Petroleum Geology Conference & Exhibition 2003, December 17 – 18
Shangri-La Hotel, Kuala Lumpur, Malaysia

Tectonostratigraphy and trap styles of the Half-Graben sub-province in West Luconia, offshore Sarawak

Donald Sim & Guenter Jaeger

Sarawak Shell Berhad
Locked Bag No. 1
98009 Miri, Sarawak

Abstract: The Half-Graben sub-province in West Luconia, offshore Sarawak is characterised by a series of NNW trending, SW dipping extensional faults, creating significant sub-basins within the half-grabens. Structural extension is interpreted to have taken place mainly during the Middle Miocene. The timing is supported by age dating of tilted syn-rift carbonate wedges at the base of the half-graben. These carbonates probably drowned as a result of the half-graben formation and the related rapid subsidence and influx of clastics. Middle Miocene fluviomarine to shelfal sediments later filled the half-grabens. The beginning of the Upper Miocene coincides with the end of rifting. Post-rift sediments in this area are separated by two main hiatuses: the Upper Miocene (SB 3.1, ~10.6 Ma) and the Lower Pliocene (SB 3.4, ~5.6 Ma) unconformities, which are consistently observed throughout the study area. They can be identified by the presence of lowstand features such as erosional truncations and channel incisions. Thick, seismically transparent transgressive shales lie above the unconformities. Pliocene to Recent fluviomarine to shelfal sedimentation is dominated by sea-level fluctuations; evidence of the latest lowstand is still present in the form of a sea-bottom trough/channel, which is interpreted as the Proto Rajang/Lupar River. The Miocene-Pliocene boundary was also the time of the last major structural deformation during, which large, highly faulted, anticlinal structures formed locally within the NW part of the area. The origin of these anticlines may be attributed to wrench related inversion on some of the extensional faults. The structural and sedimentation history of the area produced a variety of trapping configurations and a diverse portfolio of leads.

INTRODUCTION

In 2002, Sarawak Shell Berhad signed a Technical Evaluation Agreement (TEA) for the block SK303, which is located on the eastern side of the marine border between Sarawak and Indonesia (Figure 1). Shell's NW Borneo Basin Framework Study, completed in 2003, has provided the regional context for the structural setting of the half-graben sub-province, and has resulted in further insights into the complex geological history of West Luconia.

GEOLOGICAL SETTING

SK303 is located at the intersection of three major geological provinces (PETRONAS, 1999), namely; the Tatau province, which comprises the West Luconia-Tatau Basin, the SW Sarawak province in the SW of the block and the West Luconia Rim, which is part of the West Luconia Delta to the north (Figure 2). The fact that the area is a juncture of major geological provinces gives rise to the structural complexity of the area.

Figure 2 shows a map of the 'economic' basement that covers all of Sarawak's offshore basins and the Tinjar onshore basin. The 'economic' basement is defined as the surface, below which no hydrocarbon reservoirs are expected to be found. SRK Consulting (Teasdale *et al.*, 2002) generated the map using all available data such as gravity and magnetic, seismic, wells, regional understanding and structural control.

The West Luconia Delta to the north of SK303 features prominently on this map as a major depocentre bounded by two relatively stable tectonic provinces, the carbonate-prone Central Luconia Province to the east and the Natuna Arch to the west. In fact an extension of the Central Luconia carbonate Province can be found in the NE part of SK303 where carbonate reefs of equivalent age have been found. The West Luconia-Tatau Basin in the SE is characterised by a series of NNW trending, SW dipping extensional faults. These faults create major half-grabens, with throws of up to five kilometres, which were later filled by Middle to Late Miocene fluviomarine sediments.

TECTONIC EVOLUTION

The Palaeocene to Eocene boundary marks the onset of the collision between India and Eurasia (Figure 3). The collision forced a dominant N-S compression across South-East Asia (Tapponnier *et al*., 1986, in Teasdale *et al*., 2002), and initiated the subduction of the Proto South China Sea

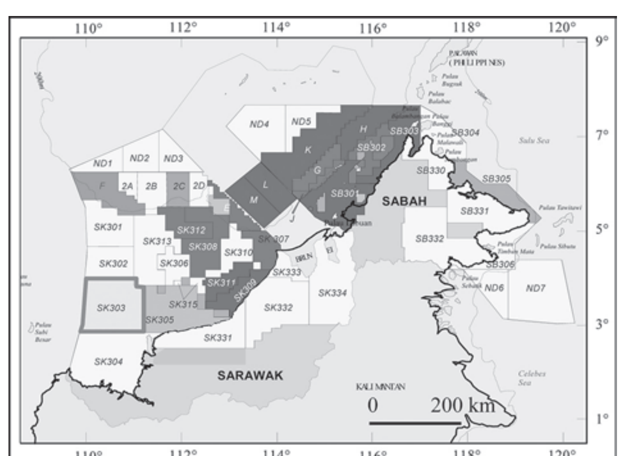

Figure 1. Sabah and Sarawak exploration acreages.

beneath the southern part of Borneo and northern Meratus Terrane (Sarawak Orogeny). This event also caused extensive deformation upon the Rajang Group sediments overlying the basement fabric. The collision established the framework controlling the formation of younger major basins in Sarawak, as well as the basement architecture of NW Borneo until the present day. Younger tectonic events merely reactivated the structures formed during the Sarawak Orogeny.

The N-S compression across South-East Asia persisted until the Lower to Middle Miocene. At the same time, the Australian continent had been moving northwards steadily until it finally collided with South-East Asia during the Early Miocene (Figure 4). The combination of the north moving Australian plate and the west moving Pacific plate created a left-lateral strike-slip system across South-East Asia (Ben-Avraham & Emery, 1973, in Teasdale *et al.*, 2002). Oblique E-W compression as the result of this change in structural style reactivated the Proto-South China Sea subduction zone and eventually led to the closure of the Proto-South China Sea. A direct result of the left-lateral strike-slip movement also caused the opening of pull-apart basins in NW Borneo margin as well as the reactivation of basement thrust faults into half-graben forming extensional faults in the Half-Graben sub-province.

The last phase of major structural deformation in West Luconia is believed to have taken place during Upper Miocene to Pliocene, and is related to the continued northward push of the Australian continent. Inversion of existing faults produced large rollover structures in younger Middle Miocene sediments.

STRUCTURE AND STRATIGRAPHY

The Half-Graben sub-province is characterised by a series of NNW trending half-grabens formed from a series of SW dipping extensional faults. These half-grabens are believed to have formed during the Middle Miocene by reactivation of SW dipping Eocene thrusts. Although made up of several half-grabens, the Half-Graben sub-province has two distinct major NW trending parallel half-grabens, namely the NE Half-Graben and the SW Half-Graben (Figure 5).

The pink horizon (SB 2.1) has been mapped as the base of the Half-Graben fill, and marks the onset of the rifting at the end of the Early Miocene. The timing is supported by the observation of tilted carbonates interpreted as the blue horizon on the seismic section and being calibrated to wells in the area. These Middle Miocene carbonates occur at the base of the half-graben fills and are clearly early syn-rift deposits.

The overlying syn-rift section of the half-grabens is made up of mainly fluviomarine sediments of Middle Miocene age. The Base of Upper Miocene unconformity (SB 3.1) is mapped as the green horizon on the seismic section. It is a clear regional unconformity that marks a major lowstand typified by erosional truncations and

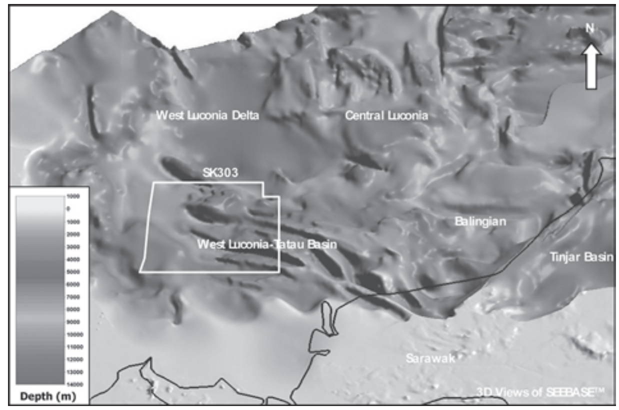

Figure 2. Sarawak basin architecture. Colours indicate depth to economic basement.

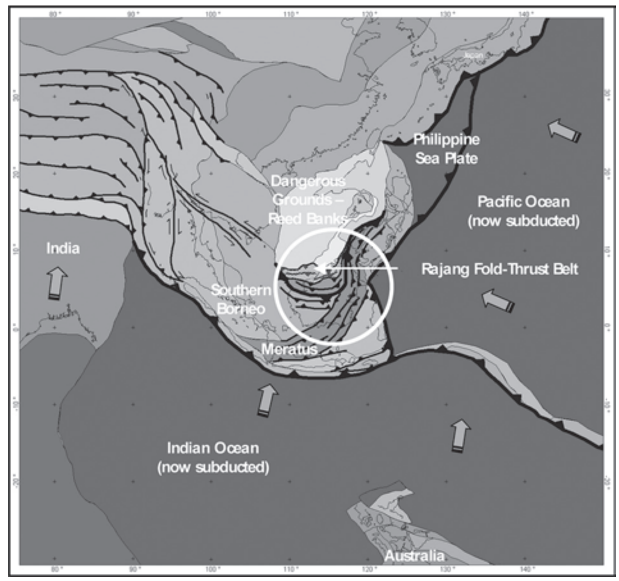

Figure 3. Tectonic evolution of South East Asia during the Palaeocene to Eocene.

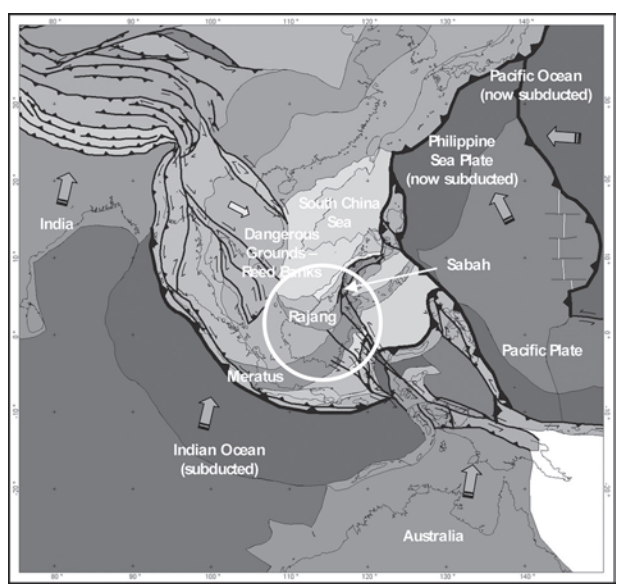

Figure 4. Tectonic evolution of South East Asia during the Lower to Middle Miocene.

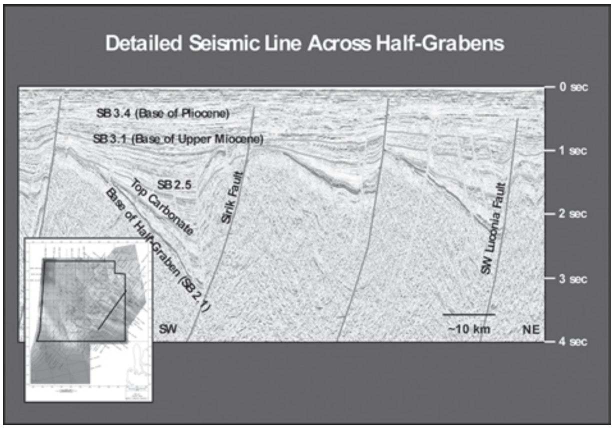

Figure 5. Seismic line across the two major half-grabens. Inset map shows the depth map of the base of half-graben (SB 2.1) and the black line on the map shows the seismic line orientation. Warm colours are shallower and the cool colours are deeper.

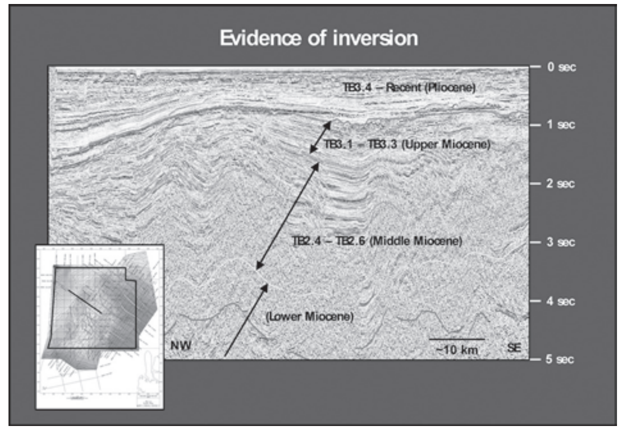

Figure 6. Seismic line across an inverted rollover anticline. Inset map shows the depth map of the base of Pliocene (SB 3.4) and the black line on the map shows the seismic line orientation. Warm colours are shallower and the cool colours are deeper.

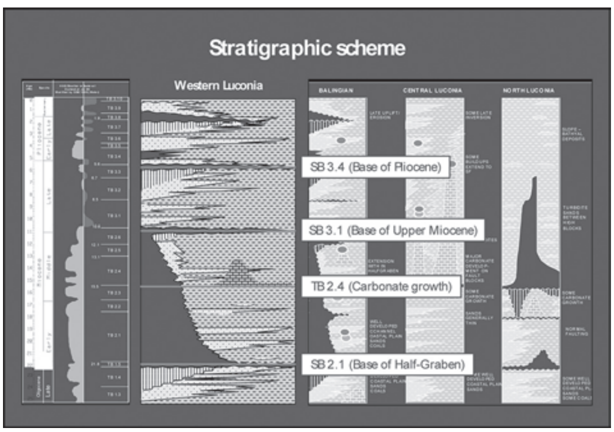

Figure 7. Stratigraphic scheme of West Luconia and other major provinces in offshore Sarawak.

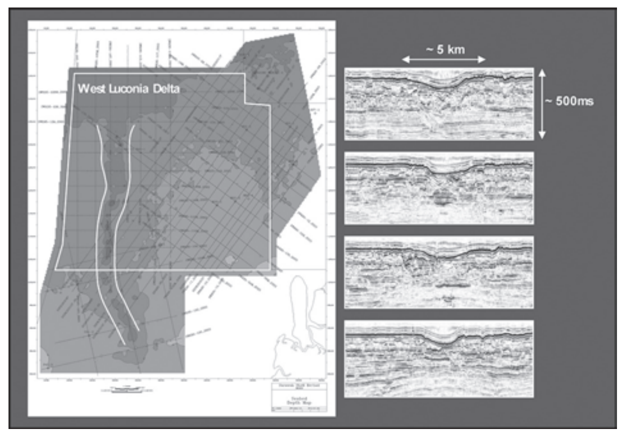

Figure 8. Present-day seabed map of West Luconia showing the Proto Rajang/Lupar River flowing into the West Luconia Delta. Seismic sections on the right are cross section examples across the seabed channel.

incised channels overlain by a transparent package of marine shales indicating the subsequent rise in sea level.

A second, and even more pronounced, regional unconformity occurs at the Base of the Pliocene (SB 3.4) that is the yellow horizon on the seismic section of figure 5. Again, the lowstand is typified by erosional truncations and incised channels, overlain by thick layers of transgressive marine shales. However, there were clearly several episodes of sea level fluctuations during Upper Miocene to Pliocene, as younger erosional features at times appear to cut into and rework the earlier erosional features.

The most recent major structural deformation is interpreted to have occurred during the Upper Miocene to Pliocene and resulted in inversion features observed on seismic (Figure 5). These are not very pronounced in the Half-Graben sub-province but are very obvious further NW towards the West Luconia Rim (Figure 6). Two inversion events may have taken place, an earlier inversion during the end of the Middle Miocene, reflected in thickness variations in the core of the larger anticline and a later one during the Pliocene (red horizon on seismic) producing a large rollover anticline of some 20 kilometres across. The Pliocene sequence consists of mainly fluviomarine to shelfal sediments. Figure 7 shows a summary of the stratigraphy of the area.

The present day seabed expression shows a major N-S trending channel of several kilometres wide and 50-100 metres deep (Figure 8). This channel is believed to be caused by the Proto Rajang/Lupar River that was feeding sediments from the Sarawak hinterland to the West Luconia Delta during the last major lowstand when the coastline was further to the north compared to today. It may be that this channel has been supplying the West Luconia Delta with sediments for much longer than just the recent lowstand.

TRAP STYLES

As a result of its complex geological and structural evolution, block SK303 comprises of a diverse portfolio of trap styles (Figure 9). To the NE, the classic carbonate reef build-ups typical of Central Luconia are present; in

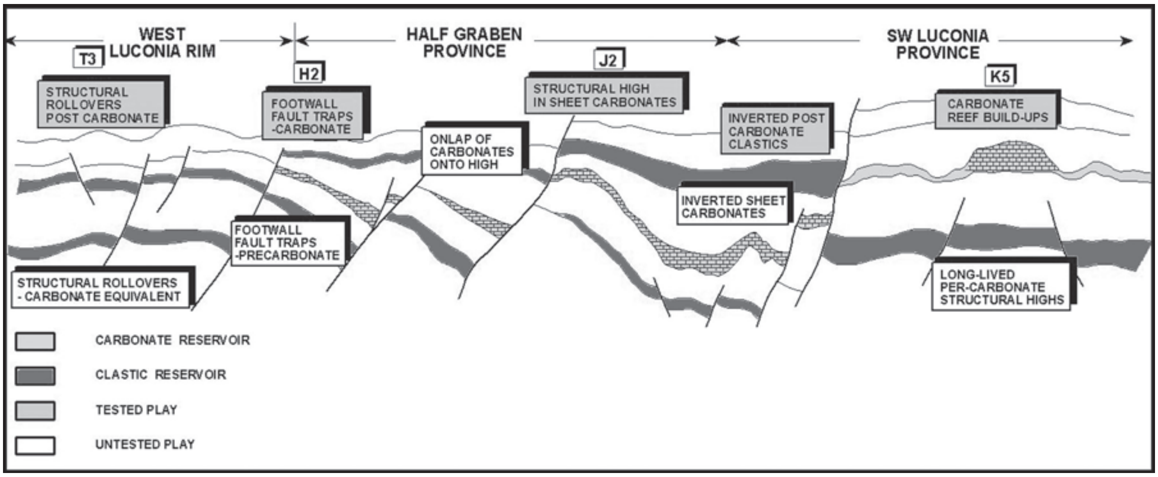

Figure 9. Schematic diagram showing trap styles in the area.

fact they represent the edge of the Greater Luconia Carbonate Platform (Figure 10). Southwards to the Half-Graben sub-province, carbonates occur as tilted sheet carbonates. As a result of rapid subsidence in the half-grabens these carbonate factory shut off early and no build-ups could form. The main trap styles here are footwall/ hanging wall traps of tilted or inverted thin carbonate platforms. Stratigraphic traps might occur where potentially porous carbonates pinch-out updip within the half-grabens.

The most common post-carbonate traps are typical rollover anticlines formed during the late inversion phase. One such example is shown on Figure 6 and is a proven hydrocarbon trap. The reservoir was deposited during the Late Miocene and the structure was formed during the subsequent Pliocene inversion.

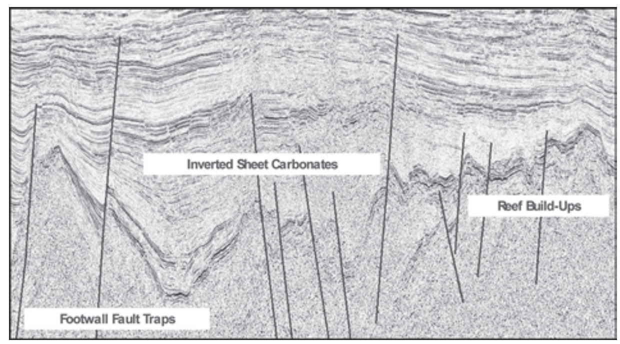

Figure 10. Seismic section showing different types of carbonate trapping styles.

CONCLUSIONS

Block SK303 in West Luconia is located at the intersection of three main geological provinces. Consequently, it has a complex geological and structural history, which is reflected in the stratigraphy as observed in the area and in a variety of trap styles. The recently completed NW Borneo Basin Framework study by Shell has greatly improved our regional understanding of NW Borneo Shelf and it provides a framework for more detailed evaluations of specific basins in NW Borneo.

ACKNOWLEDGEMENT

The authors would like to thank Sarawak Shell Berhad and PETRONAS for granting the permission to present and publish this paper. The authors also acknowledge and thank the reviewers for their constructive comments. Appreciation is also expressed to SRK Consulting for their contribution on the tectonic evolution of South East Asia and regional structural framework of NW Borneo.

REFERENCES

BEN-AVRAHAM, Z. & EMERY, K. O., 1973. Structural framework of Sunda Shelf. *The American Association of Petroleum Geologists Bulletin* 57, 12, 2323-2366.

PETROLIAM NASIONAL BERHAD (PETRONAS), 1999. *The Petroleum Geology and Resources of Malaysia*, ISBN 983-9738-10-0, 665p.

TAPPONNIER, P., PELTZER, G. & ARMIJO, R., 1986. On the mechanics of the collision between India and Asia. *In*: Coward, M.P. and Ries, A.C. (Eds.), *Collision Tectonics, Geological Society Special Publications* 19, 115-157.

TEASDALE, J. P. *ET AL.*, 2002. SE Asian regional studies: NW Borneo – South China Sea. SRK Confidential Report to Shell.

Manuscipt received 17 June 2004
Revised manuscript received 9 October 2004