Morphological Lineament Analysis: Implication to Tectonics of Sarawak

ANIS SALWA BT ABD RANI

13672

Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Technology (Hons)
(Petroleum Geosciences)

FYP II MAY 2014

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CERTIFICATION OF APPROVAL

Morphological Lineament Analysis: Implication to Tectonic Of Sarawak

By

Anis Salwa Bt ABd Rani

13672

A project dissertation submitted to the Geoscience and Petroleum Engineering Department

Universiti Teknologi PETRONAS

In partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(PETROLEUM GEOSCIENCES)

Approved by,

____

(Dr David Menier)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATE OF ORIGINALITY

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

ANIS SALWA BT ABD RANI

ABSTRACT

Digital Elevation Model (DEM) data are produced from Geographic Information Systems (GIS) and express topography based on elevation sets. It is a remarkable tool to observe and analyse tectonic and structural lineaments especially in areas of limited or no access. Limited work has been done in the field of morpho-tectonics and morpho-structural analysis in the area which limits the understanding of the tectonic evolution of Sarawak. The primary objective of this work was to observe and understand the lineament trend of the area and its relation to tectonic implications. Due to inaccessibility of many onshore parts of Central Sarawak, the location of study was divided into several zones and high resolution Digital Elevation Models were used to carry out structural lineament analysis in this study. Processing of DEM data sets help to control factors pertaining to sun azimuth and sun angles in order to create shaded relief images by illumination method. Manipulation of these attributes aid in obtaining images with different enhanced features and to observe the continuity of lineaments. From the resulting images, lineaments will be mapped and interpreted based on tectonic evolution that occurred in the area either locally or regionally. By understanding geomorphology and tectonic history of a region, it could help in the exploration of new prospect.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my Supervisor, AP Dr David Menier his patience in guiding me throughout the project. I really appreciate the time spent under his tutelage by sharing lots of advice and knowledge and keep in check with my progress.

I would also extend my gratitude towards graduate's assistant, Mr Manoj Matthews who has given me knowledge, idea and resources to complete my project. Not to forget other fellow student who is supervised together, Ms Nur'Azri Nabilah Bt Dahalan, who are being supportive throughout completing this report.

I will never forget all their effort and advice as well as all experience given to me throughout months I have spent for the project. Finally, I would like to thank all my family and friend for their continuous support and motivation in order for me to improve and prepare myself for the future. Thank you.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Geographic Information System (GIS) is a tool used to collect, control, evaluate, and produce information related to the surface of the Earth. GIS could assimilate hardware, software and data to manage geographical information (Esri, 2013). One of the applications of GIS is through Digital Elevation Model (DEM).

Digital Elevation Model or DEM is a digital data that use elevation set to record topographic surface of an area (Chenrai, 2012). DEM are contemporary tools to study about tectonics and morphology but it is gaining more popularity as it can be applied to many geological research areas. By using Digital Elevation Model and other software possible, regional study of an area is getting easier with better view of different dimension and perspective as in Figure 1.

GIS and DEM proved to give good result while extensively being used in the study to develop relationship between tectonics and morphology (Kuterdem and Dirik, 2007). Availability of good resolution digital terrain data, GIS successfully gives precise analysis of quantifying and mapping structural features like lineaments on Earth's surface.

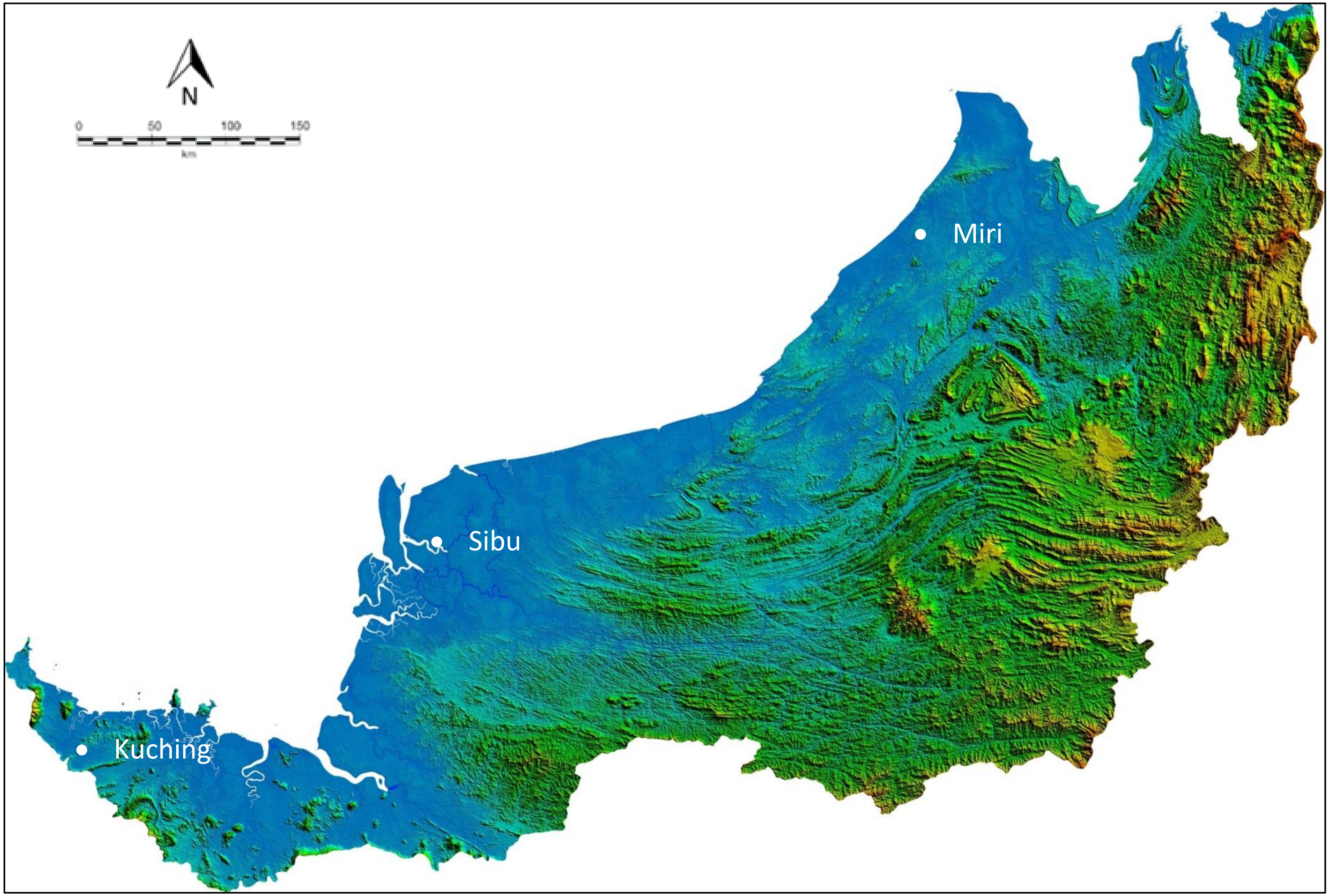

Figure 1 : High resolution Digital Elevation Model of Sarawak, East Malaysia.

Manipulation of shaded relief images applied to DEM are able to enhance lineament like in the Figure 2. Shaded relief model can be defined as visualisation of the terrain under an artificial illumination with bright sides and shadow to bring out clear definition of lineament features (Meijninger, 2001). Better visualisation of lineament would add further confidence to map them and plot rose diagrams.

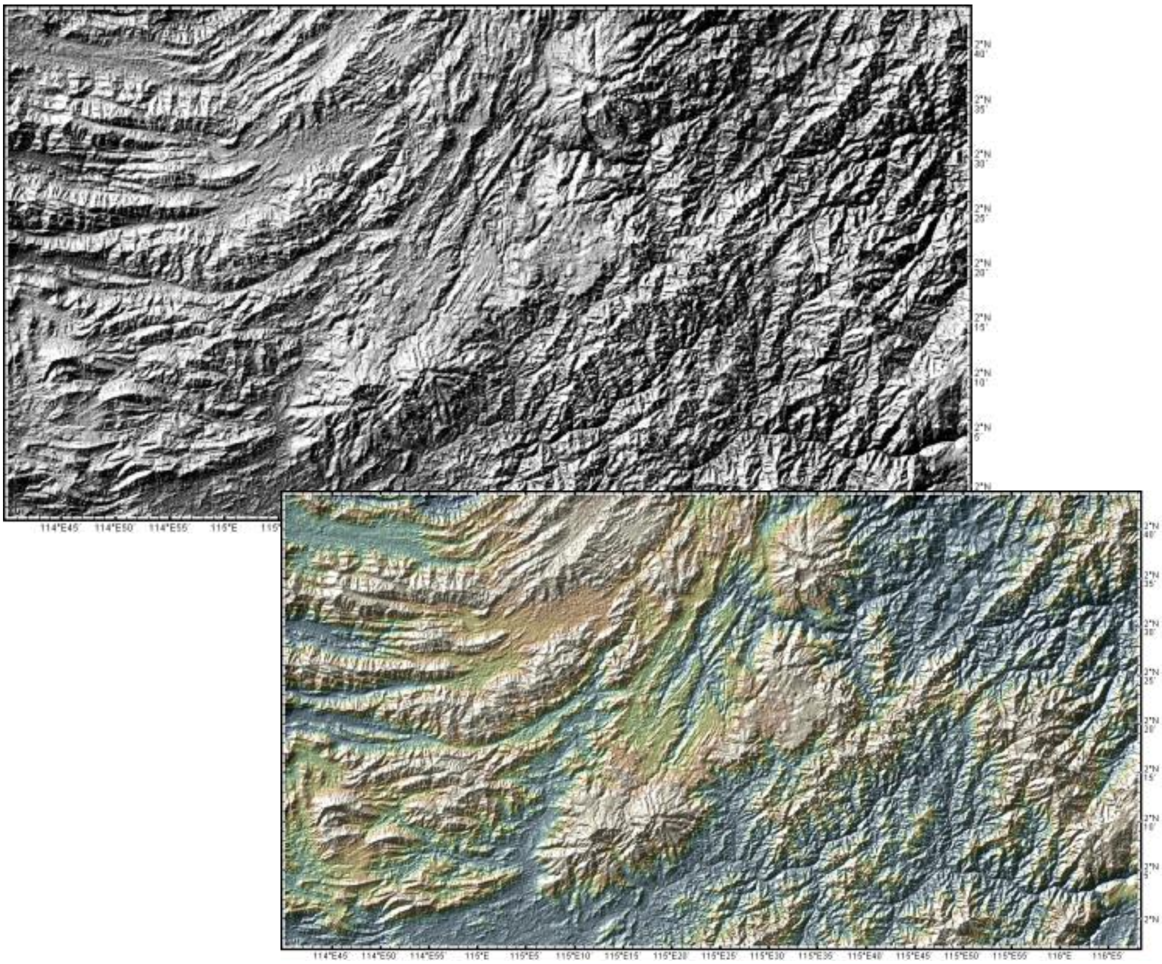

Figure 2 : Shaded relief of DEM overly with coloured DEM. Examples of DEM with SRTM data layered with GMRT (Global Multi-Resolution Topography)

Lineament analysis is a one of the analysis to associate the knowledge of tectonic events to morphology (Figure 3a). Frequency of lineament orientation will be plotted into rose diagram and stereonet (Figure 3b). Azimuth of the force, mode of fracturing will be correlate to the tectonic events occurred to the area.

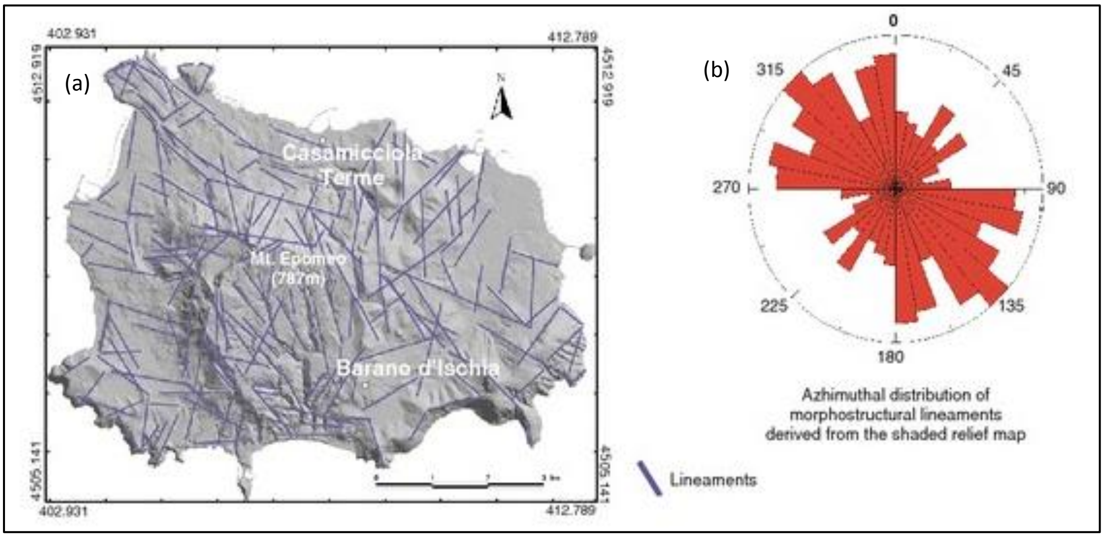

Figure 3 : (a) The shaded relief map shows the morphostructural lineaments extracted; (b) relative frequency distribution plot into rose diagram. (Rosa *et al*., 2010)

1.2 Problem Statement

In the past, numerous studies have been performed in Sarawak in fields of sedimentology, stratigraphy, basin analysis and more. However, inadequate work has been done pertaining to geomorphology and morpho-tectonics of onshore Sarawak due to constraints of access and logistics, limiting our knowledge of tectonic activities that shaped and deformed the surface morphology. Entirely, lack of this kind of information will act as barriers to understanding the tectonic evolution of Sarawak itself.

1.3 Objectives

Main objectives of this research are :

- To map and analyse lineament trends of geological structure in the area using remote sensing techniques.
- To understand the orientations and general trend of faults, fold and other lineament observed.
- To make interpretations of tectonic activities that occurred over time using structural data.

1.4 Scope of study

Geomorphology is a broad knowledge about landform and how they formed. For the purpose of the project, the study on geomorphology is done exclusively in the aspect of lineament analysis. Lineament features will be observed through manipulation of the shaded relief images on DEM. Lineament analysis will be carried out based on orientation, frequency of appearing, and lineament zone. All information will be represented by rose diagrams and stereonets. Interpretation of lineaments by rose diagrams and stereonets will be based on azimuth of forces which will correlate to the tectonic events that occurred.

CHAPTER 2

LITERATURE REVIEW

2.1 Geological and Structural Setting of Sarawak

The evolution of sedimentation and tectonic events in Central Sarawak started in the late Cretaceous. Exposed outcrop in the Batang Lupar gave some evidence of deposition of shale, sandstone and chert which believed to be from Late Cretaceous time (About Sarawak, 2011). End of deposition of sedimentary rock were dated to Middle Tertiary as most were subjected to several tectonic events such as uplifting, folding and faulting. Similar or perhaps more thorough studies have been done in the area by Madon (1991).

Madon (1991) also agreed that age of the oldest rock exclusively in the Late Mesozoic. However he became more specifically suggesting that deposition and deformation is getting younger from west to east and from south to north. While in the aspect of structure and stratigraphy complexity is decreasing towards the east part of Sarawak.

Tectonic evolution of NW Borneo believed to be related closely to the tectonic history of South China Sea (SCS) rifting and sea floor spreading (Holloway, 1982). James (1984) originally published a paper to describe a geological model showing that Central Luconia, offshore of Sarawak being underlain by rifted SCS crust. Another published paper by Tan and Lamy (1990), also approve the idea that continental blocks that rifted off SCS had collided with NW Borneo. Madon (1999) then interpreted that Sarawak Basin as post-orogenic foreland basin that resulted from uplift and closure proto- South China Sea or known as 'Rajang Group' as being illustrated in Figure 4.

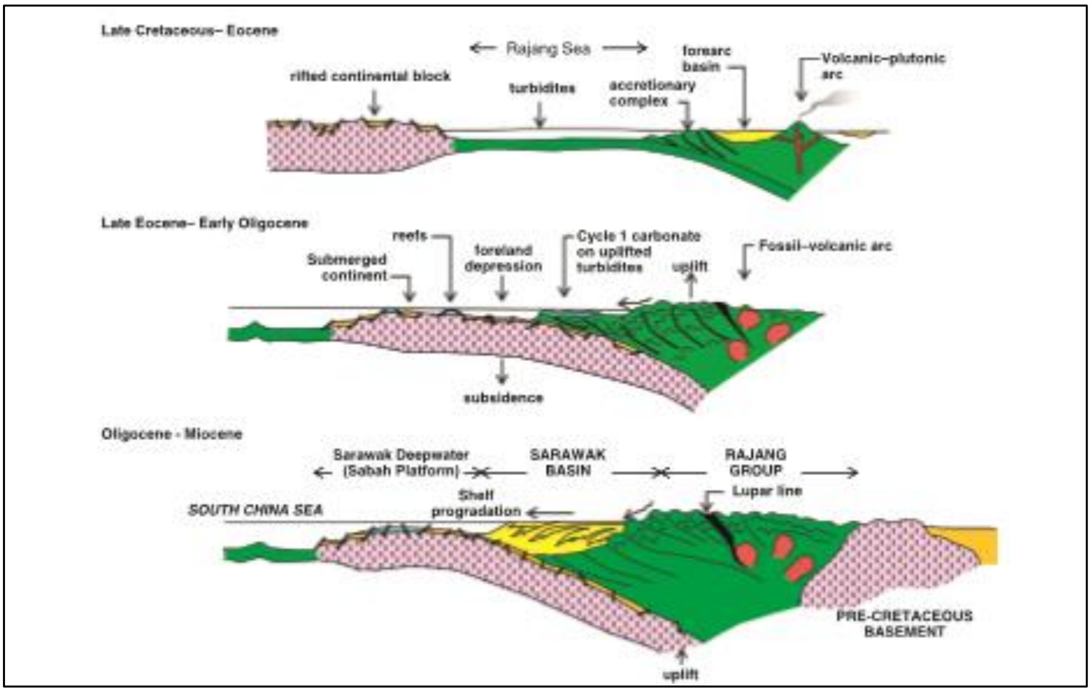

Figure 4 : Schematic tectonic model for the evolution of Sarawak Basin (Madon *et al*, 2013)

This schematic tectonic model shows three different stages of tectonic evolution of Sarawak Basin might work perfectly with offshore studies. But since the tectonic forces are quite regional, the effect or deformation of it could possibly the same to the onshore Sarawak. Following the chronological timescale, Late Cretaceous to Eocene series witnessed the rifting of southern margin of South China coupled with subduction of proto-South China Sea (Rajang Sea). It produced an accumulation of complex stratigraphy which was later uplifted to the onshore.

Next, Late Eocene to Early Oligocene believed to form flysch which is a sequence of rock deposited in deep marine of a foreland basin at developing orogeny. This occurs because of collision of Luconia Block with Borneo at end-Eocene, and cessation of subduction and deep-marine sedimentation. Foreland basin developed on the rifted lithosphere while undergoing subduction. Besides, this time series also witnessed the important tectonic event which is spreading of South China Sea.

Finally, in Early Oligocene to Early Miocene believed to form molasses that related closely to waste product or deformed of flysch. Spreading of the South China Sea caused an accelerated strike-slip movement and a major uplift and erosion in the Rajang fold belt. This is where sediment supply of foreland basin came from (Madon, 1999)

There was also some theory or model of Borneo tectonic history which implies that India-Asia collision also affected the geological structure of Borneo made by Tapponier *et al*. (1982). It is much more known as extrusion model that suggests large crustal blocks have been extruded laterally from India-Asia collision zone which formed deformation with concentrated strike-slip fault. They believe that Borneo situated at the centre of a large SE Asia block initially, India moved northward into Asia which later extruded eastward. Due to the collision, Borne has rotated clockwise direction and moved little bit south. Figure 5 show The reconstruction of continental block at 40Ma also was being provided by Replumaz and Tapponier (2003) to support their idea.

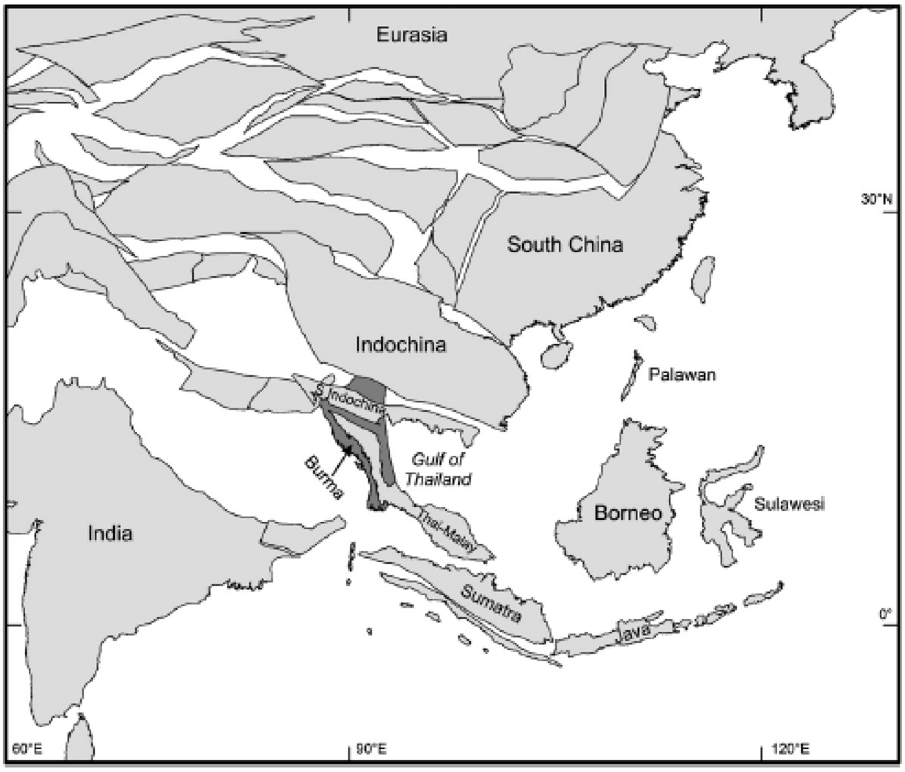

Figure 5 : Reconstruction of SE Asia region at 40 Ma based on Replumaz and Tapponnier (2003)

Another tectonic reconstruction model also have been done by Hall (2002) based on paleomagnetic data from east Indonesia that recording Philippine Sea plate motion and interpret the geological and paleomagnetic data from SE Asia. This model is known as SE Asia-centered model. It is a total contrast from Tapponier’s extrusion model. With the reconstruction of continental block at 40Ma as in Figure 6, the model focused on Paleogene closure of a proto-South China Sea followed by Neogene counter-clockwise rotation of the island.

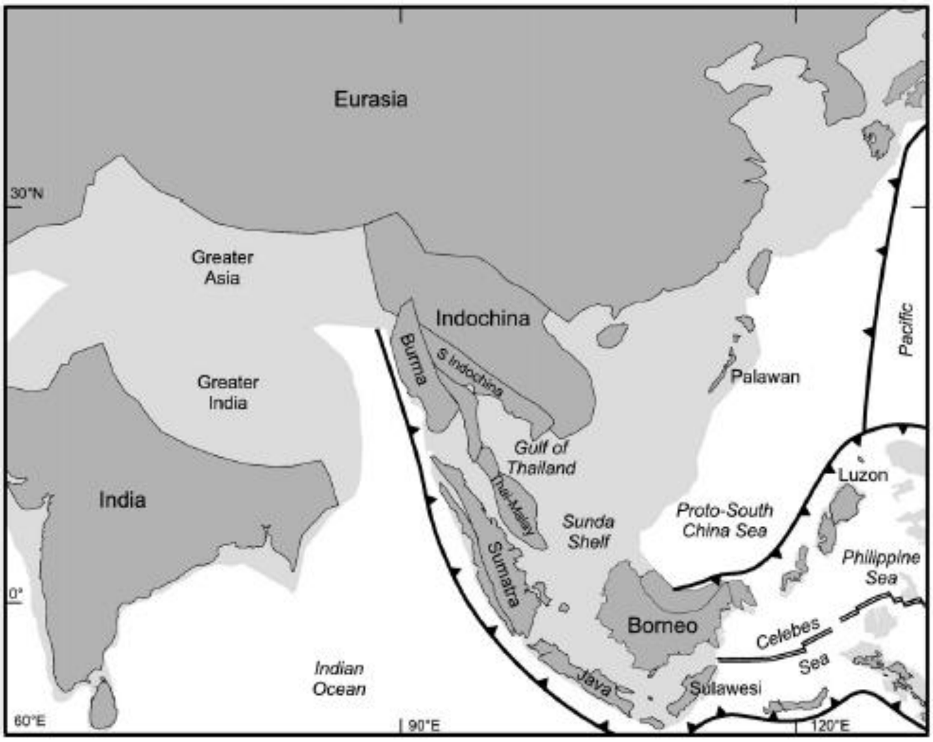

Figure 6 : Reconstruction of SE Asia region at 40 Ma modified from Hall (2002)

Throughout the research by Hall *et al*., (2008), they conclude the geological history of Borneo is not consistent with the extrusion model. This is due to clockwise rotation are incompatible with paleomagnetic evidence. Thickness of sediments also proved that it is more likely derived from local source instead of coming from elevation by India-Asia collision. Better tectonic reconstruction of Sundaland region based on Hall (2002) is also provided to support the model as in Figure 7.

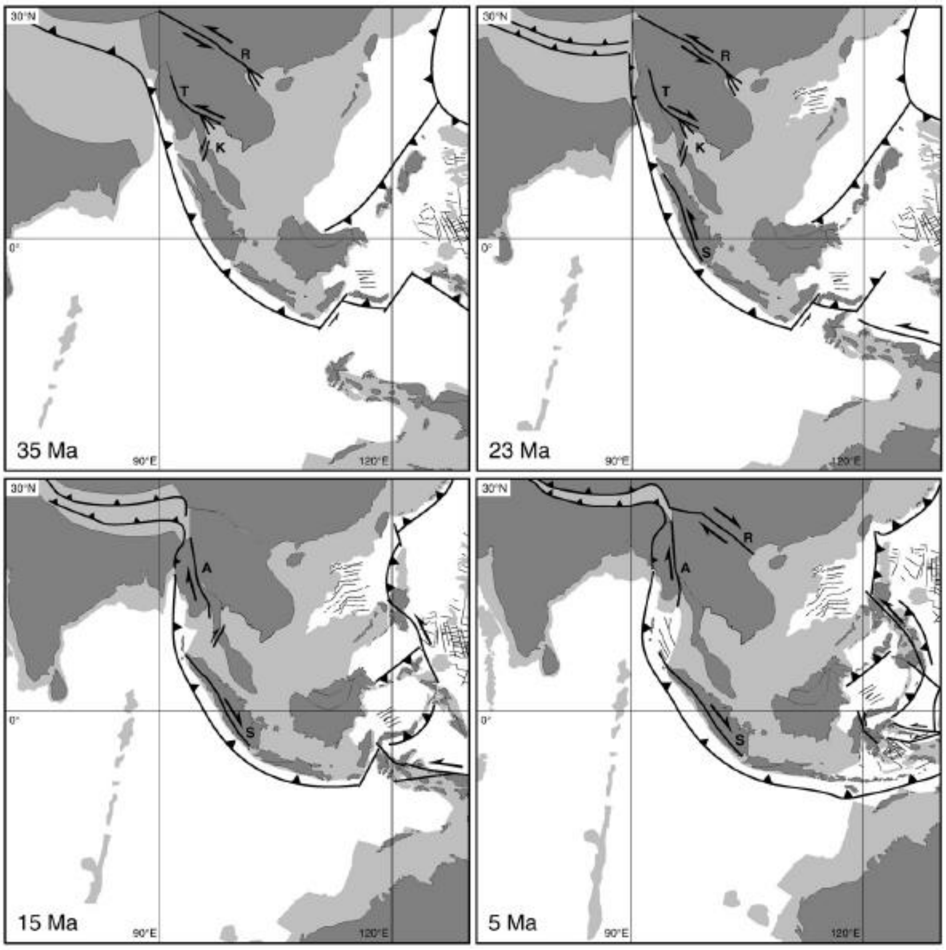

Figure 7 : Reconstructions of the Sundaland region at 35 Ma, 23 Ma, 15 Ma and 5 Ma based on Hall (2002)

India–Asia collision was underway at 35 Ma and extrusion of Indochina began by sinistral movement along the Red River (R) Fault and sinistral movement along the Three Pagodas-Mae Ping (T) Faults and there was sinistral movement on the Ranong–Klong Marui (K) Fault system. Collision with Australia began at 23 Ma in east Indonesia and widespread plate reorganization began. The Red River Fault remained sinistral but movement direction changed to dextral on the Three Pagodas-Mae Ping Faults. Dextral movement on the Sumatran Fault (S) began. Movement on the Red River Fault ceased at 15 Ma. Dextral movement on the Sumatran and Sagaing Faults was linked via extension in the Andaman Sea. At 5 Ma there was dextral movement on the Red River Fault, the Sumatran and Sagaing Faults and oceanic spreading was underway in the Andaman Sea.

2.2 Rajang-Crocker

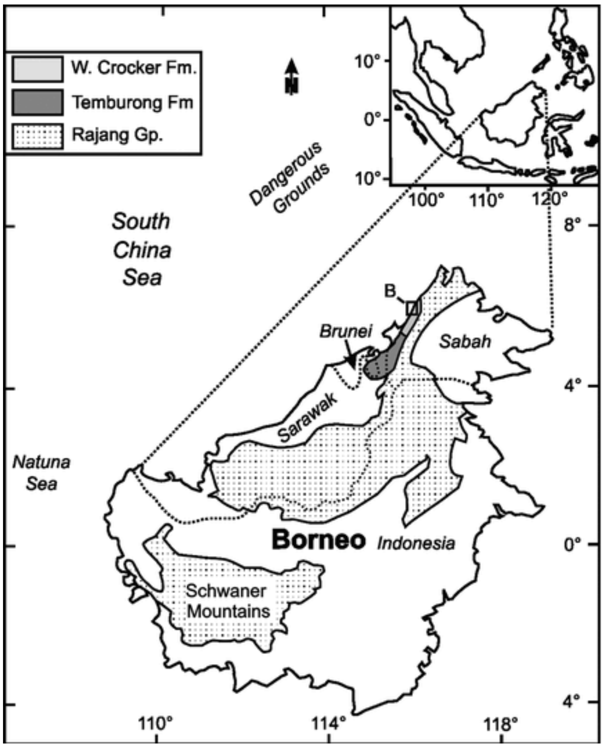

Figure 8 : Rajang-Crocker formation (Joseph J. Lambiase *et al*, 2008)

Northwest Borneo region is bounded by South China Sea in the northwest, Sulu Sea and Celebes Sea in the east, closure by Sundaland shield in the south. It formed highly complex deformation belt with distinctive structural element called Rajang-Crocker mountain belt (Figure 5). It is approximately 1000km long and up to 500km wide, stretches from central-south Sarawak to the northern Sabah (Liechti *et al*., 1960; Hamilton, 1979; Benard *et al*., 1990).

Rajang-Crocker convergent mountain belt can be interpreted as in terms of early stage of accretion together with later stage of collision between the Sundaland plate and Eurasian plate. Early stage of accretion complex can be proved by uplifted hinterland in Brunei together with consecutive collision with mitigated continental crust of South China Sea. In addition, the suture probably continued toward southwest, below Balingian and Tinjar basins of Sarawak (Gower, 1990; Hazebroek and Tan, 1993). Deformation of this massive mountain belt however is highly non-uniform and diachronous along the northwest Borneo active margin. Generally, the structural deformation became younger from southeast to northwest. On the other hand, from southwest to northeast direction, oblique convergences happen between the Sundaland plate and Eurasian plate.

2.3 Digital Elevation Model

Studies done to develop relationship between the structure and stratigraphy have been developing either in Sarawak or other part of the world. However, there is less work done to relate lineament trend observed throughout the Central Sarawak and correlate it with structural geology and tectonic history happen to the area. In addition to that, the study is not really feasible to the aspect of time, cost and accessibility for a one-man job. To study the lineament trend and structural geology in regional scale, Digital Elevation Model (DEM) is applied.

DEM application is usually used to present digital data of topographic surface. Other than determining the attributes of terrain, features of terrain such as drainage network and other landforms could also be define by the application of DEM (Unit 38 - Digital Elevation Model, 1997). DEM application used to interpreting structural geology is usually done in regional study because of its ability to increase visual to interpret the data. Furthermore, DEM could also provide information on the nature of vertical movement of faults and folds. Nevertheless, disadvantage of using DEM is that the method will not distinguish between rock units (Chenrai, 2012)

Map to prepare DEM are using remote sensing like Shuttle Radar Topography Mission, SRTM. It is an international research that obtained DEM to generate the most complete high resolution digital topographic database of Earth (Shuttle Radar Topography Mission (SRTM), 2013). SRTM is more desirable because of its consistency and comparable across large areas compared to the image produce by individual satellite images (C. Mohanty, D. J. Baral & J. N. Malik, 2004). The common parameter used for SRTM is 90m for its pixel resolution with 3 arch seconds for the capture resolution.

2.3 DEM application in tectonic interpretation

Chenrai (2012) used DEM to map the linear trend in Koh Samui area in Thailand. He used several attribute of DEM to reach his result such as shaded relief images, several of vertical exaggeration, sun angle and azimuth. As the result, Chennai were able to relate linear pattern observed to regional compression that produce right lateral strike slip fault in the area.

Another work using DEM to study lineament density is done by in North-West of Himalaya. Satellite image was manipulated by edge enhancement filter before extracting the linear feature. Major faults and lineament were been mapped by visual interpretation such as fracture traces, alignment of streams or sudden bending streams (C. Mohanty, D. J. Baral & J. N. Malik, 2004). In addition to that, DEM have been extensively used in revealing the morphology and tectonic features in the western part of North Anatolian Fault Zone where strike slip fault has dominant role in the formation of landform (N. K. Kuterdem and K. Dirik, 2007). Interestingly, all the three paper mentioned to use DEM successfully in the studies of lineament is done in the area that mainly formed by strike-slip faulting.

2.4 DEM Attributes

Raw DEM image obtained need to be modified and manipulate to enhance the lineament feature. Commonly, the main technique used for this purpose is shaded relief image. Shaded relief in DEM can be defined as the visualization of the terrain under an artificial illumination with association of bright and shadow side (Meijnnger, 2001). Hill shading is when the portion of surface that face towards the light source will reflect with more light toward the viewer, and thus appear lighter, while portion that face away from the light will appear darker. The position of the light source or analogically the sun will help in performing hill shading. Different cartographic azimuth and altitude are used. Note that 'altitude' was the term used in DEM which also means the sun angle. Sun azimuth defines which direction the sun is, while sun angle/altitude defines how high the sun is (Solar azimuth angle). 0˚ azimuth means the sun is reflecting to the north while 90˚ azimuth means the sun is to the east, 180˚ means to the south and 270˚ means the sun is to the west. Therefore, altitude or sun angle of 0˚ means the sun is on the horizon whereas 90˚ means that the sun is directly overhead

2.5 Lineament Analysis

On its sense, lineament is a distinctive shape, contour or line. According to Clark and Wilson (1994), lineament to the geologist is lines or edges which assumed to be geologic origin that is visible on remotely sensed images. Such feature should be linear and prior to availability of aerial image, lineament also applied to specific geologic or geomorphic features like drainages system or zones of fractures. Similar definition given by Kassou *et al* (2012), as they mentioned lineament are linear or curvilinear discontinuities in direct connection with the faults and composite fracture which also associated with geomorphological features and tectonic structures.

Certain linear line observed might represent cultural features like pipeline corridors and road. There is also cases features which is not from fault or fracture such as linear stream channel or other surface alignment which do coincide with pattern in geologic substrate and also taken as lineament (Caran *et al*, 1981). Lineament analysis is a useful tool to study tectonic geomorphology and tectonic studies. With variation of attribute and parameter done through DEM image, texture and linear pattern in the area were enhanced and mapped. Lineament derived from the image analysed by means of rose diagram (N. K. Kuterdem and K. Dirik, 2007).

Lineaments directions are plotted into rose diagram according to their frequency of appearing in order to define structural trend of the area (Chenrai, 2012). Rose diagram is a circular histogram plot which displays directional data and the frequency of each class. It is an excellent method to plot orientation of lineament (Allaby, 1999). The technique of rose diagram will highlights the existence of lineament orientation and can be interpreted as major structural trend.

CHAPTER 3

METHODOLOGY

Traditional field work would be carried out for detailed outcrop and topographic analysis in order to investigate evidences of fracture or fault in the outcrop that matches with lineament observed through DEM.

Utilizing 90m resolution SRTM data downloaded from CGIAR-CSI SRTM website (http://srtm.csi.cgiar.org), a detailed preliminary analysis of the structures and lineaments will be carried out. Initial DEM images are improved using shaded relief image technique. Different shading and different vertical exaggerations are used to increase the sharpness of the image and clearly distinguish features.

Using several software and available map extension, the lineament orientation will be map and measured. Frequency of lineament orientation is taken and transfer to rose diagram and stereonet to represent the quantitative analysis. Based on these factors, the azimuth of major and subsidiary lineament will be interpreted as well as deduction of direction of tectonic forces.

Chronology events will be summarized from literature review and will be compared with trend of lineament observed from the resulting data. Following Figure 9 give simple workflow on the methodology. Table 1 then is the schedule or Gantt Chart organized to ensure all work being done according to the workflow.

3.1 Workflow

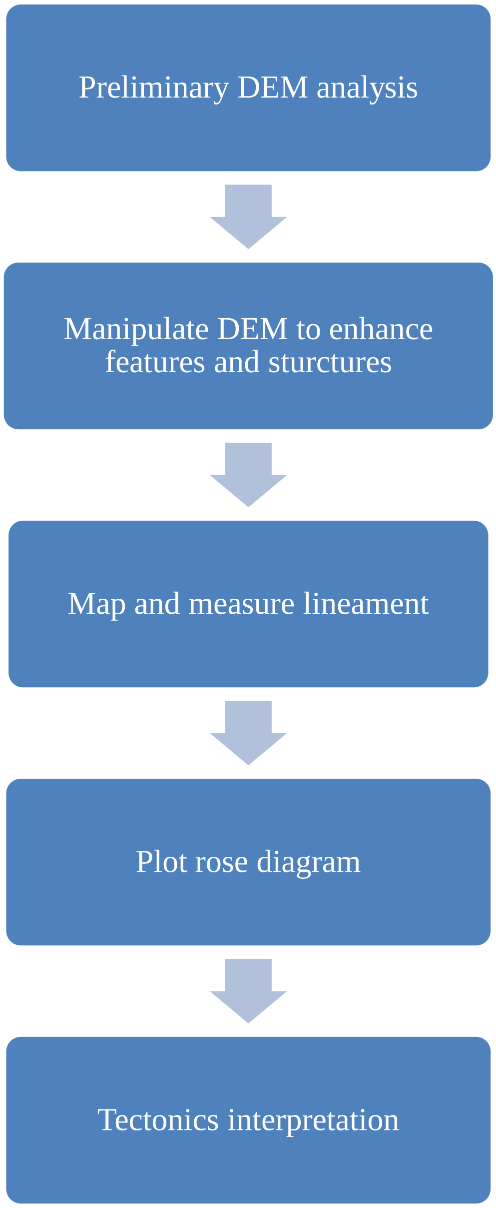

Figure 9 : General methodology workflow

Table 1 : Gantt Chart and Key Milestone

	FYP 1											FYP 2											
TASK/ WEEK	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Preliminary research work																							
DEM manipulation																							
Map and measure lineament																							
Plot and interpret rose diagram																							
Tectonic interpretation																							
Report Writing																							

Table 2 : Key milestones of the project

Key milestones	**Date**
Proposal Defence	13rd March 2014
Interim Report	8th April 2014
Progress Report	1st July 2014
Pre-Sedex	17th July 2014
Project Report and Technical Paper	8th August 2014
VIVA	12th August 2014
Full submission	28th August 2014

Note : The project estimated to be done before Pre-Sedex

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Lineament Zone

The study area was divided into 4 zones. The zone is divided equally following their longitude and latitude (Figure 10). The purpose of putting the study area into different zone is to observe whether the structure is continuous or not. Since the area also quite big, to create a rose diagram comprises of all lineament in the whole study area is not effective. One small area could consist of many lineaments, therefore easier observation and measurement could be made in each zone.

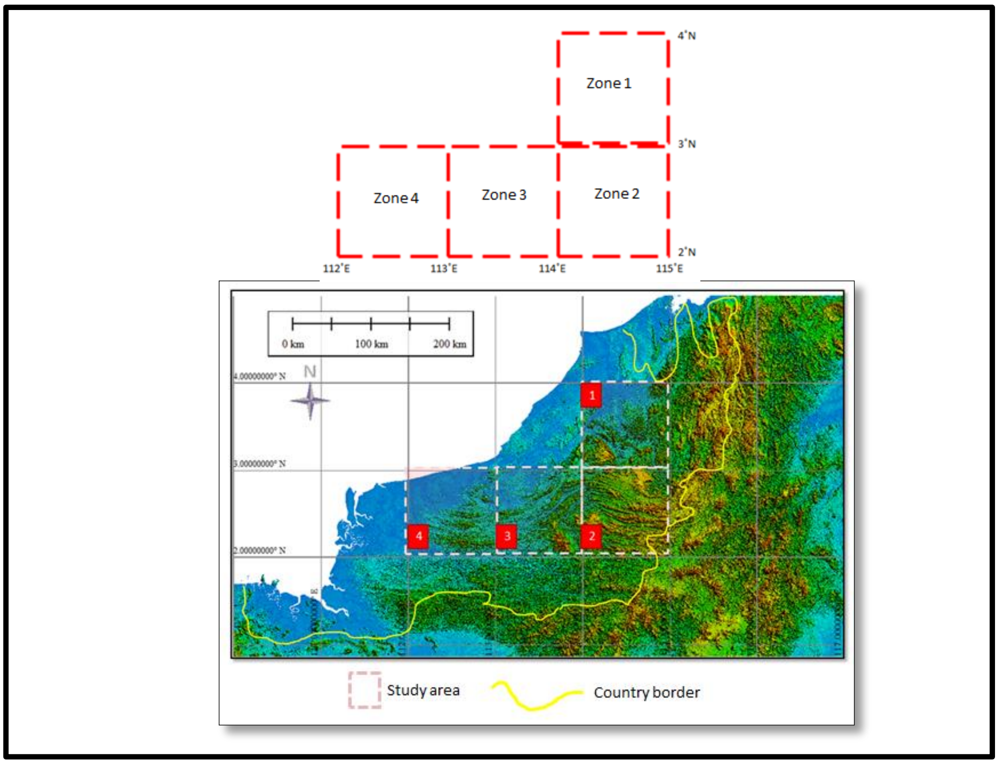

Figure 10 : 4 identified zone as study area and their latitude/longitude coordination

4.2 DEM Attribute Manipulation

Shaded relief image is one of the techniques that can assist in showing features on the surface with different elevation and slope (Figure 15). It provides apparent 3D properties showing flat feature with smooth appearance while steep slopes and mountain appears rough. By the used of artificial lighting, lineament feature in the area with different elevation can be observed.

Shaded relief images are produced by applying different sun azimuths and different sun angles. However, for this particular paper, comparison between sun azimuth and sun angle are using only two different degrees. Sun azimuth is set to 45˚ and 315˚. While sun angles that were used are 45˚ and 60˚.

Following Figure 11, 12, 13 and 14 will show distinguish features observed in respective zone with different manipulation of DEM attribute.

Preliminary observations and discussions have been made with these figures;

- Lineament trend in the 4 different zones are different showing no continuity of the lineament from one zone to another. More interpretation of the lineament trend will be made after each of lineament features is mapped and represented by rose diagram later on.

- In most cases, DEM with sun azimuth 315˚ and sun angle 45˚ show the best and most clear lineament feature

- Feature that effect the most by DEM was mountain or volcano present in the Zone 2 and Zone 3

- Lineament feature in Zone 4 is not very clear even with 4 different variation of DEM attribute which is probably due to low elevation in the area with high vegetation.

- Suggestion to manipulate DEM with another attribute which is vertical exaggeration to bring up low elevation area to be more clear for lineament mapping

Therefore, for identification of lineament and lineament tracing are done in shaded relief image with sun azimuth of 315˚ and sun angle of 45˚ as in Figure 15. The figure is also focusing on 4 zone of interest. Figure 16 is then showing shaded relief map with the structural lineaments traced.

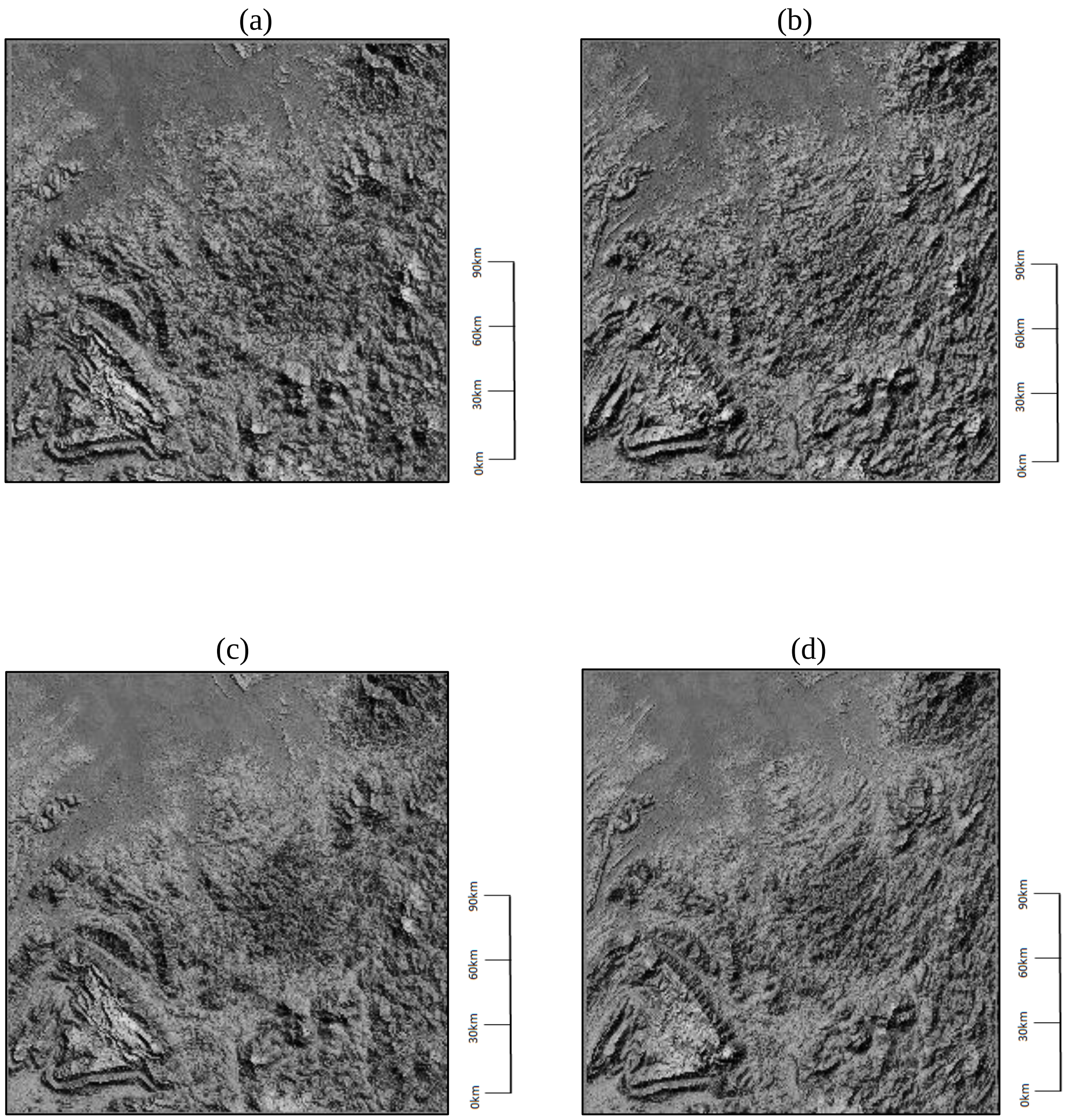

Figure 11 : DEM manipulation at Zone 1. (a) 45˚ azimuth, 45˚ angle. (b) 315˚ azimuth, 45˚ angle. (c) 45˚ azimuth, 60˚ angle. (d) 315˚ azimuth, 60˚ angle.

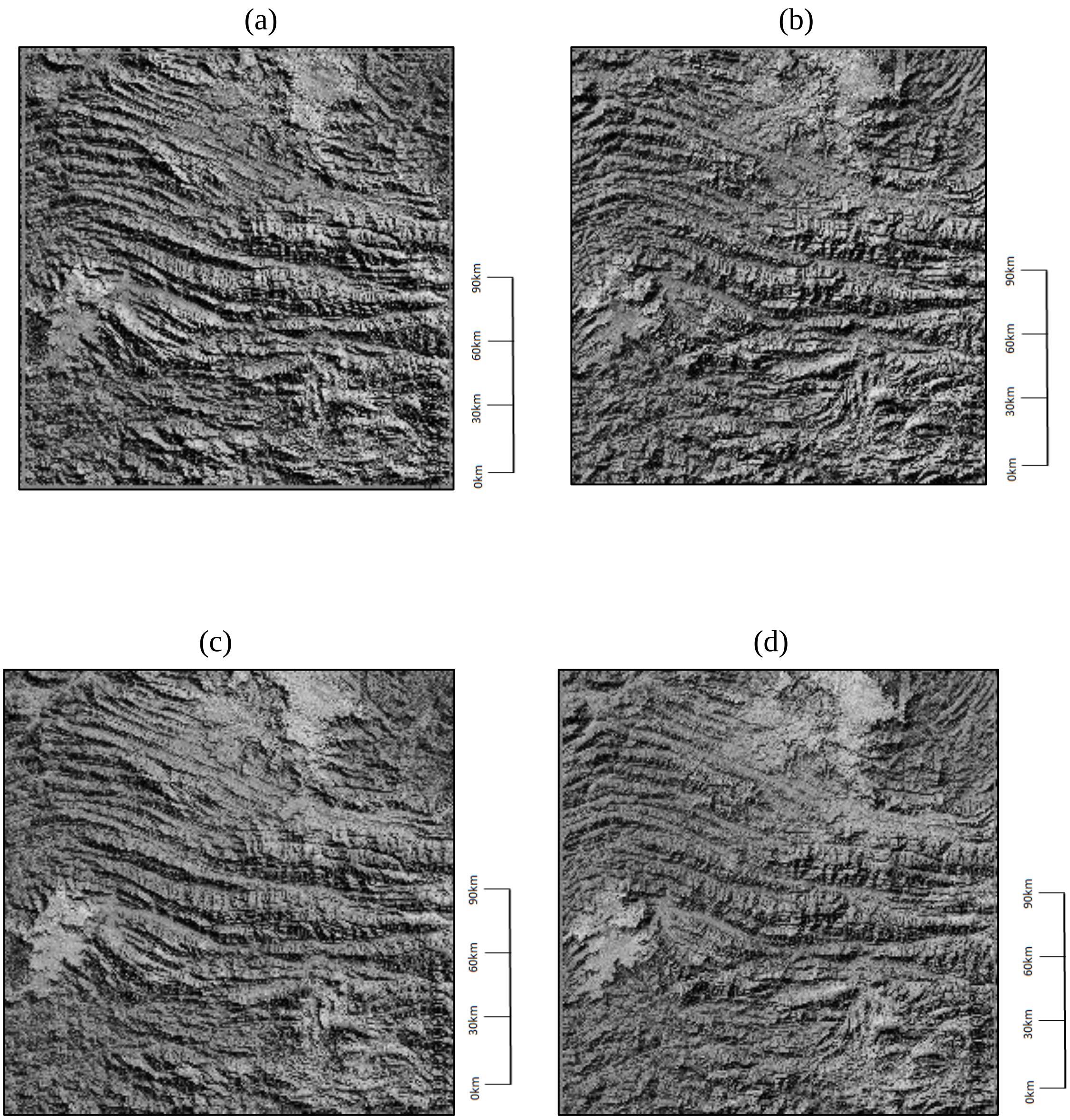

Figure 12 : DEM manipulation at Zone 2. (a) 45˚ azimuth, 45˚ angle. (b) 315˚ azimuth, 45˚ angle. (c) 45˚ azimuth, 60˚ angle. (d) 315˚ azimuth, 60˚ angle

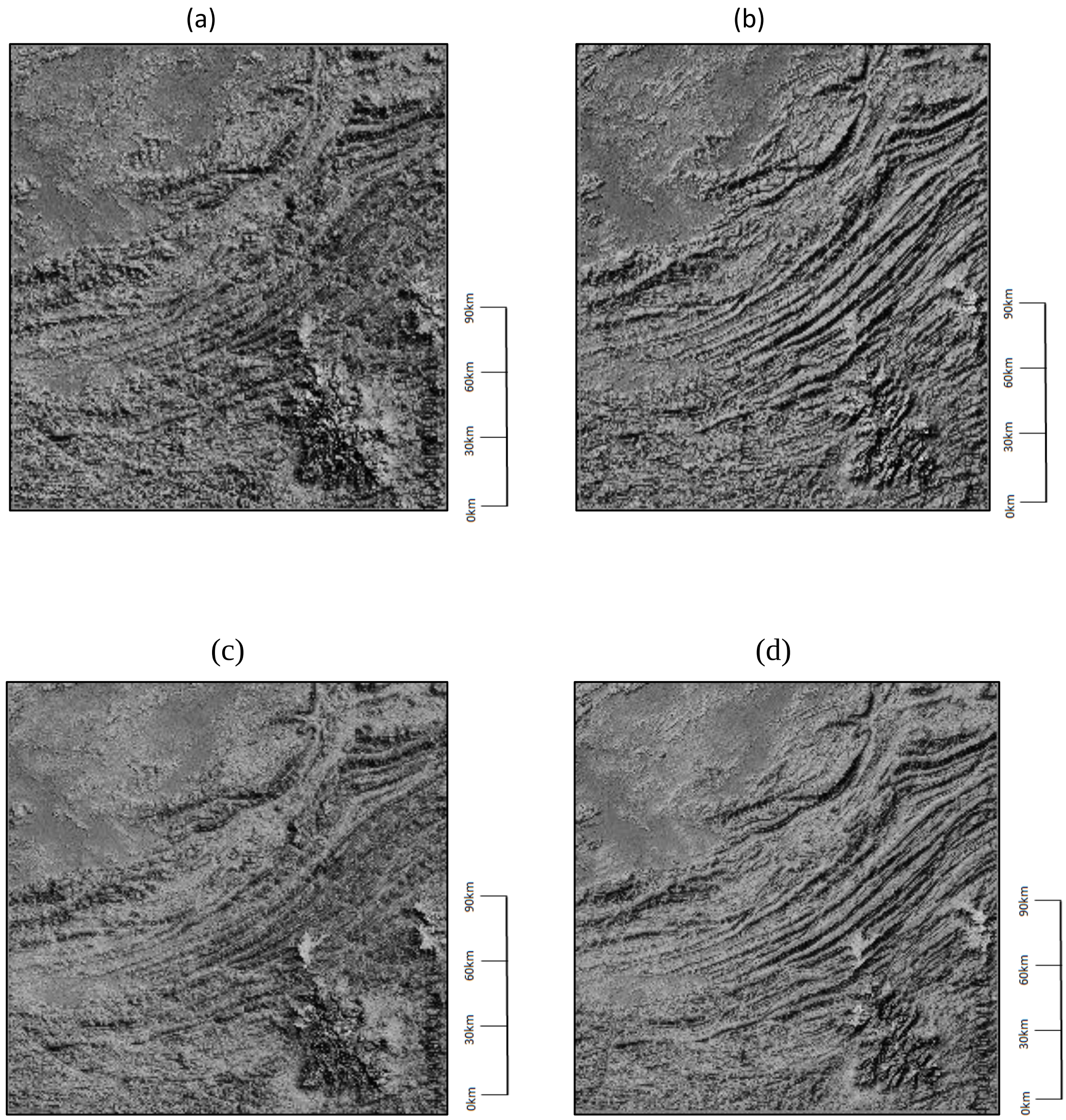

Figure 13 : DEM manipulation at Zone 3. (a) 45˚ azimuth, 45˚ angle. (b) 315˚ azimuth, 45˚ angle. (c) 45˚ azimuth, 60˚ angle. (d) 315˚ azimuth, 60˚ angle.

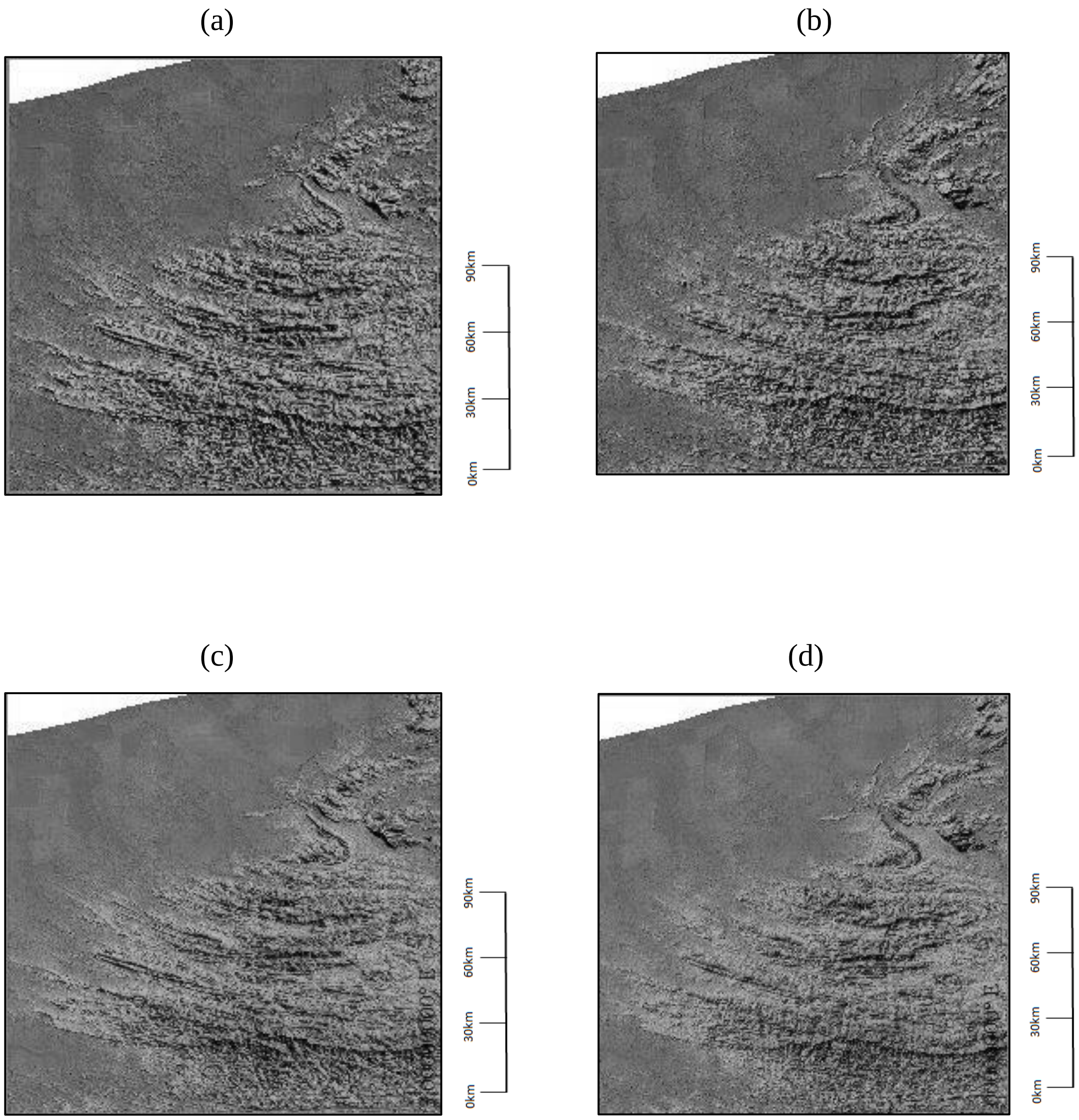

Figure 14 : DEM manipulation at Zone 4. (a) 45˚ azimuth, 45˚ angle. (b) 315˚ azimuth, 45˚ angle. (c) 45˚ azimuth, 60˚ angle. (d) 315˚ azimuth, 60˚ angle

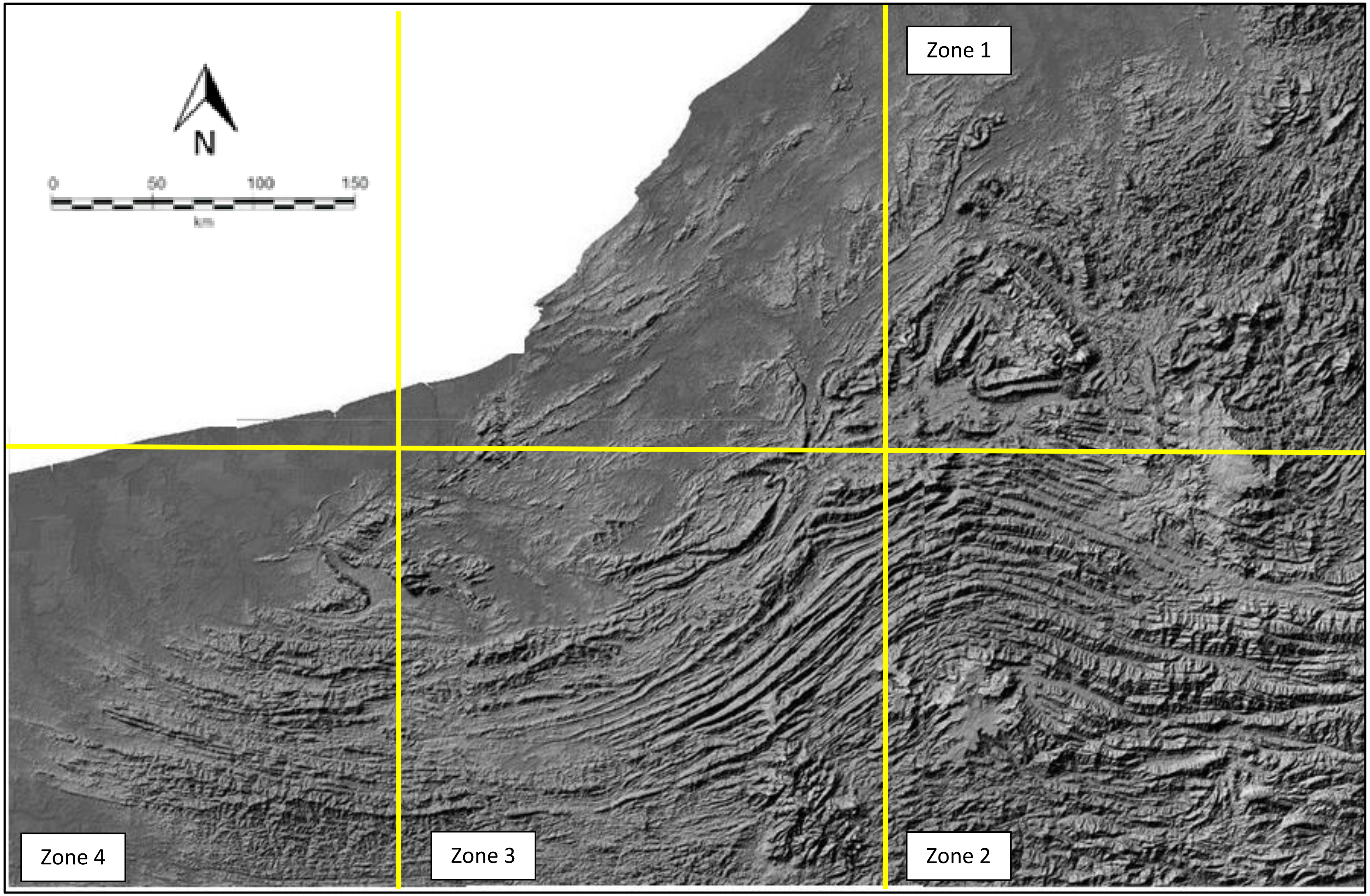

Figure 15 : Shaded relief images focused on 4 zone of interest

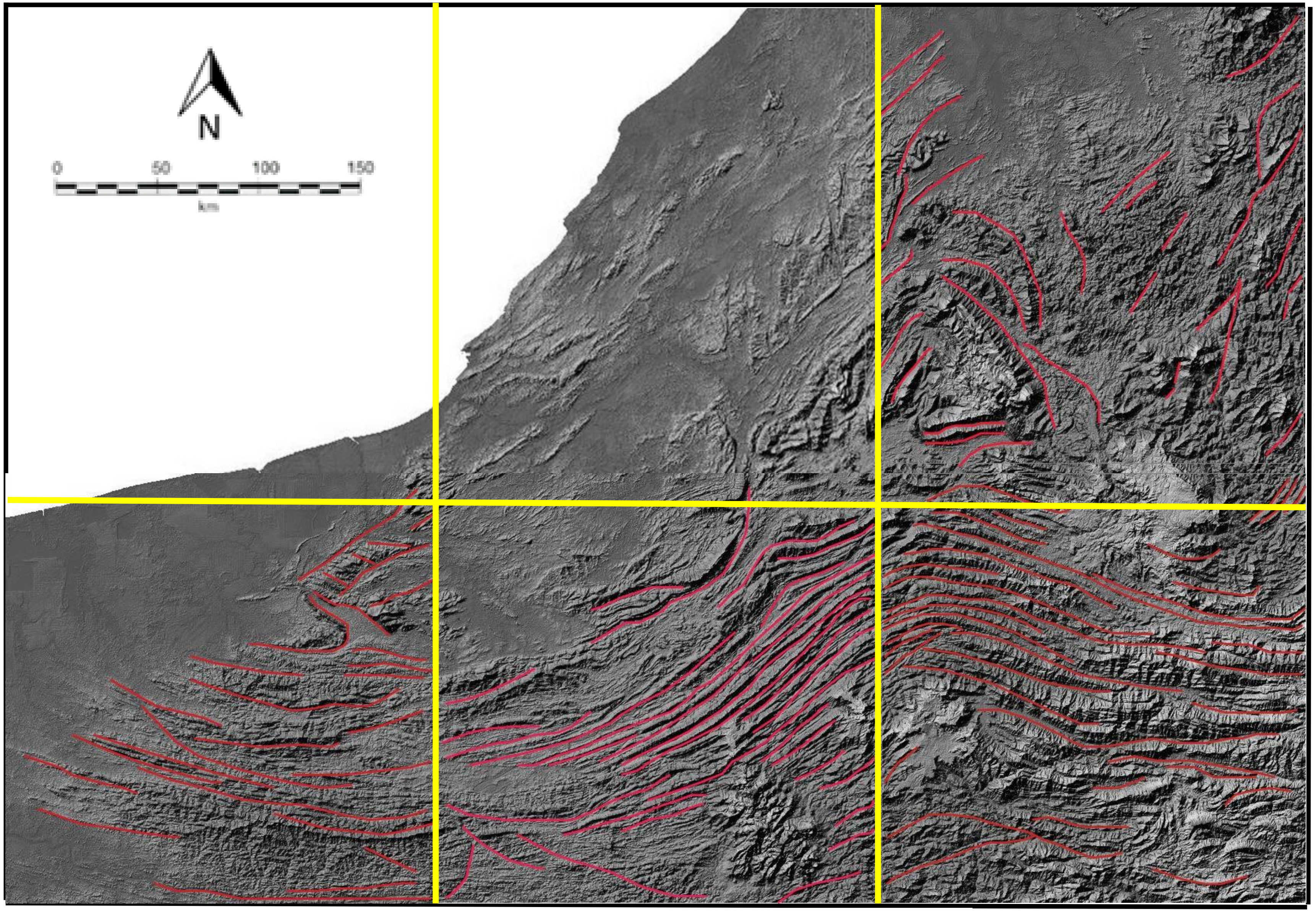

Figure 16 : Shaded relief image with extracted lineament in 4 interest zones

4.3 Geological Map

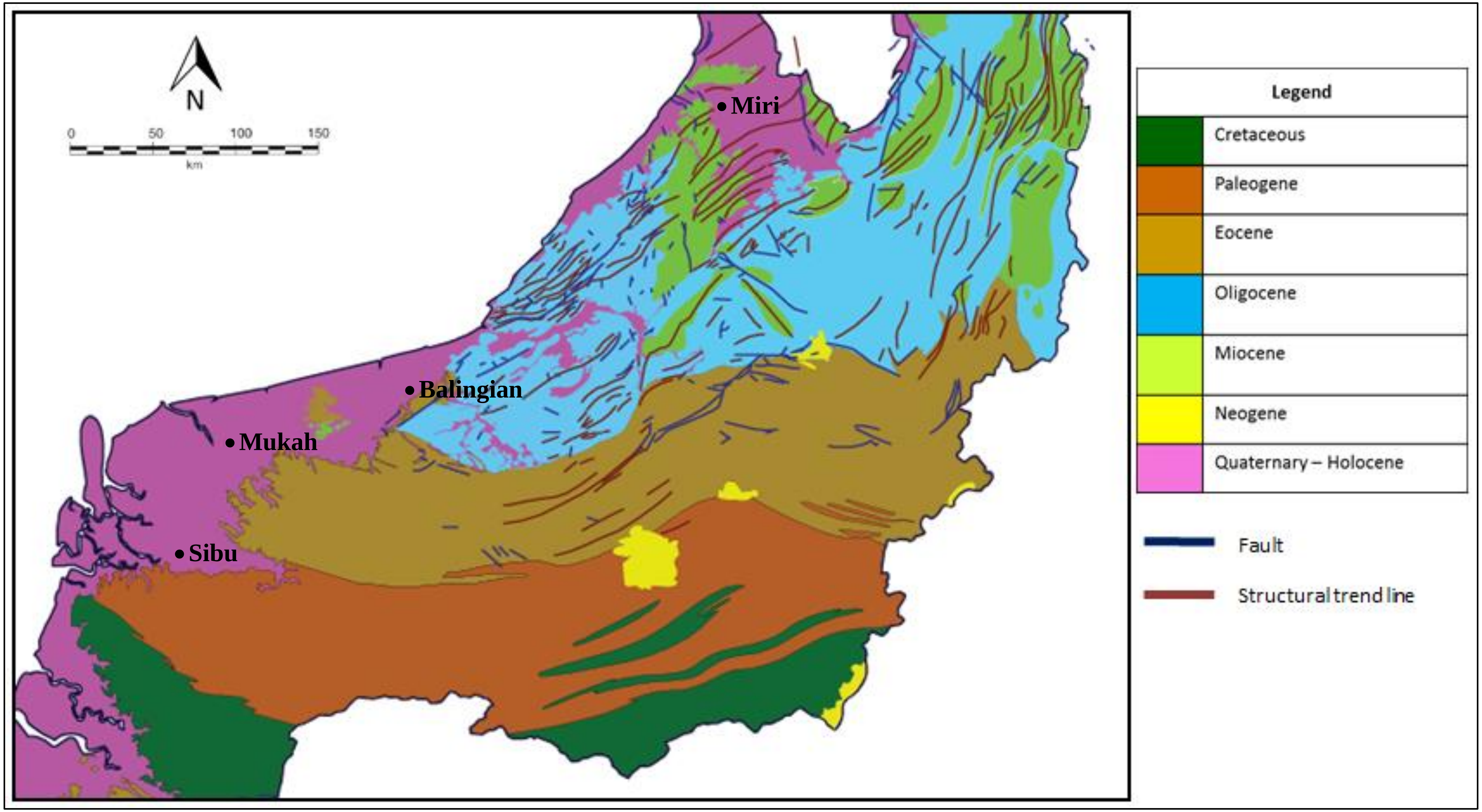

Figure 17 : Geological Map for study area modified from Robert Tate (2002)

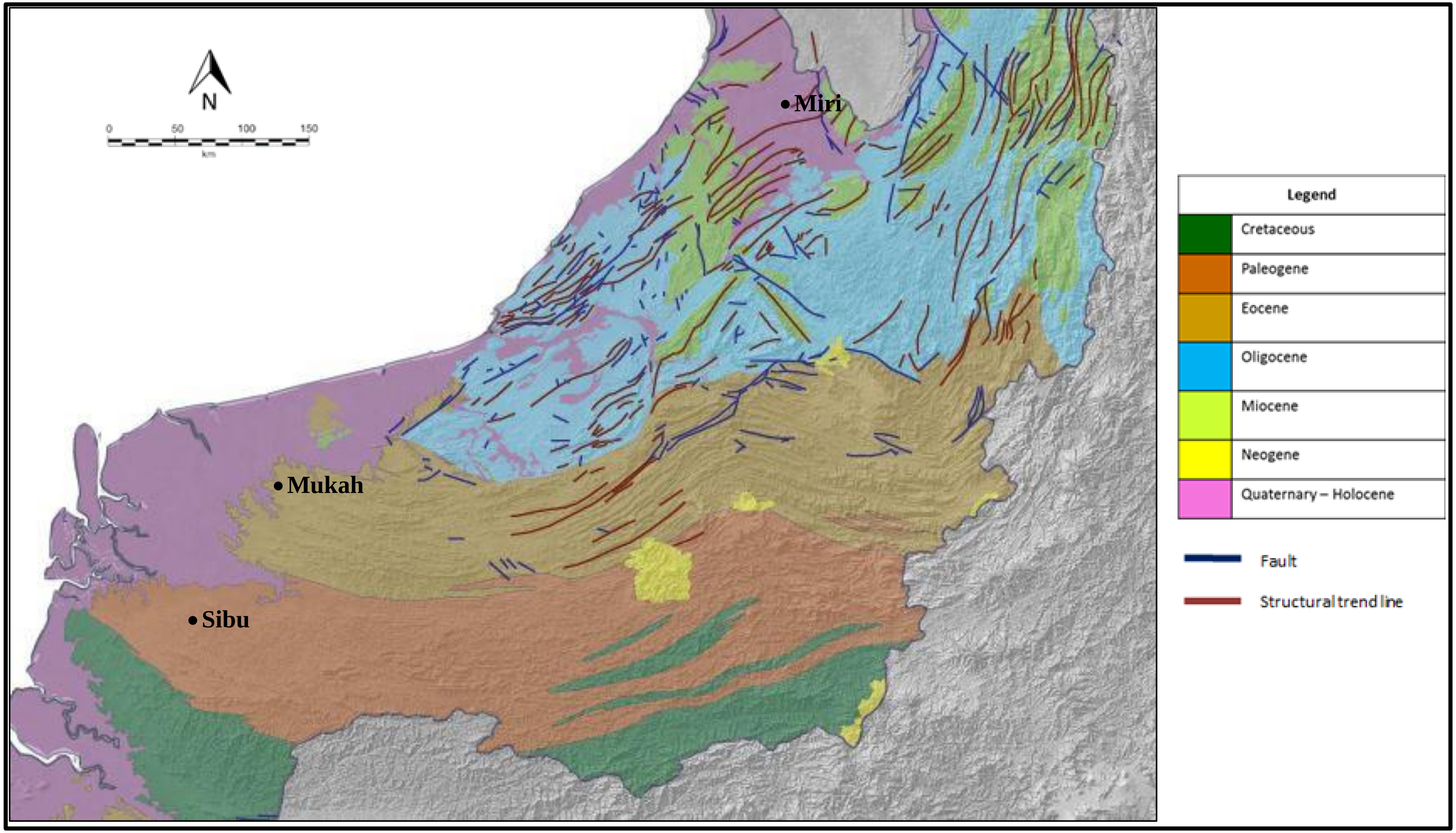

Figure 18 : Geological map overly with shaded relief images of DEM

4.4 EXTRACTED LINEAMENT AND ROSE DIAGRAM

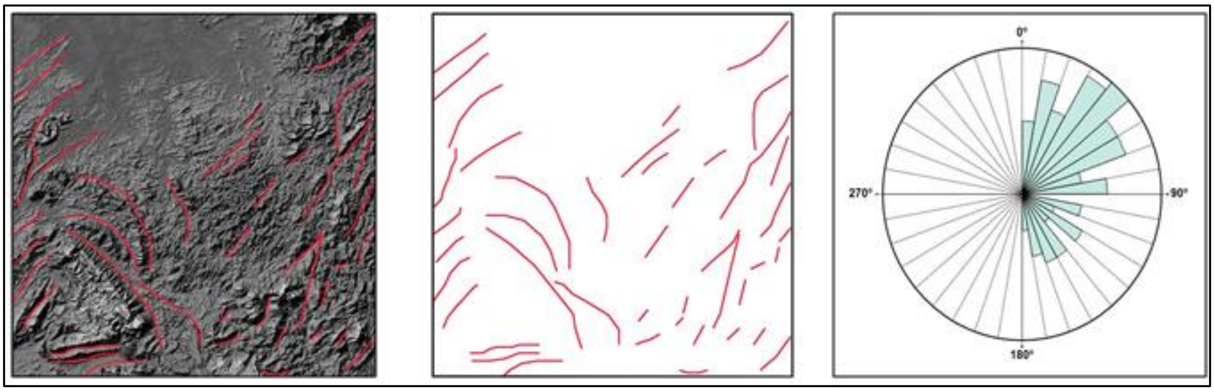

Figure 19 : Extracted lineaments and respective rose diagram of Zone 1

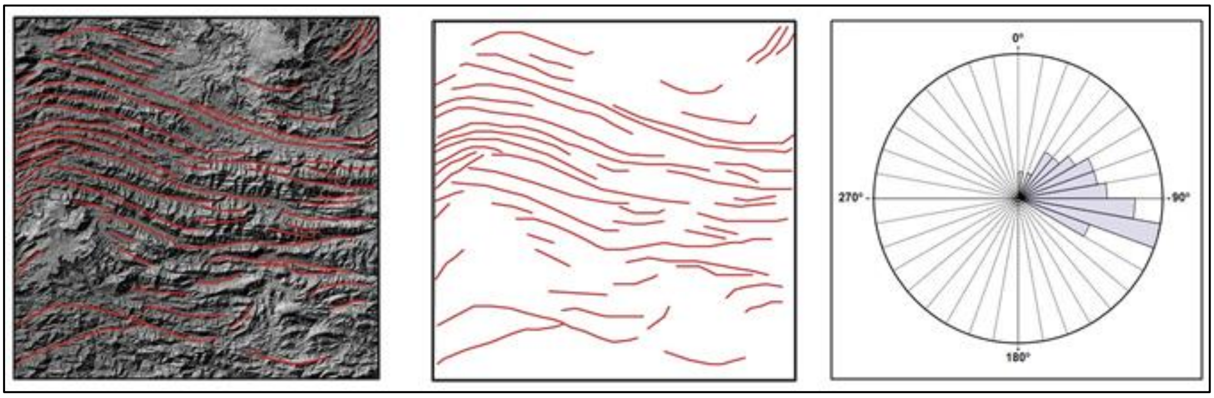

Figure 20 : Extracted lineaments and respective rose diagram of Zone 2

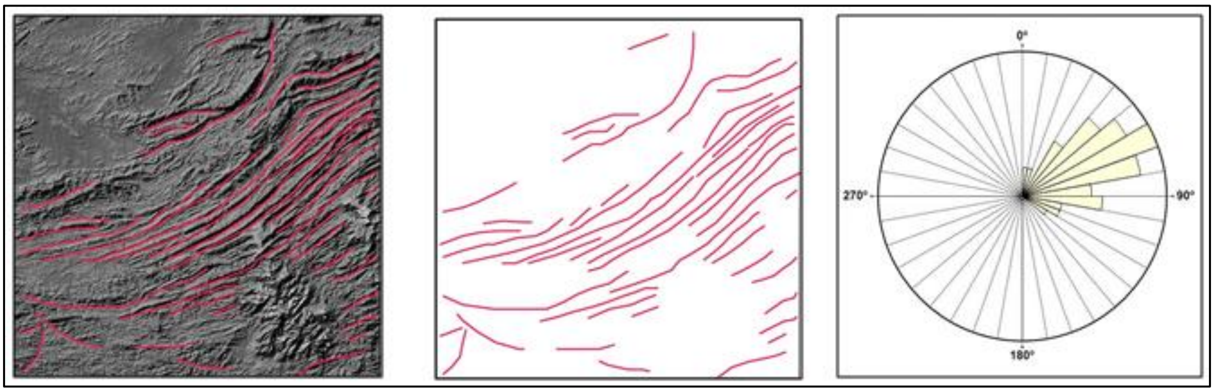

Figure 21 : Extracted lineaments and respective rose diagram of Zone 3

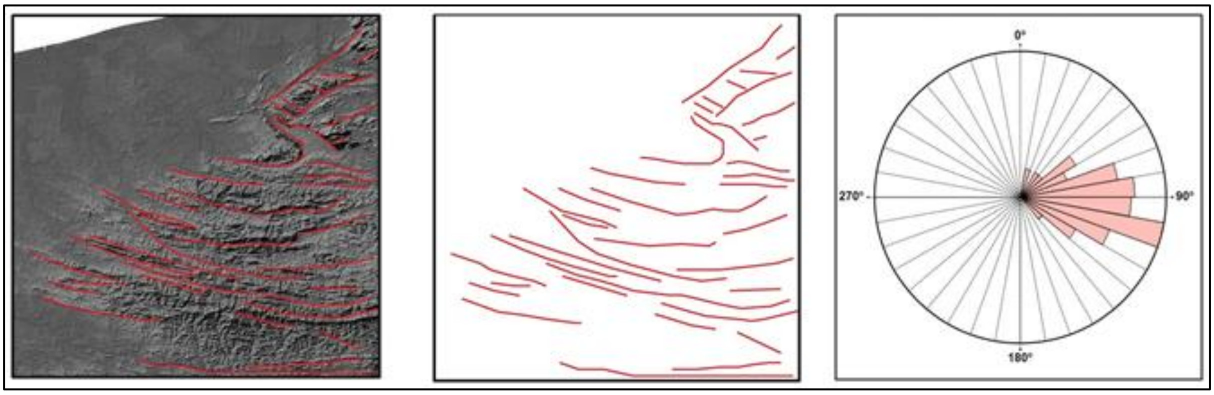

Figure 22 : Extracted lineaments and respective rose diagram of Zone 4

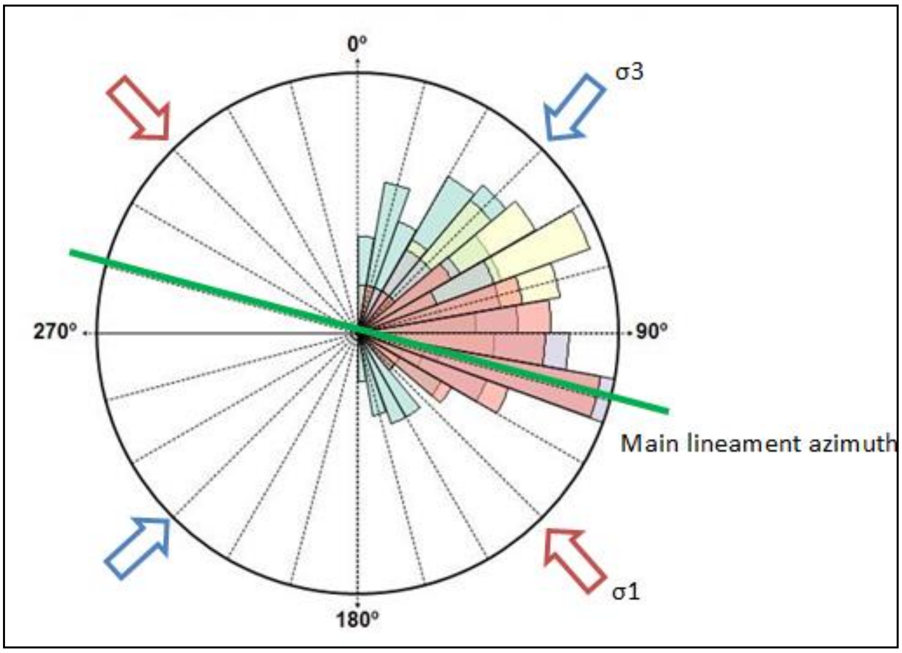

Figure 23 : Rose diagram comprises the entire lineament in the all zone

More than 70 lineaments have been interpreted in each zone and mapped. In addition to that, respective lineaments were plotted into rose diagram to assist in define the structural trend of the area (see Figure 19, 20, 21 and 22).

Zone 2, 3 and 4 have more prominent lineament observed as the area is part of highly deformed fold thrust belt with associated with curvilinear and continuous features. Looking at the rose diagram, the structural trend of the study area tends to be towards NE and SE. Interval with maximum values can also be considered as major structural trend.

Orientation of lineaments and geological structure observed in DEM are related closely to tectonics effect. Lineament pattern then suggest that the motion is in the response to the NE extension and SW compression as source of shear strength. Interpreted structural trend coincide to the direction of tectonic activities specifically compression due to the opening of South China Sea and subduction of proto South China Sea into Borneo Basement that were said to be generated during Eocene. Compression also coming from southern part as Australia was docking towards Borneo. Both of these compressions that have been occurred simultaneously re-enact Mode II type of fracturing that give rise to fractures or lineament around 30° from σ1 as well as 45° to 60° from σ3.

Since the spreading of SCS still going until Oligocene as well as the collision with Australia, major uplift occurred to the Rajang Range because of simultaneous compression from different direction. This is probably why we have such clear and highly deformed of lineament on Zone 2, 3 and 4. Based on the elevation that observed in the area, it appeared higher and has more vertical exaggeration compared to the rest of the Sarawak.

In regards to much recent tectonics, Pliocene age witnessed volcanism as volcanic plateau can be observed in the certain area. The volcanic activity might also affect the lineament. Most probably because of the existence of volcano in Zone 2, the lineaments have been cut. The volcanism might also reactivate some tectonics such as uplift to the area after it has been terminated by Mid Miocene Unconformity as there are proved that the uplifting still continue until today.

Tectonic evolution of Sarawak coincides and agrees well with the direction of shear strength. The author also construct chronology table of tectonic evolution consist of key events that might affect the lineament as it is on present day.

Table 3 : Chronology of tectonic evolution of Sarawak

<table>
<tr><th colspan="3">Geological Time</th><th colspan="2">Key events</th></tr>
<tr><td>Period</td><td>Epoch</td><td>Stage</td><td></td><td></td></tr>
<tr><td rowspan="2">Quarternary</td><td rowspan="2">Pleistocence</td><td>Late</td><td rowspan="4">Volcanic plateau
Subsequent uplift</td><td></td></tr>
<tr><td>Early</td><td></td></tr>
<tr><td rowspan="4">Neogene</td><td>Pliocence</td><td></td><td>NW-SE compressional inversion started.
Tranpression movement in Celebes Sea</td></tr>
<tr><td rowspan="3">Miocene</td><td>Late</td><td></td></tr>
<tr><td>Middle</td><td>Mid Miocene Unconformity</td><td></td></tr>
<tr><td>Early</td><td rowspan="3">Major uplift and erosion in the Rajang fold belt</td><td></td></tr>
<tr><td rowspan="9">Paleogene</td><td rowspan="3">Oligocene</td><td>Late</td><td></td></tr>
<tr><td>Middle</td><td></td></tr>
<tr><td>Early</td><td rowspan="2">Sarawak orogeny</td><td></td></tr>
<tr><td rowspan="3">Eocene</td><td>Late</td><td>.</td></tr>
<tr><td>Middle</td><td rowspan="6">Subduction of proto SCS
NW-SE rifting of southern margin of SCS
SE extrusion of Indochina</td><td></td></tr>
<tr><td>Early</td><td></td></tr>
<tr><td rowspan="3">Paleocene</td><td>Late</td><td rowspan="4">Collision between SW Borneo & continental block rifted from Australia</td></tr>
<tr><td>Middle</td></tr>
<tr><td>Early</td></tr>
<tr><td>Cretaceous</td><td></td><td></td></tr>
</table>

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Conclusions

Through DEM, lineament or linear trends of faults can be observed, especially in large geographical areas and have limited access. DEM data is also sufficient to image and map geological structures. Besides, different variation of DEM attribute can help in bringing the best feature for better interpretation. Results from lineament analysis agree well with the tectonic history. Lineaments map and rose diagram give more evidence and support the idea suggest that Sarawak is highly affected due to the opening of South China Sea as well as the subduction of proto South China Sea and uplift events occur on the Central Sarawak. Understanding the lineament trend will give more insight to the knowledge of tectonic evolution of Sarawak. Therefore, it gives us prior information for what kind of basin that we are looking for.

Recommendations

The scope of study involves structural lineament analysis and its implications to tectonic activity that shaped the surface topography. However, certain lineaments might not be of geological origin and the lack of capability of DEM to distinguish lithology opens further opportunities for future work with regard to extensive field survey and sample analysis.

By DEM, we are only looking at the surface. It would be much better if there are some seismic shots taken so that we have prior knowledge on what also happen underneath. Therefore, with this kind of tectonic deformation, we could have better understanding on how it would affect the subsurface.

REFERENCES

A. Briais, P. P. (1993). Updated interpretation of magnetic anomalies and seafloor spreading stages in SOuth China Sea; implications fro the tertiary tectonics of Southeast Asia. *Journal of Geophysical Research*, 6329-6388.

A. Kassou, A. E. (2012). Extraction of Structural Lineaments from Satellite Images Landsat 7 dETM+ of Tighza Mining District (Central Morocco). *Research Journal of Earth Sciences*, 44-48.

About Sarawak. (2011). Retrieved 16 February, 2014, from State Planning Unit, Chief Minister's Department of Sarawak: http://www.spu.sarawak.gov.my/geography.html

Allaby, A. A. (1999). *Rose Diagram*. Retrieved 14 February, 2014, from A DIctionary of Earth Sciences: http://www.encyclopedia.com/doc/1O13-rosediagram.html

Benard, F., Muller, C., Letouzey, J., Rangin, C. and Tahir, S. (1990). Evidence of multiphase deformation in the Rajang - Crocker Range (northern Borneo) from Landsat imagery interpretation: geodynamic implications. . *Tectonophysics*, 321-339.

C. D. Clark and C. Wilson. (1994). Spatial analysis of lineaments. *Computers & Geosciences*, 1237-1258.

C. M. Z. Ismail, R. E. (1997). The tectonic evolution and associated sedimentation history of Sarawak Basin, easterm Malaysia : a guide for future hydrocarbon exploration. In A. M. Fraser, *Petroleum Geology of SE Asia* (pp. 237-245). Geological Society of London Publication.

C. Mohanty, D. J. Baral & J. N. Malik. (2004). Use of Satellite Data For Tectonic Interpretation, NW Himalaya. *Journal of the Indian Society of Remote Sensing*, 241 -247.

C. S Caran, C. M. (1982). Lineament Analysis and Interference of Geologic Structure - Examples from the Balcones/Ouachita Trend of Texas. *Geological Circular 82-1*, 59-69.

C. S. Caran, C. M. (1981). Lineaments - a critical appraisal. *Geological Society America, 15th Annual Meeting*, 234-235.

Chenrai, P. (2012). DEM Application for Geological Structure Interpretation : A Case Study at the Koh Samui ARea, Gulf of Thailand. *World Applied Science Journal*, 1516-1520.

Cullen, A. B. (2010). Transverse segmentation of the Baram-Balbalac basin, NW Borneo: refining the model of Borneo's tectonic evolution. *Petroleum Geosciences 16*, 3-29.

Esri. (2013). Retrieved 18 February, 2014, from What is GIS?: http://www.esri.com/what-is-gis/overview

Gower, R.J.W. (1990). Early Tertiary plate reconstructions for the South China Sea region: constraints from Northwest Borneo. *Journal Southeast Asian Earth Sc. 4*, 29-35.

Hall, R. M. (2008). Impact of India-Asia collision on SE Asia : The record in Borneo. *Tectonophysics*, 366-389.

Hamilton, W. (1979). Tectonics of the Indonesian region. 345.

Hazebroek, H.P. and Tan, D.N.K. (1993). Tertiary tectonic evolution of the Northwest Sabah continental margin. *Geol. Soc. Malaysia, Bull. 33*, 195-210.

Holloway, N. H. (1982). North Palawan block, Philippines - Its relation to Asian mainland and role in evolution of South Cina Sea. *American Association of Petroleum Geologist Bulletin*, 1355-1383.

Ismail, C. S. (1997). The tectonic evolution and associated sedimentation history of Sarawak Basin, eastern Malaysia: a guide for future. *Geological SOciety of London Special Publication*, 237.

James, D. M. (1984). Regional Geological Setting. In *The Geology and Hydrocarbon Resources of Negara Brunei Darussalam* (pp. 34-42). Brunei: Brunei Museum and Brunei Shell Petroleum Company.

L. D. Setijadji, N. I. (2010). Kalimantan mineral resources: an update on exploration and mining trends, synthesison magmatism history and proposed models for metallic mineralisation. *39th IAGI Annual Convention and Exhibition*, (p. 14). Lombok.

Liechti, P., Roe, R.W., Haile, N.S., . (1960). Geology of Sarawak, Brunei and western North Borneo. *British Borneo Geological Survey Bulletin*, 3.

Madon, M. (1991). Geological setting of Sarawak. In *The Petroleum Geology and Resources of Malaysia* (pp. 273-290). Kuala Lumpur: Petroliam National Berhad (PETRONAS).

Madon, M. and Redzuan, A.H. (1999). Tatau Province. In *The Petroleum Geology and Resources of Malaysia* (pp. 411-426). Kuala Lumpur: PETRONAS.

Madon, M., Abolins, P. (1999). Balingian Province . In *The Petroleum Geology and Resources of Malaysia* (pp. 343-368). Kuala Lumpur: PETRONAS.

Meijnnger, B. M. (2001). *Geographic information system analysis of northern-western Greece: A testonic investigation of north-western Greece by means of remote sensing analysis and digital terrain analysis.*

Morshidi, N. F. (2013). *Morphostructural Analysis of Onshore and Offshore Sabah using Digital Elevation Model.*

Moss, S. J. (1998). Embaluh Group turbidites in Kalimantan: evolution of a remnant oceanic basin in Borneo during the Late Cretaceous to Paleogene. *Journal of the Geological Society in London*, 509-524.

N. K. Kuterdem and K. Dirik. (2007). Determination of the Morpho-Tectonic Features and Stress-State of a Region Using Geographic Infromation Techniques : A Case Study from the Ismetpasa-Gerede Segment of the North Anatolian Fault Zone. *Geological Buletin of Turkey*, 41-55.

P. E. Peters, D. S. (1987). Correlation of Early Tertiary rocks across Kalimantan. *Indonesian Petroleum Association 16th Annual Convection*, (pp. 291-306).

Replumaz, A. and Tapponier, P. (2003). Reconstruction of the deformed collision zone between India and Asia by backward motion of lithospheric blocks. *Journal of Geophysical Research*.

S. Christopher Caran, C. M. Woodruff, Eric J. Thompson. (1982). Lineament ANalysis and Interference of Geologic Structure - Examples from the Balcones/Ouachita Trend of Texas. *Geological Circular*, 59-69.

Shuttle Radar Topography Mission (SRTM). (2013). Retrieved 2014 February, 2014, from Global Land Cover Facility: http://glcf.umd.edu/data/srtm/

Sim, D & Jaegar, G. (2003). Tectonostratigraphy and trap style of the Half-Graben sub-province in West Luconia, offshore Sarawak. *Bulletin of Geological Society in Malaysia 49*, 107-110.

Solar azimuth angle. (n.d.). Retrieved 5 April, 2014, from Wikipedia: http://en.wikipedia.org/wiki/Solar_azimuth_angle

Taib, N. (2010). Upper Rajang Valley, Sarawak – is Borneo rifting?

Tan, D. N. K. & Lamy, J. M. (1990). Tectonic Evolution of NW Sabah continental margin since the Late Eocene. *Bulletin of Geological Society of Malaysia*, 241-260.

Unit 38 - Digital Elevation Model. (30 August, 1997). Retrieved 16 February, 2014, from University of British Columbia, Department of Geography: http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/u38.html#SEC38.1.1