ENHANCING GEOLOGICAL INTERPRETATION WITH SEISMIC ATTRIBUTES, GULF OF THAILAND.

Mr. SANHASUK KOSON

GEOLOGY

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SANHASUK KOSON

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Title: Enhancing Geological Interpretation with Seismic Attributes in Gulf of Thailand

Researcher: Sanhasuk Koson

Advisor: Assoc. Prof. Montri Choowong

Co Advisor: Piyaphong Chenrai

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Abstract

This work has generated the seismic attributes from horizontal time slice at 0.4 second from the Kra Basin of the western graben domain in the Gulf of Thailand. The seismic attributes can be separated into two major groups based on their response form the study area. The first group is good at lithology contrast detection providing, channel boundaries, channel belts, point bars, meander scars, and oxbow lakes. The, attributes in this group include envelope, RMS amplitude, sweetness, chaos, and spectral decomposition. The second group is good at geological structure detection providing, faults, fractures, folds, and bedded slope. This group comprises structural dip, variance, and ant-tracking attribute. Multi seismic attributes analysis using ant tracking with variance and chaos attribute can extract us more useful information to interpret geomorphology and delineating faults, especially chaos attribute with aggressive-aggressive parameter of ant-tracking attribute. Geomorphology interpretation suggests that the main features of this study area are channels that their sizes are varied. The major channels (width: approximately 0.5-1.3 km) are less sinuosity than minor channels (width: approximately 0.1-0.35 km), most of their direction is northeast-southwest, side-attached point bars are dominant features either displayed as high amplitude spots, and some of them show lateral accretions, meander scars and oxbow lake are in this area too, so we can suggest that paleo-environment should be the fluvio-delta environment. Moreover, the result maps from this study show higher resolution such as high-amplitude anomalies or bright spots, probably due to gas accumulation in shallow depth that cannot be observed from previous work

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ผู้ทำการศึกษา: นายสัณหสุข โกศล

อาจารย์ที่ปรึกษา: รศ.ดร.มนตรี ชูวงษ์

ที่ปรึกษาร่วม: อาจารย์ปิยพงษ์ เชนร้าย

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บทคัดย่อ

ข้อมูลที่นำมาศึกษาอยู่ในบริเวณแอ่งตะกอนกระ ตั้งอยู่บริเวณฝั่งตะวันตกของอ่าวไทย โดยทำการศึกษาข้อมูลในแนวระนาบเวลาที่ 0.4 วินาที เมื่อทำการปรับปรุงข้อมูลด้วยวิธีต่างๆ พบว่าการปรับปรุงข้อมูลดังกล่าวสามารถแบ่งออกเป็นสองกลุ่ม กลุ่มแรกเหมาะสมกับการตรวจสอบความแตกต่างของลักษณะทางธรณีวิทยา เช่น ตะกอนทรายที่สะสมตัวในแม่น้ำและตะกอนดินเหนียวในที่ราบลุ่มน้ำท่วมถึง เป็นต้น ลักษณะธรณีสัณฐานที่เด่นชัดได้แก่ ขนาดและขอบเขตของทางน้ำ สันทราย ร่องรอยทางน้ำโค้งตวัดหรือทะเลสาบรูปแอก การปรับปรุงข้อมูลในกลุ่มนี้ได้แก่ เอนเวอโลปแอมพลิจูดเฉลี่ยกำลังสอง สวีทเนสเคออส และสเปคตรัล ดีคอมโพสิชัน กลุ่มที่สอง ตรวจสอบลักษณะเชิงโครงสร้างอันเนื่องมาจากความไม่ต่อเนื่อง เช่น รอยแตก รอยเลื่อน ชั้นหินคดโค้ง หรือความลาดเอียงของชั้นหินได้ดี ได้แก่การปรับปรุงข้อมูลดิพโครงสร้าง วาเรียนซ์ และแอนท์แทรคกิ้งในส่วนของการทำการปรับปรุงข้อมูลโดยใช้แอนท์แทรคกิ้งร่วมกับการปรับปรุงชนิดอื่น พบว่าสามารถช่วยดึงรายละเอียดออกมาเพื่อแปลลักษณะธรณีสัณฐานและลักษณะไม่ต่อเนื่องต่างๆ เช่นแนวรอยแตก หรือรอยเลื่อนในพื้นที่ศึกษาได้ดี โดยเฉพาะอย่างยิ่งการใช้แอนท์แทรคกิ้งร่วมกับการปรับปรุงข้อมูลเคออส ด้วยตัวแปรแอกเกรสซีฟ-แอกเกรสซีฟเมื่อนำข้อมูลจากแต่ละวิธีมาประมวลผลร่วมกันก็จะได้ภาพของสภาพแวดล้อมที่ประกอบด้วยทางน้ำเป็นหลัก มีขนาดของทางน้ำหลากหลาย โดยทางน้ำใหญ่จะมีความคดโค้งน้อยกว่าขนาดเล็ก พบสันทรายสะสมตัวจำนวนมาก และมีรอยทางน้ำเก่า ทะเลสาบรูปแอกที่ช่วยให้เราแปลสภาพแวดล้อมในอดีตได้ว่าน่าจะอยู่ในช่วงของระบบธารน้ำไปจนถึงระบบสามเหลี่ยมปากแม่น้ำและนอกจากนั้นภาพผลลัพธ์ที่ได้ยังมีรายละเอียดสูง ใช้บอกข้อมูลที่มีประโยชน์ เช่น ก๊าซที่สะสมตัวในระดับตื้นได้ ซึ่งปรากฏไม่เด่นชัดในงานวิจัยที่ศึกษาก่อนหน้านี้

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To my family, thanks for always supporting and believing, many thanks for mom and dad, who were my motivators throughout this work. I also thank all geology society for helpfulness and moral cheer. Finally, I appreciate all support from others that I have not mentioned here too.

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Chapter 1

Introduction

1.1 General Statement

Nowadays, fossil fuel or petroleum has played an important role in our daily activities including source of energy and transportation. The fossil fuels are formed by natural processes such as anaerobic decomposition of buried dead organisms included coal, petroleum and natural gas. One of a powerful tool for exploration these fossil fuels is using seismic wave to estimate the properties of the earth's subsurface. Seismic survey is widely accepted that it is a preferential method for investigating subsurface geology, especially in oil and gas exploration by petroleum industrial companies around the world. The artificial seismic wave is generated and sent to Earth's surface. The reflected seismic wave is used to image change in the sub-surface geology by inducing waves from near surface of the Earth and receives for the reflected wave from deeper stratigraphic boundaries. Generally, the objective of seismic survey is to image structures and stratigraphy of the sedimentary basins. However, the interpretation of seismic data is not easy, particularly the conventional seismic data. Nowadays, new technologies and advance techniques in seismic interpretation allow us to increase the ability for understanding subsurface geology such as seismic attributes.

Seismic data interpretation is a primary method of viewing, mapping subsurface geologic features, and making interpretation of structure and stratigraphy possible away from well control. The fundamental seismic data type is amplitude data, but seismic attributes can reveal characteristics which are not easily seen in amplitude data themselves. The seismic attribute technique should allow us to increase the ability of geological interpretation of a formation, particularly in the thin bed reservoir formation.

The seismic attributes typically provide information relating to the amplitude, shape, and position of seismic waveform. Since 1990s the seismic attributes have been developed into many types of them such as structural attributes and stratigraphic attributes (Chopra and Marfurt, 2005). For instance, the spectral decomposition method, one of recent seismic attributes for detecting channel complex area, calculates the amplitude of spectrum of a short time window covering the zone of interest (Nissen, 2007). So, the units with different rock properties or thicknesses will be shown different amplitude response. These seismic attributes have been provided many advantages, for example, to compute the information easier, to reduce rig stand by time from days to hours, to improve the success rate in an economic field, to avoid shallow hazard, etc. From past to present the accuracy of seismic attributes is increasing significantly (Li et al., 2013).

Also, recent development of three-dimensional (3-D) seismic datasets enables geologists to visualize and analyze buried-land and sea-scapes revealed by subsurface geophysical data in a manner resembling surface geomorphology. Seismic geomorphology is useful to interpret seismic patterns for geomorphology of a formation, which is similar to using satellite and aerial photos of the Earth's surface.

1.2 Geological Background

The Gulf of Thailand is composed of a series of north-south oriented basins, which separate N-S fault bounded sedimentary basins. These basins are separated by KoKra Ridge into the western graben area and the main basinal area (Polachan and Sattayarak, 1989). The western graben area consists of small basin such as Chumphon, Nakhon and Songkhla basins, while the main basinal area comprises only Pattani and Malay basins. The Kra basin lies west of the Ko Kra ridge.

The strike-slip model of rift basin as pull-apart basin for the Gulf of Thailand is influenced since Polachan, 1989 (Figure 1.1). This strike-slip motion is related to Himalayan escape tectonics (Tapponier et al., 1986). Contrary to this, Morley (2002) reported that most of the strike slip motion along major faults of Thailand was ceased at about 30 Ma, prior to the formation of the most rift basins of Thailand and he proposed an alternate explanation for the opening of the rift basins is the subduction roll back of the Indian plate west of Thailand. In Eocene there is regional thinning of the crust causing the development of widespread extensional basin across this region. As multi-phase of stress involved in this region, inversion character may appear in Tertiary basins particularly during the Late Oligocene and Miocene.

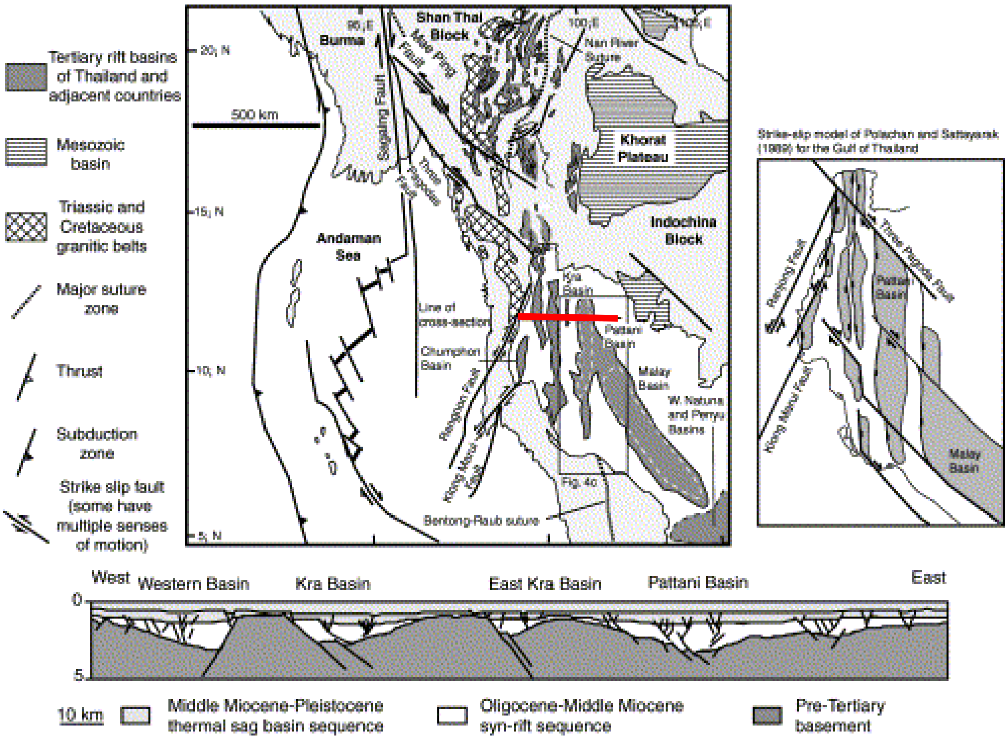

Figure 1.1 Structures of ramp-flat model for the Gulf of Thailand, the cross-section line is shown on the regional map as a red line (Watcharanantakul and Morley, 2000).

The stratigraphic framework of the Pattani basin was published by Jardine (1997). He divided sedimentary sequences of the Pattani basin into five major sequences (Table 1.1). The oldest sediments deposited after initiation of rifting are of Oligocene age. There are two periods of regional non-deposition around 25 and 10 Ma interpreted as the Mid-Tertiary Unconformity (MTU) and the Mid-Miocene Unconformity (MMU), respectively.

The stratigraphic evolution described by Jardine (1997) is as follows:

- Sequence I is deposited from Late Eocene (?) to Oligocene which consists of lacustrine shale and alluvial deposits.

- Sequence II composed of mainly fluvial and alluvial sediments of Early Miocene.
- Sequence III indicates the presence of transgressive fluvial and marginal marine sediments of Middle Miocene.

- The top of sequence III gradually changes to fluvial red beds of the sequence IV, which are commonly referred as "Upper Red beds".

- Sequence V is represented by sands and shales deposited from the time of MMU to modern sea floor.

Depositional Sequence.	Generalized Lithology		Age (Ma.)	Geological age	Tectonics
5	Grey claystones, extensive coals and shales, point bars and channel sands	Delta plain, Marginal marine, Marine	5 10	Quaternary Pliocene Upper Miocene	Continued Subsidence EROSION Mid-Miocene Unconformity MMU
4	Red beds, Point bars and channel sands, few coals	Fluvial-Floodplain		Middle Miocene	
3	Grey shales and coals	Marginal Marine-Lagoonal	15		Extension/ Faulting Subsidence
2	Interbeded grey shales/red beds, fluvial point bar and channel sands, coal locally overpressured	Fluvial Floodplain-Delta plain	20 25	Lower Miocene	Mid-Tertiary Unconformity MTU
1	Lacustrine shales and alluvial fan complexes multiple unconformities	Lacustrine	30 35	Oligocene (?)	Erosion/ Extension Pre-Tertiary Unconformity PTU
	Pre-Tertiary complex, Cretaceous granites emplaced into Paleozoic and Mesozoic Sequence.			Pre-Tertiary	Pre-Rift

Figure 1.2 Stratigraphy and tectonic evolution of the Pattani Basin, Gulf of Thailand (modified after Jardine, 1997).

1.3 Objectives

The aims of this study are to compare the ability of different types of seismic attributes for geological interpretation and to image the geomorphology of the focused interval based on shallow seismic data from the Gulf of Thailand.

1.4 Study Area

The Kra basin is located in the western portion of the Gulf of Thailand trending north-south (Figure 1.2) and is relatively small, the study area covers approximately 1,300 square kilometers. The lithology consists of grey claystone, extensive coal, shale, and channel sand. Reijensteinet, al., (2011) and Mahareunthong(2012) suggest that depositional environments comprise fluvial-deltaic, and marginal marine-marine environment.

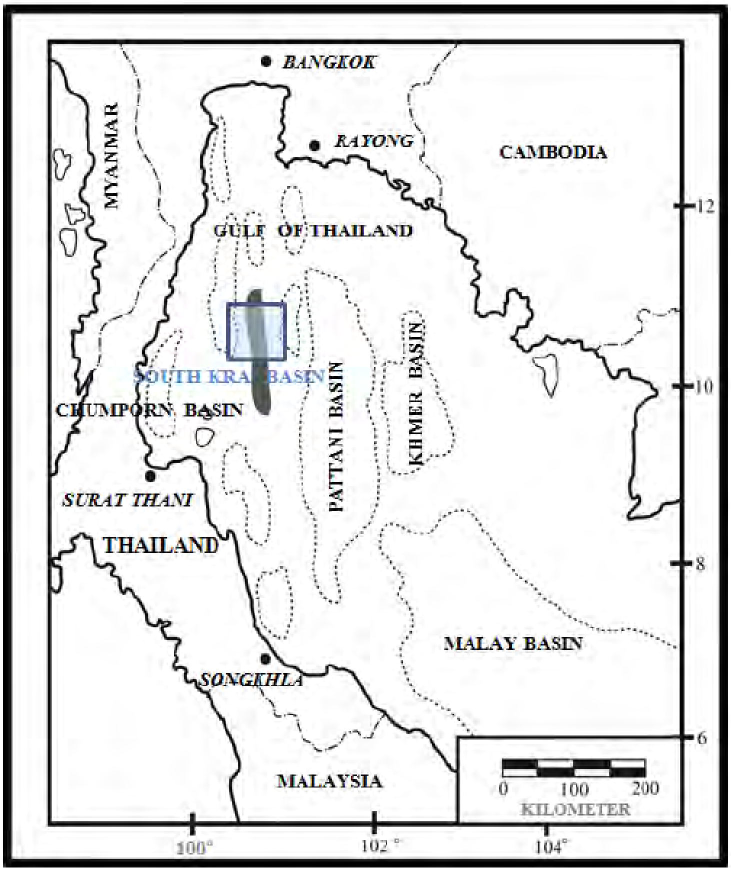

Figure 1.3 Location map of the study area within Kra basin at the western portion of the Gulf of Thailand trending north-south and location near Pattani basin. (Chenrai, 2012)

1.5 Hypothesis

Seismic attributes can be used to improve our ability to image and interpret complex patterns representing complicated geological features such as stratigraphic boundaries, small channels, and small scale faulting in the Gulf of Thailand**.**

1.6 Literature Review

PatinyaJaithan (2008) studied the geological structure and depositional environment from Trat field of Pattani Basin, Gulf of Thailand by using 3-D seismic data and wire-line logs data from 5 wells in the North Trat area.

SiriBronlund (2010) studied the reservoir modelling of fluvial system by combination of shallow 3D seismic data in the Gulf of Thailand and the data from outcrop analog studies in the Blackhawk Formation of Woodside canyon area, eastern Utah, USA.

HernanReijensteinet al, (2011) identified the principal depositional systems present in the continental shelf of the Gulf of Thailand and documented the seismic facies manifestation of estuarine and deltaic deposits.

John D. Pigottet al, (2012) indicated first order seismic attributes which best describe the variety of clastic seismic facies, East China Sea.

WorawatMaharernthong (2012) documented the distribution and internal architecture of the paleo-environment and its evolution using shallow 3D seismic data from Kra Basin, Gulf of Thailand.

Chapter 2

Methodology and Data Source

2.1 Methodology

Methodology of this study isfollowing by these steps (Figure 2.1) and the important details are described below.

1. Literature reviews including geological framework, seismic interpretation and seismic attributes concerning principles and methods of seismic geomorphology and attributes such as ant tracking, spectral decomposition, etc.
2. Generating seismic attribute volumes and determination of geological features from seismic attributes.
    - Generate the 400 ms time slice and horizon slice at the sequence boundary of about 400 ms. The attributes include envelope (Figure 2.2), RMS amplitude (Figure 2.3), structural dip (Figure 2.4), sweetness (Figure 2.5), variance (Figure 2.6), chaos (Figure 2.7) and ant attribute (Figure 2.10) by using Petrel software. The parameter and display choices were set to default for this study. Also, spectral decomposition attribute (Figure 2.8) is done by using Geoteric software. In order to supplement seismic interpretation and to understand the combination for attribute flowchart, ant attribute was conducted by using the different combination of seismic attribute volumes (Figure 3.13). In this case, variance and chaos attributes were used as a primary volume before generating ant attribute. To achieve this flowchart (Figure 3.14), the following steps were undertaken: (1) different attributes, variance and chaos, were first applied to original seismic amplitude volume; (2) ant attributes were then applied to both variance and chaos volumes by using parameter justification, aggressive and passive methods, to produce ant attribute volumes; (3) ant attribute were reapplied to those output volumes to create ant-ant attribute by both aggressive and passive methods; (5) the final output attribute volumes were used to determine the fractures and stratigraphy.
    - Determination the advantages and disadvantages of seismic attribute volumes including geomorphic features, faults, fractures of the study area.

3. Determination of paleo-environment
    - To understand the paleo-environment of the study area, seismic geomorphology interpretation was performed. The geological features from every seismic attribute volumes were combined to examine the channel pattern and variation of the channel geometry. The spectral decomposition volume was used to investigate varying channel thickness
4. Discussion and Conclusion

2.2 Data Source

The data used in this study were available 3D seismic. The study interval is 0.35 to 0.5 sec and this project study at time slice of 0.4 sec. The dimensions of 3D seismic data are 33 kilometer in width, 41 kilometer in length, and 1,353 kilometer square in area. The data acquired by Mubadala Petroleum Thailand, Ltd., with bin spacing of 12.5 x 12.5 meters and zero phase display.

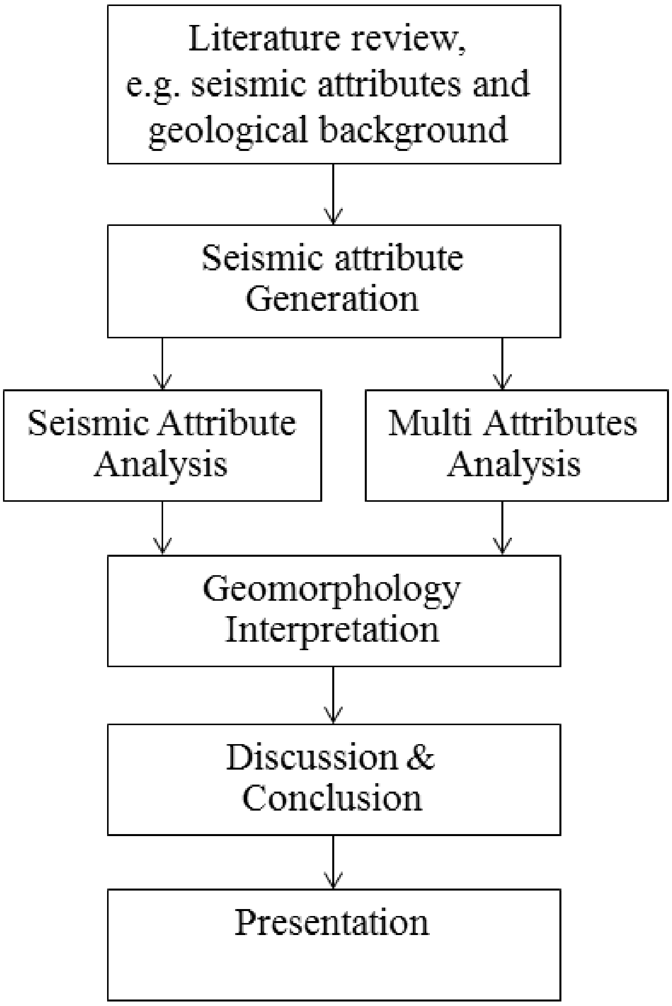

Figure 2.1 Workflow diagram of this study, using horizontal time slice, vertical section, and multi attributes analysis to interpret the paleo-environment.

2.3 General Background of Seismic Attributes

2.3.1 Envelope Attribute

Reflection strength, also known as trace envelope or instantaneous amplitude, is the most popular trace attribute. It is calculated from the complex trace of seismic signal used to highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient. The envelope is useful in highlighting discontinuities, changes in lithology, faults, deposition variation, tuning effect, and sequence boundary. Bright spots from this attribute are important as they can indicate gas, especially in relatively young clastic sediments (Figure 2.2). The advantage of using this attribute instead of the original seismic trace values is that it is independent of the phase or polarity of the seismic data, both of which affect the apparent brightness of a reflection.

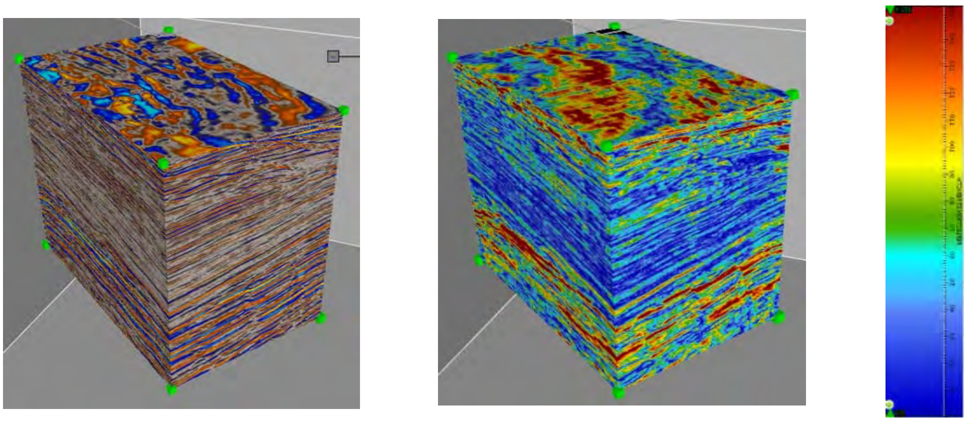

Figure 2.2 Examples of original volume (left) and resultant envelope attribute volume (center). In this example, the attribute values range from 0 (blue) to 152.4 (red), as shown on the color bar (http://esd.halliburton.com).

2.3.2 Root Mean Square (RMS) Amplitude

RMS amplitude provides a scaled estimate of the trace envelope. It is computed in a sliding tapered window of N samples as the square root of the sum of all the trace values x n squared where w n are the window values:

$$x_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} w_n x_n^2}$$

RMS amplitude resembles a smoother version of reflection strength. It is applied in the same way as reflection strength to reveal bright spots and amplitude anomalies in the seismic data (Figure 2.3). In contrast with reflection strength, you can set the resolution by changing the window length; longer windows produce a smoother amplitude estimate. This is sometimes useful. For example, a sequence of closely spaced bright events, perhaps a stack of gas-charged channels, can be imaged or extracted as a single unit by using low resolution RMS amplitude.

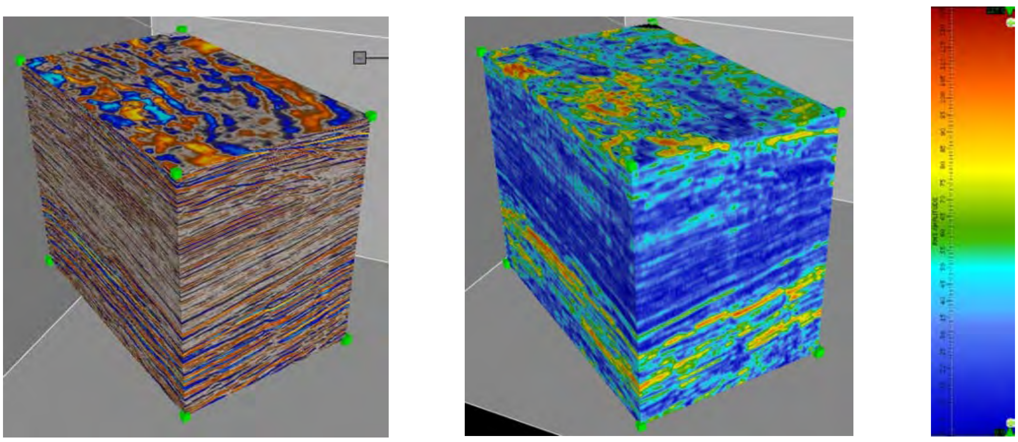

Figure 2.3 Examples of original volume (left) and resultant RMS amplitude attribute volume (center). In this example, the attribute values range from 0 (blue) to 127 (red), as shown in the default color bar (http://esd.halliburton.com).

2.3.3 Local Structural Dip

The structural dip or dip deviation attribute is an edge detection method which designates rapid changes in local dip, e.g. such as is indicative of reflectors proximal to faults or fractures, channel margins, etc (Figure 2.4).

The dip deviation attribute does indicate disruptions in reflectors but in this case only roughly indicates the position of the channels owing to the depositional variability indicated by the shallow reflectors (Pigott et al., 2013).

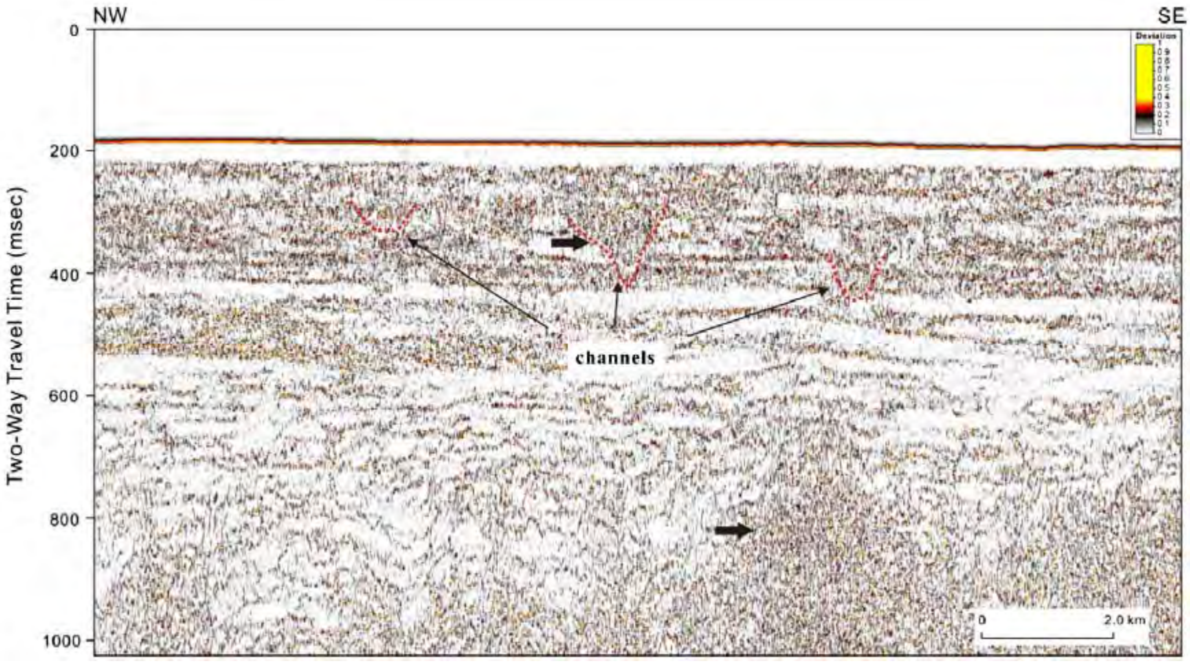

Figure 2.4 Structural dip attribute shows interpreted channels from seismic cross section. The black arrows highlight the reflector discontinuity (Pigott et al., 2013).

2.3.4 Sweetness

Sweetness s(t) is defined as the trace envelope a(t) divided by the square root of the average frequency f a(t)

$$s(t) = \frac{a(t)}{\sqrt{f_a(t)}}$$

Sweetness is an attribute designed to identify "sweet spots," places that are oil and gas prone. The definition of sweetness is motivated by the observation that, in young clastic sedimentary basins, sweet spots imaged on seismic data tend to have high amplitudes and low frequencies. High sweetness values are those that most likely indicate oil and gas (Oliveros and Radovish, 1998).

Sweetness tends to be driven more by amplitude than by frequency and often closely resembles reflection strength (Figure 2.5). Sweetness anomalies of interest are, therefore, corresponded to reflection strength anomalies (Das et al., 2013). Hart (2008) suggests that sweetness is particularly useful for channel detection.

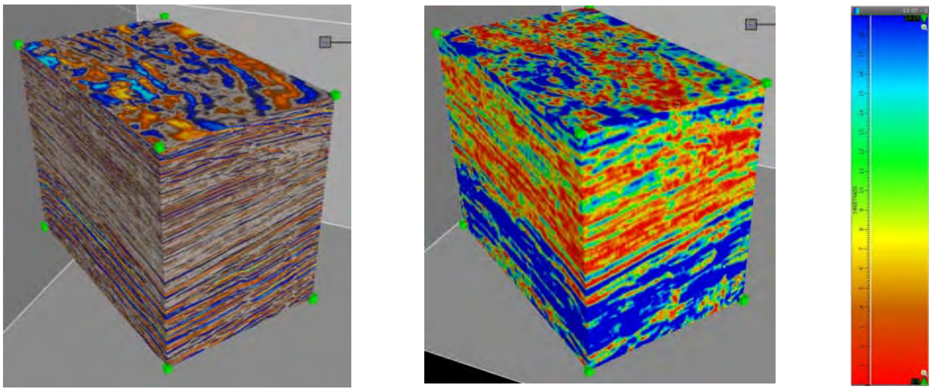

Figure 2.5 Examples of original volume (left) and resultant sweetness attribute volume (center). In this example, the attribute values range from 0 (red) to 19.05 as blue color (http://esd.halliburton.com).

2.3.5 Variance Attribute

Variance is an edge method which measures differences from a mean value and, while producing similar results to coherence attribute. Variance attribute is good to display channels and faults (Pigott et al., 2013).

This variance is also used to display directly the major fault zones, fractures, unconformities and the major sequence boundaries (Figure 2.6). The darkest regions which make vertical strips might suggest fracture zones.

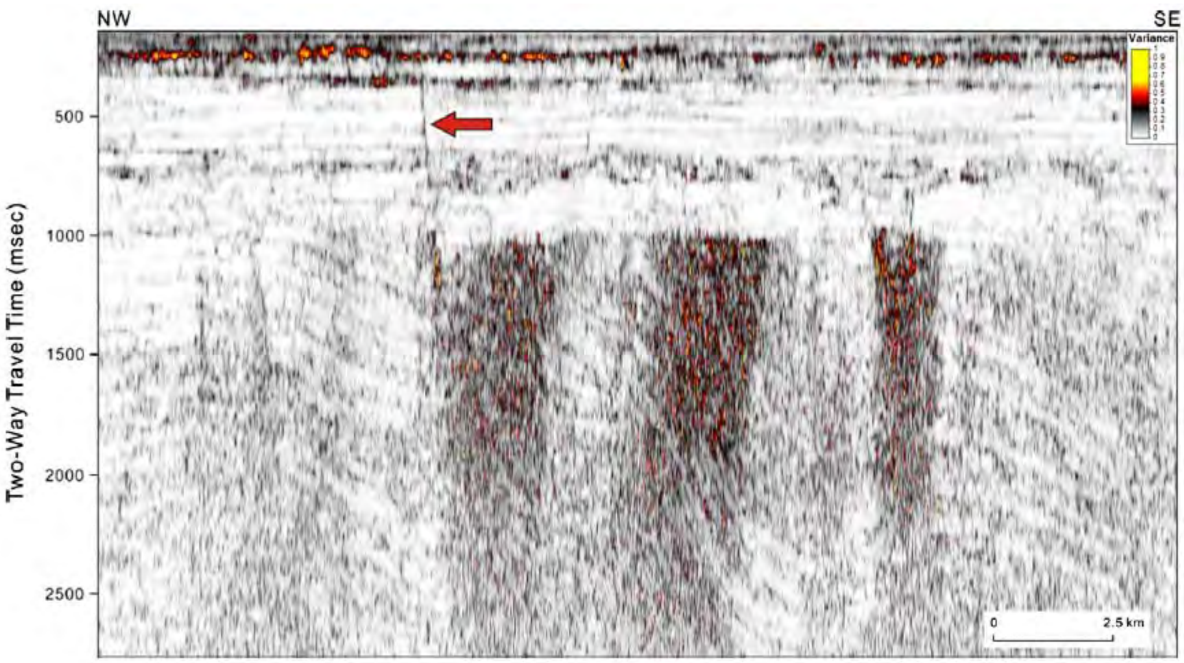

Figure 2.6 Example of the variance attribute showing fault highlighted by red arrow. The darkest regions which make vertical strips might suggest fracture zones (Pigott et al., 2013).

2.3.6 Chaos Attribute

The chaos attribute or chaotic attribute illustrates differences in dip and azimuth, termed chaoticness, which can highlight directly positions of reflector disruption. Zones of maximum chaoticness indicate zones of reflector discontinuities such as fault zones, angular unconformities, channel sand bodies and possible zones of fractures. From figure 2.7 the uncolored values indicate minimum chaoticness and correspond to inferred bed continuity (Pigott et al., 2013).

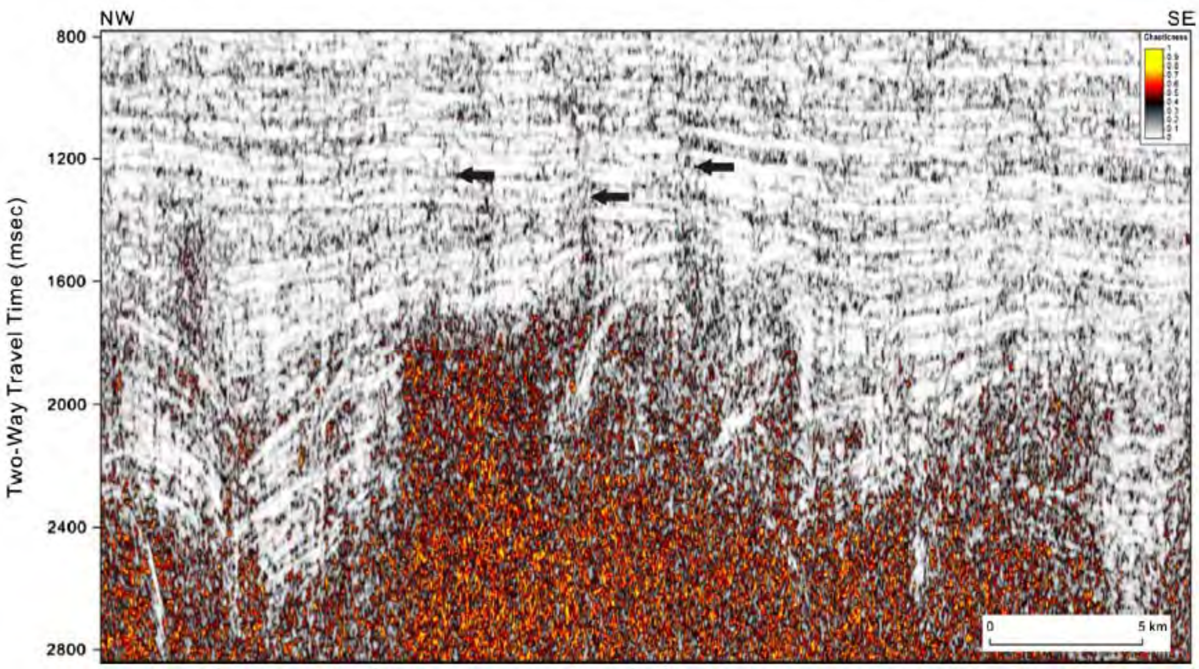

Figure 2.7 Chaos attribute displays the fault zone and the black arrows point to some of these faults which well-revealed (Pigott et al., 2013).

2.3.7 Spectral Decomposition

Spectral decomposition attributes enables you to illuminate more the information with different frequency bands. This attribute gives you several such volumes for combining the volumes in order to display in color blend method (Figure 2.8). At a specific frequency band certain size structures are more visible due to tuning effects, etc. This means that for example instead of looking at one phase volume for a cube of stacked data, you are able to view several of them and see if any single one shows a structure or geomorphological information better (Subrahmanyam, 2008).

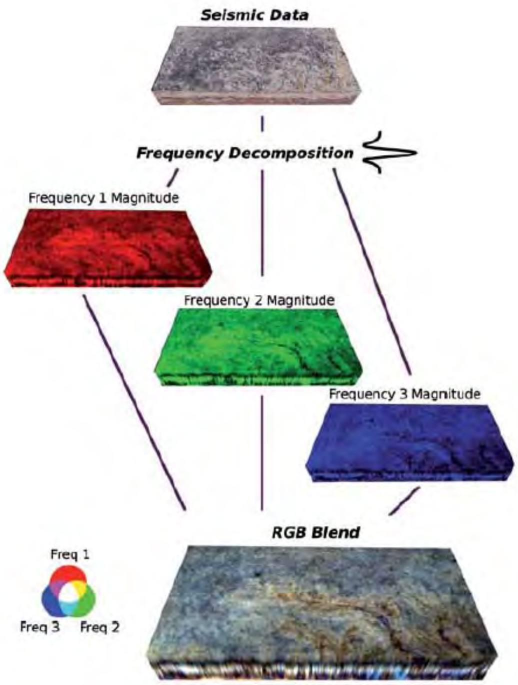

Figure 2.8 Concept of spectral decomposition(McArdleandAckers, 2012)

Spectral decomposition or frequency decomposition is attribute which sensitive to subtle interference patterns, such as thin-bed tuning effect associated with channels show in a seismic horizon section (Chopra and Marfurt, 2010). Since the data were previously spectrally whitened during the seismic processing stage, the spectral components exhibit the effects of the geology with different channel thicknesses and infill exhibiting different spectral responses(Del Moro, 2012). In general, thinner beds will be better displayed with higher frequency components, and thicker beds with lower frequency (Figure 2.9).

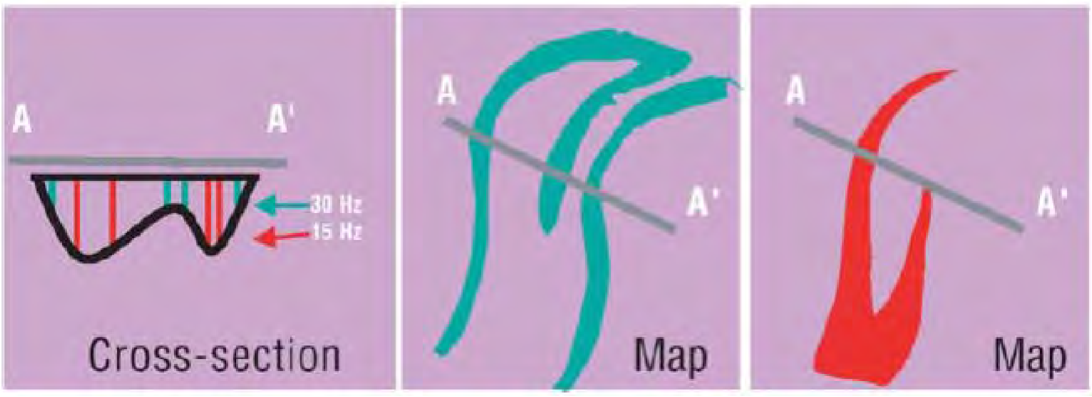

Figure 2.9 The effect of thin bed tuning in different frequencies (Laughlin et al., 2002).

2.3.8Ant Tracking

Ant Tracking is one of useful attribute in detecting discontinuity in the seismic data such as faults, joints, fractures by using agents which have the same behavior as insect "ant" moving around the surface and tracking the detail (Figure 2.12). A key advantage of the technique is that it provides a means of rapidly obtaining detailed, automatic unbiased fault and fracture interpretation from 3D seismic amplitude data compared to the standard interpretation (Miller et al, 2012). Ant tracking workflow includes 3 key steps(Figure 2.10) as well as workflow of this multi attributes study (figure 2.11).

- **Preconditioning** enhances spatial discontinuity associated with fractures, faults and to get rid of coherent and random noise in the seismic data.

- **Attribute Computation -** generate usable attribute detecting the discontinuity in the seismic amplitude data such as Variance and Chaos.

- **Ant Track -** optimizes the seismic discontinuity attribute responses relating to fractures and faults and clears the others that not fitting the criteria**.**

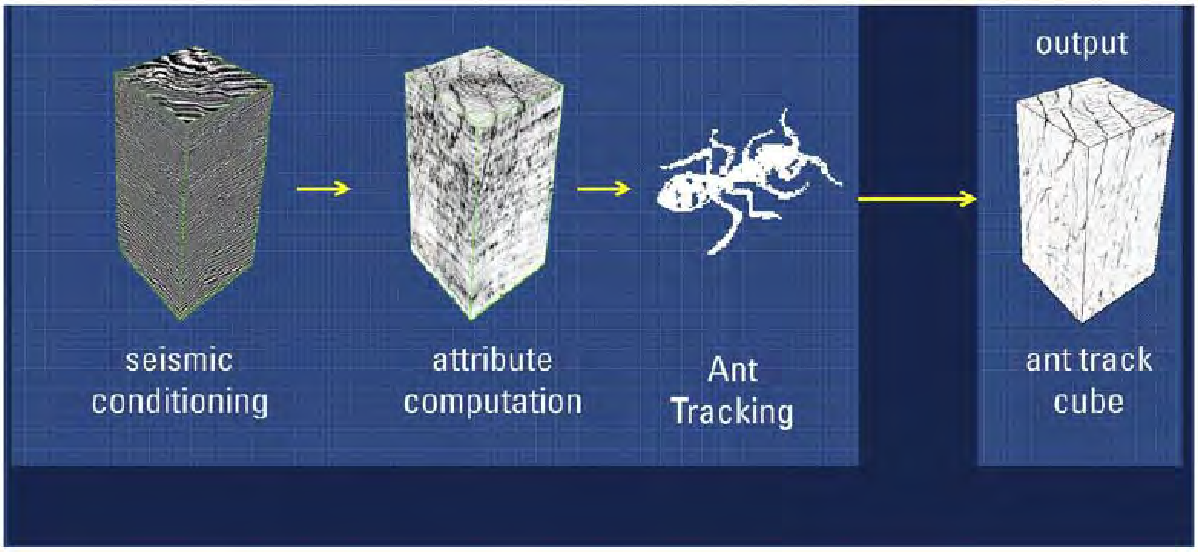

Figure 2.10 Workflow of ant-tracking attribute (Miller et al, 2012).

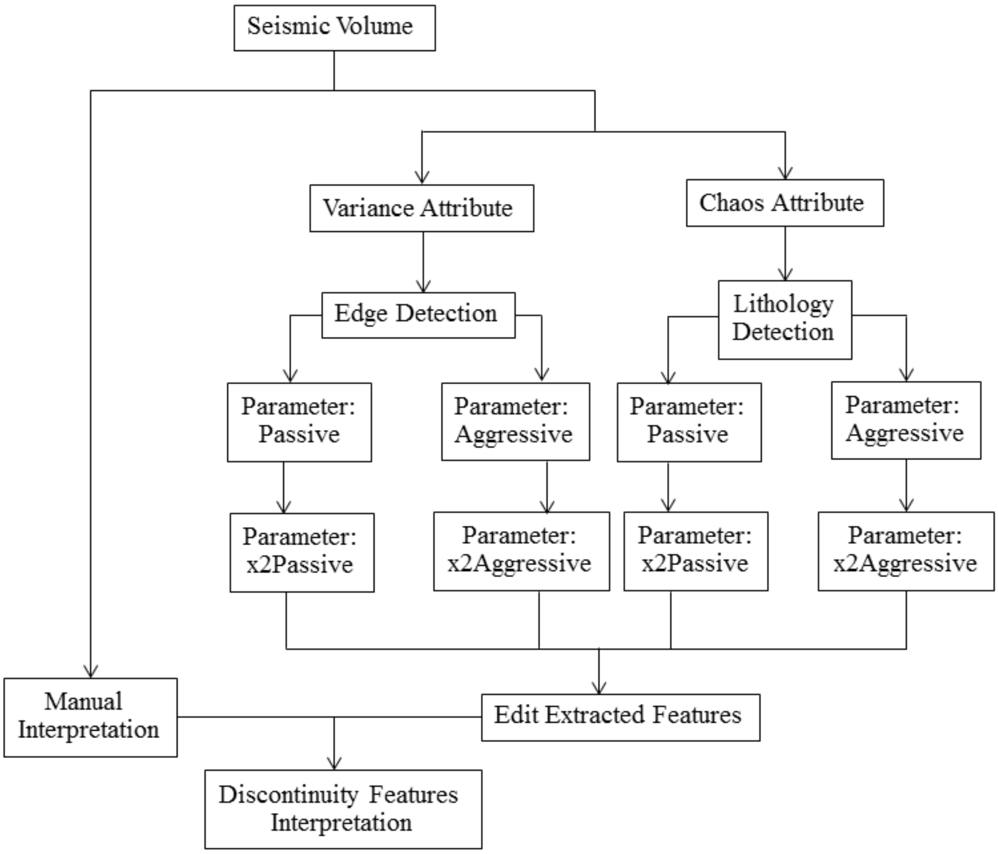

Figure 2.11 Diagram of ant tracking flowcharts with variance and chaos attribute.

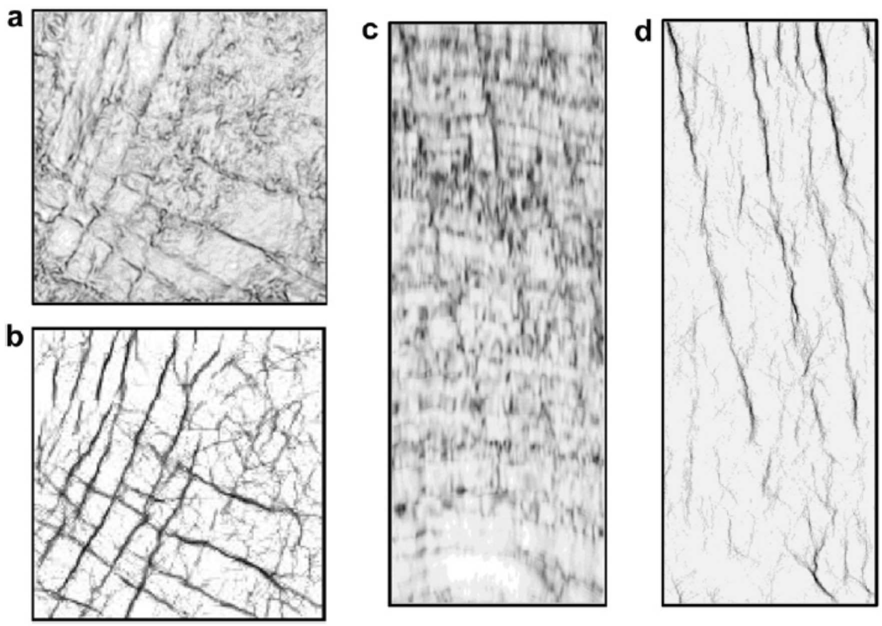

Figure 2.12 Comparisons of input seismic discontinuity attribute with resultant Ant Track attribute. (a) Time slice of fault attribute with (b) corresponding ant-track results, and (c) Inline section of fault attribute with (d) corresponding ant-track results (Miller et al, 2012).

Chapter 3

Results

3.1 Attribute Analysis

Seismic attributes represent mathematical manipulations of seismic trace performed to highlight stratigraphic and structural features within the seismic data. In this study, seismic attributes are used to investigate geomorphic features and faults and to image Pleistocene channel networks in the shallow depth. The attributes in this study are envelope, RMS amplitude, sweetness, structural dip, variance, chaos and spectral decomposition. The detailed observations of the seismic attributes are described in this chapter.

- **Envelope Attribute**

Envelope attribute or reflection strength displays acoustically strong (bright) events on both negative and positive events. In this study area, high amplitude spots can be seen in the seismic data and they stand out in envelope hot colors in Figure 3.1. These spots probably are channel bodies or sand layers due to the geological background of the study area (fluvial-delta) giving acoustic impedance contrast between sand and shale. The very high amplitude spots are possibly a gas-saturated sand body due to very high acoustic impedance contrast compared to surrounding sediments. Faults in this envelope attribute are characterized by lateral discontinuous features as shown in black lines in Figure 3.1. However, it is difficult to observe within this attribute.

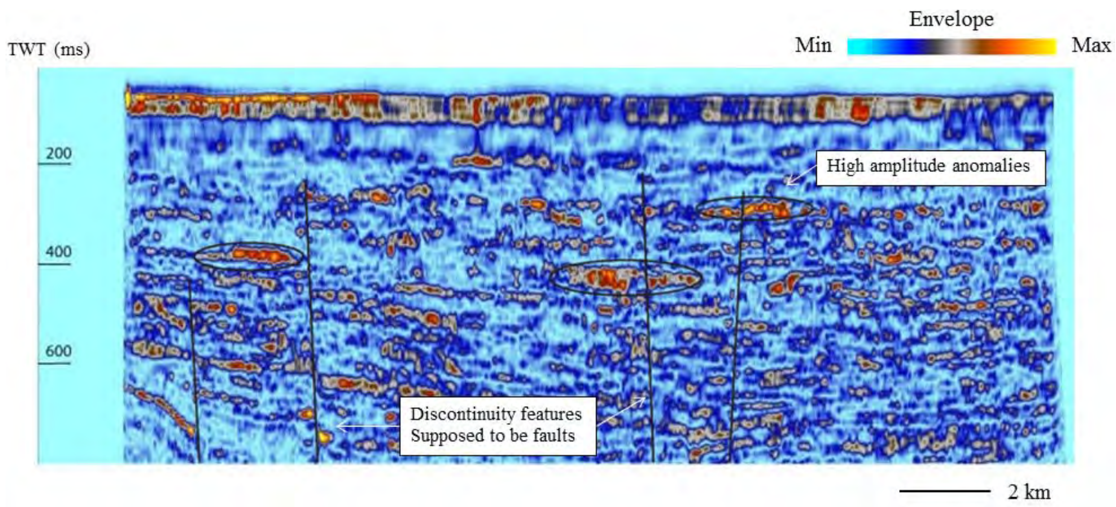

Figure 3.1 Vertical seismic profile of inline 3800 (see location in figure 3.2) from envelope attribute volume showing high amplitude anomalies and faults.

Envelope map at 400 ms shows geomorphic features in plan view (Figure 3.2). This map suggests that some channel elements such as channel edge and point bar are easily seen from this attribute compared to conventional amplitude volume. However, faults are difficult to see on this map.

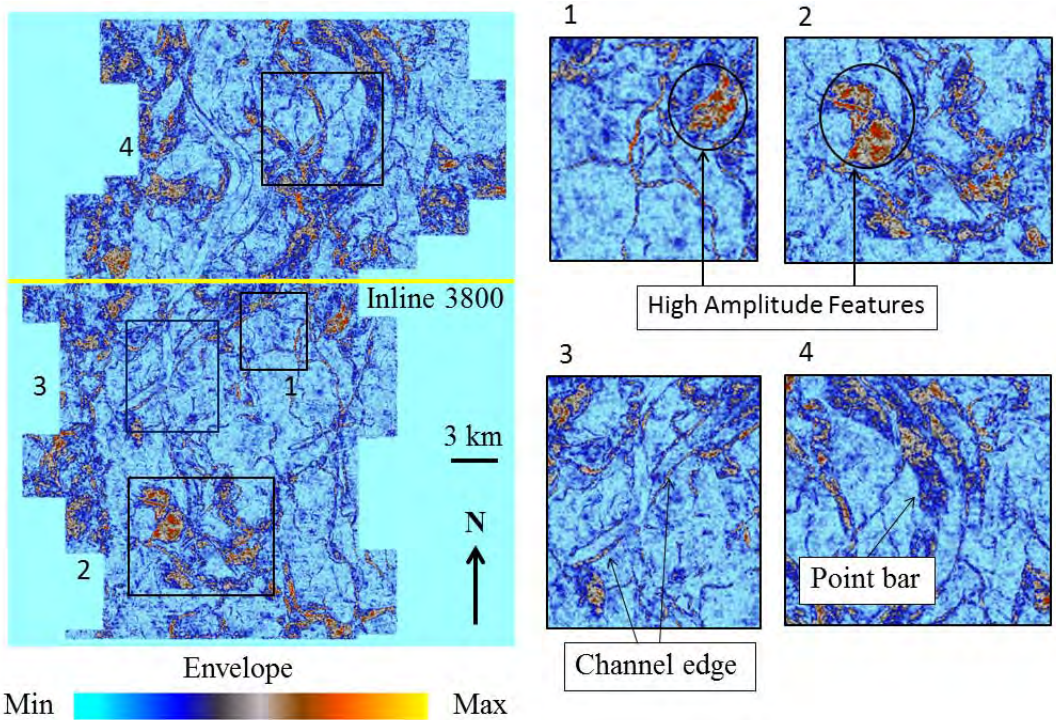

Figure 3.2 Seismic horizontal time slice at 400 ms from envelope attribute volume showing observed features in plan view; high amplitude (1 and 2), channel edge (3) and point bars (4).

- **RMS Attribute**

This attribute is useful to highlight coarser-grained facies, compaction related effects (e.g. in marl and limestone) and unconformities. In this study, this attribute are very good for detecting high amplitude anomalies caused by the lithology between channels (sand) and nearby floodplain (shale) as bright-spot anomalies (Figure 3.3). However, it is not necessary that all observed bright spots must be channel bodies, some of them probably be the unconformity between two rocks with high contrast of acoustic impedance.

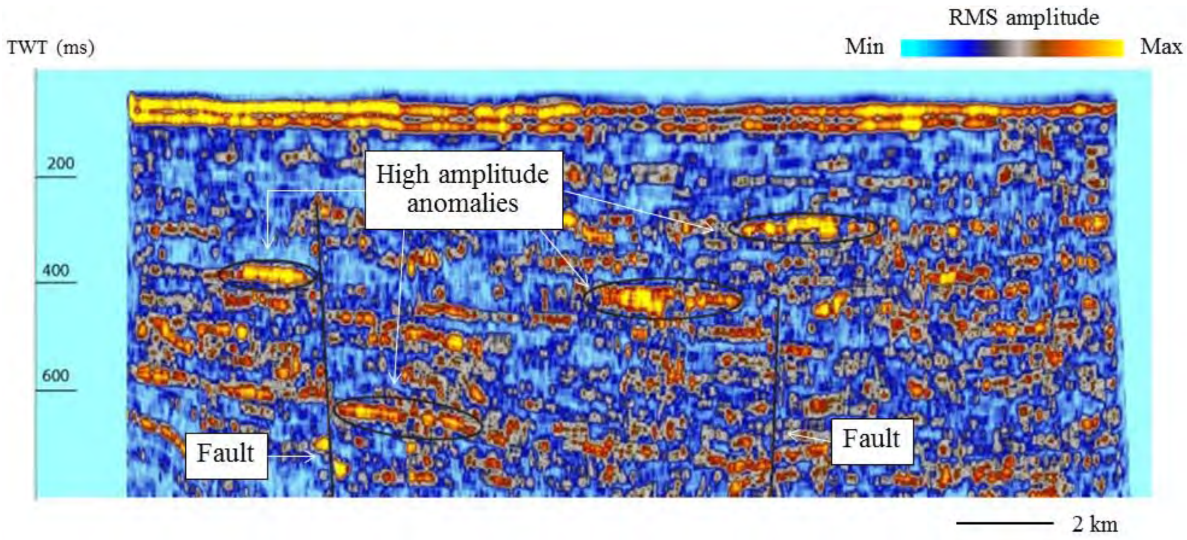

Figure 3.3 Vertical seismic profile of inline 3800 (see location in figure 3.4) from RMS amplitude attribute volume showing high amplitude anomalies and faults.

RMS amplitude map highlights high amplitude areas in plan view (Figure 3.4). This map clearly shows the channels and their patterns due to the lithology contrast between channels (sand) and nearby floodplain (shale).

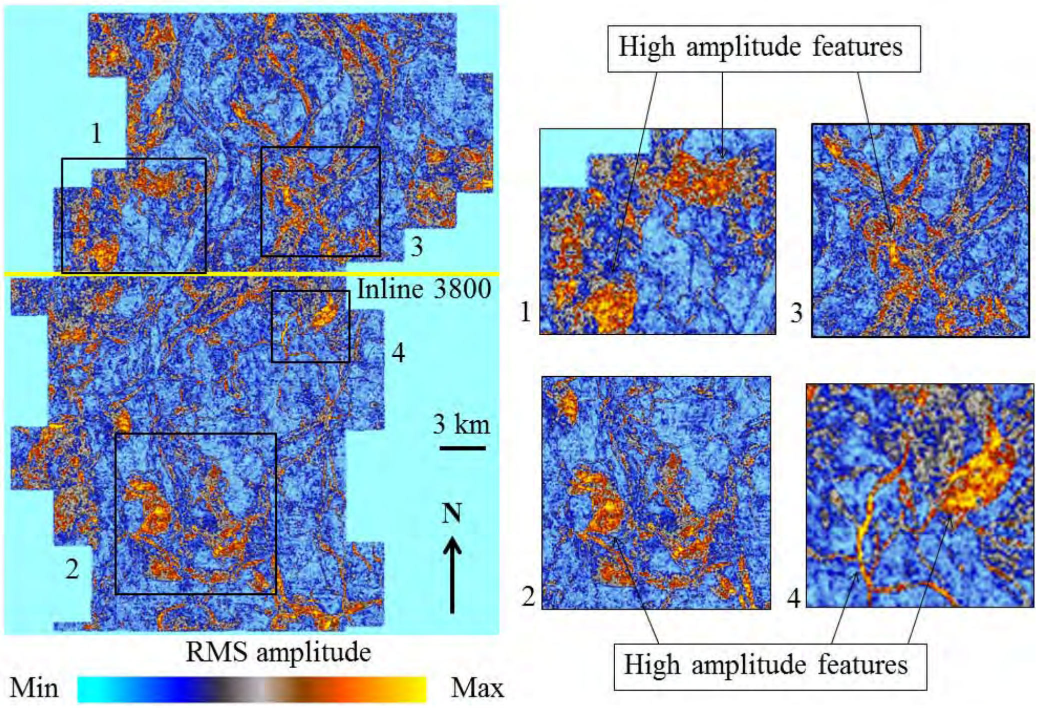

Figure 3.4 Seismic horizontal time slice at 400 ms with RMS amplitude attribute volume showing high amplitude area possibly due to lithology contrast (1-4).

- **Sweetness**

Sweetness (instantaneous amplitude divided by the square-root of instantaneous frequency) is very useful for detecting channels in coastal-plain settings or features associated with deep-water clastic sediments. In this study, the sweetness attribute improve the imaging of relatively coarse-grained (sand) intervals or bodies (Figure 3.5). However, the vertical seismic profile of this attribute is found not improve significantly on the insight grained from conventional amplitude volume. The high anomalies from this attribute are located in the same location to the RMS amplitude and envelope attributes.

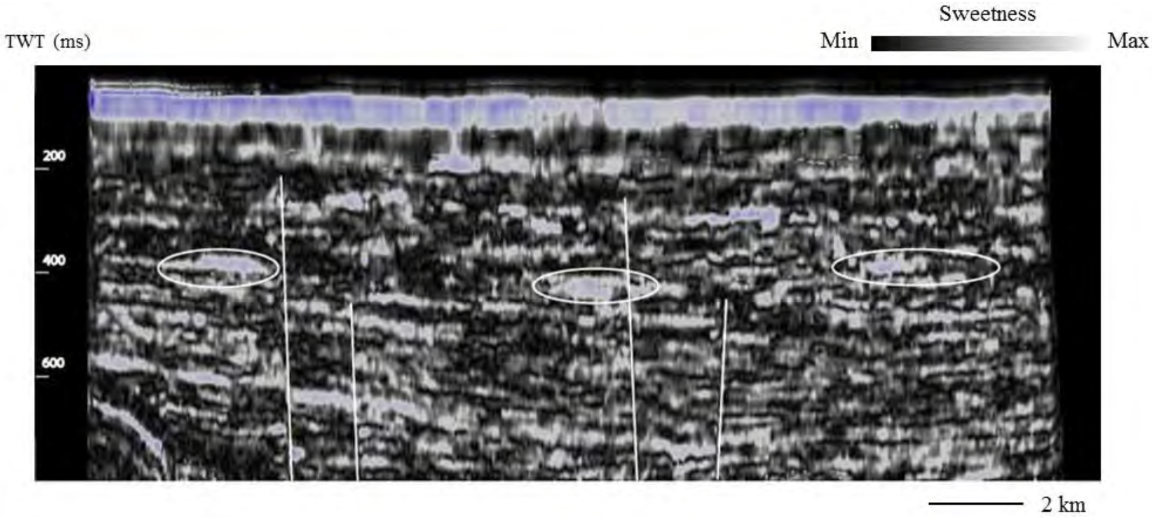

Figure 3.5 Vertical seismic profile of inline 3800 (see location in figure 3.6) from sweetness attribute volume showing high amplitude anomalies (white ellipses) and faults.

The plan view image of the sweetness attribute shows a great detail on geomorphic feature such as sand bodies from point bars and distributary channels (Figure 3.6). Also, channel edges are dramatically highlighted in comparison to the surrounding area. Although, sweetness attribute can improve channel edges, faults/fractures are difficult to identify from the horizontal map possibly due to little to no lateral lithology contrasts along fault planes.

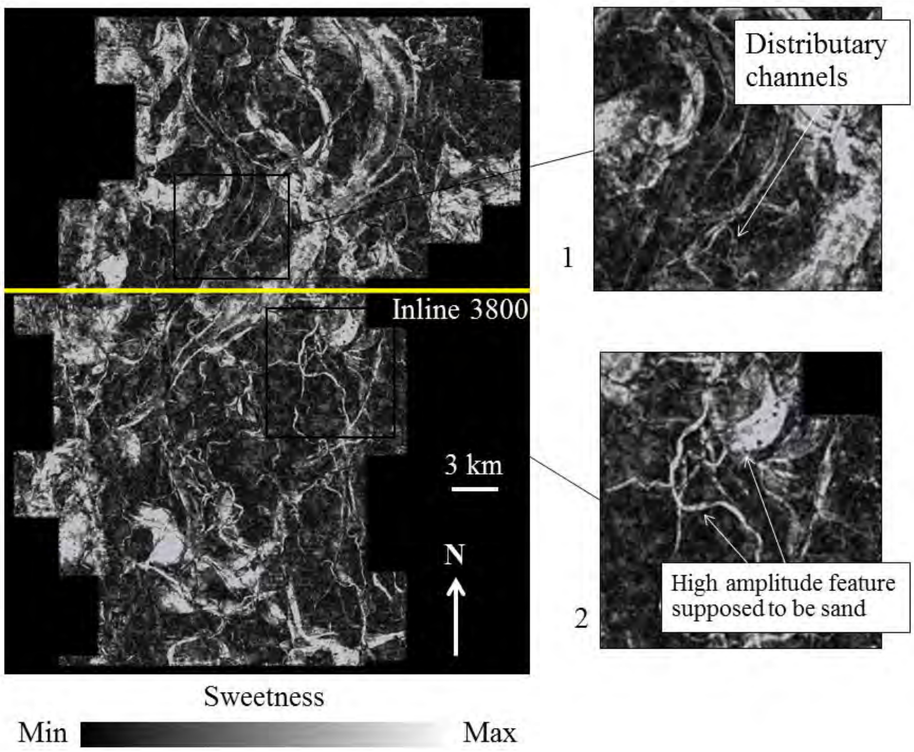

Figure 3.6 Seismic horizontal time slice with sweetness attribute volume showing distributary channels (1) and high amplitude area possibly due to lithology contrast (2).

- **Structural Dip Attribute**

Structural dip attribute has a good ability for detecting features from dip of reflections such as channel edges and faults (Figure 3.7 and 3.8) but the resolution is not quite well, possibly due to too much noise at the shallow depth of the study area (e.g. lithology variation). For the vertical section analysis, this attribute clearly displays discontinuity features which are interpreted as faults and channel bodies (Figure 3.7). Hence, this attribute can be used to outline channel geometry and channel edge. The combination of structural dip attribute with other attributes can enhance interpretation of seismic data.

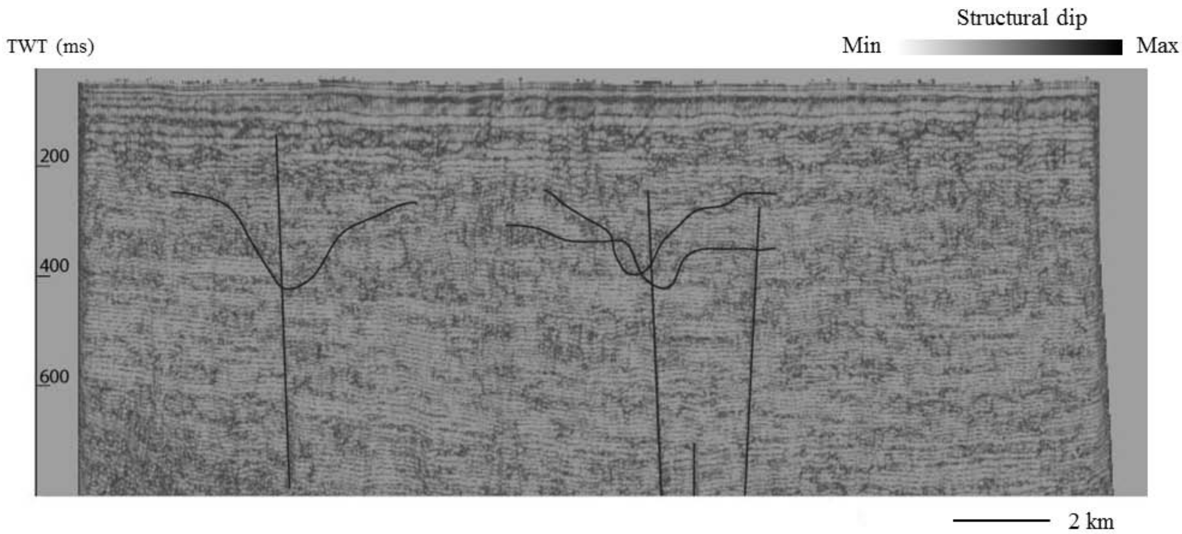

Figure 3.7 Vertical seismic profile of inline 3800 (see location in figure 3.8) from structural dip attribute volume showing discontinuity features possibly channels (curved lines) and faults (straight lines).

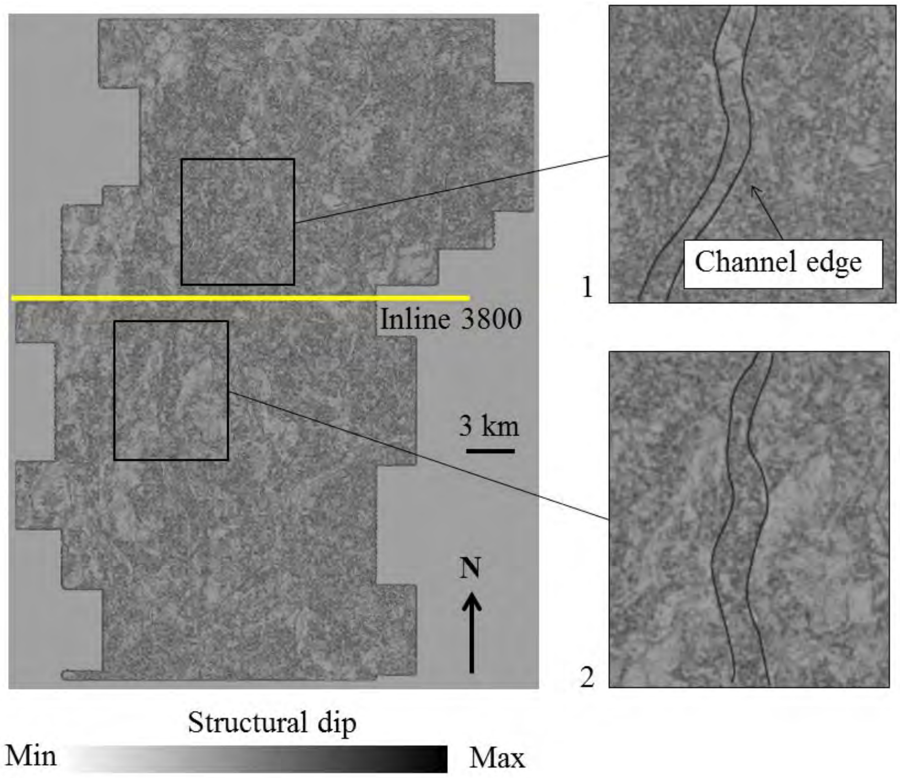

Figure 3.8 Seismic horizontal time slice at 400 ms with structural dip attribute volume showing observed features in plan view; channel edge (1 and 2).

- **Variance Attribute**

Variance attribute which is an edge method measures the similarity of waveforms or traces adjacent over given lateral and/or vertical windows. So, it can image discontinuity of seismic data related faulting or stratigraphy. In this study, variance attribute is a very effective tool for delineation faults and channel edges (Figure 3.9). From variance map of time slice at 400 ms (Figure 3.10), the map shows features such as small faults and channel edges including major and minor channels. Edges and faults are displayed by hot variance color. Minor faults are significantly appeared in this attribute compared to other attributes.

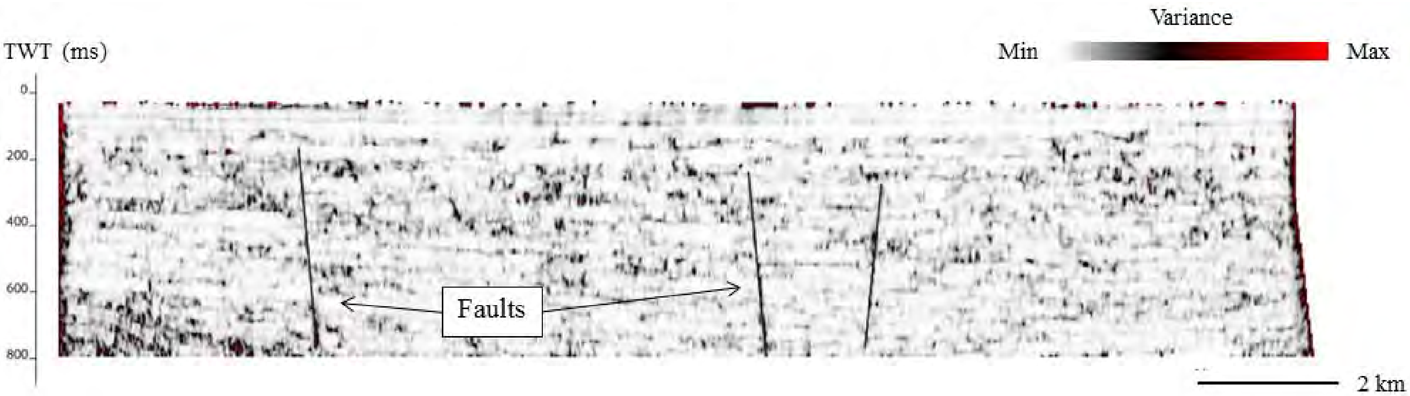

Figure 3.9 Vertical seismic profile of inline 3800 from variance attribute volume showing discontinuity features possibly faults.

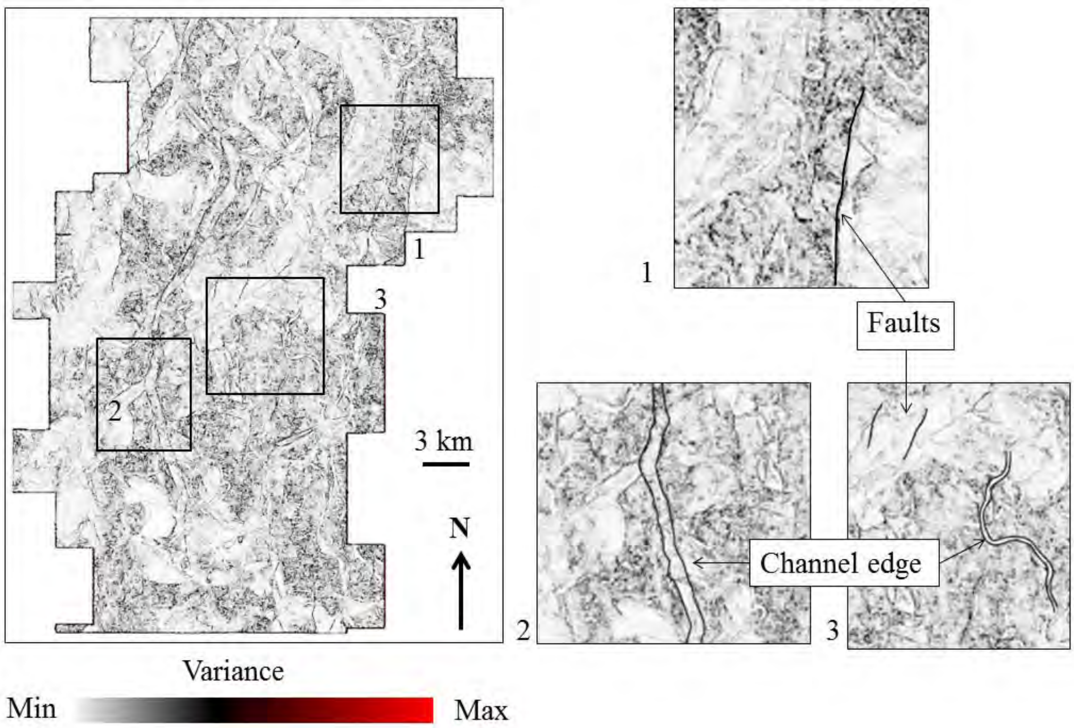

Figure 3.10 Seismic horizontal time slice at 400 ms with variance attribute volume showing observed features in plan view; channel edge (2 and 3) and faults (1 and 3).

- **Chaos Attribute**

Chaos attribute is defined as a measure of the "lack of organization" in the dip and azimuth estimation method. In another word, chaos attribute can detect chaotic textures within seismic data. Due to the discontinuous character of coarse-grained sediments within channel infills, this can give the chaotic signal pattern contained within seismic data. Hence, chaos attribute can be used to distinguish different sediment facies in lithology variation environments (e.g. sand and shale). In this area, point bars and channels are observed on both seismic profiles (Figure 3.11) and horizon time slice (Figure 3.12) of chaos attributes as chaos hot colors. The uncolored values indicate minimum chaoticness and correspond to inferred bed/layer continuity. Point bars and continuous channels appear as a zone of lacking chaoticness or less disturbed. Faults also show in vertical profile (Figure 3.11), but it is difficult to identify on horizontal map (Figure 3.12).

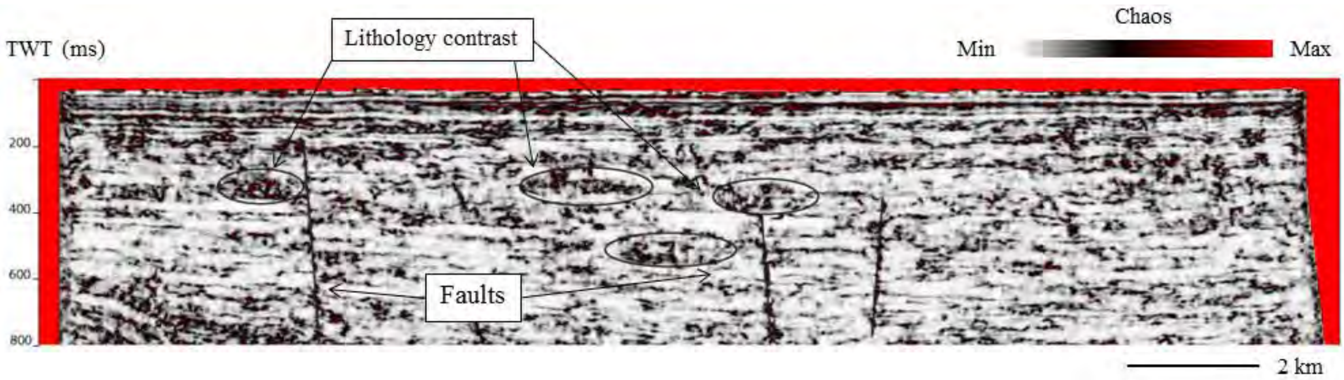

Figure 3.11 Seismic horizontal time slice at 400 ms with chaos attribute volume showing faults and lithology contrast possibly channel bodies.

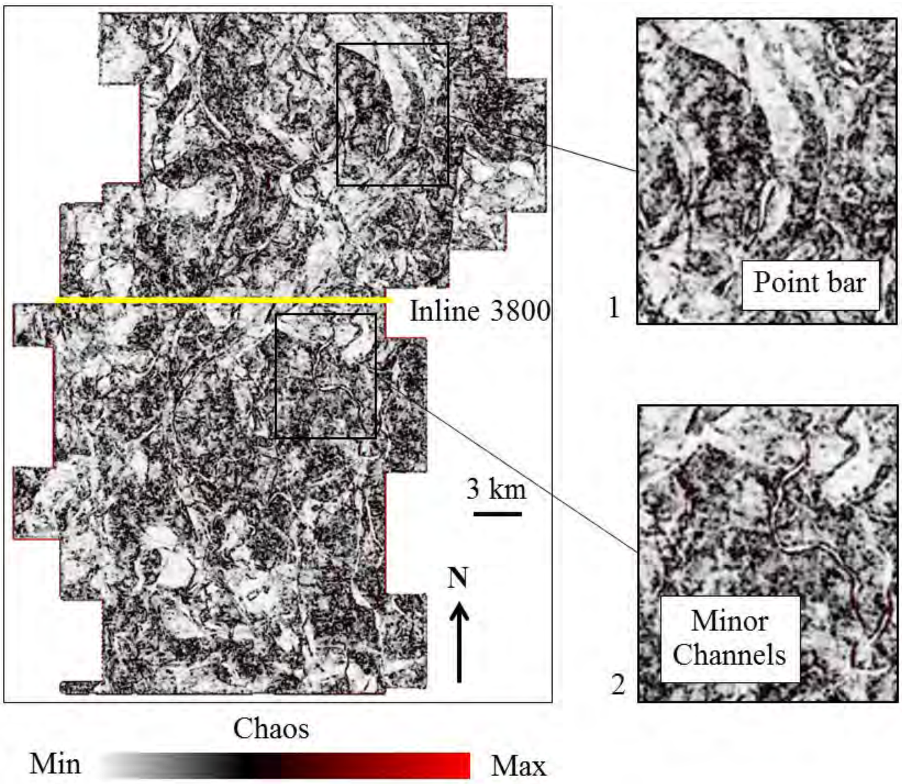

Figure 3.12 Seismic horizontal time slice at 400 ms with chaos attribute volume showing observed features due to lithology contrast in plan view; point bars (1) and channels (2).

- **Spectral Decomposition**

The concept of this attribute comes from the seismic data which response each frequency in different ways (higher frequency, shorter wavelength, detecting thin channel). To investigate the effect of thickness variation of the channels in the study area, the combination of resulting images of three different frequencies are blended within one volume. The blending image shows a great detail on the geomorphic features in this area such as discontinuity (channel edge), channel patterns, point bars, meander scars, distributary channels and especially the minor channels (Figure 3.13). The thin-bed sand layers/channels that never be displayed in other attributes are clearly seen in this spectral decomposition map (Figure 3.13). This attribute is very useful for solving the problem of thin-bed sand layer in this area. In addition, the smallest channel detected from this attribute is approximately 60 meters. The colors of blending image (Figure 3.13) are due to interference effects from the top and bottom layers and are consequence of the decomposition method. For example, red color (48 Hz) represents thin-bed sediments, while blue color (65 Hz) represents thick-bed sediments. The color in-between two colors mean that the thickness is between those two colors.

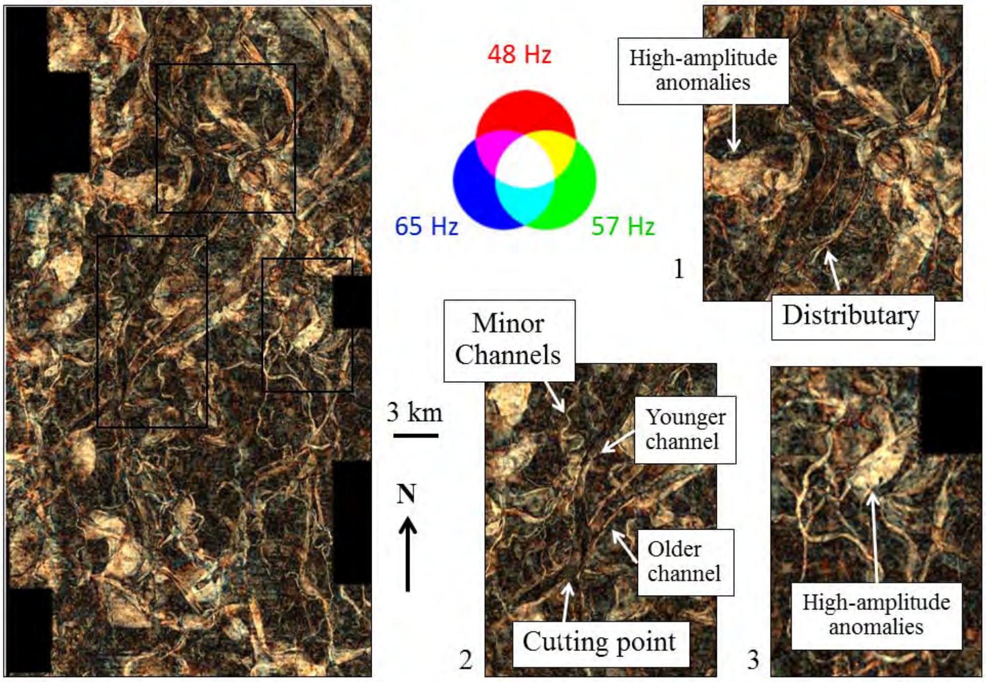

Figure 3.13 Spectral decomposition attribute map at 400 ms displays many observed features including point bars (1 and 3), minor channels which are difficult to be seen in other attribute because of tuning-effect, and a cutting point that can represent a relative age of channels (2).

3.2 Multi Seismic Attributes Analysis

- **Ant-Tracking Attribute**

Generally, Ant tracking workflow consists of four main activities: 1) seismic conditioning; 2) edge detection; 3) edge enhancement (ant tracking) and 4) interactive interpretation (Figure 3.14). The ant tracking attribute enhances discontinuity on edge-detection volume (e.g. variance, chaos and coherence), because it only captures features that are continuous and likely to be faults. Therefore, edge enhancing volume, usually variance attribute, is used in ant tracking flowchart.

In this study, chaos attribute is used in the flowchart in order to test the ability of ant attribute on chaotic textures caused by lithology variation within seismic data, particularly fluvial-deltaic environment of this area and to apply in this environment for investigating channel patterns of the area. The resolution of this seismic dataset at shallow depth is considered as a good condition with high signal-to-noise ratio. Hence, the workflow of this ant attribute is change as presented in Figure 3.15. In order to find the most suitable attribute for the study area, the controlled parameters for processing ant attribute are passive and aggressive parameters form petrel software. Therefore, the final attribute volumes from this workflow (Figure 3.15) are eight volumes including variance-ant with passive (Figure 3.16), variance-ant with aggressive (Figure 3.16), variance-ant-ant with passive (Figure 3.17), variance-ant-ant with aggressive (Figure 3.17), chaos-ant with passive (Figure 3.18), chaos-ant with aggressive (Figure 3.18), chaos-ant-ant with passive (Figure 3.19), chaos-ant-ant with aggressive (Figure 3.19).

The variance-ant with passive (left side of Figure 3.16) shows a poor quality image, but the quality is better on the variance-ant with aggressive (right side of Figure 3.16). Some discontinuous lines can be seen on the variance-ant-ant with passive (left side of Figure 3.17), but it is difficult to interpret faults or geomorphic features. While the variance-ant-ant with aggressive (right side of Figure 3.17) shows a very poor image that cannot be used to interpret any significant features, possibly due to too much detail information when we use aggressive parameter such as small channels and small fractures.

The chaos-ant with passive (left side of Figure 3.18) shows a low resolution image, but can delineate channel patterns in this image. Also, the chaos-ant with aggressive (right side of Figure 3.18), improves imaging of channels and faults. The chaos-ant-ant with passive (left side of Figure 3.19) presents some channel patterns, while the chaos-ant-ant with aggressive (right side of Figure 3.19) significantly enhances imaging of channel elements including channel edges, point bars and minor channels. Also, faults can be detected with a good condition on the chaos-ant-ant with aggressive.

As the result, chaos attribute is preferred rather than variance in this area because chaos attribute enhance not only faults but also channel edges.

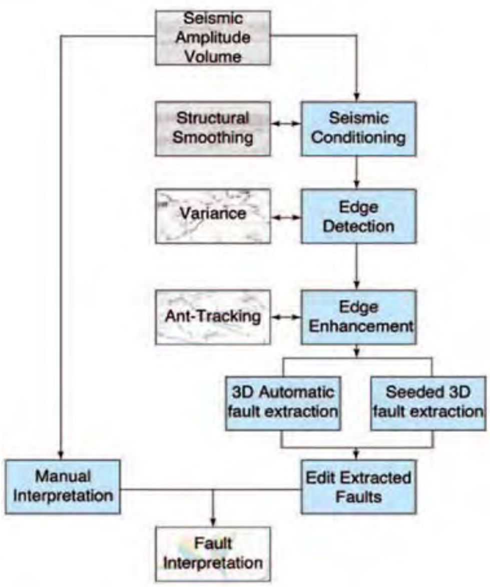

Figure 3.14 Ant tracking with variance attribute flowchart.

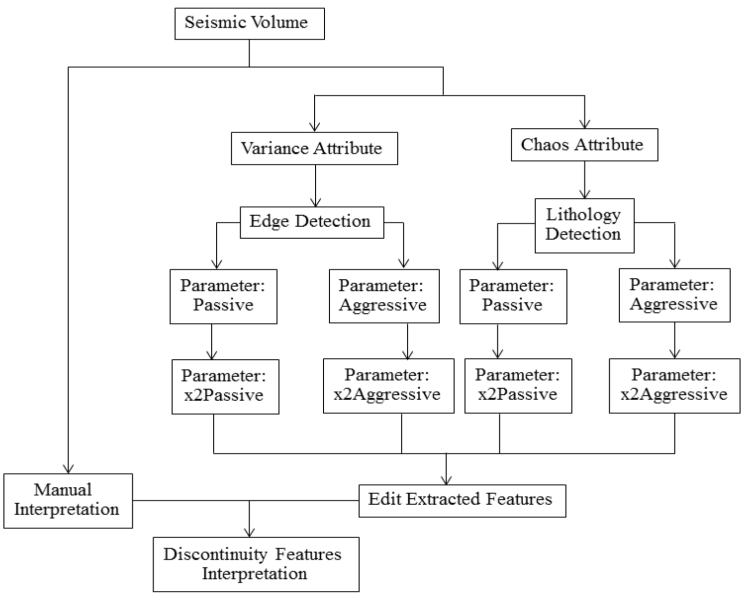

Figure 3.15 Multi attributes flowchart using in this study: Various parameters of ant-tracking attribute with variance and chaos attribute.

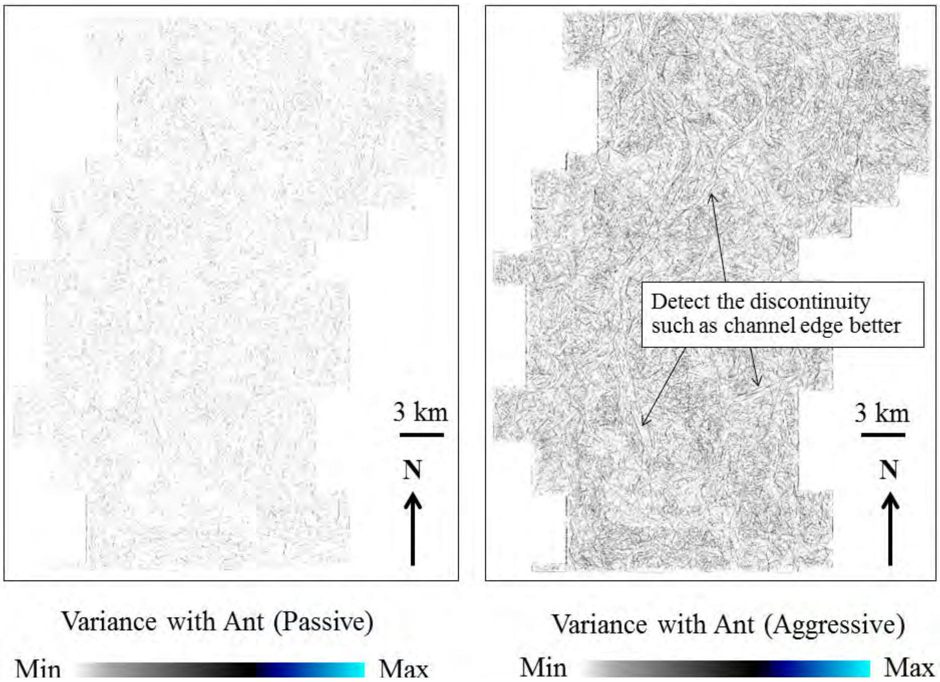

Figure 3.16 Seismic horizontal time slice at 400 ms of variance-ant with passive (left) variance-ant with aggressive (right). The observed features from this attribute are discontinuity features (e.g. boundaries of meandering channels, faults). Also, the resolution of variance-ant with aggressive is better than variance-ant with passive.

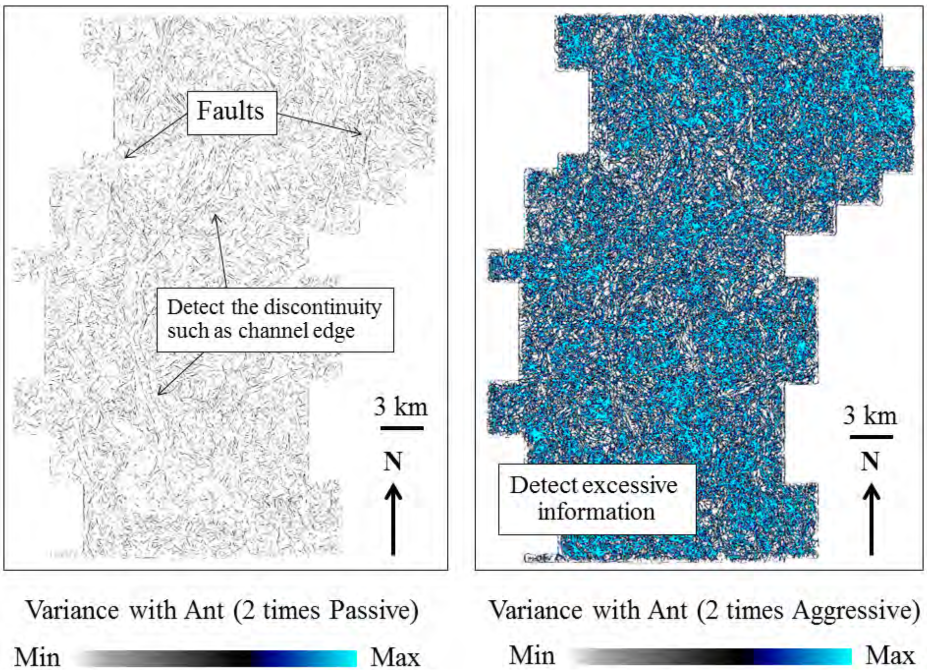

Figure 3.17 Seismic horizontal time slice at 400 ms of variance-ant-ant with passive (left) variance-ant-ant with aggressive (right). The observed features from this attribute are discontinuity features (e.g. boundaries of meandering channels, faults). Variance-ant-ant with aggressive (left) shows excessive information which is not suitable for this study area. So, the resolution of variance-ant-ant with passive is better than variance-ant-ant with aggressive.

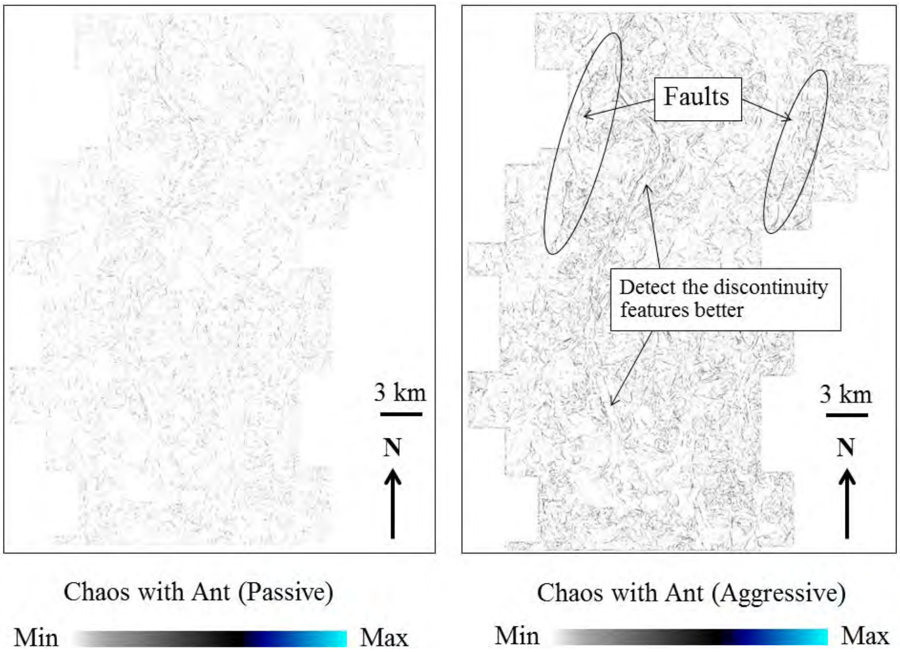

Figure 3.18 Seismic horizontal time slice at 400 ms of chaos-ant with passive (left) chaos-ant with aggressive (right). The observed features from this attribute are discontinuity features (e.g. boundaries of meandering channels, faults). The resolution of chaos-ant with aggressive is better than variance-ant with passive.

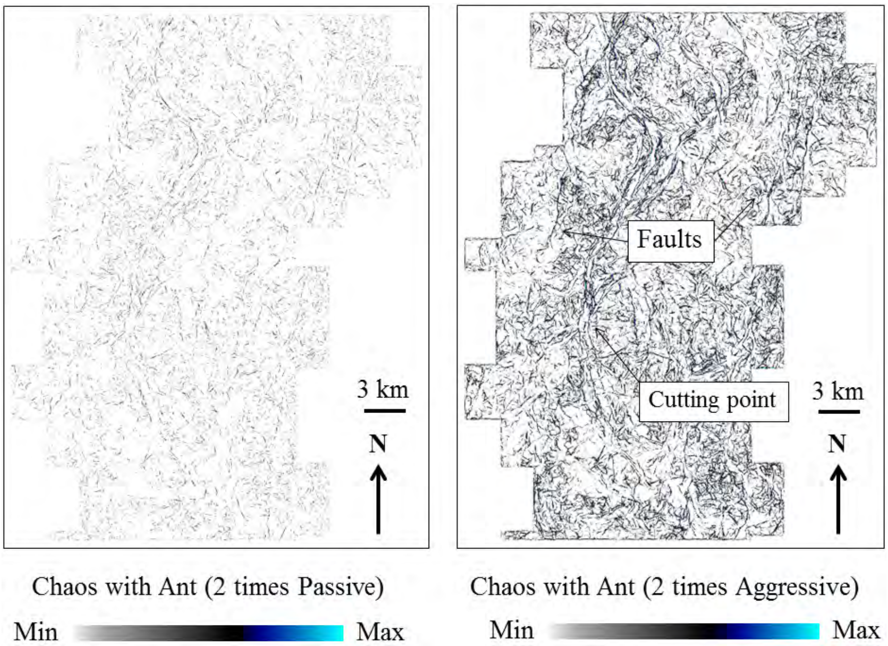

Figure 3.19 Seismic horizontal time slice at 400 ms of chaos-ant-ant with passive (left) chaos-ant-ant with aggressive (right). The observed features from this attribute are not only discontinuity features (e.g. boundaries of meandering channels, faults) but also the stacking of channels (cutting point) which represent as younger and older channels. Chaos-ant-ant with aggressive (left) shows a significant improvement on geomorphic features and faults. Also, the resolution of chaos-ant-ant with aggressive is better than chaos-ant-ant with passive.

3.3 Seismic Geomorphology Analysis

From each attribute in seismic attribute analysis at400 ms horizontal time slice (Figure 3.20), there are many kinds of geomorphological observed features displayed on the result (Figure 3.21) which can provide interpreter the paleo-depositional environment and the consequential details such as channel pattern, discontinuity features are described below.

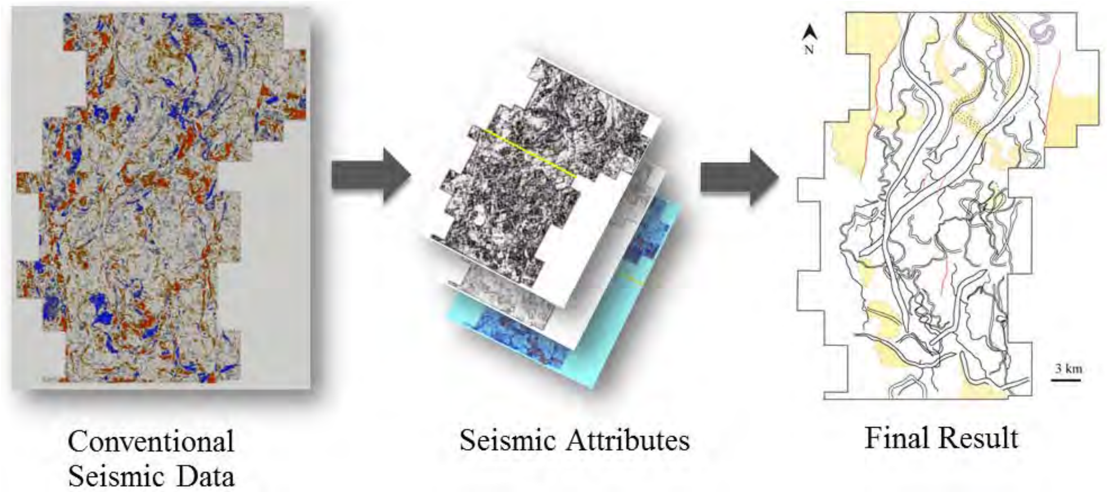

Figure 3.20 Geomorphology interpretation using conventional seismic data with the considering attributes to create high resolution mapped surface of the study area.

1. Channels

This feature is the most dominant feature in this study area and channel sizes are varies. This study using their sizes to classify them into 2 types: major and minor channels.

1.1 Major channels (width: approximately 0.5-1.3 km) can be observed clearly from all attributes (Figure 3.21). Most of them are low sinuosity. The cutting points which show the relative age of the channels are well displayed in the following attributes; sweetness attributes, variance attribute, and Spectral decomposition.

1.2 Minor channels (width: approximately 0.1-0.35 km) have the sinuosity ratio higher than the major channels (Figure 3.21). They can be observed in some attributes which are good at detection lithology contrasts such as sweetness attribute, envelope, RMS amplitude, and especially spectral decomposition which detects some channels that we cannot observe from other attributes because of their tuning effect.

2. Point bars

Point bars display as high amplitude anomalies in horizontal time slice because of the difference between lithology of sand that filled in channels and mud filled in meander scars or nearby floodplain. This feature is usually detected near the channels but we can see them without channels either (Figure 3.21) because the channel edges were detected in other time slices. Seismic attributes which show great details of this feature are envelope, RMS amplitude, sweetness and spectral decomposition.

3. Meander scars

Meander scars are an evidence of abandoned channels filled with fine-grain sediment. Their physical properties are close to floodplain so they are not displayed as bright spots (Figure 3.21). Attributes with good to detect meander scars are envelope, rms amplitude, chaos attribute, and also spectral decomposition.

Not only geomorphology can be observed from this study but also structural features such as faults and fractures. The fault trend in this study area is almost north-south. There are 2 major faults along with both east side and west side of the rims. Their lengths are about 12 km and 17 km, consecutively. Moreover, there are some minor faults in the central area (Figure 3.21). The attributes which are good to detect discontinuity features are structural dip attribute, variance attribute and ant-tracking attribute.

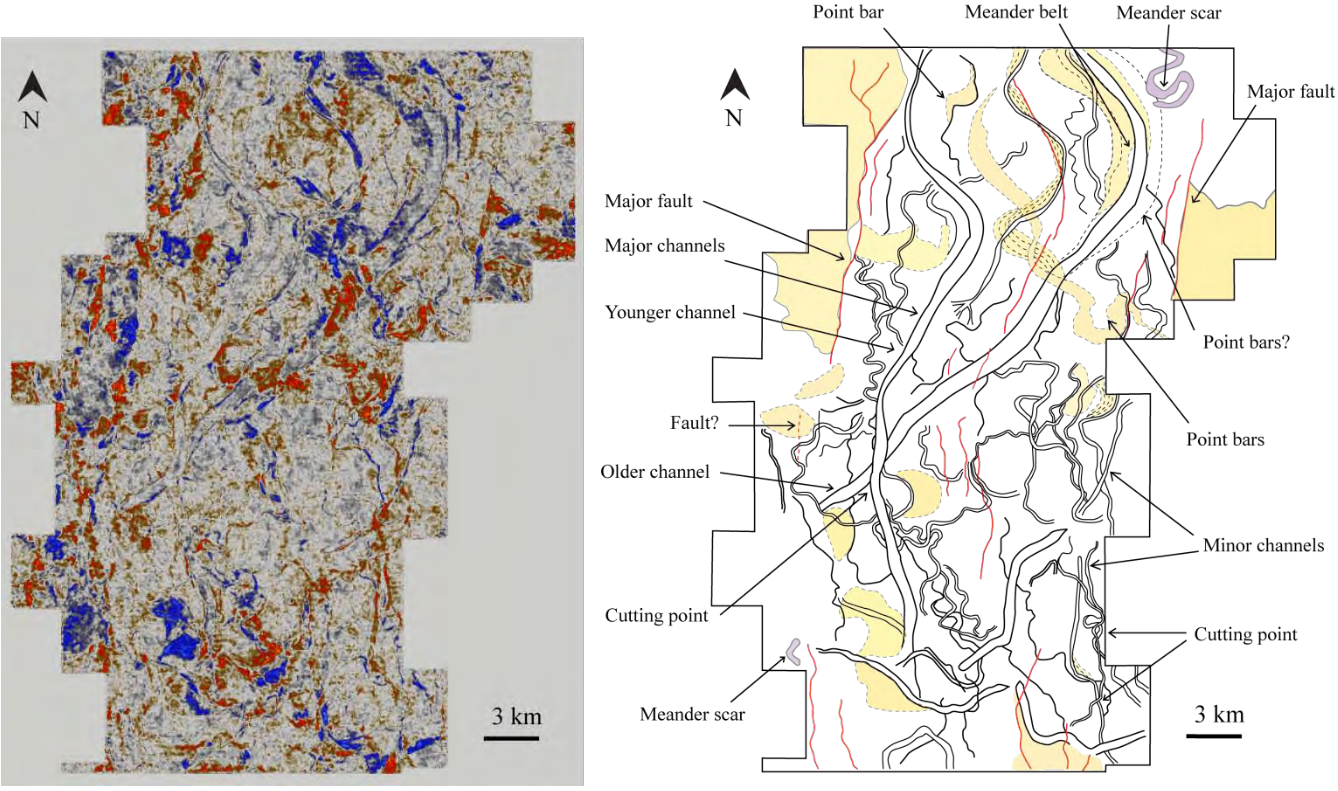

Figure 3.21 Horizontal time slice at 400 ms (left) compare with mapped surface delineating the major geomorphic and depositional elements (right).

Chapter 4

Discussion

Seismic Attributes

From this study, seismic attributes can be divided into two major groups according to their dominant observed features; lithology and structure detection. The first group is good for detecting lithology contrast. Lithology change is one of the weaknesses of a direct seismic interpretation until validation can be provided by borehole control. However, there are attributes which can assist in performing an initial suggestion of possibilities, or at the very least, demonstrate a change in lithology (Pigottet, al., 2013). In this study the suitable attributes are envelope, RMS amplitude, sweetness, chaos, and spectral decomposition. The observed features are easily seen as high-amplitude anomalies causing by difference between sand filled in channel bodies or point bars and mud filled in nearby floodplain.Therefore, this observation may correspond to the differentdepositional environments sandstones.Moreover, high-amplitude anomaliesmay, sometimes, related to fluids in the pore space of a formation such as gas, so we can make the potential area map for petroleum exploration (Figure 4.1) or create shallow gas map to avoid gas leaked hazard that could harm the rig.The second group that is good for detects geological structure comprises structural dip and variance attributes. The observed features are easily seen as discontinuity that probably be faults, fractures, and channel edges. Faults and fractures displayed can help the interpreter predict petroleum position which trapped in structural traps, this type of trap are very common, the majority of the world's petroleum reserves are being found in structural traps, including the Gulf of Thailand (Samorn, 2006).

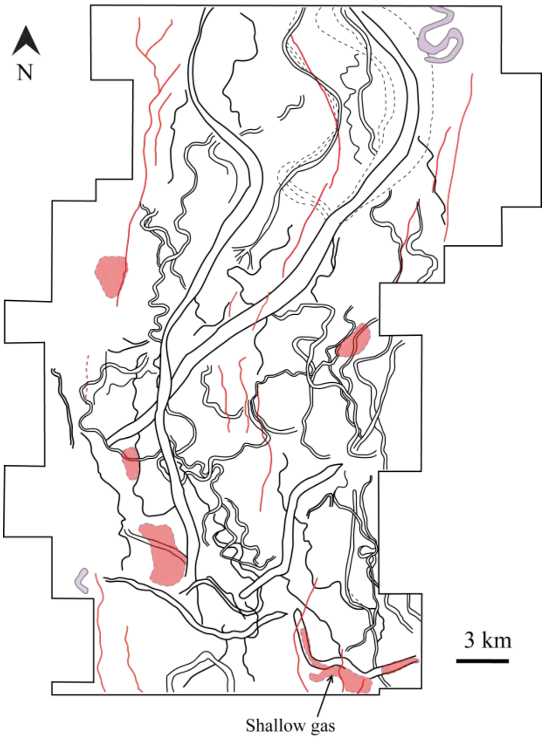

Figure 4.1 Mapped surface exhibits the location of very high amplitude areas (red marks) which probably gas accumulation areas in the study area.

Multi Seismic Attributes: Ant Tracking Flowchart

This study reveals the existence of channels in the study area which are clearly detected by using chaos attribute volume as an input volume. However, the result of each step suggests that the attribute computation may visualize the different results which are probably good for specific purposes. The study area is considered to have different contrast between coarse- and fine-grained sediments, so the chaos attribute is preferred rather than variance in this area for detecting channels. Normal faults are also observed in both variance-ant and chaos ant attributes. The aggressive and passive parameters may control the limitation of the information that we need to interpret. Generally, passive parameter is used for regional information or large scale while aggressive parameter is used for local information or small scale.

This method helps the interpreter compare all the image results more comfortable, and it can be fixed easily if we need to change some conditions in order to better results. For instance, we can change the attribute computation in the flowchart for the area which reservoir rocks are different types (maybe carbonate rocks), or changing ant-tracking parameter type in the area which consists of complex geological structure zones.

The techniques described in this work are an importantstep in providing the ability to extract geological elementsfrom multi-attribute andrepresent the first steps in developing ant-attribute analysis workflow for seismic interpretation in other areas. This multi-attribute analysis should be continued to develop techniques for different areas and objectives.

Geomorphology Interpretation

The interpretation map of seismic geomorphology shows observed features as well as previous works in this area (Mahareunthong, 2012) and adjacent region (Reijensteinet, al., 2011) because the observed features comprise various-sized channels, sand-filled point bars and meander scars. The minor channels show high sinuosity while, the major channels are almost straight, the observed features correspond with the depositional environment, upper-delta plain (Reijenstein et al., 2011). However, the result of this study exhibits more details of the depositional systems including small channels that never be seen in previous works because of the tuning-effect, more point bars enable to be observed, andminor faults delineated more clearly in the study area (Figure 4.2). The result maps from this study also show high-amplitude anomalies, probably due to gas accumulation in shallow depththat cannot be observed from previous work (Figure 4.1).

According to the information we observe from this study such as channels, meander scars or point bars, the depositional environment of this study area should be controlled by fluvial-delta system (upper delta plain) that corresponds to previous works in this area (Maharuenthong, 2012) and adjacent region (Reijenstein et., al, 2011). The resulted map can be interpreted more information such as pattern of sea level change that seems to be lowstand period of sea level change at 0.4 second time slice as well as the previous work (Mahareunthong, 2012) because the sizes of major channels are rather big (0.5-1.3 km width approximately) that suggest us the fluvio-delta system still developing when the environment from the fluvial system region merge into the marine system region.

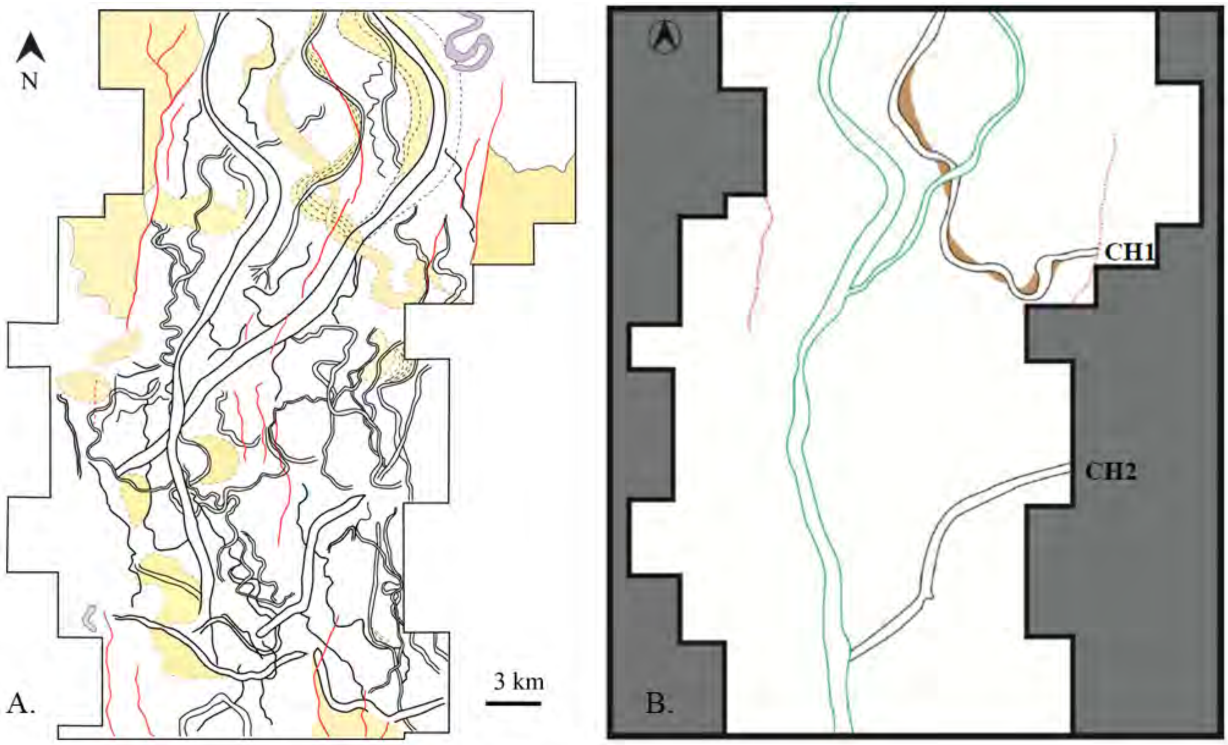

Figure 4.2 Comparison of the results between this study at time slice 400 ms (A.) and previous work (B.) at time slice 390 ms (Mahareunthong, 2012).

Chapter 5

Conclusion

From this study, both seismic attribute and multi attributes analysis can help the interpreter to extract more information from conventional seismic data which can support the geomorphology and also paleo-environments interpretation. The main types of fluvial system elements are major channels that almost straight pattern, minor meandering channels, and point bars that correspond with fluvio-delta environment. These features are well displayed with envelope, rms amplitude, sweetness, chaos attribute and spectral decomposition. Geological structures such as faults and fractures are displayed well with structural dip, variance, and ant-tracking attribute.

Multi seismic attributes also help investigator to interpret the type, distribution, and orientation of discontinuity features in collaboration with low coherence of seismic amplitude more clearly, so these benefits can help the investigator to interpret geological information of the complicated area more easily. According to the flowchart, the image results which reveal the most geological information with variance and chaos attribute to enhance detection are2x passive parameter and 2x aggressive parameter respectively.

The fluvial-delta depositional environments derived from geomorphology we observe from seismic attributes in this study, the main features that displayed on time slice are common for this environment such asstraight to meandering channels, point bars, and meander scars.

For further study, this area can be used to study more seismic attribute to extract more useful details such as spectral decomposition responses considering the azimuth variations analysis or study about dependence between the frequency and rock physics properties that might be beneficial for applying with the deeper petroleum explorations either.

References

Brondlund, S., 2010, Reservoir modeling of fluvial systems, An example from Gulf of Thailand: M.Sc Thesis, University of Bergen, Norway, 130 p.

Chenrai, P., 2012, Structure style and tectonic evolution of the Nakhon basin, Gulf of Thailand: M.Sc Thesis, Chulalongkorn University, Thailand, 73 p.

Chopra, S., Marfurt, K.J., 2005, Seismic attributes for prospect identification and reservoir characterization: SEG Geophysical Development Series No. 11, 464 p.

Del Moro, Y., 2012, An integrated seismic, geologic and petrophysical approach to characterize the Red Fork incise valley fill system in the Anadarko Basin, Oklahoma: M.Sc Thesis, The University of Oklahoma, USA, 121 p.

Hart, B, S., 2008, Channel detection in 3-D seismic data using sweetness: AAPG Bulletin, v.92, 733-742 p.

Laughlin, K., P Garossino, and G. Partyka, 2002, Spectral decomp applied to 3D: AAPG Explorer, v.23, No. 5, 28-31 p.

Jaithan, P., 2008, 3-D Seismic interpretation on the northern Trat of the Pattani basin, Gulf of Thailand: Senior Project, Thailand, 58 p.

Jardine, E., 1997, Dual petroleum systems governing the prolific Pattani Basin, Offshore Thailand: Indonesian Petroleum Association, Proceedings of the Petroleum Systems of SE Asia and Australia Conference, 351-363 p.

Maharernthong, W., 2012, Paleo-environment analysis from near-surface 3D seismic data, Northern Gulf of Thailand: Senior Project, Thailand, 43 p.

McArdle, N.J.andAckers, M.A., 2012, Understanding seismic-thin bed responses using frequency decomposition and RGB blending: First Break, v.30, 57-65 p.

Miller, P., Dasgupta, S., andShelander, D., 2011, Seismic imaging of migration pathways by advanced attribute analysis, AlaminosCanyon 21, Gulf of Mexico: Marine and Petroleum Geology, v.34, 111-118 p.

Nissen, M.T., Fournier, A., and Dahlen, F.A., 2007, A two-dimensional spectral-element method for computing spherical-earth seismograms: Geophysical Journal International, v.38, Issue 3, 1067-1092 p.

Pigott, J.D., Kang, M.H., and Han, H.C., 2013, First order seismic attributes for clastic seismic facies interpretation: Examples from the East China Sea: Journal of Asian Earth Sciences, v.66, 34-54 p.

Polachan, S., and Sattayarak, N., 1989, Strike-slip tectonics and the development of Tertiary basins in Thailand: International Symposium on Intermontane Basins: Geology and Resources Chiang Mai, Thailand: Journal of the Geological Society, London, v. 146, 243-253 p.

Radovich, B. J., and R. B. Oliveros., 1998, 3D sequence interpretation of seismic instant-aneous attributes from the Gorgon Field: The Leading Edge, v.17, 1286-1293 p.

Reijenstein, H., Posamentier,H.W., and Bhattacharya, J.N., 2011, Seismic geomorphology and high-resolution seismic stratigraphy of inner-shelf fluvial, estuarine, deltaic, and marine sequence, Gulf of Thailand: AAPG Bulletin, v.95, no.11., 1959-1990 p.

Samorn, H., 2006, Fluvial reservoir architecture from nearsurface3-D seismic data, Block B8/32, Gulf of Thailand: M.S. thesis,Colorado School of Mines,Golden, Colorado.

Tapponnier, P., Peltzer, G., and Armijo, R., 1986, On the mechanism of collision between India and Asia, in Coward, M. P., and Ries, A. C., eds., Collision Tectonics: Geological Society of London, Special Publication, v. 19, p. 115-157.

Watcharanantakul, R., and Morley, C. K., 2000, Syn-rift and post-rift modeling of the Pattani Basin, Thailand: Evidence for a ramp flat detachment: Marine and Petroleum Geology, v.17, 937-958 p.