*Geophysics Undergraduate Thesis*

# GAS POTENTIAL ANALYSIS ON PENOBSCOT FIELD, CANADA USING INTEGRATION OF SEISMIC INVERSION AND SPECTRAL DECOMPOSITION METHODS


**BY**

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**DEPARTMENT OF GEOPHYSICS**

**FACULTY OF MATHEMATICS AND NATURAL SCIENCE**

**UNIVERSITAS HASANUDDIN**

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In partial fulfillment of the requirements for the degree

Bachelor of Science

**BY**

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**To fulfill one of the examination requirements to obtain a bachelor of science degree in the department of geophysics undergraduate program, it has been approved by the supervisory team on the date as stated below.**

**Makassar, 11 August 2020**

**Approved By:**

| **Main Supevisor** | **First Supervisor** |
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***Undergraduate Thesis Statement Sheet***

Hereby declare that :

1. My work, this thesis is original and submitted to get a bachelor of science degree at Universitas Hasanuddin.
2. This work is pure of provision and investigation from the writer without the help of other parties, except the direction of the supervisory team and the input of the examining team.
3. In this work, there are no works or opinions of works or opinions that have been written or published by others except in writing clearly stated as a reference in the text with the mention of the author's name and included in the references.
4. I make this statement truly and if in the future there are deviations and untruths in this statement, I am willing to accept academic sanctions in the form of revocation of the degree that has been obtained because of this work and other sanctions by the norms prevailing in university.

Makassar, 10 March 2020
Stated By,

Muh Resky Ariansyah
NIM. H22115511

## ABSTRACT

### Gas Potential Analysis on Penobscot Field, Canada using Integration of Seismic Inversion and Spectral Decomposition Methods

Seismic inversion and spectral decomposition methods have been carried out in the Penobscot field, Scotian basin to identify the distribution of reservoirs and gas content in the field. The seismic inversion method is used to identify reservoir distribution, then combined with spectral decomposition to determine gas content.

The model-based seismic inversion method is carried out to give a more feasible result because this method calculates seismic synthetics using forward modeling concepts by inversing geological models to find the rock properties. For the spectral decomposition method, a continuous wavelet transform (CWT) is used because this method can produce high data resolutions in the time and frequency domains.

From the model-based seismic inversion method, reservoir distribution areas have been identified with acoustic impedance values ranging from 6,900,000 kg/m$^3$*m/s to 9,000,000 kg/m$^3$*m/s. Further is to analyze the low-frequency anomaly from CWT using frequencies of 15 Hz and 30 Hz. Low-frequency anomaly with high amplitude can be seen on the 15 Hz time-frequency map. After the two results are combined, it is found that the low-frequency anomaly is in the reservoir area which is the result of the analysis of seismic inversion. The combination of these two methods produces a feasible method to be applied to identify the reservoir with gas content.

**Keywords : Seismic Inversion, CWT, Low Frequency Anomaly, Gas Content Reservoir**

# ABSTRAK

## Analisa Potensi Gas pada Lapangan Penobscot, Kanada menggunakan Integrasi Metode Inversi Seismik dan Spektral Dekomposisi

Metode inversi seismik dan spektral dekomposisi telah dilakukan pada lapangan Penobscot, cekungan Scotia untuk mengidentifikasi distribusi reservoar dan reservoar yang berisi gas pada lapangan. Metode inversi seismik dilakukan untuk mengidentifikasi distribusi reservoar, kemudian dikombinasikan dengan spektral dekomposisi untuk menemukan reservoar berisi gas.

Metode inversi seismik *model-based* dilakukan untuk memberikan hasil yang lebih layak karena metode ini mengkalkulasikan sintetik seismik menggunakan konsep pemodelan kedepan dengan menginversi model geologi untuk mencari properti batuan. Untuk metode spektral dekomposisi, digunakan *continues wavelet transform* (CWT) karena metode ini dapat menghasilkan resolusi data yang tinggi dalam domain waktu dan frekuensi.

Dari metode inversi seismik model-based, area distribusi reservoar telah teridentifikasi dengan nilai akustik impedansinya mulai dari 6.900.000 kg/m$^3$*m/s hingga 9.000.000 kg/m$^3$*m/s. Selanjutnya adalah menganalisa anomali frekuensi rendah dari CWT dengan menggunakan frekuensi 15 Hz and 30 Hz. Anomali frekuensi rendah dengan amplitude yang tinggi terlihat pada peta time-frequency 15 Hz. Setelah kedua hasil dikombinasikan, ditemukan bahwa anomali frekuensi rendah berada pada area reservoar hasil analisa dari inversi seismik. Kombinasi dari kedua metode ini menghasilkan metode yang layak diaplikasikan untuk mengidentifikasi reservoar berisi gas.

**Kata Kunci : Seismik Inversi, CWT, Anomali Frekuensi Rendah, Reservoar Berisi Gas**

## FOREWORD

I praise to Almighty God, Allah SWT, the owner of all science on earth who has bestowed his mercy and guidance to me so I can complete the final project and complete the preparation of the undergraduate thesis entitled "**Gas Potential Analysis on Penobscot Field, Canada using Integration of Seismic Inversion and Spectral Decomposition Methods**" at PT. Pertamina EP - Asset 5 with well and on time. The final project is the main requirements needed to be able to graduate from the Department of Geophysics, Universitas Hasanuddin, Makassar.

On this occasion, I would like to thank all of you who have helped in completing this thesis and final project both directly in the form of science and material or indirectly in the form of motivation, enthusiasm, and prayer. For that, I would like to say thank you to:

1. Allah SWT who has bestowed the ability of thinking and health for me and the Prophet Muhammad SAW who provided a good role model.
2. My parents and family who always provide prayer, affection, enthusiasm, and attention are very meaningful, especially during my final project.
3. Lecturers of the Universitas Hasanuddin, Department of Geophysics that has been provided knowledge and support to me, especially to Pak Ir. Bambang Harimei, M.Si as my main supervisor and Kak M. Fawzy Ismullah. M, S.Si, M.T as my first supervisor in conducting this thesis, as well as Pak Muh. Alimuddin Hamzah, M.Eng as the chairman of the Department of Geophysics FMIPA Universitas Hasanuddin who strongly supports this final project.
4. Mas Husein Agil Almunawwar, my technical supervisor for this final project at PT. Pertamina EP - Asset 5, thank you for guiding and teaching me very well. Mba Triana Sulistia, HR Officer who helped me adapt to the office environment and Mba Jessica Doza who helped me get the position as an intern in PT. Pertamina EP - Asset 5.
5. All my friends in SPE Unhas SC who have always provided support and encouragement to me when I had to do the final project far from home and through Ramadhan in another city. And also all Unhas Geophysics class of

2015, 2016 and 2017, thank you for helping me in completing all campus tasks that I have not completed because I have to leave to carry out the final project.

Finally, I hope that this thesis can be useful for readers. I also realize that this work has many shortcomings and is far from perfect. I am willing to accept all criticisms and suggestions for the creation of a thesis that is useful for all of us, especially for those who want to explore the reservoir characterization using seismic inversion and spectral decomposition methods. Hopefully, this thesis can be useful for future academic research and readers.

Makassar, 10 March 2020

Muh Resky Ariansyah

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# CHAPTER I

# INTRODUCTION

## I.1 Background

The rapid development of the human population also affects increases the demand for energy needs. One of the biggest energy needed by humans is energy derived from hydrocarbons. Hydrocarbon energy is non-renewable energy because it takes a very long time to form.

The seismic method is still considered as the main method to detect the presence of hydrocarbon in reservoirs. But often during interpreting the data, the ratio of the uncertainty in the seismic method is still too high. Whereas to carry out production in a hydrocarbon field, a reservoir model is needed that not only provides information on the subsurface geological structure but can also provide detailed rock physical properties.

One of the methods that can be used to characterize the reservoir is the seismic inversion and spectral decomposition methods. Seismic inversion is known to be able to predict subsurface models from the seismic recording information obtained (Samaun, 2018). While spectral decomposition is one type of seismic attributes commonly used to display seismic cross-sections at a particular frequency (Asim et al., 2016). The seismic cross-section shown is a composite of a certain frequency range. Seismic cross-sections with different frequency content will show different geological features. This can happen because the geological properties of rocks such as thickness and fluid content will be more clearly observed in a certain frequency range.

In this day and age, seismic attributes that develop rapidly help researchers in the process of identifying reservoirs to see hydrocarbon indications in reservoirs. The presence of gas is usually easier to identify than oil and water because of the gas effect attenuation. Gas will attenuate at high frequencies and oil will be attenuated at lower frequencies.

Previously, (Lasono, 2011) had used both methods to complete her thesis at Universitas Indonesia using the South Sumatra Basin. (Choir et al., 2018) in their paper also used the integration of these two methods in the East Java Basin to identify reservoir and gas content. The weakness of this paper is that there is no explanation of the regional geology or stratigraphy of the research area. It means no geological correction that can be applied to the results of those studies.

Using the same principle, in this final project, Penobscot field in Canada will be investigated. The results of the integration of seismic inversion and spectral decomposition methods are expected to result in an adequate method that is applicable for the identification of reservoir with gas content with maximum results.

## I.2 Scope

The scope of this final project is to examine Penobscot Field, Scotian Basin by integrating model-based seismic inversion methods with AI variables to identify reservoir areas from the field with spectral decomposition methods to analyze the low-frequency shadow zone so that the contents of the reservoir can be known. The data used are open source seismic data and 1976 well data from Penobscot Field which can be accessed at the link https://terranubis.com/datainfo/Penobscot.

## I.3 Objective

The objectives of this final project are:

1. Identifying reservoirs based on model-based inversion methods using AI variable.
2. Confirm the target zone by analyzing the low-frequency shadow zone.
3. Mapping the target zone for the next development.

# CHAPTER II

# THEORY AND GEOLOGICAL BACKGROUND

## II.1 Geological Review

The Penobscot Field is located in the Scotian Basin in the northern Atlantic, southeast of the Province of Nova Scotia, Canada (Rezki, 2012). In detail, this field is 25 km NW from Sable Island with water depths from 50 to 150 meters (Figure 2.1).

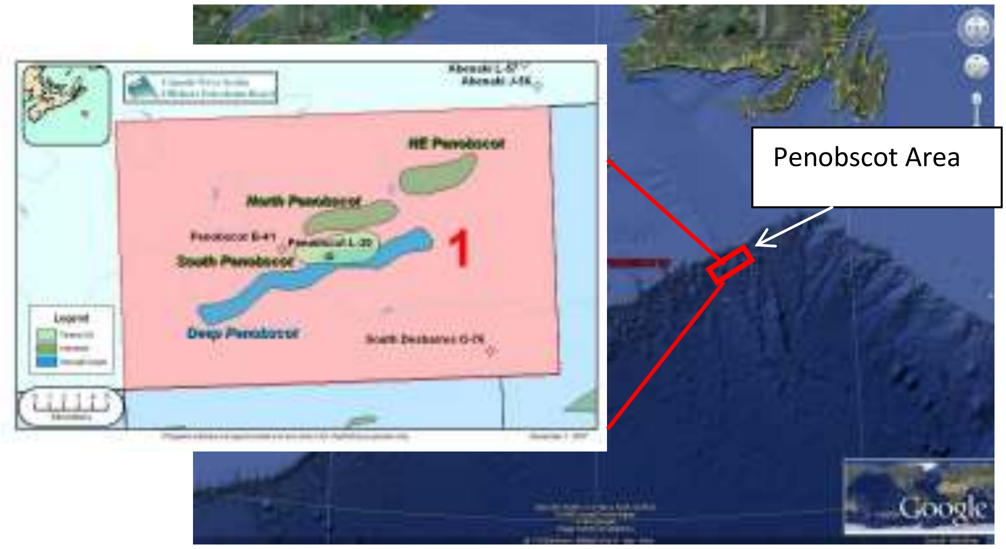


**Figure 2.1** Map of research locations in the Penobscot area, Nova Scotia, Canada. (Source: modification of the official OpendTech website, 2011)

In 1976 and 1977, the Penobscot L-30 well was drilled with a total depth of 4237.5 m in the water depth of 138 m and Penobscot B-41 with a total depth of 3414 m in the water depth of 118 m by the Petro-Canada Shell Oil Company. Petrophysical analysis on well L-30 indicates the presence of light oil, condensate, and gas in seven layers of sandstone in the Middle Missisauga Formation while in well B-41, no significant hydrocarbon indications were found (Kidston et al., 2005).

### II.1.1 Regional Geology

The Scotian Basin, with a total area of about 300,000 km$^2$, is located in the offshore area of Nova Scotia with a length of about 1200 km from the border of Yarmouth Arch / United States in the southwest to Uplift Avalon in Grand Banks - Newfoundland in the northeast. This basin formed on the passive continental margin that formed during the Pangea crack until the Atlantic formation. The Pangea crack which separates North America from the African Continent took place in the mid-Triassic period, then formed a basin filled with the earliest layers of fluvial and lacustrine sediments and volcanic rock intrusions. In the early Jurassic period, the basin gradually filled with clastic and carbonate rocks and developed into a full ocean in the middle of the Jurassic period which triggered the formation of the alluvial plain, delta, and carbonate formation (Kidston et al., 2005).

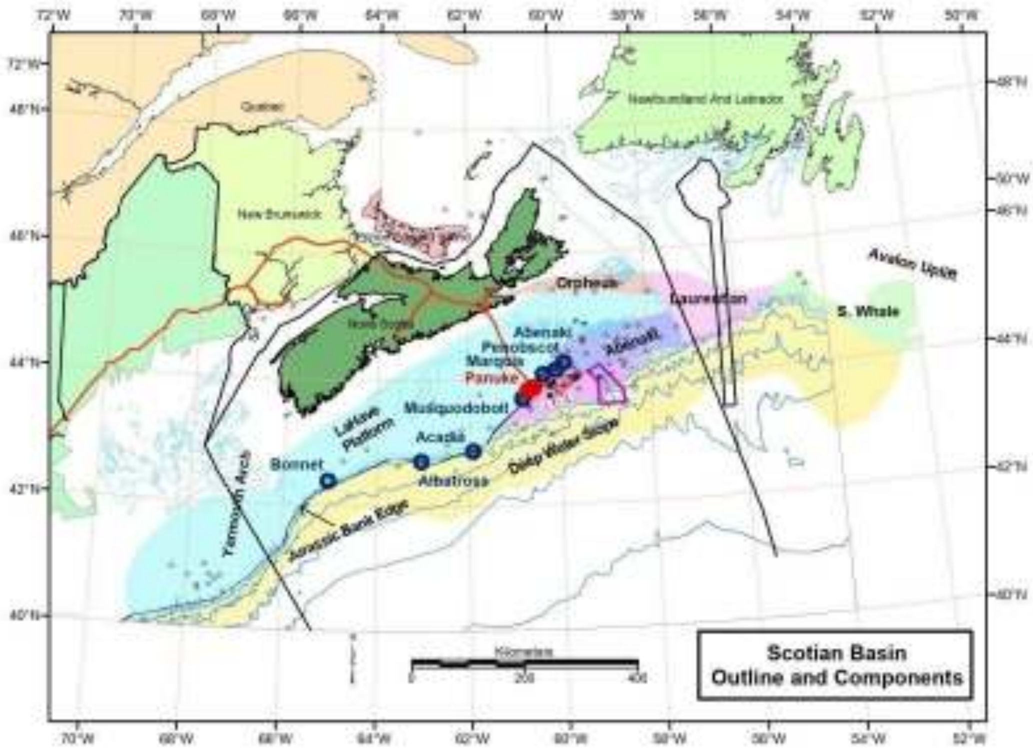


**Figure 2.2** Scotian Basin Outline and Components (Kidston et al., 2005).

As carbonate platforms form, rising sea levels result in the carbonate environment being covered by shale, which then re-forms in the late Jurassic period. Precipitation in the Cretaceous period is dominated by a series of thick sandstone of the deltaic type, strand plain, carbonate shoal, and succession of shelf seas. The relative fluctuation of sea level in the Tertiary period results in unconformity in the sedimentary layer. The layer is eroded by fluvial flow which carries sediment towards the Abyssal Plain. In the Quaternary period, there were marine and glacial sediment deposits on the outside of the shelf (Kidston et al., 2005).

### II.1.2 Regional Stratigraphy

The Scotian Basin contains Mesozoic-Cenozoic sedimentary rocks up to a thickness of 16 km, these rocks were deposited during the period of movement of the Pangea. The earliest deposition occurred during the Triassic period, which consisted of clastic and evaporites. Then there was a transition by seabed expansion at the beginning of the Jurassic so that the gap in the basin was gradually filled with clastic and carbonates. Conditions that are entirely oceanic and develop in middle Jurassic, trigger the formation of the alluvial plain, delta, and carbonate facies. Late Cretaceous and early Cretaceous deposition are dominated by transgressive shale, limestone, and carbonate. The relative fluctuations in sea level during the Paleocene and Neocene form a mixture of sandstone and shale interspersed with coarse clastic rocks and marine carbonates. The layer is also coated by unconsolidated glacials, glaciomarine silts, and ocean sediments deposited during the Quaternary (Almunawwar, 2014).

In general, stratigraphic rock layers that filled the Scotian basin consist of at least 14 rock formations as follows:

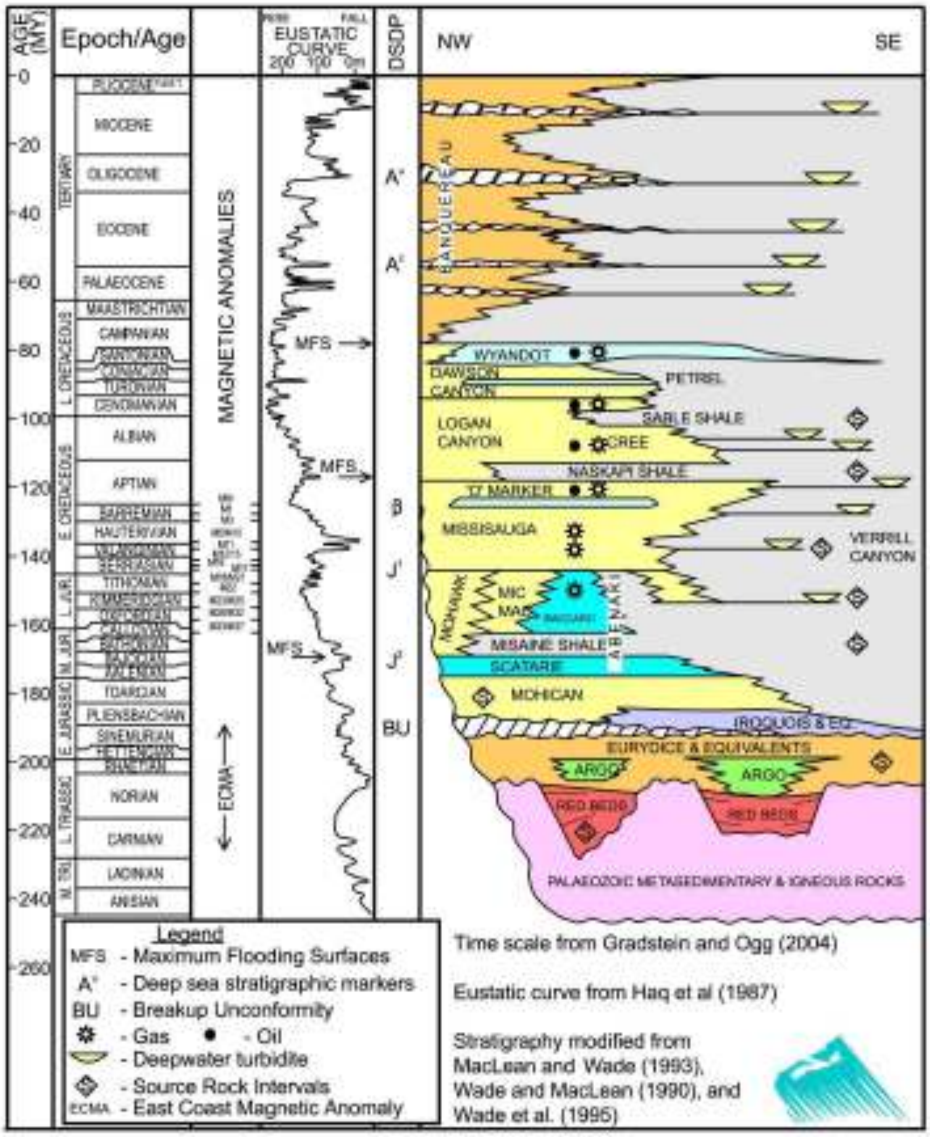


**Figure 2.3** Stratigraphical column of Scotian Margin (Kidston et al., 2005).

### II.1.2.1 Eurydice Formation

The Eurydice Formation is the oldest Formation to fill the Scotian basin which is still related to the formation of the Atlantic continent and is a row of red sandstone, siltstone, and shale in Triassic / Jurassic. Several wells have been drilled until they reach the Eurydice Formation. In the Orpheus graben, nearly 600 meters of the Eurydice Formation were drilled and from seismic data, the total thickness of the Formation reached 3 km. More than 1.5 km of the Eurydice Formation was drilled in the Grasken Naskapi complex on the La Have platform and seismic data indicate that the thickness is also around 3 km in the area (Almunawwar, 2014).

### II.1.2.2 Argo Formation

Argo Formation is a rock formation that is directly facing the Eurydice Formation and is on the edge of the basin. The main constituent is salt. The distribution of salt in the Scotian basin triggers the main graben on initial deposition to accumulate a thin layer of evaporite and redbeds. The salt flow extensively fills in sedimentary subsequent and may periodically reactivate the rift fault system during the continental drift stage. Salt pillows that are flanked and canopy are common in salt layers, which separately in the main zone of the flanking structure tend to be under the continental slope of the eastern Georges Bank towards Grand Banks in the west (Almunawwar, 2014).

### II.1.2.3 Breakup Uncomformity

There is an unconformity structure, which is the breakup unconformity that occurs between the syn-rift and post-rift sequences in the Scotian basin and possibly formed in Jurassic. The unconformity cuts the shallow graben on the La Have platform and is far outside the salt flank zones (Almunawwar, 2014).

### II.1.2.4 Iroquois and Mohican Formation

Under the Scotian shelf, the Iroquois and Mohican Formations overlay unconformity breakups. The Iroquois Formation, whose main constituent is dolostone, has a similar age to the bottom of the Mohican Formation on the La Have platform which reaches a maximum thickness of up to 800 meters. The formation is a representation of a row of dolomitic beds. Sandstone and shale from the Mohican Formation are formed very thick in the middle Jurassic and are deposited until the subsiding of active subbasins is adjacent to the hinge zone. This formation extends to the Scotian shelf and several wells have successfully drilled to the depth of this Formation. The thickest part of the Mohican Formation was drilled only to a depth of 400 meters on the La Have platform, but seismic data indicate that the Mohican Formation has a thickness of up to 4 km in the southern part of the hinge zone in the Abenaki subbasins and up to 5.5 km in the syn-rift sequence below the east part of Scotian shelf. The Mohican Formation thinned in the hinge zone and was cut off by post-Jurassic Avalon unconformity (Almunawwar, 2014).

### II.1.2.5 Mic Mac and Mohawk Formation

Above the Mohican Formation, there is a second thickest Formation composed by predominant clastic rocks formed after the crust drift (post-rift), called the Mic Mac Formation. In the Scotian basin, the Mic Mac Formation, the Abenaki Formation, the Mohawk Formation, and the Verrill Canyon Formation were formed in the Early Jurassic, Middle Jurassic, and Late Jurassic. The Mic Mac Formation has a thickness of 6 km on the Laurentian subbasin to the tip of the deposition or erosion of the La Have platform, the Burin platform, and the Avalon Uplift. Southeast of Sable Island contains 4 to 5 km of interbedded sandstones, shale, and limestone. Towards North and West of Sable Island, along the hinge zone, there are a carbonate facies that are quite prominent, namely in the Abenaki Formation. Other continental facies, more landward, have the Mohawk Formation which includes mature textures, felspathic sandstone, and siltstone with the alternation of shale and limestone (Almunawwar, 2014).

### II.1.2.6 Verrill Canyon Formation

Formed in the Middle Jurassic to Early Cretaceous, the Verril Canyon Formation is a deep-sea facies similar to the Mohawk, Abenaki, Mic Mac, and Missisauga Formations. This formation is composed of gray to black calcareous shale with a thin layer of limestone, siltstone, and sandstone. The Verrill Canyon Formation is deposited on the prodelta, outer shelf, and continental slope setting. This formation has a thickness of 360 meters in the Southwest part of the Scotian basin and more than 915 meters in the Northeast. The Shortland Shale Sandstone from the Logan Canyon formation is far apart from the deep-sea shale facies of the Shortland Shale which is deposited on the prodelta, outer shelf, and continental slope setting (Almunawwar, 2014).

### II.1.2.7 Abenaki Formation

The Abenaki Formation is divided into four parts: Scatarie, Misaine, Baccaro, and Artimon. This formation is formed from a special limestone that has a complex and prominent seismic sequence. The best part that can be developed from this Formation is the hinge zone between the La Have platform, the Shelburne subbasin, and the Sable subbasin. During Final Jurassic, the eastern part of Canada's margin was affected by the separation of Iberia from North America. The strongest influence is on the southern part of Newfoundland where there are uplift, deformation and wide erosion in the Jurassic and older strata. Breakup Uncomfirmity, Avalon Uncomfirmity is found from Avalon Uplift to the west to the eastern part of the Scotia basin. During this incident, there was a shift in the depocenter to the west from the Laurentian subbasin to the Sable subbasin (Almunawwar, 2014).

### II.1.2.8 Missisauga Formation

The Missisauga Formation is widespread in the Scotian basin which varies in facies and thickness. Throughout the La Have, Burin and Canso Ridge platforms, the thickness reaches 1000 meters and contains 60 to 80 percent sandstone with several local limestone facies in the Southwest. In the Sable subbasin, more than 2770 meters of this formation was drilled in the Sable Island area and is thought to have a thickness of more than 3 km with 30 to 50 percent containing sandstone or siltstone. Towards the basin, the Missisauga Formation turbidite and shale grades are from the Cretaceous portion of the Verrill Canyon Formation (Almunawwar, 2014).

### II.1.2.9 Logan Canyon Formation

Logan Canyon has a thickness of about 2.5 km and is divided into four parts, two of which are dominated by shale. This formation is similar to the distant turbidite or shale on the Shortland Shale (Almunawwar, 2014).

### II.1.2.10 Dawson Canyon Formation

Marine shale, carbonate, and small amounts of limestone were deposited throughout the Scotian basin during the Late Cretaceous. The first transgressive unit is the Dawson Canyon Formation, which has a thickness variation of more than 700 meters in the South Whale subbasin and the Scotian shelf about 200 meters in the Canso Ridged and about 100 meters outside the Sable subbasin (Almunawwar, 2014).

### II.1.2.11 Wyandot Formation

The Wyandot Formation is composed of carbonate, mudstone, marl, and a little limestone. Its thickness varies between less than 50 meters on Sable Island and about 400 meters southeast of the edge of the Scotian shelf but is largely lost to the basin due to Tertiary erosion. Under the outer part of the Shelf and Slope, above the Wyandot Formation is often marked by unconformity overlaying with Tertiary sediments (Almunawwar, 2014).

### II.1.2.12 Banquereau Formation

The Banquereau Formation is a succession of sediments between the upper part of Wyandot and upper Cenozoic Formations. It has a thickness from zero to 4 km (Almunawwar, 2014).

### II.1.2.13 Laurentian Formation

The Laurentian Formation is a "progradational wedge" sediment from the Quarternary and Upper Pliocene. In the thickest part, along the outer and inner slopes, there are about 1500 meters of glaciomarine sands, marine sands, silt, and claystones (Almunawwar, 2014).

## II.1.3 Petroleum System

### II.1.3.1 Source Rock and Migration

Source rocks are rocks or layers of soil that are believed to produce hydrocarbons. Usually, the source rock has the main material in the form of organic material as a staple to produce hydrocarbons (Almunawwar, 2014).

While migration is the transfer of hydrocarbons from the source rock to the reservoir rock. Migration needs to be known to estimate whether a reservoir rock can be filled or not by hydrocarbons (Almunawwar, 2014).

Because the position of the Penobscot Field is located in Missisauga Ridge, any hydrocarbons that emerge or are generated from sources will migrate into the Penobscot structure from both north and south. Based on (Almunawwar, 2014) and the official website of the Canada-Nova Scotia Offshore Petroleum Board, source rocks are likely to form during Late Jurassic which was deposited during the transition from carbonate (Abenaki Formation) to deltaic (Mic Mac Formation) sedimentation corresponding to the lower part of the Verrill Canyon Formation.

#### II.1.3.2 Reservoir Rock, Trap and Seal

Reservoir rocks are rocks that can be filled by fluid, in this case, the desired fluid is hydrocarbons. The main requirement to be a reservoir is that rocks must have a fairly good level of porosity. Porosity is usually interpreted as a comparison between the pores of a rock with the total volume of the rock (Almunawwar, 2014).

A trap is a form of the earth's layer that can make hydrocarbons trapped. There are several types of trap classification including structural traps, stratigraphic traps, and a combination of both (Almunawwar, 2014).

The seal is an impermeable layer that can prevent hydrocarbons from migrating again from reservoir rocks. A good seal must be widespread (Almunawwar, 2014).

The Penobscot area has a good reservoir in the middle Missisauga Formation. This formation has sandstone that is thicker than in the lower Missisauga. The type of sandstone in middle Missisauga is moderate-well sorted, fine to coarse-grained. The seal is likely to have lots of shale rock which is the main rock type of seal (Almunawwar, 2014).

## II.2 Geophysical Literature

The seismic reflection is still the most widely used geophysics method in oil and gas exploration (hydrocarbons). In general, the main purpose of seismic measurements is to obtain good quality records. The quality of this recording can be assessed from the signal-to-noise ratio (S/N), which is the ratio between the number of reflection signals recorded compared to the signal noise and the accuracy of travel time measurements. Seismic measurements will produce a seismic profile that shows the response of the earth's reflection to seismic waves and the position of rock layers in geology (Redini et al., 2017). Seismic wave reflection will occur every time there is a change in the value of Acoustic Impedance (AI) which is one of the unique acoustic properties of rocks. AI is the multiplication of density with the velocity of wave propagation in a medium. One of the main problems of the reflection seismic method is the emergence of seismic response interference from the very tight AI boundary. Such interference can be destructive if it weakens other reflectors or is constructive with the appearance of apparent reflectors as noisy and will become a trap in interpretation. With the above limitations, many ways are done to get a good seismic cross-section resolution so that the seismic data is capable describe subsurface conditions precisely.

### II.2.1 Seismic Reflection Component

The components produced here are things that can be produced or derived (derivative value) from the parameters and basic seismic reflection data. (Hutabarat, 2009).

#### II.2.1.1 Acoustic Impedance

One of the unique acoustic properties in rocks is the acoustic impedance (AI) which is the result of the multiplication between the density and the velocity propagation, expressed in equation 2.1. (Hutabarat, 2009)

$$AI = \rho . \mathrm{v} \tag{2.1}$$

with : $AI$ = acoustic impedance (kg/m³*m/s)

$\rho$ = density (kg/m³)

ν = velocity (m/s)

In controlling the value of AI, velocity has a more important meaning than density. For example, porosity or rock pore-filling material (water, oil, gas) affects velocity prices more than density (Hutabarat, 2009). Sukmono, (1999) analogizes AI with acoustic hardness. Hard rocks and the one that difficult to compress, such as limestone has a high AI, while soft rocks such as clay which are more easily to compressed have low AI.

### II.2.1.2 Reflection Coefficient

The reflection coefficient is a reflection of the medium boundary which has a different acoustic impedance value. For the reflection coefficient at zero angle, it can be calculated using equation 2.2 as follows (Hutabarat, 2009):

$$RC = \frac{(AI2-AI1)}{(AI2+AI1)} = \frac{(\rho2.\mathrm{v}2)-(\rho1.\mathrm{v}1)}{(\rho2.\mathrm{v}2)+(\rho1.\mathrm{v}1)} \quad (2.2)$$

with : $RC$ = reflection coefficient

$AI_1$ = acoustic impedance upper layer

$AI_2$ = acoustic impedance bottom layer

The reflection coefficient has a value between –1 to 1 (Hutabarat, 2009). If the acoustic impedance in a layer is greater than the acoustic impedance of the layer above it, or waves propagate from rocks with a density/low-velocity value to rocks with a higher density/velocity value, then the reflection coefficient value will be positive. The value of acoustic impedance contrast can also be estimated from the amplitude of the reflection, the greater the amplitude the greater the reflection and contrast of the acoustic impedance (Sukmono, 1999).

### II.2.1.3 Polarity

Although the use of the word polarity only refers to recording and display conventions and does not have its special meaning, in seismic recording, determining polarity is very important. The Society of Exploration Geophysicists (SEG) defines normal polarity as follows (Hutabarat, 2009):

1. A positive seismic signal will produce a positive acoustic pressure on the hydrophone in water or the initial upward movement of the geophone on land.
2. A positive seismic signal will be recorded as a negative value on the tape, negative deflection on the monitor and trough on the seismic cross-section.

After using this convention, in a seismic cross-section with normal SEG polarity displays expect (Hutabarat, 2009) :

1. The reflection limit is a trough in the seismic cross-section, if $AI_2 > AI_1$
2. The reflection limit is a peak in the seismic cross-section, if $AI_2 < AI_1$

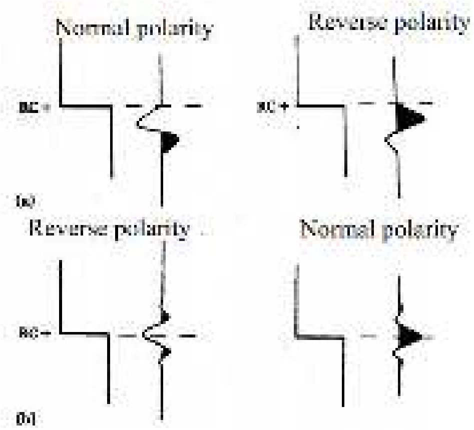


**Figure 2.4** SEG Standard Polarity wavelets for (a) minimum phase and (b) zero-phase (Sukmono, 2018)

### II.2.1.4 Seismic Vertical Resolution

Resolution is the minimum distance between two objects that can be separated by seismic waves (Sukmono, 1999). The frequency range of seismic is only between 10-70 Hz which directly causes the limited resolution of seismic. The value of seismic vertical resolution is (Hutabarat, 2009):

$$\text{vertical resolution} = \frac{v}{4f} \tag{2.3}$$

with : $v$ = velocity (m/s)

$f$ = wave frequency (Hz)

It can be seen from equation 2.3 that only rocks that have thickness above ¼ λ can be distinguished by seismic waves. This thickness is called tuning thickness. As depth increases, velocity increases and frequency decreases, the tuning thickness will be increased (Hutabarat, 2009).

### II.2.1.5 Wavelet

Wavelets are transient signals that have a limited time interval and amplitude. There are four commonly known types of wavelets, namely zero phase, minimum phase, maximum phase, and mixed-phase. (Hutabarat, 2009).

### II.2.1.6 Synthetic Seismogram

Synthetic seismograms are artificial seismic records made from speed and density log data. Velocity and density data form the reflection coefficient function which is then convoluted with the wavelet, as shown in Figure 2.5 (Hutabarat, 2009).

Synthetic seismograms are made to correlate well information (lithology, age, depth, and other physical properties) to seismic traces to obtain more complete and comprehensive information (Hutabarat, 2009).

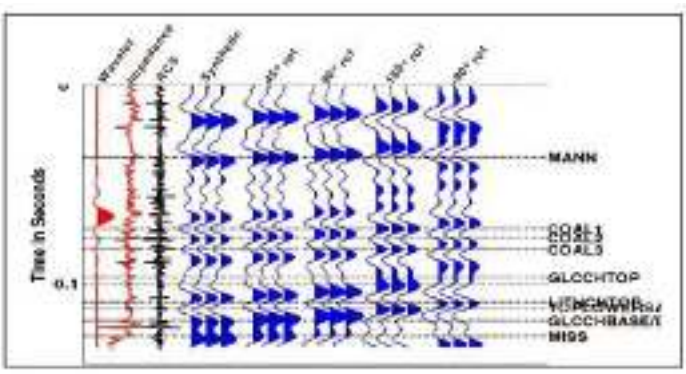


**Figure 2.5** Utilization of synthetic seismograms for variations in subsurface conditions (Hutabarat, 2009).

### II.2.2 Check-shot

Check-shot is carried out to get the relationship between the time and depth needed in the process of binding the well data to seismic data (Hutabarat, 2009). The working principle can be seen in Figure 2.6.

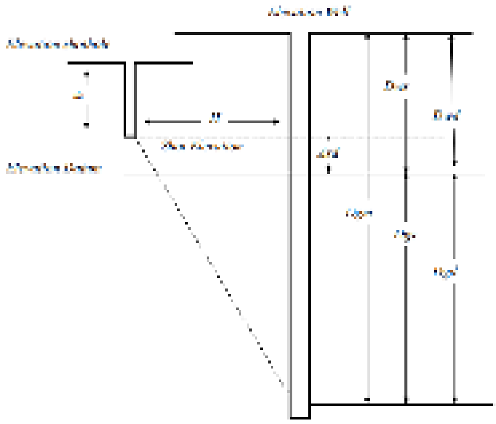

**Figure 2.6** Check-shot Survey (Sukmono, 2018)

This survey has similarities with seismic data acquisition in general, but the position of the geophone is placed along the wellbore or known as the Vertical Seismic Profiling (VSP) survey with the intent that the data obtained in the form of one-way time recorded at a specified depth to get a relationship between the seismic wave times in the drill hole (Hutabarat, 2009).

### II.2.3 Seismic Inversion

Inversion is an integration of mathematical and statistical calculations to obtain information on the physical properties of rocks based on observations of the research area system. In general, seismic inversion is a technique for obtaining subsurface geological models from existing seismic data with well data as a controller (Sukmono, 2001). The inversion method is divided into several methods pre-stack inversion and post-stack inversion (Putra, 2010). In the discussion chapter in this project, the inverse used is classified as post-stack inversion. In the post-stack inversion itself is further divided into several methods and in this project, the model-based method is used. The results obtained from seismic inversion are a cross-section of the distribution of acoustic impedance to depth for each seismic trace. An illustration of the pre-stack and post-stack inversion methods can be seen in Figure 2.7 below (Almunawwar, 2014).

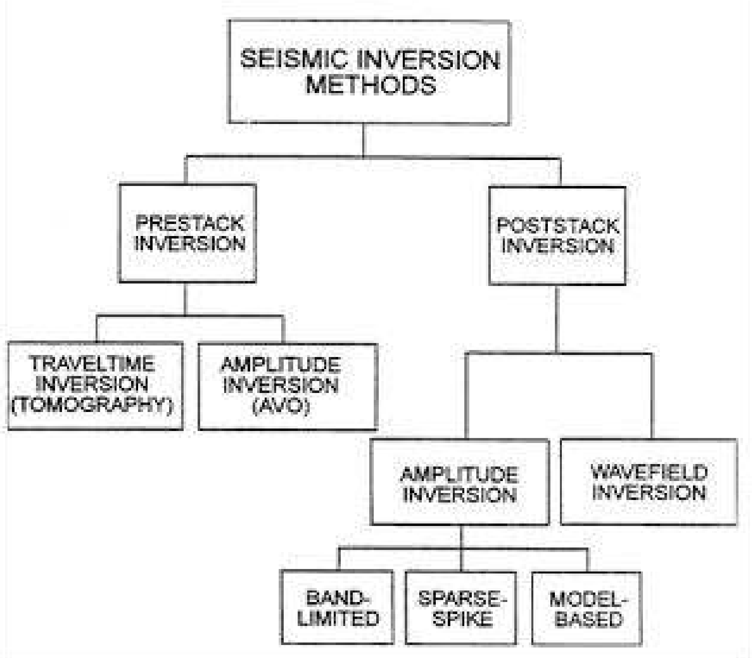


**Figure 2.7** Types of Seismic Inversion Methods (Almunawwar, 2014)

### II.2.3.1 Seismic Inversion Model Based Method

One type of seismic inversion method is a model-based method. The principle of this method is to create a geological model and compare it with real seismic data. The comparison results are used iteratively to update the model to match the seismic data. This method was developed to overcome problems that cannot be solved using recursive methods.

In this method, the inversion process depends on the model used. The mathematical functions for doing model-based inversions are:

$$S_t = W_t * r_t + n_t \qquad (2.4)$$

From the equation above, it can be explained that S is a seismic trace, which results from the convolution of W (wavelet) and r_t (the reflectivity value) added with the noise. The application of this method begins with initial assumptions that are iteratively corrected. This method iterates to look for reflectivity values that are convoluted with wavelets to produce traces that are close to the original seismic data.

The advantage of using a model-based inversion method is that this method does not inverse directly from seismic but instead inverses its geological model. This model also produces many iterative models so that the solutions of the inversion results are very numerous, causing the results not to be unique but in the inversion process the data entered contains all the frequencies of the seismic data.

Based on (Sukmono, 2018), Model Based inversion can be developed with workflow as follows:

1. Averaging the AI value to make an initial model and its blocky version based on the given block size.
2. Recover the synthetic model trace by convert the AI into reflectivity then convolute it with the estimated wavelet.
3. Get the trace error by subtracting the seismic synthetic trace from real seismic trace.
4. Decrease the error-value by updating the AI model and its thickness iteratively using the GLI (Generalized Linear Inversion) inversion method.
5. Iterate it to find a good solution.

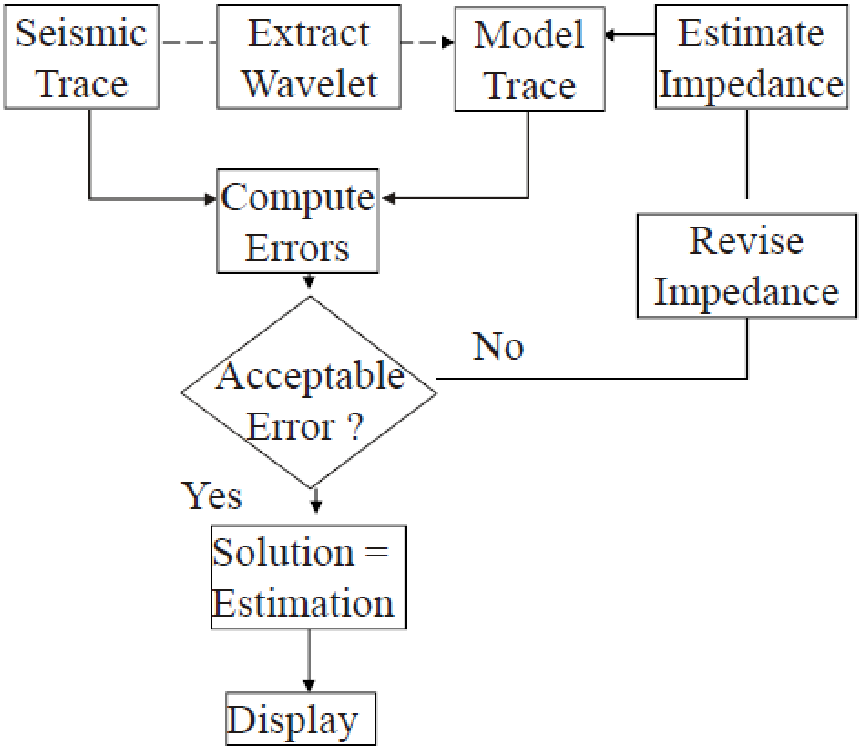


**Figure 2.8** The model based inversion flowchart (Sukmono, 2018)

### II.2.4 Spectral Decomposition

The subsurface state of the earth is recorded in the form of seismic data, where the seismic data has a natural characteristic that is not stationary which means it has various frequency contents in the time domain. The seismic attribute which aims to characterize the frequency response that is dependent on the time of the rock and subsurface reservoir is spectral decomposition (Putra, 2017).

Spectral decomposition using Fourier transforms to Perform amplitude spectrum calculations for each trace from a short time window covering all target zones. Analysis of non-stationary signals such as seismic signals using software based on Fourier transforms, often does not provide real subsurface information (Putra, 2017).

The reflection signal shows the boundary plane between the two media. The thick medium is represented by the frequency of the low seismic signal, while the thin medium is represented by the high signal frequency. The selection of reflection signals at the right frequency and the reintegration of selected signals will produce a seismic signal that is noise-free and still contains reflection information. The mechanism of signal decomposition at reflection frequencies and recombination of decomposed signals is called multi-resolution analysis. To get a good decomposition results and not shift phases, the right tools are needed. Frequency characteristics are obtained from the condition of rock thickness and layer density and the speed of the signal traversed by seismic waves. The layer is derived from a number of rock layers with different frequency characteristics. To obtain the frequency from each layer, the thickness is included in the frequency range until the desired maximum frequency is obtained (Putra, 2017).

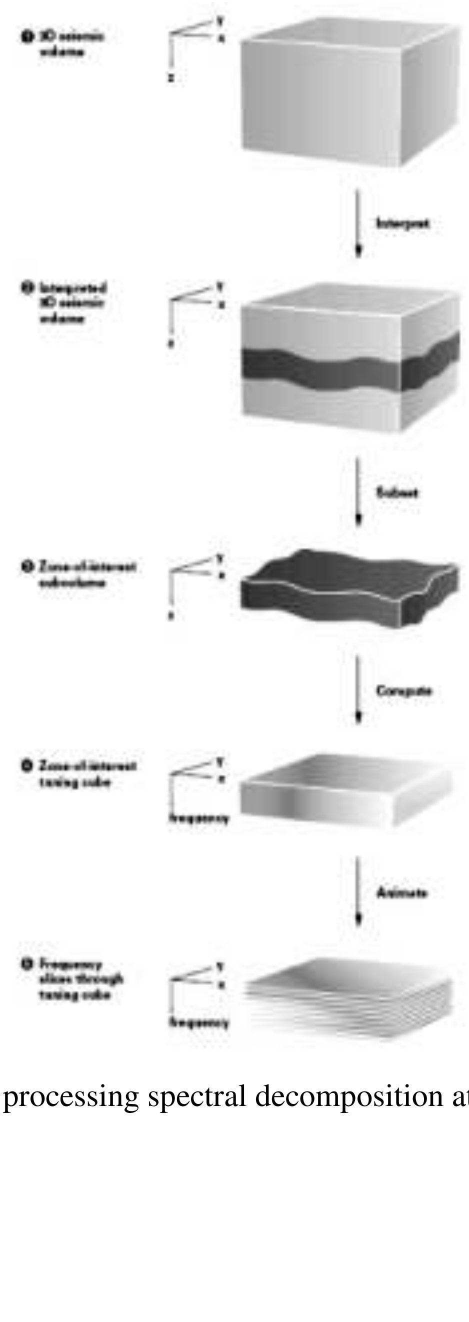

**Figure 2.9** Process in processing spectral decomposition attributes. (Putra, 2017)

The sequence of processing the spectral decomposition attribute can be seen in Figure 2.9, it appears that to characterize frequencies using the spectral decomposition attribute, the initial step taken is a seismic interpretation by picking horizons from 3D seismic data and determining the window to produce a volume portion of the target zone. Reflective seismic waves in the zone will be processed into frequency characteristics at each layer depth. This effect is called cube tuning, with the z-axis of the seismic data changing to a frequency scale. From the tuning cube process, the appropriate frequency can be chosen to see the desired geological display. Each frequency selected will display an animated spectral decomposition model that describes the geological conditions in the target zone layer (Putra, 2017).

#### II.2.4.1 Continuous Wavelet Transform (CWT)

Spectral decomposition has several algorithm methods including CWT (Continuous Wavelet Transform). The time-frequency decomposition method, also known as spectral decomposition, is intended to characterize seismic responses at certain frequencies (Putra, 2010). In converting seismic data into the frequency domain using CWT, wavelet analysis is a fairly new method to overcome the problems found in the previous conventional method, namely the STFT method (Haryono, 2012).

The CWT method has good time resolution at high frequencies as well as at low frequencies. The CWT method uses dilation and translation to produce a time scale map (scalogram). CWT is defined as:

$$Fw(\sigma,\tau) = \big(f(t),\psi(t)\big) = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{\sigma}}\psi * \left(\frac{t-\tau}{\sigma}\right)dt \qquad (2.5)$$

as seen in the equation above consists of σ is a scale parameter, τ is a translation parameter, and ψ conjugation is a mother wavelet (Haryono, 2012).

The advantages of the CWT method that do not require window length determination also have good time resolution at high frequencies and low frequencies can be used for time-frequency analysis for non-stationary signals such as seismic signals (Haryono, 2012).

### II.2.4.2 Low-Frequency Shadow Zone Effect

Seismic low-frequency amplitude information plays an important role in reservoir characterization and hydrocarbon detection. One of the methods to easily detect gas anomaly on seismic cross-section are by lookout for low-frequency anomaly. Low-frequency amplitude anomalies are believed by many researchers as a direct indicator of gas-bearing reservoir due to the absorption of energy by gas in the reservoir. The absorption phenomenon in gas has led to significant and wider geologic connotations in exploration applications. Techniques are developed based on energy attenuation studies for direct detection of hydrocarbons by studying amplitude spectra for the decay of higher frequencies (Figure 2.11).

Since the inception of bright spot technology in the 1960s, low-frequency shadows beneath amplitude anomalies have been used as a substantiating hydrocarbon indicator. These shadows are often attributed by explorationists to abnormally high attenuation in gas-filled reservoirs (Castagna et al., 2003).

On Figure 2.10, it shows different respond by various frequency horizon slice divided by low, mid to high frequency. On 6 Hz, the dotted line shows a bright area, but on 14 Hz it is decreasing and on 21 Hz it is gone completely. This indicates that there is a gas anomaly on the area.

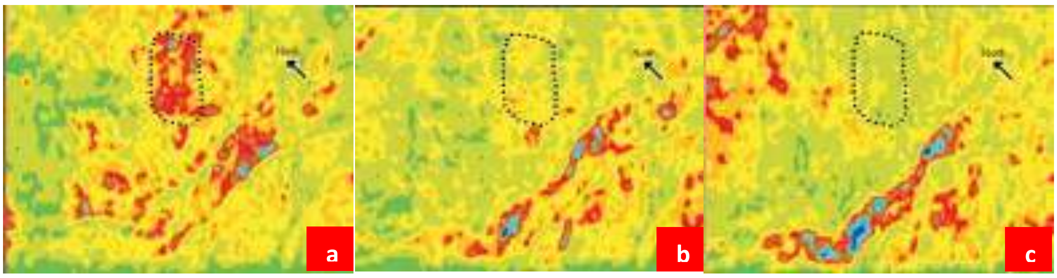


**Figure 2.10** (a) 6 Hz frequency horizon slice, (b) 14 Hz frequency horizon slice and (c) 21 Hz frequency horizon slice from the Gulf of Mexico (Castagna et al., 2003)

# CHAPTER III

# METHODS

## III.1 Time and Location on doing the Project

This project was conducted on May 21 - July 19, 2019 at PT. Pertamina EP - Asset 5, Balikpapan Residence Jl. Marsma R. Iswahyudi, Ex. Peaceful Bliss, Kec. South Balikpapan, Balikpapan, East Kalimantan - 71115.

While the location of this project is in the Penobscot Field, Scotian Basin in the northern Atlantic Ocean region, southeast of the Province of Nova Scotia, Canada

## III.2 Data and Equipments

### III.2.1 Data

The data used are an open-source Penobscot seismic and well data that can be accessed at the link [https://terranubis.com/datainfo/Penobscot](https://terranubis.com/datainfo/Penobscot).

### III.2.2 Equipments

The equipment used in this project is a laptop that has been equipped with the CGG Hampson Russell Suite v10.0.2, Petrel 2009 and OpendTect 6.4.0.

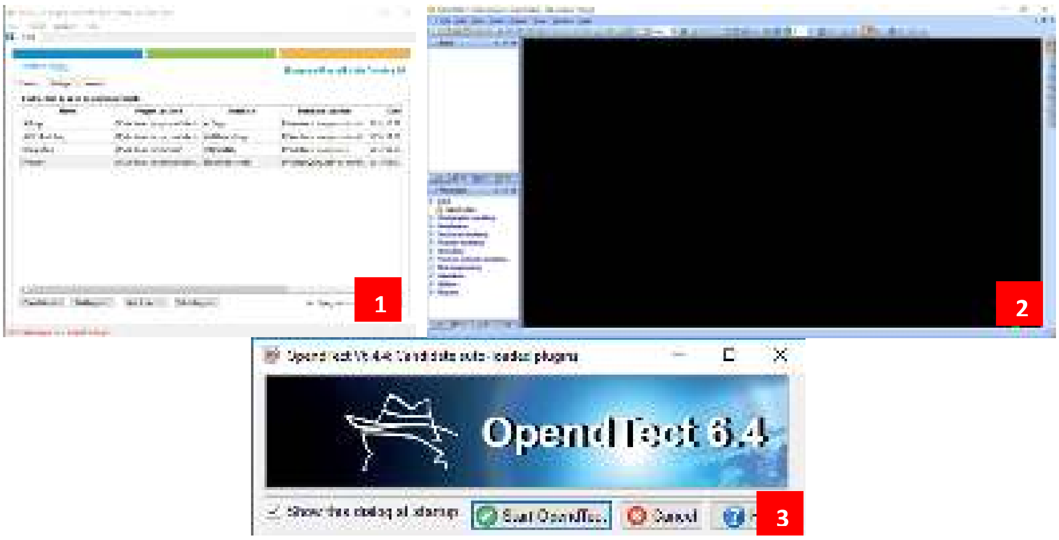


**Figure 3.1** Initial preview of the software 1) CGG Hampson Russell Suite v10.0.2, 2) Petrel 2009 and 3) OpendTect 6.4.0

### III.3 Data Preparation and Processing

#### III.3.1 Data Preparation

In this study, seismic, well, and check-shot data are used. The following is an explanation of each data used.

##### III.3.1.1 Seismik 3D Data

Seismic data used are 3D post-stack time migration (PSTM) seismic data with an inline number of 441 inline from inline 1080-1520 and x-line totaling is 461 x-line counted from x-line 1020 - 1480 with normal polarity standard SEG in Penobscot, Nova Scotia, Canada.

##### III.3.1.2 Well Data

In this project, 2 wells were used with density logs and sonic was used in the process of well seismic tie. Then gamma-ray data and resistivity data for determining well marker correlation.

##### III.3.1.3 Check-shot Data

The use of check-shot data is to get the relationship between time and depth, which is then used to bind well data to seismic data. Check-shot data are available on both wells used for the well to seismic tie process.

#### III.3.2 Processing Data

##### III.3.2.1 Import Well Data, Check-shot, Marker and Seismik Data

The first step to take is to enter well data, check-shot, markers and seismic data in the CGG Hampson Russell Suite software v10.0.2. After all the data have been entered, don't forget to do Quality Control (QC) on the data by changing and improving parameters that maybe will affect the seismic attributes analysis.

### III.3.2.2 Well Seismic Tie

Well seismic tie is done to integrate the well data that is in depth with seismic data that in time, so that marker data can be combined from wells to determine horizon in seismic data (Ginting, 2019). The initial step is to determine the wavelet that can represent the relationship between seismic and well data, then input the check-shot data, and lastly, the stretch-squeeze process is performed (Niatunai, 2019).

The stretch-squeeze process is carried out to match the seismic trace with a synthetic trace. But before that, the depth range of the geological marker must known beforehand, so the errors in the well seismic tie process can be avoided. Stretch-squeeze has a shift tolerance limit of around 10 ms. The shift limit needs to be considered because if it exceeds 10 ms it will cause the well data to experience shifting. This will affect when determining the phase value of the well data, where the phase value will experience a shift from the actual phase value.

### III.3.2.3 Sensitivity Analysis

Sensitivity analysis is an analysis carried out to identify rock lithology and the location of reservoirs based on well data. This analysis is done by cross-plotting 2 log data which are placed on the x and y axes.

### III.3.2.4 Horizon and Fault Picking

Horizons and faults picking are used to analyze the structural and stratigraphic of the field. The horizon and fault picking process in this study used Petrel 2009. Horizon picking is done by making a horizon line on the continuity of the layer on the seismic section.

A good well seismic tie is needed to tie the seismic horizon with well data so that the seismic horizon can be placed at the actual depth. Therefore the well seismic tie process is very important and influential in determining which horizon that will be pick to determine the reservoir (Ariansyah, 2020).

### III.3.2.5 Initial Model

After the horizon and fault are determined, the next process is the AI inversion process. This process begins by creating an earth model based on well and horizon data information. In making the earth model, wavelets and P-wave sonic data are needed. The sonic data used is data that has the optimum correlation with seismic data, while the wavelet used is wavelet generated from synthetics.

### III.3.2.6 Pre-inversion Analysis and AI Inversion

Before conducting an AI inversion, what must be done beforehand is a pre-inversion analysis. This analysis is done to minimize the inversion results that are not good. The parameters are entered until the correlation value obtained is high and the error value is low. After the correlation and error values obtained are believed to be the maximum values, AI analysis is then performed.

### III.3.2.7 Spectrum Analysis and Spectrum Amplitude

Spectrogram analysis is the initial analysis performed in the spectral decomposition process. This analysis is carried out to find out the frequency content of each unit of time in 1 seismic trace. From the results of this spectrogram analysis, the frequency anomaly can be seen in the seismic trace at a time. After that, spectrum amplitude analysis is performed to select low, high and medium frequencies to see the low-frequency anomaly effect.

### III.3.3 Workflow

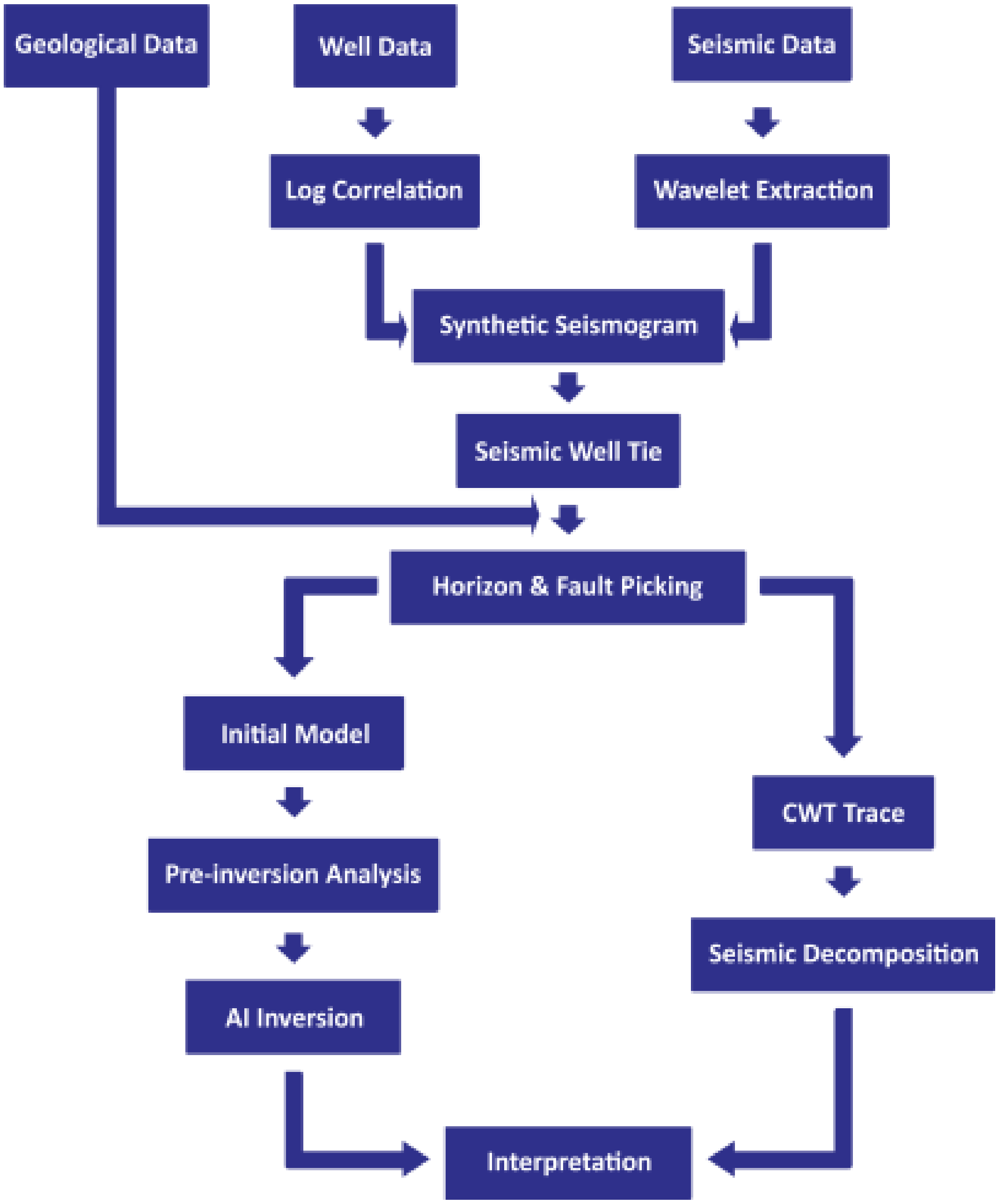


**Figure 3.2** Project workflow