The Integration of Remote Sensing Data for Lineament Mapping in the Semanggol Formation, Northwest Peninsular Malaysia

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Abstract. The objective of this study is to prepare a final lineament map of three parts of the Semanggol Formation and its adjacent areas, located in northern Peninsular Malaysia. Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, digital elevation model (DEM) and drainage pattern were used to trace lineament. These data were digitally processed to enhance the visibility of data and derive to twenty-four images. Only negative lineaments with length more than 2 km were traced by using manual lineament extraction method. Based on the results, there are differences in the number of lineaments and total length in each data, caused the lineaments to have to compare each other. The lineaments identified from all data were integrated and evaluated to produce a final lineament map. A total of 645 lineaments were identified with a total length of 2264.42 km and a maximum length of 26.84 km. The trend of the lineaments was correlated with faults in the published geological map, especially in the Bok Bak Fault. This method proved that lineaments could be traced more accurately with the utilisation of various remote sensing data.

Keyword: DEM, drainage pattern, Landsat, lineament, Semanggol Formation

1. Introduction

Hobbs [1] introduced lineaments in terms of geology as lines indicate the rock basement due to fracture (fault or joint). Other researchers defined lineaments as lines on satellite imageries, aerial photographs or topographic maps that can be divided into two types of lineaments – positive lineament and negative lineament [2–4]. Positive lineament represents bedding, which can be identified from ridges or ranges, while negative lineament represents fault or joint, which can be identified from valleys or rivers [2]. Lineaments are mappable from local to continental scales [4]. The interpretation of the lineament study is vital in structural analysis, oil and gas exploration, landslide susceptibility analysis and other geological applications since the 1940s [5, 6].

The Semanggol Formation is located in the northwest Peninsular Malaysia, which was discovered and introduced by Alexander [7]. The formation consists of Chert Unit, Rhythmite Unit and Conglomerate Unit [8], and stretches from the northern border of Kedah southwards to the north part of Perak. In terms of formation parts, the Semanggol Formation is divided into three parts – North Kedah, Central Kedah and North Perak, and there are two adjacent areas of the formation which are
igneous intrusions [9]. The intrusions were split up from the Semanggol Formation by the Bok Bak Fault [10–14]. The distribution of radiolaria at the exposed chert outcrops indicated that the depositional environment is deep marine environment. Based on previous studies, the Semanggol Formation were ranging from Permian to Triassic [15].

This study aims to generate a final lineament map for the Semanggol Formation and its adjacent areas. Various remote sensing data were used and integrated for this study to delineate lineaments, and these data are Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, digital elevation model (DEM) and drainage pattern. The study area covers approximately 10,800 km^2 (Figure 1).

Figure 1. Location of the study area.

2. Literature Review

2.1. Geological setting of the study area

The study area has various types of formations, which are the Semanggol Formation, Jerai Formation, Baling Formation, Mahang Formation, Kubang Pasu Formation, Siaong Beds, Quaternary deposits and igneous intrusions (Figure 2). However, this study focuses on the Semanggol Formation and igneous intrusion at the adjacent to the mentioned formation.
The Semanggol Formation was a continuous formation which was later separated into three parts by two wrench faults and followed by two igneous intrusions at the adjacent areas of the formation [12]. The parts are North Kedah, Central Kedah and North Perak. The major fault which separated the formation is the Bok Bak Fault, which was initially recognised by Burton [10], which estimated the initial net displacement of 55 km. Raj [11] estimated the displacement to be 20 km. Based on lithofacies equivalents by Abdullah et al. [12], the displacement was estimated to be 25 km. The estimation of the displacement of the fault is 30 km, based on gravity studies [13]. Burton [10] noted that a strand of the Bok Bak Fault was injected with granite, suggesting that movements were initiated concurrently with the Upper Triassic intrusion. Based on the disposition of the related faults, the maximum compressive force must have been in a WNW to ESE direction. The transpressive movements were believed to have been Late Cretaceous. The age of the intrusion was proven by Salmanfarsi et al. [14], which resulted in an age of 136.1 ± 1.6 Ma, based on ⁴⁰Ar/³⁹Ar radiometric dating of biotite in mylonite.

2.2. Application of remote sensing for lineament mapping
Lineaments identification can be conducted via two principle techniques, namely, manual and automatic extraction [16]. The manual technique is mainly based on visual interpretation and involves the utilisation of image enhancement processes such as image ratio, image fusion and directional
filters [17, 18]. The automatic technique consists of the computer’s software and algorithms [19]. Both methods have advantages and disadvantages, according to the quality and the experience of the interpreter to interpret the imagery data (Table 1). There are more advantages of using manual lineament extraction method compared to automatic lineament extraction method.

Table 1. Manual and automatic lineament extraction method comparison, adapted from Ramli et al. [4].

| Manual lineament extraction | Automatic lineament extraction |
|-----------------------------|--------------------------------|
| Partly depend on the complexity of the research area | Totally depend on the complexity of the research area |
| Depend on human experience and ability | Depend on the mathematical function of software |
| Time consuming to extract lineaments | Very quick to extract lineaments |
| Strong effect of human interpretation | Little effect of human interpretation |
| Easy to distinguish the lineament (tectonic setting, humanmade) | Cannot recognise the lineament (the result may be confused) |
| Simple but subjective method | Complex but objective method |

3. Methodology

3.1. Data gathering
There are three Landsat 5 TM images, two Landsat 7 ETM+ images and one Landsat 8 OLI image which covers the whole study area. The Landsat images were selected based on the cloud coverage percentage, which must be less than 10%. The images of Landsat 5 TM and Landsat 7 ETM+ were mosaicked respectively to have a single image for each Landsat sensor. Then, all Landsat images, including Landsat 8 OLI image, were subsetted into the study area. Twelve topographic maps with scale 1:50,000, which cover the whole study area, were used to obtain contour line with 20 m intervals, elevation point and drainage pattern.

3.2. Data processing
The data processing is divided into 2 parts – Landsat imageries and topographic maps.

3.2.1. Data processing for Landsat imageries. The data processing for Landsat imageries are false colour composite (FCC) and directional filter.

Lineaments identification was undertaken using the false colour composite (FCC) of RGB 7, 5, 3 combination which was obtained from different band combinations [20] and found to be the most optimum combination for Landsat 5 TM and Landsat 7 ETM+ images. While for Landsat 8 OLI image, FCC of RGB 7, 6, 4 was used.

The edge detection filter (directional filter) used for this study was Sobel 3x3 filter, which was commonly used for lineament extraction [21]. This filter was applied to band 4 Landsat 5 TM and Landsat 7 ETM+ and band 5 Landsat 8 OLI images in four directions: N-S, E-W, NE-SW and NW-SE (Table 2).

Table 2. Sobel filter in four main directions, adapted from Koçal [21].

| N-S | NE-SW | E-W | NW-SE |
|-----|-------|-----|-------|
| -1  | 0     | -2  | -1    |
| -2  | 0     | 1   | 0     |
| -1  | 0     | 1   | 2     |
| -2  | -1    | 0   | 1     |
| -1  | 0     | 1   | 2     |
| -2  | -1    | 0   | 1     |
3.2.2. Data processing for topographic maps. The data processing for topographic maps was applied to generate DEM and drainage pattern.

From DEM, eight shaded relief images (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° solar azimuths) were created [22]. The creation of various shaded relief images was done to avoid bias of lineament tracing if only use one solar azimuth [23]. An ambient light setting of 0.2 was applied for all solar azimuths to produce a good contrast [22]. Low solar elevation angle such as 30°, enhances topographic expression and highlights geologic structures, and orientation of the illumination source, enhances features perpendicular to the line of solar illumination [24].

The drainage pattern was used because most of the surfaces in Central Kedah and North Perak area are covered by the recent alluvium (elevation <20 m) and the rivers flow on top of them. The underneath bedrocks are hidden by sediments, causing difficulties in studying the rocks directly [25]. The river tends to flow in the shortest path to the shoreline, according to the regional slope formed by the smoothing topography [26]. However, if the rivers do not do so, it is interpreted as a drainage anomaly, and it probably influenced by the local geological structures, topographic anomalies or other external factors [27].

3.3. Lineament extraction
There were 24 images used based on data processing. For this study, only negative lineaments with more than 2 km length were traced by using manual lineament extraction method within the study area.

General features that can lead to lineament identification from the images are topographic features such as sudden tonal variations and alignment of vegetation, straight rock boundaries, straight valleys and continuous scarps and systematic offset of rivers. The method was entirely subjective, depends on the image interpretation skills, to ensure the lineament was distinguished correctly.

3.4. Evaluation of lineament
There were 24 lineament maps produced, and each lineament map represented as a GIS layer that was linkable to each other. However, these layers may result in confusion and complexity. Based on these problems, a final lineament map was generated – the layers were combined into a single lineament map.

Two lineament layers extracted from different data were overlaid onto the same map (Figure 3). Duplicated lineaments were manually removed from the map every time a new layer was added. If there are two lineaments at the same location having different lengths, the shorter lineaments were deleted. Besides, non-geologic lineaments such as roads, field boundaries and paths were removed as well. All lineaments outside the Semanggol Formation and its adjacent areas were erased.

4. Results and Discussion

4.1. Lineament maps
The results of lineament maps generated from each remote sensing data were shown in terms of lineament frequency, total length and the maximum length of lineament (Table 3).
Based on FCC images, the lineaments were clearly seen in granitic areas. The lithological boundaries between sedimentary and igneous rocks were clearly observed at the adjacent areas of the Semanggol Formation. The boundaries could be considered as lineaments. The straight line of the river, which is also classified as lineaments. Although FCC image of Landsat 5 TM has a lower resolution compared to Landsat 7 ETM+ and Landsat 8 OLI images, the lineaments were still easily recognised, as previously done by Raj [11] using Landsat MSS images which have the same resolution as Landsat 5 TM images. More lineaments were extracted from Landsat 7 ETM+ and Landsat 8 OLI images due to the higher resolution image (Table 3). There were some areas which the lineaments observed from Landsat 5 TM and Landsat 8 OLI images, but not in Landsat 8 OLI image. This case is because the areas might be excavated or blasted; thus, the lineaments were eradicated. So, it is an advantage in using different Landsat sensors. Furthermore, roads and trenches spotted from FCC images could avoid the extraction of non-geological lineaments as this identification of this type of lineaments was already applied by Ramli et al. [4] and Abdullah [22]. The disadvantage of using FCC images is the lineaments were hardly observed in the alluvium area.

**Figure 3.** Steps of integration of lineament maps generated from different remote sensing data to produce a final lineament map (maps were not to scale).
The directional filter of 3x3 Sobel filter yields an effective way to evaluate lineaments. This type of filter enhanced detecting the lineaments which were not favoured by the illumination source [28]. Four derived images generated from four directional 3x3 Sobel filters (N-S, NE-SW, E-W and NW-SE) allows detecting lineaments in all possible directions. The Sobel images with the directional filter of N-S and NE-SW for all Landsat imageries have more lineaments extracted compared to E-W and NW-SE directional filter (Table 3). These directional filters allow highlighting longer lineaments according to different directions [29]. The disadvantage identified from this filtering method is that the lineaments cannot extract in low-contrast areas effectively, which the features extended parallel to the mountain shadows and sun directions [30].

The number of lineaments was very high at shaded relief images of 0°, 45°, 90°, 270° and 315°, and less lineaments were extracted at shaded relief images of 135°, 180° and 225°. The existence of light from a few angles in shaded relief images caused False Topographic Perception Phenomena (FTPP) [31]. The visualisation of valleys as ridges and vice versa in some areas are the results of FTPP. A few azimuth angles were ideal for identification of more lineaments, where there was no FTPP affected in that particular azimuth angles of DEM. However, DEM affected by FTPP showed an inverse picture of the rugged terrain, which makes it difficult to identify either the lineament is positive or negative [31, 32].

The development of the drainage depends on the characteristics of the bedrock such as lithology, fracture set, slope gradient etc. Lithology can be observed on the surface is those in high topography or relief [27]. The river flowed down from the hilly area (igneous intrusion) to the lowland (Semanggol Formation), was transporting and deposited sediments within the river or stream and formed the low topography or relief of sediments which is dominant within the Semanggol Formation. This type of sediment may have hidden geological structure which can only be traced based on

Table 3. Details of lineaments extracted from various remote sensing data.

| Raw Data       | Image                  | Lineament Frequency | Total Length (km) | Maximum Length (km) |
|----------------|------------------------|---------------------|-------------------|---------------------|
| Landsat 5 TM   | FCC (7, 5, 3)          | 195                 | 692.108           | 10.809              |
|                | 3x3 Sobel (N-S)        | 114                 | 450.450           | 8.402               |
|                | 3x3 Sobel (NE-SW)      | 124                 | 489.932           | 10.754              |
|                | 3x3 Sobel (E-W)        | 72                  | 246.493           | 7.520               |
|                | 3x3 Sobel (NW-SE)      | 83                  | 274.911           | 14.426              |
| Landsat 7 ETM+ | FCC (7, 5, 3)          | 229                 | 841.418           | 16.404              |
|                | 3x3 Sobel (N-S)        | 112                 | 473.728           | 13.839              |
|                | 3x3 Sobel (NE-SW)      | 108                 | 482.105           | 15.457              |
|                | 3x3 Sobel (E-W)        | 92                  | 403.069           | 11.952              |
|                | 3x3 Sobel (NW-SE)      | 83                  | 310.332           | 12.310              |
| Landsat 8 OLI  | FCC (7, 6, 4)          | 208                 | 636.469           | 11.795              |
|                | 3x3 Sobel (N-S)        | 105                 | 424.367           | 17.664              |
|                | 3x3 Sobel (NE-SW)      | 122                 | 483.694           | 16.677              |
|                | 3x3 Sobel (E-W)        | 111                 | 443.215           | 14.618              |
|                | 3x3 Sobel (NW-SE)      | 96                  | 397.721           | 11.285              |
| Topographic map| DEM 0°                 | 194                 | 875.794           | 21.293              |
|                | DEM 45°                | 186                 | 775.546           | 18.466              |
|                | DEM 90°                | 172                 | 688.601           | 14.891              |
|                | DEM 135°               | 111                 | 517.185           | 16.668              |
|                | DEM 180°               | 123                 | 516.403           | 16.736              |
|                | DEM 225°               | 120                 | 512.587           | 14.618              |
|                | DEM 270°               | 182                 | 661.988           | 14.913              |
|                | DEM 315°               | 199                 | 742.587           | 19.252              |
|                | Drainage pattern       | 434                 | 1151.554          | 9.026               |
drainage pattern. The drainage pattern is controlled by structure and lithology in the study area. Based on the lineament extraction from the drainage pattern, it is evident that this is the most lineament traced compared to previous remote sensing data. There were 434 lineaments identified, however over 90% of the lineaments are lineaments ranging from 2 to 2.99 km long, mostly extracted from Quaternary sediments, which were not easily recognised from Landsat imageries.

4.2. Final lineament map

A final lineament map was produced from the validation of lineament maps generated from various sources (Figure 4). A total of 645 lineaments with 2264.42 km total length identified for the whole study area. The maximum length of the lineament is 26.84 km. Generally, the pattern of the map suggests that the fault line which belongs to the Bok Bak Fault was identified correctly, particularly in the boundaries between the Semanggol Formation and its adjacent areas, trending to NW-SE direction. Lineaments in other parts, mainly in the igneous intrusion, display a typical pattern of the faults as already mapped in the existing geological map (Figure 2).

![Figure 4. Final lineament map of the Semanggol Formation and adjacent areas.](image-url)
various source of remote sensing data. Previous studies only used a source of data with low-resolution images for lineament mapping, which may have inaccuracy in terms of lineament identification. The Landsat images should be compared with other sensors to identify any changes in the features in a specific area. Furthermore, the various DEM data could differentiate the presence of lineaments by the effect of FTPP [31, 32]. The drainage pattern was useful to delineate lineaments on surfaces with elevation less than 20 m. The manual lineament extraction method was suitable to apply for this study because of the high vegetation of the study area and easy to identify non-geological lineaments.

5. Conclusion and Recommendation
Lineaments could be traced by using not only from Landsat imagery, but also from DEM, drainage pattern or any other data. Previous researchers mostly used only one source of remote sensing data for lineament mapping. The method might have inaccuracy of lineament identification. By using the integration of various remote sensing data, the lineaments will be more accurate to trace since the comparison of lineaments can be made before producing a final lineament map.

Lineament mapping in the Semanggol Formation is an example of using the integration of remote sensing data. From 24 images, a final lineament map of the study area was produced. A total of 645 lineaments with a total length of 2264.42 km and a maximum length of 26.84 km were identified from the lineament map. The accuracy of this map is proven by comparing the map with the published geological map, and the trend of the lineaments shows similarity.

The lineament mapping can be more precise by integrating remote sensing applications with gravity data which can identify subsurface structures. Besides, a more high-resolution image, e.g. IKONOS, QuickBird etc. can be used for lineament mapping.

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