StereoSAR DEM for Mapping of Geological Structures in Selangor, Malaysia

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Abstract

Radar is ideally suited for the study of tropical countries, which have extensive cloud cover. These countries are usually heavily vegetated and although radar does not penetrate the vegetation cover, its sensitivity to subtle topographic features means that geological structures are clearly visible. Stereo radar images can also be used to generate a Digital Elevation Model (DEM). Images acquired with Radarsat modes S2 and S7 were used to generate a DEM for Selangor, Malaysia. The resultant DEM shows that Selangor can be divided into two sub-areas comprising rugged hills to the east and a flat, coastal, plain to the west. The topography was enhanced by applying a synthetic sun illumination to the DEM with elevation of 60° and azimuths of 030°, 120°, 210°, and 300°, respectively. From this image the topography was used to interpret geological lineaments. Three major directions trending between 240°- 300°, 285°- 330° and 350°- 045° are identified. These features are present in both the flat regions and the hilly regions and represent a pervasive regional structural trend.

StereoSAR DEM untuk Pemetaan Struktur Geologi di Selangor, Malaysia

Abstrak

Radar adalah sesuai untuk kajian di negara beriklim tropika, yang diselubungi oleh awan tebal. Negara-negara ini biasanya dilitupi tumbuhan dan walaupun radar tidak boleh menembusinya, kesensitifannya terhadap fitur topografi membolehkan struktur geologi kelihatan jelas. Imej stereo radar juga boleh digunakan untuk menghasilkan Model Digital Ketinggian (DEM). Imej yang digunakan dengan mod S2 dan S7 Radarsat telah digunakan untuk menghasilkan satu DEM untuk Selangor, Malaysia. Hasil DEM menunjukkan Selangor boleh dibahagikan kepada dua sub-kawasan; perbukitan di sebelah timur dan dataran pantai rata di sebelah barat. Topografinya boleh ditingkatkan dengan mengaplikasikan illuminasi sintetik matahari kepada DEM pada ketinggian 60° dan azimut 030°, 120°, 210° dan 300° masing-masing. Daripada imej ini, topografi digunakan untuk mentafsirkan lineamen geologi. Tiga arah utama berjurus antara 240° - 300°, 285° - 330° dan 350° - 045° telah dikenalpasti. Fitur ini hadir di kawasan rata serta perbukitan dan mewakili tren struktur serantau.

INTRODUCTION

Synthetic Aperture Radar (SARs) has become one of the most attractive sensors for obtaining geological data in tropical countries. These countries, which have extensive cloud cover and are heavily vegetated, require a remote sensing system, which can penetrate cloud cover and is sensitive to subtle topographic features. Stereo radar images from the same system can also be used to generate a Digital Elevation Model (DEM).

Most DEMs generated for Malaysia has been extracted using manual measurements from a topographic map. This procedure is uneconomic and too time consuming to complete. This paper discusses the generation of a DEM using StereoSAR Radarsat images. Images acquired with Radarsat modes S2 and S7, dated July 10 1998 and May 20 1998, respectively were used to generate a DEM for mapping geological structures in Selangor, Malaysia.

DESCRIPTION OF STUDY AREA

The study area is located between 2° 45' to 3° 31' N and 101° 09' to 102° 00' E in the state of Selangor, Peninsular Malaysia and comprises approximately 10,000 km^2 (Figure 1). In the northeast section of the study area, the Main Range granite has narrow valleys and steep crests covered by virgin forests. Some parts of the area have been cleared but it was replanted with different types of timber and has now regrown as secondary forest.

Moderate relief terrain ranging from 20° to 30° slopes consisting of Howthornden Schist and Kenny Hill Formation covers the north and south of the study area. This terrain consists of schist, sandstone, mudstone and shale and has largely been planted with oil palm and rubber. The Klang Valley consists of limestone and granite and is located in the centre of the study area.

Quaternary deposits consisting of clay and sand are located in the southwest section of the study area. Sedimentation from the Kelang and Langat Rivers have formed delta structures at the mouths of both rivers. Most of the plains are covered with agriculture plantations especially oil palm and coconut. Along the coastal fringe, most areas still remain as mangrove tidal swamps.

DEM GENERATION FROM STEREOSAR RADARSAT

Radarsat can collect imagery from different directions (ascending or descending), different beam positions and modes, and at different resolutions ranging from 10 m to 100 m. Radarsat images are popular for DEM generation because it is possible to acquire many images with suitable geometry and radiometric characteristics.

It is possible to use either ascending and descending mode stereo pairs for DEM generation. The right combination of beam modes and directions is an important first step in obtaining quality output result. Maximum geological information is obtained when the structural features are perpendicular to the SAR viewing geometry. Riopel *et al.* (1999) and Singhroy *et al.* (1999) found that the best results are obtained from side stereo (ascending/ascending or descending/descending) with large overlaps and large stereo intersection angles. Same side stereo direction images provide the best results because of the parallax problem with opposite side directions, particularly in an area with rugged topography. Therefore, the images acquired for this study used Standard Beam modes S2 and S7, have an intersection angle of 19° and were both acquired descending from an orbit. Figure 2 shows the study area as viewed by modes of S2 and S7. Large parallax effects are visible in these images because of the high relief.

The DEM was generated using the IMAGINE StereoSAR DEM Module at the Centre of Remote Sensing and GIS, University of New South Wales, Australia. The main procedure consists of three stages; viz. Image Registration, Image Matching, and Image Correlation. The two images in a right precise orbital modelling, S2 and S7

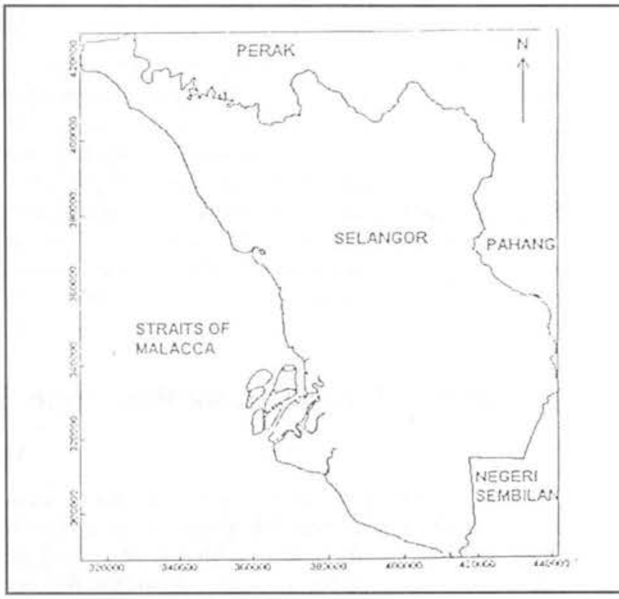

Figure 1: Location of the study area in Selangor, Malaysia.

Figure 2a: High terrain area, Standard 2 Mode.

Figure 2b: High terrain area, Standard 7 Mode.

were adjusted to Flight Path State parameters by registration to the orbital parameters using six well-distributed known ground control points (GCPs). S2 was chosen as the reference image because of its shorter Near Slant Range while S7 was chosen as the matching image.

For image registration, eight tie points were selected to cover the whole image. S7 was resampled so that most of the parallax with respect to S2 is along the X-axis. The X-axis parallax values for each pixel were used by the Imagine StereoSAR DEM module to calculate the height of the area.

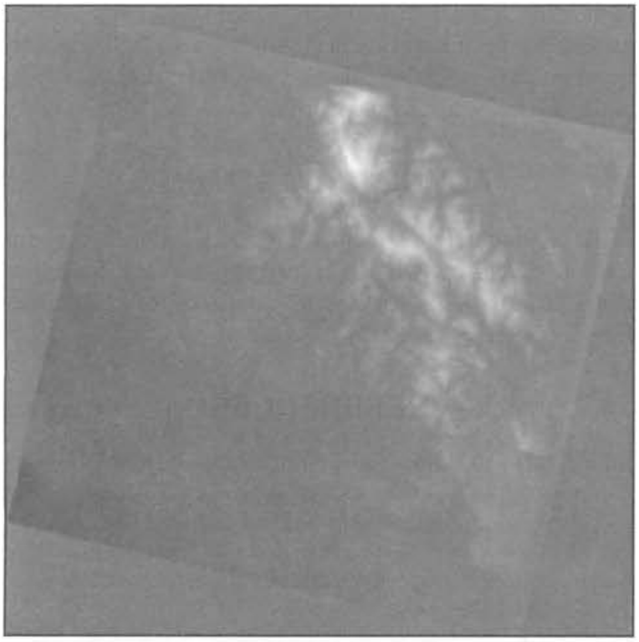

Figure 3: DEM generated from S2 and S7 StereoSAR Radarsat.

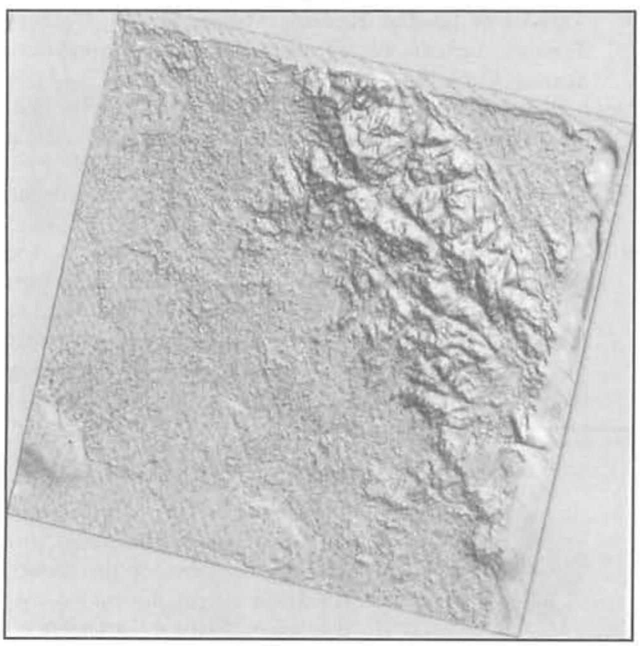

Figure 4: Synthetic Sun illuminated DEM with an azimuth of 030° and an elevation of 60°.

After processing the imagery for tie point selection, an estimation of high or low information density was made by selecting the right correlator. Two types of correlators were used in this study. These were STD_HP_LD for hilly regions with low density in land cover details and STD_LP_LD for flat regions also with low density in land cover details. It is very important to choose the right correlator because an unsuitable correlator can cause a missing values (holes) in the output DEM. The DEM created is shown in Figure 3. The height RMS error is approximately + or – 10 meter.

MAPPING OF GEOLOGICAL STRUCTURES

Radar data is useful for structural mapping because the amplitude of the radar echo is highly sensitive to the physical properties of the surface. This causes the brightness of the surface to vary much more than in the case of optical or infrared images (Robinson *et al.*, 1999). Lineaments on the radar image are due to straight or aligned surficial topographic features, such as valleys and ridges. Lineaments in the study area are believed to be due to weathering and erosion along faults and joint sets.

To highlight the geological structure and maximise the topographic information, the DEM was enhanced by applying a synthetic sun illumination with an elevation of 60° and azimuths of 030° (Figure 4), 120°, 210°, and 330°, respectively. Seven hundred and twenty six lineaments that are straight, parallel or sub-parallel, and are longer than 300m were then visually interpreted from the synthetic sun illuminated DEM (Figure 5).

The interpreted lineaments were statistically analyzed using the Lineament Wizard in ER-Mapper software. The frequency of lineaments, total length and mean length rose diagrams indicate that there are three major sets of

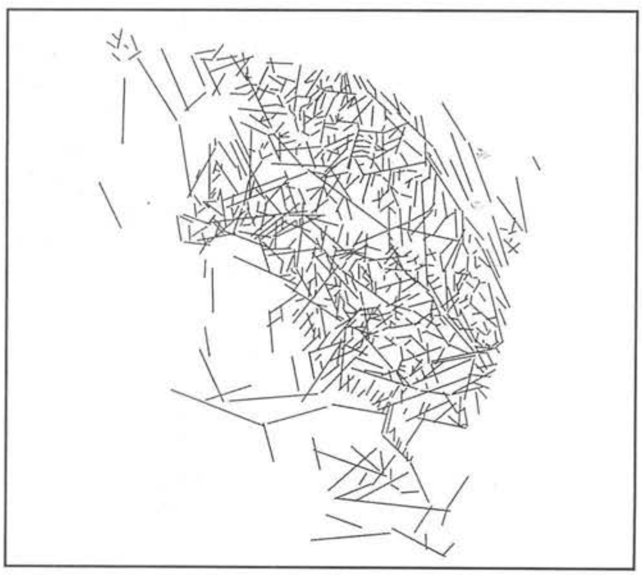

Figure 5: Lineaments traced from the synthetic sun illuminated DEM of Selangor, Malaysia.

lineaments in the study area (Figure 6). These groups comprise lineaments trending between 350°- 045°, 285°-330° and 240°-300°. The total lineament length plot (Figure 6, centre) shows that the group trending 350° to 045° collectively represent a greater degree of fracturing. The major lineaments in this direction are mostly concentrated in the hilly regions. The second group of lineaments between 285° to 330° are found throughout the study area. Furthermore, the mean lineament length plot (Figure 6, right) suggests that the longest lineaments in the region trend between 240° and 300°. The group in this trend is found throughout most of the study area but is absent in the northeastern margin.

DISCUSSION

The tectonic model for Selangor has been interpreted based on the information acquired from the lineament analysis of the DEM and previous studies such as Burton (1965), Gobett *et al*. (1973), Tjia (1989), Tjia (1994) and Noraini Surip *et al*. (1996). Two major periods of tectonism have created geological structures in this area. The Gondwana Terrane became welded to the Laurasia Terrane before the Middle Triassic (Figure 7). As a result of this tectonism, the Bentong-Bengkalis Suture was formed and this is interpreted in northeastern part of the study area (Figure 8).

During the Late Triassic to Early Jurassic, a large-scale granite was emplaced in Peninsular Malaysia (Tjia, 1994). The granite magma was squeezed upward between the Lower Carboniferous to Lower Triassic sedimentary rocks (Burton, 1965) in the study area.

Two major faults, the Bukit Tinggi fault zone and the Kuala Lumpur – Ulu Endau fault zone (Figures 8 b and c) and other lineaments, which can be mapped on the output DEM image were formed after Early Jurassic. Tjia (1994) found that the areal tectonic compression for the granite exposed along the Selangor-side of the Karak Highway is in the NNE-NE sector and parallel to the edges of the Genting thrust belt. Therefore, the granite was already solidified when thrusting took place. Structural features including lineaments, fault zones and fracture zones are widely believed to be most favorable for groundwater potential because they typically increase permeability and porosity, compared to the host rock (Brown, 1994). Moreover, regional structures strongly influence groundwater flow.

CONCLUSION

Radarsat standard S2 and S7 descending mode images are suitable for generating a DEM for mapping geological structure in Selangor, Malaysia. The DEM output result has provided a new structural prespective of the study area which was unidentified from the earlier study due to cloud and vegetation covers. The stereoscopic observations images taken from different Standard Beam Positions render the work of structural interpretation easier and more interesting.

Three major lineament trends are observed. The lineaments interpreted as the Bentong –Bengkalis Suture, Bukit Tinggi fault zone and Kuala Lumpur- Ulu Endau fault zone trend between 350° – 045° and represent a greater degree of facturing in the study area. The lineaments between 285° – 330° are found throughout the study area, while the longest lineaments trend between 240° – 300°.

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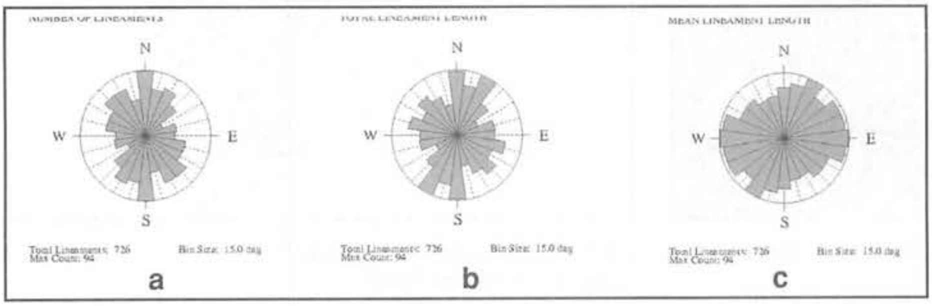

Figure 6. (a) Density directional rose diagram of Selangor lineaments. (b) Total length directional rose diagram of Selangor lineaments. (c) Mean length directional rose diagram of Selangor lineaments.

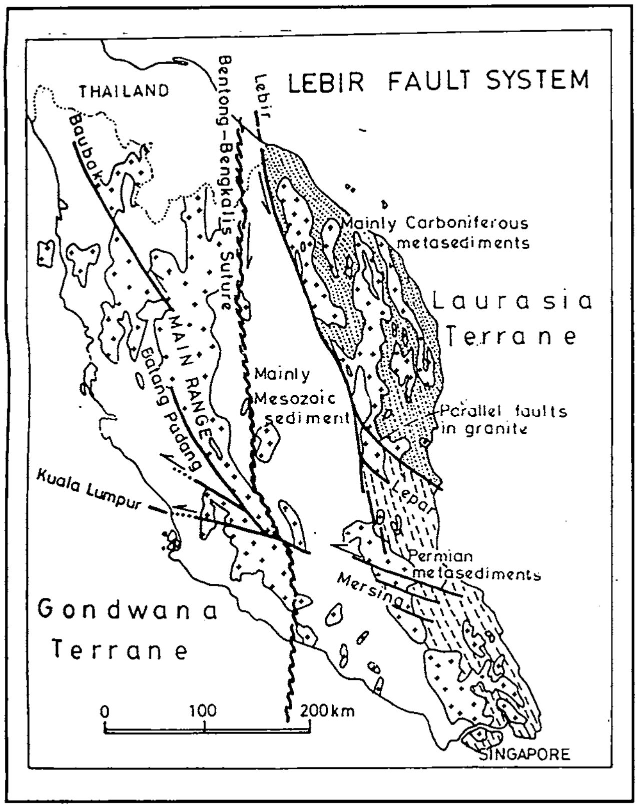

Figure 7: Major tectonic element of Peninsular Malaysia. (after Tjia, 1989).

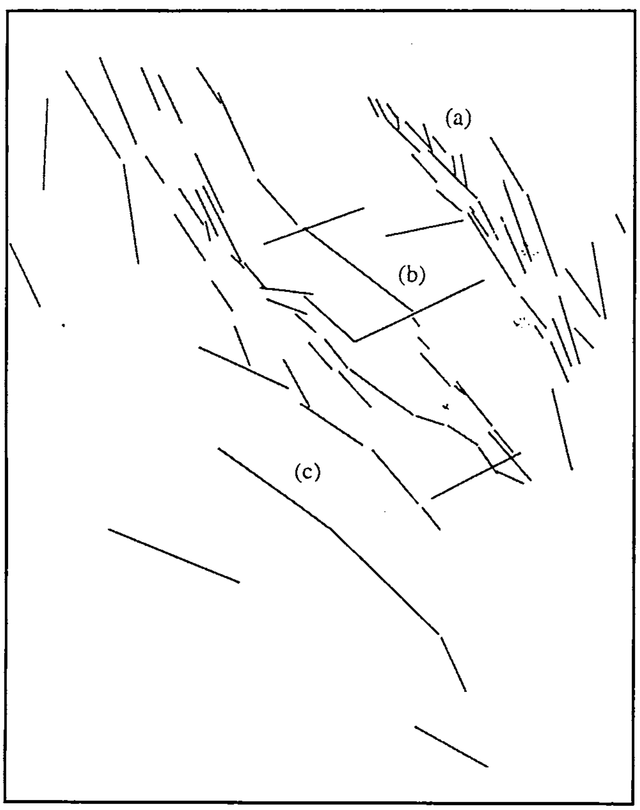

Figure 8: (a) Lineaments related to subduction activity. (b) Bukit Tinggi fault zone. (c) Kuala Lumpur fault zone.

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