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Occurrence, origin and implications of overpressure in the Malay and Penyu Basins, offshore Malaysia

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Abstract: There are four (4) common reasons why drilling of a well is terminated, namely reservoirs are not economical in the deeper section, reservoirs are poorly developed, operational problems and overpressure.

Eighty percent of wells drilled in the Malay-Penyu Basin have been terminated either in anticipation or due to overpressure. This study uses pressure versus depth plots generated from RFT and DST readings taken in 94 exploratory well spread throughout the Malay-Penyu Basin.

Overpressure in this area is found to be neither depth dependent nor age related. The margins of the Malay Basin and the entire Penyu Basin are found to be normally pressured. The central portion of the Malay Basin is overpressured. The onset of overpressure appears to be abrupt in the north and more gradual in the southern portion.

Carigali drilled Resak 6F-18.4 in 1993 and successfully penetrated an overpressured zone finding hydrocarbon bearing reservoirs within and beneath this zone. An understanding of this phenomenon is crucial in the planning of safe and efficient drilling campaigns.

INTRODUCTION

The study area comprises the entire Malay and Penyu Basins located offshore and sub-parallel to the east coast of Peninsular Malaysia. This large area extends approximately 700 km along its Northwest-Southeast axis and is 300 km wide (Fig. 1). The Malay Basin contains up to 13 km of Tertiary siliciclastic sediments in the depocentre and the Penyu Basin contains up to 4 km. Both basins have been divided into several stratigraphic groups (Figs. 2 and 3). The first well was drilled by ESSO in 1969. Since then, approximately 300 exploratory and appraisal wells have been drilled. Of these, statistics show that 80% of the wells were terminated due to either the well being overpressured or in the anticipation of this phenomenon (Fig. 4). Nevertheless, blowouts and subsequent loss of technical data have always been a concern during drilling operations.

This study was therefore initiated to analyse the occurrence, origin and the influence of overpressure on the drilling programmes in the Malay and Penyu Basins.

PHYSICS OF OVERPRESSURE

A state of overpressure is considered to exist when the pressure exerted by the fluids within a rock at a specified depth exceeds from the pressure exerted by an equivalent column of water to that same depth. The pressure gradient of a free-standing column of fresh water is 0.433 psi/ft (9.79 kPa/m). Any variation is considered abnormal. The terms overpressure and Underpressure refer to values above and below the hydrostatic gradient respectively (Barker, 1972; Bradley, 1975; Carstens, 1981, Fertl, 1976; Hunt, 1990; Mudford, 1988; Walls and Bourbie, 1982).

DATA BASE

A total of ninety four (94) exploratory wells have been selected which are geographically spread throughout both basins. They consist of fifty eight (58) drilled by ESSO, seventeen (17) by CARIGALI, five (5) by CONOCO, four (4) by TEXACO, three (3) by HAMILTON OIL, three (3) by LASMO, three (3) by JTOC and one (1) by WMC (Fig. 5).

METHODOLOGY

There are several methods of identifying overpressure such as by using velocity profiles and sonic transit times. However, they do not measure real formation pressure. The introduction of the Repeat Formation Tester (RFT) to the exploration industry has made it possible to take a large number of accurate pressure measurements at various depths in a single well. The pressure data, primarily taken from RFT's and DST's, have been selectively chosen as they are not supercharged and are

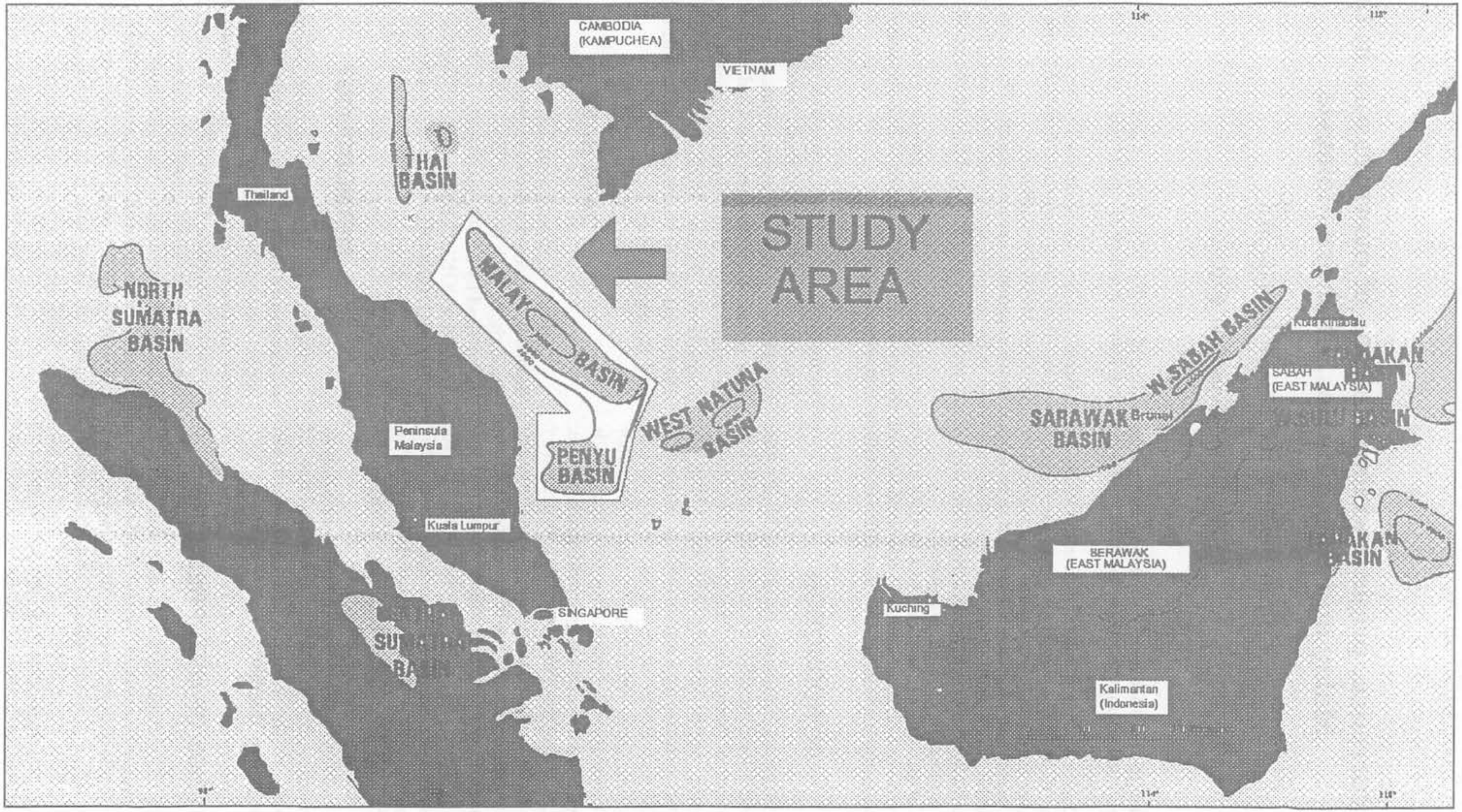

Figure 1. Tertiary sedimentary basins of Malaysia and adjacent territories.

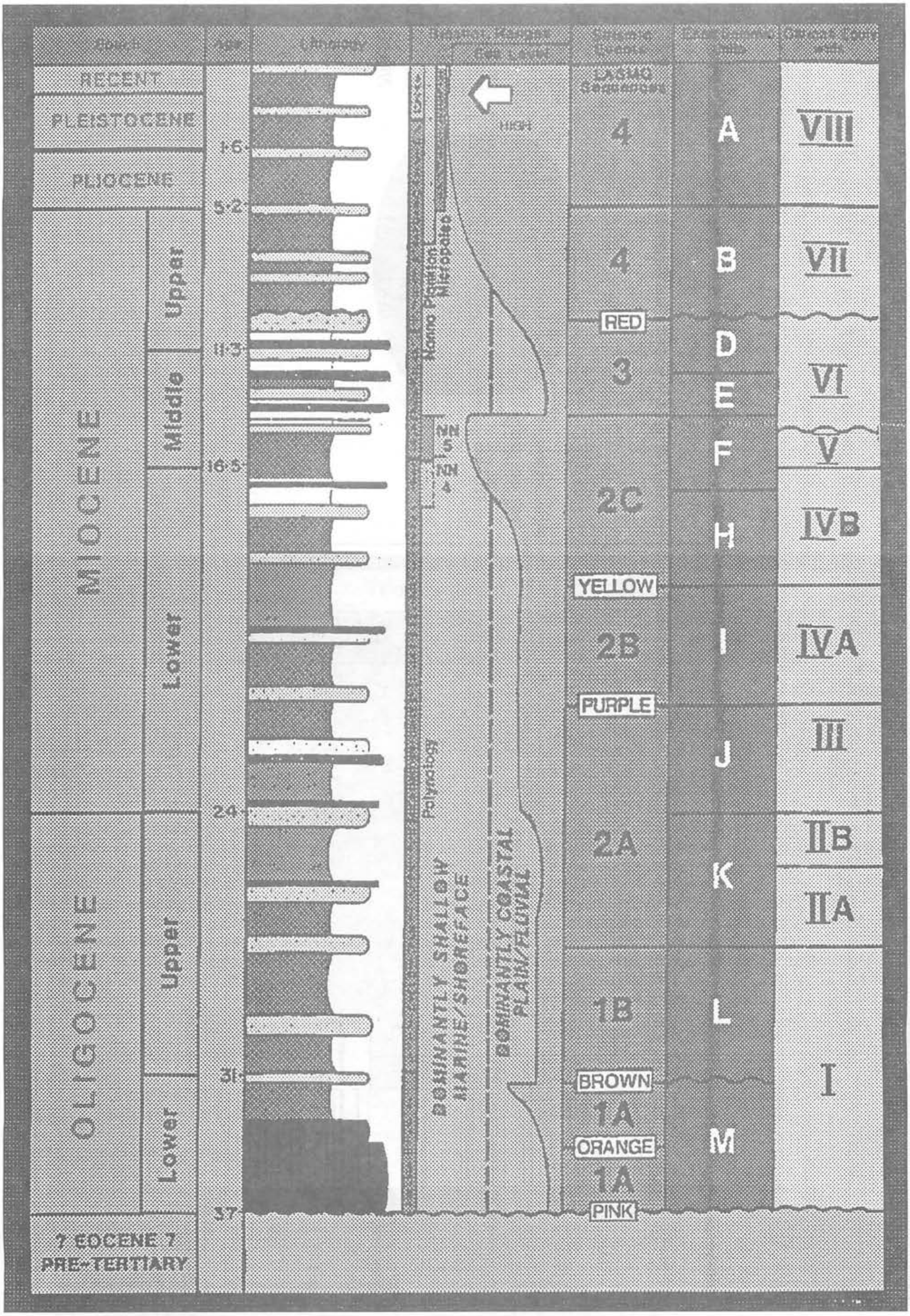

Figure 2. Malay Basin stratigraphy.

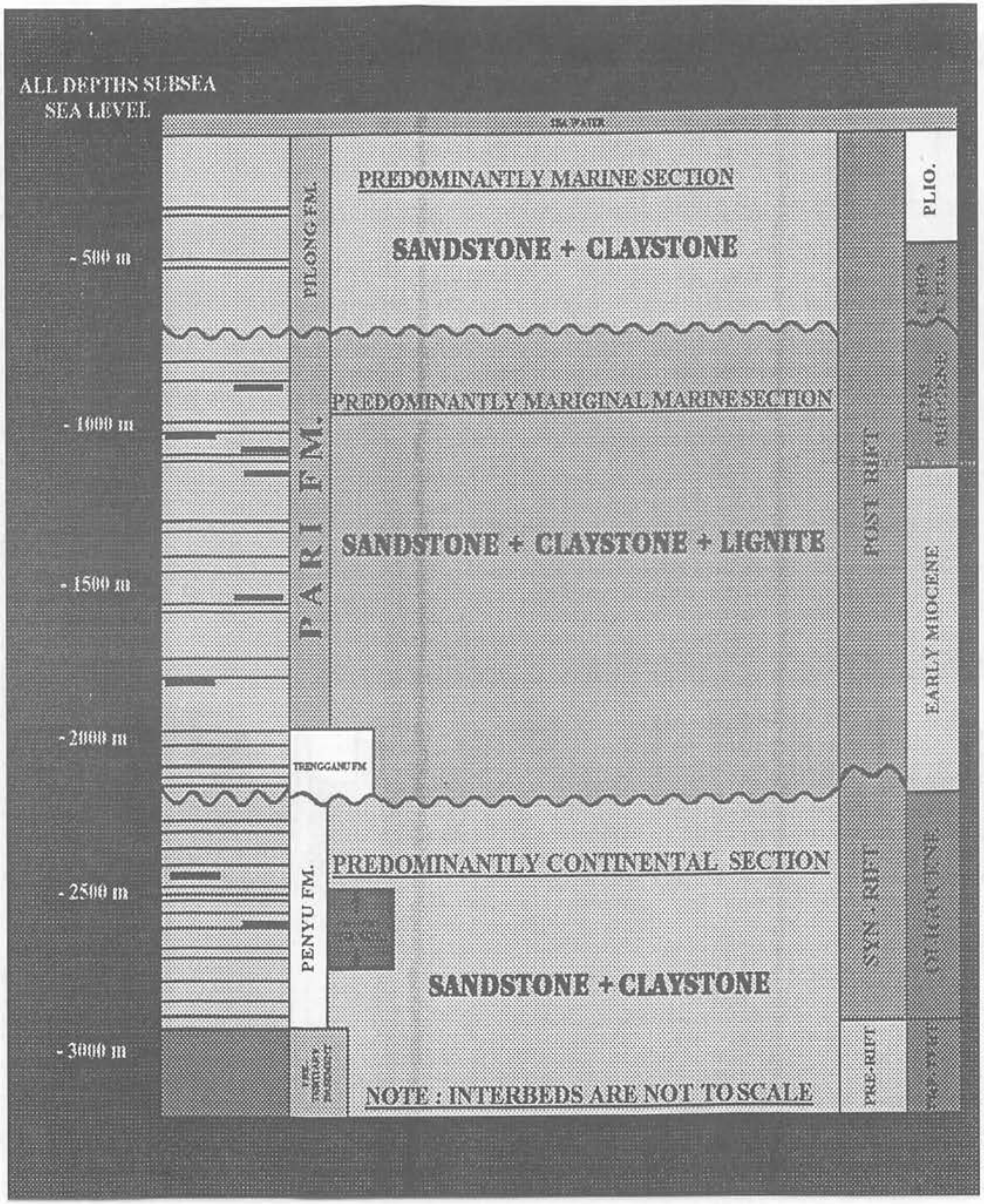

Figure 3. Penyu Basin generalized stratigraphy.

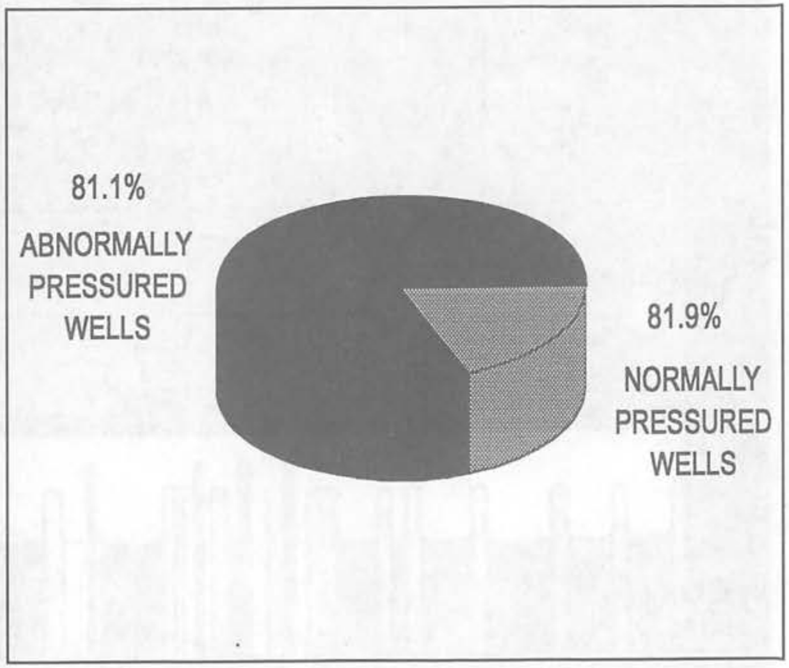

Figure 4. Rationale — Malay and Penyu Basins well statistics.

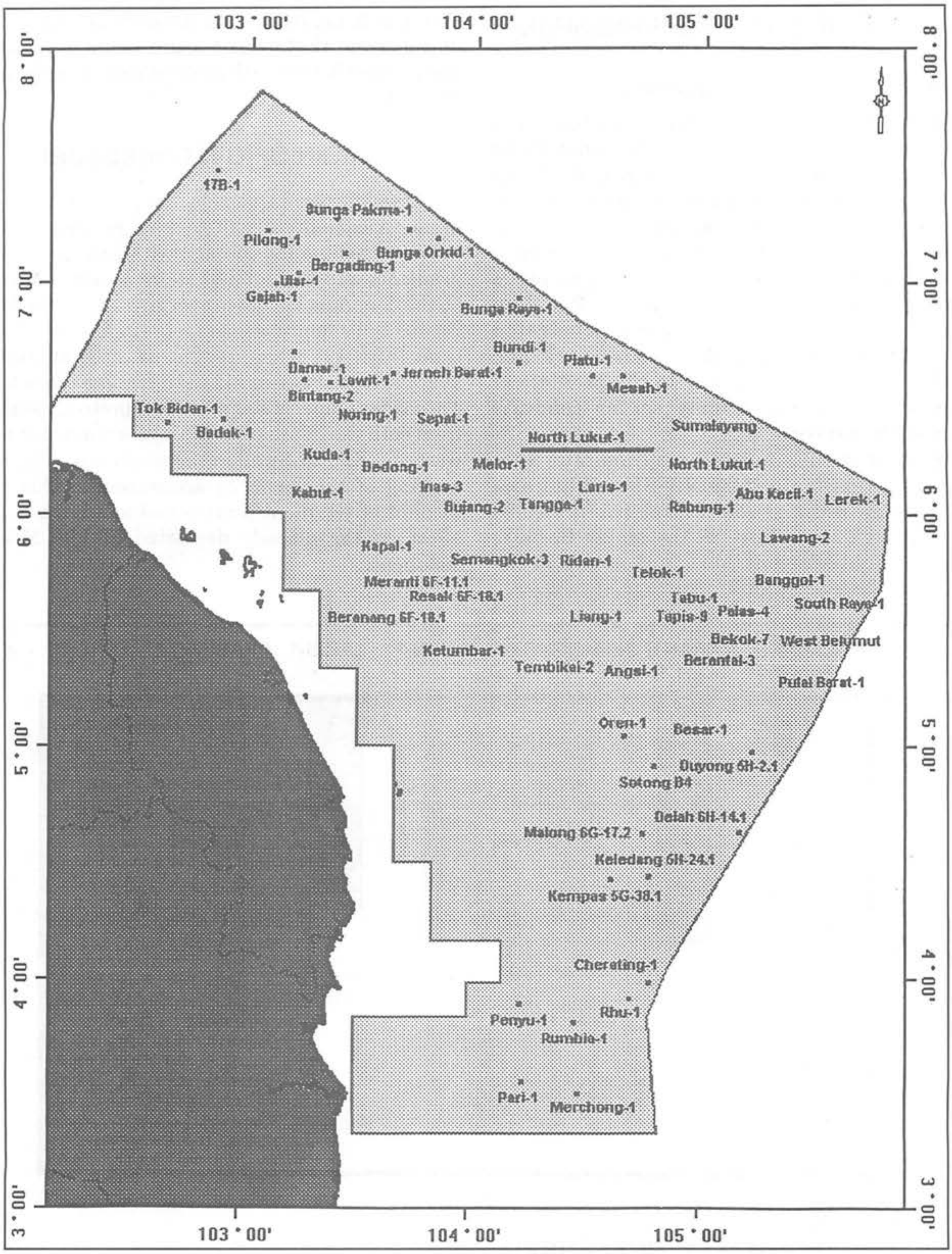

Figure 5. Abnormal pressure study regional database.

therefore valid tests. Plotting such data from the wells gives or indicates a clear picture of the onset of overpressure.

OCCURRENCE OF OVERPRESSURE

Lateral and Vertical Configuration

Figure 6 is a well section across the basin and indicates that the overpressure in the Malay Basin is structurally shallower in the centre of the basin and deeper towards the basin margins. It also indicates that overpressure occurs in progressively older stratigraphic units towards the basin margins. Based on the existing well data, the margins of the basin are normally pressured (Fig. 7). Two deep wells drilled in the Penyu Basin penetrated basement but did not encounter overpressure (Fig. 8). This is most probably due to the presence of permeable sands which may act as conduits releasing the pressure.

Figure 9, a subsea depth map indicates that overpressure exists along the NW-SE trending axis of the Malay Basin. The control points (wells) indicate that overpressure in the Malay Basin is clustered in discrete envelopes and occurs in the stratigraphically younger units in the centre of the basin and in progressively older units towards the basin margins (Fig. 10).

There is sufficient measured maximum bottomhole pressure data throughout the basin to demonstrate that overpressure tends to be severe and greater in the northwestern portion of the basin (Fig. 11).

ORIGIN OF OVERPRESSURE

Many factors can cause overpressure. In some areas, a combination of factors prevails. Rapid burial of sediments, coupled with high geothermal gradients and low sand-shale ratio are believed to be the dominant causes of overpressure in the Malay Basin. Subsidence was greatest in Middle Miocene time (Fig. 12) when sediments accumulated an average rate of 900 m/Ma in the centre of the basin. The large volume of sediment was probably supplied from both the Peninsular Malaysia landmass to the west and Khorat Swell to the northeast. The rapid sagging of the basin to accommodate this large amount of sediment contributed to an overloading effect on the already deposited Middle Miocene sediments.

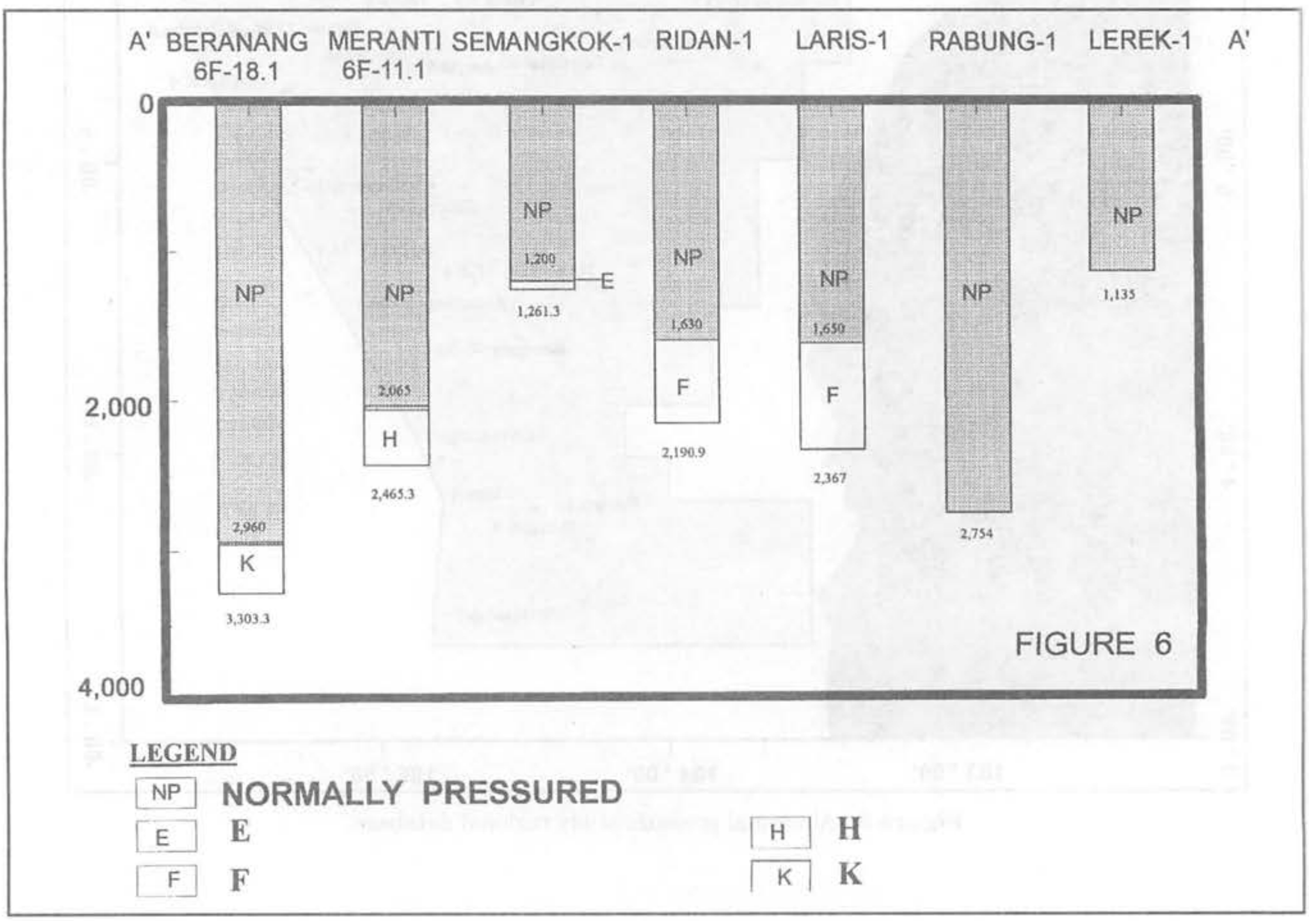

Figure 6. Central Malay Basin cross section.

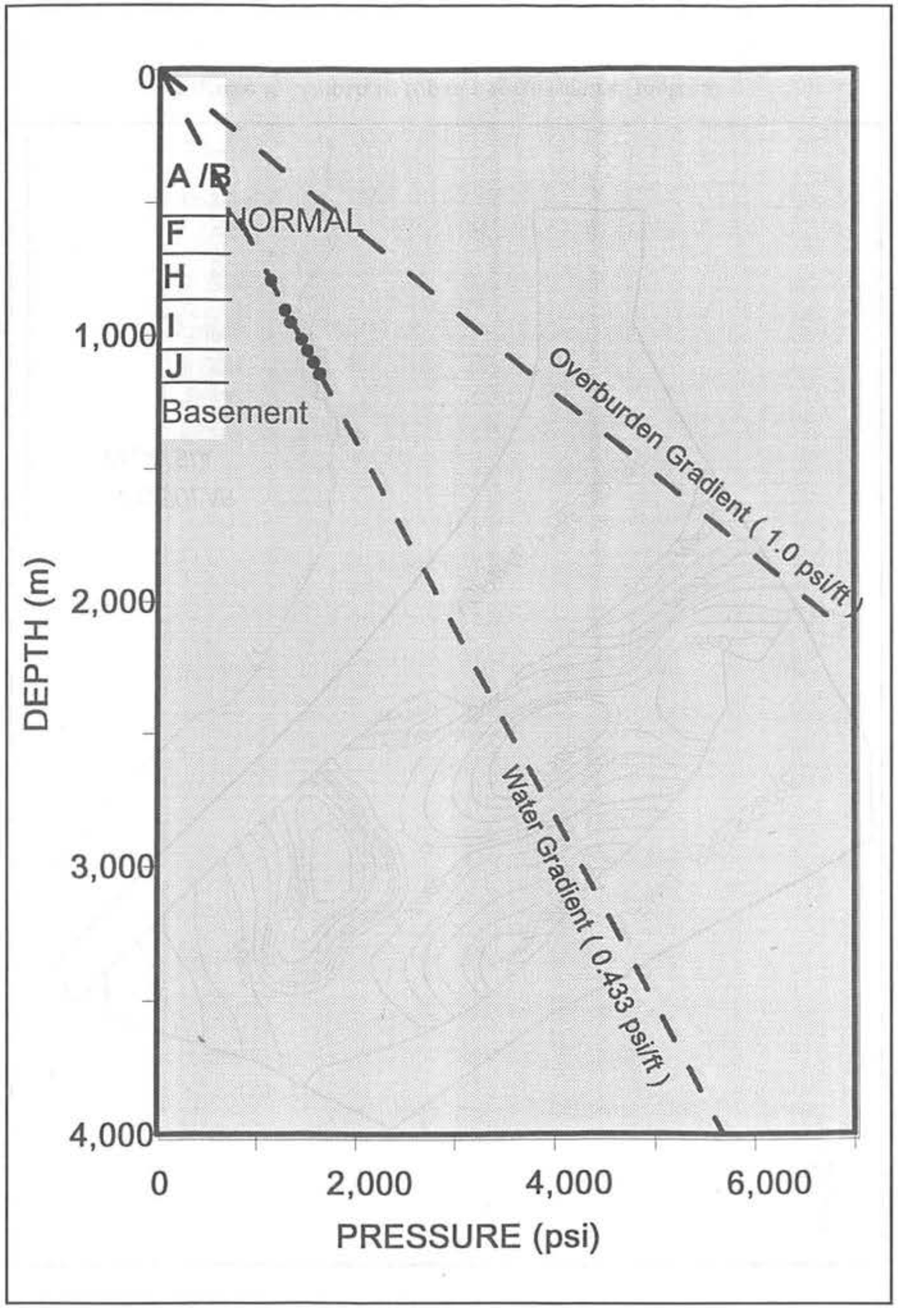

Figure 7. Pressure versus depth plot, Lerek-1.

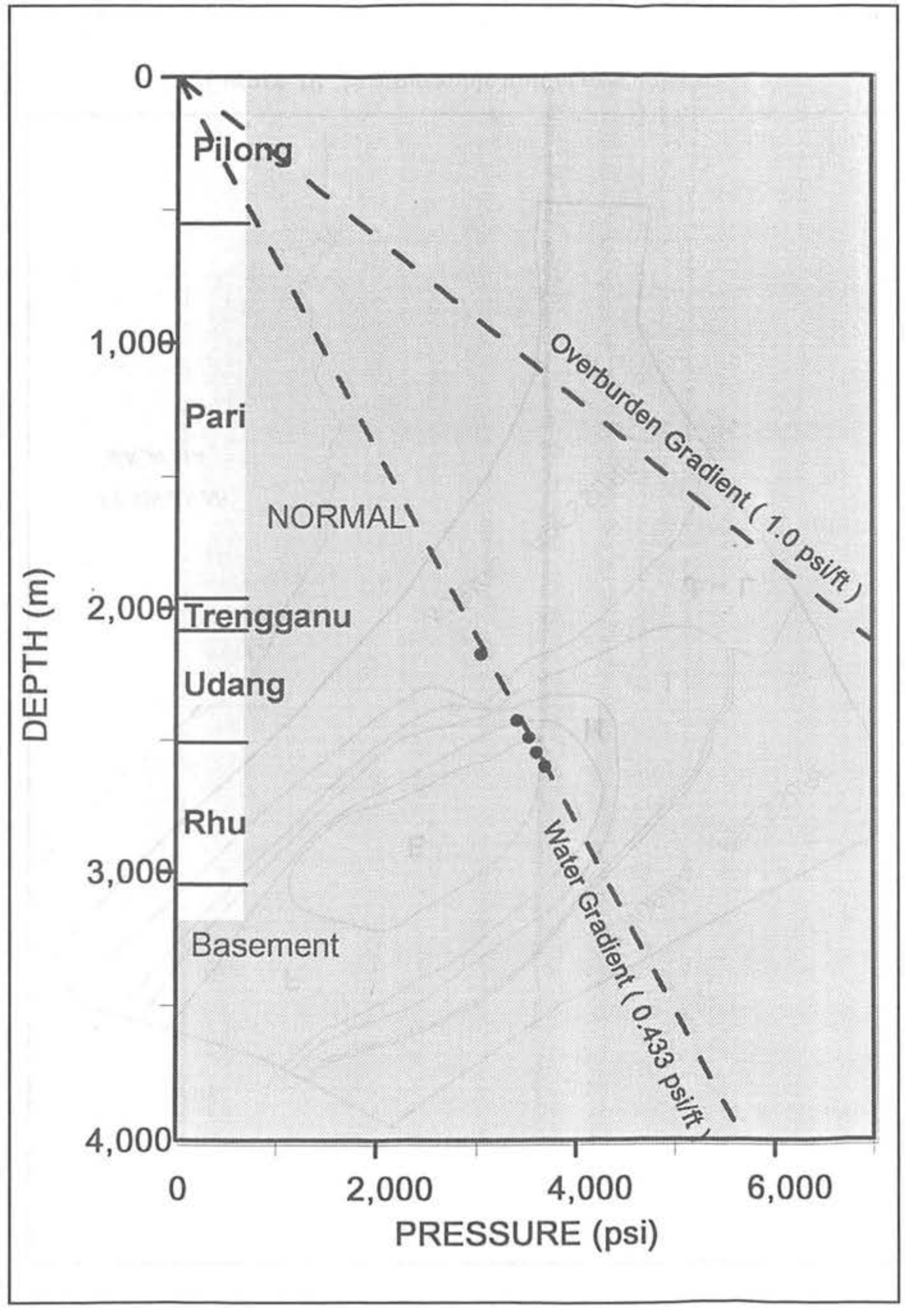

Figure 8. Pressure versus depth plot, Rhu-1.

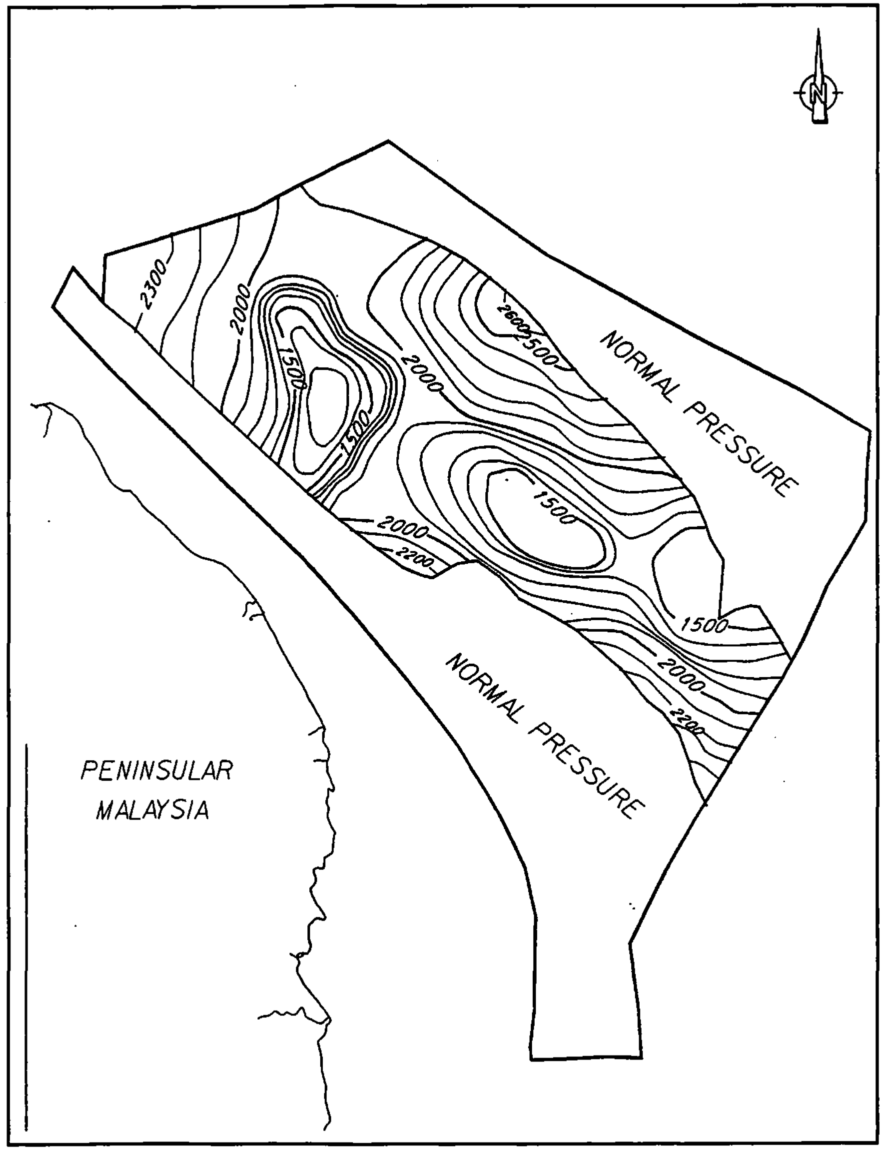

Figure 9. Depth to top of overpressure (metres).

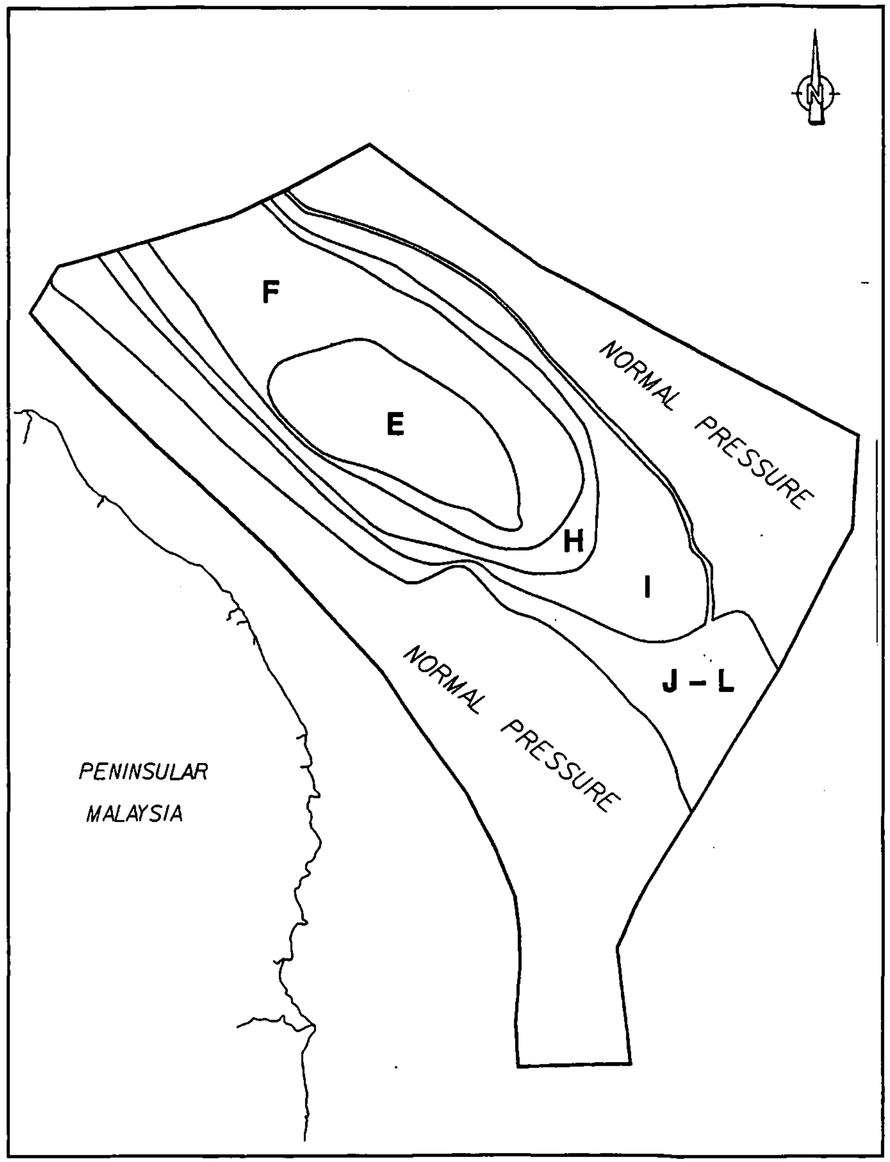

Figure 10. Stratigraphic unit of overpressure.

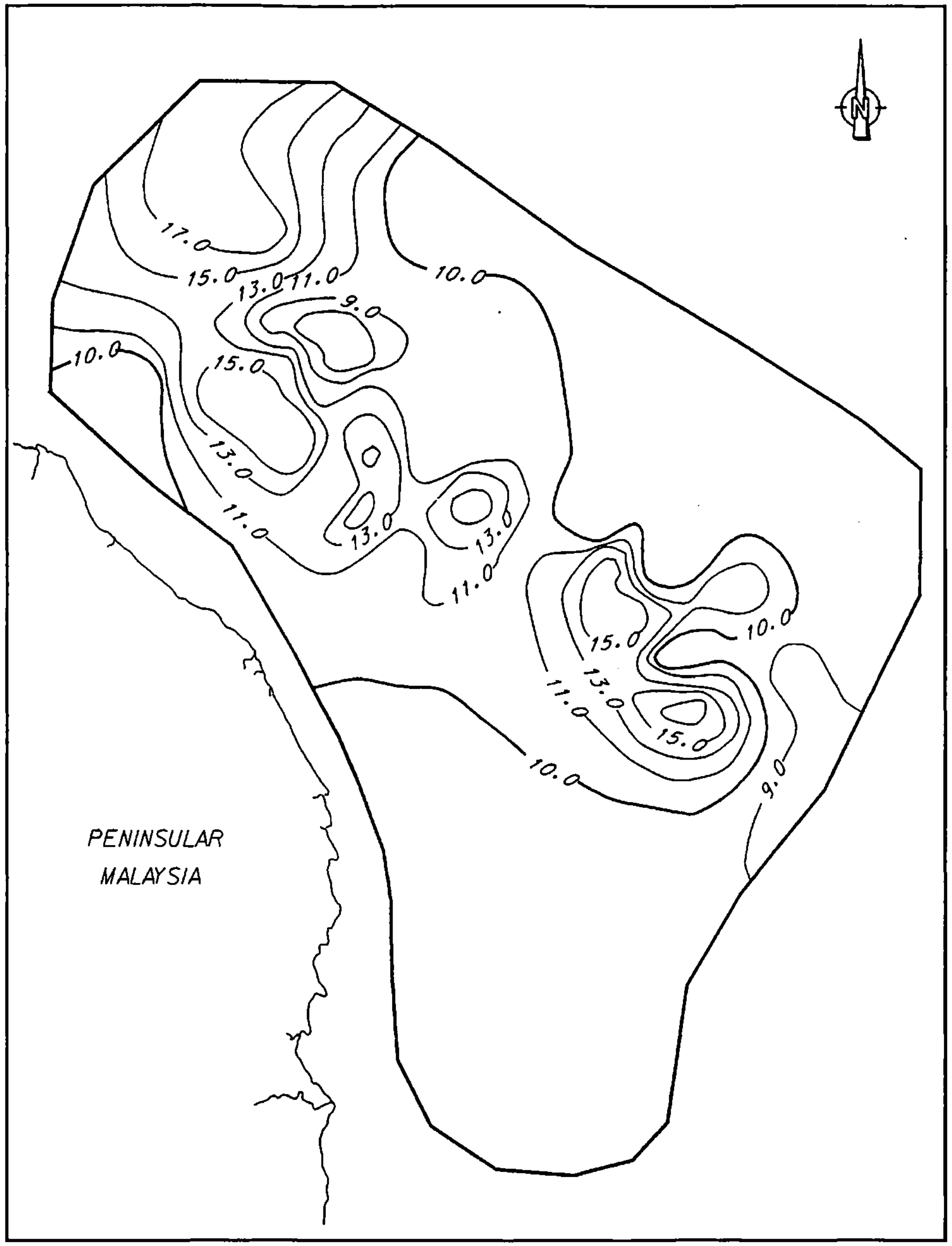

Figure 11. Pore pressure gradient (emw in ppg).

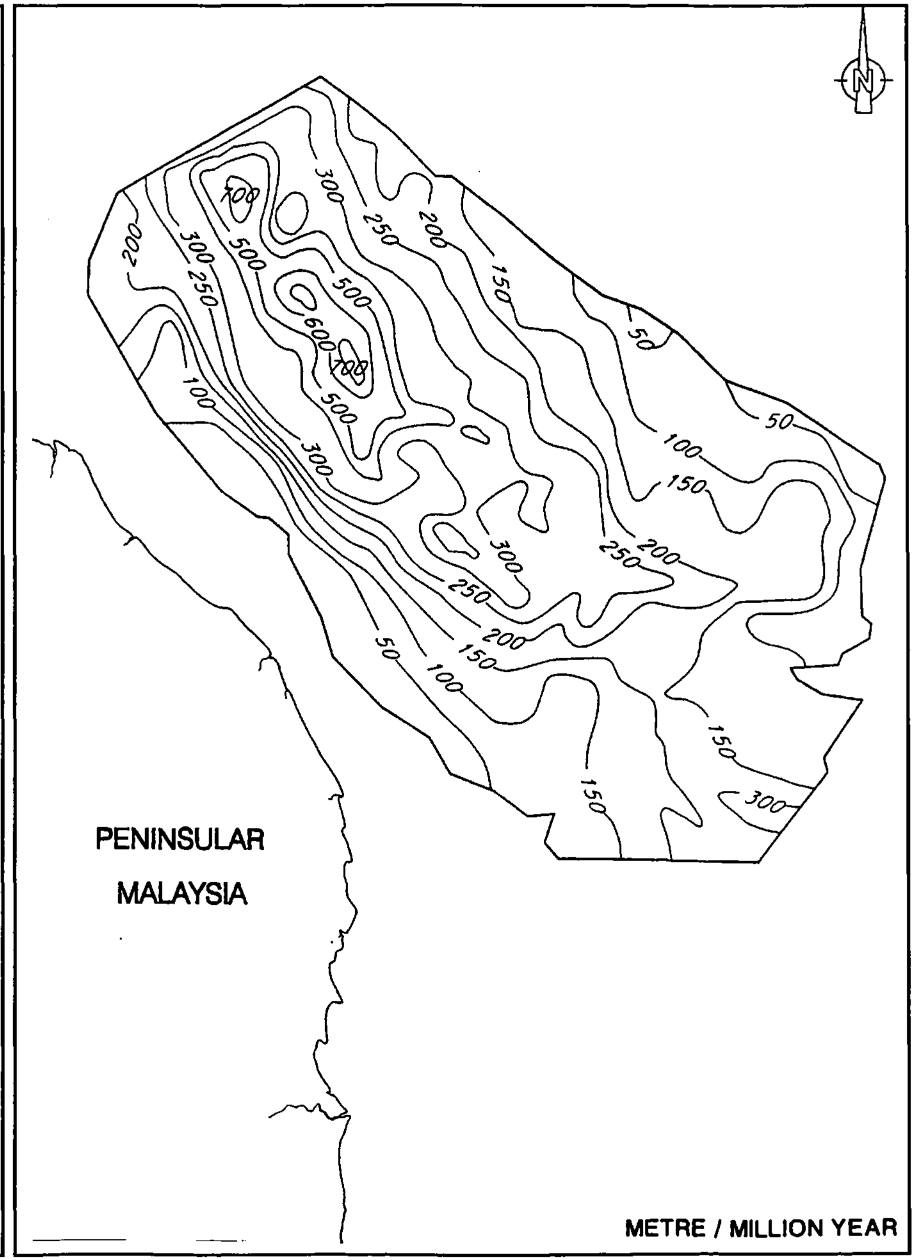

Figure 12. Sedimentation rate of Group F.

Low sand-shale ratios along the basin axis particularly in the centre of the Malay Basin, (Fig. 13) are also believed to contribute to overpressuring.

Clays generally exhibit low permeability which inhibits the escape of the water. During deposition, as sediments compact water will usually find a passage to escape. The presence of clays due to this low permeability will retard this water movement. It is known that as the mixed layer clays, composed of smectite, kaolinite and montmorillonite, undergo heating due to burial, the crystal structure progressively alters to illite. This transformation also releases water held between the crystal lattice. If this released water cannot escape due to the lack of an extensive porous and permeable network, resulting from low sand-shale ratios, then the section could become overpressured.

In the centre of the Malay Basin, due to high geothermal gradients (5.0°C/100 m), the dewatering zone is shallow and thin. This may support the fact that overpressure occurs at structurally shallower depths and in stratigraphically younger units in the centre of the basin and is progressively deeper and older towards the basin margins where the geothermal gradient is less.

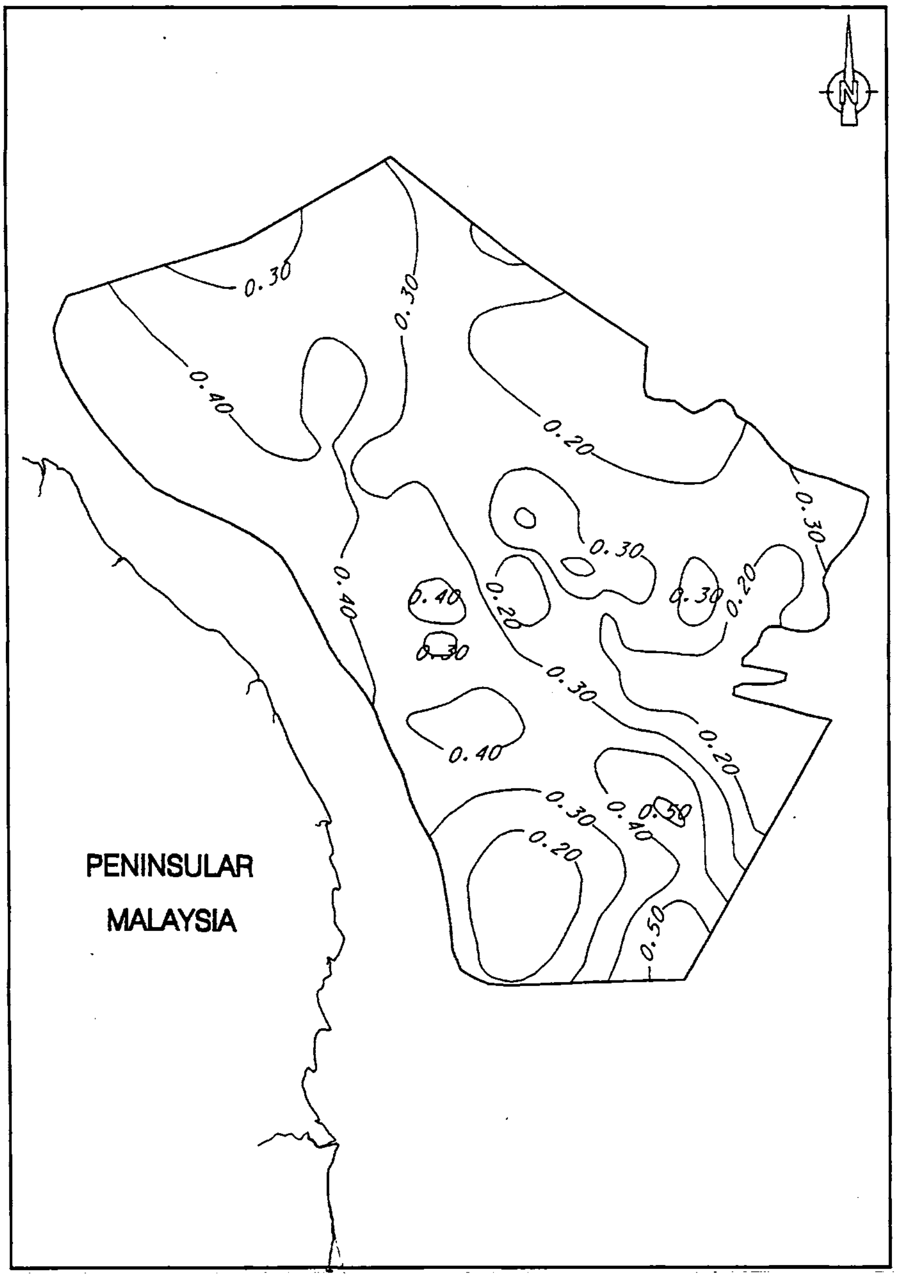

Figure 13. Sand-shale ratio of Group F.

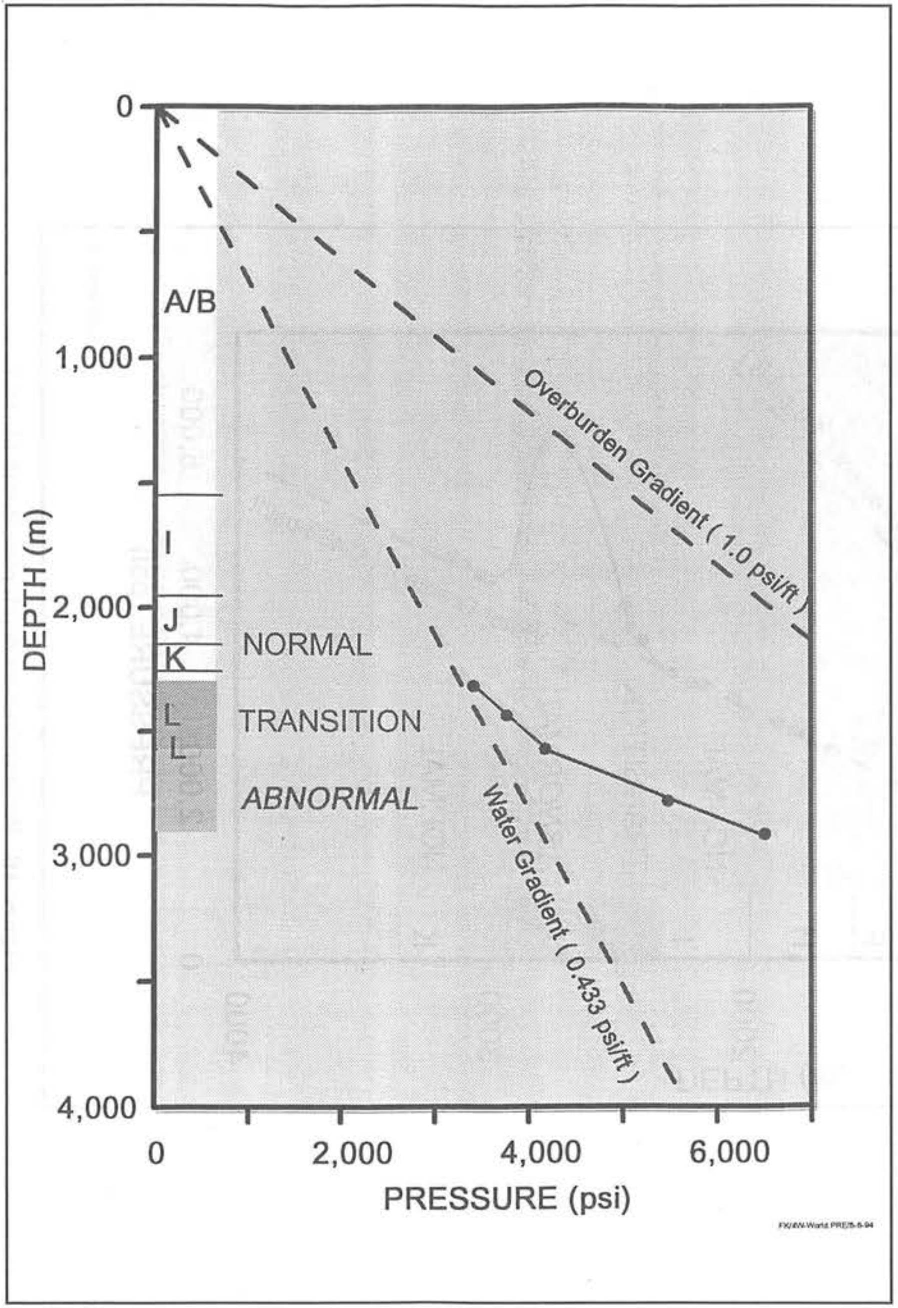

Figure 14. Pressure versus depth plot, Angsi-1.

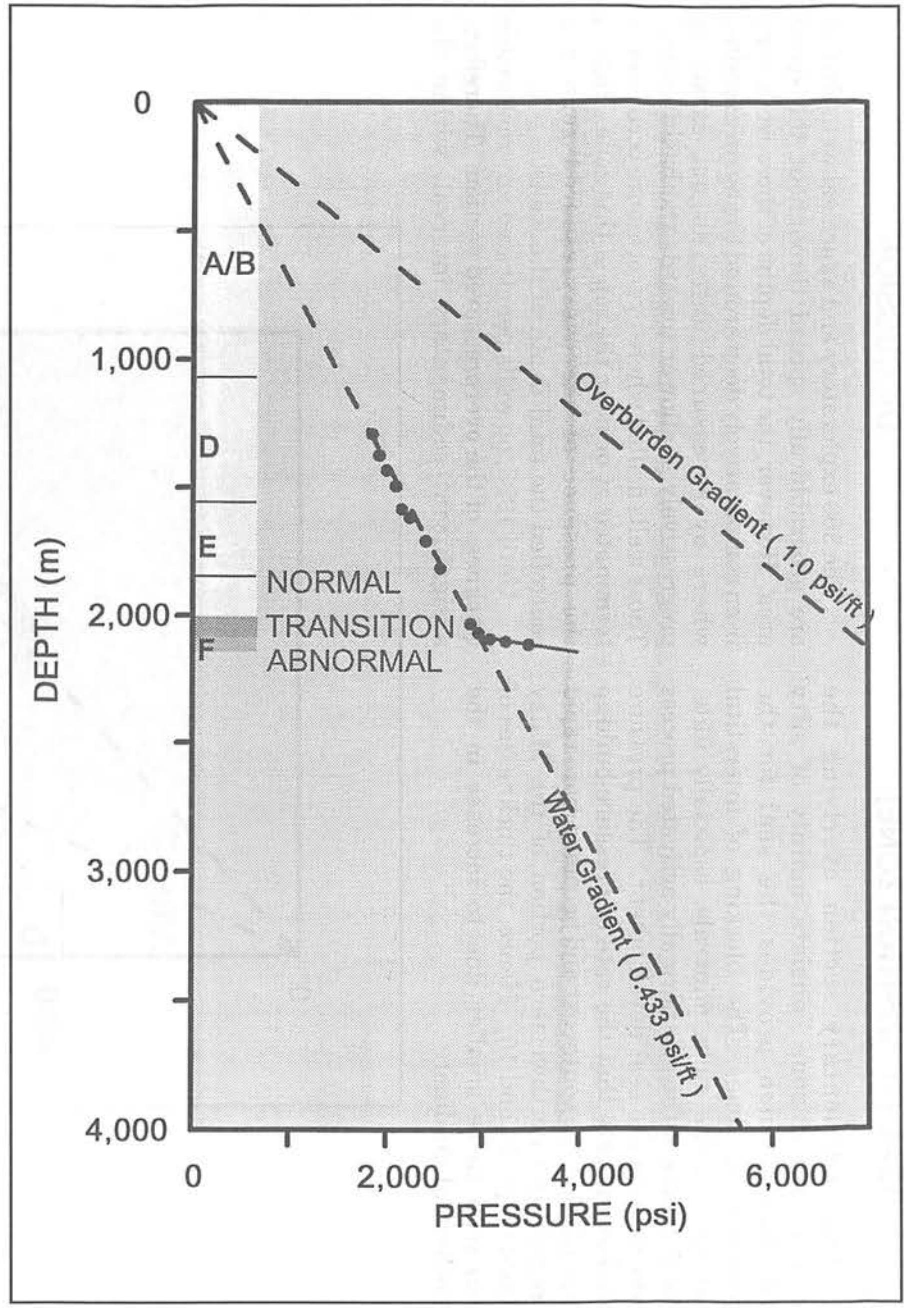

Figure 15. Pressure versus depth plot, Jerneh Barat-1.

SEAL (TRANSITION ZONE)

The sedimentary section overlying the overpressured zone consists mainly of silty lithofacies which provides the seal for the overpressure zone. The blocking of interstital passages by the silica minerals, especially illite, the products of the geothermally activated process may explain the seal development. The pressure profiles indicate that the rate of pressure-buildup is gradual in the southeast and becomes more rapid towards the northwestern portion of the Malay Basin (Figs. 14 and 15). Hence, the thicknesses of seal tend to be smaller due to increase in the geothermal gradient.

DISCUSSION

The 300 exploratory and appraisal wells drilled are geographically spread throughout the study area. However, the total depths of these wells vary from comparatively deep around the basin margins, where overpressured units do *not exist*, to progressively shallower towards the basin centre. Those wells drilled where overpressure occurs were terminated at or near the top of this zone. Hence, the presence of the overpressured zone has controlled the total depth of the wells.

Until 1993, no wells penetrated any reasonable thickness of the overpressured section. Therefore, a significant sedimentary interval, within the

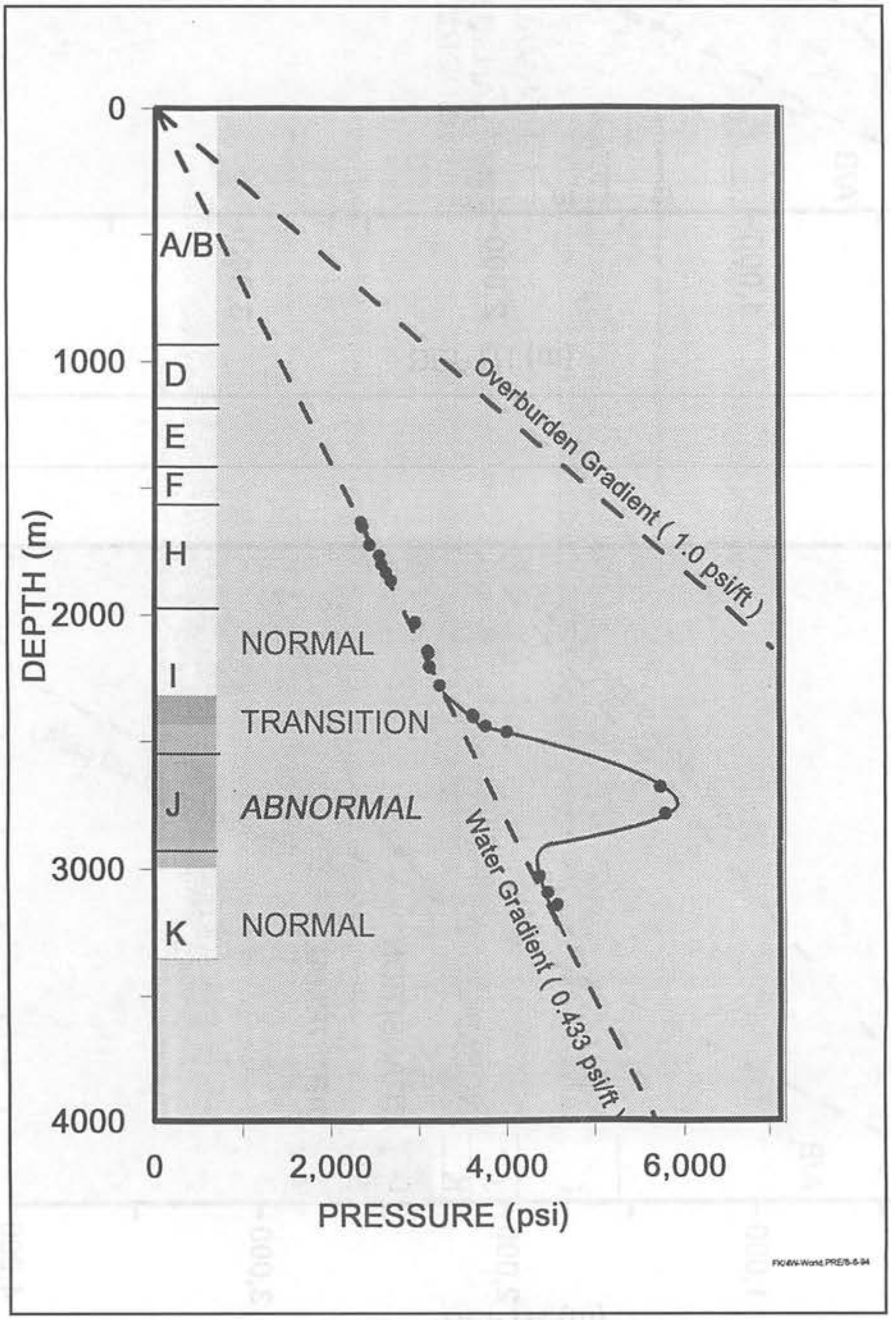

Figure 16. Pressure versus depth plot, Resak 6F-18.4.

overpressured zone, remained untested.

Carigali successfully penetrated an overpressured zone in 1993 by drilling Resak 6F-18.4. At this location, the zone was found to be approximately 400 metres thick (Fig. 16) and hydrocarbon bearing reservoirs were found both within and beneath this overpressured zone. Successful drilling was accomplished by utilising improved techniques and having a better understanding of the pressure regimes.

The optimistic outlook for oil and gas exploration and development in this area can be exemplified by the drilling result of this Resak well. Potential hydrocarbon bearing reservoirs both within and beneath the unexplored overpressured zones can therefore be achieved after detail studies on the overpressure regimes and utilization of state-of-the-art drilling techniques (Fig. 17).

CONCLUSIONS

This paper documents the occurrence of overpressure in the Malay and Penyu Basins which provides a framework for more detailed study of this phenomenon within the area. The main conclusions concerning the occurrence of overpressure are summarized below:-

1. Overpressure is not confined to a specific stratigraphic unit in the Malay Basin.
2. The depth to the top of overpressure zone varies in a predictable manner in the Malay Basin.
3. Overpressure appears to be abrupt and severe in the northwestern portion of the Malay Basin.
4. Overpressure has not been noted in the Penyu Basin.
5. A better understanding in the pressure regimes and by using improved drilling techniques, penetration of the overpressured zones can be accomplished as demonstrated by Resak 6F-18.4.

It would seem that the era of windfall discoveries are over in the Malay-Penyu Basin. Exploratory efforts must therefore now be focused on the difficult-to-find play types, possibly within the overpressured zones.

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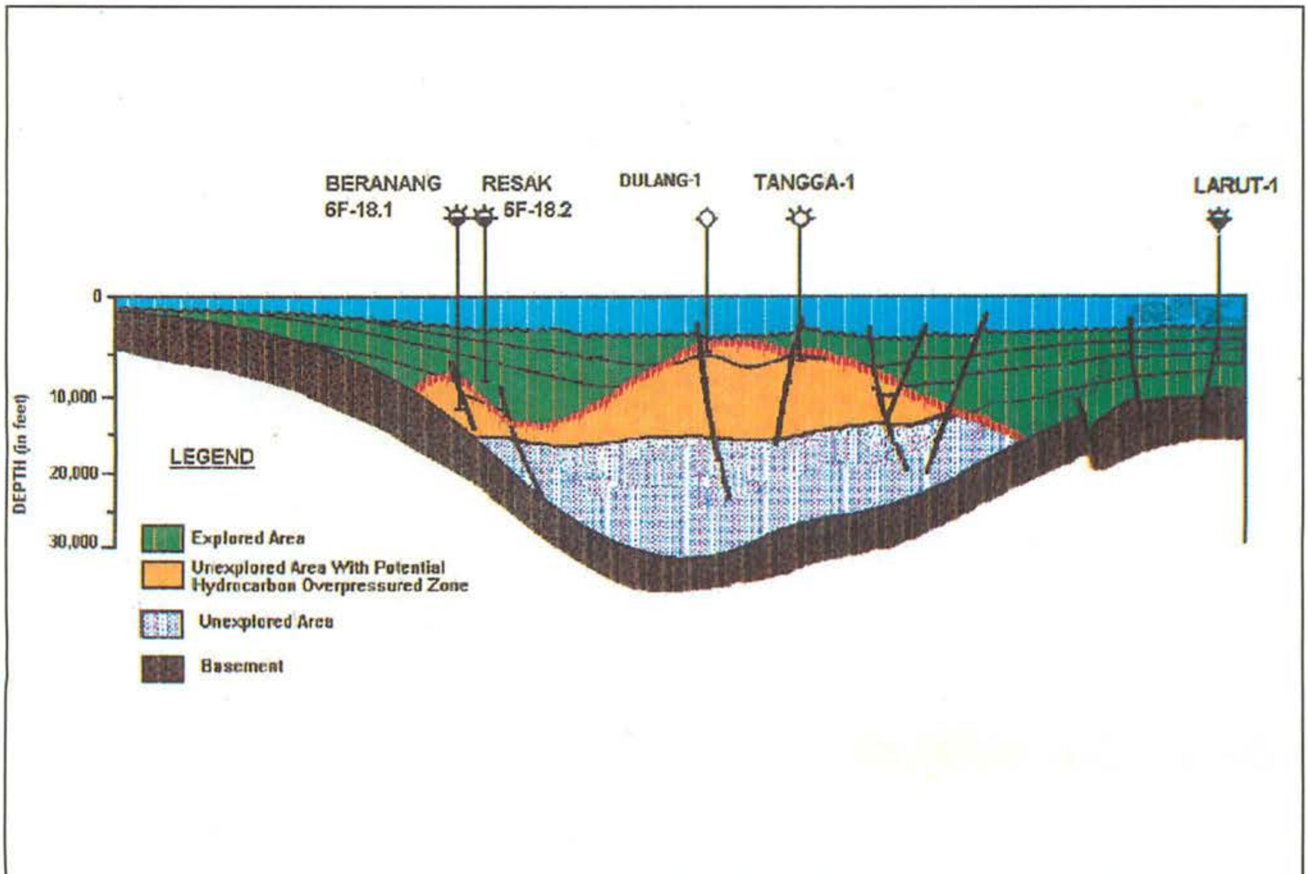

Figure 17. Abnormal pressure surface in the Malay Basin.

Regional Study Team of Petronas Carigali for their constructive reviews and comments.

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