Source to Sink Modelling in NW Borneo: Improving Understanding of the Deepwater Slope Delivery System and Utilising DEM and Shallow Analogues for Deeper Prospectivity*

Nicholas Hoggmascall[1], Christian Gibson[2], Dina Blades[2], and Jose Torres[2,3].

Search and Discovery Article #50755 (2012)*
Posted November 30, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Convention and Exhibition, Singapore, 16-19 September 2012, AAPG©2012

[1]XGR, Exploration, Brunei Shell Petroleum, Jalan Utara, Panaga, Seria, KB3534, Negara Brunei Darussalam (nick.hogg@shell.com)
[2]XGR, Exploration, Brunei Shell Petroleum, Jalan Utara, Panaga, Seria, KB3534, Negara Brunei Darussalam
[3]Exploration, Shell Development Australia, 2 Victoria Avenue, Perth, WA6000, Australia

Abstract

A key element in the play based exploration approach to the Brunei portion of the Neogene NW Borneo Margin has been broad integration to further refine our understanding of the distribution and processes behind sediment delivery into the deepwater. For the first time in BSP a complete analysis from floodplain to basin floor has been completed for discrete intervals spanning the last 12 million years. For BSP it was critical to understand if and how the Baram and Champion drainage systems differ over time regarding deepwater delivery and how efficient they transport sediment to the basin floor. In addition it was critical to understand how our observations differ from published data from Sabah and ultimately how this information can update our view on sand supply to deepwater.

Analysis reveals distinct differences in sediment supply between the Baram and Champion systems in Brunei. Spatial and temporal variations in the structure of the palaeo slope strongly influence the degree to which sediment reaches the basin floor. The Baram System appears to dominate sediment supply to the basin floor. The Champion System in contrast feeds from a salient into a complex and confined tectonic stepped slope setting characterised by restricted entry points and linear turbidite development. Overall fan architecture reveals distinct trends in sediment supply and delivery strength through time. However in addition, unique spatial variations in processes are interpreted to have been driven by hinterland uplift, shelf storage capacity and slope rugosity.

Introduction

Combined analysis of the shallow analogue stratigraphy and the evolution of the erosional hinterland has been instrumental in gaining an improved understanding of the deeper Mio-Pliocene aged prospectivity on the NW Borneo margin in the Brunei deepwater. The Brunei shelf and deepwater slope provide excellent quality data and, combined with well control, allow characterization and mapping of the point sources and delivery tracts from the shelf to the deepwater and ultimately the basin floor (Figure 1). In addition, combining remotely sensed datasets of the present day catchments with tectonic reconstructions has allowed a complete source to sink reconstruction study to be undertaken to understand whole system dynamics controlling the deepwater sedimentary sequences through time.

Since the Miocene, the NW Borneo margin has prograded over an Eocene to Oligocene foreland fold and thrust belt into the NW Borneo trough via a series of clastic shelf clinoforms, which have been intermittently influenced by compressional phases (Gartrell et al., 2012; Torres et al., 2012; Figure 3). Miocene to present day evolution of the margin from Brunei north east to the northern tip of Sabah State has been the topic of numerous publications over past decades and many models and theories exist to explain the observed distribution of the sand depositional systems along the deepwater margin (e.g. Demyttenaere et al., 2000; McGilvery and Cook, 2003; Grecula et al., 2010). For the shallow analogue, it is possible to identify several key input sources from south to north; the Luconia platform, the Baram River, the Champion River, the Ranau Canyon, and the Kepabangan Canyon. Only the Baram has a present day river system delivering sediment to the shelf edge; all other systems are drowned by present day sea levels.

Drainage Basin Evolution

Reconstructing the drainage basin evolution through time is a challenge in a largely eroded upland landscape. We have used several lines of evidence to guide us in our interpretations.

Subsurface sequence analysis enables the recognition of several discrete periods where the deltaic cover sequence was folded over numerous inversion structures, most of which form current day anticlines on both onshore and offshore areas. The oldest inversion events are seen to affect the east of Brunei, especially the Jerudong-Punyit Anticline and the Muara-Labuan Anticline. To the west there is little evidence from onshore 2D seismic data to suggest similar inversion in the earlier deltaic sequences. Therefore early segmentation of the Brunei drainage basins in the Miocene is interpreted to have occurred along the current Jerudong and Muara-Labuan anticline trends which show the earliest evidence for inversion uplift.

Most published data points to the formation of the current axial zone of the Crocker Mountains range by the start of the Miocene (Morley and Back, 2008). Since then there has been no significant major tectonic event that has fundamentally altered the gross drainage patterns of the west side of the Crocker ranges (Figure 2). Blue line analysis of present day river systems draining into the South China Sea points to an overall shortening and steepening of drainage profile from south to north along the margin (Cullen, 2010), reflecting significant narrowing of the floodplain from south to north and close proximity of the axial subduction zone to the shelf edge in the north. Antecedent drainage on the Padas River at the Tenom Gorge, Sabah, the Trusan River at Trusan, Sabah, the Temburong River at Bangar and the Tutoh River in the Tutoh Gorge, Mulu indicate large old river systems whose erosional powers were able to keep up with uplift in the axial zone since the Miocene. In the shallow offshore subsurface the present Muara Channel reflects the course of the drowned Champion river system which was also antecedent across the earlier Muara-Labuan inversion trend and the Champion Anticline.

On the present day floodplain, conversely, there is little evidence of antecedence, suggesting that current drainage basins in Brunei and Limbang District were formed more recently since the Pliocene, and that the most recent inversion event calibrated to the Plio-Pleistocene Boundary (~2Ma, UC8 of Gartrell et al., 2012) was of such magnitude that the uplift and the relatively limited powers of the active rivers were unable to maintain river courses, leading to segmentation of the older Baram drainage basin and formation of the current Belait and Tutong drainage systems. Such hinterland evolution has a fundamental impact on the flux and nature of sediment along the erosional and depositional tracts. The Belait and Tutong rivers have been significant delivery systems to the shelf edge during the Pleistocene, as indicated by shallow seismic depositional facies mapping (Figure 3).

Sediment Capture on the Floodplain and Delta

Comprehensive subsurface sequence analysis onshore and offshore Brunei has allowed the reconstruction of seismic sequence distribution and geometries of Brunei since the Miocene (Gartrell et al., 2012; Torres et al., 2012). An overall pattern can be seen across the depositional area through time where sediment loading initiates extensional faulting typically on the outer shelf. A number of large down to basin and counter regional faults can be seen to have acted as major sediment traps on the shelf through time (Figure 3 and Figure 4). This overall pattern is interrupted by regional compressional events at ~9 Ma, ~5Ma, and ~2Ma, which cause the cessation of extension and inversion of the extensional structures. We see strong evidence, once we map these inversion events into the deepwater, that these are key periods where enhanced volumes of sediment are bypassed across the shelf and delivered to the slope and deepwater. The inversion pulses commonly force the shallow marine depocentres to jump seawards where sediment loading is refocused and extension is initiated once the critical sediment loading point is reached.

Slope and Basin Floor Analysis

A traverse across the NW Borneo margin from Brunei to Sabah shows a sharp contrast in sediment delivery from the shelf to basin floor. This study supports the view that the Champion and Baram systems are both sourced by surprisingly long lived and pervasive supply conduits set along regional lineaments. Both appear to store large volumes of sediment above the slope edge on the floodplain and the episodically extensional shelf.

In terms of slope delivery, the Champion and Baram systems contrast each other. The Champion System feeds from the apex of a rigid indenter expressing the deep mechanical basement into a complex and confined tectonic stepped slope setting characterised by restricted entry points and linear turbidite development. The greater fold density creates greater bathymetric control on the deepwater sediments. This is highlighted by the ability of the slope mass transport complexes (MTCs) to traverse the slope. These MTCs in the east show a decapitation of the fold thrusts but are quickly buttressed by outboard bathymetry.

Analysis of the Brunei slope reveals that the Baram feeds unconfined slope architecture and consequentially is more efficient at sediment delivery to the basin floor. This study further cements this view but postulates that there appears to be limited penetration of these sediments onto the basin floor. More fundamentally, the Baram system builds volumetrically large shelf edge systems that are prone to failure on a scale equivalent to that documented in the Brunei Slide (Gee et al., 2007). Figure 5 highlights these observed patterns from shallow analogue analysis. This is shown to be a powerful tool in understanding deeper slope architecture, providing important insights into slope morphology.

Extractions from the shallow analogues (Figure 6) are also used to support definition criteria for slope subdivision. Based on the proportion of linear and sinuous channels, apron development and MTCs, criteria were created to incorporate observed facies variations with slope angle. The same was repeated for the deeper stratigraphic sequences to map the facies variations per slope segment. The observations support the wider global observations of increasing apron and lobe development in the lower slope and basin floor domain. Particularly prominent is the ability of the MTC to deliver sediment to the basin floor. This is highlighted in Figure 7 which describes the observed fan architecture. This illustrates that the predominant makeup of the delivery systems is that of moderately discrete fans which are controlled in size by the host slope profile.

Conclusion

An integrated source to sink study has characterised the link between hinterland erosion, sediment transport across a complexly subsiding floodplain, sediment load delivery to the shelf edge, and morphology of slope and basin floor delivery systems through time.

Individual systems are unique along their tracts and multiple factors characterize the slope and basin floor morphologies observed.

The Baram System has remained a major system through geological time, with a large upland erosional catchment, a long mature floodplain, and a relatively tectonically benign shelf allowing the aggradation of large mud rich sediment loads that are regularly delivered to the basin floor through major mass transport events.

The Champion System is presently a drowned system but was of approximately 50% areal size of the Baram, drained a sizable upland hinterland, traversed a moderately wide floodplain, and crossed a tectonically active shelf where sediments were effectively captured behind large often long lived counter regional faults. Despite this, sand–rich delivery systems down the complex stepped slope have been proven in a number of exploration wells in the Miocene and Pliocene sequences.

It is interesting to speculate the evolution of the adjacent Padas drainage system in Sabah and whether this major montane system fed into the Champion System back in time; it currently drains into the drowned Champion System but there is offshore subsurface evidence that it formed its own source to sink system in the Miocene and Pliocene (Cullen, 2010).

References

Demyttenaere, R., J.P. Tromp, A. Ibrahim, P. Allman-Ward, and T. Meckel, 2000, Brunei Deep Water Exploration: From Sea Floor Images and Shallow Seismic Analogues to Depositional Models in a Slope Turbidite Setting, *in* P. Weimer, R.M. Slatt, J. Coleman, N.C. Rosen, H. Nelson, A.H. Bouma, M.J. Styzen, and D.T. Lawrence, (eds.), Deep-water reservoirs of the world; GCSSEPM Foundation 20th Annual Research Conference, v. 20, p. 304-317.

Cullen, A.B., 2010, The Klias Peninsula and Padas River: NW Borneo: A possible example of hinterland drainage capture in a tropical orogenic highland: AAPG Search and Discovery Article #90102, 2 p. Web accessed 14 November 2012.

http://www.searchanddiscovery.com/abstracts/pdf/2010/hedberg_indonesia/abstracts/ndx_cullen.pdf

Gartrell, A., J. Torres, N.M. Hoggmascall, 2012, A Regional Approach to Understanding Basin Evolution and Play Systematics in Brunei - Unearthing New Opportunities in a Mature Basin: SPE 15171-MS, 5 p. Web accessed 14 November 2012. http://www.onepetro.org/mslib/servlet/onepetropreview?id=IPTC-15171-MS

Gee, M.J.R., H.S. Uy, J. Warren, C.K. Morley, and J.J. Lambiase, 2007, The Brunei Slide: A giant submarine landslide on the North West, Borneo margin revealed by 3D seismic data: Marine Geology, v. 246/1, p. 9-23.

Grecula, M., S. Kattah, and P. Shiner, 2010, Role of Mass Transport Deposits in the Creation and Fill of Tectonically Active Slope Accommodation, Deepwater Sabah, NW Borneo: AAPG Annual Meeting Abstracts, unpaginated.

McGilvery, T.A., and D.L. Cook, 2003, The Influence of Local Gradients on Accommodation Space and Linked Depositional Elements Across a Stepped Slope Profile, Offshore Brunei, *in* H.H. Roberts, N.C. Rosen, R.H. Fillon, and J.B. Anderson, (eds.), Shelf Margin Deltas and Linked Down Slope Petroleum Systems: Global Significance and Future Exploration Potential: SEPM Gulf Coast Section Program and Abstracts, v. 23, p. 387-419.

Morley, C.K., and S. Back, 2008, Estimating hinterland exhumation from late orogenic basin volume, NW Borneo: Journal of the Geological Society of London, v. 165/1, p. 353-366.

Torres, J., A. Gartrell, N.M. Hoggmascall, 2012, Redefining a Sequence Stratigraphic Framework for the Miocene to Present in Brunei Darussalam: Roles of local tectonics, eustacy and sediment supply: IPTC 15167, Bangkok Conference Abstract, 12 p. http://www.iptcnet.org/2011/pages/schedule/tech_program/documents/IPTC-15167.pdf

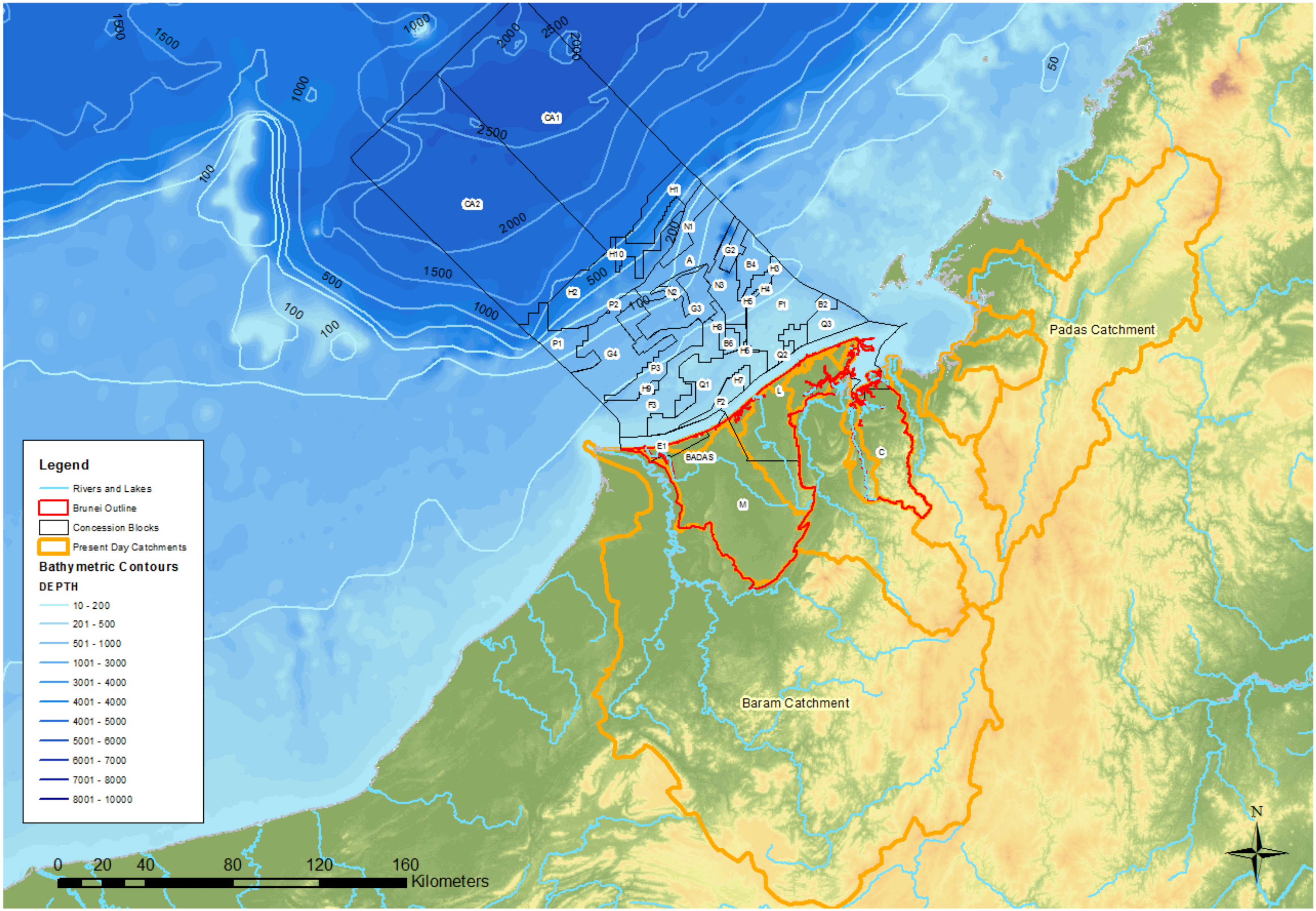

Figure 1. Area of investigation; Brunei License acreage; the study had access to 3D seismic data from most of the offshore blocks.

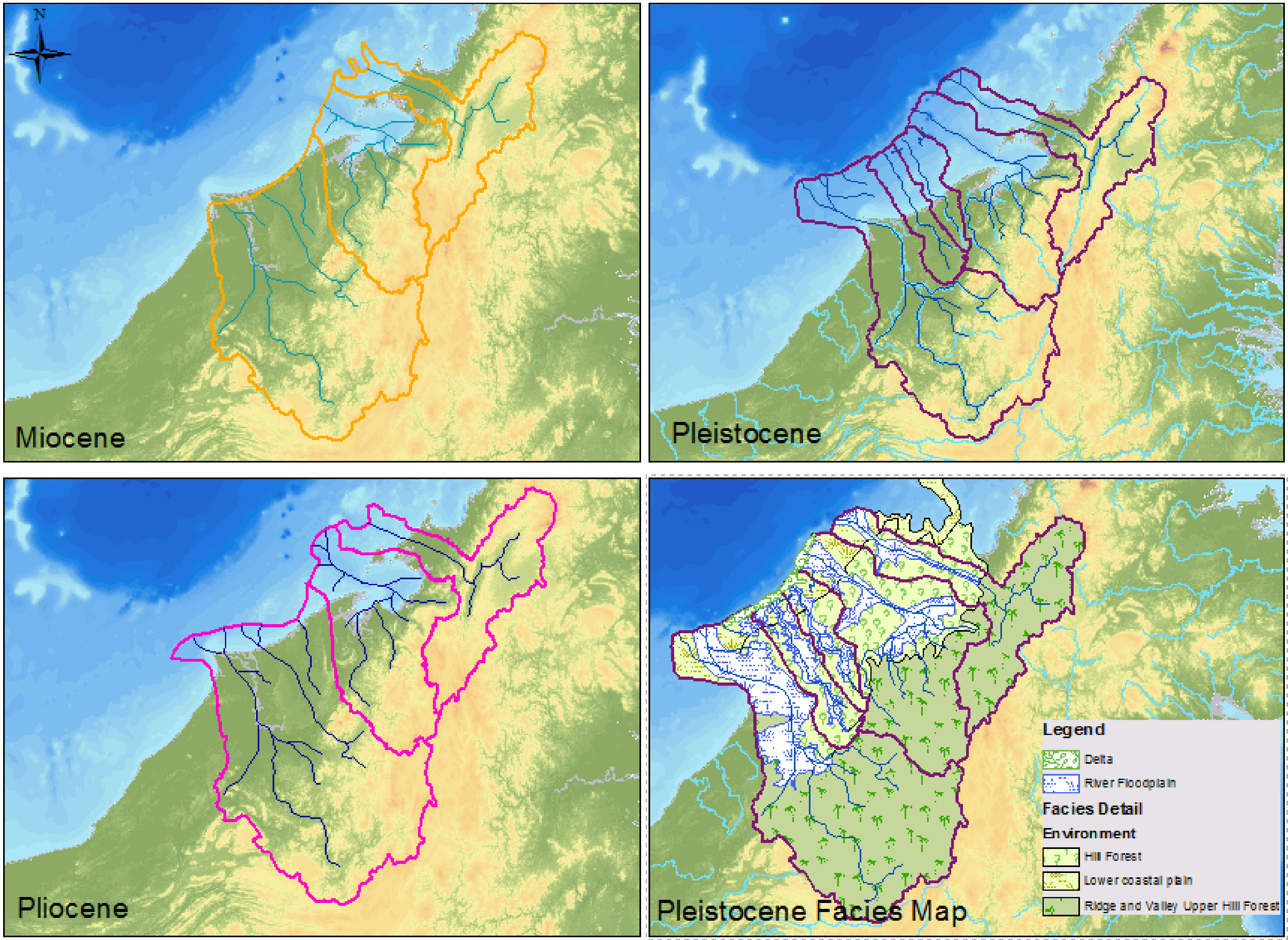

Figure 2. Catchment evolution, Miocene to present. Pleistocene facies map based on shallow seismic interpretation.

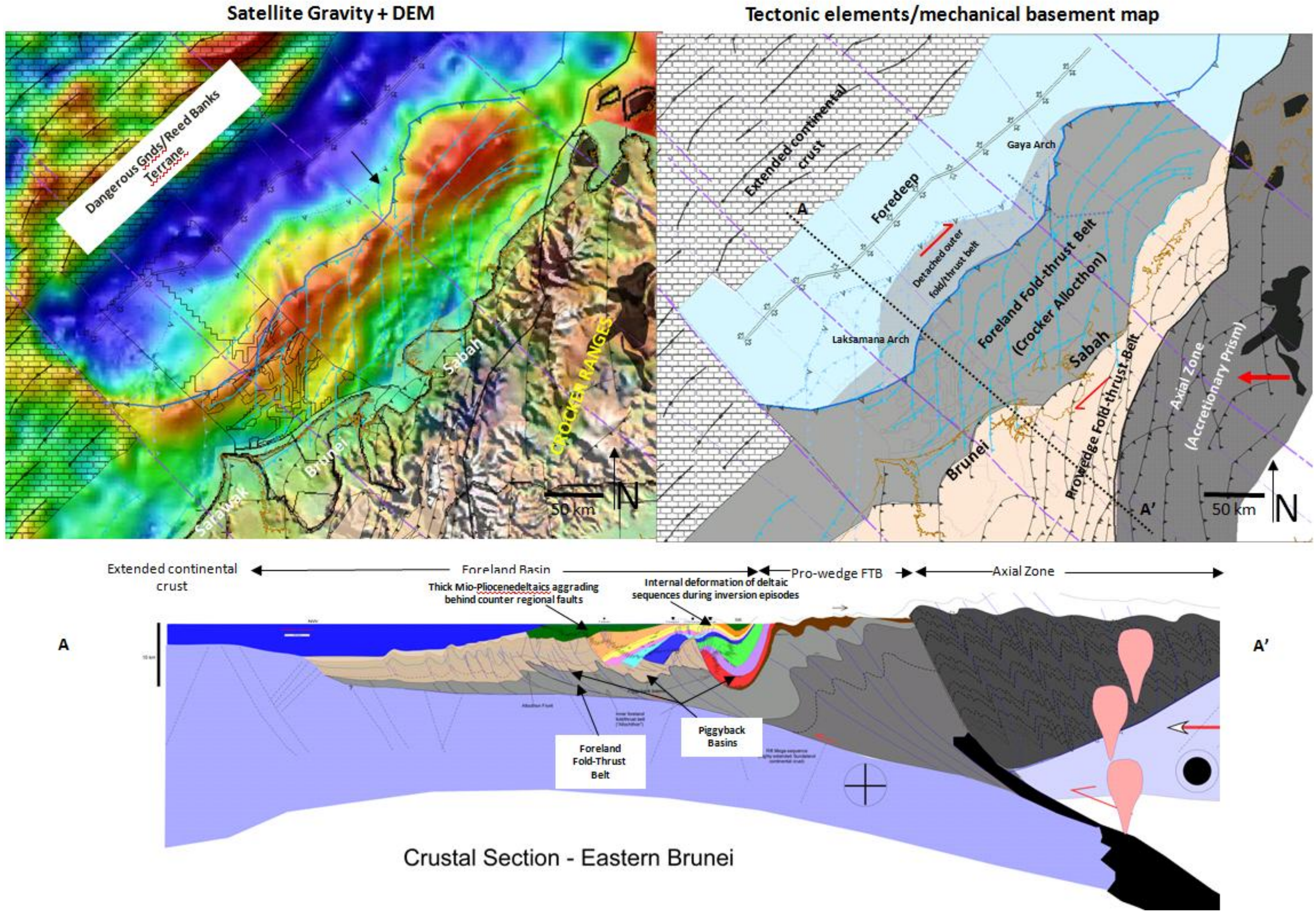

Figure 3. Tectonic Elements derived from gravity + DEM. 2D seismic line interpretation of subducted continental margin, accretionary prism and deltaic cover sequence (after Gartrell et al., 2012).

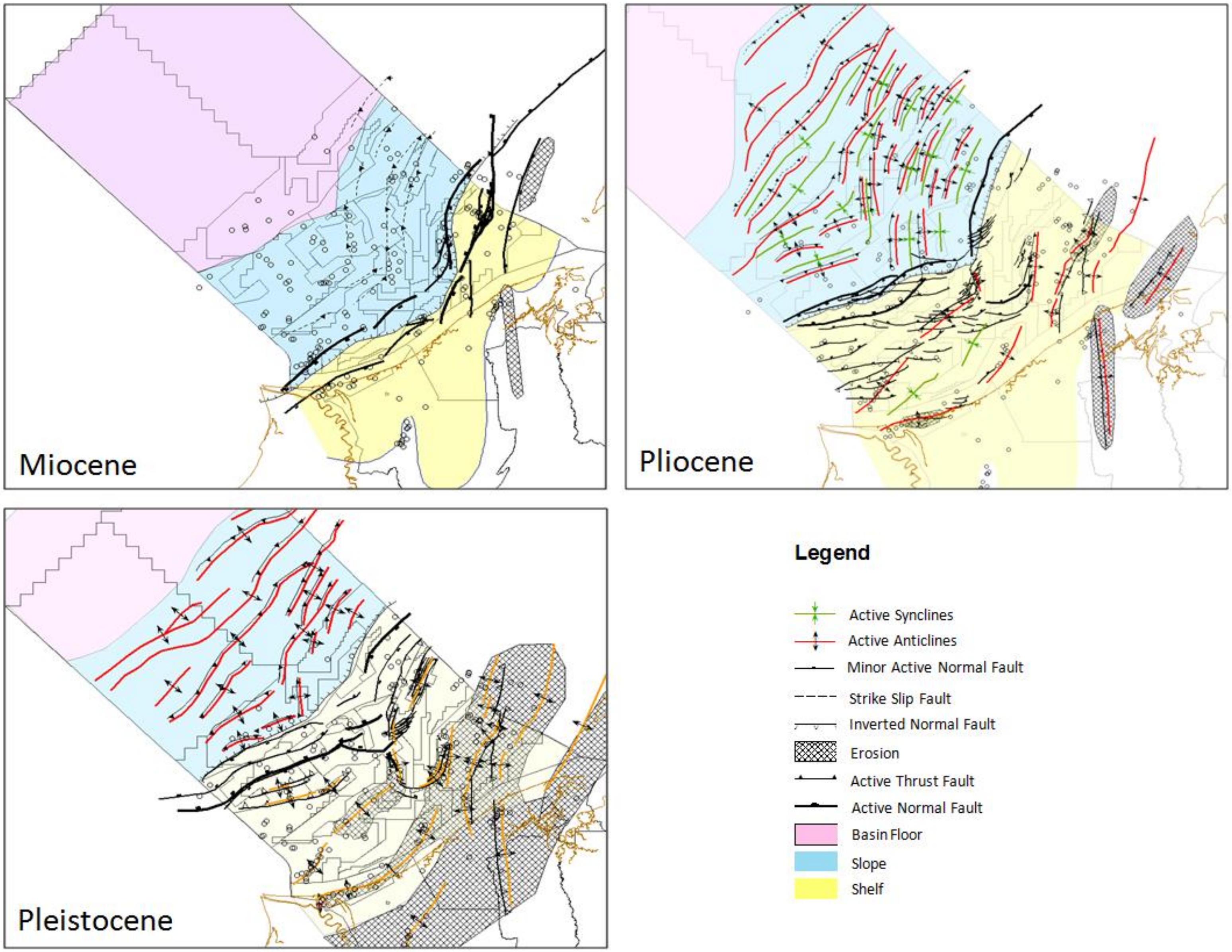

Figure 4. Dynamic gross depositional environment maps for Miocene to Pleistocene (after Gartrell et al., 2012).

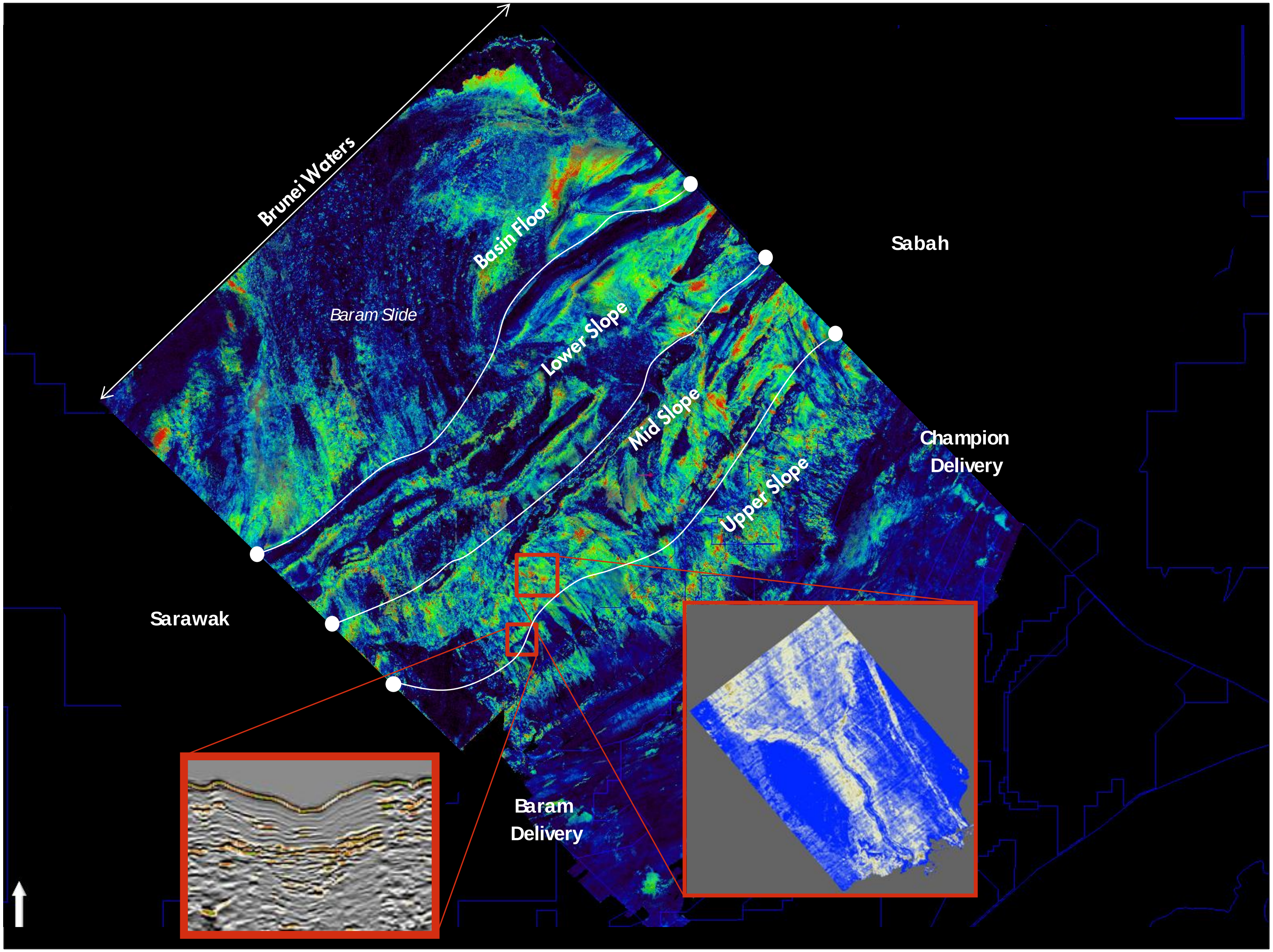

Figure 5: Shallow Analogue Analysis of the Brunei Shelf and Stepped Slope. Windowed extraction highlighting slope delivery to the basin floor.

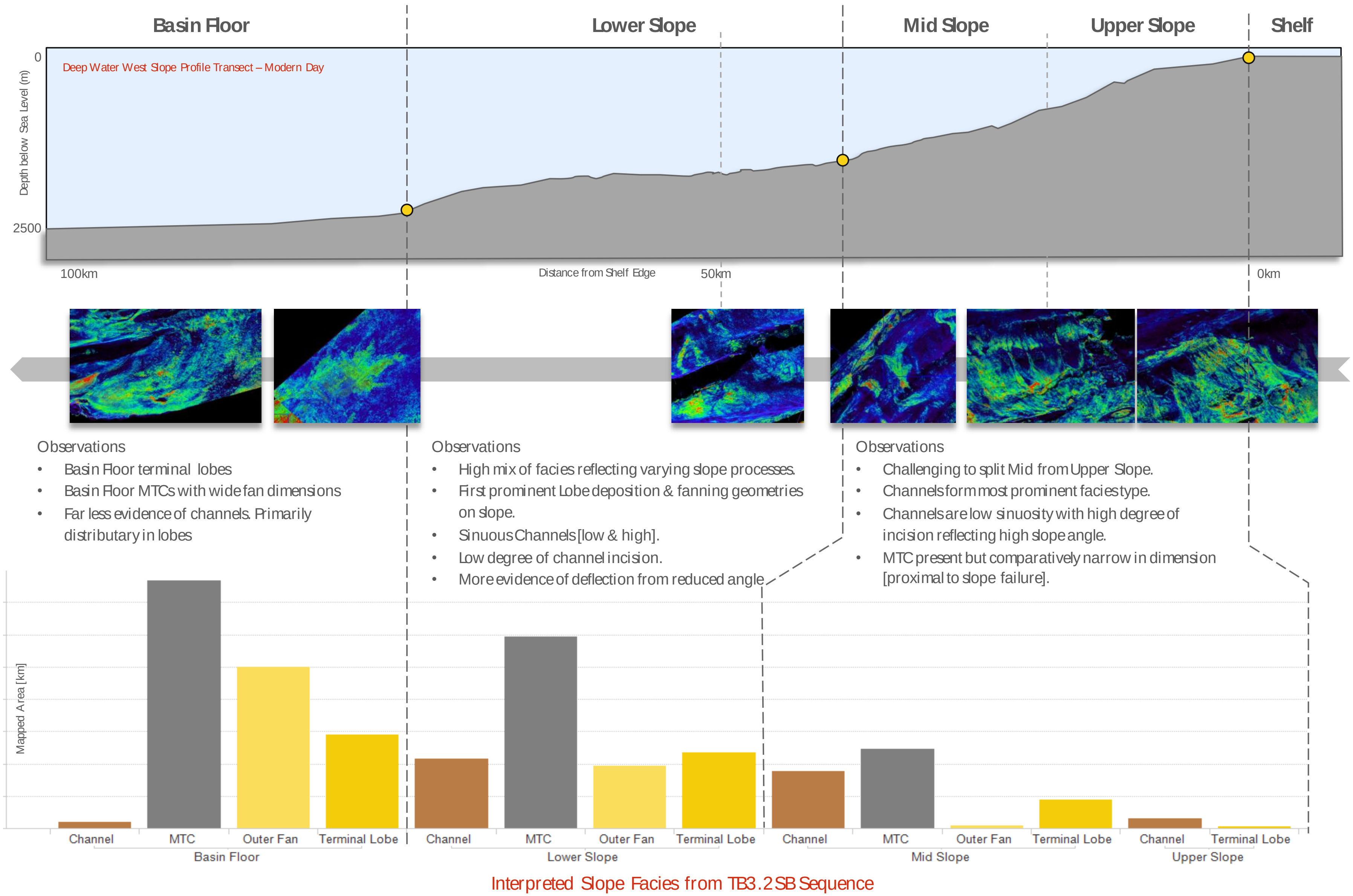

Figure 6: Defining the Slope Profile. Identified Diagnostic Criteria for determining Slope Partitions.

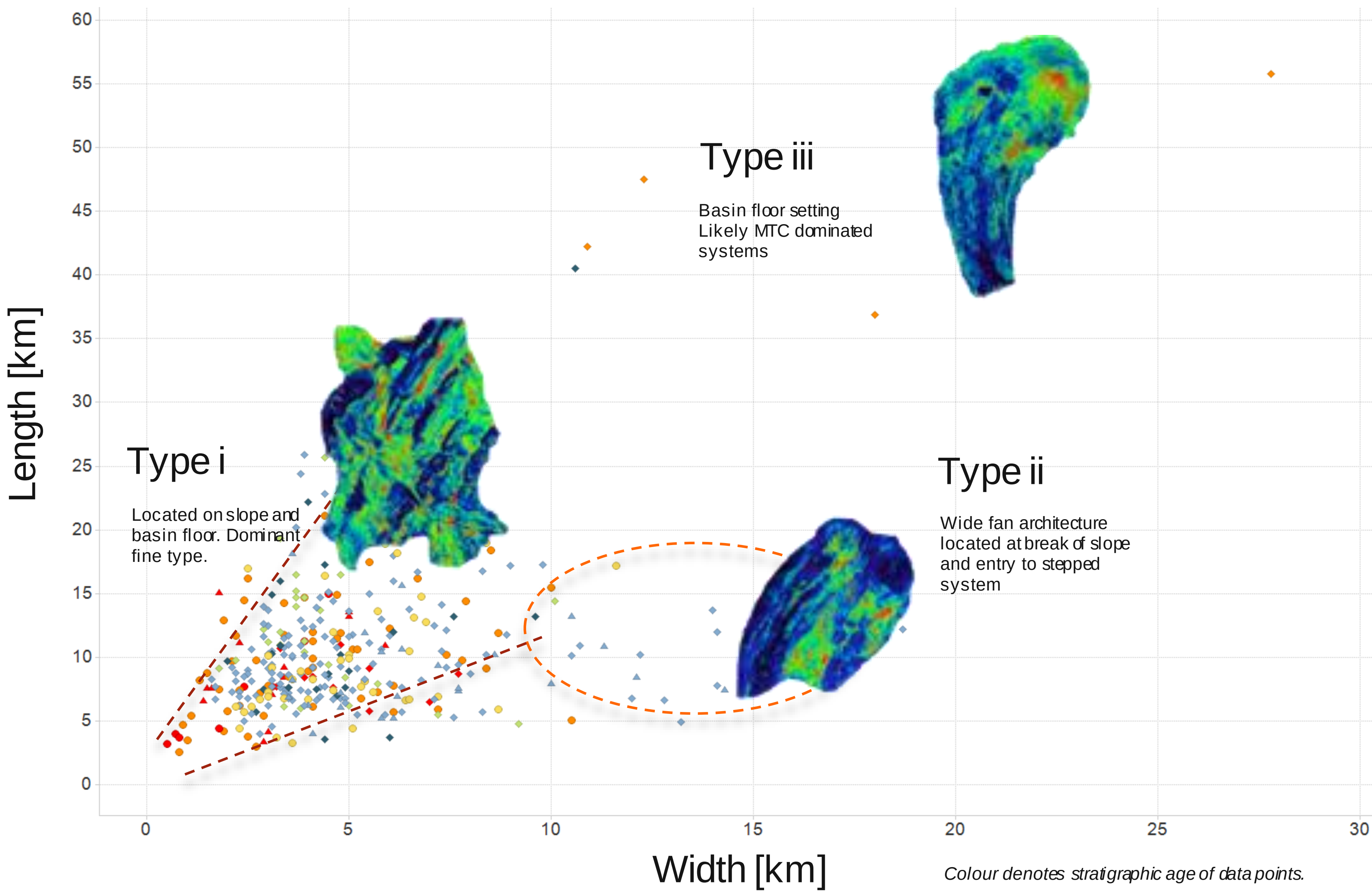

Figure 7: Identified Fan Architecture in the Brunei Deepwater. Observed fan sizes interpreted from window based seismic extractions.