The Empirical Relationship Acoustic Impedance and Thermal Conductivity

by

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11725

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CERTIFICATION OF APPROVAL

THE EMPIRICAL RELATIONSHIP BETWEEN ACOUSTIC IMPEDANCE AND THERMAL CONDUCTIVITY

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A project dissertation submitted to the Petroleum
Engineering Programme Universiti Teknologi
PETRONAS in partial fulfilment of the requirement for
the Bachelor of Engineering (Hons) (Petroleum
Engineering)

Approved:

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July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HAFIZZUDIN BIN ABDUL WAHID

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Thank You.

With Utmost Gratitude,

(Muhammad Hafizzudin bin Abdul Wahid)

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ABSTRACT

Final Year Project (FYP) is an individual research project in connection with a special engineering problem and under the guidance of a faculty member. The project undertaken may fall under one of the following areas; mathematical analysis, experimental tests, computer simulation, hardware and/or software development, device fabrication.

The course outcome:

- Produce an acceptable project proposal.
- Obtain and evaluate the relevance and quality of information and data from related literatures
- Identify and propose various implementation strategies and select the appropriate methodology. (experiment, design, modeling)
- Produce reports on the project and present orally.

The project selected was The Empirical relationship between Acoustic Impedance and Thermal Conductivity.

Rock have different kind of property and as student in Universiti Teknologi PETRONAS, which related in oil and gas industry, the properties of rock that have to be look for is porosity and permeability. With this kind of properties, the field can be describing as good or bad reservoir. The main purpose of the project is to find a relationship between the Acoustic Impedance and Thermal Conductivity. This will provide information on thermal properties of subsurface from the seismic data.

CHAPTER 1: INTRODUCTION

1.1 Project Background

The interior heat of the earth is transmitted to its surface mainly by three mechanisms: radiation, convection and conduction [1]. In the earth's lithosphere conduction of heat generally dominates among these mechanisms. Reference [2] in evaluating the permanent heat flow form the Earth's interior to its surface, estimated that 17% of the heat flow can be attributed to the earth's cooling, whereas 83% would be attributed to radiogenic heat production.

The basic concept of heat flow defines this property as a temperature difference between two locations resulting in a heat flow q. The magnitude of q depends on the thermal conductivity of the material and the distance between the two locations mentioned earlier. Heat flow studies provide information on the occurrence and nature of geothermal resources, oil source rock maturation, secondary migration of petroleum and subsurface structures [3], [4] and [5]. Heat flow studies in geological systems are paramount interest to the oil and gas industry. The studies give an indication on the thermal maturity of the hydrocarbon reserves and also provide a better enhanced understanding of the reservoir.

Acoustic impedance is the product of density and seismic velocity (in geophysics definition) at which varies among different rock layers, commonly symbolized by Z. The difference in acoustic impedance between rock layers affects the reflection coefficient. Acoustic velocity or seismic velocity is the rate at which a wave travels through a medium (a scalar) or the rate at which a body is displaced in a given direction (a vector), commonly symbolized by *v*. Unlike the physicist's definition of velocity as a vector, its usage in geophysics is as a property of a medium-distance divided by travel time.

Velocity can be determined from laboratory measurements, acoustic logs and vertical seismic profiles or from velocity analysis of seismic data. Velocity can vary vertically, laterally and azimuthally in anisotropic media such as rocks, and tends to increase with depth in the Earth because compaction reduces porosity.

Velocity also varies as a function of how it is derived from the data. For example, the stacking velocity derived from normal move out measurements of common depth point gathers differs from the average velocity measured vertically from a check-shot or vertical seismic profile (VSP). Velocity would be the same only in a constant velocity (homogeneous) medium.

The reflection coefficient is the ratio of amplitude of the reflected wave to the incident wave, or how much energy is reflected. If the wave has normal incidence, then its reflection coefficient can be expressed as:

$$R = (\rho_2 V_2 - \rho_1 V_1)/(\rho_2 V_2 + \rho_1 V_1),$$

where R = reflection coefficient, whose values range from -1 to $+1$
ρ_1 = density of medium 1
ρ_2 = density of medium 2
V_1 = velocity of medium 1
V_2 = velocity of medium 2.

The reflection coefficient will be affected by the difference in acoustic impedance between rock layers.

1.2 Problem Statement

Several problem statements are identifying which result for this project:

- Lack of information on the reservoir properties and characterization from the Thermal Conductivity data used nowadays. It was a lot of information of the reservoir properties using Acoustic Impedance.
- Difficulties to find the relationship of Thermal Conductivity to Acoustic Impedance.

1.3 Objective

The main objectives of this project are:

- to find the empirical relationship between the Acoustic Impedance and Thermal Conductivity
- To interpret the empirical relationship with respect of depositional of environment and facies
- To come out with physical rock properties database with respect to log interpretation for each depositional of environment and facies

1.4 Scope of Work

This project is relevant to the study of Petroleum Geoscience and Reservoir Engineering as well as the field of Formation Evaluation. It concerns us with the evaluation of thermal conductivity and geothermal gradients of the reservoir. It does also give some understanding about the temperature that is as important as pressure to determine reservoir properties. Temperature is also required for calculations of hydrocarbon recovery factors, including pressure-volume-temperature relationships, and gas-oil ratios (S.Prensky, 1992). Another way to get the reservoir properties is by well-log correlations data.

This project focuses on how to interpret the log data such as gamma ray log, density log, and resistivity log. All this logging tools describe the formation of the rock to interpret the reservoir parameters. The data obtain from the log as well as well report, are integrate to get the thermal conductivity and acoustic impedance for each sequence in the reservoir.

As a result, the database obtained for each sequence of the reservoir would be useful for petrophysicist to make a decision according the data.

The scope of studies covers on:

- Interpretation the log data such as gamma ray log, density log, sonic log and neutron log.
- Integration sample data and log interpretation.
- Study of various log parameters with respect to environment of depositional and facies

CHAPTER 2: LITERATURE REVIEW AND THEORY

In order to obtain a good understanding of the study, a lot of literature review had been performed since the beginning of the project. It includes the understanding and knowledge from journals, trusted articles, reference books, research-based websites and other available resources.

The literature review was divided into four topics:

Topic 1: Rock Physical Properties

Topic 2: Acoustic Impedance

Topic 3: Thermal Conductivity

These chapters were divided according to relevant studies in Petroleum Engineering field.

2.1 Topic 1: Rock Physical Properties

When we talk about reservoir rock, there were two kinds of physical properties that are related which are porosity for storage capacity and permeability for production capacity.

2.1.1 Porosity

Porosity can be defined as:

- A measure of the void spaces in a material and is measured as a fraction between 0 – 1 or as a percentage between 0 – 100%. (Wikipedia)
- The percentage of pore volume or void space or that volume within rock that can contain fluids. (Schlumberger Oilfield Glossary)
- A measure of the space available for storage of petroleum hydrocarbon. ($0.1 < \Phi < 0.4$)

Mathematical expression for porosity:

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Bulk Volume}}$$

$$= \frac{\text{Bulk Volume} - \text{Grain Volume}}{\text{Bulk Volume}} = \frac{V_b - V_s}{V_b}$$

For the type of porosity, according to mode of origin, there were two types which are:

1- Primary porosity – formed at the time sediment was deposited
2- Secondary porosity – the porosity created through alteration of rock, commonly by process such as dolomitization, dissolution and fracturing

For type of porosity according to connectivity, there were two types which are:

1- Absolute porosity – the ratio of the total void space in a rock to the bulk volume of that rock
2- Effective porosity – the ratio of the interconnected void space in a rock to bulk volume of that rock. This type of porosity is important for the reservoir engineering standpoint.

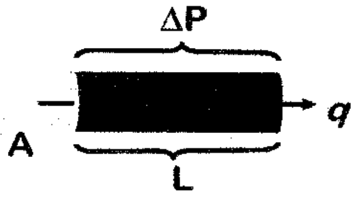
The porosity of a reservoir rock may be determined by:

- Core analysis
- Well logging technique
- Well testing

2.1.2 Permeability

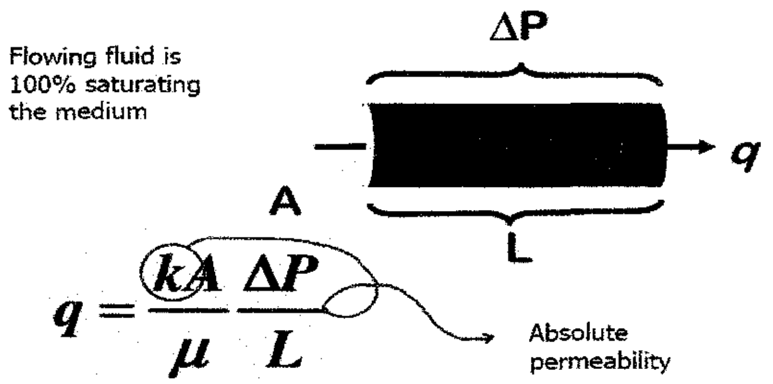
Permeability defines as a measure of the capacity of the porous medium to transmit fluids. This method introduced by Darcy in 1856 while investigating the flow of water through sand filters for water purification. Permeability can be express mathematically:

$$q = \frac{kA}{\mu}\frac{\Delta P}{L}$$



There are 3 types of permeability which are:

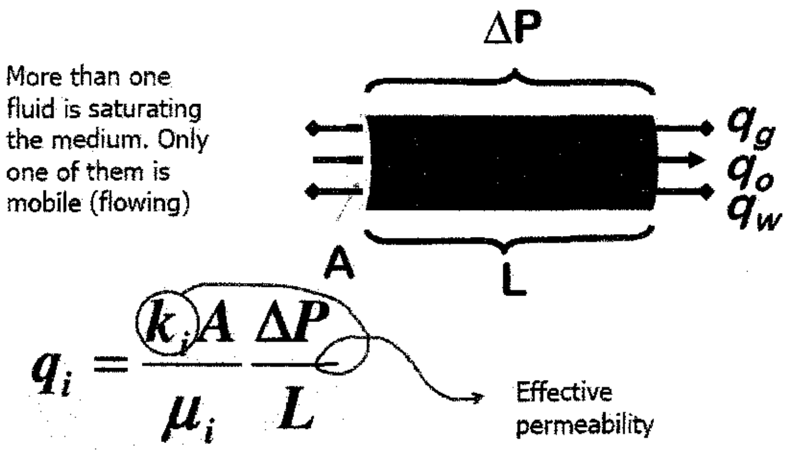
1- Absolute permeability



Flowing fluid is 100% saturating the medium

$$q = \frac{kA}{\mu}\frac{\Delta P}{L}$$

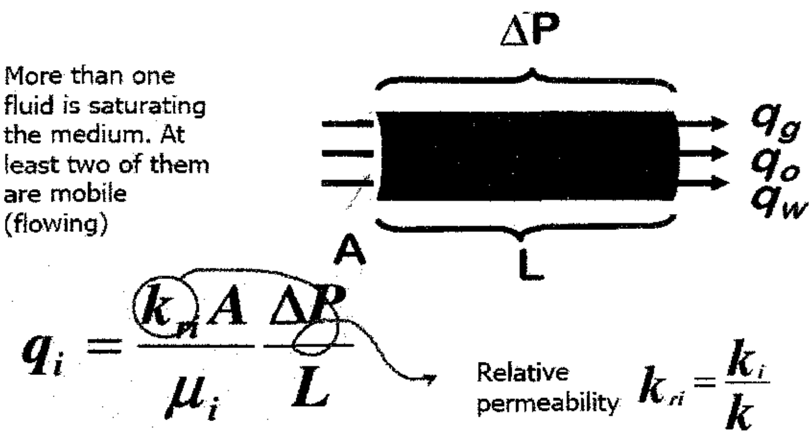
2- Effective permeability



More than one fluid is saturating the medium. Only one of them is mobile (flowing)

$$q_i = \frac{k_i A}{\mu_i}\frac{\Delta P}{L}$$

3- Relative permeability



More than one fluid is saturating the medium. At least two of them are mobile (flowing)

$$q_i = \frac{k_{ri} A}{\mu_i}\frac{\Delta P}{L}$$

$$k_{ri} = \frac{k_i}{k}$$

2.2 Topic 2: Acoustic Impedance

Acoustic impedance (Z) is the product of rock density and P-wave velocity, both of which can be directly measured by well logging. The determination of such parameter is important for identifying reflectors, detecting lateral variations of lithology, and used for detailed investigation hydrocarbon fields. The variation of Z is highly affected by density and velocity.[1]

The relationships between these two parameters is given by Gardner et al. (1974), which is approximately correct for brine saturated sedimentary rocks, over a wide range of basins, geologic ages and depths. This enables velocity to be computed from acoustic impedance, and vice versa, in most sedimentary rocks: except for salt, anhydrite and hydrocarbon reservoirs.

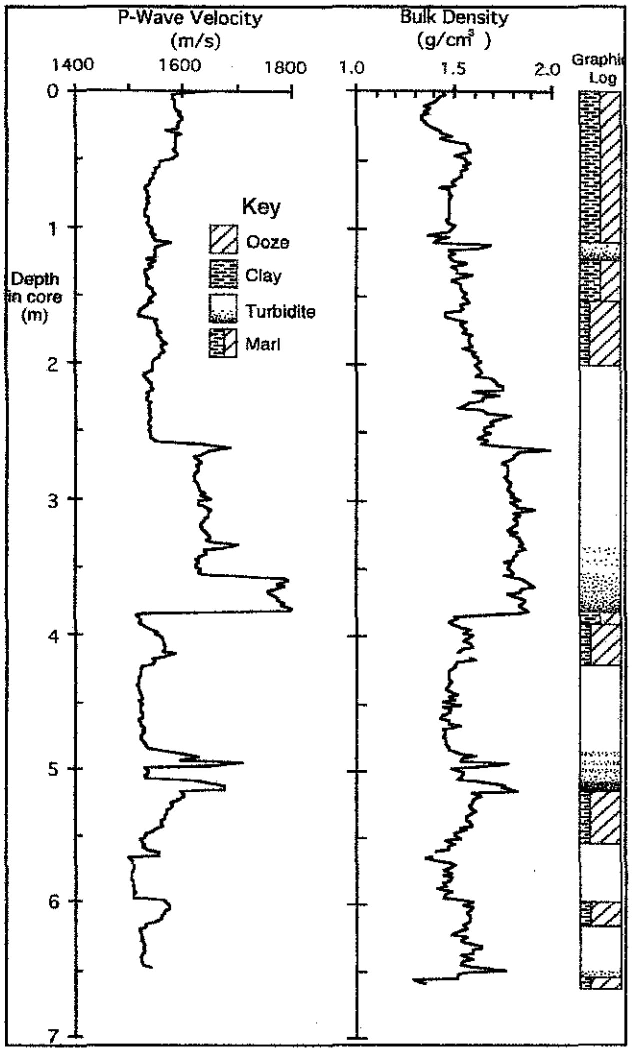


Fig.1. Lithology log and example P-wave velocity and gamma density data collected with SOC's MSCL on a split core from the North Atlantic[2]

Acoustic impedance is the product of rock density and compressional (P-wave) velocity. It is thus a measure of physical properties that are commonly measured in boreholes, such as bulk density and sonic velocity, as well as being qualitatively observed in core and outcrop as the dhardnessT of the rock. Seismic inversion is a method of deriving seismic parameters, such as acoustic impedance, from reflection seismic data constrained by borehole data [2].

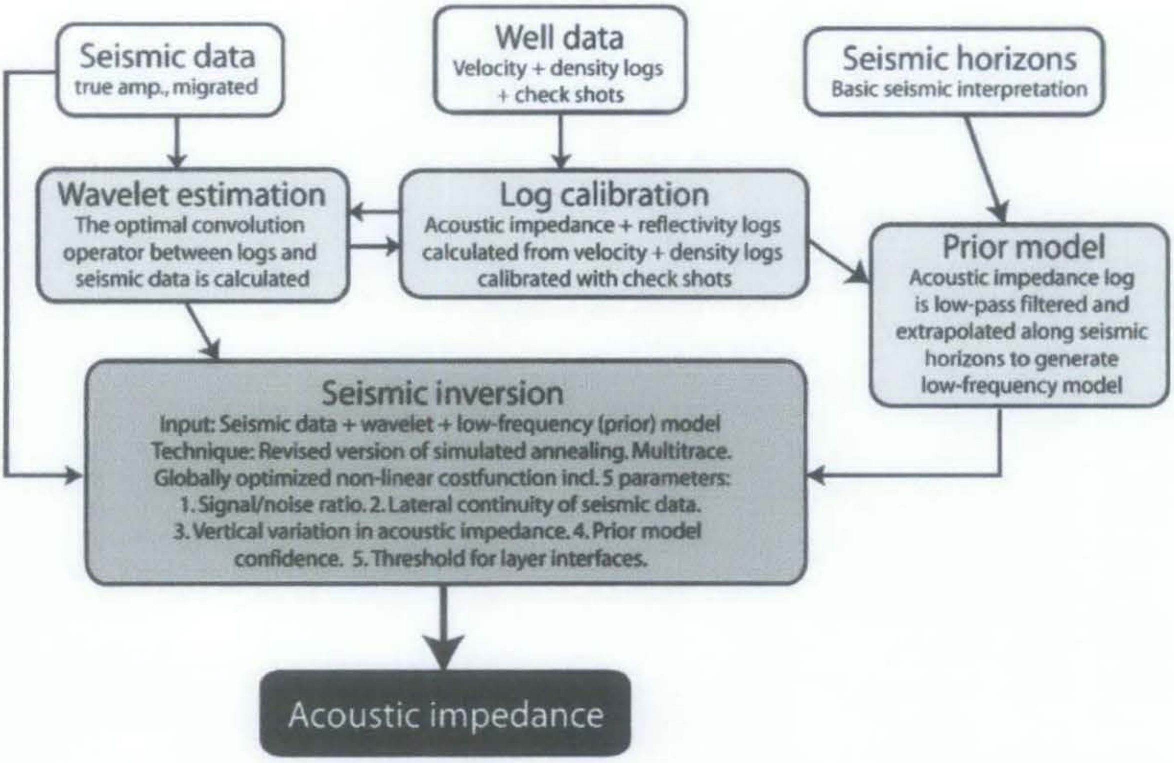


Fig. 2 Flow diagram illustrating the major steps in the model-driven inversion of the seismic data to yield acoustic impedance[3]

The minimum, maximum and average values of acoustic impedance determined with the Eq. (I-15) are in a good agreement.[1]

$$Z = \frac{1}{\Delta_t}\left[\left\{V_{sh}\left(\frac{\rho_{sh}-\rho_{ma}}{\rho_f-\rho_{ma}} - \frac{\Delta_{tsh}-\Delta_{tma}}{\Delta_{tf}-\Delta_{tma}}\right) + \frac{\Delta_t-\Delta_{tma}}{\Delta_{tf}-\Delta_{tma}}\right\}(\rho_f-\rho_{ma}) + \rho_{ma}\right] \qquad \text{(I-15)}$$

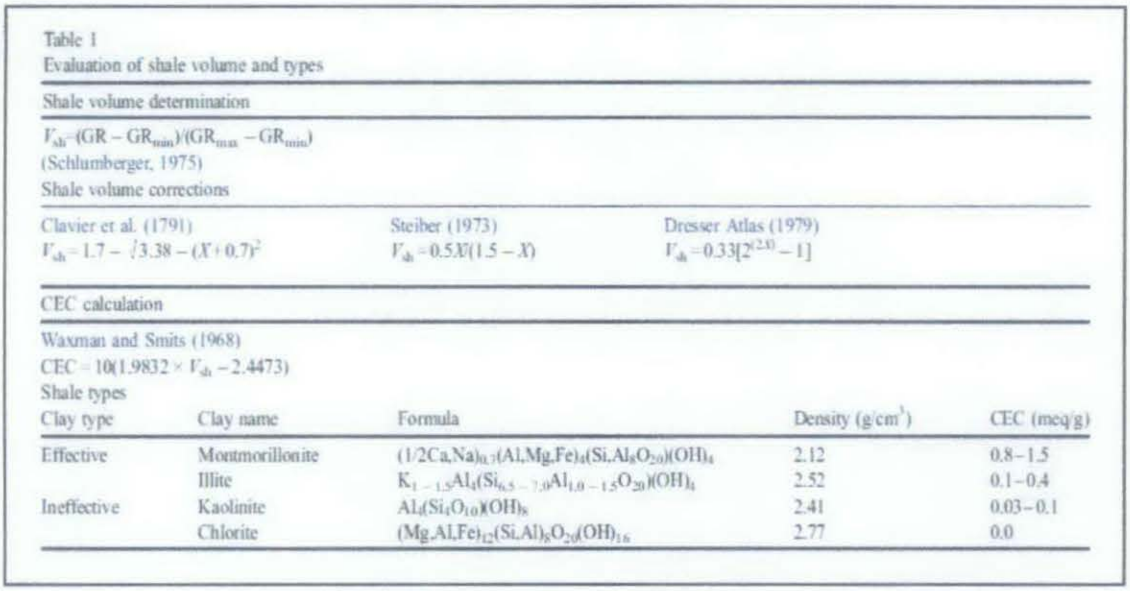


Table 1

Evaluation of shale volume and types

Shale volume determination

$V_{sh}=(GR-GR_{min})/(GR_{max}-GR_{min})$

(Schlumberger, 1975)

Shale volume corrections

Clavier et al. (1791)	Steiber (1973)	Dresser Atlas (1979)
$V_{sh}=1.7-\sqrt{3.38-(X+0.7)^2}$	$V_{sh}=0.5X/(1.5-X)$	$V_{sh}=0.33[2^{(2X)}-1]$

CEC calculation

Waxman and Smits (1968)

$CEC=10(1.9832\times V_{sh}-2.4473)$

Shale types

Clay type	Clay name	Formula	Density (g/cm^3)	CEC (meq/g)
Effective	Montmorillonite	$(1/2Ca,Na)_{0.7}(Al,Mg,Fe)_4(Si,Al_8O_{20})(OH)_4$	2.12	0.8–1.5
	Illite	$K_{1-1.5}Al_4(Si_{6.5-7.0}Al_{1.0-1.5}O_{20})(OH)_4$	2.52	0.1–0.4
Ineffective	Kaolinite	$Al_4(Si_4O_{10})(OH)_8$	2.41	0.03–0.1
	Chlorite	$(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	2.77	0.0

Fig. 3 Evaluation of Shale Volume and Types[3]

2.3 Topic 3: Thermal Conductivity

The transfer of energy between two adjacent parts of rock mainly depends on its thermal conductivity. Energy transfer arising from the temperature difference between the adjacent parts of the body is called heat conduction. The amount of heat to be transferred through any body depends upon a number of factors, such as the particle shape, porosity, temperature range, solid constituents, moisture content, uniaxial and/or triaxial pressure exerted on the rock, It widely influences the energy transfer between adjacent rocks in underground mines and in insulation of the building by providing an energy efficient solution.[4]

The thermal conductivity is determined by the measurements of temperature gradient in the rock and heat input [6]. In general, the thermal conductivity can be calculated using Fourier's Law as given below:

$$\frac{dQ}{dt}=-kA\frac{dT}{dx}$$

Thermal conductivity can be determined by different methods, e.g.:(1)laboratory measurements,(2) estimation from mineral composition,(3) in situ field measurement sand(4)large- scale field experiments. The various common rock forming minerals have different thermal conductivities. Knowing the thermal conductivity of the constituent minerals, one can estimate the thermal conductivity for any rock with known mineral composition.[5]

The thermal conductivity of inorganic, solid materials is generally regarded as being proportional to density. This is normally a function of porosity. Increasing porosity gives both lower density and lower thermal conductivity. This is obvious in porous media such as soils and sedimentary rocks. The denser the internal structure, the lower is the resistance to the transfer of heat energy between the different parts of the solid material.

In an anisotropic crystal, the thermal conductivity varies according to crystallographic orientations. The thermal conductivity of a crystalline rock depends largely on mineral composition, density, and the thermal conductivity of the constituent minerals {15}.[5]

2.3.1 Thermal Conductivity for igneous rocks

Rocks can be grouped according to the method of formation (igneous, sedimentary and metamorphic).For a systematization of igneous rocktypes, the SiO2 level is of special significance: felsic >63% SiO2, intermediate 52–63% SiO2, mafic 45–52% SiO2, and ultramafic <45% SiO2. When classifying igneous rock types according to the internationally accepted UGS system, the division is based on the content of three mineral components in the rock: quartz (Q), alkali feldspar (A) and plagioclase (P).[5]

The chemical composition of the different minerals is influenced by the composition of the parent magma, as well as the temperature at which crystallization occurs from the magma. For example, minerals that crystallize at high temperatures (1100–1200 1C) contain high amounts of iron, magnesium and calcium whilst minerals that crystallize at low temperatures (700–800 1C) are richer in potassium ands odium.[5]

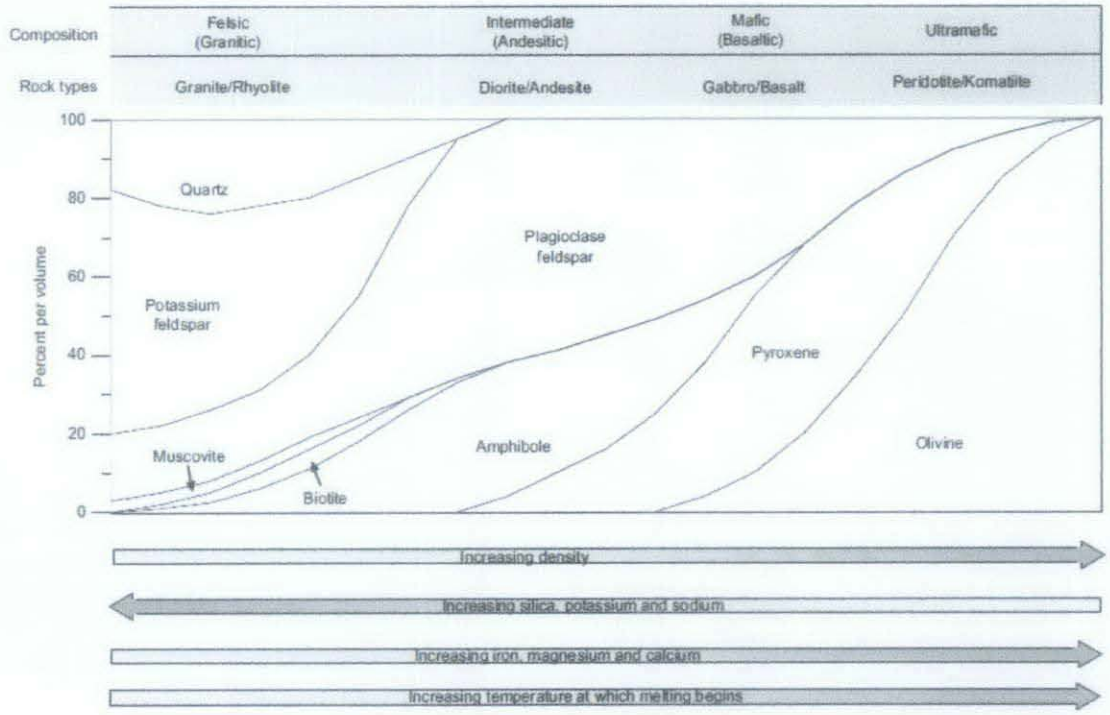


Fig. 4 Mineralogy of igneous rocks and the magmas [5]

The average density of rock types in the earth's crust is 2850 kg/m3. The density of a rock obviously depends on the density of the minerals in the rock. The density of a mineral depends on its chemical composition and crystalline structure. Most common rock-forming minerals have a density of between 2000 and 3000 kg/m3. So-called heavy minerals, with a density greater than 2850 kg/m3, include, for example, oxide and sulphide minerals and the solid metals. For igneous rock, Quartz has highest thermal conductivity of the common rock forming minerals.[5]

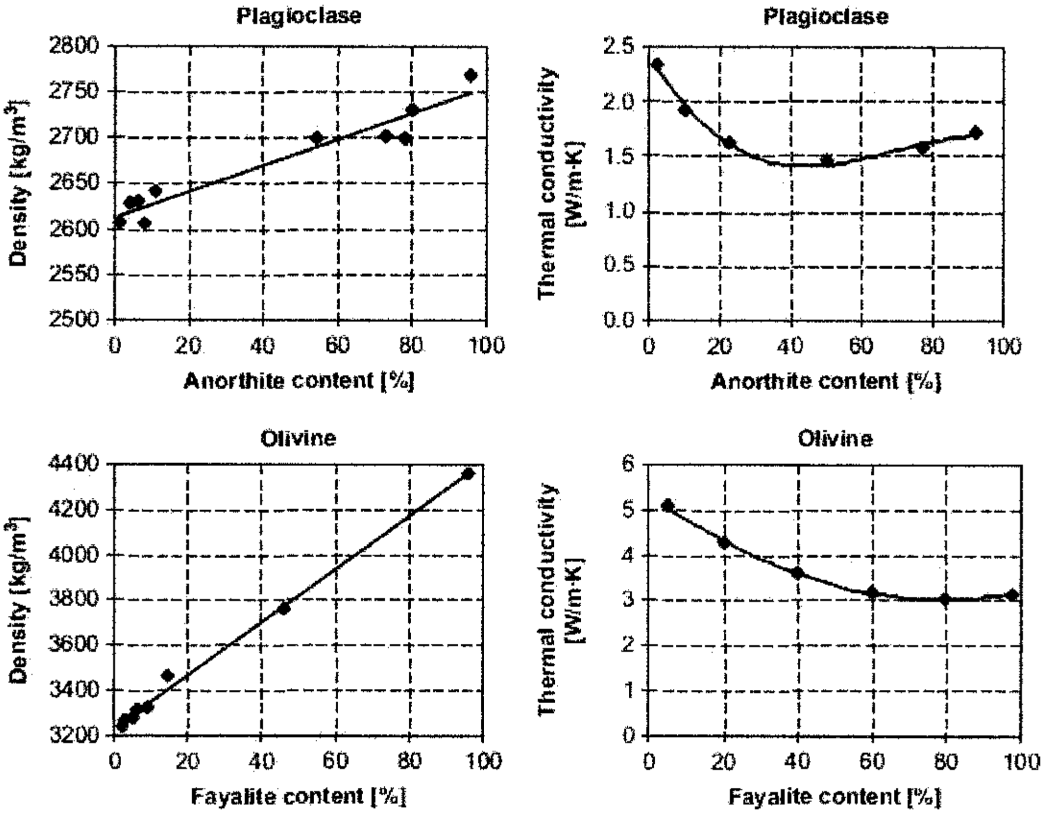
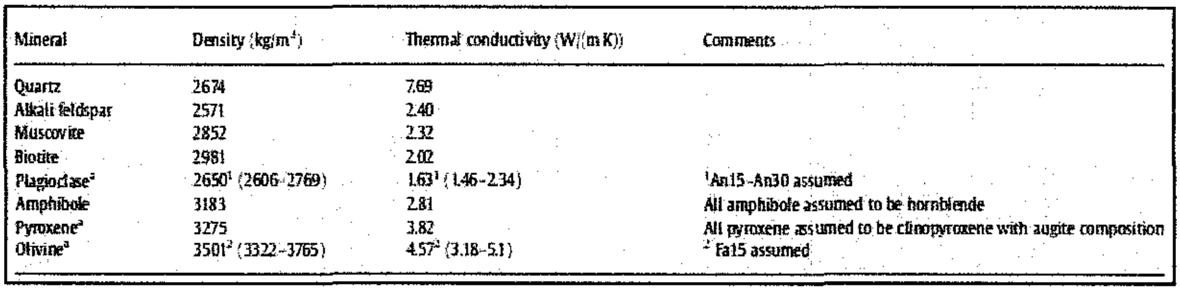


Fig.5 Density and thermal conductivity for plagioclase and olivine depend on the anorthite and fayalite content, respectively. [5]



Mineral	Density (kg/m^3)	Thermal conductivity (W/(m K))	Comments
Quartz	2674	7.69	
Alkali feldspar	2571	2.40	
Muscovite	2852	2.32	
Biotite	2981	2.02	
Plagioclase^a	2650^1 (2606–2769)	1.63^1 (1.46–2.34)	^{1}An15–An30 assumed
Amphibole	3183	2.81	All amphibole assumed to be hornblende
Pyroxene^a	3275	3.82	All pyroxene assumed to be clinopyroxene with augite composition
Olivine^a	3501^2 (3322–3765)	4.57^2 (3.18–5.1)	^{2} Fa15 assumed

Table 1: Density and thermal conductivity of certain minerals which dominate the composition in igneous rock types [5]

2.4 Topic 4: Interpretation of well logs

Well log is the continuous recording of a geophysical parameter along a borehole. The value of the measurement is plotted continuously against depth in the well. It has often been called an 'electrical log' because historically the first logs were electrical measurement of electrical properties. However, the measurements are no longer simply electrical, and modern methods of data transmission do not necessarily need a wire line. Well logging was first invented by Conrad Schlumberger and Henri Doll. (Rider, 2002)

Well logging is necessary because geological sampling during drilling (cuttings sampling) leaves a very imprecise record of the formations encountered. Entire formation samples can be brought to the surface by mechanical coring, but this is both slow and expensive. The results of coring are unequivocal while logging is precise but equivocal. Logs fill the gap between 'cuttings' and 'cores'. (Rider, 2002)

	Log Type	**Formation parameter measured**
Mechanical measurement	Caliper	Hole diameter
Spontaneous measurement	Temperature	Borehole temperature
	SP (self-potential)	Spontaneous electrical currents
	Gamma ray	Natural radioactivity
Induced measurement	Resistivity	Resistance to electrical current
	Induction	Conductivity of electrical current
	Sonic	Velocity of sound propagation
	Density	Reaction to gamma ray bombardment
	Photoelectric	Reaction to gamma ray bombardment
	Neutron	Reaction to neutron bombardment.

Table 2: Classification of the common wireline log well measurements

CHAPTER 3: METHODOLOGY

In order to fulfill the objective mentioned, first step is to perform the literature review of the project. The literature review can be the current or relevant materials including journals, books, encyclopedia and articles. The literature review was conducted by referring to the information resources available in Universiti Teknologi PETRONAS such as internet, UTP Information Resource Centre, research officer, lecturer, post-graduate student. The information resources also could be obtained from outsiders such as personnel from industrial. The literature review covered on the understanding of physical rock properties, understanding of the thermal conductivity and acoustic impedance in different type of reservoir, and understanding the calculation and interpretation of the well-log correlation to get the similarities between thermal conductivity and acoustic impedance.

Then, select and get data from the well-log interpretation from the Field Development Planning that significant with the project. Afterward, experiment will be conduct by comparing the data between thermal conductivity and acoustic impedance to the similarity from both of it.

In second semester, after we get the data that are related to the project, the research can be started. There were two kind of research which is:

1- Logging interpretation
2- Data integration

For logging interpretation, it will covered on how to reading the log data, the log pattern for various kind of log so, the logs that were choose is SP logs, Porosity Log and Gamma Ray Log. Then, the data from well-log interpretation was compiled in the table for calculation of acoustic impedance and thermal conductivity. A graph of acoustic impedance versus thermal conductivity had been plotted to get a clear relationship between both parameters.

Lastly, the result of the research will be combined and integrated according to respective environment of deposition.

3.1 Project Flow Chart

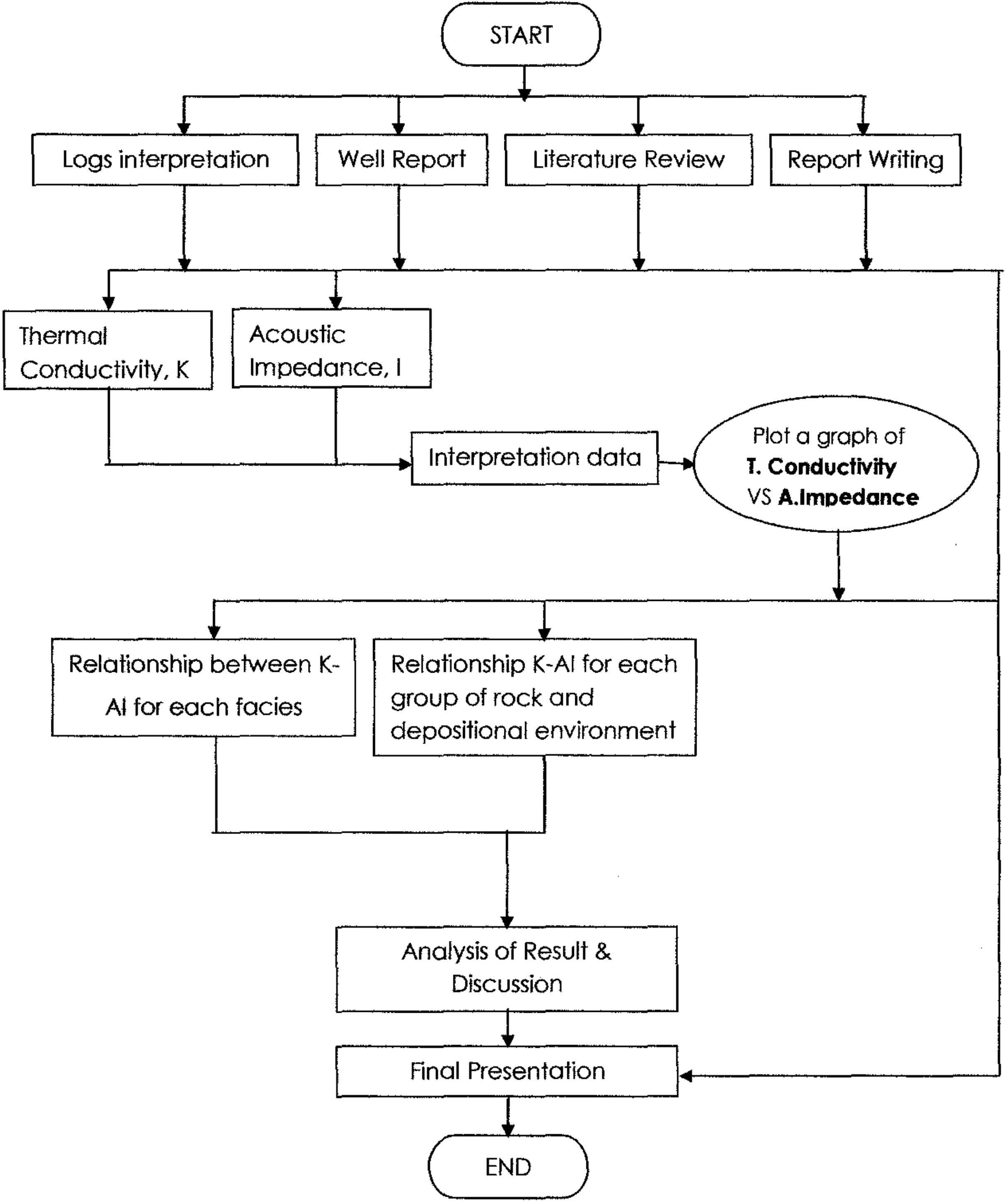


Fig. 6: Flow Chart of the Project

3.2 Flow Chart description:

Summary of activities with respect to each item in the flow chart (Figure 6) are as follows:

1. Project was proposed to FYP1 committee.
2. Doing literature study on this project.
3. Collecting the data:
    - Well log
    - Well report
    - PVT analysis
    - Field report
4. Interpreting and analyzing the sample data.
5. Integrating the data from log interpretation with respect of depositional of environment and facies.
6. Calculation

A. Volume of Shale, Vsh

$$V_{sh} = (GR - GR_{min})/(GR_{max} - GR_{min})$$

(Schlumberger, 1975)

Where:
IGR = gamma ray index
GRlog = gamma ray reading of formation
GRmin = minimum gamma ray (clean sand or carbonate)
GRmax = maximum gamma ray (shale)

B. Acoustic Impedance

AI= Velocity x Density

Example:

Depth interval = 5900 m

Density, ρ = 2.47 gm/cm^3

Sonic Transit time, Δt= 150 µsec/ft

Velocity = 1/ Δt (ft/µsec)

= 1000000 x 1/ Δt (ft/sec)

$= 0.3048 \times (1000000 / \Delta t)$ m/sec

$= 0.3048 \times (1000000 / 150)$

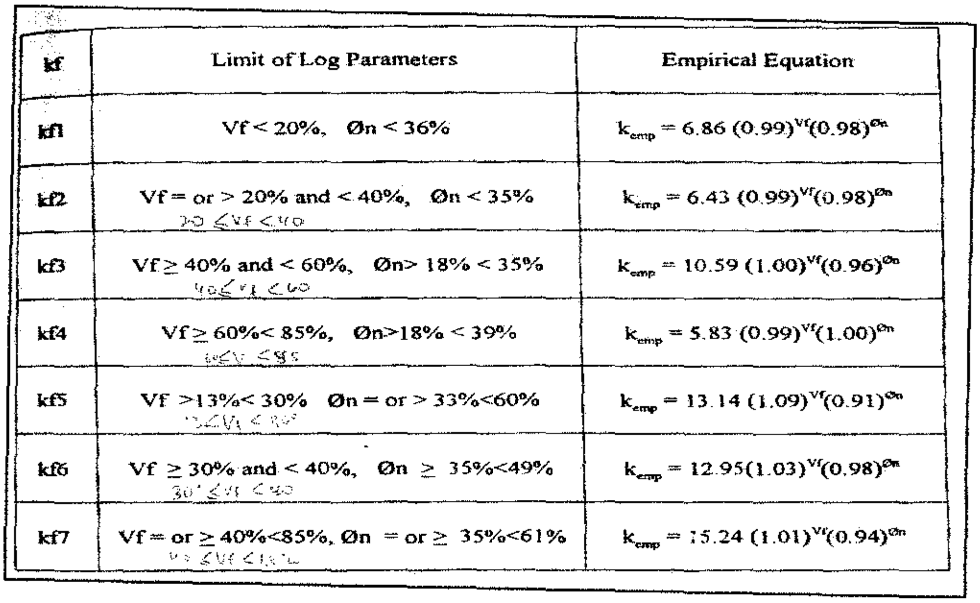
Velocity = 2032 m/sec

∴ AI = 2032 m/sec x 2.47 gm/cm^3

= 5019.04 gm.m/ cm^{3}sec

C. Thermal Conductivity

- Depend on thermal facies (Φn and Vsh)



kf	Limit of Log Parameters	Empirical Equation
kf1	Vf < 20%, Øn < 36%	$k_{emp} = 6.86\ (0.99)^{Vf}(0.98)^{Øn}$
kf2	Vf = or > 20% and < 40%, Øn < 35% 20 ≤ Vf < 40	$k_{emp} = 6.43\ (0.99)^{Vf}(0.98)^{Øn}$
kf3	Vf ≥ 40% and < 60%, Øn> 18% < 35% 40 ≤ Vf < 60	$k_{emp} = 10.59\ (1.00)^{Vf}(0.96)^{Øn}$
kf4	Vf ≥ 60%< 85%, Øn>18% < 39% 60 ≤ Vf ≤ 85	$k_{emp} = 5.83\ (0.99)^{Vf}(1.00)^{Øn}$
kf5	Vf >13%< 30% Øn = or > 33%<60% 13 ≤ Vf < 30	$k_{emp} = 13.14\ (1.09)^{Vf}(0.91)^{Øn}$
kf6	Vf ≥ 30% and < 40%, Øn ≥ 35%<49% 30 ≤ Vf < 40	$k_{emp} = 12.95(1.03)^{Vf}(0.98)^{Øn}$
kf7	Vf = or ≥ 40%<85%, Øn = or ≥ 35%<61% 40 ≤ Vf < 85	$k_{emp} = 15.24\ (1.01)^{Vf}(0.94)^{Øn}$

Table 3: The empirical equation rlating thermal conductivity and log parameter (Thermal facies) [8]

Example:

Depth interval =5900 m

Neutron porosity, Φn = 24%; Vsh= 31.74 %; formation temp= 322°C

Thermal facies = kf2

Kemp= 6.43(0.99^31.74)*(0.98^0.24)

Kemp= 3.98

Corrected:

K corrected= (372*(3.98-1.84)*(1/(322+273)-0.00068))+1.84

= **2.80**

7. Compile the data. - The data were compiled into the tables prepared which indicate the type of thermal facies and the rock properties.

depth interval (m)	gamma ray (gr)	neutron porosity (Φn)	density ρ,gm/cm 3	sonic transit time(ms/ft)	velocity (m/sec)	Vsh	formation temp (°C)	Acoustic Impedance ($x10^2$)	Thermal Conductivity	Thermal Facies

8. Project Timeline

Subject	**First Semester**	**Second Semester**
Project Proposal	/	
Literature Review	/	
Collecting Data	/	
Log interpretation		/
Data integration		/
Compile database		/

9. Raw Materials:

- Logging data
- Well report
- FDP report

10. Softwares Use:

- Microsoft Office 2007 Excel

3.3 Project Activities and Key Milestone

The student plays an important role as an investigator/researcher with the assist and supervision from the supervisor and collaborators. This project requires a precise monitoring from them, and this could be done through a good communication medium such as weekly meeting, progress report and consultations. The student also might want to visit certain the real problem in the industry by having a sharing session from industry personnel which related to the project. Progress report shall be submitted according to the schedule to get to find if there is any corrective action. This is done so that both student and supervisor will have a good and up-to-date communication.

3.4 Project Gant Chart:

WEEK ACTIVITES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Progress Report															
Submission the Progress Report															
Design the Poster															
Poster Presentation															
Technical Report															
Submission the Technical Report															
Dissertation															
Submision the Dissertation															
Submission the Hardbound Copy															
Oral Presentation.															

CHAPTER 4: RESULTS AND DISCUSSION

4.1 DELTA-1 and HONEY-1 Well

4.1.1 DELTA-1 Well Background

DELTA-1 well was been drilled in one field in offshore in the block PM315 that call Duyong field. This field located in the Malay Basin that can be divided into 6 regions namely; Northeast, Southeast, North, West, Central and South based on their respective play types and geological location. Duyong field was in the Southeast Region of the Malay Basin. Figure below shows the location of Duyong field on the Malay Basin. [9]

The reservoir is dominated by sand, and intercalated with shale. The sand which is located in this field shows small variation in grain size and sorting. This field produces gas. The Southeast Region contains 62% of entire Peninsular Malaysia gas reserves. 86%ad all associated gas and 15% of all non-associated gas in the Malay Basin occurs in the Southeast Region. [9]

4.1.2 HONEY-1 Well Background

HONEY-1 well was drilled in the Baram Delta that located in the Miri Field. The Baram Delta province is roughly triangular in shape, with its apex occurring onshore and centred in Brunei and the northeastern coastal area of Sarawak. The province expands offshore to cover the whole width of Brunei waters, and encroaches southeast into Sarawak (where it is known as West Baram Delta) and northeast into offshore NW Sabah (Where it is named the East Baram Delta). [9]

The western margin of the Baram Delta is marked by the West Baram Line, system of large, northest-hading, down-to-the-basin faults that separate the delta from the older Balingian and Central Luconia provinces to the west. The eastern margin of the Baram Delta is defined by the Morris Fault-Jerudong Line which separates the delta from the older, intensely tectonised Inboard Belt of offshore NW Sabah. [9]

4.2 Data Gathering and Data Analysis

The data in table below was from the data interpretation of the log correlation for DELTA-1 well in Duyung field. This data use for calculate the Acoustic Impedance and Thermal Conductivity to find the similarity.

depth interval(m)			gamma ray (gr)	neutron porosity (Φn)		density ρ,gm/cm3	sonic transit time(ms/ft)	velocity (m/sec)	Vsh		formation temp (°C)	Acoustic Impedance (x10^2)	Thermal Conductivity		Thermal Facies
top	bottom	mid		value	%				value	%			original	corrected	
5200	5235	5218	75	0.26	26	2.43	150	2032	0.4491	44.91	288	49.38	3.66	2.59	kf3
5235	5264	5250	90	0.3	30	2.45	180	1693	0.6287	62.87	289	41.49	3.10	3.10	kf4
5264	5297	5281	83	0.26	26	2.38	186	1639	0.5449	54.49	291	39.00	3.66	2.58	kf3
5297	5320	5309	98	0.41	41	2.36	204	1494	0.7246	72.46	292	35.26	2.48	2.48	kf7
5320	5355	5338	103	0.36	36	2.46	165	1847	0.7844	78.44	294	45.44	3.59	3.59	kf7
5395	5428	5412	97.5	0.365	36.5	2.41	189	1613	0.7186	71.86	298	38.87	3.26	3.26	kf7
5428	5450	5439	100	0.38	38	2.45	188	1621	0.7485	74.85	299	39.72	2.75	2.75	kf4
5450	5467	5459	85	0.375	37.5	2.44	195	1563	0.5689	56.89	300	38.14	2.64	2.64	kf7
5467	5500	5484	85	0.38	38	2.51	176	1732	0.5689	56.89	301	43.47	2.56	2.56	kf7
5500	5510	5505	105	0.38	38	2.47	181	1684	0.8084	80.84	302	41.59	3.24	3.24	kf7
5522	5550	5536	90	0.309	30.9	2.4	162	1881	0.6287	62.87	304	45.16	3.10	3.10	kf4
5600	5630	5615	95	0.365	36.5	2.41	190	1604	0.6886	68.86	308	38.66	2.92	2.92	kf4
5630	5660	5645	84	0.35	35	2.47	186	1639	0.5569	55.69	309	40.48	3.04	3.04	kf7
5660	5680	5670	95	0.345	34.5	2.4	190	1604	0.6886	68.86	311	38.50	2.92	2.92	kf4
5680	5710	5695	93	0.37	37	2.45	194	1571	0.6647	66.47	312	38.49	2.99	2.99	kf4
5710	5760	5735	85	0.35	35	2.42	193	1579	0.5689	56.89	314	38.22	2.54	2.11	kf3
5770	5790	5780	40	0.195	19.5	2.31	190	1604	0.0299	2.99	316	37.06	4.78	2.95	kf1
5798	5812	5805	45	0.204	20.4	2.32	165	1847	0.0898	8.98	317	42.86	4.60	2.88	kf1
5821	5846	5834	55	0.26	26	2.43	165	1847	0.2096	20.96	319	44.89	3.66	2.53	kf2
5855	5885	5870	45	0.215	21.5	2.28	182	1675	0.0898	8.98	321	38.18	4.40	2.80	kf1
5885	5915	5900	64	0.24	24	2.47	157	1941	0.3174	31.74	322	47.95	3.98	2.63	kf2
5915	5945	5930	54	0.19	19	2.43	143	2131	0.1976	19.76	324	51.79	4.88	2.97	kf2
5945	5960	5953	69	0.24	24	2.48	150	2032	0.3772	37.72	325	50.39	3.98	2.63	kf2
5960	5990	5975	80	0.29	29	2.52	173	1762	0.5090	50.90	326	44.40	3.24	2.36	kf3
6007	6040	6024	58	0.24	24	2.45	148	2059	0.2455	24.55	328	50.46	3.98	2.62	kf2
6040	6072	6056	88	0.24	24	2.48	148	2059	0.6048	60.48	330	51.07	3.17	3.17	kf4
6072	6092	6082	119	0.35	35	2.56	155	1966	0.9760	97.60	331	50.34	4.62	4.62	kf7

Table 6: DELTA-1 well data interpretation of the log correlation

From the data in the table, a graph of thermal conductivity versus acoustic impedance had been made. In the graph below, the real relationship between acoustic impedance and thermal conductivity can be obtained and the distribution of different thermal facies in the DELTA-1 well.

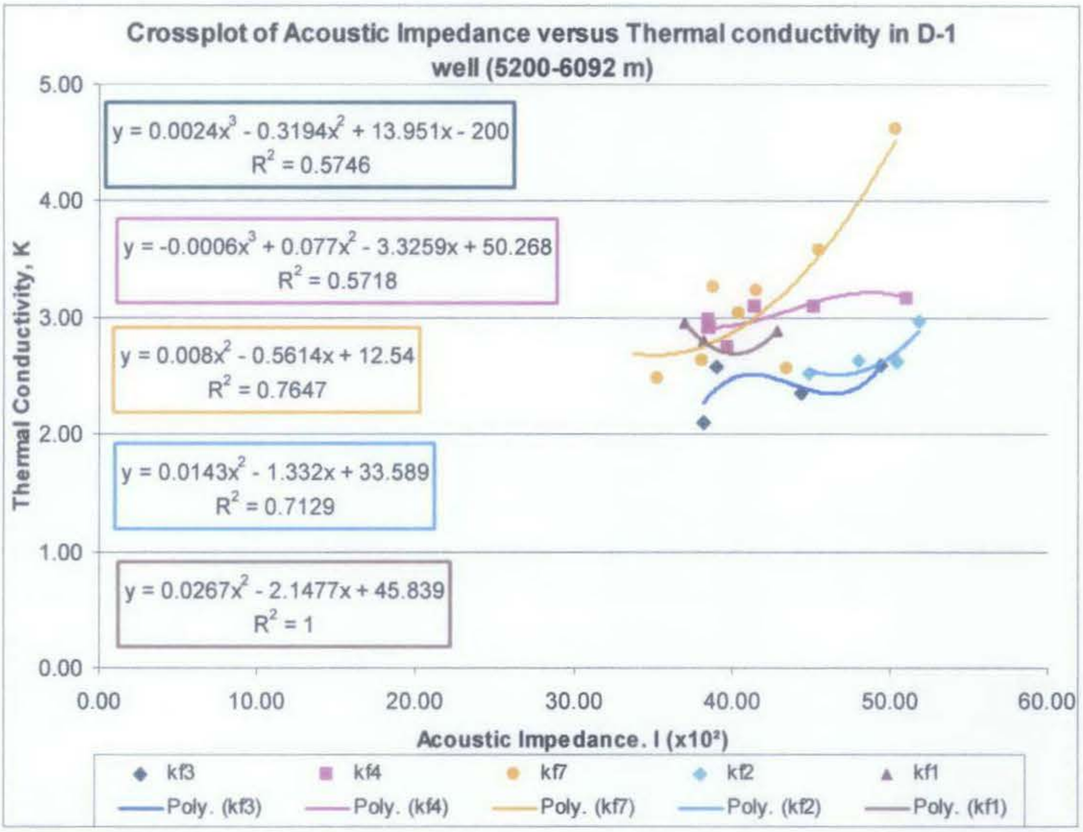


Fig.7 Crossplot of Thermal Conductivity versus Acoustic Impedance in DELTA-1 well

All the points that have their own thermal facies are plotted in the graph in figure 8 above. The points in the graph had been interpreted from the depth of 5200m to 6092m in the DELTA-1 well. It is about 5 types of thermal facies, kf1, kf2, kf3, kf4 and kf7. The range of the acoustic impedance value for this analysis is in between 2.48 to 4.88. On the other hand, the thermal conductivity is in between 20.84 to 27.34. From the table in the figure 7, each depth interval that had been interpreted has different thermal facies. Meaning that, each depth interval has different type of rock properties.

From the well log correlation, there are 4 types of rock in this reservoir in the range of 892 m from top and base. The rocks are sandstone (40%), siltstone (30%), shale (26%) and claystone (4%). Each of this rock has different thermal facies and different value of acoustic impedance and thermal conductivity because of different value of porosity and permeability. Table below shows the summary in DELTA-1 well for each facies and rock property.

Facies	**Type of rock**	**Neutron porosity, Φn**	**Volume of shale, Vsh**	**Rock Properties**
Kf1	Sandstone	19-22%	3-9%	- light grey to green - fine grain to very fine grain - moderate to poor visual porosity and silty matrix
Kf2	Sandstone	19-26%	19-31%	- light grey to off white - fine grain to very fine grain - moderate to poor visual porosity, silty matrix, calcareous argillaceous
	Siltstone	24%	37%	- Light grey to green grey - Firm to moderate hard - Non calcareous with micro pyretic
Kf3	Siltstone	26%	44-54%	- Light grey to brownish grey - Hard and quartzite carbonaceous, calcareous
	Shale	35%	56%	- Medium grey - Hard fissile splintery

Kf4	Shale	30-36%	62-68%	- Light greenish grey to medium grey - Fissile moderate hard to hard fissile splintery - Occasionally slity
	Siltstone	37-38%	66-74%	- Light grey to brownish grey - Hard and quartzite carbonaceous, calcareous
	Sandstone	24-30%	60-62%	- Light grey - Fine grain friable and slightly glauconitic - Low porosity visual and faint crush cut
	Claystone	34.5%	68%	- Cream to light grey swell
Kf7	Shale	35-41%	55-80%	- Light greenish grey to medium grey - Fissile moderate hard to hard fissile splintery - Occasionally slity
	Sandstone	36-38%	56%/78%	- Light grey - very fine grain and slity at the base - fairly good visual porosity(5338m) and blocky(5484m)
	Siltstone	35-38%	56-79%	- Light grey to brownish grey/light brow - Hard and quartzite carbonaceous, calcareous - Very fine grain sandstone

Table 7: Summaries of rock properties for DELTA-1 well

Further studies had been done in the different region which is in HONEY-1 well in Baram Delta at Miri Field. The data had been compiled in a table that shows below and a graph of thermal conductivity versus acoustic impedance had been made.

Depth interval(m)	gamma ray(gr)	neutron porosity (Φn)	density ρ,gm/cm3	Vsh	Acoustic Impedance(x10²)	Thermal Conductivity	Thermal Facies
2675	40	25	2.4	41	91.2	3.22	2
2681	59	26	2.4	71	96.7	2.54	1
2688	62	24	2.5	76	98.8	2.47	1
2696	43	22	2.5	45	102.5	3.68	2
2703	65	24	2.5	81	100.4	2.37	1
2710	60	24	2.4	73	97.3	2.51	1
2718	36	23	2.4	34	98.9	2.95	2
2732	54	30	2.4	64	97.3	2.67	1
2747	61	25	2.5	75	100.6	2.47	1
2754	43	20	2.4	45	99.3	3.92	2
2769	62	23	2.4	76	89.2	2.46	1
2776	71	26	2.4	91	92.5	2.21	1
2783	31	19	2.4	26	95.1	3.27	2
2791	23	21	2.5	13	100.7	3.50	3
2798	22	22	2.5	12	96.5	3.43	3
2805	56	25	2.4	66	85.8	2.64	1
2812	35	23	2.5	32	96.7	2.98	2
2820	31	26	2.5	27	98.5	2.94	2
2827	44	20	2.4	47	97.8	3.94	2
2834	48	19	2.5	53	101.6	4.17	3
2849	24	20	2.5	15	105.8	3.53	3
2856	35	21	2.5	32	100.5	3.06	2
2864	31	19	2.5	27	107.2	3.26	2
2871	43	21	2.5	45	108.3	3.80	2
2878	57	24	2.5	68	102.0	2.60	1
2885	18	24	2.5	5	105.1	3.44	5
2893	16	24	2.5	0	102.0	3.51	5
2900	37	18	2.5	35	103.8	3.12	2
2907	19	24	2.5	4	99.9	3.45	4
2915	30	21	2.5	23	95.6	3.18	2
2929	63	22	2.4	78	86.4	2.42	1
2944	37	20	2.4	36	89.7	3.05	2
2951	31	17	2.5	25	95.8	3.35	2
2958	64	16	2.5	79	99.6	2.41	1

Table 8: HONEY-1 well data interpretation

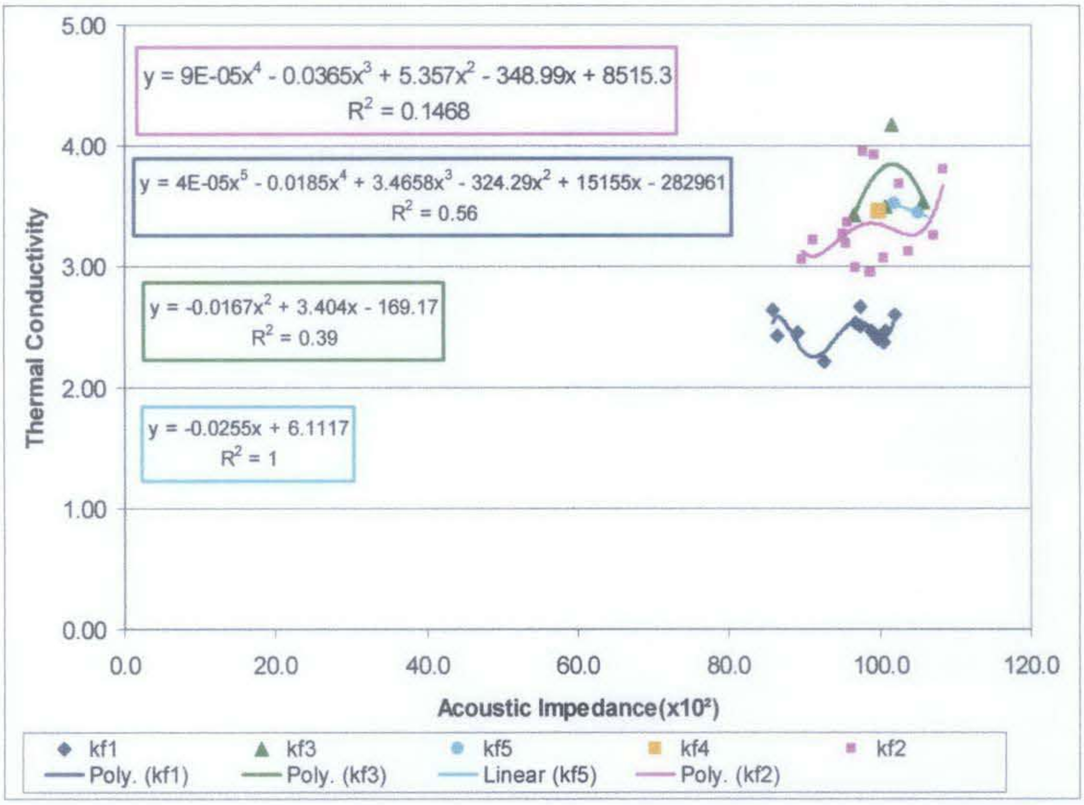


Fig.8 Crossplot of Thermal Conductivity versus Acoustic Impedance in HONEY-1 well

From the result above in HONEY-1 well, all the data are different form the DELTA-1 well data. The value of acoustic impedance in HONEY-1 well is different than the value acoustic impedance in DELTA-1 well. The value is about 2 times higher than the value acoustic impedance in DELTA-1 well. This is because of the different of location of field and type of the field that had been explained in the background of the wells. Moreover, the acoustic impedance and thermal conductivity in HONEY-1 well shows that it is difficult to make a relationship by facies compare to DELTA-1 well.

For the facies in this well, all the point at each depth interval was sandstone and a few of shale. Therefore, the thermal facies in this well is kf1, kf2, k3 and a few of kf4 and kf5.

CHAPTER 5: CONCLUSION

The quantitative database was developed through the analysis of crossplots between thermal conductivity and acoustic impedance derived essentially, from well logs. Although this project uses only two wells, the database that has been developed will be useful for showing the empirical relationship between the acoustic impedance and thermal conductivity.

The database was compiled based on the type of thermal facies, the rock properties such as neutron porosity, gamma ray, density, and volume of shale, formation temperature; velocity and the depth intervals. From these factors, we can see the R^2 value indicate a good trend or not. Hence, the empirical relationships of thermal conductivity in well DELTA have better trends than those of well HONEY. From the equations developed, we can identify the thermal properties of other wells from seismic impedance data. This project shows that the database could be developed from the crossplots method applied in developing empirical equations relating thermal conductivity to acoustic impedance.

The outcome of this project could be the database and the equation developed from the crossplot. The techniques has been developed which use to identify the reservoir characteristic according to environment of deposition and thermal facies. We can predict the thermal conductivity by knowing the seismic data or acoustic impedance. In order to increase the efficiency and the accuracy of the result, this project could be further studied using different wells from different basins.

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CHAPTER 7: APPENDICES

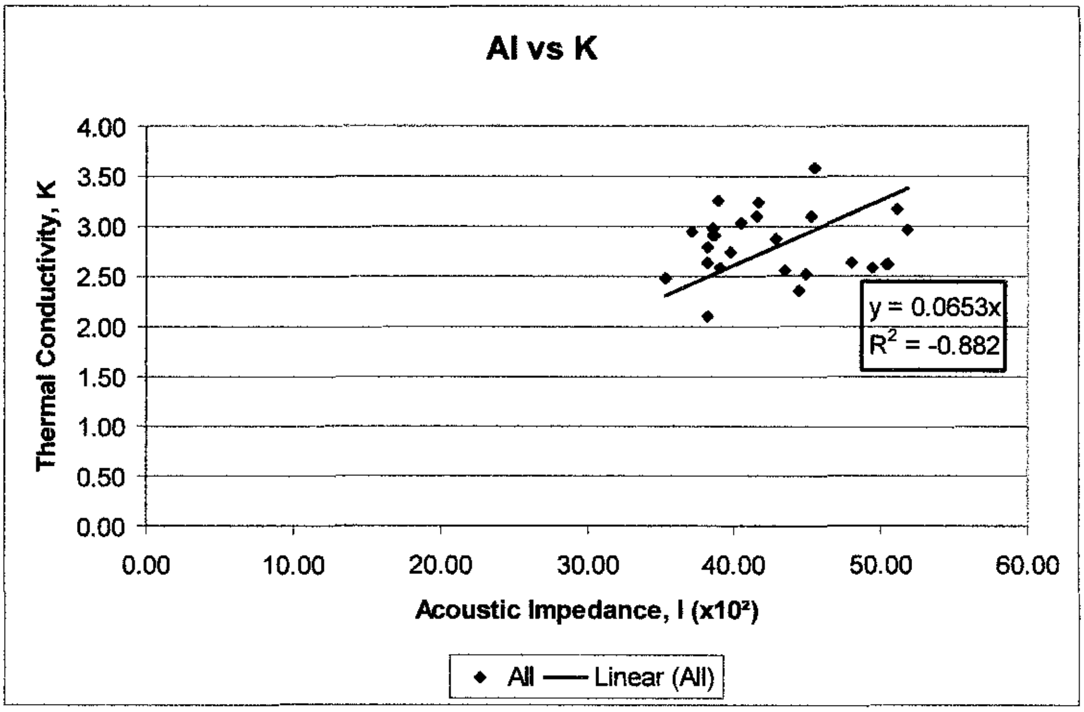

Fig 9: Crossplot of Thermal Conductivity versus Acoustic Impedance in DELTA-1 well without consider facies

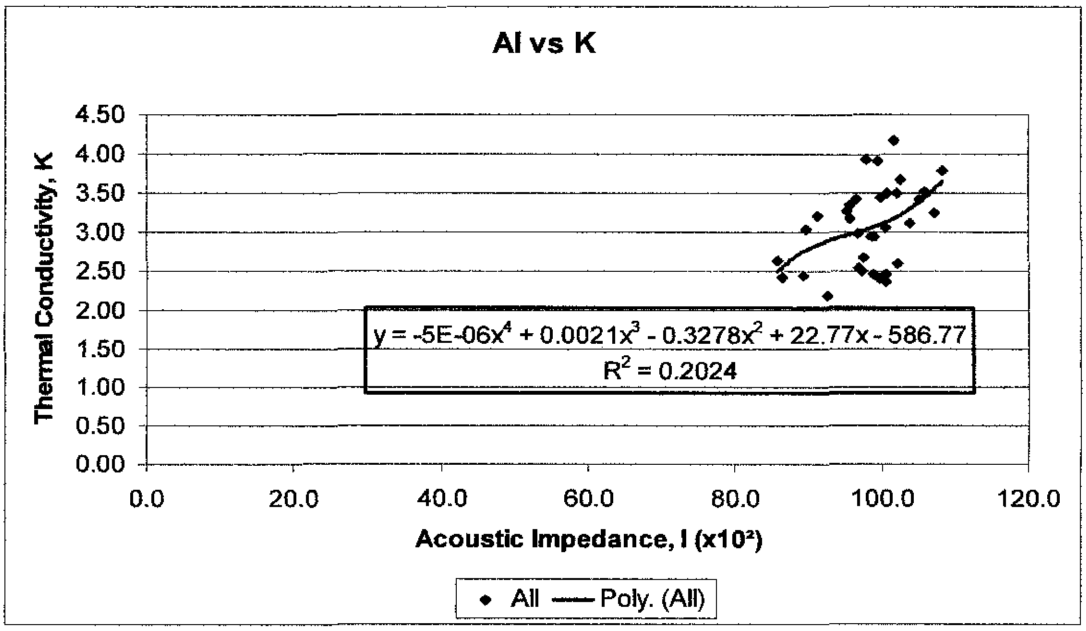

Fig 10: Crossplot of Thermal Conductivity versus Acoustic Impedance in HONEY-1 well without consider facies

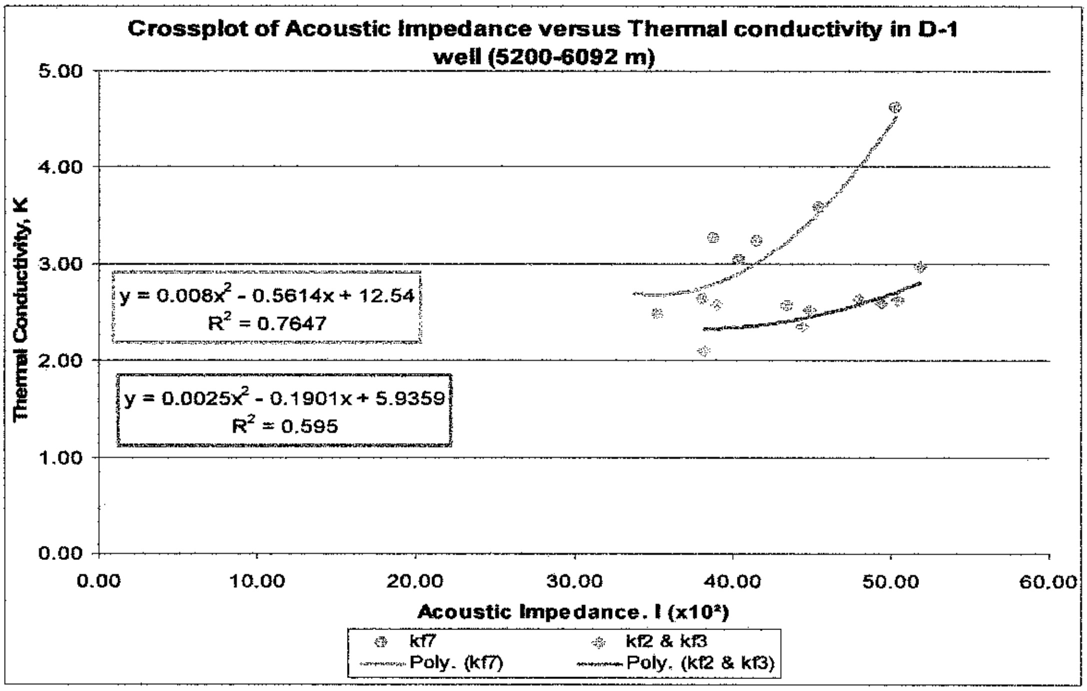

Fig 11: Crossplot of Thermal Conductivity versus Acoustic Impedance in DELTA-1 well for sand only

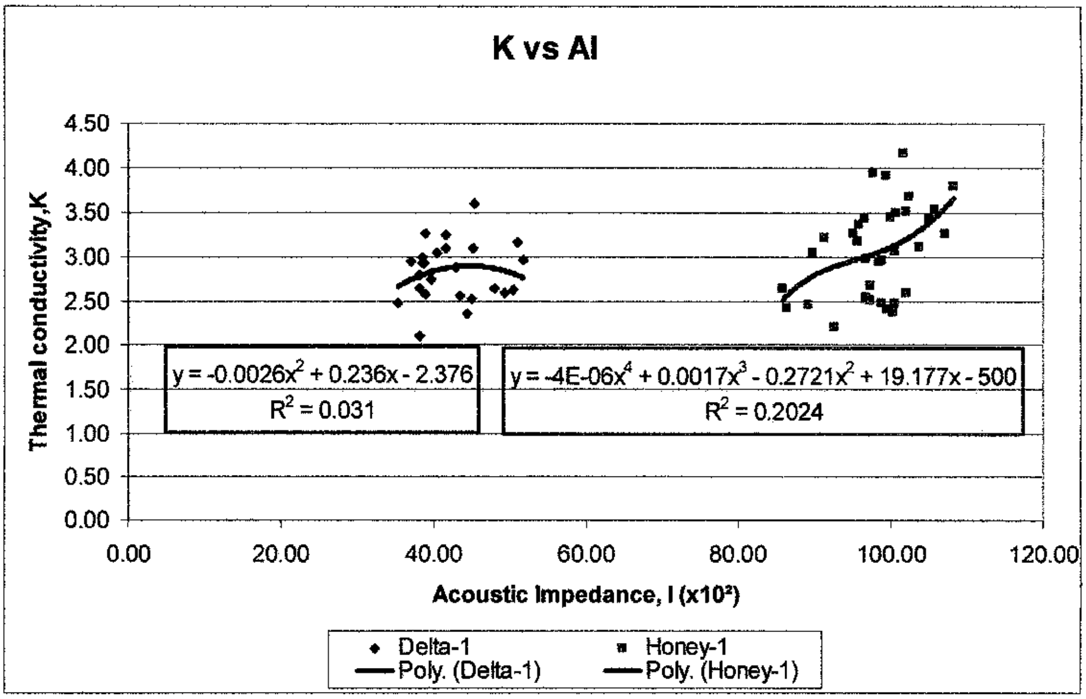

Fig 12: Crossplot of Thermal Conductivity versus Acoustic Impedance in DELTA-1 well and HONEY-1 well without consider facies