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Modern morphology – ancient analogue: insights into deep water sedimentation on the active tectonic margin of West Sabah

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Abstract: The potential for long term growth of the EP sector within Sabah is heavily dependent on the successful exploration and development of the deep water Middle/Late Miocene-Pliocene turbidite play offshore West Sabah.

With the top ranking prospects in this frontier area all lying in water depths in excess of 900 m, a major challenge is to optimise the use of the limited available data in reducing reservoir related risks and developing new play concepts. This requires an understanding of the complex interaction of sedimentary and tectonic processes along this under-explored, active tectonic margin.

The application of analogues taken from the "classical" turbidite provinces (e.g. Gulf of Mexico) is not seen as directly applicable. There is an exceptionally large height differential of 7 km, over the relatively short distance of 200 km between the sedimentary hinterland and the base of the continental slope offshore West Sabah. This setting coupled with the intense and continued transpressional tectonic activity along the margin affords a different perspective on deep water sedimentation from the better known passive continental margins. As such new models and concepts are being developed to explain many of the observations noted within the area from both wells and seismic.

INTRODUCTION

Figure 1 shows SSPC's current strong acreage position with 2 strategic deep water blocks (Blocks G and J) covering a total of 6,328 km² in a water depth range from 150 m to 2,000 m. Within this area only 3 wells have tested the play and two of these wells, Keabangan-1 and Kinarut-1, have discovered hydrocarbons in exceptionally sand rich deep water deposits.

MODERN MORPHOLOGY

One of the methods employed has been the study of modern depositional processes as a potential analogue to the Miocene-Pliocene turbidite play. The study involved the establishment of a regional digital terrain model for the topography and bathymetry of the area. This extensive database (>100,000 km²) has been compiled from a variety of data sources including conventional 2D and 3D seismic, high resolution seismic, sonar, navigation charts and cartographic maps.

Figure 2, generated from this dataset, shows a 3D perspective view of the modern sub-marine and

sub-aerial morphology of Sabah. This figure highlights the proximity of West Sabah's mountainous hinterland, including the coastal Crocker Ranges and the 4,101 m high Mt. Kinabalu plutonic complex. This setting is in marked contrast to the better-known passive Atlantic margin settings (Fig. 3).

The submarine morphology is no less spectacular (Fig. 4). A broad 80-100 km shelf, currently the site of mixed clastic/carbonate sedimentation, passes beyond the shelf break into a steep continental slope. The average slope angle is > 2° (compared to < 1° in the GOM) but locally it can reach almost 10°.

The slope profile is heavily influenced by the shore-parallel thrust ridges, the dominant tectonic style for the outboard region (Fig. 5). In the proximal upper-slope setting the intra-thrust depressions have been filled and are now characterised by sediment by-pass features such as canyons, channels and slump scars. Many of these features are illustrated in detail on figure 6a and 6b, an illuminated bathymetric map of the Keabangan-Kamunsu 3D survey, straddling the current shelf margin and extending to water depths of 1,400 m.

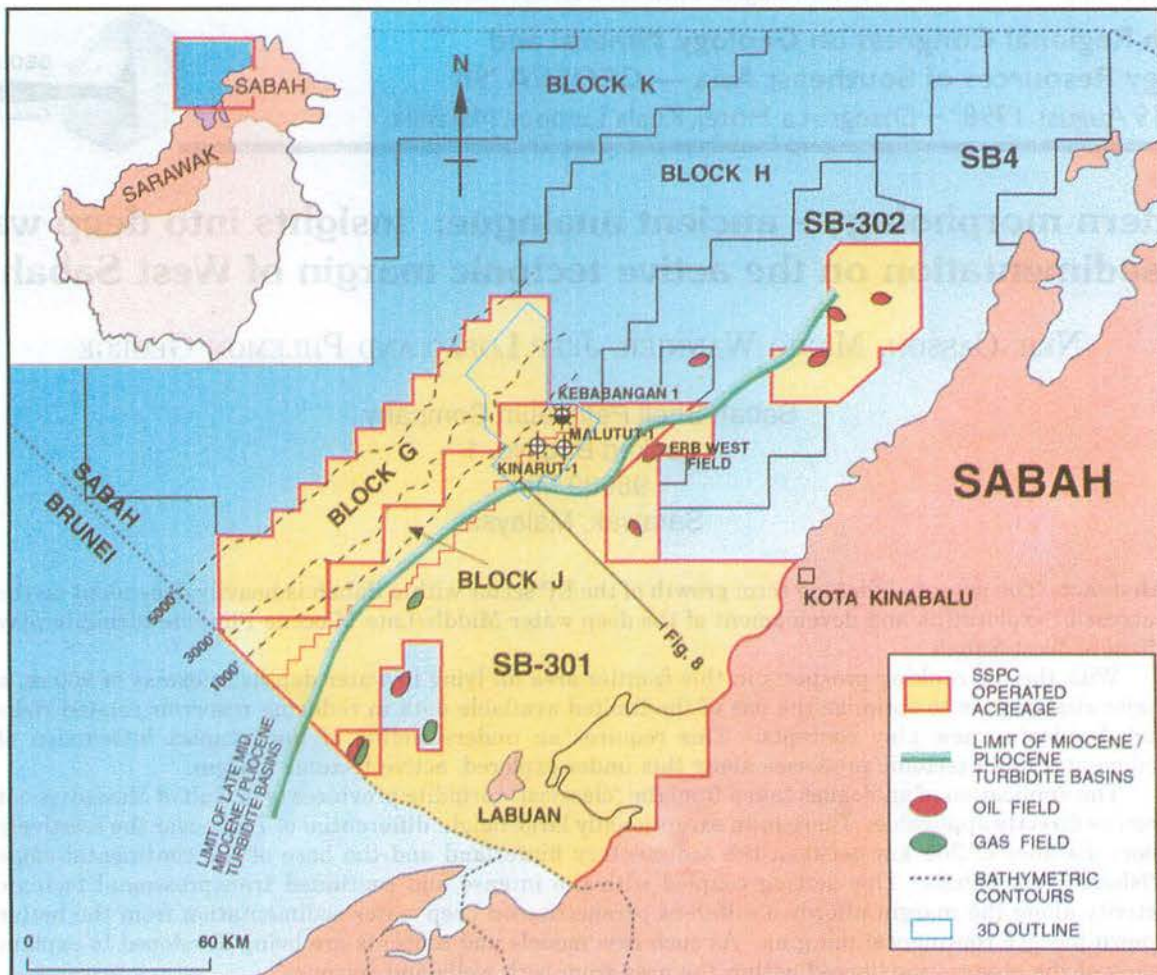


Figure 1. West Sabah situation map.



Figure 2. 3D visualisation of the NW Sabah digital terrain model. There is a 7 km height differential between the 4,101 m peak of Mt. Kinabalu and the 3,000 m deep NW Sabah Trough over a distance of just 200 km.

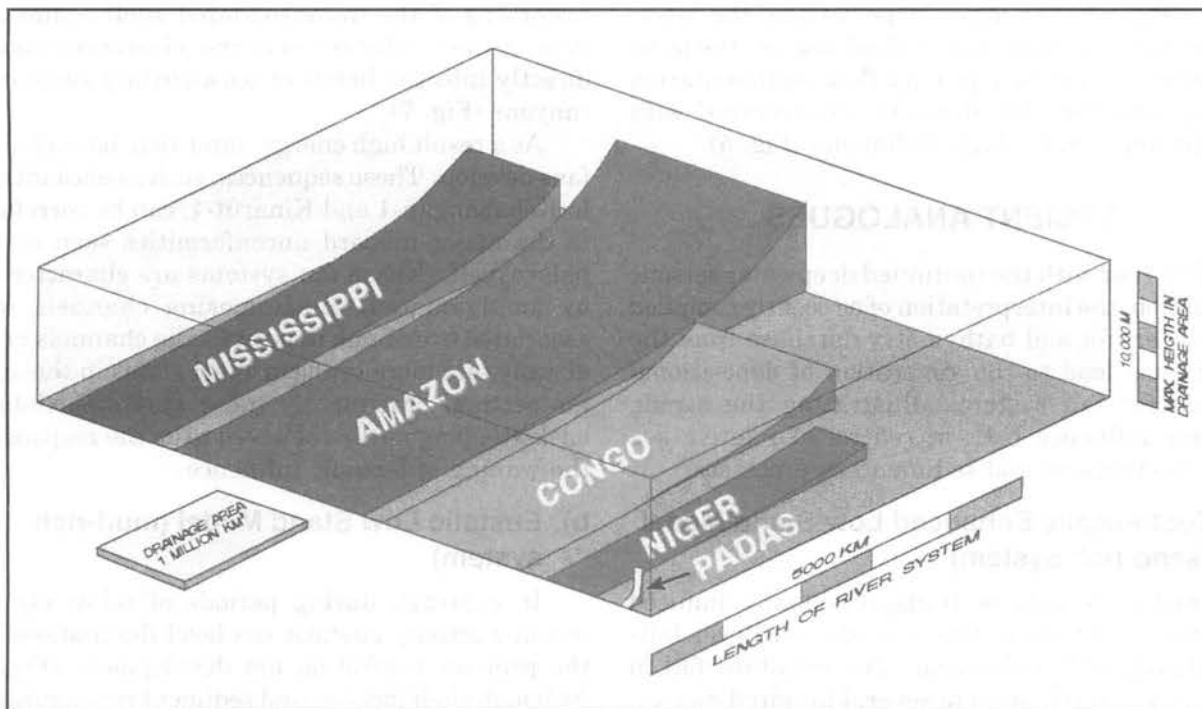


Figure 3. Comparison of river system statistics. The Padas is the largest of the many small river systems that drain the West Sabah hinterland. The comparison of the Padas with the major river systems feeding the passive Atlantic margin illustrates the dissimilarities between settings.

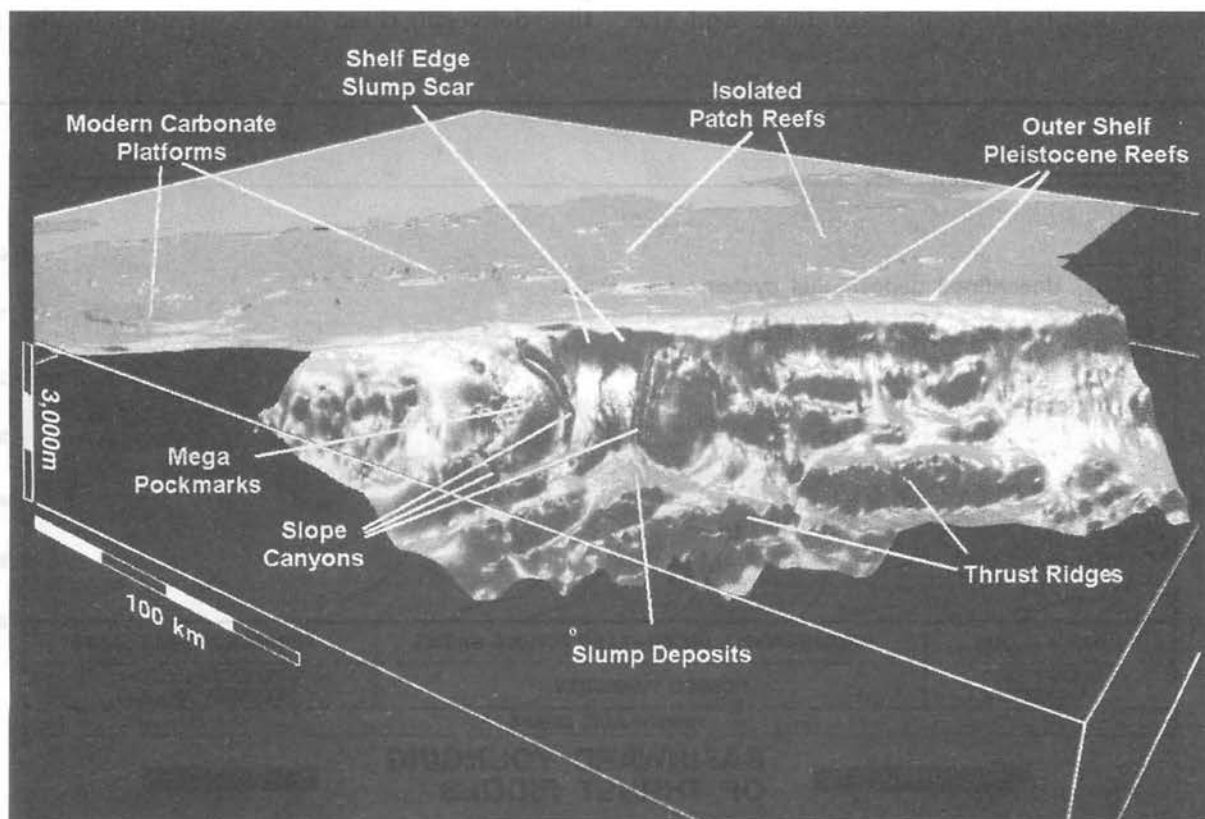


Figure 4. Visualisation of the West Sabah bathymetry. The broad shelf constitutes a mixed carbonate/clastic depositional setting during the current relative sea level high stand. The steep ($> 2^\circ$) slope shows many of the features that illustrate the interplay between tectonics (thrust ridges) and sedimentary processes (slumps, canyons, channels) along this active margin.

Distally, in the lower slope setting, the intra-thrust basins remain under-filled and are the focus of laterally confined gravity-flow sedimentation (slump and turbidite deposits) interspersed with pelagic and hemi-pelagic sediments (Fig. 5).

ANCIENT ANALOGUES

Together with the continued deepwater seismic evaluation, the interpretation of a recently compiled digital terrain and bathymetry database from the region has led to the generation of depositional models for fan systems illustrating the strong tectonic influence both in control of relative sea level fluctuations and sedimentary processes.

a) Tectonically Enhanced Low-Stand Model (sand-rich system)

During periods of transpressionally induced tectonic up-lift coincident eustatic sea level falls are significantly enhanced. The resultant fall in relative sea level, of up to several hundred metres, completely exposes the former shelf area. Remobilisation of the shelf sediments to the deep water is intense, with massive shelf edge failure and deep valley incision. River systems, now carrying an enhanced load as a result of the hinterland uplift, drop in base level and the

reworking of the unconsolidated shelf sediments, deposit their substantial coarse clastic component directly into the heads of back-cutting submarine canyons (Fig. 7).

As a result high energy, sand-rich, base-of-slope fans develop. These sequences, such as encountered in Keabangan-1 and Kinarut-1, can be correlated to the major inboard unconformities seen on the palaeoshelf. These fan systems are characterised by amalgamated, anastomosing channels with associated over-bank deposits. The channels grade distally into more uniform sheet sands in the outer fan setting. Frequently these systems exhibit a back-stepping nature believed to be the response to the waning of tectonic influence.

b) Eustatic Low Stand Model (mud-rich system)

In contrast, during periods of relatively low tectonic activity eustatic sea level fluctuations are the primary control on fan development (Fig. 8). Although shelf incision and sediment remobilisation is active the fall in relative sea level, without enhancement through tectonic uplift, is insufficient to entirely expose the shelf. River systems deliver their sediment to a narrow shelf and rely on shelf processes to bring sand to the shelf edge rather than delivering them directly to canyon heads. The

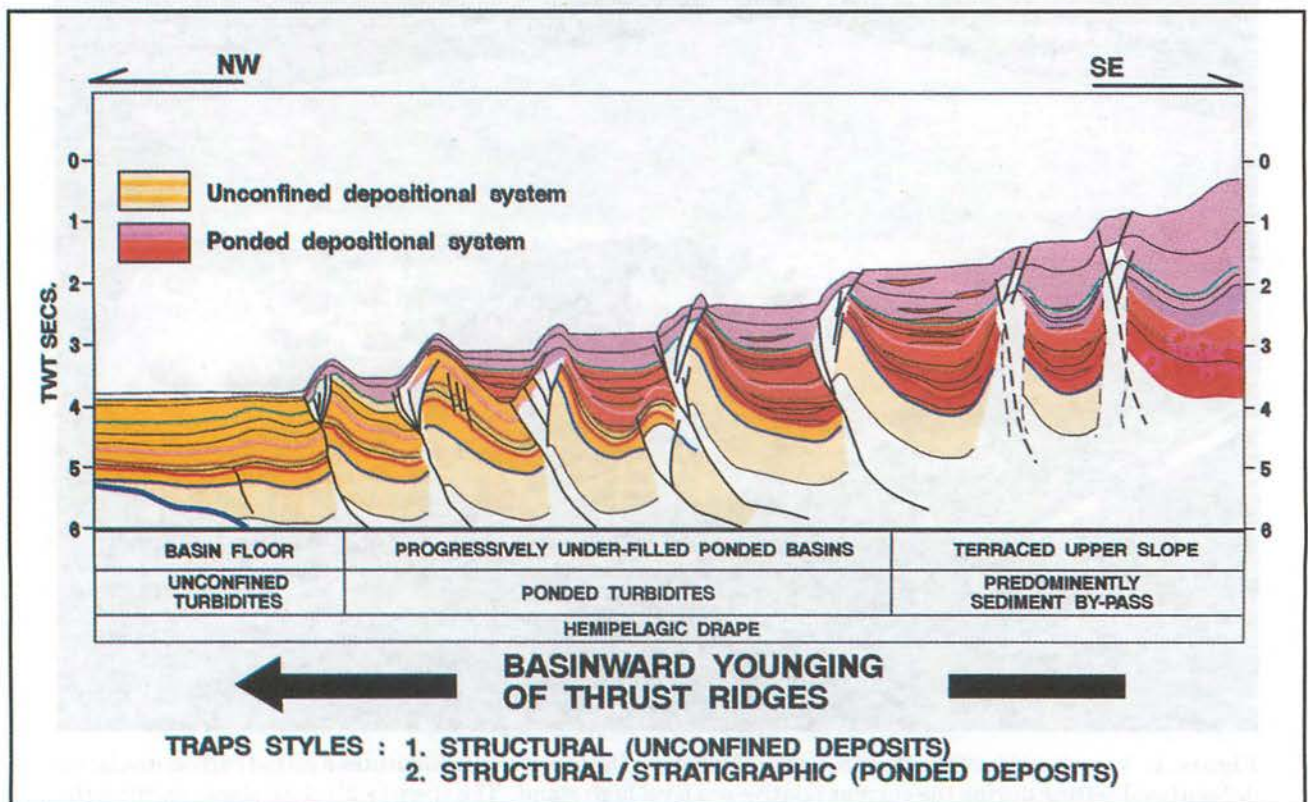


Figure 5. Tectono-sedimentary model for the West Sabah Middle/Late Miocene turbidite play.

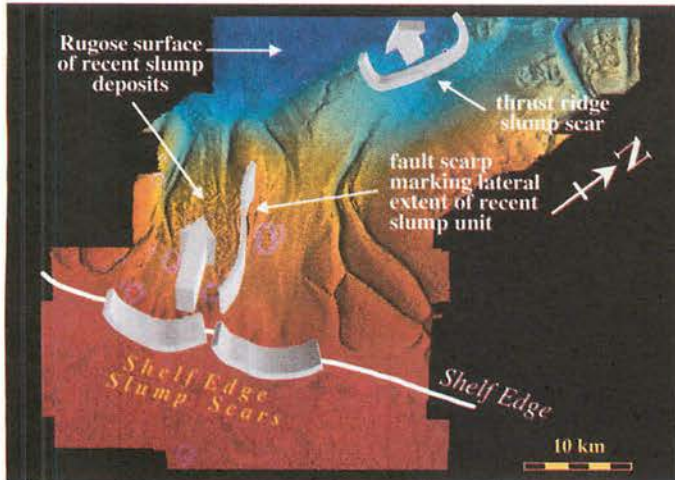


Figure 6a. Illuminated image of the sea floor from the Kebabangan Kamunsu 3D survey illustrating slump related features.

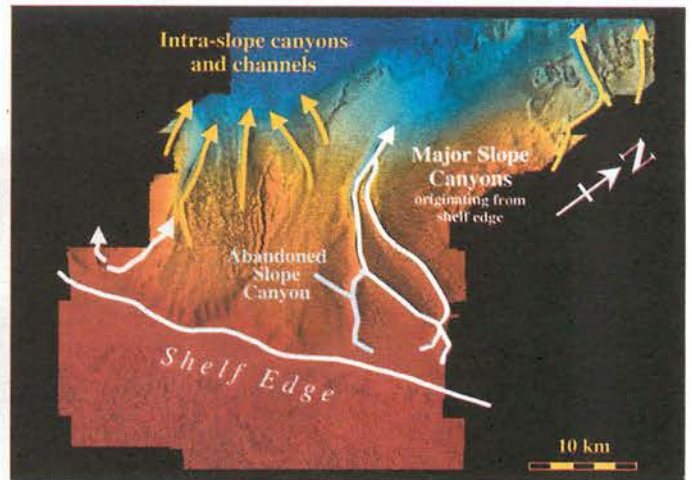


Figure 6b. Kebabangan Kamunsu 3D survey: submarine channels.

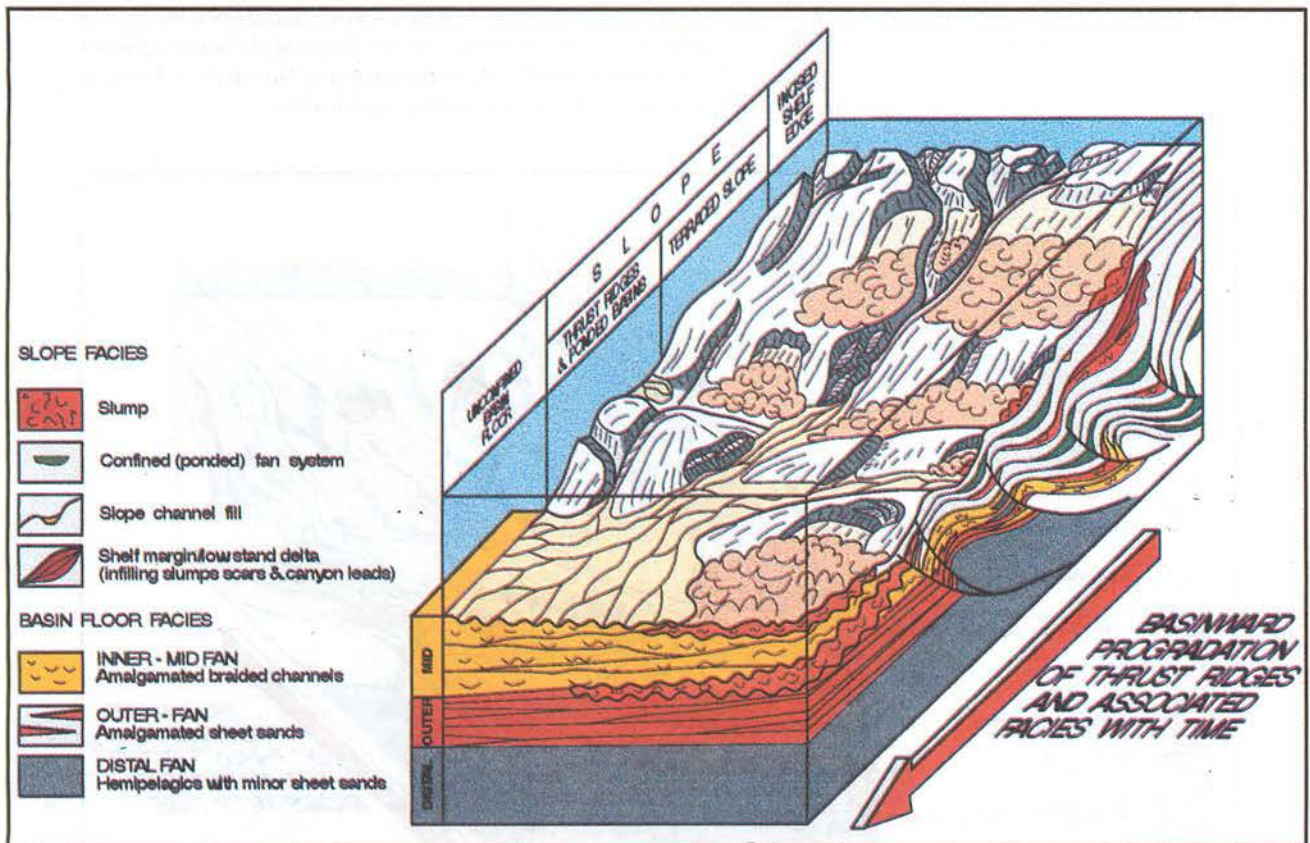


Figure 7. Tectonically enhanced low-stand model. Tectonic uplift of the inboard, shelf area during periods of transpression leads to total exposure of the pre-existing shelf. Shelf sediments are heavily re-worked through slumping and channel incision with river systems now delivering their sediment load directly to the canyon heads in the upper slope. The result is a high energy, sand-rich system.

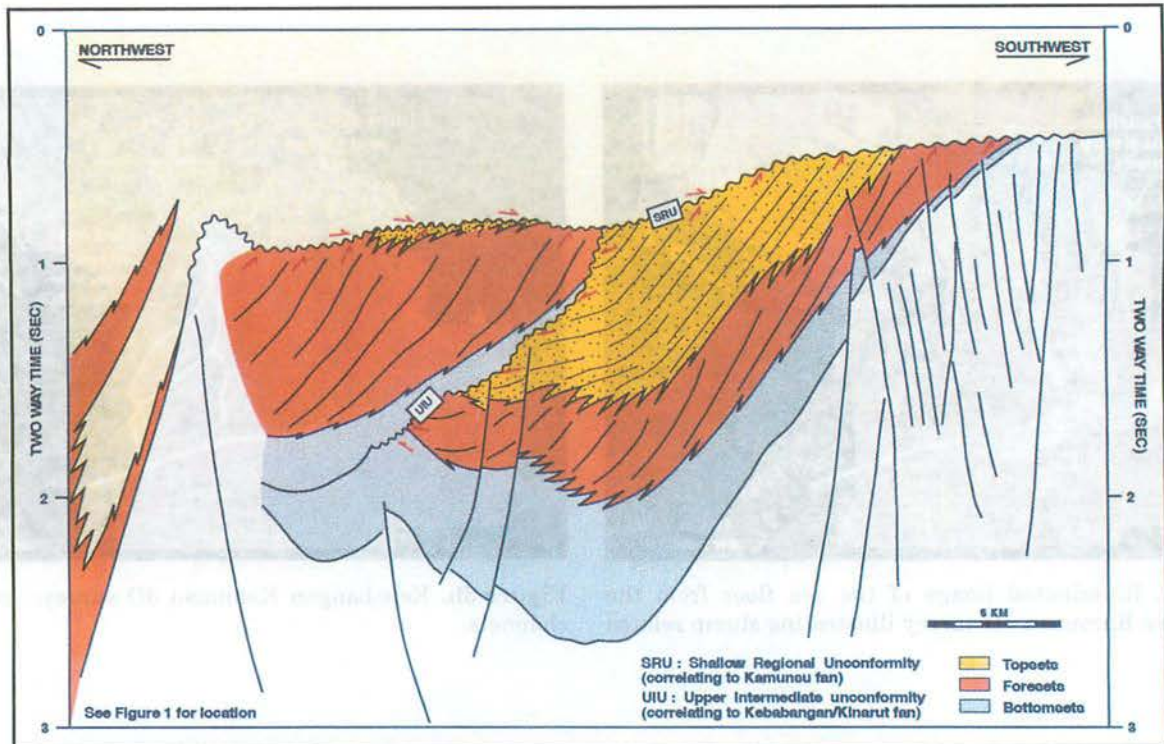


Figure 8. Simplified inboard Middle/Late Miocene seismostratigraphy. Extensive regional unconformities are the result of major inboard uplift. The unconformities are testimony to the large scale denudation of the former shelf during these “tectonically enhanced low stands”. Remobilisation of the shelf sediments gives rise to the subsequent high energy, sand-rich fan systems of the deep water area.

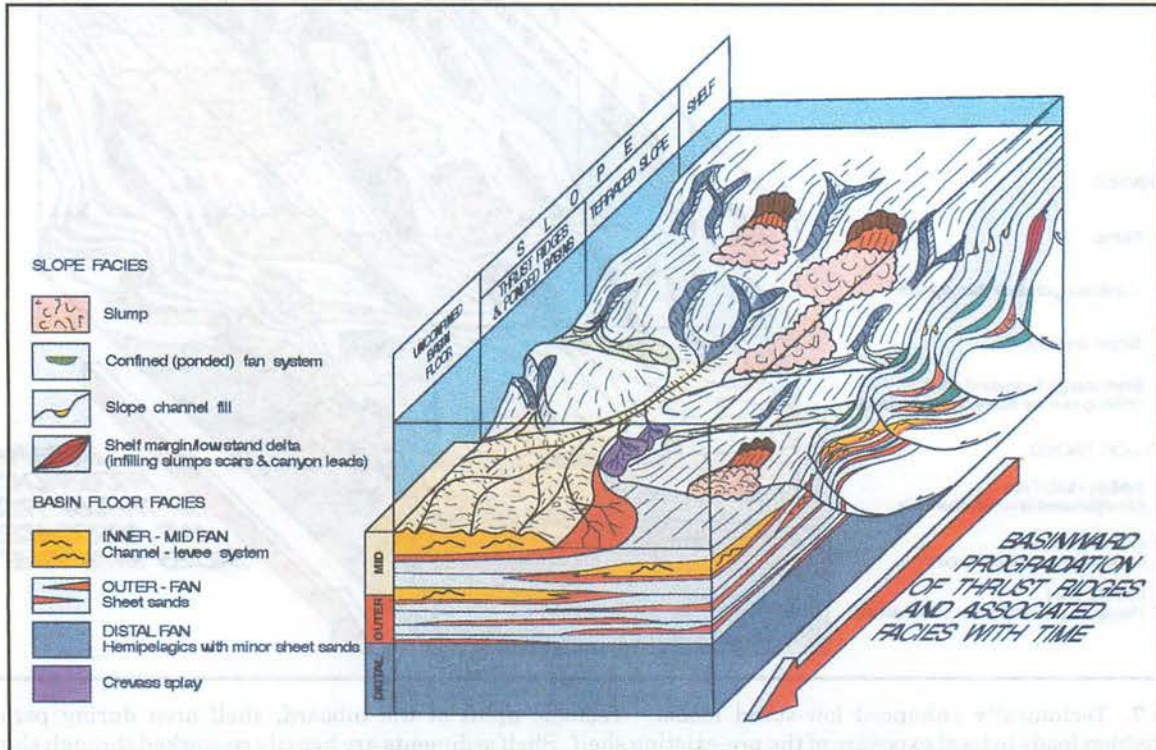


Figure 9. Eustatic low-stand model. Eustatic sea level fall alone results in partial exposure of the pre-existing shelf. Remobilisation of shelf sediments through slumping and channel incision is less intense. River systems now delivering their sediment load to a narrow shelf and rely on shelf processes (wave, tide and current action) to transport sand to the shelf edge. The result is a relative low energy, mud-rich fan system.

resulting fan systems are low-energy and mud rich, and are characterised by channel-levee systems in the mid-fan setting grading distally into discrete sheet sands. Although these systems can develop on the base-of-slope setting (Fig. 8) they are more frequently observed as intra-slope fans proximal to the shelf margin where established slope canyons/channels provide a conduit for the relatively limited supply of coarser clastic material.

SUMMARY

The active tectonic margin of West Sabah makes it a relative anomaly amongst turbidite provinces.

Continued transpressional tectonics, active since the Middle Miocene, have resulted in:

- a) a rugged, proximal hinterland for abundant sediment supply.
- b) a steep profile to the continental slope with high potential to deliver turbidite sands far offshore.
- c) periodic inboard uplift, leading to total shelf exposure and subsequent intense denudation of unconsolidated sediments and river capture (tectonically enhanced low-stands).
- d) a trigger for frequent mass gravity transport (slumps and turbidites) of sediment from the shelf edge and steep intra-slope area.

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