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Investigation of Thermophysical Parameters Properties for Enhancing Overpressure Mechanism Estimation. Case Study: Miri Area, West Baram Delta

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Investigation of Thermophysical Parameters Properties as A New Work Flow for Enhancing Overpressure Mechanism Estimation. Case Study: Miri Area, West Baram Delta.

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Abstract. Determining the pore pressure data and overpressure zone is a compulsory part of oil and gas exploration in which the data can enhance the safety with profit and preventing the drilling hazards. Investigation of thermophysical parameters such as temperature and thermal conductivity can enhance the pore pressure estimation for overpressure mechanism determination. Since those parameters are dependent on rock properties, it may reflect the changes on the column of thermophysical parameters when there is abnormally in pore pressure. The study was conducted in "MRI 1" well offshore Sarawak, where a new approach method designed to determine the overpressure generation. The study was insisted the contribution of thermophysical parameters for supporting the velocity analysis method, petrophysical analysis were done in these studies. Four thermal facies were identified along the well. The overpressure developed below the thermal facies 4, where the pressure reached 38 MPa and temperature was increasing significantly. The velocity and the thermal conductivity cross plots shows a linear relationship since the both parameters mainly are the function of the rock compaction. When the rock more compact, the particles were brought closer into contact and making the sound wave going faster while the thermal conductivity were increasing. In addition, the increment of temperature and high heat flow indicated the presence of fluid expansion mechanism. Since the shale sonic velocity and density analysis were the common methods in overpressure mechanism and pore pressure estimation. As the addition parameters for determining overpressure zone, the presence of thermophysical analysis was enhancing the current method, where the current method was the single function of velocity analysis. The presence of thermophysical analysis will improve the understanding in overpressure mechanism determination as the new input parameters. Thus, integrated of thermophysical technique and velocity analysis are important parameters in investigating the overpressure mechanisms and pore pressure estimation during oil and gas exploitation in the future.

Keywords – Overpressure, Thermal Conductivity, Temperature, Heat Flow

1. Introduction

Many methods have been suggested and used to predict the accurate pore pressure, even in shallow or in deep reservoir (i.e overpressure zone). These parameters are crucial for exploration, drilling and resource estimation since the accurate pore pressure can affect safety and profit. Eaton method (Eaton, 1975) has been frequently used for determining the pore pressure and overpressure zone. In this method, one of main parameters that should be constructed is normal compaction trend (NCT) of an attribute of slowness and the deviation which come from that parameters was used for developing the trend and constructing the exponent to predict the high pore pressure which named as Eaton-exponent (typically 3 or 4), which assumed that the higher pore pressure was only developed by undercompaction of sediments. The effective pressure or effective stress refers to the difference between the overburden pressure and pore pressure. Based on that concept, the velocity will decrease when the sound travels from normal pressure region to overpressure zone. This happened due to effective stress or effective pressure in overpressure zone is lower than normal zone (Adha et. all, 2017). In normal condition, the pore pressure is equal to hydrostatic pressure or water column from the formations depth to sea level. Formation pore pressure is constantly estimated or predicted based on well log analysis in combine with terzaghi hypothesis, which function of compaction the overburden stress and effective stress consist of matrix stress and fluid pressure. The difference between the *overburden pressure (Po)pore pressure (Pp)* is *effective stress (σ)*which can be written as following equation 1.

$$\sigma = Po - PP \quad (1)$$

If pressure is higher or less than the normal pressure, it is called as abnormal pressure. Overpressure generated by varies mechanism which has different characteristic with dissimilar treatment. Normally, abnormal pressure (above or below normal pressure) mechanism is caused by i.e *stress related mechanism, fluid volume increase mechanism and Fluid Movement and Buoyancy mechanism*. Those mechanisms were happened by the rapid change of formation due to different medium and fluid properties at particular depth. However, from the all mechanisms, two main mechanisms are highlighted, which are disqualibirium compaction and fluid expansion where that mechanism has significant contribution in overpressure generation (Swarbick and Hills, 1999) (Osborne Swarbick, 1997).

However, there are some weaknesses in pore pressure prediction through sounds method, due to lack of seismic or velocity data and lack of understanding on the effect of pressure on physical properties of medium (Huffman, 2002). The effective pressure tends to be overestimated resulting in underestimated of pore pressure (Zhang, 2011). In addition, on 1995 through noteworthy publication, Bowers suggested that in very high pore pressure the inclusion of thermal mechanism was essential for account that mechanism since the mechanical compaction alone could make underestimate in pore pressure determination.

In this paper, the relationship of thermophysical properties investigations including temperature gradient, thermal conductivity and heat flow were carried out to investigate and predict the pore pressure and overpressure mechanism along the well. The study was worthwhile for tackle the estimation in overpressure mechanism determination. Since the mechanism that reducing the velocity not only the function of overpressure zone, it is hope that this analysis will justify the existence of sonic velocity trend. This shall also investigate the relationship of overpressure occurrences with thermal and depth profile. With this observation, the anomalies of overpressure due to rock properties and temperature can be determined.

1.1 Regional Geology

The Baram delta province is elongated in triangular shape, with its apex occurring onshore and cantered in Brunei and north eastern coastal area of Sarawak. This province exists in onshore and expend into offshore with cover the whole width of Brunei water, West Baram delta (Sarawak Province), East Baram delta (Sabah Province) and covering an area of 7500 km^2, including 2500 km^2 on shore. In western area, the Baram delta is margin by the West Baram line, a large system, northeast heading, down-to-the-basin faults that separates the delta from the older balingan and central luconia province. Meanwhile, the eastern margin is defined by the Morris Fault-Jerodung. Miri formation itself represents the lower part of Sarawak basin (West Baram delta) which is late Eocene to recent in age (Tingay, 2009). Distribution of overpressure in Miri Field can be divided into outer shelf and inner shelf. Inner shelf and outer shelf have different petroleum play types and different stratigraphic units. Predominant mechanism which is disequilibrium compaction of pro delta shale located in outer shelf is gradually shallow towards Northwest, onset at top of pro delta shale, meanwhile fluid expansion mechanism of deltaic sequence in Inner shelf has suddenly varied in depth to onset and highly compartmentalized. Temperature plays important role in the development of overpressure in the Miri Field. In certain temperature, the mechanism of disequilibrium compaction will change to the fluid expansion. Thus, temperature may lead to fluid expansion and cementation as identified (Tingay 2011).

1.2 Thermophysical Properties Overview

Thermal conductivity is defined as the rate of energy which transfer across a unit area under potential of a unit temperature gradient which has been expressed in $W(m^oK)^{-1}$ which is the function of rock type, anistrophy, pressure and temperature. Thermal conductivity across a reservoir rock is the total thermal conductivity or bulk conductivity of all medium which consists of rock properties and fluids inside the medium.

The thermal conductivity can be assumed as a rock property based on two main reasons. Firstly, the mineral thermal is much higher than fluid conductivity. Secondly, the mass fraction of mineral is higher than total fluid per bulk volume. A study found that the relationship between thermal conductivity and pressure is nonlinear relationship regardless of the rock type (Illmutdon, 2006). Yet, in general the thermal conductivity will increase with overburden pressure, since the both parameters are the functions of rock properties and net vertical forces.

Heat transfer across the earth from the core to surface through conduction and convection, which can be expressed as the product of temperature gradient and thermal conductivity is given by Fourier's law. The heat flow (Q) is directly proportional to temperature gradient in express form in Equation 2.

$$Q=-KdT/dy \tag{2}$$

Where K is the function thermal conductivity and dt/dy is the temperature gradient. T is in unit of ^0C while Q is in mW/m^2.

2. Methodology

The analysis used the well data, RFT data and BHT data from offshore Miri, Baram delta. For answering the objective, the study was divided in several stages. It was started with simple petrophysical analysis of rock properties which was used to determine the thermophsyical parameters such as *thermal conductivity, temperature and heat flow*. After that stage, the analysis sin crossplot analysis was applied to determine and characterize the behavior of each thermal parameters with pressure and velocity. In the final stage, those parameters were tied together for analyzing the trends of overpressure distribution along the well (vertical scale) since this analysis was not involved in the seismic data (Figure 1).

The modified workflow was designed to achieve the objective of this study. In general, the stages of this workflow were divided into three main stages. First, petrophysical analysis as in the processes was started with data preparation and quality checked, counties with petrophysical analysis for determining the reservoir zone, volume of fine, porosity as the function of thermal conductivity and heat flow determination. In addition, the pore pressure estimation corrected with pressure data was also investigated in this stage. This section involved cross plotting of the field data.

For the next stage, the thermophysical parameters were conducted with the input from well data. Thermal facies, zoning, heat flow and compaction factor were determined in this stage. Thermal facies were determined using empirical equation which developed by previous study (Yusoff, 1993) presented in Table 1.

In the final stage, each zone interest and top of overpressure were investigated to determine and characterize the trend of thermophysical parameters which tied with velocity for overpressure determination.

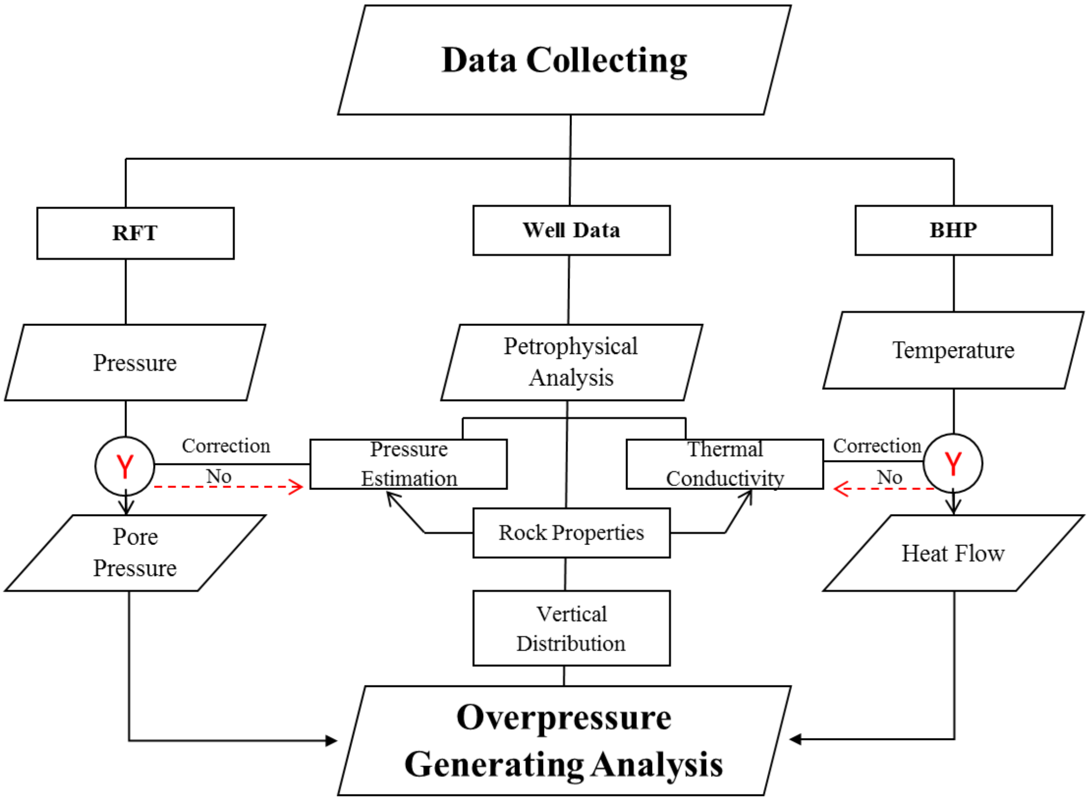

Figure 1. General work flow

Table 1. Empirical equation of thermal facies (Yusoff, 1993)

Thermal Facies. (Kf)	Limit of Log Parameters	Empirical Equation
Kf_1	Vf<20, Porosity < 36 %	$Kemp = 6.86(0.99)^{vf}(0.98)^{Porosity}$
Kf_2	20 ≤Vf< 40 , Porosity <35 %	$Kemp = 6.43(0.99)^{vf}(0.96)^{Porosity}$
Kf_3	40≤Vf<60 , 18% <Porosity <35 %	$Kemp = 10.59(1.00)^{vf}(0.98)^{Porosity}$
Kf_4	60≤Vf<80 , 18% <Porosity <39 %	$Kemp = 5.83(0.99)^{vf}(1.00)^{Porosity}$
Kf_5	13≤Vf<30 , 33% <Porosity <60 %	$Kemp = 13.41(1.09)^{vf}(0.91)^{Porosity}$
Kf_6	30≤Vf<40 , 35% <Porosity <49 %	$Kemp = 12.95(1.03)^{vf}(0.98)^{Porosity}$
Kf_7	40 ≤Vf>85 , 35% <Porosity <61 %	$Kemp = 15.24(1.01)^{vf}(0.94)^{Porosity}$

3. Result and Discussion

3.1 Petrophysical Analysis

Petrophysical analysis was conducted to carry out the rock properties of formation such as porosity and volume of fine or volume of shale. Volume of fine was determined by gamma ray while the neutron porosity (NPHI) was applied in this analysis to determine empirical thermal conductivity (Figure 4). In addition, the sandstone interval or zone was identified from several major traits which were from gamma ray (GR) log, resistivity log and also density-neutron log. In this well, the cut off for sand, silt and shale was determined. Clean sandstone (0-35 API) and siltstone were set at a range of 35-75 API while shale range is more than 75API (Figure 4). On the other hand, the interpretation of resistivity indicates the potential of fluid contents in the formation, while high resistivity indicates oil or gas (hydrocarbon). The gap between deep resistivity log (LLD) as well as shallow resistivity (LLS) log indicates the permeability of the layers identified. Coarsening upwards which is mostly stratigraphic sequence was found on this well. These facies indicate that the sediment was deposited in delta environment while the sedimentation was influenced by low energy current.

3.2 Thermophysical Parameters and Pressure Correlation

Thermal facies were used to differentiate the variance of thermal conductivity along the depth of well. It has been accepted that thermal conductivity of the formation are function of the lithology and porosity. In clastic sediments, the thermal facies were increasing due to the reducing of porosity as the function of burial and compaction. There were 4 thermal facies identified in “MRI 1” well. That was thermal facies 1 to thermal facies 4 from depth 1800 m ft-30480 ft.

According to the data, the thermal facies 3 had the highest values of thermal conductivity, followed by facies 1, facies 4 and facies 2. Not only the values of thermal conductivity, the distribution of thermal facies 3 was dominant along the wells (Table 2).

Table 2. Average thermal conductivity of Well MRI 1

Thermal Facies	Log Parameters		Average Thermal Conductivity
	Volume of Fine (Vf)	Porosity (Øn)	
Kf_1	17.4	33	3.91
Kf_2	21.3	29	1.56
Kf_3	57.20	24	5.97
Kf_4	63.24	22	2.73

The thermal conductivity was mandatory in heat flow determination where the heat flow is the function of thermal conductivity and temperature gradient. The heat traveled from the lowest thermal conductivity to high thermal conductivity. The movement of the heat transfer was influenced by the temperature, where the heat anomaly can be developed as the function of overpressure generating. In general, the high thermal conductivity tended to be developed high heat flow with the control by of formation temperature. In addition, the Figure 2 shows that similar behavior from velocity and thermal conductivity, where both parameters are the function of rock compaction and rock properties.

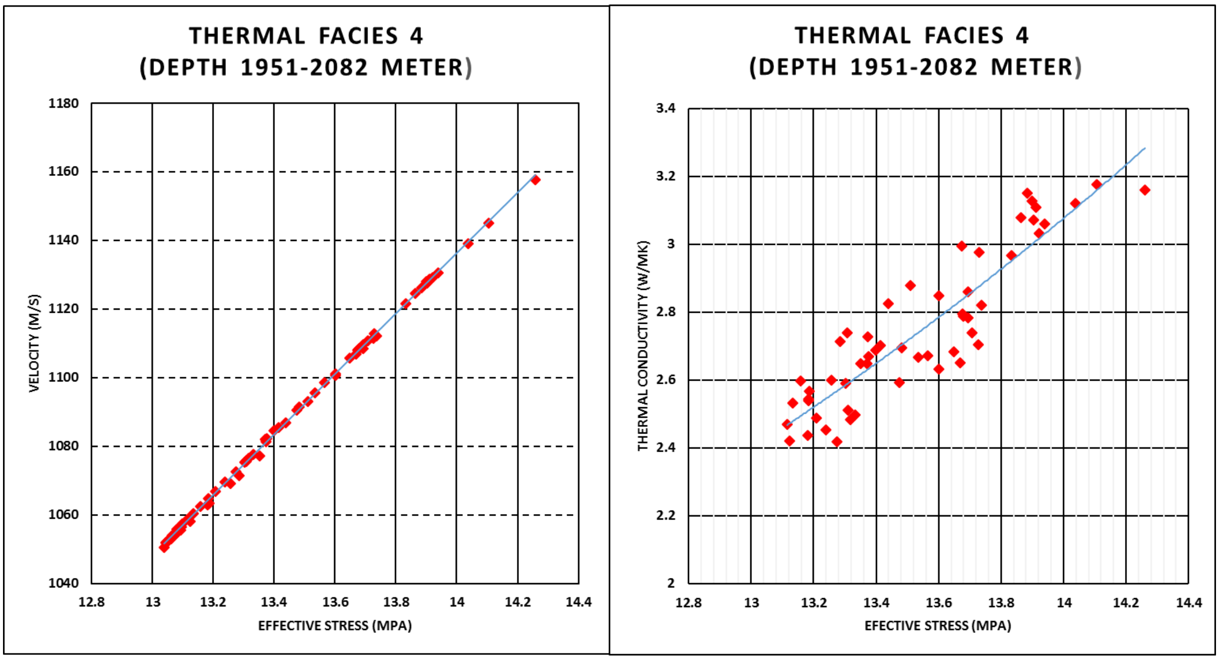

Figure 2. Velocity and thermal conductivity trends against effective stress for thermal facies 4, where both parameters were increased due to increasing of effective stress. That condition was proven by rock compaction theory.

3.3 Pressure and Thermal Depth Profiles

The pressure data was carried out from pore pressure estimation using Eaton method which was justified by the Repeat Formation Test (RFT) and Drill Stem Test (DST). The temperature and thermal conductivity were derived from estimated formation temperature which was justified by BHT data and thermal derived from petrophysical analysis. Meanwhile, the vertical heat flow profiles were determined by the multiple the average thermal and temperature gradient.

Based on this analysis, the top of overpressure was identified at 2872 meter depth (figure 3). On that particular depth, the pore pressure moved from the hydrostatic line to lithostatic line. In addition, the temperature and the heat flow show the similar trend where the pore pressure was increasing in 5.8 MPa followed by the increasing of 20^{0}C in the temperature.

The increasing of the heat flow and reducing of fluid flow indicator was interpreted as fluid expansion. That condition was interpreted as in fluid expansion the fluid was trapped and tried to escape and causing the increasing of heat flow and overpressure was developed. As mentioned in introduction, the fluid expansion is of mechanism that generates the overpressure. The movement of the fluids will be one of factors that increase the temperature. In addition, the convex form of the temperature indicates the movement of the fluid was horizontal. However, the horizontal movement of the fluid was tended to seal existence and hydrocarbon present (Figure 3).

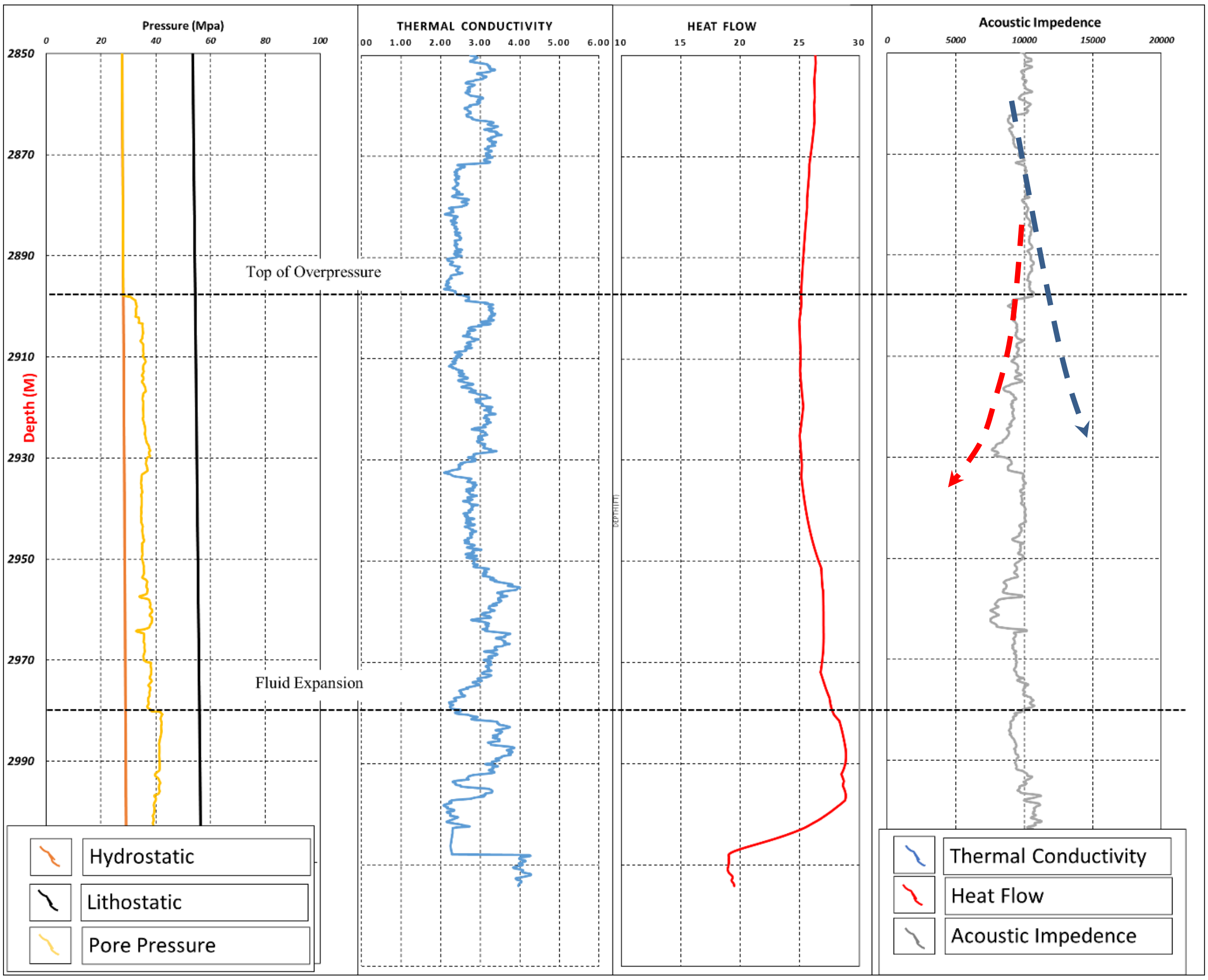

Figure 3. Overpressure mechanism respecting the thermophysical parameters, the top of overpressure (2872 m depth) was indicated when the pressure going high while the AI was decreasing. The trend shows that AI should increase due compression (blue line with arrow), but the AI going decreasing due to overpressure was developed.

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4. Conclusion and Recommendation

Several conclusions can be drawn from this study. First, from petrophysical analysis of this well, the cut off for sand, silt and shale was determined. Clean sandstone (0-35 API) and siltstone were set at a range of 35-75 API while shale range is more than 75 API. On the other hand, the interpretation of resistivity indicates the potential of fluid contents in the formation, while high resistivity indicates oil or gas (hydrocarbon).

Through four thermal facies identified in “MRI 1” well (from the depth of 1800 m -30480 m), data shows the thermal facies 3 had the highest values of thermal conductivity, followed by facies 1, facies 4 and facies 2. In addition, this study found that velocity and thermal conductivity had similar behavior (trend) against effective stress. Along the well, the sandstone and sandy shale was dominated.

Lastly, based on this analysis, the top of overpressure was identified at 2872 m depth. On that particular depth, the pore pressure moved from the hydrostatic line to lithostatic line. In addition, the temperature and the heat flow show the similar trend where the pore pressure was increasing in 5.8 MPa followed by the increasing of 20^0C in the temperature. The increasing of the temperature was interpreted as fluid expansion. As mentioned in the introduction, the fluid expansion is of mechanism that generates the overpressure.

The investigation of thermophysical properties provides the enhancement for pore pressure estimation. In addition, by evaluating and considering the thermophysical parameters then correlating them with burial history or geochemical data, more accurate pore pressure estimation will be obtained.

5. Acknowledgements

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