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Analysis of overpressure zones at the southern margin of the Baram Delta Province and their implications to hydrocarbon expulsion, migration and entrapment

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Abstract: The Baram Delta oil and gas province covers a major part of the onshore and offshore areas of northern Sarawak, Malaysia and Brunei. Thick marine to deltaic sediments of Late Eocene to Pleistocene age were rapidly deposited in the basin resulting in widespread abnormal formation pressures. Overpressure zones are normally encountered within thick marine-deposited claystone intervals occurring below and/or just at the basal part of major oil and gas accumulations in the offshore areas of the Baram Delta Province. Due to drilling hazards, the onset of overpressuring is regarded as an arbitrary economic limit for oil exploration.

In onshore Sarawak, south of the Baram Delta Province are thick Late Eocene to Miocene (Cycle I–V) sediments deposited and uplifted after latest Miocene age. Abnormal pressure zones have been encountered in three different settings *viz.* a) in undercompacted claystone-predominant interval, b) in uplifted tight sandstone beds with hydrocarbons and c) in hydrodynamically pressured shallow sand intervals. A unique overpressure zone which occurs below stacks of hydrostatic and permeable coastal-deltaic sands has been observed.

The formation of these varied overpressure zones and the pressure regime in the area are studied in combination with the burial and structural development history of the southern margin of the Baram Delta Province. The implications to hydrocarbon expulsion, migration and entrapment are analyzed.

INTRODUCTION

Idemitsu Oil Exploration (East Malaysia) Co. Ltd. has explored the southern margin of the Baram Delta Province as a PS contractor with Petroliam Nasional Berhad for the last four years. This paper is based on the results of the recent exploration work in Block SK-17 by Idemitsu, and describes the overpressure zones observed in the Block and discusses the model of their formation mechanisms and its implications to hydrocarbon expulsion, migration and entrapment.

GEOLOGICAL SETTING

The Baram Delta Province covers a major part of the onshore and offshore areas of northern Sarawak in Malaysia and Brunei (Fig. 1). Thick marine to deltaic sediments of Late Eocene to Pleistocene age were rapidly deposited in the basin resulting in widespread overpressures. The sedimentary sequences in the Baram Delta Province have been subdivided into eight sedimentary Cycles (Cycles I–VIII) which were developed by Shell (Ho, 1978). Each Cycle starts with a transgressive claystone interval followed by thick regressive sand-dominated sediments (Fig. 2).

In the offshore areas of the Baram Delta Province (Fig. 3), Cycle V–VII are exploration targets and overpressure zones are normally encountered within thick undercompacted marine claystone intervals occurring below and/or at the basal part of major oil and gas accumulations (Scherer, 1980; Johnson *et al.*, 1989). Due to drilling hazards, the onset of overpressuring is regarded as an arbitrary economic limit for oil exploration.

In onshore Sarawak, south of the Baram Delta Province are thick Late Eocene to Miocene (Cycle I–V) sediments and these sediments were uplifted from the latest Miocene age to form Lambir Hill. Recent exploration work has identified overpressure zones in three different settings in the Pasir area of the northern Block SK-17 as follows,

a) in undercompacted claystone-predominant interval,
b) in uplifted tight sandstone beds with hydrocarbons,
c) in hydrodynamically pressured shallow sand intervals.

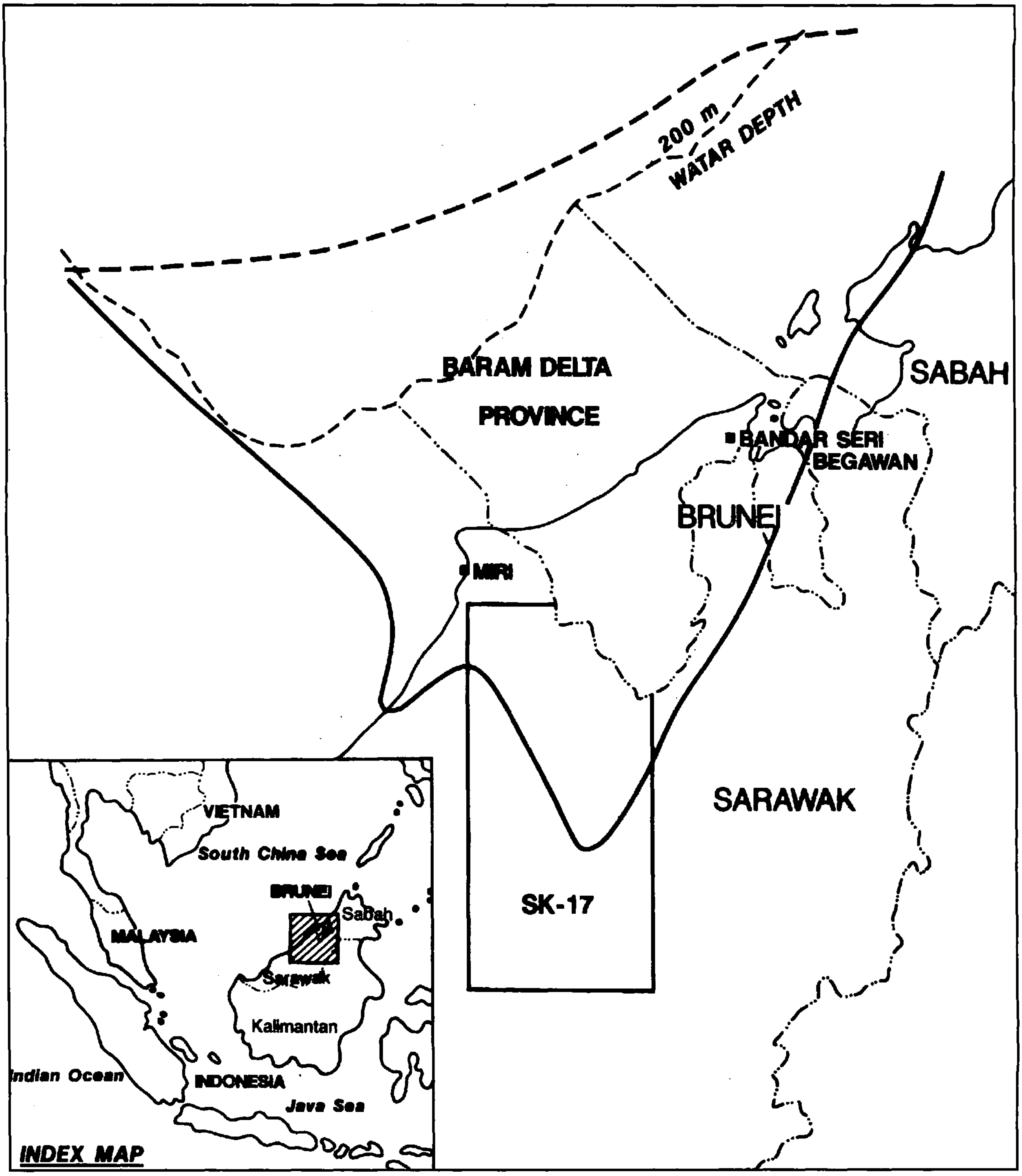

Figure 1. Location map of the Baram Delta Province and Block SK-17.

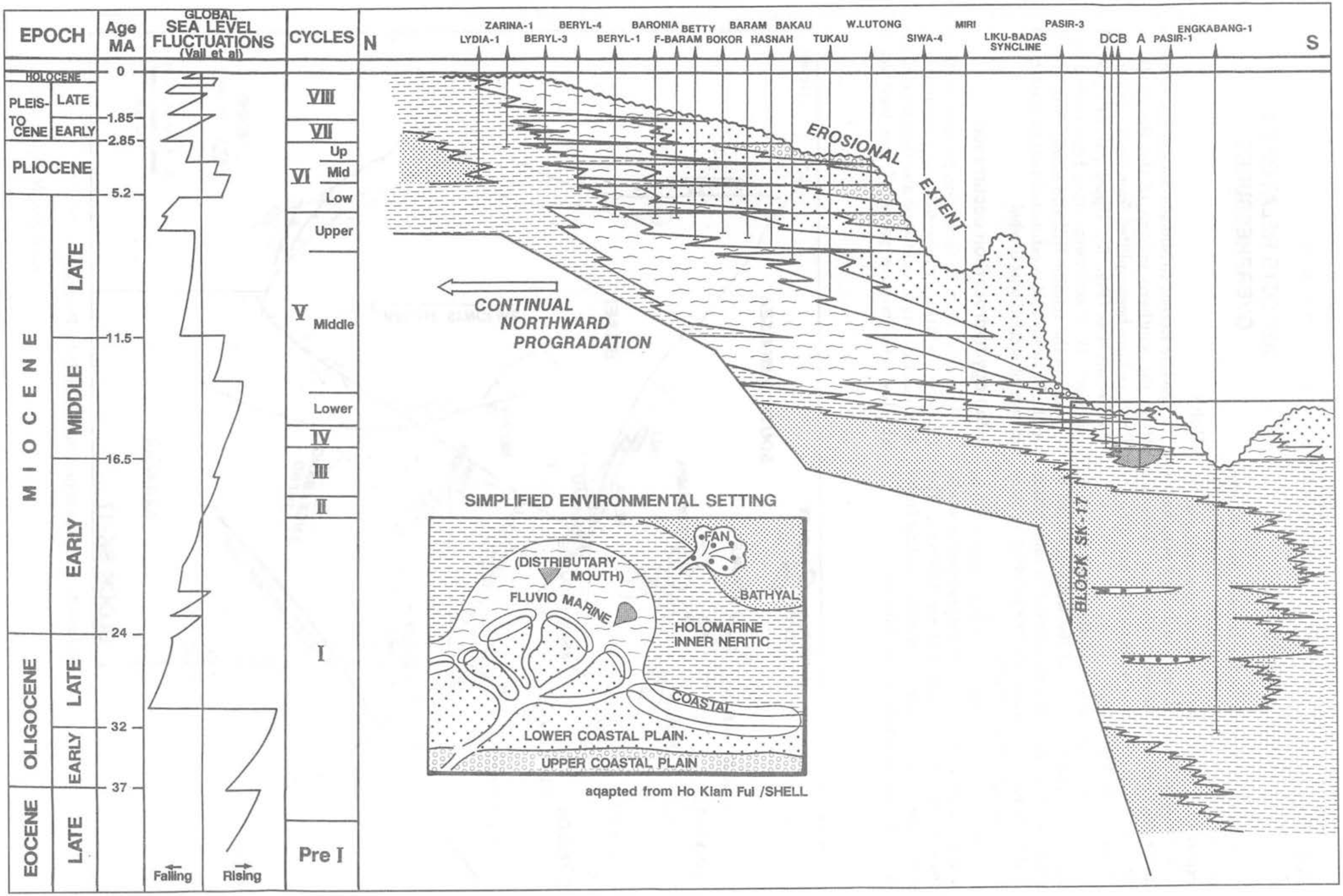

Figure 2. Stratigraphic framework of the Baram Delta Province (modified from Ho, 1978).

PRESSURE REGIME

Nine wells were drilled in the southern margin of the Baram Delta Province. These wells experienced various degrees of overpressuring which were shown either by changes in drilling parameters and E-log responses or actual blow-out. Pressure profiles of four available wells in the Pasir area are shown in the Figure 4.

The classic deflections in the sonic log, shale resistivity, and Dxc plots of the wells are used to recognize the top of overpressuring in conjunction with increase in mud gas and corresponding increase in mud weight (Fertl, 1976).

The onset of overpressures is around 2,000 m (subsea) and occurs at different stratigraphic levels. Pressure regimes in each well are different. The differences may be caused by possible sealing faults or lateral sedimentary facies changes.

ASPECTS RELATED TO OVERPRESSURES

Uplift

The late Eocene to Miocene sediments (Cycle I–V) in the southern margin of the *Baram Delta* Province have been uplifted from latest Miocene to the Recent time (Fig. 5). Upper part of Cycle III and Cycle IV–V sediments have been eroded and exposed in the Lambir Hill and Engkabang Trend. In the Pasir area, it is estimated that at least 2,000 meters of section was eroded.

Lithology/hydrocarbon occurrence

In well A (Fig. 6) formation pressure data in Cycles IV and III were recorded nearly continuously. Alternating beds of sandstone and claystone in the shallow and middle parts of the well have

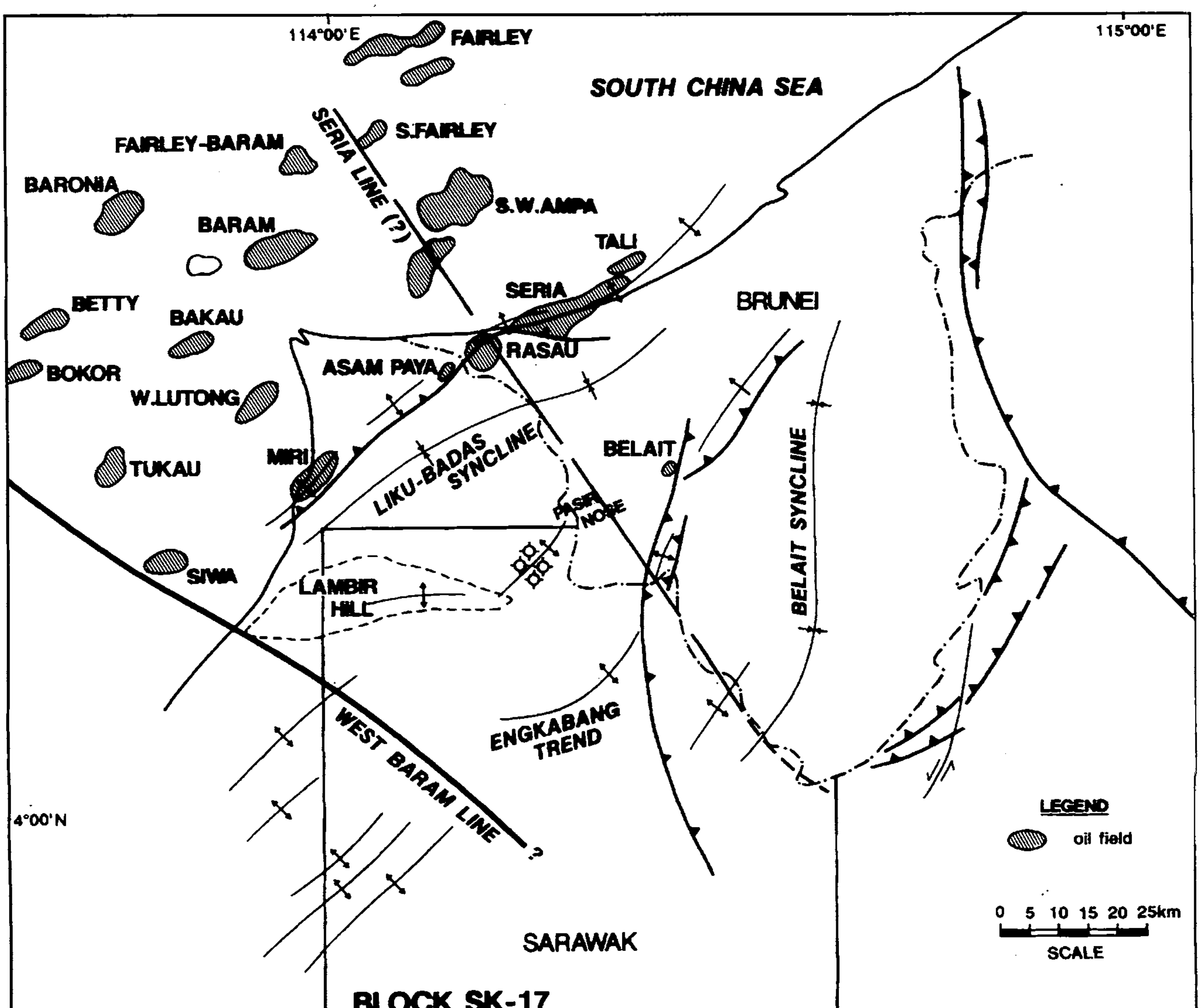

Figure 3. Structure map of the Baram Delta Province.

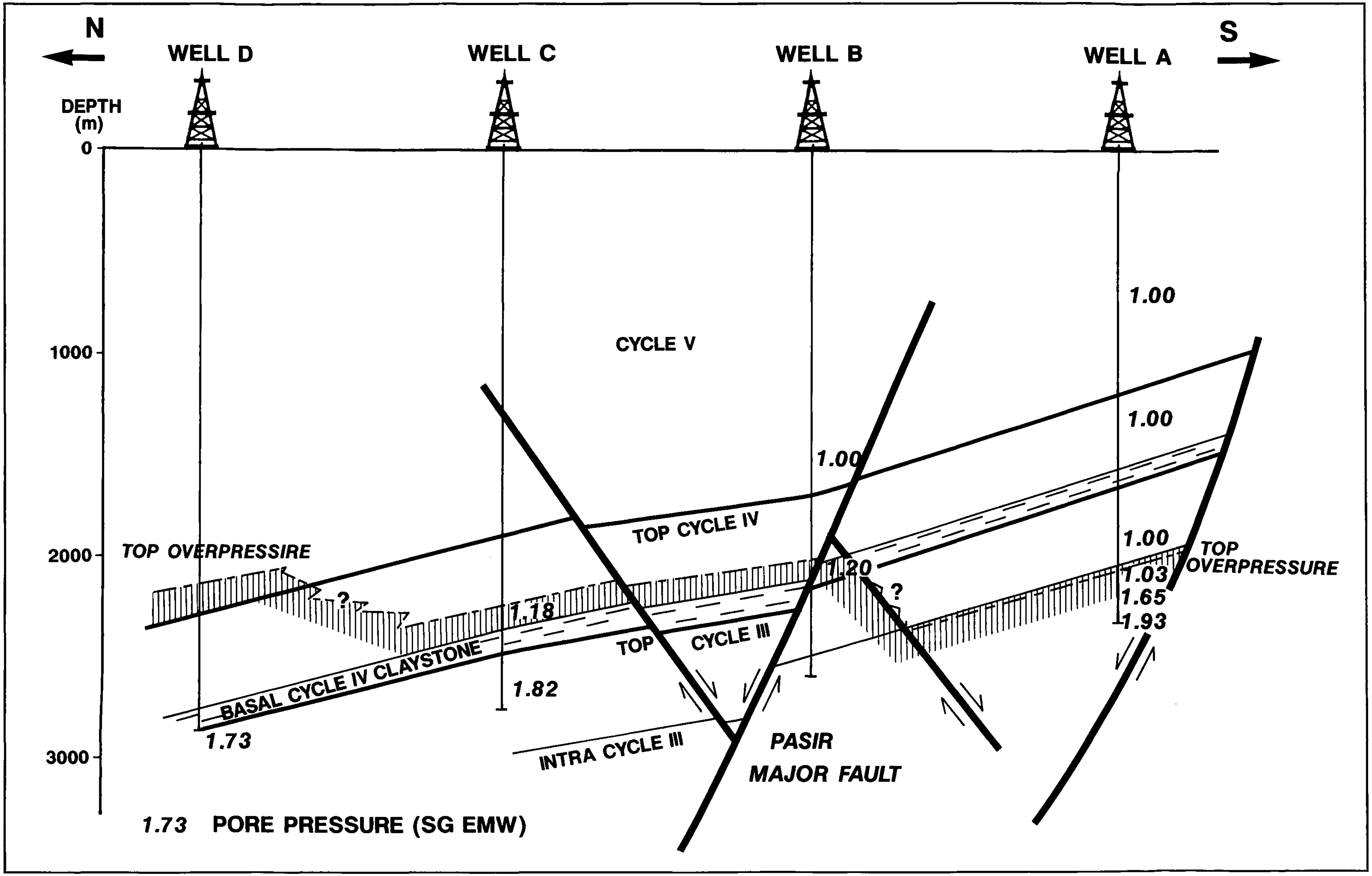

Figure 4. Formation pressures in Pasir area.

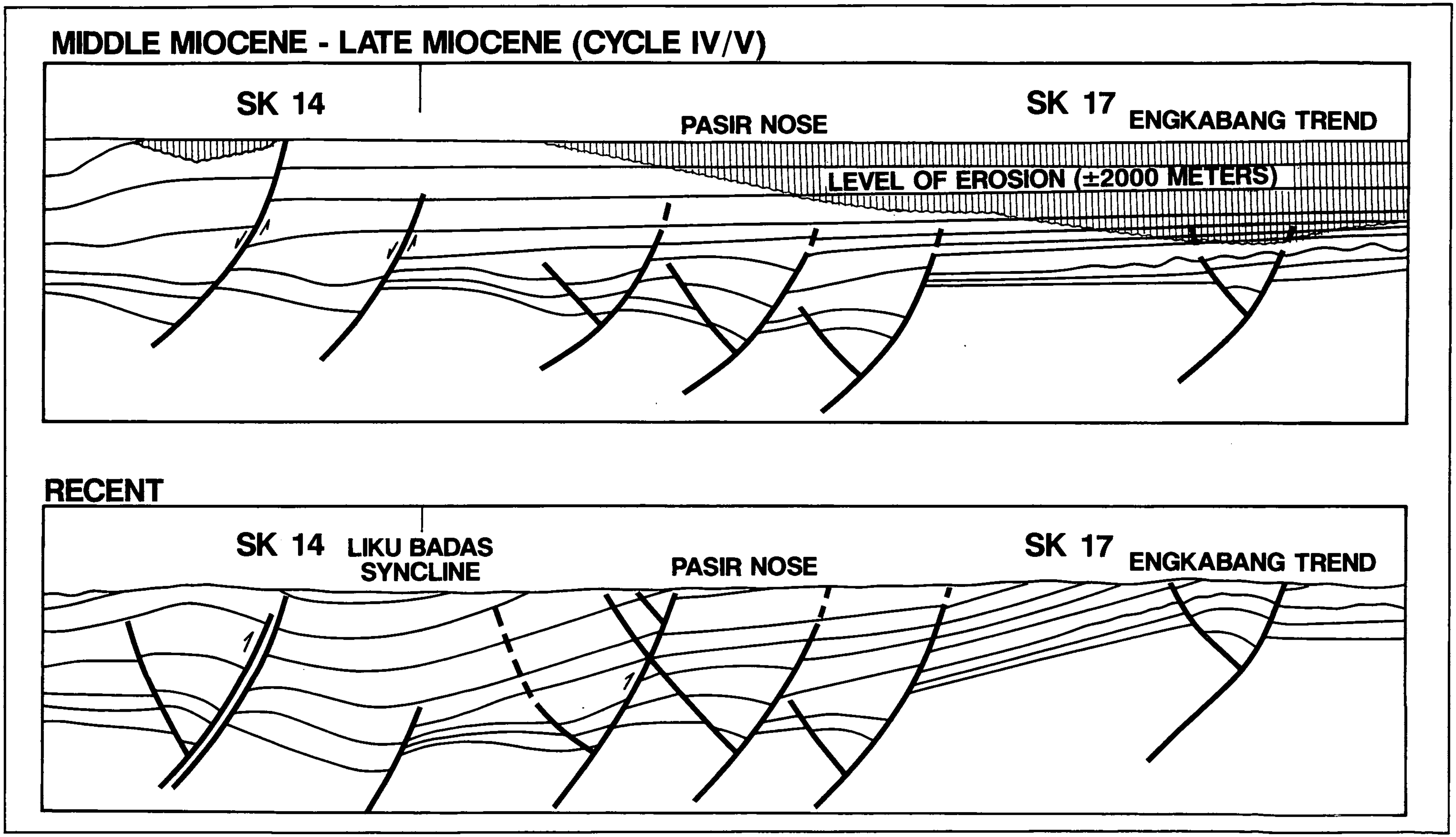

Figure 5. Schematic sections showing structural development in the southern margin of the Baram Delta Province.

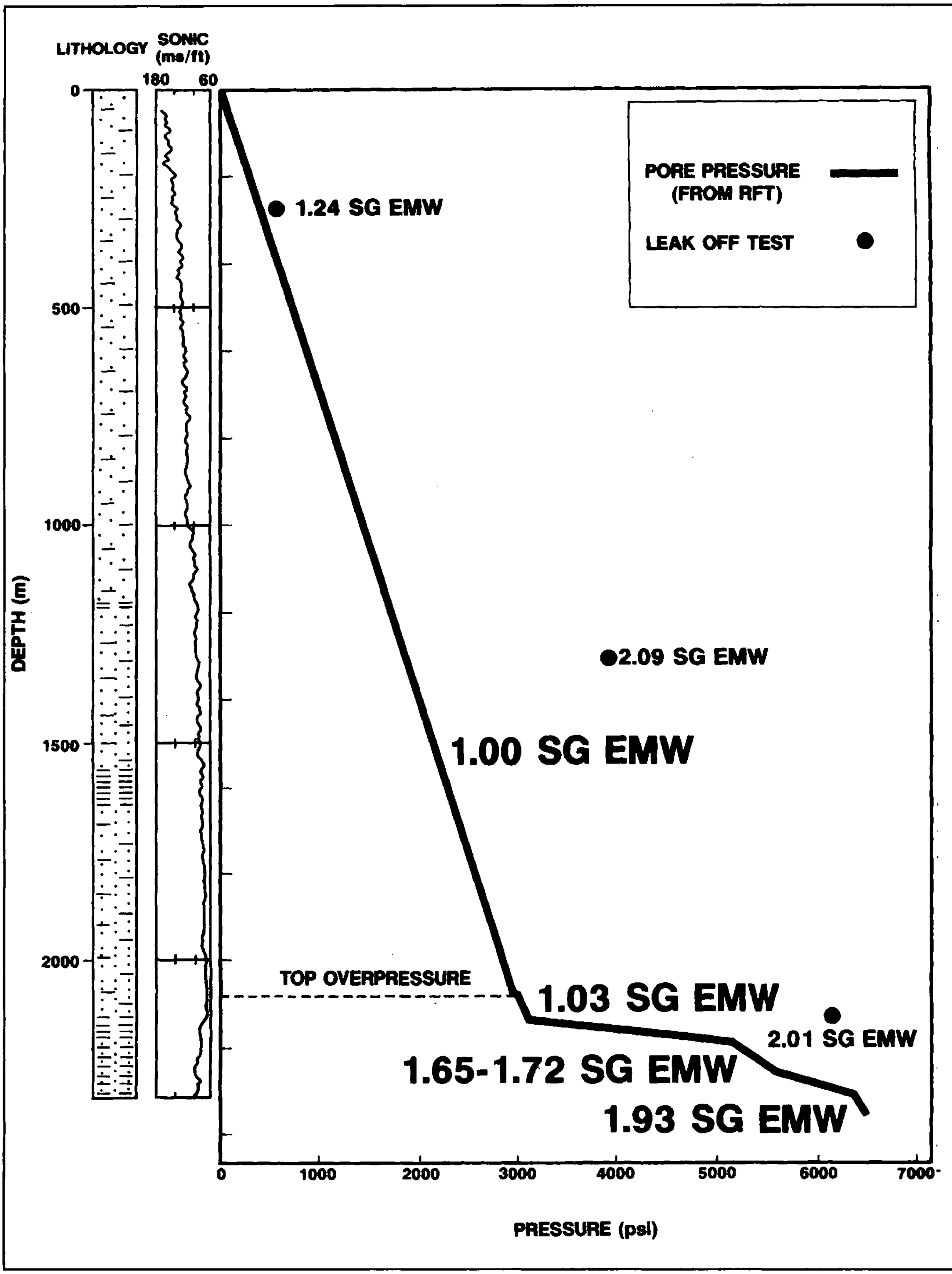

Figure 6. Formation pressure profile of Well A.

hydrostatic pressure regime, EMW 1.00 SG. These sections have porous sandstone beds with excellent reservoir quality. The sections have fresh meteoric water invasion and oil samples recovered from these intervals are biodegraded. Generally, the degree of meteoric water invasion and the biodegradation of oil are more severe in the shallower sections. Invasion and biodegradation become lesser in the deeper sections.

Slight overpressures with EMW 1.03 SG are encountered in the lowermost part of alternating beds. Sandstone beds in this zone are generally tight but some porous sandstone beds are also observed. Oil samples recovered in this interval are without biodegradation.

The thick undercompacted claystone interval underlies the alternating beds, and is overpressured up to EMW 1.65 SG. Underlying this claystone-predominant interval, alternating beds of claystone and tight sandstone with gas and condensate shows are encountered and are overpressured up to EMW 1.65 SG to 1.72 SG.

Other tight sandstone beds with gas and condensate shows near TD have more severe overpressure of EMW 1.93 SG, which is close to the formation fracture gradient in this interval.

Undercompacted claystone

Undercompacted claystones are encountered in Basal Cycle IV and Intra Cycle III (Fig. 4) and base line shift of sonic transit time to slower velocity is encountered (Fig. 6). These undercompacted claystone intervals are normally overpressured below 2,000 meters.

Temperature/maturity

Temperature data of wells A and C is shown in Figure 7. Top oil window is estimated at VRo = 0.6% and this is at 1,850 meters in well A and at 2,000 meters in well C. These depths are equivalent to formation temperatures of 75–77°C. 1D maturation modelling indicates that matured source rocks in the Pasir area have been generating oil and gas from the early stage of the uplift. Cycle III at the deeper locations has been producing gas.

Overpressures occur below top oil window and the temperature in these overpressure zones is more than 80°C.

Diagenesis

The main diagenetic process is mechanical compaction and formation of pseudo matrix from intraformational rock fragments. Since there are

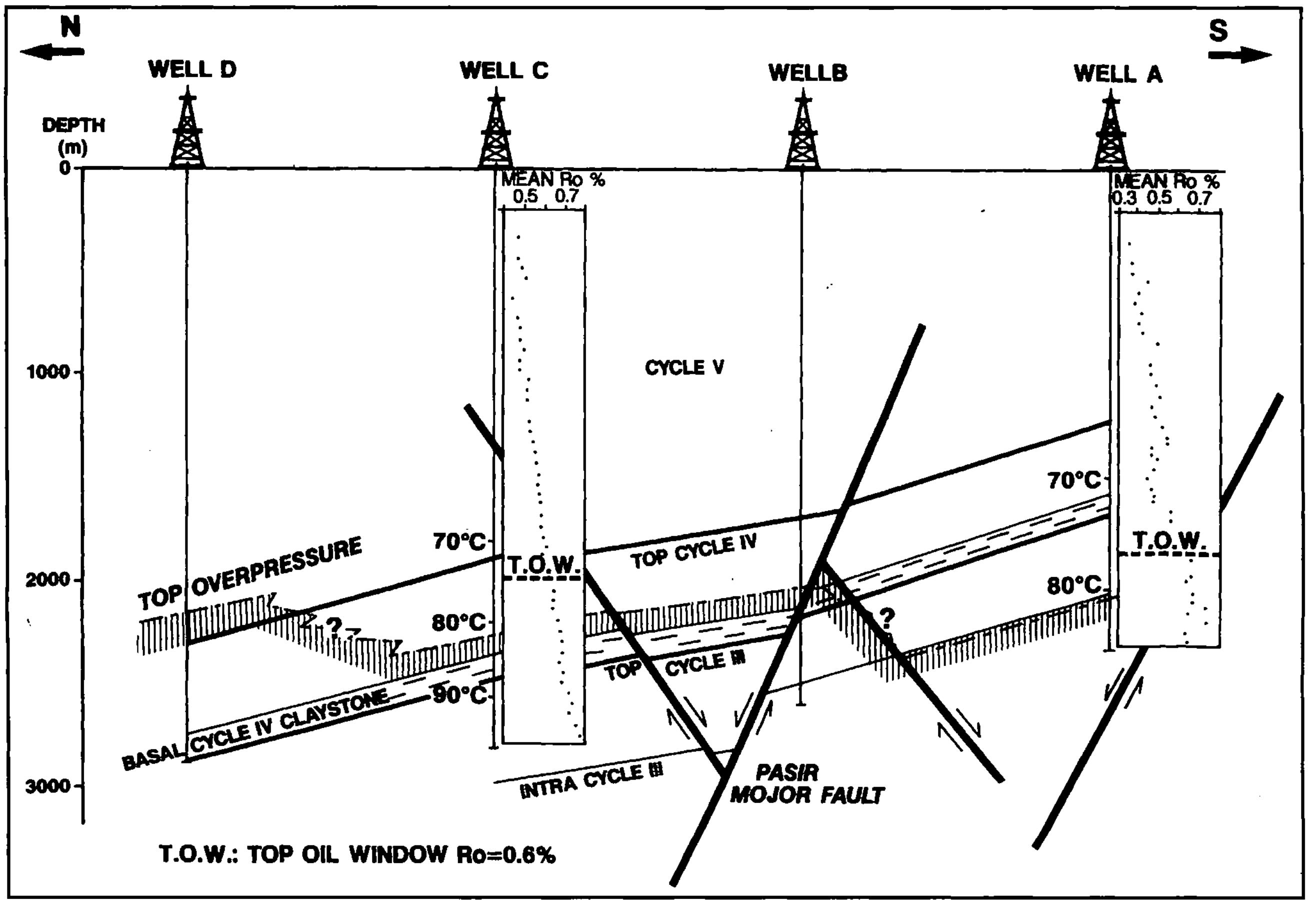

Figure 7. Formation temperature and maturity in Pasir area.

more reworked fragments in the older sequences, the formation of pseudo clay matrix at depth level around 2,000 meters has occluded intergranular pores thus lowering permeability considerably. It is noted that this depth level coincides with the top of overpressures. Temperature-related diagenetic processes are not well advanced although traces of silica overgrowths have been noted.

Fractures

VSP and seismic data shows that antithetic faults are associated with major growth fault (Fig. 8). One antithetic fault was encountered in the well. This interpretation is based on caved hole condition, FMS image data and VSP data. This zone is fractured and have significant gas kick. This is considered to be the result of released pressure from the deep-seated overpressured sections.

MODELS FOR DEVELOPMENT OF OVERPRESSURES

Based on well data and regional geological data, three settings of overpressures are interpreted in the Pasir area in the southern margin of the Baram Delta Province. Models of development for these overpressures in the Pasir area are discussed.

i) Overpressures related with undercompacted claystone

Severe overpressures in the Pasir area (Fig. 9) are encountered at depths below 2,000 meters in the undercompacted claystone-predominant sections. This type of overpressure is typical of the one reported previously in the Baram Delta Province (Schaar, 1976). The original overpressures in this interval are considered to be developed at maximum burial before the onset of uplift. Their causes are considered as follows,

- The compaction by enough overburden for the physical dewatering of claystone.
- Possible clay mineral transformation that released water in deeper sections with higher formation temperatures.
- Ineffectiveness of these pore fluids to escape due to rapid sedimentation
- Effective sealing potential of faults which form the trapping mechanism.

The original causes of overpressures have persisted after the uplift due to the preservation of subsurface conditions such as effective fault seals established at the early stage of uplift and kept during the uplift.

ii) Overpressures in uplifted tight sandstone beds with hydrocarbons

Overpressured sands are observed within undercompacted claystone in Intra Cycle III in well A, and just above the Basal Cycle IV claystone and sandstone beds within Cycle III in well C (Fig. 9).

These sandstones have poorer reservoir quality than sandstone beds in the hydrostatic pressure regime, and are even tight in the deeper sections mainly due to pseudo matrix. These sandstone beds have continuous gas/condensate shows. The mechanism of overpressuring in these sandstone is interpreted as follows.

- Poor dissipation of original overpressures at the burial depth due to effective fault seal and poor permeability. Original overpressure might had been caused by pressure transmission from nearby overpressured claystone.
- Additional charge of gas and pressure from down dip or deep-seated matured source rock via antithetic faults during the uplift.

These antithetic faults are interpreted based on VSP, seismic and well data. The deeper faults are interpreted to terminate in overpressure zones and might act as conduits for pressure and gas from deeper sections. Antithetic faults in the shallower sections may be leaking pressures to the shallower sections

iii) Overpressures due to hydrodynamics

This type of overpressure was not reported in the offshore main Baram Delta, and has been observed in the well in the Pasir area.

RFT data indicates that slight overpressures of EMW 1.10 SG in the hydrostatic pressure regime may be caused by hydrodynamics (Fig. 10). These formations outcrop at Lambir Hill to the south of the Pasir area where the formations were uplifted to the heights of 100–200 meters with maximum elevation of 465 meters to the west. This hilly area may provide water head higher than mean sea level (Fig. 11). This may cause the invasion of the meteoric water and slight overpressures. The invasion of the meteoric water caused the biodegradation of oils in the hydrostatic pressure regime.

IMPLICATIONS TO HYDROCARBON EXPULSION, MIGRATION AND ENTRAPMENT

The following two comments can be made on the implications to hydrocarbon expulsion, migration and entrapment.

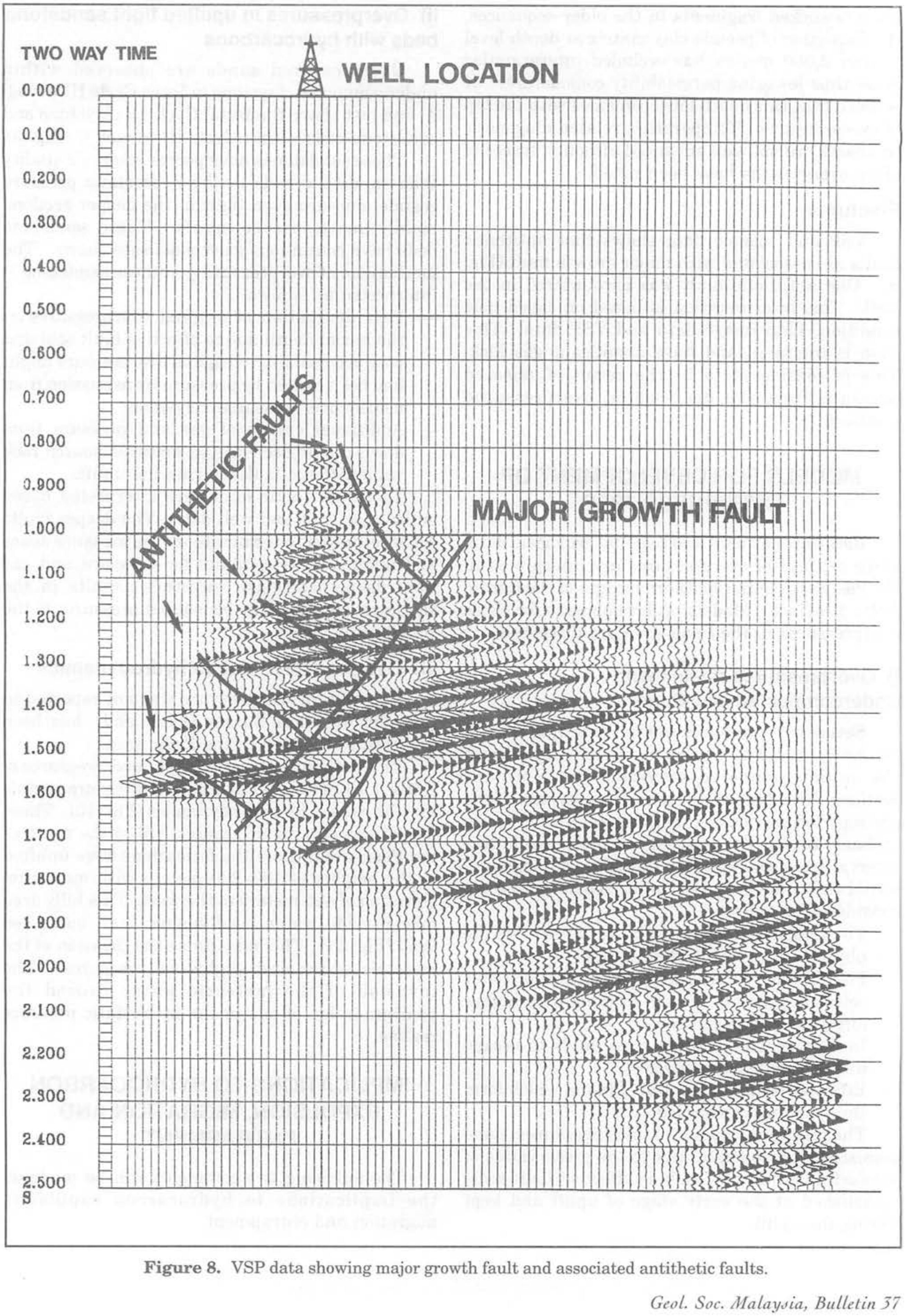

Figure 8. VSP data showing major growth fault and associated antithetic faults.

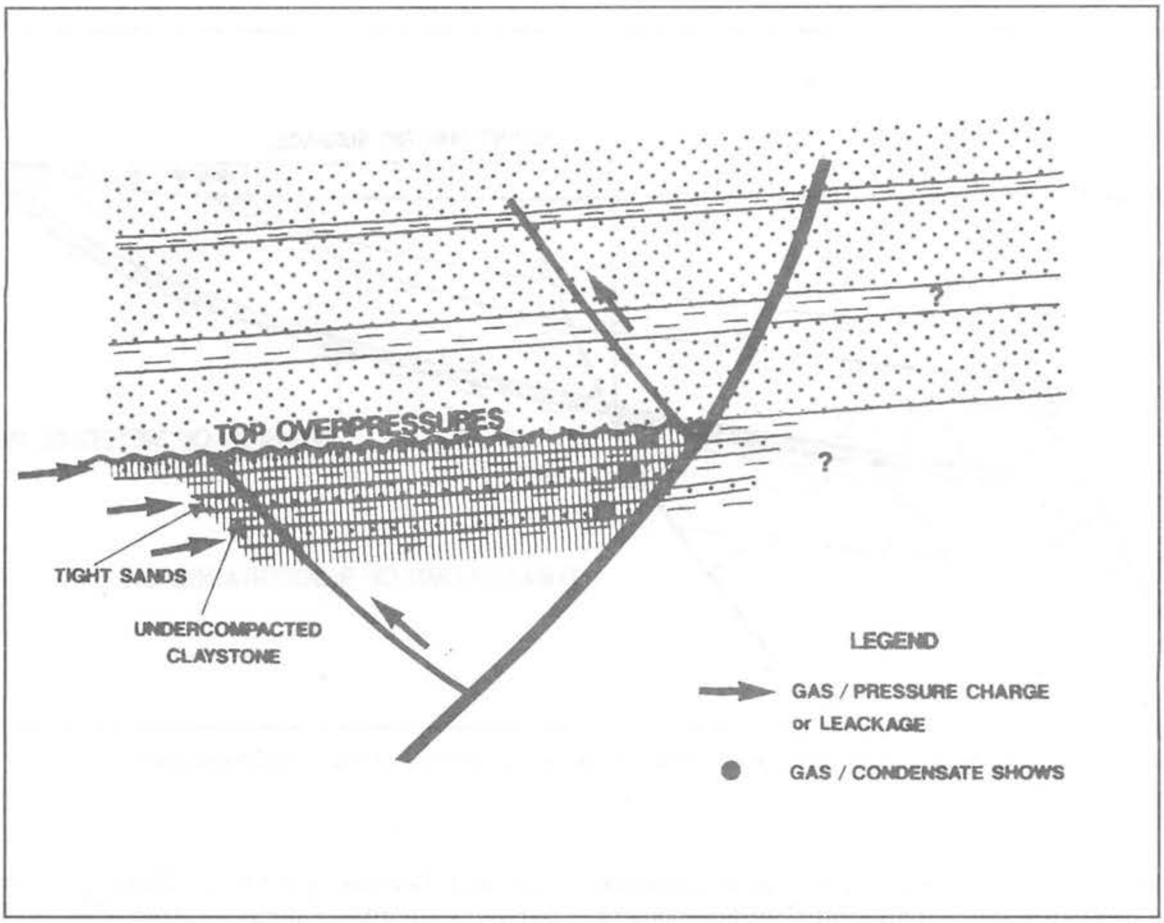

Figure 9. Schematic cross section showing overpressures in undercompacted claystone and tight sands.

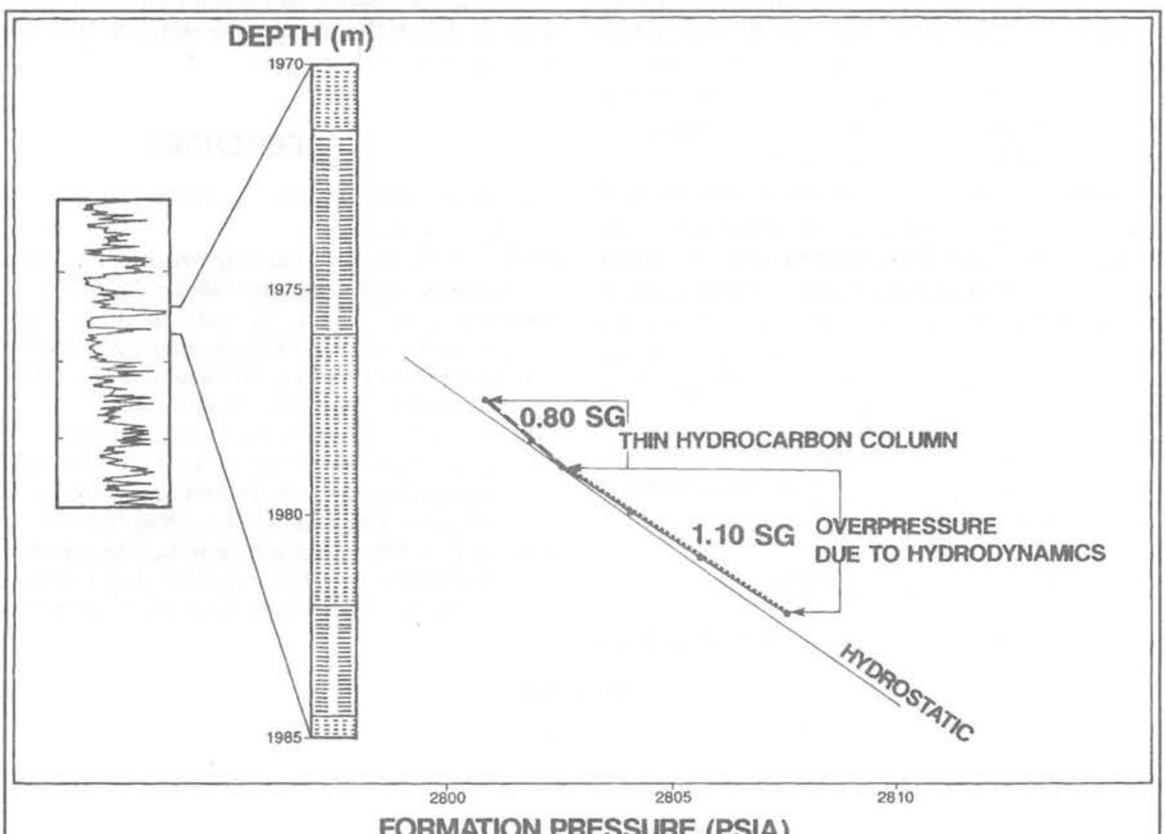

Figure 10. Formation profile of sandstones in Well A with possible overpressures due to hydrodynamics.

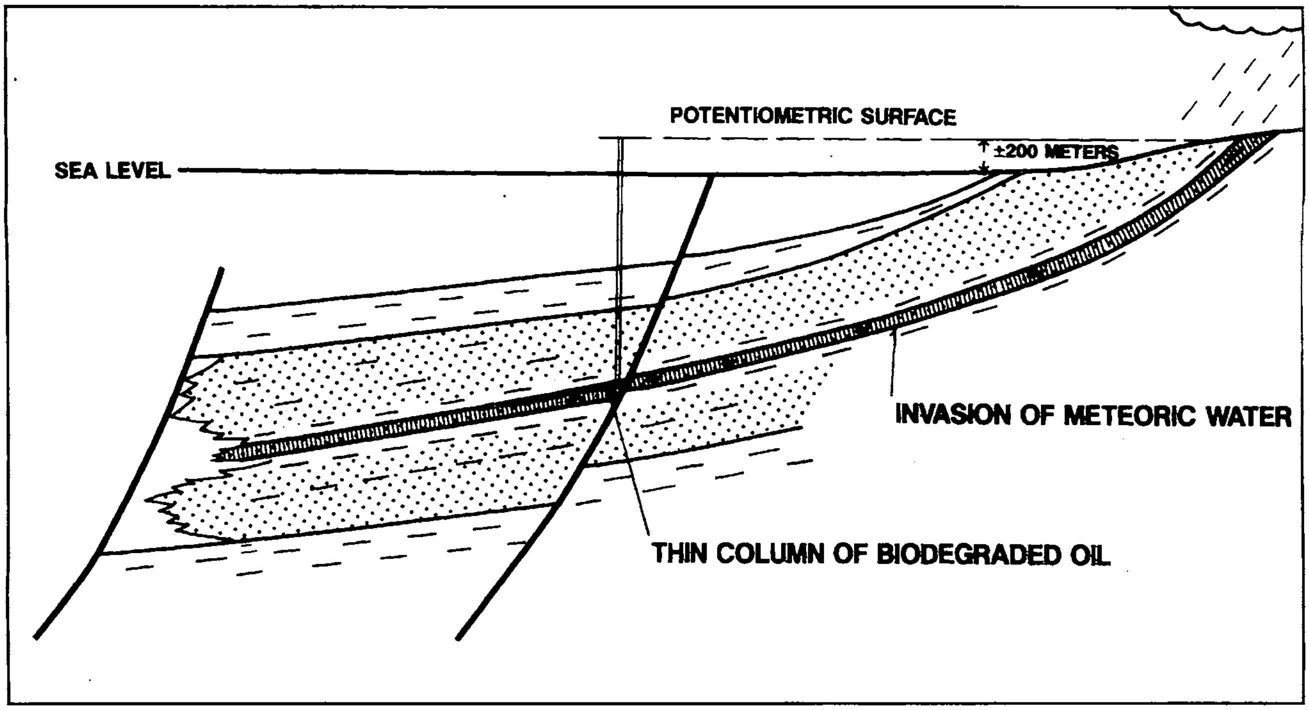

Figure 11. Schematic cross section showing overpressures due to hydrodynamics.

— In the Pasir area, the depth of top overpressure coincide with the top tight sand. The development of overpressures is considered to be coincident with degradation of reservoir quality of sandstones. Both processes are considered to predate hydrocarbon migration. Therefore, for possible favourable traps in the overpressure zones, hydrocarbons need to migrate from deep-seated matured source rocks prior to overpressuring. If hydrocarbons had been trapped prior to overpressuring, namely prior to development of the diagenetic process, reservoir quality would be maintained after overpressuring.

— Signs of overpressures caused by hydrodynamics are observed in the shallow porous reservoir sections. A hydrodynamic trap may be possible to the north of Lambir Hill.

We believe that these models and idea give us a reason to pursue untested play in the southern Baram Delta Province.

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