. Abandoned channels are found crossed by the straight big channel at the middle of study area. The length and width of these channels are about 10 X 1.2 km.

A highly-sinuous meandering river with several point bars in the inner bend clearly appears in the central part of study area of the 150 ms panel time slice. This meandering river is underlain and crossed by the major straight river (Figure 2(v)). The dimensions of this highly-sinuosity meandering river are about 1 X 0.5 km length and width. Along this river, many point bars are developed in the inner bend and clearly observed in the time slice. The dimensions of these point bars are about 3 X 1.5 km length and width.

All the point bars along the meandering river are disappeared in the time slice of 110 ms (Figure 2 (vi)). On the other hand, a major river tributary was observed in the western part consisting the dendritic tributaries. Another very long river meander appeared in the most western part and is connected to the major straight river in the north. The length and width of this newly formed meander river is approximately 32 X 0.3 km. An abandoned channel was observed underlain by the major river with dimensions of about 20 X 1 km length and width.

The youngest time slice (Figure 2(vii)) at 15 ms is not very clear and informative. Its only shows the major river, some anastomosing rivers, and a few remaining dendritic tributaries, while the major tributary in the western part has disappeared. An anastomosing river is still observed in the northern part with a size of approximately 13 X 0.7 km length and width.

3.2 Factors Controlling Channel Evolution

Multiple river channels with frequent branches and interconnections are seen in places in which the gradient is very low. The positions of channels tend to remain fixed with time, and most of the sedimentation occurs in the overbank regions during flooding. New channels may develop as a consequence of flooding as the water makes a new path across the floodplain, leaving an old channel abandoned. Recognition of anastomosing rivers in the stratigraphic record is problematic, because their key feature is that there are several separate active channels. In ancient deposits, it is not possible to demonstrate explicitly that two or more channels were active at the same time. Similar patterns may form as a result of a single channel repeatedly changing position. Meandering and anastomosing rivers characteristically occur on lower slopes and carried finer grain sediment loads. Anastomosed rivers have numerous channels of variable sinuosity. They are rather stable in position, and do not migrate laterally, as do the meander bends of meandering river. There is growing evidence that an anastomosed pattern develops when a river is affected by a downstream controlling or back tilting process. This may occur where a river crosses a tectonically positive area, or flows toward an area of postglacial rebound. Based on these observations, the difference in the fluvial system architectures at different time slices is likely to be mainly due to the effects of sea-level changes throughout the geological age

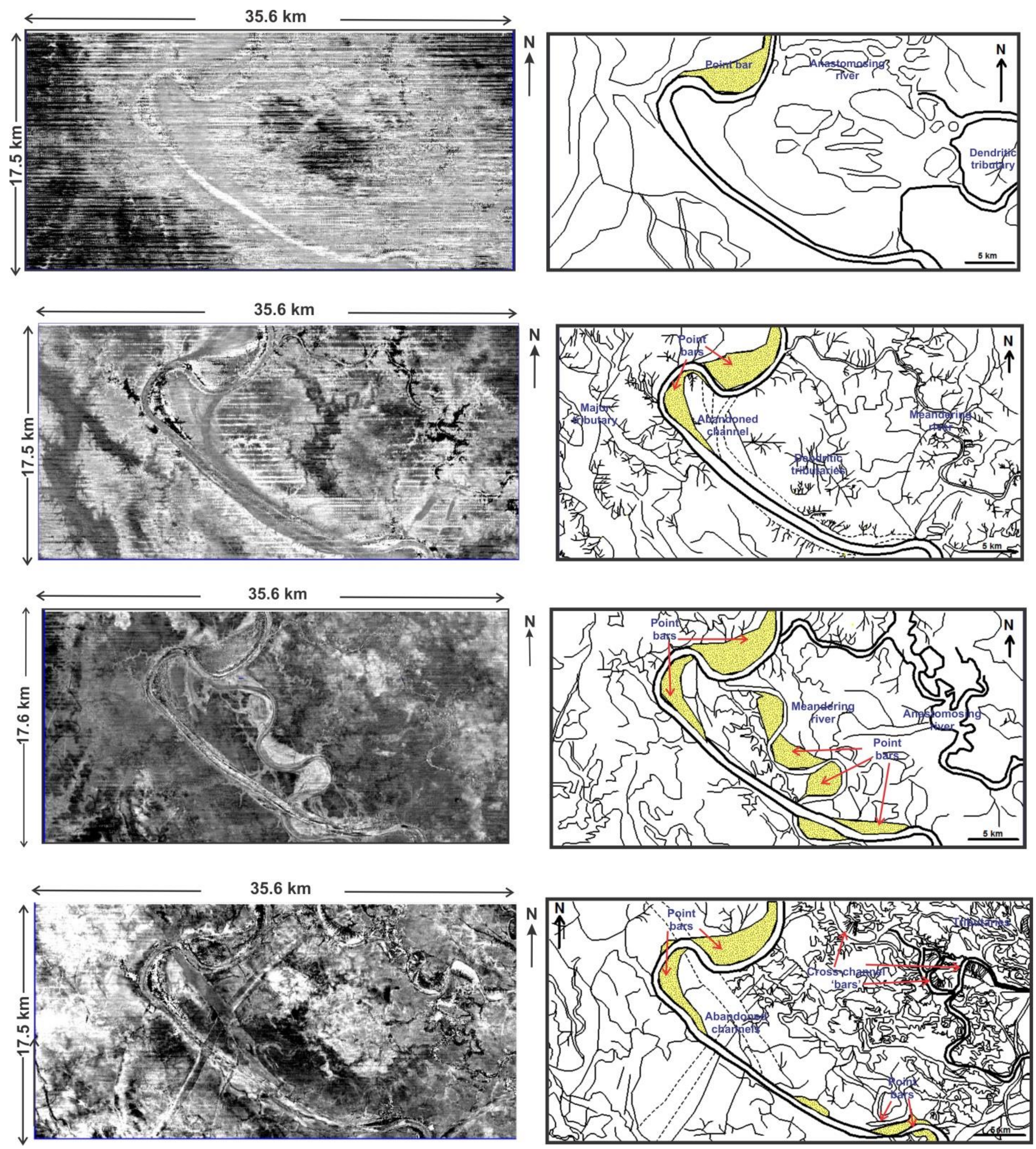


Figure 2 The untraced and traced river morphology at time slice (i) 15 ms (ii) 110 ms (iii) 150 ms and (iv) 220 ms)

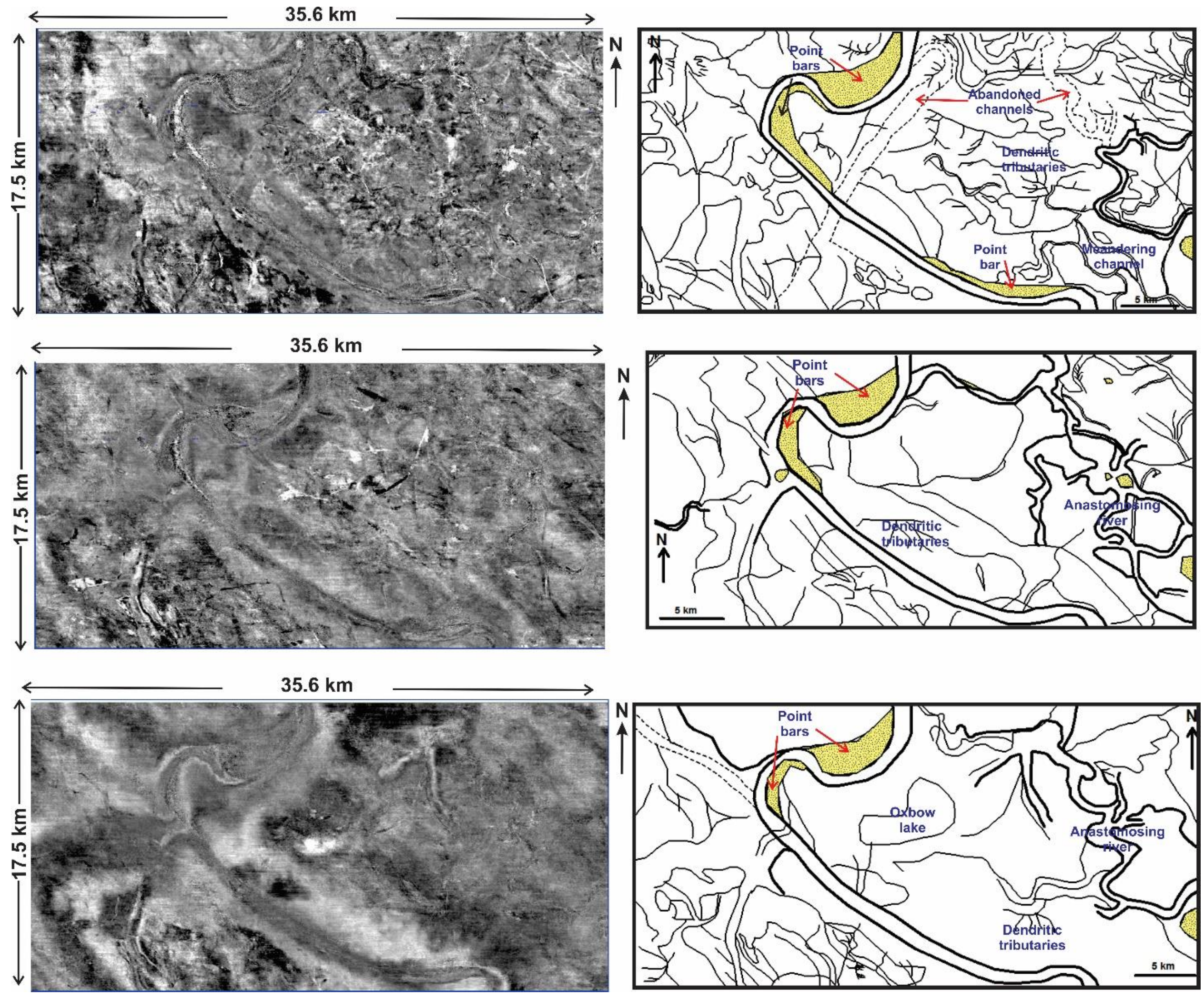


Figure 3 The un-traced and traced river morphology at time slice (v) 310 ms (vi) 450 ms and (vii) 525 ms

4.0 CONCLUSION

The characteristics of the oldest rivers' morphology include increases in width and low-sinuosity, becoming narrower and gaining higher sinuosity in the youngest river. This occurred due to global sea-level fluctuation in terms of the size and geometry of river morphology. The river became highly-sinuous with the existing of point bars. The channel river became narrower while sea-level decreased. Consequently, sediments were deposited on the downstream area because of the low velocity current. According to [16] and [17], meandering river sandstones always being in a fluvial channel shape, meanwhile the river sandstone in sheet shape always deposited in braided river environment. The depositional features of meandering channels of the sandstone bodies accumulated through the lateral transportation of fluvial channel during avulsion channel or oxbow lake formation [18].

The river has changed in size and geometry. Subsequently, the river has become more sinuous (highly-sinuous) with the existence of bar deposits associated with the increasing lateral surface of fluvial deposits. The fluvial performed to be narrow and low- and moderate sinuosity in plan-view during the high-stand to low stand tract system. The evolution of the channel system in the Pleistocene-Recent succession has confirmed that sea-level fluctuation affected channel morphology in the study area. Besides that, there were transgression and regression events during this period.

Overall, based on the seven interpreted panels of the time slices, several types of rivers including straight, meandering, anastomosing and dendritic tributaries have been observed. These streams can be classified as unconfined channels as defined by [15]. Since the river sinuosity is greater than 1.5, according to [19], these streams are classified as high-sinuosity channels. With a ratio of width and depth (W/D) between the values 12-30, the river patterns in the study area are classified as a mixed-load and suspended-load channels following [20] classification. According to [20], channel pattern is closely related to the type of sediment transport and can be classified based on the ratio of width and depth (W/D) where W/D for mixed-load is 25 and for suspended-load is 8. They also classified the sinuosity of mixed-load as between 1.4 to 1.7 and that of suspended-load as 2.5. It may be observed that the anastomosing rivers originating from braided rivers and meandering rivers became straight rivers towards the downstream. Fluvial systems are always affected by the sea-level changes, especially in terms of the sinuosity, width, or depth of the river. By analyzing each of the time slice panels in Figure 2(i-iv) and Figure 3 (v-vii), the relation of sea-level position and channel morphology may be determined.

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