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Lineaments Analysis from Landsat Data for Structural Geology and Mineral Occurrences in Loei Area, Northeastern Thailand

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ABSTRACT

Digitally enhanced Landsat thematic mapper 5 and data on mineral deposits of the Loei area, northeast Thailand, were used, along with geological and mineral occurrence information, in the investigation. Contrast stretching, edge enhancing, and directional filter analyses were determined to be the most appropriate enhancement methods to highlight linear features. Image interpretation indicated three major lineament systems: north-south, northwest-southeast, and northeast-southwest. The north-south trending lineaments are inferred to be closely related to substantial, nearly parallel thrust faults and fold axes and to follow major regional structural features. A combination of major lineaments and pre-existing structural geology is useful for improving the definition of structural features of the area. Maps of mineral occurrences with lineaments when overlayed show that mineral occurrences have good coincidence with short notheast-southwest lineaments intersected by long northwest-southeast lineaments and are related to intrusive igneous rocks. The mineral occurrences are concentrated in areas of high-density lineaments. Preliminary analysis also indicates that lineaments from Landsat interpretation fit fairly well with those from geologic data. It is concluded that lineaments observed from enhanced space-borne images can be used to improve the tectonic picture and to select target areas for mineral exploration.

KEYWORDS: enhanced Landsat image, lineament, fault and thrust, mineral occurrence, northeastern Thailand.

INTRODUCTION

The Loei area, the major province of northeast Thailand close to Laos (Figure 1), has been a focus of interest for several decades (Bunopas, 1981, 1988; Chairangsee, 1990) Jacobson and others (1969) made the first systematic mapping of the Loei area and surrounding areas. Charusiri (1989) made a reconnaissance survey of granitic rocks in the Loei area proposed a Triassic age, based on $^{40}Ar/^{35}Ar$ analyses. However, not much focus has been placed on remote-sensing interpretation of the Loei area. Jantaranipa and others (1981) applied MSS space-borne images from the National Research Council of Thailand to visualize lineaments of the Loei area.

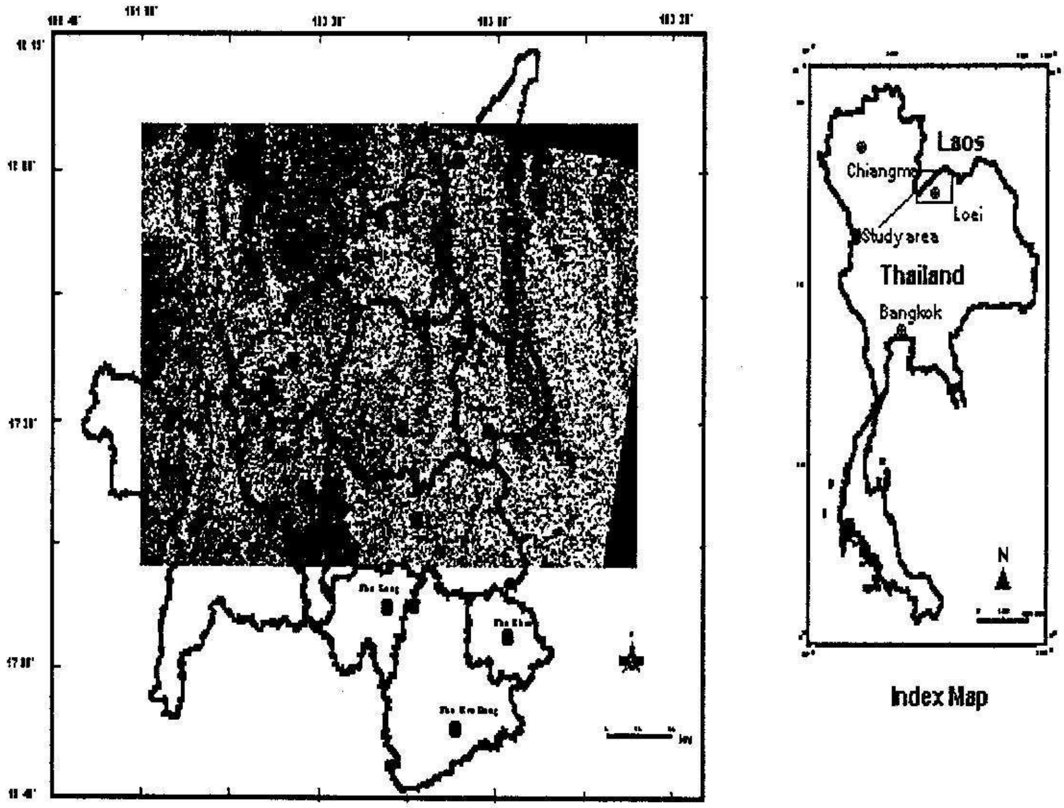

Figure 1 Landsat map showing location of the study area in Loei, NE Thailand with geographic boundaries of major districts and index map.

This study was an attempt to relate lineaments (or geologically linear features) visible on Landsat thematic mapper imagery in the northern part of Loei Province to mineral occurrences. To achieve this, an analysis of lineament geometry, pattern, distribution, and density was done. Mineral occurrence maps overlayed on lineament maps helped to define these relationships. Not all bands of Landsat image could be applied. Only band-7 images showed contrast and clarity. In this study, enhanced images were applied for interpretation without field support of real ground-truth evidence. Interpretation was done together with the geological map of Chairangsee and others (1990) and mineral occurrence maps from Economic Division of the Department of Mineral Resources.

The study area is located in the northern part of Loei Province, between 101° and 102° 24' north latitude and between 17° 12' and 18° 05' east longitude (Figure 1).

GEOLOGIC SETTING

In the Loei area, rock sequences begin with Lower Paleozoic metamorphic rocks, which include quartzite and phyllite. In the eastern part of the area, these metamorphic rocks are unconformably overlain by shale, siltstone with tuff, and intercalated limestone of Silurian-Devonian age. Intensely folded chert occurs in the western part of the area. This chert unit is situated adjacent to spilitic basaltic volcanic rocks, which ascended in several long north-south trending strips. The basaltic magma either intruded at shallow depths or was extruded at the sea floor, forming huge masses of volcanic tuff and pillows. Moreover, exposed serpentinite, which is likewise elongated in a north-south direction, is probably the same age. In late Middle Devonian to Early Carboniferous time, thick graywacke intercalated with shale and reef limestone was deposited in many places. During the Late Carboniferous to Permian time, reef limestone was deposited unconformably on the older rocks. Felsic igneous rocks, such as rhyolitic tuff and granodiorite, of Triassic age cover a large area located mostly in the central part of the investigated area. Early Jurassic non-marine strata occur principally in the eastern margin of the area.

Three major structural features, unconformities, folds, and faults, were recognized by Bunopas (1988) and Chairangsee and others (1990). The unconformities occur between strata of different ages, for example, between Permian and Late Triassic rocks and Early Carboniferous and Devonian rocks.

Large anticlines and synclines whose axes are mainly oriented north-south are especially notable in Silurian and Permian rock sequences. Many of these folds are dislocated by several sets of faults. Strike-slip faults seem dominant and they dislocate major folds and pre-existing thrust faults. Sinistral fault movement, which is more common than dextral fault movement, occurred especially in the western part of Loei the area. This was probably due to the continuous clockwise rotation of continental Southeast Asia (Bunopas, 1981). A large overthrust separates Silurian metamorphic rocks from Carboniferous rocks. A large shear zone at the Siam Graphite mine and the absence of Devonian strata in this zone perhaps provide good evidence of this thrust. Normal faults were also observed, especially in the Loei and Pak Chom River valleys.

IMAGE PROCESSING TECHNIQUES AND DIGITAL ENHANCEMENT IMAGERY

Remotely-sensed images distributed by the Thailand Remote Sensing Center of the National Research Council played a significant role in defining geological structures and tectonic fabrics of the study area. Lineaments were deciphered primarily using satellite imagery from Landsat thematic mapper 5.

The remote-sensing images exist in digital form as two-dimension arrays, or rasters, made up of pixels. A digital number that represents the energy of the electromagnetic radiation waveband being monitored assigns each pixel. An image processing normally consists of three main steps: rectification, enhancement, and data extraction.

The rectification step is used to improve correspondence of image data with the represented scene. The enhancement step is normally undertaken to improve the ability to identify features of interest in the imagery. The data extraction step is used to interpret and classify each project, such as land cover and geology. The details for each step are described in Neawsuparp (1997). In this study, only the enhancement for structural analysis is involved.

Image enhancement consists chiefly of an operation designed to optimally display information from images for photo interpretation. An image usually contains more information to be displayed in a single picture. The image enhancement entails selection of the subset of information to be displayed as well as the optimum display of that information. The digital images from Landsat thematic mapper were processed and displayed by using the IDRISI, MapInfo, and GEOSOFT programs in this study.

Contrast stretching is valuable in enhancing Landsat data. Because the exposure time in the Landsat is not variable, the sensitivity of the instrument must be set so those scenes of different albedo do not saturate the sensor. Thus, in any given scene, the data are likely to occupy only the available gray level. The unstretched image appears very flat, or low contrast, when displayed.

Filtering is also useful in image enhancement. An edge-enhancing filter can be used to highlight any changes of gradient within the image feature, such as structural lines, communication lines, or circular features. Directional filters are applied to images using a convolution process by mean of constructing a window normally with a 3x3 pixel box. The directional filters can be applied in order to highlight lineaments by controlling the sunlight direction in cross with the main structural geology.

In this study, edge enhancement, directional filters in north and northeast directions, and contrast stretching constituted the main image enhancement. The contrast stretching included the linear and 2.5 saturation rate (the maximum brightness that can be assigned to a pixel on the display device and corresponds to a DN of 255) and were applied for lineament mapping. The results showed that lineaments totaled 589 lines. The results of edge and directional filters are shown in Figure 2.

IMAGERY INTERPRETATION

Figure 3 shows the lineaments mapped using the enhanced image of the Landsat thematic mapper band 7. This mapping was done prior to examining a geological map and prior to acquiring any knowledge of mineral occurrences in order to eliminate any possible bias.

Since the image requested was prepared in the rectangular form, a part of the study area includes an area of Laos P. D. R. This map, then, shows the continuity of long lineaments extending from Thailand into Laos.

The study area was divided into three parts, western, central, and eastern, by using the differences in pattern, geometry, and density of lineaments, as shown in Figure 3. The geological map of this area (Department of Mineral Resources, 1992) was overlayed onto the lineament map for comparing the nature and styles of lineaments. The length of lineaments was described in terms of being major, or long (>10 kilometers), and minor, or short (<5 kilometers). Linear features of this study could generally be equated with structural elements, such as faults, joints, and fractures. Minor linear features, such as small-scale faults and joints, often were not apparent on the imagery because of limitations of resolution.

Western part

The major lineaments are oriented generally in a north-south direction. Other lineament patterns trend in a roughly northeast-southwest direction. In the northern part of this zone, the long major lineaments trend north-south and northwest-southeast. Lineaments with these directions extend from Wang Saphung to Laos (Figure 1). These lineaments are located almost at the contact between Mesozoic clastic rocks and Upper Paleozoic rocks. The northern part of these north-trending lineaments shifts direction to the southeast in the southern part. These lineaments are subsequently cross-cut by the northeast-trending lineaments. The linear features in this zone form a complex pattern, especially in the northwest (in Laos) where many multidirectional lineaments are clearly evident.

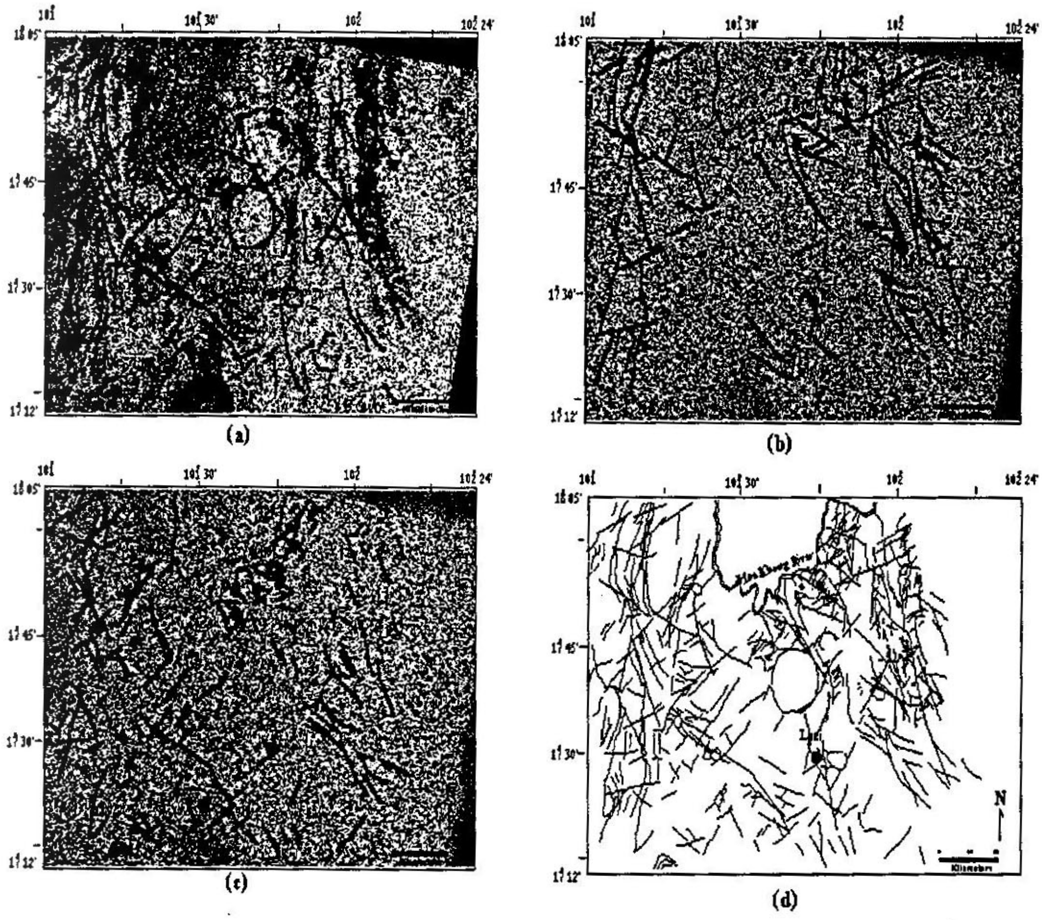

Figure 2 Enhancement of Landsat image in Loei and nearby area showing

(a) lineaments using Edge Enhancement (b) lineaments using NE directional filter

(c) lineaments using N directional filter (d) lineaments combined from (a), (b), and (c)

Central part

Curvilinear and circular features represent particular features of the central part. The circular features, indicated by curved drainage patterns, mark areas of concealed igneous plugs. The main lineaments of the central part trend northeast-southwest and they are short. In the northern part (Chiang Khan area in Figure 1) a large number of multidirectional lineaments are prominent, but in other parts, only a few lineaments are present. The geological map of the central part shows Permian sedimentary rocks, Permian-Triassic volcanic rocks, and Triassic granite as the main rocks.

Eastern part

Main lineaments in the eastern part are mostly aligned north-south. They are mostly of medium length and are related to some extent to major fold axes and to a pre-existing thrust fault. This thrust fault occurs at the boundary between at the Devonian metamorphic rocks and Carboniferous sedimentary rocks. In the vicinity of the thrust fault several minor lineaments concentrate in the northeast-southwest direction. It is quite obvious that the northwest-trending lineaments in the south and the northeast-trending lineaments in the north are cross-cut by the north-trending lineaments.

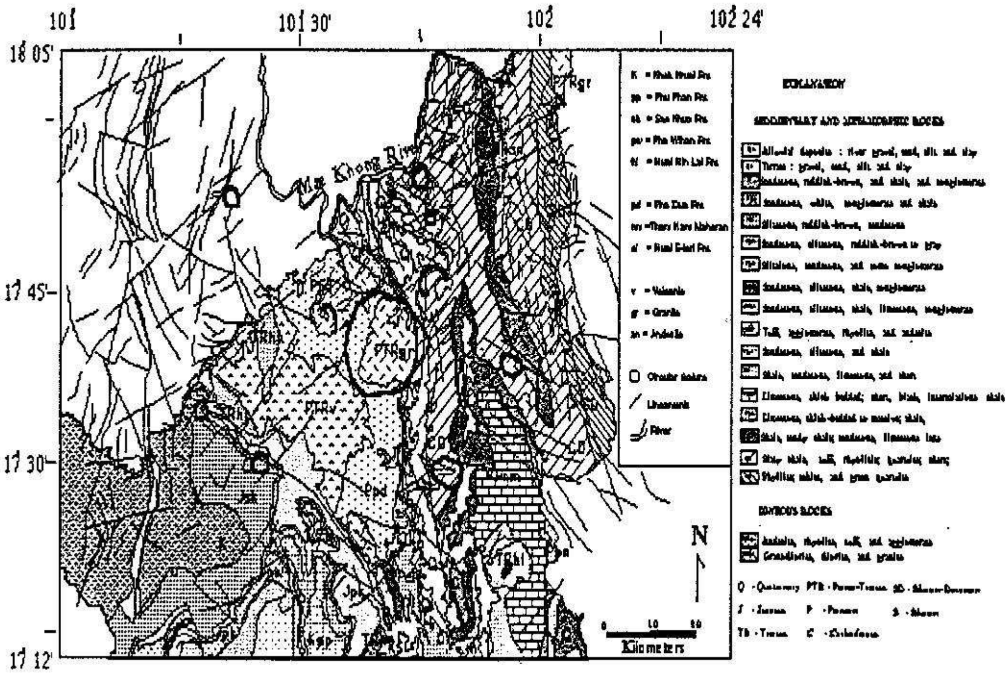

Figure 3 Lineament map (this paper) overlayed with the published geological map of Loei area (DMR, 1992)

LINEAMENT ANALYSIS

Lineament analysis, which integrates the analysis of linear patterns, geometry, kinematics, and dynamics (Katz, 1982), can be applied to mineral exploration in an attempt to define the most favorable locations for mineral concentrations on the basis of tectonic environments.

Figure 4 (a) shows all lineaments within the study area and appears difficult to analyze because of the recognized complicated features in term of length and direction. Figures 4 (b) shows only lineaments oriented north-south, Figure 4 (c) shows those lineaments oriented northwest-southeast, and Figure 4 (d) shows those northeast-southwest. The scheme of work can be easily done using the

MapInfo program. For each lineament direction, the distribution, pattern, and length of lineaments are considered.

North-south direction

The north-trending lineaments on Figure 4 (b) occur mostly in the eastern and western parts of the study area. The number of these lineaments almost equals the number of known major folds and faults and these lineaments are parallel to them. The main lineaments are about 20 kilometers long. Some shorter lineaments occur in the zone of the thrust fault. Most lineament patterns are not straight lines. They have swinging lines and possibly represent fold axes in this area.

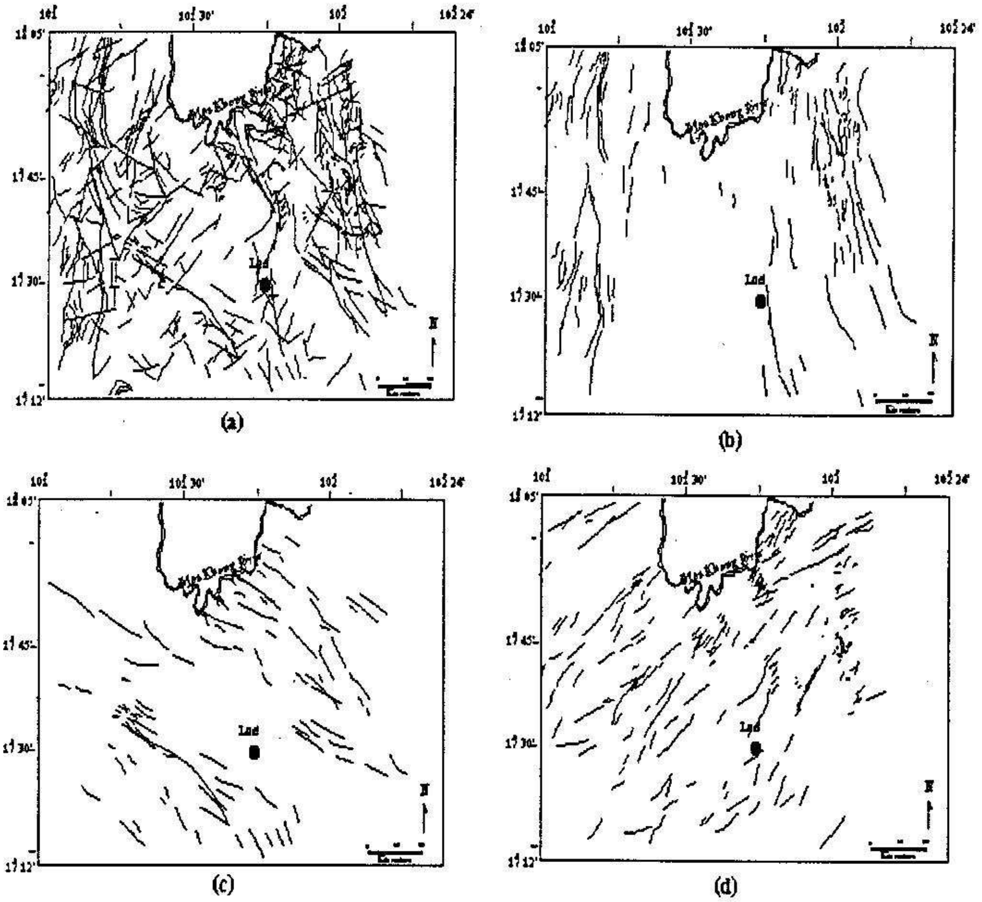

Figure 4 Lineament map of Loei and nearby areas displaying
(a) lineaments of all directions (b) N-trending lineaments
(c) NW-trending lineaments (d) NE-trending lineaments

Northwest-southeast direction

Figure 4 (c) shows two remarkably straight and continuous, major northwest-trending lineaments, especially in the central part of the area. These lineaments presumably extend from the Loei area into Laos. A number of less obvious lineaments form second-order fractures that branch from the two major faults. Many of the lineaments are distributed in the northern and southern parts of the study area.

Northeast-southwest direction

Figure 4 (d) shows the northeast-trending lineaments that are shorter, but more numerous, than those of other directions. These northeast-trending lineaments are distributed throughout the study area. Major lineaments that have this direction are considered to be important because they may conform to mineralization zones.

DISCUSSION

Lineaments related to structural geology

Figure 5 shows major lineament patterns in the study area compared with structures shown on the geological map of the study area, including the area's faults, fold axes, and thrust fault. These major lineaments can generally be equated with the fault structures, as shown in Figure 5 (a). The major lineaments from Landsat data correspond fairly well with the faults of the geological map in Figure 5(c), though a few lineaments do not conform to the mapped faults. The combined Landsat and geological data show the new structural features of Figure 5 (d).

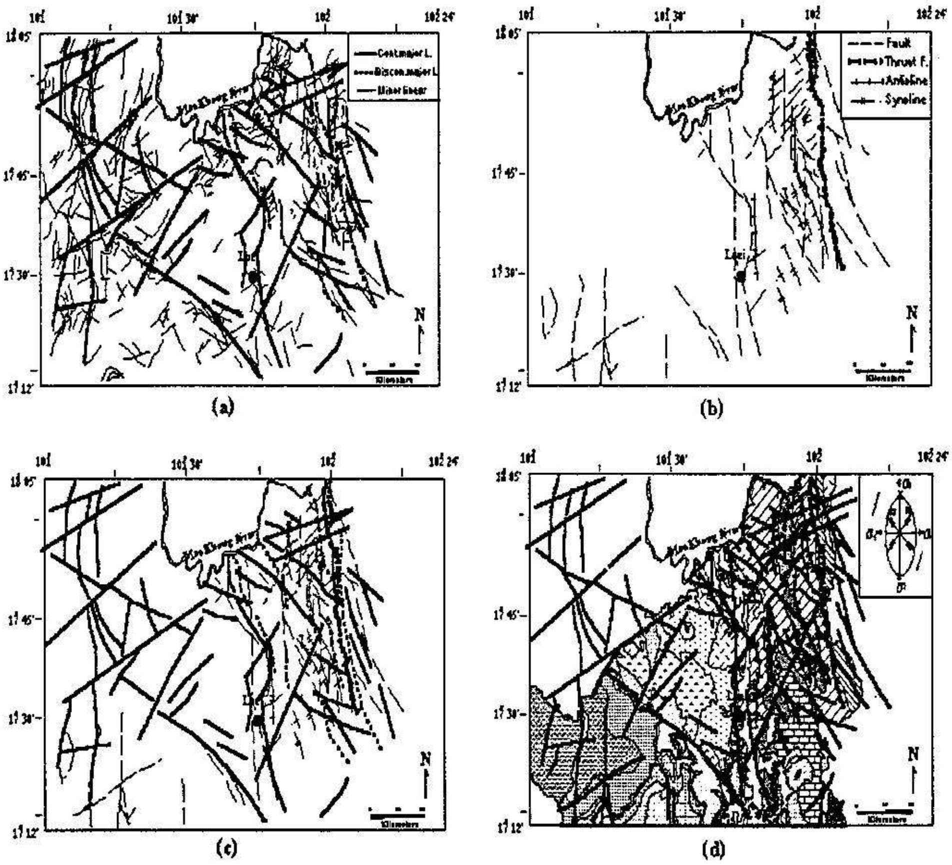

Figure 5 Map of Loei and nearby areas showing

(a) lineament map showing continuous major, discontinuous major, and minor lineament.

(b) structural map showing major faults, folds and thrust (DMR, 1992, 1988)

(c) overlayed map of major lineaments and previously-reported structures from (b)

(d) geology and continuous major lineaments with strain ellipsoid (in the inserted box).

Many lineaments of the study area provide adequate evidence of horizontal displacement and can be considered to be strike-slip, or wrench, faults. In the northwestern part, the major fault structure along north-south and northwest-southeast directions was significantly displaced by the northeast- trending strike-slip fault. This indicates that the northeast-trending strike-slip fault is younger than the north-trending and northwest-trending faults. In the northern part of the area some large northeast-trending lineaments, considered as faults that interrupt the north-trending and northwest-trending faults without significant offset, may be affected by normal faults. The fault patterns in the northeastern part show structures with minor movement and this may indicate a difference in stress regimes. Their kinematic relationships can be described on the basis of assuming a simple shear mechanism, using the strain ellipsoid (Figure 5 (d). On the basis of fold axis and thrust fault directions in the study area, the compression force ($\sigma 1$) was oriented east-west and the extension force ($\sigma 3$) was oriented north-south. The strike-slip faults in northwest-southeast and northeast-southwest directions are the R and R', respectively. The strain ellipse of the study area is shown in the top right corner of Figure 5 (d).

Lineaments as related to mineral deposits

Figure 6 shows the relationship between mineral occurrences of the northern Loei area and lineaments. Most mineral occurrences are located in central part of the study area and are clearly related to circular features, as shown in Figure 6 (a). Circular features in Thailand were earlier interpreted to represent granite intrusions that produced abundant fractures (Charusiri and others, 1994). Such fractures were able to serve as channels for hydrothermal fluids, or mineralizing solutions, as discussed by Sawkim (1976), Mitchell and Garson (1981), and Hutchison (1988). Figure 6 (b) shows that mineral occurrences are related to the northeast-southwest short lineaments, which generally are branches of the long northwest-southeast lineaments, and are especially at lineament intersections. Density and total length maps were performed using the MapInfo and GEOSOFT programs, as shown in Figure 6 (c) and 6 (d), respectively. Most mineral occurrences are likely concentrated in areas where lineaments have both high density and total length.

On the basis of lineament relationships, it appears that the northeast-trending lineaments may have served to control ore mineralization. Further exploration should select targets along this direction, starting at prominent intersections. Attention should be focussed on areas where there is a high density and total length of lineaments, such as the area in the northwest corner of the map.

CONCLUSION

Digital image processing is a useful tool to help analyze Landsat data. The interpretation of images is a qualitative technique and should be tested against other data, such as airborne geophysical data, aerial photo data, and ground-truth field checks. For this study, a combination of major lineaments from enhanced Landsat data and structures from a prior geological map delineated new structural features of the area. Areas suitable for further mineral exploration on the basis of lineament analysis have been defined.

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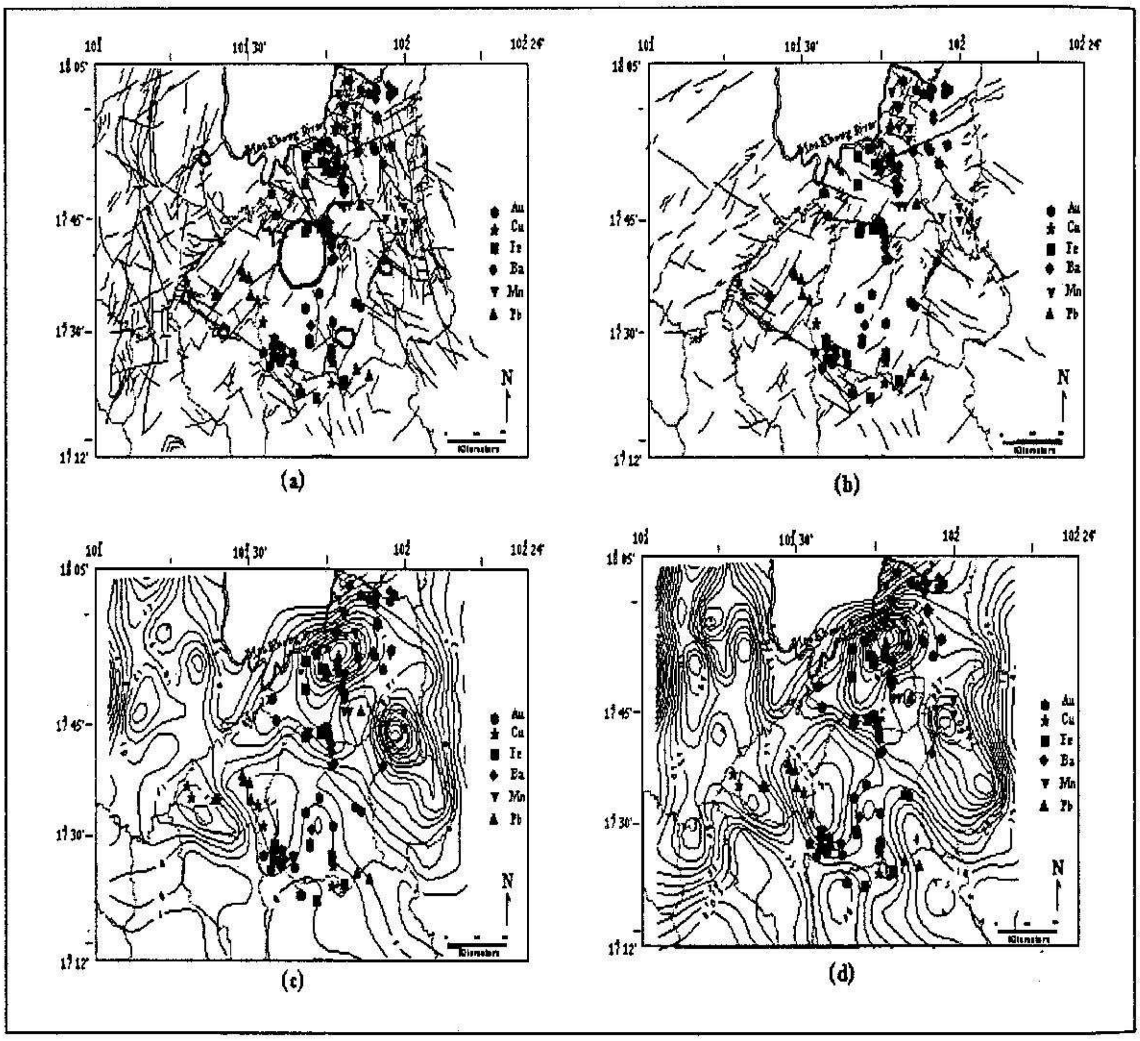

Figure 6 Map of Loei and nearby areas showing mineral occurrences (DMR, 1988) and lineaments (this paper)

(a) mineral occurrences related to circular features

(b) mineral occurrences related to NE-and NW-trending lineaments

(c) mineral occurrences related to density lineament

(d) mineral occurrences related to total length lineaments

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