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GEOLOGICAL APPLICATIONS POTENTIAL OF LANDSAT MULTISPECTRAL SCANNER SATELLITE DATA IN MALAYSIA:
A Kedah-Perak Case Study

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ABSTRACT. *Satellite data has found excellent applications in geological surveys particularly in arid and semiarid areas. However, for tropical areas, like Malaysia, there are very few examples indeed of geological studies based on satellite data. The main reason is due to the tropical terrain which has hindered the wider application of the technique. In Malaysia, the lack of trained or skilled manpower in the field and inadequacies inherent in the system have made the situation worst. However, the areas which may be of economic potential, need to be studied. The advantages offered by remotely sensed data are possibly the best alternative available in order to obtain geologic information in such difficult terrain.*

The aim of this study is to demonstrate the usefulness of Landsat Multispectral Scanner (MSS) satellite data for geological mapping for a part of Peninsular Malaysia. The data was digitally processed with the objective of producing more interpretable images. The techniques that have been found to be most useful for geological applications are band ratioing, principal component, contrast stretched MSS band 7 and filtering . Geological interpretation of the most informative images was undertaken by visual interpretation. The study shows that many image units correlate well with major mapped rocks. In addition, the study has shown that remotely sensed data can be used in locating known features and additional previously unknown features (probably faults). Despite the difficulties when involving satellite remote sensing work in this area, the study has provided some encouragement that the satellite data can be used to map major solid lithologies of the area. With more expertise and skill interested in the field, more equipment, facilities and user agencies, good quality and higher resolution data, the full potential of remote sensing technology, in geological applications and mineral exploration in Malaysia, can be exploited.

INTRODUCTION

The launch of Landsat-1 in 1972 presented geologists with the first opportunity to map large regions of the world. Satellite remote sensing has found particular application in regional geological surveys in non-vegetated or sparsely vegetated, well exposed arid and semi-arid environments (Rowan et al., 1974, and Viljoen et al., 1975), and more humid and temperate areas where vegetation is in natural communities (Talvitie, 1979; Raines and Wynn, 1982, Brooks and McDonnell, 1983). On the other hand, for the tropical rain forest zone, a combination of dense vegetation together with thick soil cover, greatly reduces the value of the imagery for geological application. Such terrain, therefore, has been largely ignored by remote-sensing geologists. As a result, there are very few examples indeed of published geological studies based on satellite remotely sensed images of these areas. Unfortunately, these highly vegetated regions (which may have economic potential), like many others, have to be studied, and surveyed and cannot be neglected simply because of the difficulties which may be encounter when involving satellite remote sensing work. In addition to the tropical terrain condition, geological remote sensing work in Malaysia is much less indeed compared to other countries in this region. One of the reasons is the lack of local trained and skilled manpower in this field and due to inadequacies in the system. In addition, many geologists are still not convinced that the technology can be used in geological applications, particularly lithological mapping, in Malaysia.

In Malaysia, nearly all previous geological works based on remotely sensed images have used relatively unenhanced images. This paper describes the result one of a first attempt to digitally process the Landsat Multispectral Scanner (MSS) data for the area and to use it for geological applications. The main aim of the study is to use and to assess the usefulness of digitally processed satellite remote sensing data for geological mapping from a portion of north-west Peninsular Malaysia. It is hoped, the outcome of this study will show that either the satellite data has a potential and can be used for geological application of the area, or vice versa due to certain factors such as dense forest, thick soil cover or perhaps related to the quality and spatial resolution of the data.

DATA AND STUDY AREA

The area selected for study occupies an area of approximately 3000 km^2, covering parts of Perak and Kedah State, Northwest Peninsular Malaysia, near the border between Malaysia and Thailand. This area was chosen for a number of reasons. Firstly, it contains a diversity of topography, so it is more appropriate for lineament mapping and analysis, and secondly, because it has several main rock types, so it is good for lithological mapping. In addition, the area is covered by one of the two scenes of Landsat MSS data with low percentage of cloud cover and good quality coverage of that part of Malaysia. The data, with 10% cloud cover, was obtained for the study area from the satellite passes of 10 January 1979 and occupies part of frame 137/56 in the worldwide reference system (WRS) and is recorded on computer compatible tape (CCT).

Figure 1 shows a generalized geological map of the area. The map shows that most of the area is underlain by intrusive igneous rocks of Lower Cretaceous-Middle Lower Jurassic (Hutchison, 1973) or Late Triassic (Geological Survey of Malaysia, 1985), and metamorphic rocks of Silurian-Ordovician age, which belong to the Baling Formation (Hutchison, 1973). Apart from these, sedimentary rocks of Triassic age, commonly affected by low grade regional metamorphism (Geological Survey of Malaysia, 1985) belong to the Semanggul Formation (Burton, 1973) and occupy the western part of the area (Figure 1). Besides these, small deposits of Recent and pre-Recent alluvium deposits occur along the meander belt of the Perak River and in area close to the present river channels, forming the alluvial plain and river terraces (Burton, 1970). In addition to the superficial deposits, it has been reported that the Tertiary basin deposits which consist of semi-consolidated and poorly bedded gravel, grit, sand and silt occur in the area (Jones, 1970). Apart from all these deposits, the weathering of bedrock under tropical conditions forms a relatively thick mantle of soil which occurs almost everywhere in the area. The major elements of the structural pattern in the area are large fractures and faults which appear to have occurred during brittle phase deformation in Post Triassic (Hutchison, 1973) or in Jurassic to Early Tertiary times (Tjia, 1978). One of the major faults in the Malay Peninsula, the Bok Bak Fault, runs in the northwest-southeast direction in the middle of the area. Besides that, there are numerous other major lineaments in the area, particularly in the upland areas, and it is likely that many of these lineaments, especially the longer ones are probably faults which may have not been mapped before.

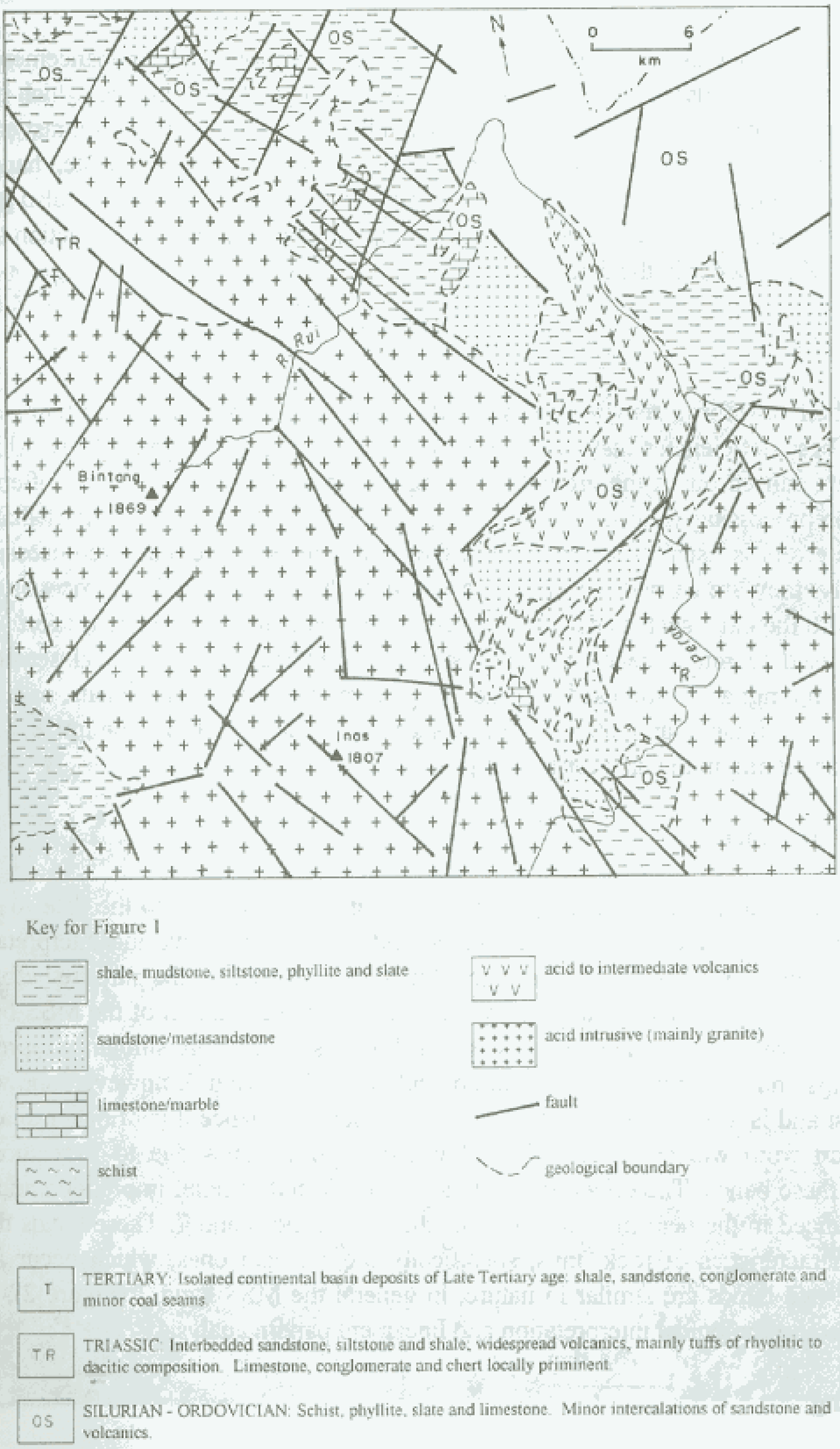


Figure 1: Slightly simplified map of the solid rock geology in the Kedah-Perak area (after Geological Survey of Malaysia, 1985).

DATA PROCESSING AND IMAGE PRODUCTS

In order to achieve the said objective of this study, various image enhancement techniques were applied to the Landsat MSS data with the objective of producing images which best enhance the lithologic units and structural features that exist in the area. These include contrast enhancement, combination of visible and reflected infrared data as false colour composite, band ratioing, principal component analysis and filtering. Before these operations, the data has also gone through several preprocessing steps such as de-striping, resampling and atmospheric correction to remove or reduce errors which occur in the data.

Preprocessing

In their raw form, remotely sensed data received from satellites may contain errors and anomalies. These deficiencies may have an impact on the result of image analysis. Although some corrections are carried out at the ground receiving station or data centre, there is often still a need for further preprocessing (Short, 1982). Hence, a series of corrective operations that remove or reduce these errors is usually necessary, and these operations are termed preprocessing because, quite logically, they are carried out prior to any use of the data. Several preprocessing techniques were applied to the data, such as de-striping, re-sampling and atmospheric correction. De-striping: a technique used to minimize or eliminate striping problems due to unequal sensitivity of the sensors; re-sampling: a method used to remove aspect ratio distortion of the data, and as well as to acquire a square image; and atmospheric correction: a step used to minimize the effect of atmospheric scattering in the data for further processing steps.

Contrast enhancement

Contrast enhancement techniques are necessary to be applied to the data to increase the apparent contrast between features in the scene and therefore improve the interpretability of an image. In this study, linear contrast enhancement method was used for the purpose before the image products were printed, evaluated and interpreted. Linear contrast stretch of the MSS band 7 of the study area is shown in Figure 2. Generally the MSS bands 4 and 5 are similar in representation of photo-elements and geological information content. The MSS band 5, however, shows maximum tonal contrast and is less effected by atmospheric interference, hence it is of better quality than the band 4. Apart from water bodies and shadows, other dark tones due to vegetation cover are prevalent in these bands. The effect of vegetation is less whereas relief impression and drainage is more pronounced in the near-infrared bands of the MSS band 6 and 7. These bands thus enhance the photo-characteristics of rock units, specifically the resistant ones, which occur in vegetated areas. These two bands are similar in nature, in general the MSS band 7 (Figure 2), however, is better for overall lithological interpretation and lineament pattern analysis.

Band ratioing

The process of numerically dividing the spectral values (SVs) in one image by the corresponding SVs in another image is well known as band ratioing. The technique is one of the most commonly used in digital image processing and widely used in geological interpretation of remotely sensed data. The band ratio technique is an effective method to enhance spectral differences or colour differences, and effectively removes the effect of variable degrees of brightness caused by the environment factors like topographic condition and shadow (Condit and Chavez, Jr., 1979; Sabin, 1987). MSS bands 7/5 (or MSS bands 5/7) is perhaps the most useful band ratio because it is positively related to vegetation amount (Tucker, 1979), which can be used to infer lithological information of this highly dense vegetated area. The MSS bands 7/4 gives better result in terms of relief impression and enhancing lineament.

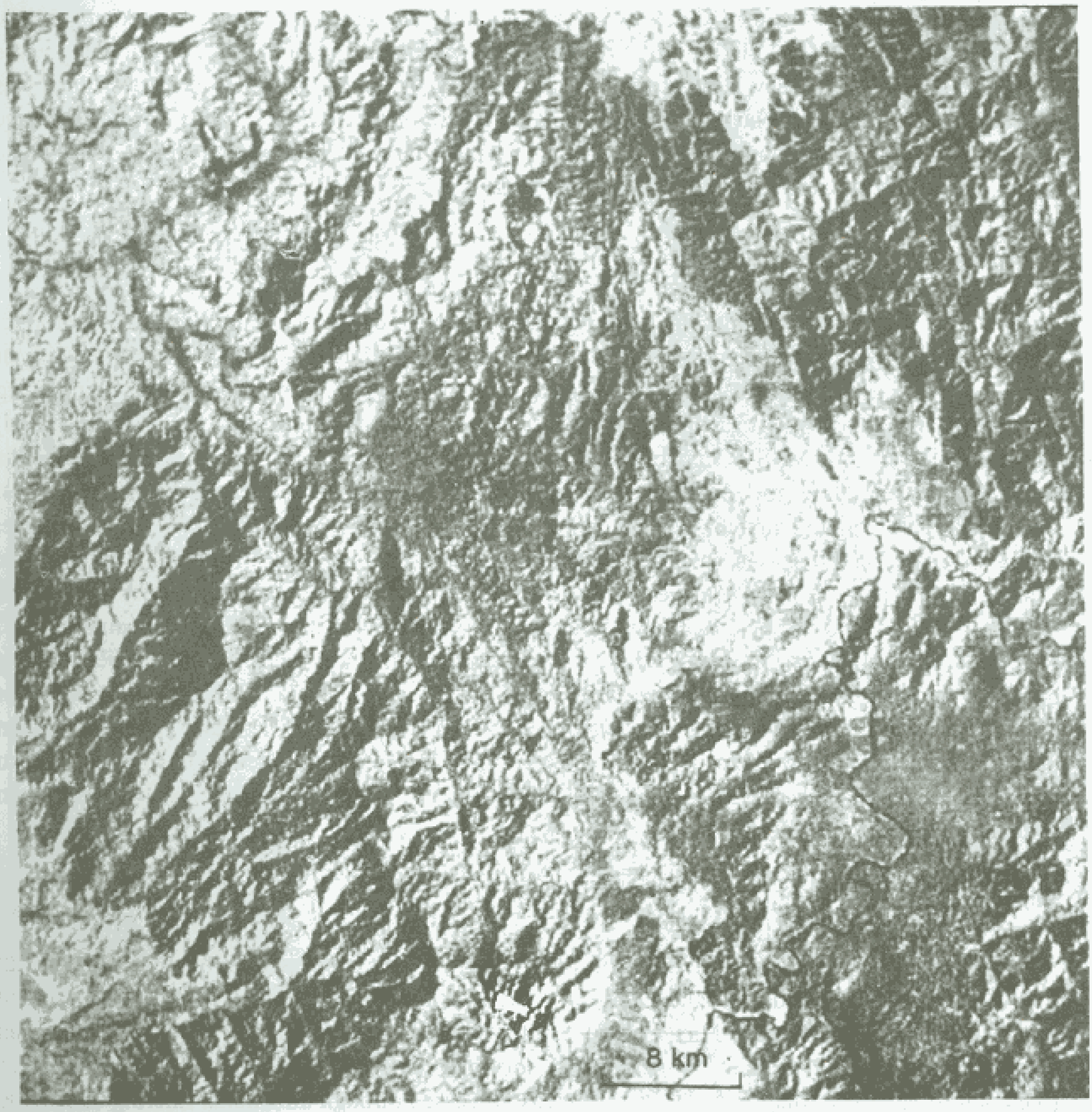


Figure 2: Linear contrast stretch of Landsat MSS band 7 of the Kedah-Perak area. The image is found best particularly for lineament analysis compared with other images. (Scale 1:300,000).

Principal component analysis

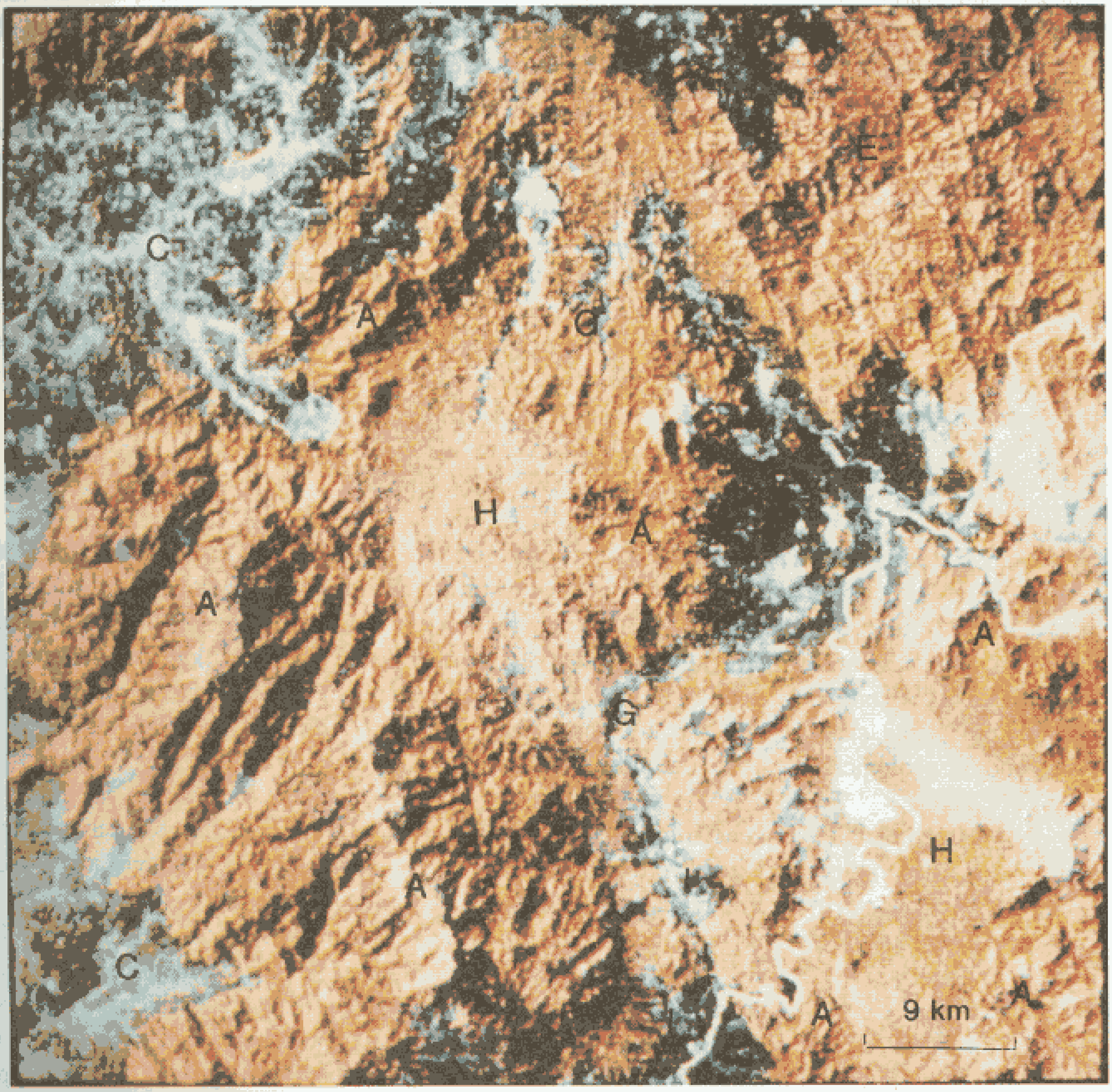
Principal component analysis (PCA) is a statistical technique that transforms a multivariate data set consisting of intercorrelated variables into a data set consisting of variables that are uncorrelated linear combinations of the original variables (Ingebritsen and Lyon, 1985). The ability of the technique to reduce the number of bands of the data set that must be analyzed to produce usable result is an important economic consideration. Moreover, the potential information recoverable from the transformed data is just as good as that from the original data (Anuta, 1977). The principal component 1 (PC1) of the data accounts for nearly 78% of the total variance while the PC2 accounts for nearly 20% of the variability in the original four-band data set. This means that the two PCs contain nearly 98% of the total variance of the original data set. The two image products, therefore, are good enough in terms of variance content, and are much easier to handle and to interpret compared to the four-band original data set.

Colour display

It is known that our eye can perceive more shades of colour than tones of grey. Therefore, coloured images can express more geologic information than do black and white images. Colour images can be generated by assigning a colour to each of three images and digitally superimposing the result. The so-called standard Landsat MSS false colour composite, MSS 7 (near infrared band) was displayed in red, MSS 5 (red band) was displayed in green, and MSS 4 (green band) was displayed in blue. The same method can be applied to other images such as PC and ratio images. The combination of the first three PC images, which contains approximately 99% of variance, forms an image which shows, in general, more information than standard false colour composite. Generally the ratio colour composites for the area did not show good colour variations compared with the two previous composites. Notwithstanding this, the combination of the MSS band 4/6, 4/7, and 5/6 with red, green and blue respectively (Figure 3) enhances very well the relief-forming bands of the resistant lithological units and also their structural trends. Therefore, several major lineaments which correspond to several major faults are better depicted, and also relief impression between the granite (higher relief), the metamorphic (subdued relief) and sedimentary rocks (low to moderate relief) are well presented. Hence these features can be used to discriminate between them instead of their colour differences.

Filtering

The contrast stretched image of MSS band 7 was processed through nondirectional filtering with the aim to detect edges and boundaries on the image. It is evident that the resultant image shows better contrast and better definition for linear features, and a few major lineaments can be seen more clearly here than on the contrast stretched image. In addition, the same data source (the contrast stretched image of MSS band 7) was processed through directional filtering in order to enhance or to depict features with a preferred orientation, including geological linear features (lineaments). Four different images were then produced from each data source by four different edge detection processes (north-south, east-west, northeast-southwest, and northwest-southeast enhancement filters). Linear features, appearing as white lines, with different length, were enhanced and quite well displayed especially in areas which are related to higher topography.



KEY:

A	granite	C	siltstone/shale/slate
E	phyllite and metasandstone	G	phyllite and slate
H	granite	I	extrusive igneous rock

Figure 3:MSS band-ratio colour composite of the Kedah-Perak area. The image is ranked first in the geological information content assessment for the area. Scale. (1: 300,000).

All the processed images were first assessed in terms of their image-characteristics and their general information content (Juhari Mat Akhir, 1990). From here, a few selected images such as the ratio colour composite, contrast stretched MSS band 7, PC colour composite, standard false colour composite and filtered MSS band 7, which show geologic features and/or enhance the geologic information of the study areas were chosen for geological interpretation and analysis.

The lithological map was prepared based on the relationship between image-characteristics and geological units. The usefulness of remote sensing data for this purpose is examined by comparison between the interpreted map with the existing map.

Lineament mapping and analysis are carried out on selected images within which linear features are best shown. The lineament map prepared from Landsat MSS data was analyzed and compared with the geological map in terms of their orientations, number, length and also their locations. The relationship between the lineaments and geological structures (faults), and its potential usefulness in mineral exploration is discussed.

RESULTS AND DISCUSSION

The assessment of the geological information content of the image products shows that the ratio colour composite (Figure 3), provides the most information on the lithology of the area. The advantages of this technique compared to others may have contributed to the result. For structural information, black and white image products are generally better than the colour composites, and for the area, the contrast stretched MSS band 7 (Figure 2) was found to be the best. In addition, PC colour composite, standard false colour composite and filtered MSS band 7 image was also found to be good for geological interpretation of the area.

Based on the three most informative colour composites for the area, the colour associations of several image units in the area were observed one after another. In terms of colour, it is evident that in all images the main colour is contributed by the dense forest cover and variation in colour is also mainly related to the variation in vegetation. During the assessment process, it was found that these two terrain categories broadly correspond to certain rock units which have different characteristics. Generally, the dense forest cover occupied higher ground areas which are underlain by high resistance rock types like granite. On the other hand, the areas which have less or no vegetation cover form lowlands, flat or undulating areas and are underlain by more soft rock types like siltstone and shale. In addition to colour, other image-characteristics of rock types such as relief impression, texture and grey tone which can be seen on several images, and also serve as important criteria in order to differentiate between different geological units, were used in the mapping process. With the help of these criteria, an interpretation exercise was carried out over the area to make use of, and to test, the practical application of the Landsat MSS data as an input to geological mapping by using the most informative image products (colour ratio, PC and standard false colour composites). Colour associations and image-characteristics of rock types in the area were examined and summarised in Table 1. The interpreted geological map for the area is shown in Figure 4.

Six image units which are observed and identified (Table 1) were delineated in the study area (Figure 4). It is evident that relief impression, bedding sign and texture are more important than the spectral information in order to identify and separate between rock types. The interpreted geological map was compared to the geological map of the area, and the correlation between image units and geologic units is summarised in Table 2.

Table 1: Colour associations and other image characteristics of rock-types of the Landsat MSS for the Kedah Perak area. Similar image unit annotation is given on the MSS image in Figure 3.

IMAGE CHARACTERISTICS						MORPHOLOGICAL EXPRESSION				COVER		CONCLUSION
Colour			Tone			Texture *	Rock/unit Properties					
BRC 5/6-4/7-4/6	BCC 457	PCC 321	B7	DF1	PC1		Resistance	Bedding	Jointing/ Lineament	Cultivation	Vegetation	Probable Lithology
A Pale brown	red	bright green to blue-green	grey	dark grey	very dark grey	coarse	very high	none	multidirec-tion persistent and high density	none	very dense	Igneous rock: granite
C greyish pale-blue	pale blue with red patches	pale blue-green with patches	light grey	white	very.light grey	fine and speckled	low	massive	very low density	intense	sparse to scattered	Sed./Met.rock: siltstone, shale, slate
E pale-brown	red	blue-green	dark grey	medium dark grey	dark grey	moderate coarse, banded & linear	moderate to high	well bedded to massive	medium to high density	none	very dense	Met. rock: metasandstone, slate
G dark pale-brown	dark red	dark blue-green	very dark. grey	medium light grey	dark grey	moderate uneven	moderate to high	massive to well bedded	low to medium density	rare to common	very dense	Met.rock: phyllite, slate
H greenish pale-brown	dark red	dark blue green	dark grey	grey	dark grey	moderate coarse to fine	moderate to low	none	low to medium density	very rare	very dense	Igneous rock: granite
I dark blue to pale-blue	pale red	bright green	very light grey	very dark grey	white	moderate fine to fine	low to moderate	none	none	common	moderate	Igneous rock: volcanics

* based on the black and white images (B7, DF1 and PC1).
BRC - band ratio composite, BCC-band colour composite, PCC- principal component colour composite, B7- band 7, DF1- discriminant function 1, PC1- principal component 1.

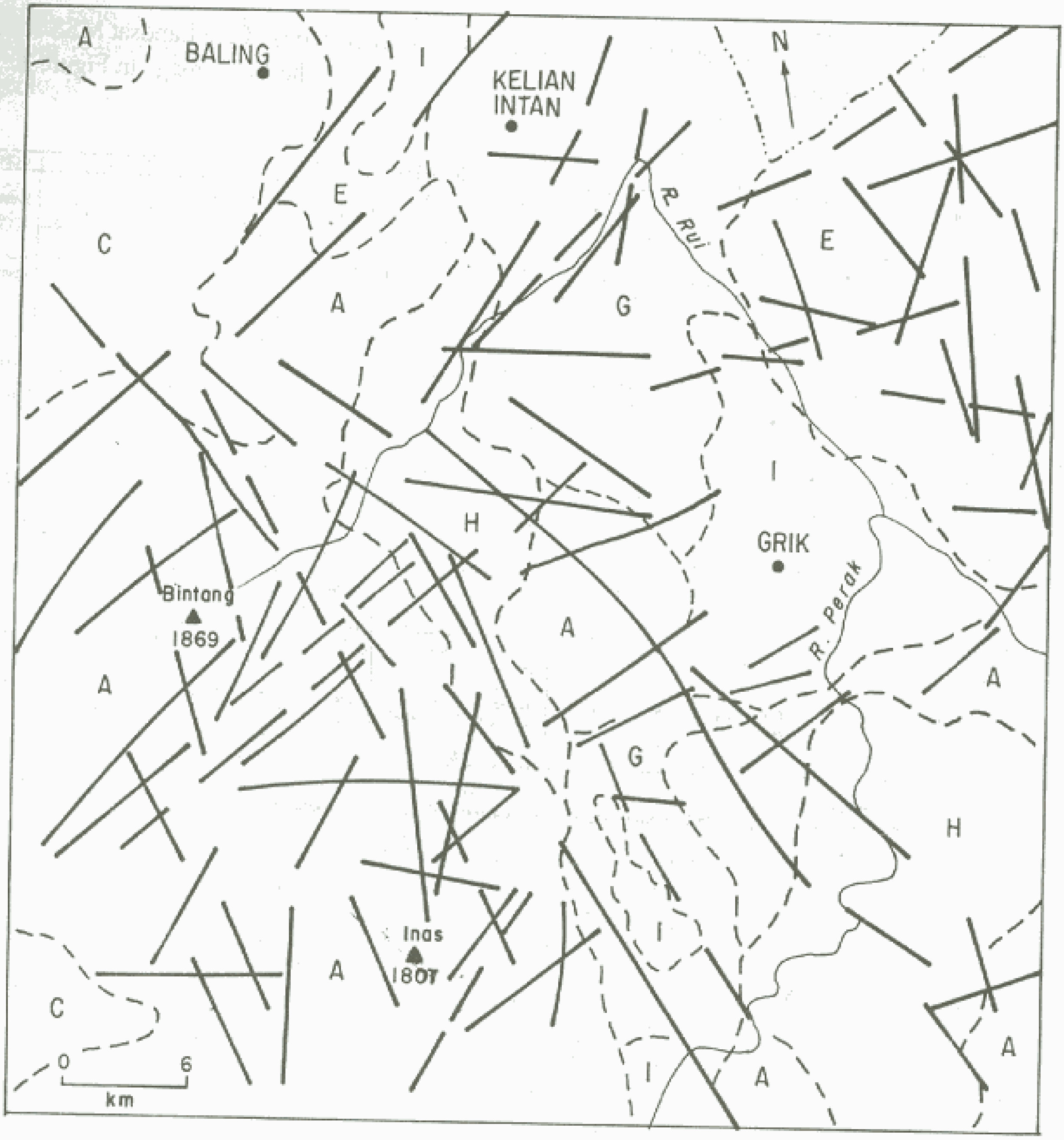


Figure 4: Geological interpretation of the Kedah-Perak area based on the Landsat imagery. Thick lines are major lineaments which may represent geological faults.

Key for Figure 4

IMAGE UNIT	IMAGE CHARACTERISTICS	PROBABLE LITHOLOGY
A	resistance: very high; no "bedding sign"; lineament/jointing: multiple direction, persistent, high density; coarse texture; vegetation: very dense.	Igneous rock : granite
C	resistance: low; massive; lineament/jointing: low density; texture: fine to speckled; cultivation: intense; vegetation: sparse to scattered.	Sedimentary/meta-morphic rock : siltstone/shale/slate
E	resistance: moderate to high; massive to well bedded; lineament/jointing: less persistent and medium density; texture: moderate coarse, banded and linear	Metamorphic rock : schist/metasandstone
G	resistance: moderate to low; massive to well bedded; lineament/jointing: low to medium density; texture: moderate uneven; cultivation: rare to common; vegetation: very dense	Metamorphic rock : phyllite/slate
H	resistance: moderate to low; no "bedding sign"; lineament/jointing: multiple direction and medium to low density; texture: medium coarse to fine; cultivation: rare; vegatation: very dense	Igneous rock : granite
I	resistance; low; no "bedding sign"; no lineament/joint; texture: fine; cultivation: common; vegetation: moderate	Igneous rock : extrusive

Table 2: Correlation between the image units and the mapped units for the Kedah-Perak area.

IMAGE UNIT	IMAGE CHARACTERISTICS	PROBABLE LITHOLOGY
A	resistance: very high; no "bedding sign"; lineament/jointing: multiple direction, persistent, high density; coarse texture; vegetation: very dense.	Igneous rock : granite
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E	resistance: moderate to high; massive to well bedded; lineament/jointing: less persistent and medium density; texture: moderate coarse, banded and linear	Metamorphic rock : schist/metasandstone
G	resistance: moderate to low; massive to well bedded; lineament/jointing: low to medium density; texture: moderate uneven; cultivation: rare to common; vegetation: very dense	Metamorphic rock : phyllite/slate
H	resistance: moderate to low; no "bedding sign"; lineament/jointing: multiple direction and medium to low density; texture: medium coarse to fine; cultivation: rare; vegatation: very dense	Igneous rock : granite
I	resistance; low; no "bedding sign"; no lineament/joint; texture: fine; cultivation: common; vegetation: moderate	Igneous rock : extrusive

Lineaments were mapped by photo-interpretation from the best two of the computer enhanced images as well as from the four directionally filtered images of the area. The total number of lineaments mapped are 370 with a total length of about 1600 km. Only the lineaments with a minimum length of about 2 km are shown in Figure 5. The preferred directions of the mapped lineaments coincide well with the line of the Bok Bak Fault System, where 325 and 035 are the most common fracture trends (Burton, 1970; Tjia and Zaiton Harun, 1985), and also correspond with the two main directions of faulting, particularly in areas underlain by the granite (Burton, 1970). Therefore, based on orientation, it is evident that the main features of the fault pattern are clearly brought out in the lineament map. The total number and length of mapped lineaments, however, are few times more than those of faults. Thus, if most of the faults agree with the lineaments in terms of location, the results may imply that the known faults must be extended or that the lineaments' traces are longer that the actual faults. When the interpreted map was superimposed with the published map, the result shows that a large number of mapped faults were revealed and are coincident with the interpreted lineaments, and in several cases, as shown in Figure 6, the mapped faults should be extended. In addition, a few prominent lineaments are shown in Figure 6 which are not coincident with the known faults. Based on their size and their prominence, they may well represent fault lines not previously mapped or reported, rather than joints. In addition, a few circular features are also depicted on the images (Figure 6). The lineament density map which represents the concentrations of lineaments per unit area (25 km^2) was constructed as shown in Figure 7. It has been reported that many mineral provinces and mining districts are not randomly distributed but tend to occur in linear zones or belt (Offield et al., 1977; and Sabin, 1987). Therefore, the location and recognition of faults and extension fractures, faults intersection patterns and such other features (like circular feature) in the area may facilitate the planning of mineral exploration programmes.

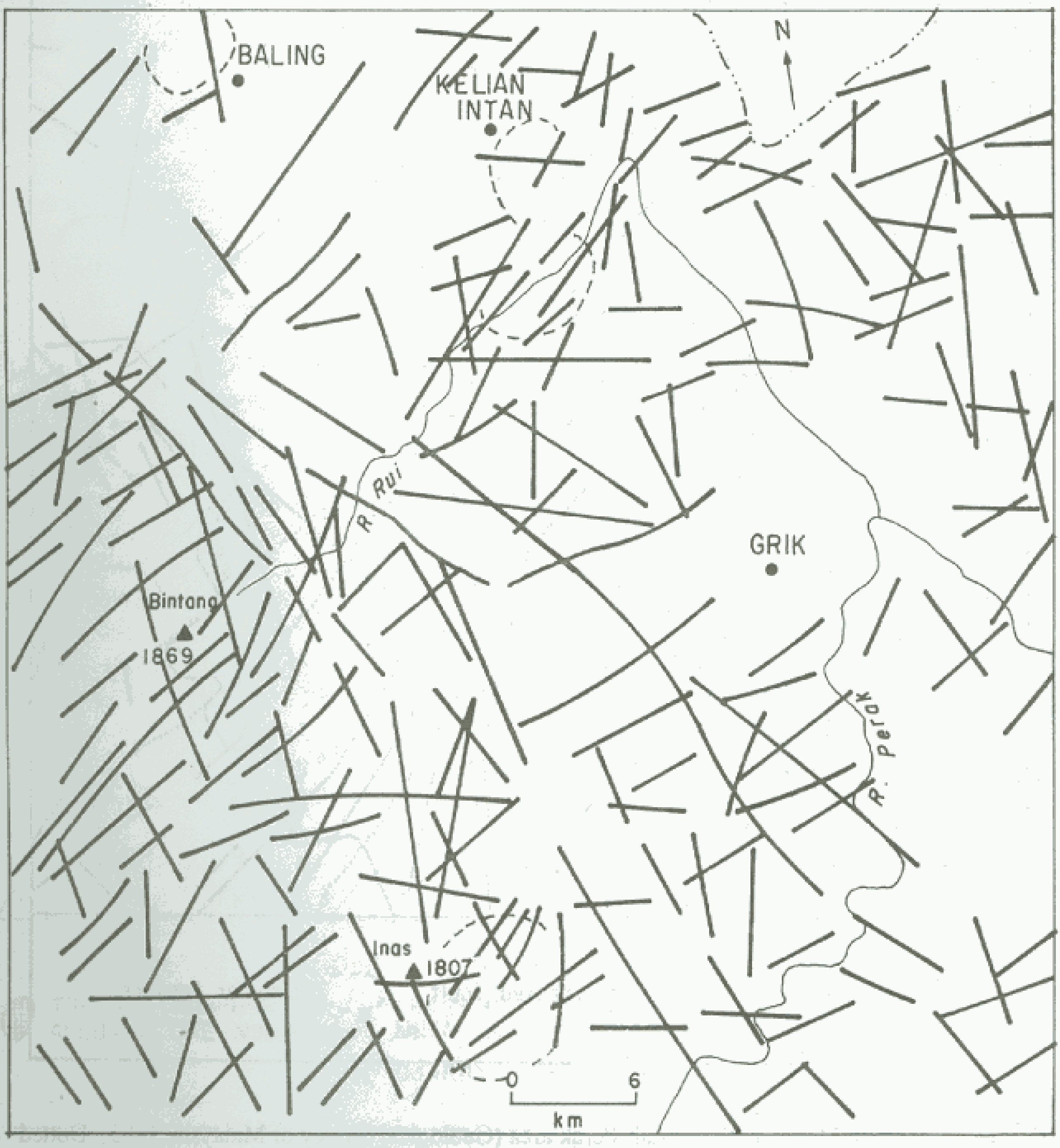

Figure 5: Lineament and circular feature map of the Kedah-Perak area derived from the Landsat MSS images. See Figure 1 for comparison with the mapped fault of the area.