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A Study of Heat Flow Analysis Techniques and Their Relationship to the Development of Pore Pressure

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ABSTRACT

Undercompaction caused by high sedimentation rate in Malay Basin is the most common overpressure mechanism, and temperature distribution has no relationship with the occurrence of overpressure. Similarly, the occurrence of overpressure is independent of any particular formation group. There are many factors for the generation of overpressure in the Malay Basin, and temperature also plays an important role in the generation of overpressure. This paper introduces heat flow analysis technology and its relationship with pore pressure development. On the basis of structural interpretation, the study area is composed of four well-defined fault blocks. The problem of shallow pore pressure is very common in Malay basin because of high geothermal gradient. Pore fluid pressure is the pressure exerted by the fluid in the confined pore space of the rock, and hydrostatic pressure is the pressure exerted by a column of water at any given depth. A one-dimensional modeling of the basin was performed using temperature data from drilling rod tests (DSTs), modular formation dynamics tests (MDTS), repeated formation tests (RFTS), and production tests to evaluate terrestrial heat flow for all fault blocks. The heat flow values of each well in the fault block are different, but the heat flow values of each fault block have little change. The pressure data of all Wells from the well test were plotted and the results of heat flow analysis were verified. It is speculated that the high temperature and high heat flow in each fault block are the main causes of hypersonic pressure.

KEYWORDS

Basin modeling; Heat flow; Overpressure; Temperature.

1. Introduction

Malay Basin is located in the South China Sea, entirely offshore to the east of Peninsular Malaysia. The trend of the Malay Basin is NW-SE, approximately 250km wide long by 500 long (Madon et al., 1999). Current study has been carried out in a field which lies in southwestern part of the basin (Figure 1). Malay Basin is a part of a rift and high heat flow has been recorded in this basin. The average geothermal gradient of the Malay Basin is 40 to 60 °C/km. This high geothermal gradient and high heat flow has influence on the generation and migration of hydrocarbons (Ismail, 2011). Heat flow depends upon the thermal conductivity of the rocks. The heat flow varies over the Malay Basin, lower heat flow in the Southeastern part and Northeast peripherals and regional highs in the Northwest, South and central portions (Ismail, 1993).

Pore fluid pressure is the pressure exerted by the fluid within the confined pore space of a rock and hydrostatic pressure is the pressure exerted by a column of water at any given depth. Overpressure is the pressure higher than the hydrostatic pressure (Bowers, 2002). Overpressure is normally generated by two most common mechanisms, undercompaction and/or fluid expansion. Undercompaction occurs when sedimentation rate is high and due to low permeability of the rock, fluid cannot escape quickly from the pores. Fluid expansion can also generate very high pore pressure due to increase in pore fluid volume caused by heating or hydrocarbon maturation (Bowers, 1995).

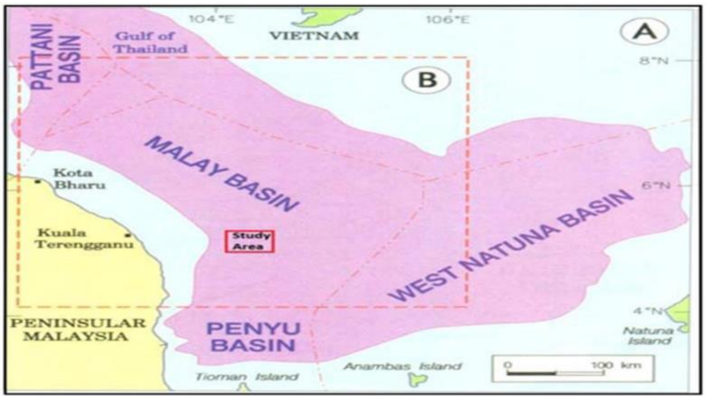

Figure 1. Map showing the location of the Malay Basin and Study area (Madon et al., 1999)

The onset of overpressure varies across the Malay basin (Figure 2). In the basin center, top of overpressure is shallowest (i.e. 1.9-2.0 km.) and deepens towards the flanks of the basin, often at depth of 3.0 km (Kader, 1994). Occurrences of overpressures in the southern Malay Basin take place at shallower depths of 1500 to 2000m (Ismail, 1993). In the study area, almost all wells are overpresusred. In some wells overpressure start at shallow depth and gradually increase with the depth, while in some wells overpressure start at greater depth and ramp up quickly.

According to previous studies, undercompaction due to high rate of sedimentation is the most common mechanism of overpressure and there exist no relationship between the temperature distribution and onset of overpressure in the Malay Basin. Similarly onset of overpressure is not related to any particular stratigraphic group (Ismail, 1993: Koch et al., 1994). Kader and Leslie (1995) discussed that in the Malay Basin, fast deposition of sediments, coupled with low sand-shale ratio and high geothermal gradient are believed to be the main cause of overpressure. Hoesni (2004) suggested that in the Malay Basin, overpressure is generated by more than one factors and temperature also plays a significant role in overpressure generation.

In many basins of the world, faults are associated with traps for oil and gas. Some faults are sealing and some are non-sealing. A systematic study is required for the determination of sealing and non-sealing properties (i.e. texture, permeability and capillary pressure etc.) of faults (Berg and Avery, 1995). A fault is sealing if it forms the lateral seal or part of it for an accumulation. Hydrocarbon migration is halted at the intersection of the reservoir and the fault for an accumulation to have formed. Fault can be sealing due to the lateral juxtaposition of reservoir after movement across the fault opposite to an impermeable bed or during the movement an impermeable material is formed along the fault zone before the hydrocarbon migration. Pore pressure data obtained from the well logs can also be used for fault seal analysis as sealing and non-sealing properties of faults have significant effect on pore pressure.

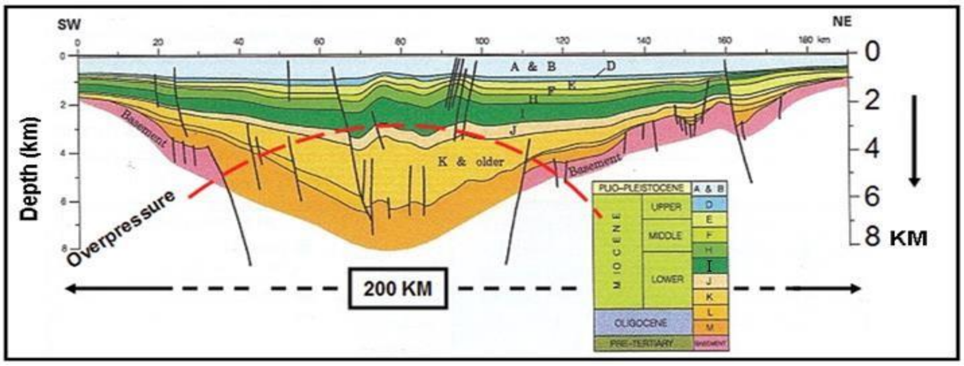

Figure 2. Top of overpressure in the Malay Basin. Red curve shows the top of overpressure in the basin center and at the flanks (Madon et al., 1999)

Basin Modeling is very useful tool for numerical simulation of burial, temperature and maturity history of rocks and mathematical modeling of hydrocarbon generation, expulsion, migration and accumulation. In the present study, 1D basin modeling technique is used to analyze heat flow and investigate the relationship between heat flow and high pore pressure (i.e. overpressure) development in the study area.

2. Methodology

The flowchart of methodology is shown in figure 3. The 3D seismic data interpretation was carried out to understand the nature of the subsurface structure and stratigraphy. For all of the interpreted horizon and faults, time contour maps and surfaces were generated to identify the trend of the subsurface structure. On the basis of the qualitative seismic interpretation, the study area is divided into four fault blocks (i.e. fault block A-D) from east to west. The wells are also grouped according to the fault blocks. The interpreted horizon and faults along the well locations is shown in figure 4. Petromod 1D is used to build the 1D basin models of all the wells. The input parameters such as lithology, Formation age, boundary conditions and temperature data is obtained from the well logs and reports. Gamma Ray (GR) and density (RHOB) logs are used to interpret the lithology of the wells. Volume of shale is also calculated from GR log to analyze shale percentage.

Chronostratigraphic chart is used to assign the ages to the different lithology groups (Group E, H etc.). Heat flow is calculated by thermal calibration with the temperature data obtained from DST, production test and well log. For the wells JM-1, JM-2and JM-3 temperature form DST and for the well temperature data from production test is used. Temperature correction is applied on the maximum recorded temperature used for the other wells. The present day heat flow is calibration derived value that best fits all or most of the temperature data, examples of heat flow calibration from 1D modeling are shown in figures 5 and 6.

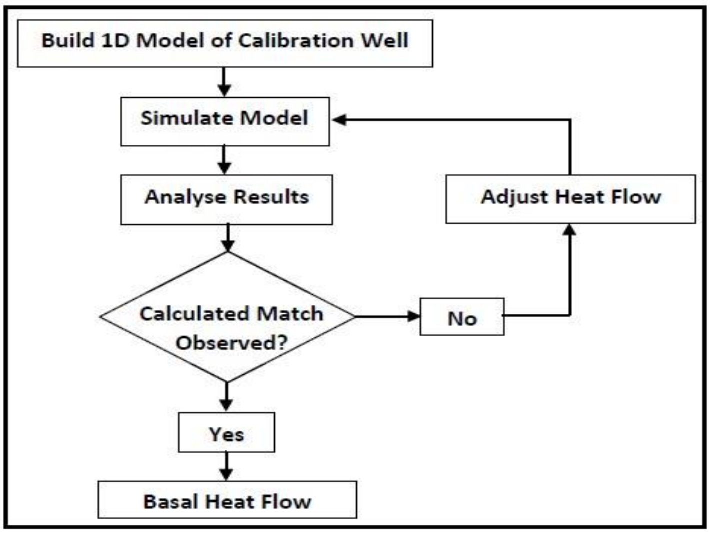

Figure 3. Heat flow analysis workflow

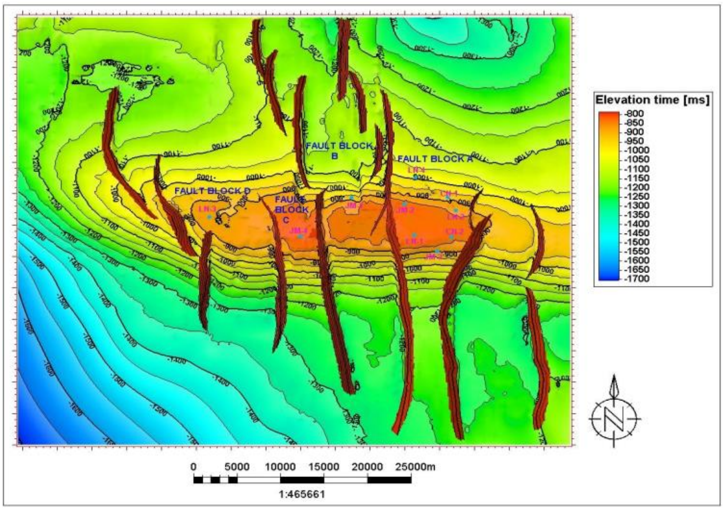

Figure 4. Time structure map of an interpreted horizon shows that the geological anticline trends East-West, whereas most of the normal faults have North-South trends

Location of fault block and wells is also shown.

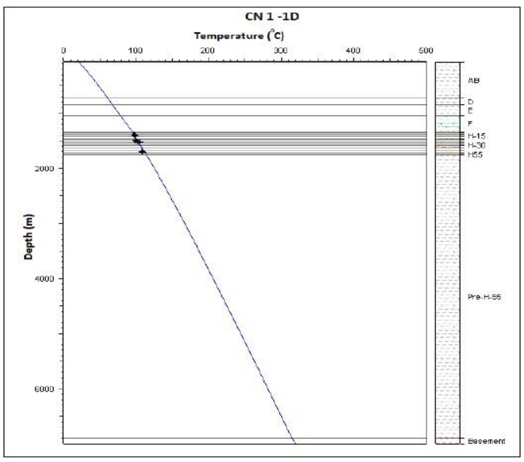

Figure 5. Heat flow calibration for the well CN 1

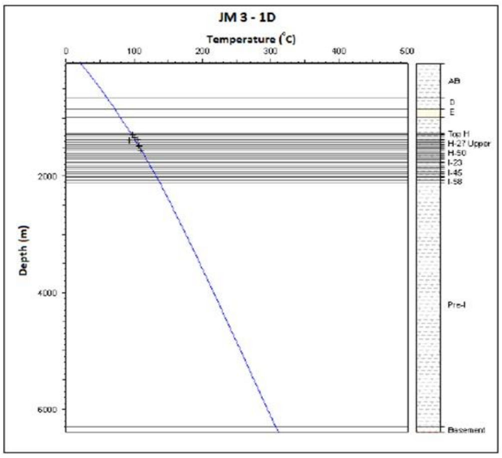

Figure 6. Heat flow calibration for the well JM 3

Temperature and pore pressure data obtained from MDT, RFT, DST and well logs is plotted block wise to check the variation across the fault blocks (Figures 7 and 8). Hydrostatic and overburden pressure is calculated using hydrostatic pressure gradient (i.e. 433 Psi/ft) and density data obtained from well logs respectively. Hydrostatic pressure is given as:

$$Ph = \varrho wgh \qquad (1)$$

where Ph is hydrostatic pressure, ϱw is the water density; g is gravitational acceleration, h is the depth interval. Overburden pressure in marine environment is given as:

$$Pob = \varrho wghw + \varrho gh \qquad (2)$$

where Pob is overburden pressure, hw is water depth and ϱ is rock density.

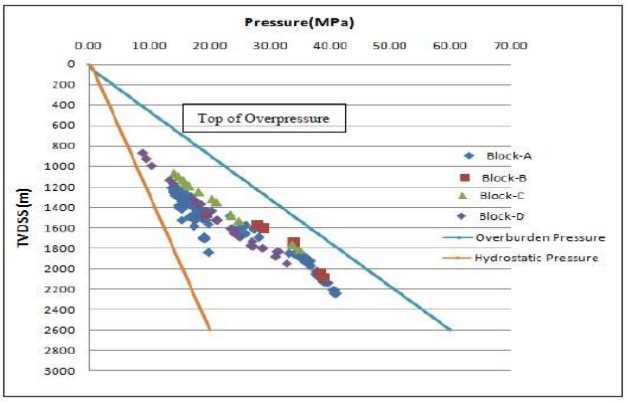

Figure 7. Pressure-depth plots for all the fault blocks

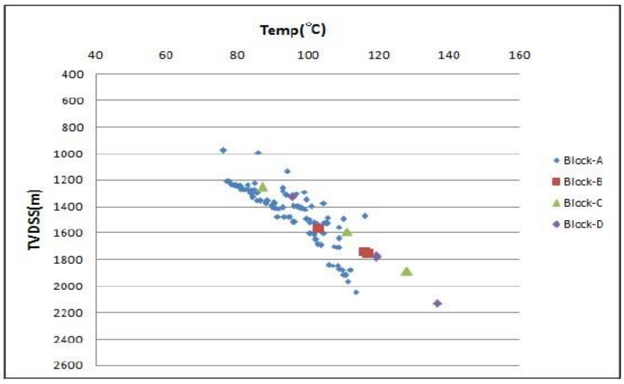

Figure 8. Temperature-depth plots for all the fault blocks

3. Results and Discussion

The structural interpretation of the seismic data shows the presence of an east-west trending anticline dissected by a succession of normal faults with north-south trend. Fault block A (main fault block) is relatively less deformed by normal faulting as compared to fault blocks B and C (shear zones). In the fault block D, en-echelon arrangements of normal faults suggests that a shear component is present in the western flank of the study area.

The heat flow values obtained from 1D basin modeling for all fault blocks are shown in table 1. Heat flow value is high in all the fault blocks and lies in the range of 70 to 75 mW/m2. The fault blocks where shale is the more dominant lithology, heat flow values are less as compared to the blocks where shale dominancy is low. Heat flow values also show small variation across the fault blocks. This heat flow variation in the fault blocks can be due to the sealing properties of faults.

Table 1. Heat flow value for all the fault blocks

Fault Block	Heat Flow (mW/m^2)
A	74
B	70
C	75
D	72

High pore pressure and temperature is observed in all the fault blocks. Like the heat flow values, temperature and pressure profiles also shows little variation across the fault blocks. This variation of pressure and temperature across the fault blocks also suggests that the faults are sealing faults. According to previous studies (Ismail, 1993) and (Koch et al., 1994) in the Malay Basin, undercompaction is the main cause of overpressure generation and there exist no relationship between temperature and overpressure generation. On the contrary, Hoesni (2004) and O'Connor et al., (2011) suggested that in the Malay Basin, there exist a relationship between temperature and overpressure generation, and more than one factors are involved in overpressure generation. But, they did not give any relationship between high heat flow and overpressure generation. The previous work was carried out on regional scale but our study is carried out on field scale. Our study gave the evidence that in the Malay Basin, overpressure is generated by more than one factors and there exist a relationship between high temperature, high heat flow and overpressure generation.

4. Conclusions

On the basis of above heat flow results, pressure and temperature profiles analysis, it is concluded that:

• There exists a relationship between heat flow and overpressure development.

• As a result of high heat flow, source rocks mature at early stages and the generation of hydrocarbon starts at shallow depth which is contributing in high overpressure generation.

• High heat flow and high geothermal gradient is responsible for high pore pressure profiles in all the fault blocks.

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