Geol. Soc. Malaysia, Bulletin 14, December 1981; pp. 1–18

Baram Delta Geology and Hydrocarbon Occurrence

E.J.H. RIJKS
(Sarawak Shell Berhad, Lutong, Sarawak)

Abstract: The Baram Delta Province constitutes a relatively small part of Sarawak's offshore acreage in East Malaysia, but contains the bulk of oil reserves so far discovered by Shell in their contract area.

These reserves are distributed over 11 fields of which only one, the Miri field, discovered in 1910, is situated on land.

The Baram Delta depocentre developed during the Late Eocene and from early Middle Miocene onwards is characterized by various regressive phases of clastic sedimentation.

The tectonic style of the Baram Delta shows the interaction of two types of deformation:

(a) gravity induced growth faults, generally hading to the north and arcuate in shape.

(b) compressional folds with NE—SW trending axes which originated during late Upper Miocene.

All fields are located at the intersection of the growth faults and the anticlinal trends.

INTRODUCTION

The Baram Delta Province in Sarawak, East Malaysia (Fig. 1) is a Tertiary basin, which developed in Late Eocene times after orogenic uplift and folding of Cretaceous to Eocene eugeosynclinal sediments.

The basin is separated from the more stable Central Luconia Province to the west by a major NW—SE trending hinge line related to basement faulting across which sedimentary thicknesses decrease dramatically. Towards the east the Brunei Border forms the acreage boundary.

The Baram Delta Province forms part of Sarawak Shell's total contract area and comprises (1-1-1981) 8 production subblocks and 9 exploration subblocks (Fig. 2).

A total of 11 oil fields and 2 gas fields have been discovered.

The main prospective sequence consists of regressive Neogene sediments deposited in a lower coastal plain and coastal environment. Sedimentation was accompanied by synsedimentary growth faulting, providing early traps for generated hydrocarbons. At a later stage, the structural picture became more complex due to a phase of compressional folding.

This paper is intended to give a brief account of the exploration history, stratigraphy, tectonic aspects and hydrocarbon habitat of the Baram Delta Province.

Presented at GSM Petroleum Geology Seminar 1980.

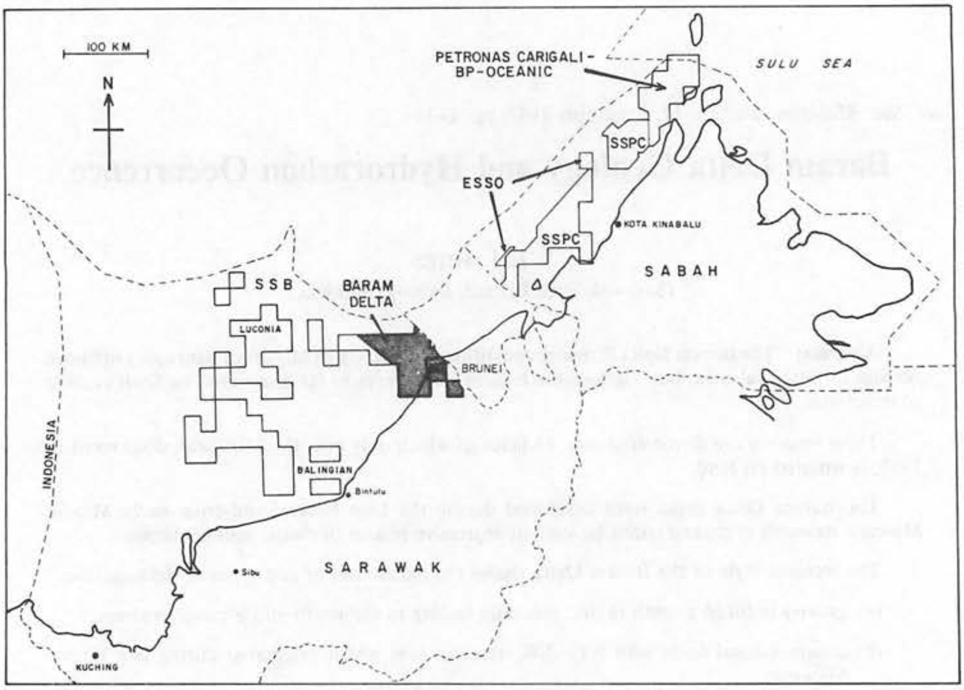

Fig. 1. SSB/SSPC Contract area (1.1.1981).

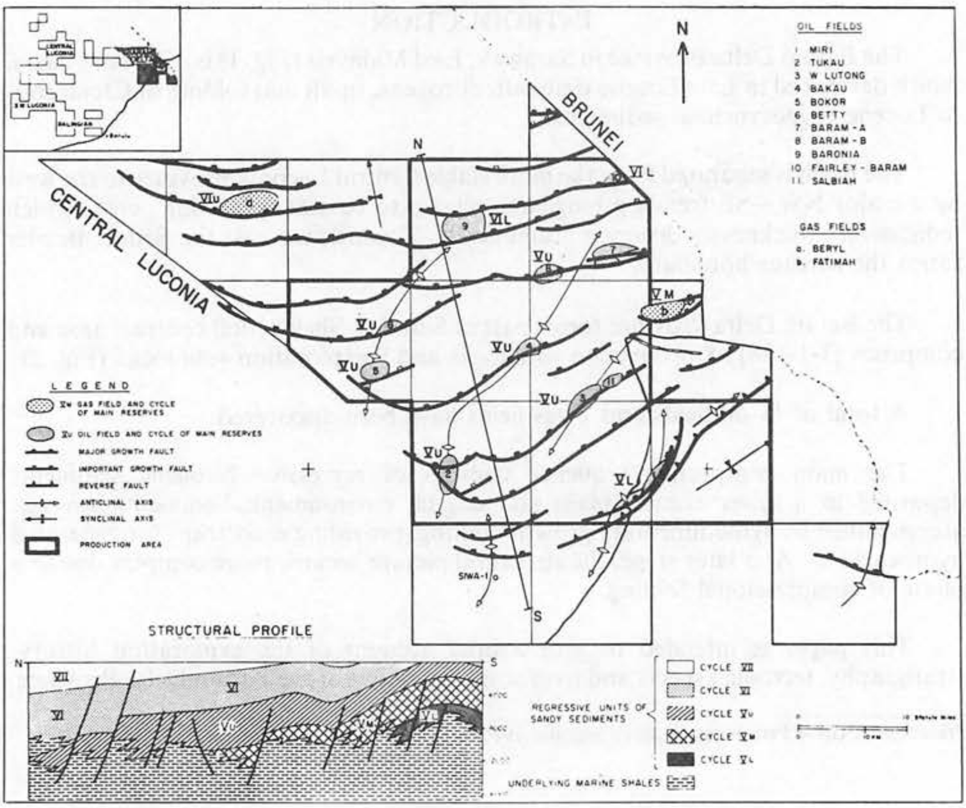

Fig. 2. Baram delta play map.

EXPLORATION HISTORY

Shell's early discovery in 1910 of the onshore Miri field in Sarawak, initiated a long and intriguing period of hydrocarbon exploration in NW Borneo. In the Miri field alone, 612 wells have been drilled of which 585 were drilled before 1931. The field, a much faulted anticline, reached a peak production of ca. 15,000 b/d in 1929 and was finally abandoned in 1972 (Fig. 3).

Despite intensive wild-catting in the early decades, no further commercial discoveries were made in Sarawak's land acreage, and when in 1950 marine seismic surveys became feasible, the emphasis of exploration activity shifted increasingly offshore.

The first offshore well was drilled in 1957 on the Siwa structure. No hydrocarbons were discovered in Siwa-1, but the well proved that the structural trend of the Miri anticline continued south-westwards into the sea.

The first commercial offshore discovery was made in 1963 by the well Baram-1 (Baram-A field).

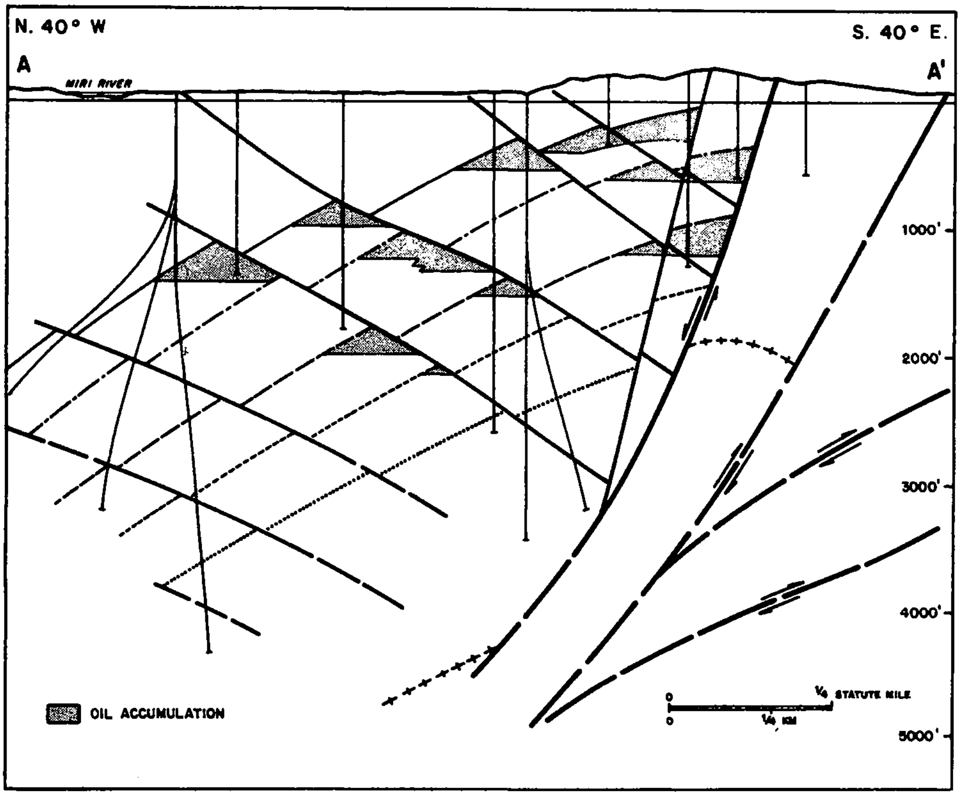

Fig. 3. Miri field—cross section.

In the following years, exploration drilling in the offshore Baram Delta Province proved to be highly successful. The bulk of the present reserves were found in the period 1966–1968 when the West Lutong, Tukau, Baronia, Baram-B and Betty fields were discovered. During the seventies, exploration drilling continued and resulted in the discovery of the smaller offshore fields namely: Bakau, Bokor, Fairley Baram and Salbiah (Fig. 2).

On land renewed activity remained unsuccessful.

To date, some 70 years after the first discovery in well Miri-1, Sarawak Shell's exploration activities still continue. It is realised that in the Baram Delta, a mature oil province, the more important hydrocarbon accumulations have already been found. However modern high quality seismic recording techniques together with sophisticated processing methods will probably determine additional drillable targets. Although these targets are expected to be relatively small, they could, under the present day circumstances, represent economically viable prospects.

STRATIGRAPHY AND SEDIMENTARY CYCLES

The Tertiary sedimentary basin of Sarawak is bounded by an orogenic belt, which is situated along the southern border of Sarawak. These mountains, which were uplifted during Eocene times, form the source for the thick post-orogenic sedimentary sequence deposited in the Sarawak basin.

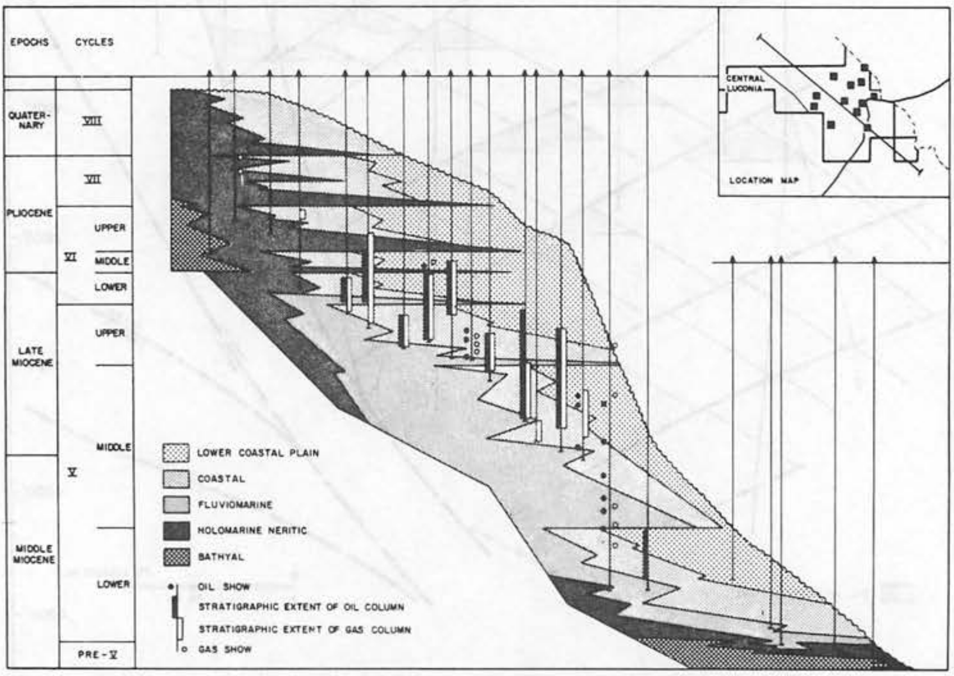

Fig. 4. Baram delta—stratigraphy and hydrocarbon occurrence.

The stratigraphy (Fig. 4) of this sequence is based on a subdivision of eight major sedimentary cycles. These cycles have been recognised by the presence of rapid and widespread transgressions, which interrupted the overall regressive sedimentation (Ho Kiam Fui, 1978). In pre-Miocene times, during a period of approximately 20×10^6 years, when Cycles I to IV were deposited, sedimentation in the Barak Delta Province took place under deep marine conditions. The resulting sequence of marls, silts and shales, up to 2286 m (7500 ft) thick, was penetrated by a number of land wells.

From Middle Miocene times onwards during Cycles V to VIII, environmental changes resulted in the shallowing of the basin and development of a prominent deltaic setting (Fig. 5).

The Cycle V sequence (Middle-Late Miocene) is present in the southern and middle part of the Baram Delta Province. Cycle VI (Late Miocene-Early Pliocene) occurs principally in the northern part where the sediments of this Cycle thicken dramatically across a major growth fault trend, along which the important Baronia field is situated.

The Cycles VII and VIII (Late Pliocene-Quaternary) developed across a number of growth faults in a north-westerly direction.

Sedimentation under deltaic condition is controlled by the ratio between the rate of deposition (Rd) and the rate of subsidence (Rs) of the basin and has been extensively covered in the literature.

The description of the important variations in the Rd/Rs ratio as studied in the Gulf Coast (Curtis, 1970) and in the Niger Delta (Evamy *et al.*, 1978) is also applicable to the Baram Delta Province and is summarised below (Fig. 6):

(1) $Rd/Rs > 1$: **Regressive Phase**
The delta is building out (prograding). Continental, paralic and marine sediments and deposited diachronously in a subhorizontal way (Fig. 7a).

(2) $Rd/Rs \approx 1$: **Equilibrium Phase**
The delta builds upwards. Continental, paralic and marine sediments are stacked subvertically in a restricted belt.

(3) $Rd/Rs < 1$: **Transgressive Phase**
The delta is receding. Marine shales transgress in a shorewards direction. These transgressive phases form the basis for differentiation between different cycles and subcycles as recognised by Sarawak Shell Berhad in their Sarawak acreage (Fig. 7b).

The recognition of a cycle or a subcycle can therefore be based on the following criteria:

(1) The base coincides with a regional transgression, —usually a marine shale on top of fluvial or coastal sands. ($Rd/Rs < 1$).

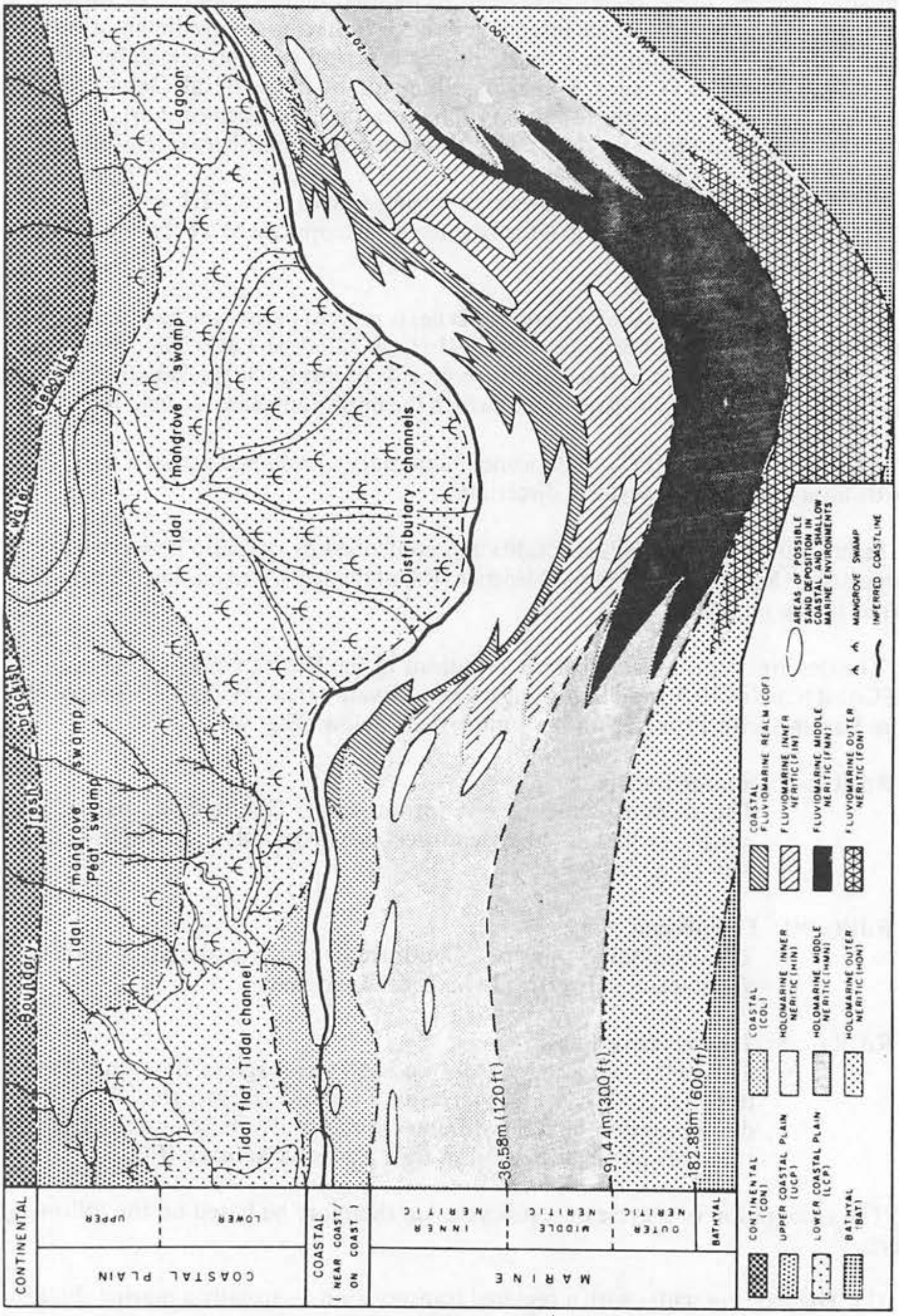

Fig. 5. Schematic outline of NW Borneo environmental units.

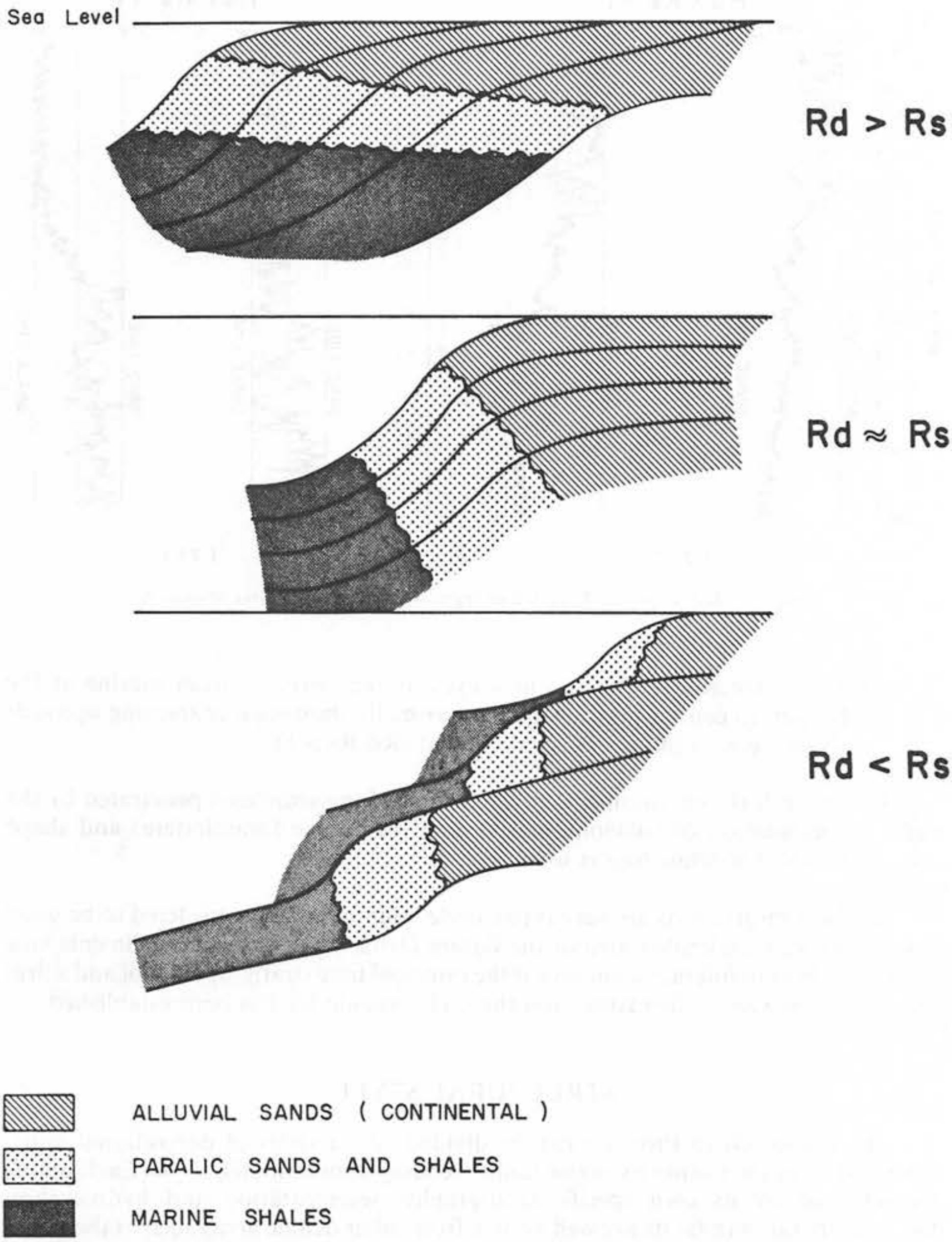

Fig. 6. Conceptual models of deltaic sedimentation (after Curtis, 1970).

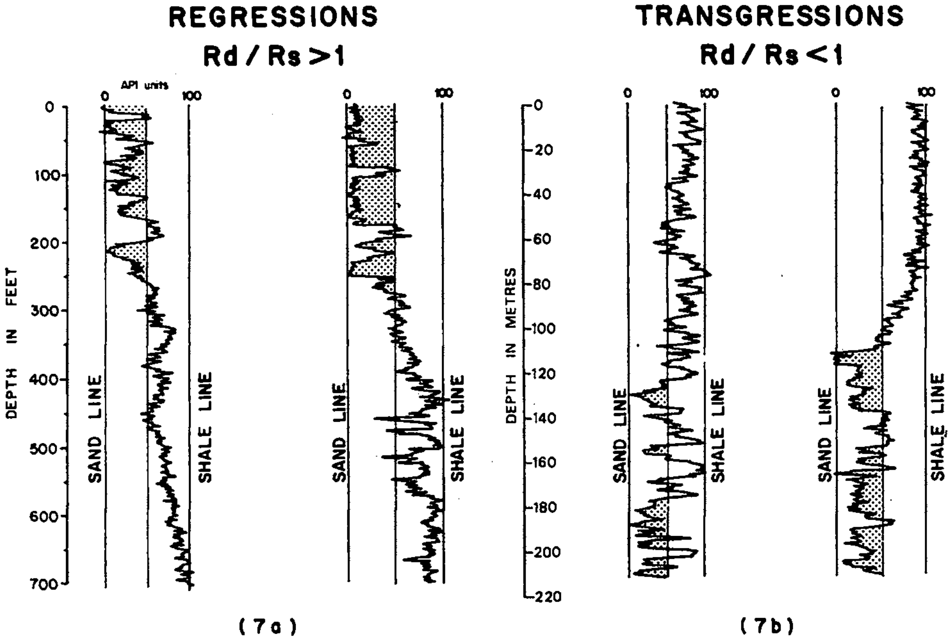

Fig. 7. Expression on γ-ray log of regressive and transgressive sequence.

(2) The sedimentary sequence in a cycle is regressive, —from marine at the bottom to coastal plain at the top, normally showing a coarsening upwards sequence with increasing sand content ($Rd/Rs > 1$).

To establish the environments of deposition of the sediments penetrated by the wells, a combination of palaeontological data (benthonic foraminifera) and shape characteristics of wireline logs is used (Fig. 8).

As the transgressions are very rapid, cycle boundaries are considered to be good time markers in the limited area of the Baram Delta. As most of the sediments lack planktonic Foraminifera, palynology is the principal time stratigraphic tool and a firm correlation between pollen zones and the cycle boundaries has been established.

STRUCTURAL STYLE

The Baram Delta Province can be divided into a series of depositional units, separated from each other by major faults trending approximately E-W. Each unit is characterised by its own specific stratigraphy, sedimentation and hydrocarbon distribution. Growth faults are well known from other deltaic areas such as the Niger Delta and the Gulf Coast in the United States. Structurally and sedimentologically the Baram Delta in Sarawak resembles these provinces, but is comparatively small in areal extent (Fig. 9).

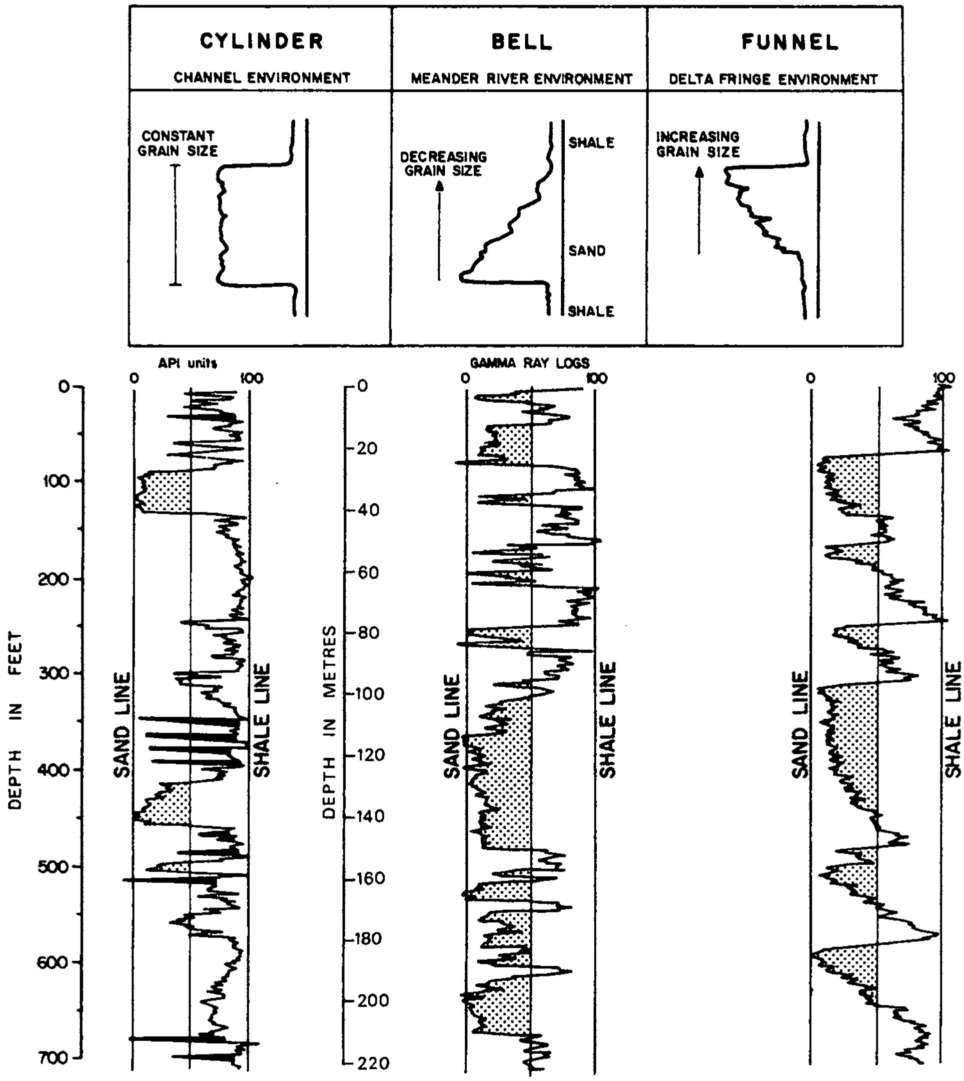

Fig. 8. Log shapes of some deltaic reservoirs.

A growth fault has been described as a fault which offsets an active surface of deposition (Fig. 10, Merki, 1970). It is an important synsedimentary tectonic feature and it can form one of the principal trapping mechanisms in deltaic provinces.

Growth faults are a result of density contrasts and gravity sliding during deltaic sedimentation. This type of fault is believed to coincide broadly with the ancient coastlines.

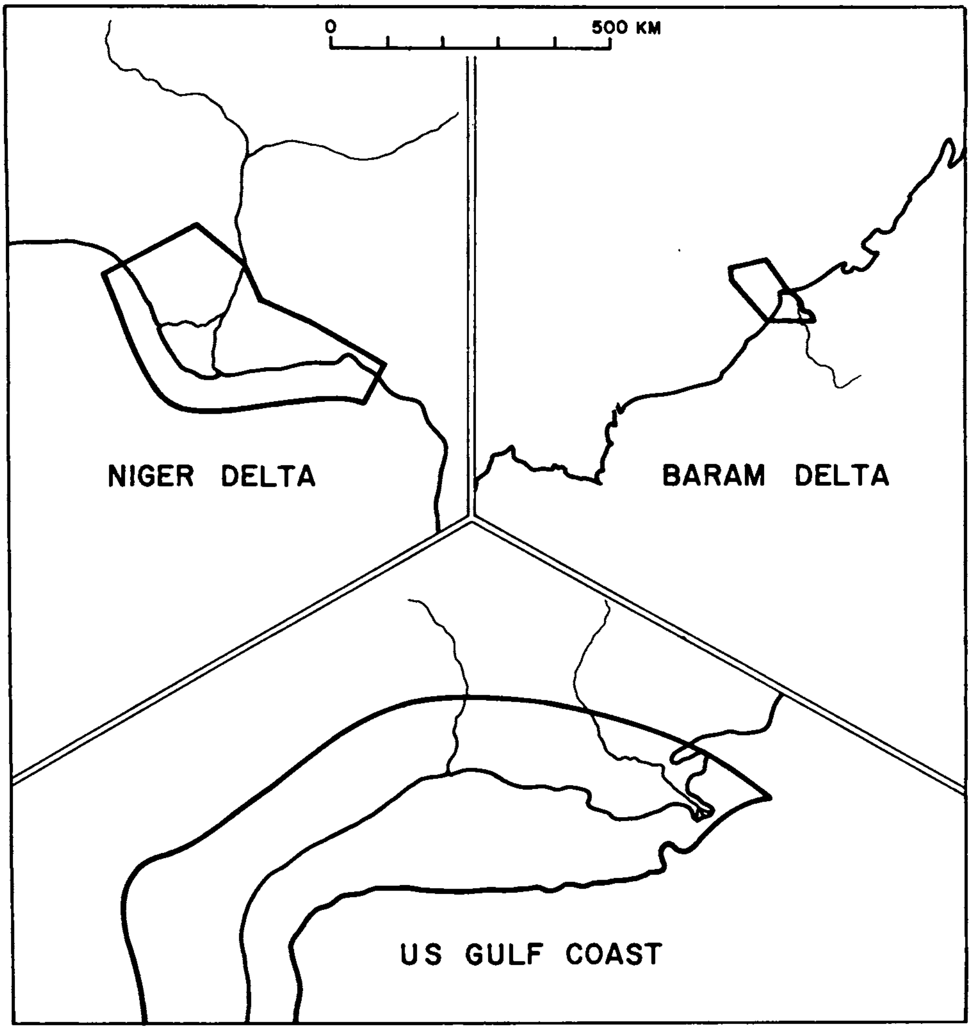

Fig. 9. Areal extent of the Niger-, Mississippi- and Baram delta provinces (schematic).

Synsedimentary tectonics are initiated when sandy deposits of a regressive cycle are prograding over mobile marine shales, whose interstitial water is retained due to very rapid sedimentation. The tectonic style is strongly related to the ratio between the rate of deposition and the rate of subsidence as described by Bruce (1973) and Evamy, *et al.* (1978) (Fig. 11).

In the Baram Delta Province the principal style of sedimentary tectonics is established under the condition of $Rd/Rs > 1$, when new fault controlled depocentres are formed in a seaward direction as sediment supply exceeds the subsidence of the basin (Fig. 12).

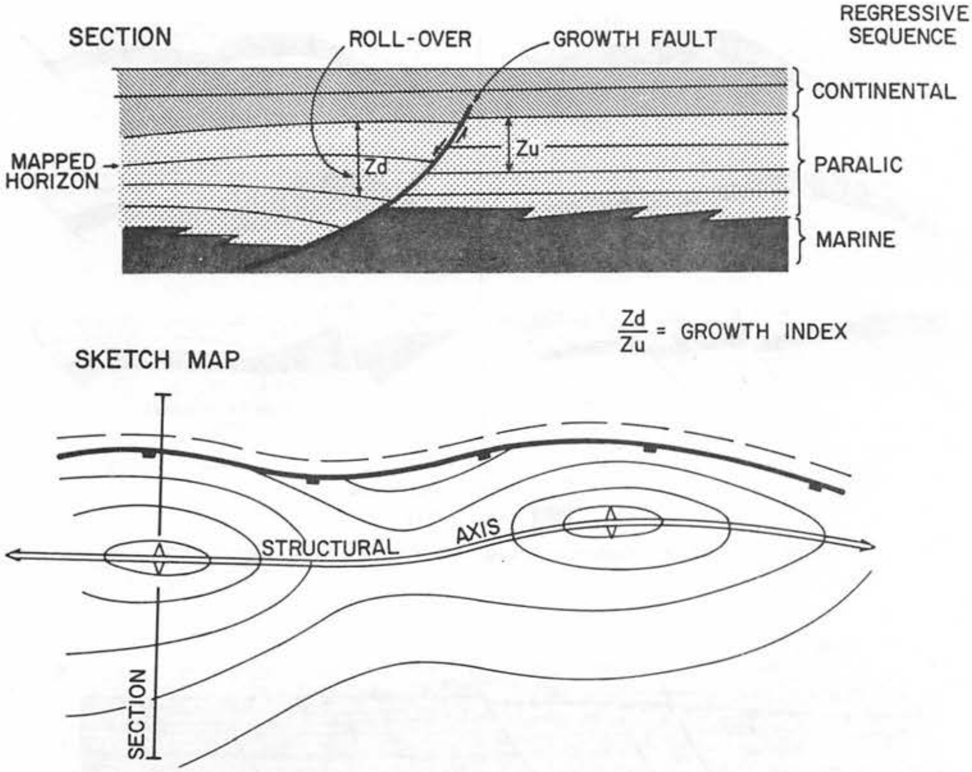

Fig. 10. Growth fault model (after Merki, 1970).

When Rd/Rs ≈ 1 (subsidence and sediment supply are in equilibrium) the depocentre will continue to grow subvertically until the ratio Rd/Rs becomes again > 1 or < 1.

Counter regional faults can develop when Rd/Rs ≈ 1, when differential loading causes synsedimentary movement along a zone of facies change in the region where a paralic sequence (sands and shales) passes diachronously into marine shales.

The northeastern part of the Baram Delta Province is an example of this type of synsedimentary tectonics (Fig. 13).

As a result of their synsedimentary nature, structural trapping conditions are created in the downthrown blocks of the growth faults already in the early stages of deposition. This aspect is of great importance, as generated hydrocarbons could migrate at any given time into a closed structure. Synsedimentary faulting, which occurs at a stage when the sediments are unconsolidated or only slightly consolidated, may allow the smearing of clays along a fault plane thereby enhancing the sealing capacity of a growth fault.

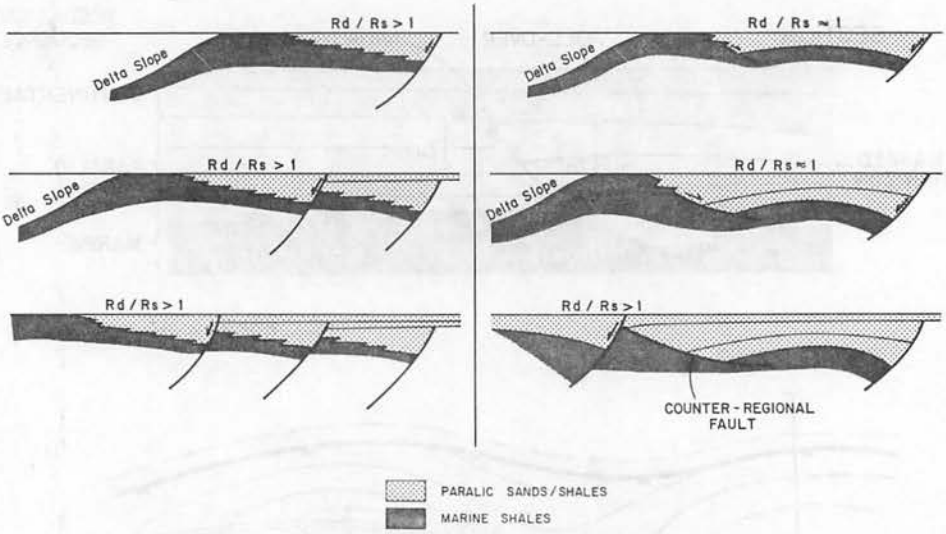

Fig. 11. Deltaic sedimentation and tectonics (after Evamy *et al.*, 1978).

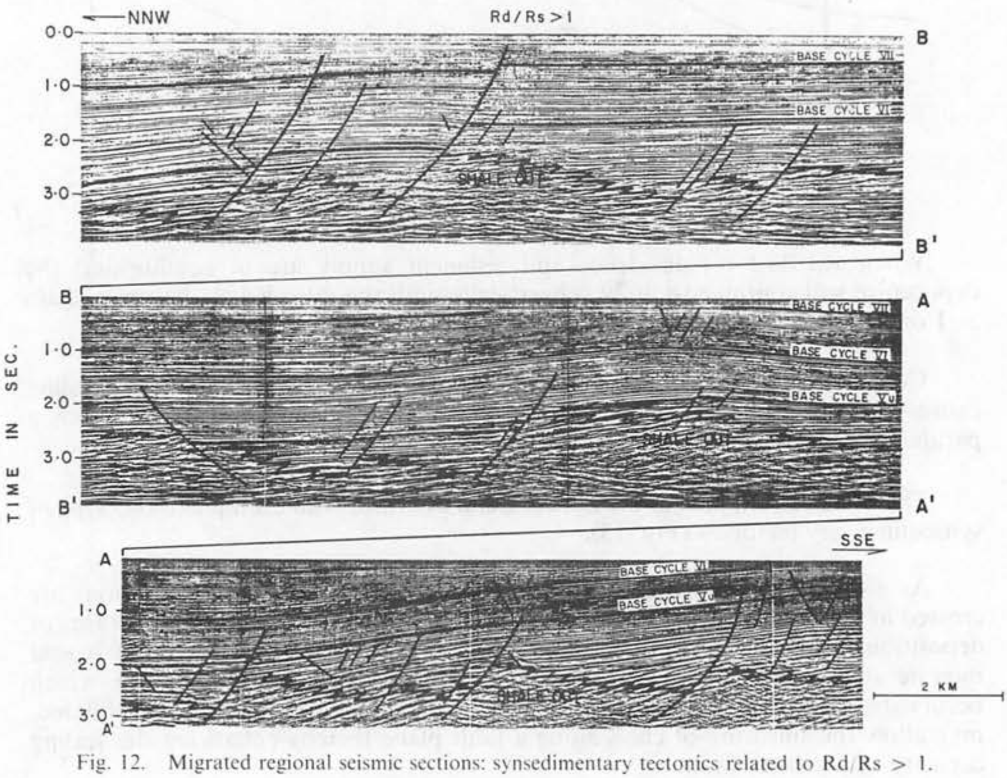

Fig. 12. Migrated regional seismic sections: synsedimentary tectonics related to Rd/Rs > 1.

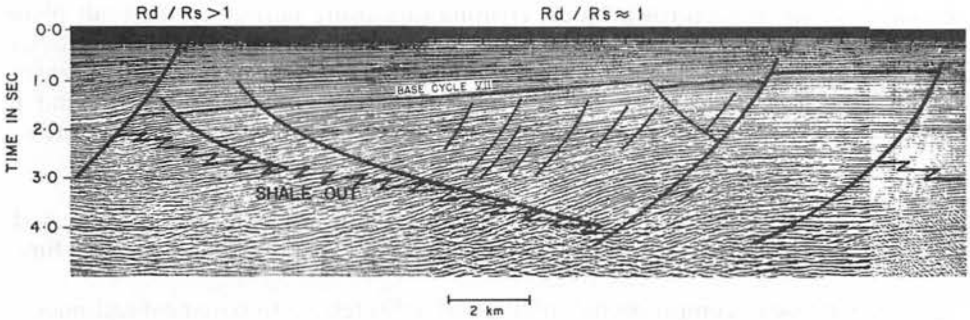

Fig. 13. Migrated seismic section across north-eastern part of Baram delta province: synsedimentary tectonics related to Rd/Rs ≈ 1.

An important characteristic of a growth fault is also the greater thickness of the downthrown block sequence relative to the upthrown block sequence (Fig. 10). The growth index $\left(\frac{\text{unit thickness in downthrown block}}{\text{unit thickness in upthrown block}}\right)$ is a measure which depicts the growth history of the fault and determines the thickness relationship of deposits in down and upthrown blocks. In the Baram Delta Province this ratio ranges between 1 and 2.5 (Figs. 10, 14).

Another feature of a growth fault is the flattening of the fault plane with depth. This flattening is a result of compaction, mainly of the shales which in a regressive sequence increase in percentage from top to bottom. Movement along a growth fault plane, which flattens with depth and is concave upward, results in a rollover of the

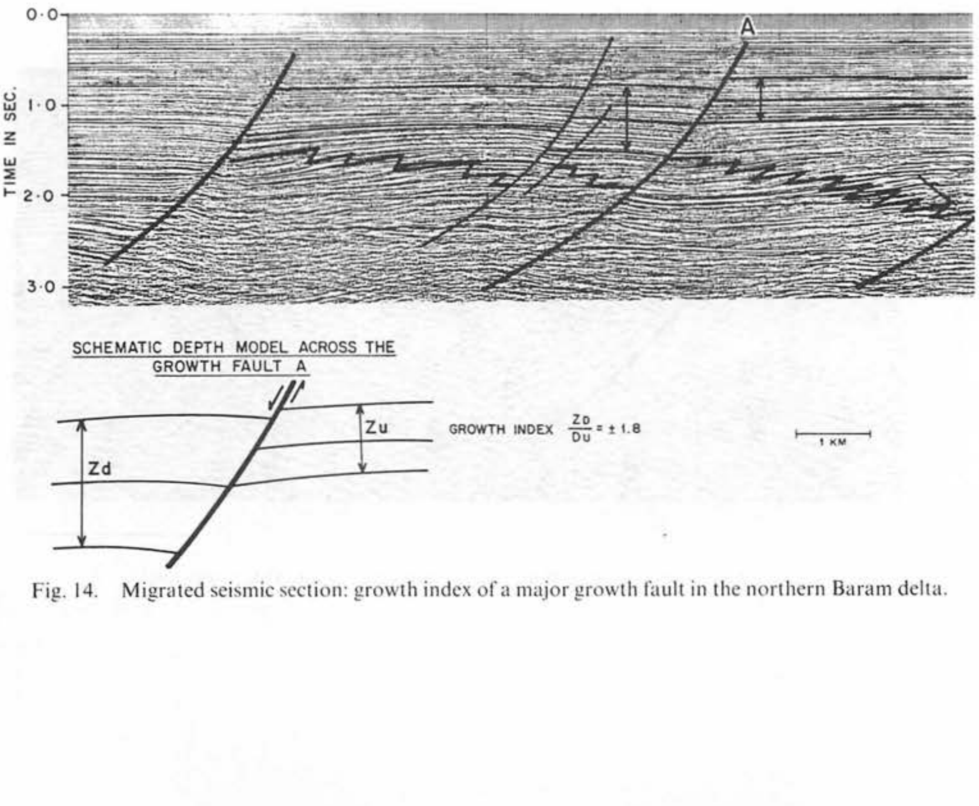

Fig. 14. Migrated seismic section: growth index of a major growth fault in the northern Baram delta.

sediments in the downthrown block, creating dipclosure normal to the fault plane direction (Figs. 10, 14). Parallel to the fault plane dipclosure in the downthrown block is often established by a more pronounced compaction on either side of the depocentre, which is normally located in the central part of the growth fault trend and is characterised by pronounced sand deposition. Away from the depocentre a gradual shaling out of the sedimentary sequence occurs.

In general a shift of the culmination with depth in a downdip direction is observed. This reflects the continuous (synsedimentary) activity of the growth fault through time.

A late phase of compressional folding and uplift related to basement tectonics of the continental margin of N.W. Borneo occurred in early Cycle VI (Upper Miocene) and is expressed in the Baram Delta Province by a series of NE-SW oriented folds and some reverse faulting.

The intensity of folding and uplift increases from north to south, resulting in the erosion of an increasing amount of sediments in a southerly direction. On land and in the southern offshore area, strong uplift was accompanied by severe normal and reverse faulting (Fig. 15). This resulted in a number of very complex structures of which the Siwa feature and the Miri field (Fig. 3) are prime examples.

In the area between the Miri-Siwa structural trend and the Cycle VI growth fault which bounds the Baronia field to the south no reverse faulting has been observed, but the folds form a dominant tectonic trend. All fields discovered so far in this area are on structural highs located at the intersection of the E-W striking growth faults and the NE-SW trending anticlines and are in general intensely broken up by normal faults (Fig. 16).

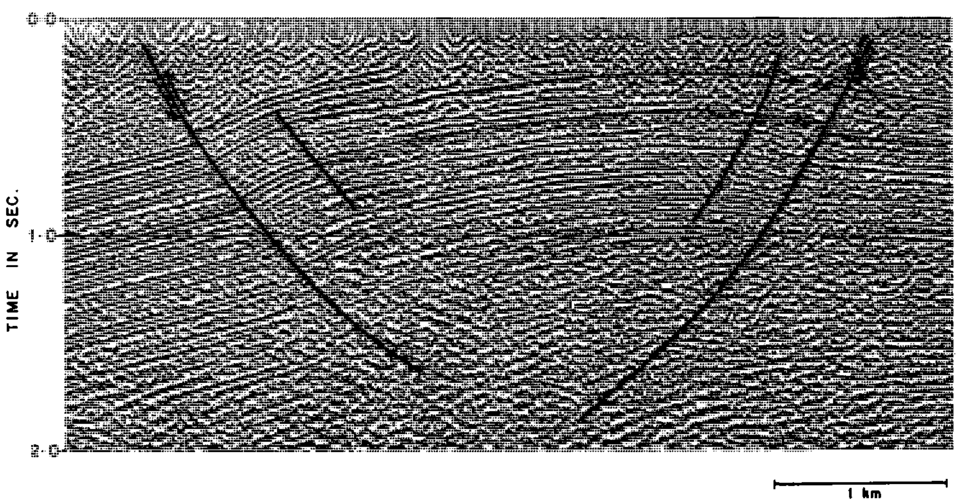

Fig. 15. Migrated seismic section: reverse faulted structure (Miri anticline).

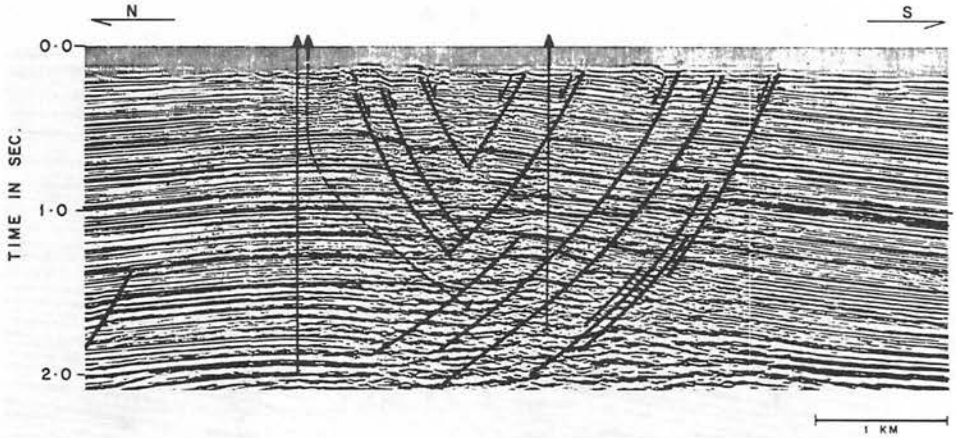

Fig. 16. Migrated seismic section: normal faulted structure (Baram field).

The area to the north of the Baronia growth fault is not affected by compressional folding and the Cycle VI-VIII structures are of the classical dipclosed rollover type, controlled by growth faults only.

RESERVOIR DEVELOPMENT AND TRAPPING MECHANISM

The Baram Delta is a clastic province and the reservoir rocks are exclusively sandstones.

During the overall regressive Cycles V to VIII times a thick sequence of regressive coastal plain, coastal and fluviomarine sediments with generally good reservoir characteristics were deposited. The principal reservoirs are beach sands coastal barriers sands and shallow neritic sand-sheets deposited in a coastal environment and channel sands belonging to the deltaic coastal plain environment of deposition.

Due to a low thermal gradient 0.9°C/30.48 m (1.5°F/100′), economic porosites ($\phi \geqslant 15\,\%$) are in general retained to a depth of ca. 3048 m–3352.8 m (10,000′–11,000′). The economic floor is at a shallower depth in the southern part of the Baram Delta Province, where erosion has removed the thick overburden and tectonism has increased the intensity of diagenesis.

Reservoir sequences in the Baram Delta are best developed in the Cycles V and VI, which locally can reach a thickness of up to 3048 m (10,000′) and 1828.8 m (6000′) respectively.

In the Baram Delta Province hydrocarbon accumulations are predominantly found to be present in fault/dipclosed structures. Although a large portion of the hydrocarbons is trapped by later faults, the major growth faults form the principal trapping mechanism. This is due to their synsedimentary origin and the very large throws which can place a thick paralic (sand/shale) downthrown block sequence against a fully marine shale sequence in the upthrown block. This juxtaposition of sands against shales appears from extensive well data, to be the critical factor for the

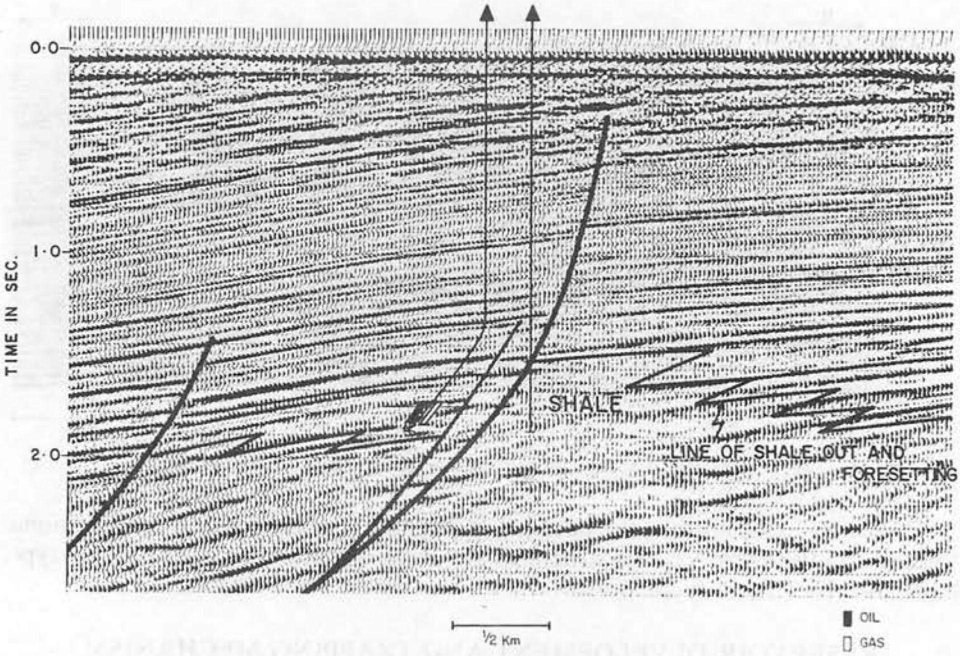

Fig. 17. Migrated seismic section: major growth fault juxtaposes paralic downthrown block sequence (good reflectivity) against shaly upthrown block sequence (poor reflectivity).

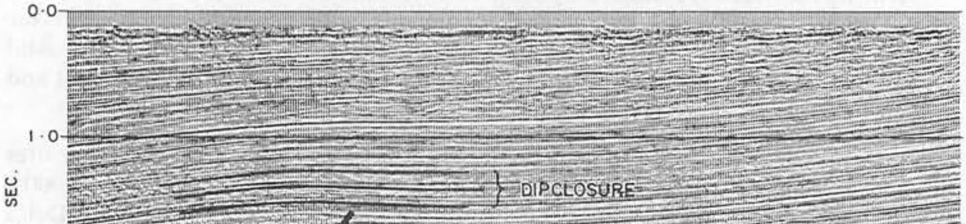

Fig. 18. Migrated seismic section: clear contrast in reflectivity between paralic downthrown block- and shaly upthrown block sequence below 2.3 sec.; shallow dipclosure caused by late compressional tectonics.

sealing of the faults. On seismic sections the paralic sequence is characterised by clear and continuous reflectors, whereas the shaly upthrown block sequence has an incoherent reflectivity pattern (Figs. 17, 18).

Dipclosed accumulations also occur and are either related to pure growth fault tectonics as depicted in Fig. 10 or to the late compressional tectonics, which gave rise to uplifted dome-shaped structures (Fig. 18). The former type of accumulation is restricted to the northern part of the delta (Baronia, Fairley Baram area) whereas the latter is confined to the more coastal region.

SOURCE ROCKS AND GENERATION/MIGRATION OF HYDROCARBONS

In the Baram Delta Province, studies concerning source rocks generation and migration of hydrocarbons can be summarized as follows: Oil/gas analyses and investigations of cuttings, cores and sidewall samples from numerous wells have proved that all hydrocarbons are landplant derived. No marine source rocks have been detected.

In general source rock recognition is difficult as organic material is not abundant and appears to be concentrated in very thin layers.

The best concentration of source rocks is found in the coastal plain environment with the organic content of the sediments decreasing rapidly when the environment becomes more marine.

Generation of hydrocarbons is widely accepted as occurring at a temperature of ca. 118.3 °C (245 °F) in the case of oil and at ca. 148.9 °C (300 °F) and above in the case of gas.

In the Baram Delta Province, which is characterised by a low temperature gradient of ca. 0.9 °C/30.48 m (1.5 °F/100′), hydrocarbons are therefore thought to be generated in a depth range of 3048 m–4114.8 m (10,000′–13,500′). The initial principle migration route is believed to be lateral from the synclinal areas (i.e. the neighbouring kitchen area) upwards along the flanks into the structures. Most hydrocarbon occurrences can be explained this way.

A remigration of hydrocarbons vertically along faults which were induced by the late compressional tectonic phase has to be assumed in some structures where hydrocarbons occur at very shallow levels.

SEISMIC

Major structures readily identifiable on seismic were drilled in the Baram Delta Province during the sixties and all important fields were found in that period.

In the last decade a dense grid of seismic data has been acquired in the area. Less obvious exploration targets could be delineated and a number of small fields were discovered.

The continuous improvement in the seismic data quality has also led to a better definition of the areal extent of existing fields and their often complex structural styles. As a result, an effective appraisal and development drilling campaign could be carried out.

The refined seismic data acquisition and processing methods will allow exploration for smaller and more complicated traps, which could still be economically viable.

CONCLUSIONS

The Baram Delta can be considered a classical deltaic province as, in general, the concepts of sedimentological development and synsedimentary tectonics as established in e.g. the Niger delta and the Gulf coast can be applied.

On land and offshore the Baram Delta Province has been thoroughly explored and a total of 11 oil fields and 2 gas fields have been discovered.

The remaining hydrocarbon potential of the province is considered to be limited as the presently undetected traps will be small and difficult to delineate.

ACKNOWLEDGEMENT

The author would like to thank PETRONAS and Sarawak Shell Berhad for the permission to publish this paper.

REFERENCES

BRUCE, C.H., 1973. Pressured shale and related sediment deformation: Mechanism for development of regional contemporaneous faults. *Amer. Assoc. Petro. Bulletin*, V57/5, 878–886.

CURTIS, D.M., 1970. Miocene deltaic sedimentation, Louisiana Gulf Coast: Deltaic sedimentation modern and ancient, edited by Morgan, J.P., *Soc. Econ. Paleontologists and Mineralogists*, Special Publication No. 15.

EVAMY, B.D. et al., 1978. Hydrocarbon habitat of the Tertiary Niger Delta. *Amer. Assoc. Petro. Geol. Bulletin*, V62/1, 1–39.

HO KIAM FUI, 1978. Stratigraphic framework for oil exploration in Sarawak. *Geol. Soc. Malaysia, Bulletin* 10, 1–13.

MERKI, P., 1970. *Structural geology of the Cenozoic Niger delta*. Proceedings of the first conference on African Geology, University of Ibadan, 635–646.

Manuscript received 29 August 1981