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Lineaments Analysis Determined from Landsat Data Implication for Tectonic Features and Mineral Occurrences in Northern Loei Area, NE Thailand

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Abstract: Digitally enhanced Landsat TM5 images along with geological and mineral occurrence information were applied for investigation of lineament systems in the northern Loei area, NE Thailand. Prior to visual interpretation, enhancement process was performed, including contrast stretching, edge enhancing and directional filter analyses. Image interpretation indicates 3 major lineament systems: north-south, northwest-southeast, and northeast-southwest trending lineaments. The north-south trending lineaments are inferred to be closely related to substantial, nearly parallel thrust faults and fold axes, which, to some extent, follow the major and regional structural feature. Combination of major lineaments with pre-existing structural geology is useful for delineating tectonic features of the area. The overlay of mineral occurrences onto the lineament map indicates that the mineralizations have good coincidence not only with the shorter in northeast-southwest lineaments intersected by the longer in northwest-southeast lineaments but also with the intrusive igneous bodies. The mineral occurrences are mostly concentrated in areas of high-density lineaments. Our preliminary analysis also indicates that lineaments from Landsat interpretation fit fairly well with those of the geologic data. It is concluded that lineaments observed from enhanced spaced-borne images can be used to comprehend the tectonic setting and to select the target areas for follow-up mineral exploration.

Keywords: Landsat image, lineament, mineralization, northeastern Thailand, Loei, tectonic.

Introduction

Loei area, the major province of NE Thailand close to Laos (Fig. 1), has been a focus of interest for several decades due to its significant mineral resources[1-4]. Jacobson et al.[5] made the first systematic mapping for metal-deposit investigation of the Loei area and its surroundings. Charusiri (1989) made a reconnaissance

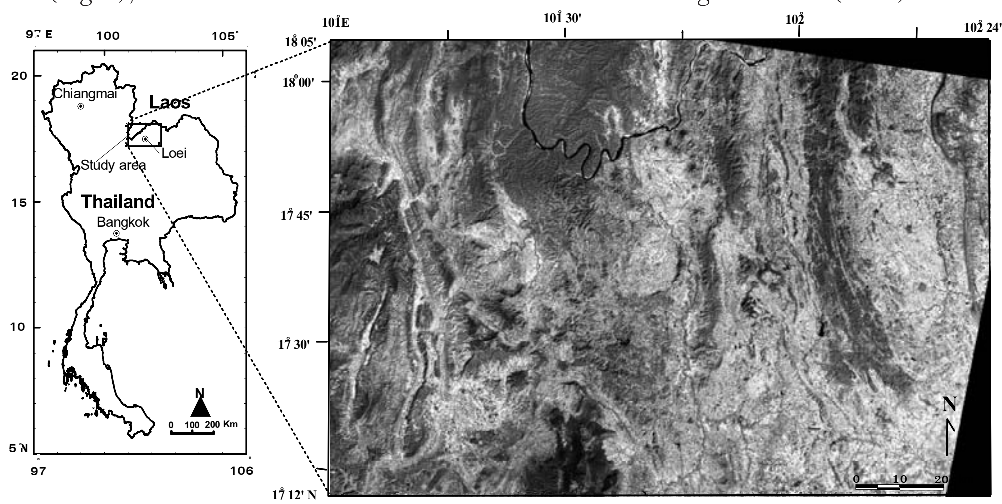

Fig 1. Map of the Loei study area with major district boundary and overlain Un-enhanced image data and Index map of Thailand showing the area under study.

survey on granitic rocks in the Loei area using the $^{40}Ar/^{39}Ar$ method, and Middle to Late Triassic was proposed for the major age of granitic magmatism. However, few works have been focused on remote-sensing interpretation of the study region. The pioneer work is that of Jantaranipa et al.[6] who applied multispectral scanner (MSS) space-borne images to visualize lineaments of the Loei area. It was demonstrated that the selection of target areas for mineral or petroleum exploration could be achieved by using integrated image data showing high-density lineaments and relevant maps.

This study is an attempt to correlate lineaments (or geologically linear features) visible on Thematic Mapper (TM) Landsat imagery, which has become the essential remote sensing tool for geological exploration. The better spatial resolution (30 m) of TM imagery compared to that of the Landsat MSS (80 m) and the extra spectral channels provide more detailed information for geological mapping. Many reviewed and specialist papers written on Landsat TM data, such as Abram et al.[7], Crosta and Moore[8] and Drury[9], also emphasized these advantages. For this study, details of lineaments, including geometry, pattern, distribution and density, are involved in the lineament analysis. The interpretation of major lineaments related to the structural tectonics and the reconstruction of structural geologic map was carried out in this work. Overlay of new mineral occurrences map onto lineament map has helped to define these relationships. Not all bands of the Landsat images can be applied. Only band-7 image depicts good contrast and clarity as earlier applied by Charusiri et al[10]. In this study, the enhanced images are applied for interpretation without field support of ground-truth evidences. Interpretation, however, has been done together with geological map of Bunopas[2] and Chairangsee et al.[4] and mineral occurrences map from Economic Division, Department of Mineral Resources (DMR), Thailand (Mineral Resources Development Project)[11].

The study area is located in the northern part of the Loei province at latitudes between 101°and 102° 24¢ and longitudes between 17° 12¢ and 18° 05 ¢, as shown in Fig 1.

Geologic Setting

There are various literatures regarding geology in Loei and neighboring areas. Geologic setting of this paper is summarized from the report of Bunopas[2] at scale 1:100,000 and of Chairangsee et al.[4] at scale 1: 50,000. According to the geological map of Loei area (Fig. 2), rock sequences begin with Middle Paleozoic metamorphic rocks, which mainly include quartzite and phyllite. In the eastern part of the area, these metamorphic rocks (Na Mo Formation) are unconformably overlaid by alternated strata of shale and siltstone with tuff and intercalated limestone (Ban Nong Formation). Intensely folded chert (Pak Chom Formation) of Middle to probably Paleozoic age[12] is restricted to the western part. The chert unit is situated adjacent to spilitic basaltic rocks ranging in age from Devonian to Permian.[13] Both chert and basalt units form a long, narrow north-south trending belt. This basaltic unit extruded on the sea floor and formed huge masses of volcanic tuff and pillow lava associated with sporadic manganese deposits. Moreover, serpentinite bodies, exposed sporadically as a narrow north-south trending zone, have been reported in the eastern part of the Loei area.[4] In Late middle Devonian to Carboniferous; thick graywacke intercalated with shale and reef limestone (Wang Saphung Formation) was discovered in several places. Late Paleozoic, reef limestone (Tham Nam Maholand, Huai E-Lert and Pha Dua Formations) lie unconformably over the older rocks. Felsic rhyolitic tuff and granodiorite of mostly Triassic age[3] cover a large area located mostly in the central part of the investigated area. Lower Jurassic non-marine sediments of the Khorat Group occupy principally in the eastern margin of the Loei area.

In the study area, we recognize two major structural features, viz. folds and faults. The main faults and fold axes orient in the north-south direction. Additionally, Bunopas[2] and Chairangsee et al.[4] reported the unconformities in the mapped area between strata of different ages, for example, between Permian and Late Triassic and between Lower Carboniferous and Devonian. However, they are stratigraphically poorly defined.

Bunopas[14] recognized the Loei area as part of the major fold belt called “Loei Fold Belt” which correspond to some extent with the Loei - Phetchabun – Ko Chang volcanic rocks. Large anticlines and synclines, whose axes are mainly in the north-south direction, are recorded especially in Silurian and Permian rock sequences. Many folds are dislocated by several sets of faults. Strike-slip faults oriented in northeast-southwest and northwest-southeast directions seem to be dominant and they dislocate major folds and pre-existing thrust faults. Sinistral movement, which is more common than dextral movement, is present especially in the western part of Loei. This is probably due to the continuous clockwise rotation of continental SE Asia.[1] The large north-south trending overthrust in the eastern part of Loei area separates Silurian-Devonian metamorphic rocks from Carboniferous sedimentary rocks.

Image processing and enhancement methods

Remotely sensed images play a significant role in defining geological structures and tectonic fabrics of

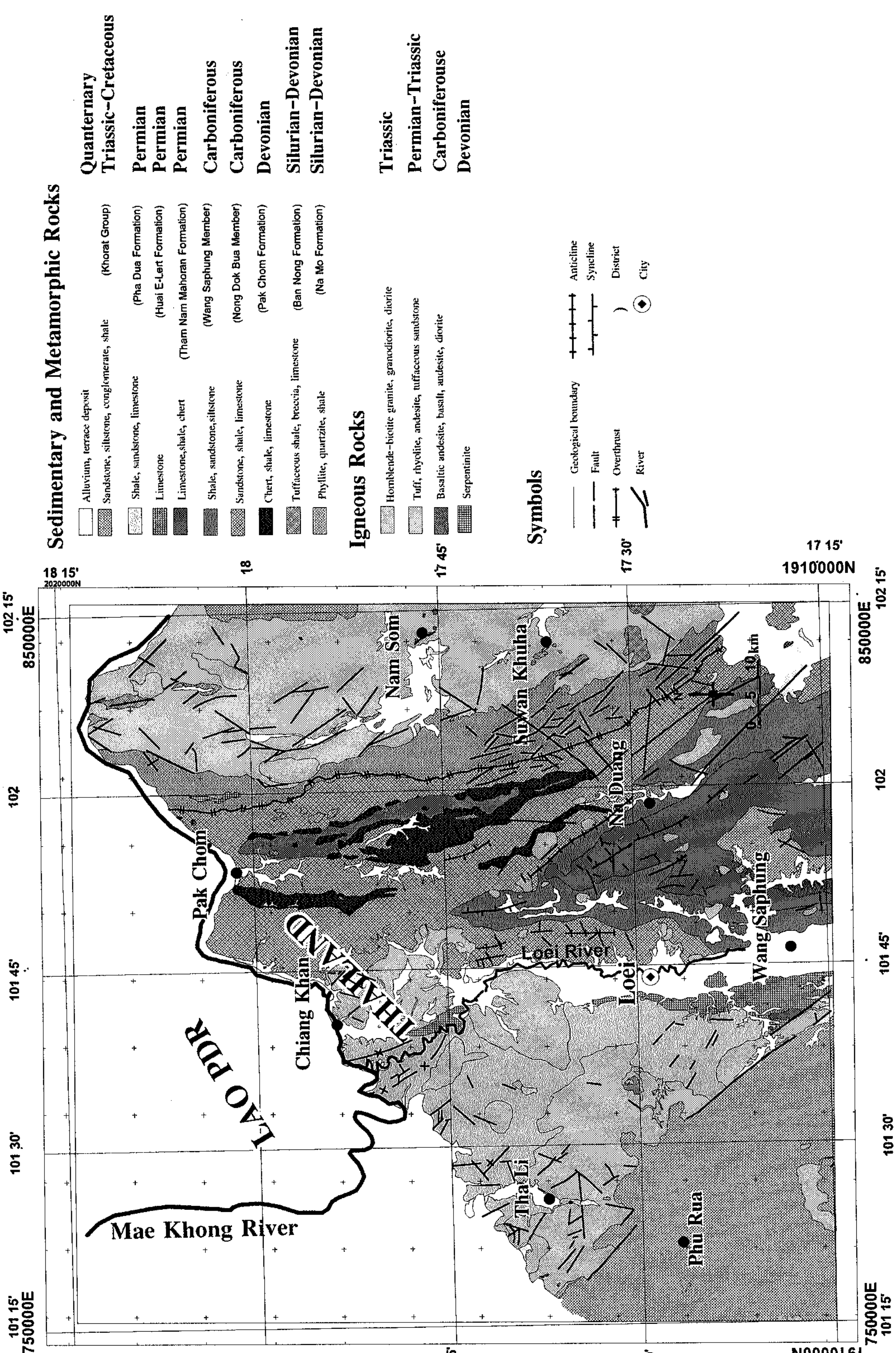

Fig 2. Geological map of the Loei area (Modified from MRDP, 1987 and Chairangsee, 1990).

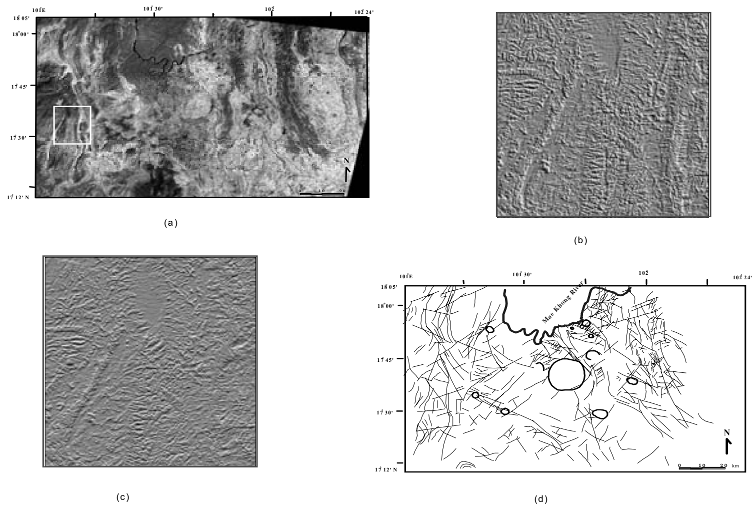

Fig 3. Interpreted lineament map
(a) with the enhanced image by edge enhancement,
(b) with the enhanced image by NS directional filtering method (zoom in block from (a)),
(c) with the enhanced image by NE directional filtering method (zoom in block from (a)),
(d) with the combination of lineaments from (a), (b) and (c).

the study area. Lineaments are deciphered primarily using satellite imageries from Landsat Thematic Mapper (TM) band 7 (see Fig. 1).

The remote-sensing images have been acquired in digital forms 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; namely, rectification, enhancement and data extraction.

The rectification is used to improve correspondence of image data within the represented scene. The enhancement step is normally undertaken to improve 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 detailed explanation for each step can be found in Neawsuparp.[15] In this study, only the enhancement for structural analysis is involved.

Image enhancement is an operation designed to optimally display information from imagery data for visual 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. In this study, the digital images from Landsat TM 5 are processed and displayed using the 3 main programs namely IDRISI, MapInfo, and GEOSOFT programs.

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, as shown in Fig. 3(a), the data are likely to occupy only the available gray level. The un-stretched image appears very flat or low contrast when displayed.

Filtering is also a useful image enhancement. The edge-enhancing filter can be used to highlight any changes of gradient within image features such as structural lines, communication lines or circular features. The directional filters are applied to image 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. Figs. 3(b) and 3(c) illustrate the enhanced images by NS and NE directional filtering method, respectively.

Based upon our analysis using IDRISI program, we consider that the edge enhancement, the directional filters in north and northeast directions and the contrast stretching, are practical enhancement method, and these constitute the main image enhancement steps. The contrast stretching includes the linear and 2.5 saturation rates (-the maximum brightness that can be assigned to a pixel on display device, and corresponds to digital number (DN) of 255) have been applied successfully for lineament mapping. The DN refers to the value of a variable recorded for each pixel in an image as a binary integer, usually in the range 0-255. As a result, the total lineaments of 589 lines are detected. The results with edge and directional filters are shown in Fig 3(d).

Results and imagery interpretation

Fig. 4 displays the lineament map using the Landsat TM image of band 7 by the combination of contrast stretching and filtering methods. The lineament analysis is done prior to the overlaid geological map was examined, and any knowledge of mineral occurrences is acquired in order to eliminate any possible bias.

Since the image requested is prepared digitally in the rectangular form, so part of the study area also includes in part of Lao PDR (see Fig.1). Thus the usefulness of this map is to describe the continuity of long lineaments extending from NE Thailand to Lao

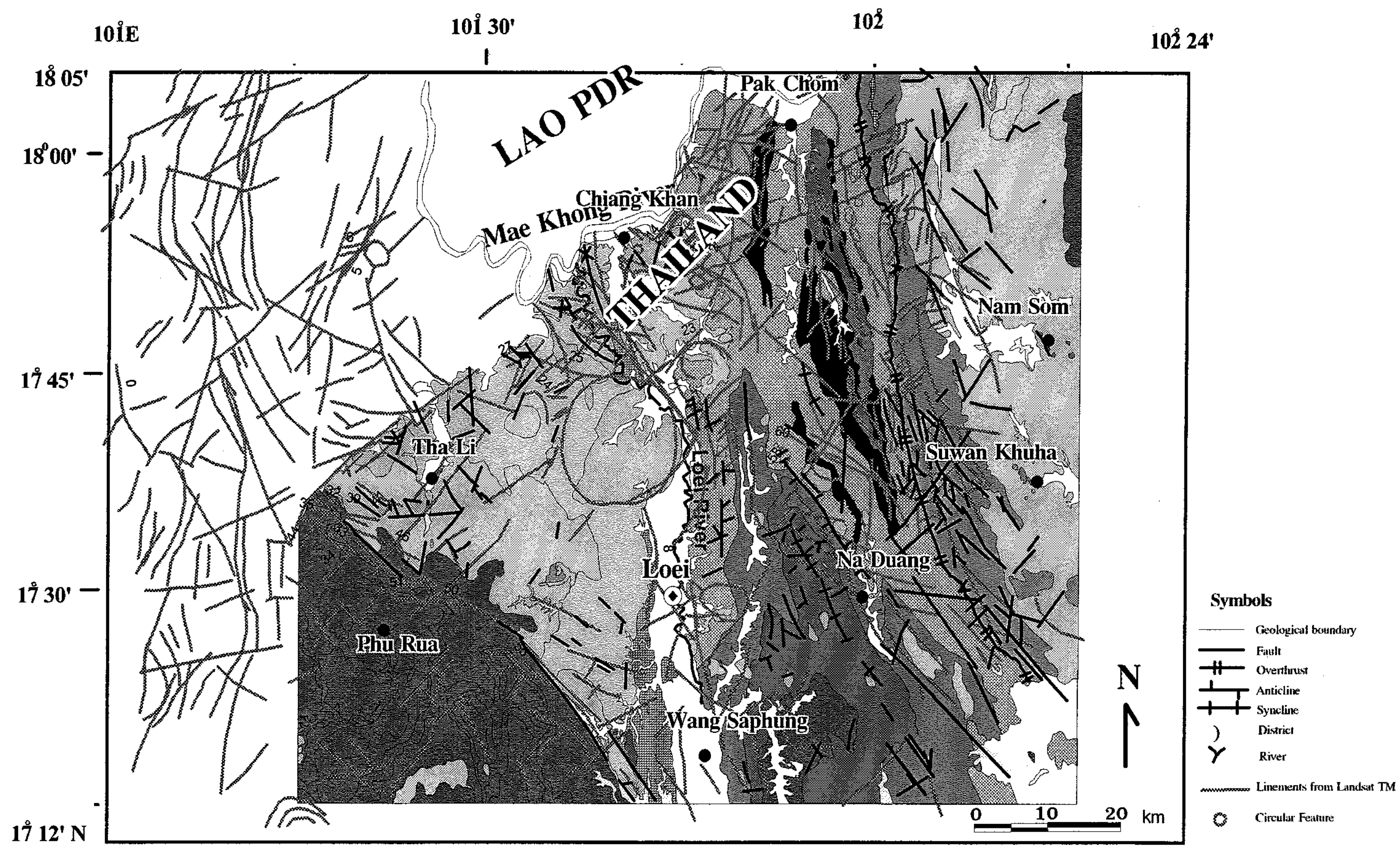

Fig 4.A combined interpreted lineament map with the overlain geological map.

PDR. In this study, interpretation is performed only in Thailand so the Mae Khong River demarcates the northern end for this analysis.

In our current investigation, we subdivide the study area into three parts, namely western, central and eastern parts by using the difference in pattern, geometry, and density of lineaments. For comparison of nature and styles of lineaments, the geological map of this area[16] is overlaid onto the lineament map as shown in Fig.4. The length of lineaments is described in term of major (>10 km long), and minor (<5 km long) lineaments. Linear features of this study area can generally be equated with the structural elements such as faults, joints, or fractures. Minor linear features, such as small-scale fault and joints, are often not apparent on the imagery due to limitations of resolution.

Western Part

Main orientations of major lineaments are roughly in the north-south direction. Some lineament patterns trend in the roughly northeast-southwest direction. In the northern part of this zone, long major lineaments are observed in north-south to northwest-southeast directions. Lineaments of these directions run from the southern part of the mapped area in Wang Saphung and extend to the north in Laos (see also Fig. 1). These lineaments are located almost at the contact between Mesozoic clastics and Upper Paleozoic rocks. These north-trending lineaments in the northern part are shifted tectonically to southeast direction in the southern part. In some part, these lineaments are subsequently crosscut by the northeast-trending lineaments. The linear features in this zone form a complex pattern especially in the northwestern (to Lao PDR) by which multi-directional lineaments are clearly observed.

Central Part

Curvi-linear and circular features are unique features of the central part. The circular features, as indicated by curved drainage patterns in the enhanced images, mark the area that is concealed by igneous plugs.[17] The main lineaments are in the northeast-southwest trend, and they have short length in northern part (Chiang Khan district in Fig.1). A large number of multi-directional lineaments are prominent, but in the other parts a few lineaments are observed. Main rocks of this part, including Permian sediments, Permo-Triassic volcanics, and Triassic granites, are shown in the geological map (see Fig.2 and Fig.4).

Eastern Part

Main lineaments in the eastern part align mostly in the north-south direction. They mostly have medium length (about 5-10 km) and are related to some extent with the major fold axes and the pre-existing north-trending thrust fault. This thrust fault is located at the boundary between Silurian-Devonian metamorphic rocks and Carboniferous sediments. In the vicinity of the thrust fault, several minor lineaments are observed to concentrate in the northeast-southwest direction. It is obvious that both the northwest-trending lineaments in the south and the northeast-trending in the north cross- cut the north-trending lineaments.

Our interpretation on lineaments displayed in combination with the geological map of DMR[16] is

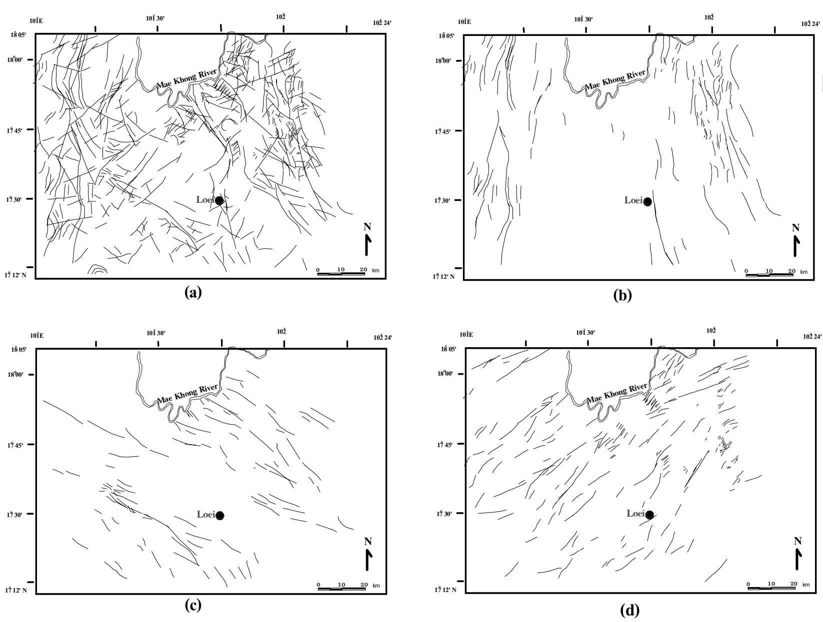

Fig 5. (a) Lineament map using combined enhancement method display by MapInfo program,
(b) Lineament map showing only the NORTH- trending lineaments,
(c) Lineament map showing only the NW-trending lineaments,
(d) Lineament map showing only the NE-trending lineaments.

illustrated in Fig.4.

Lineament analysis

Lineament analysis, which integrates the analyses of linear patterns, geometry, kinematics and dynamics,[17] can be applied to mineral exploration in an attempt to define the most favorable locations for mineral concentrations on the basis of tectonic contexts.

Fig. 5(a) displays all lineaments within the study area, which appear difficult to analyze because of the complicated features in terms of length and direction. Figs. 5 (b), (c) and (d) show the separated directions of lineaments, trending north-south, northwest-southeast and northeast-southwest, respectively. This scheme of work can be easily done using MapInfo program. For each lineament direction, the distribution, pattern, and length of lineaments are considered.

North-South Direction

Fig. 5(b) display the north-trending lineaments distributed essentially in the eastern and western parts of the study area. No distinct lineament of this direction is detected in the central part of the study area. A number of lineaments are almost parallel to the major folds and faults described above. The main lengths of lineaments are about 20 km whereas some short (less than 5 km) lineaments are in the zone of the thrust fault. Most patterns of lineaments are not straight and exhibit the swinging pattern, possibly indicating major fold axes in this area. The long lineament very close to Loei district is interpreted to represent the normal fault, which is considered to have caused the development of the Loei river valley (see Figs. 5b and 6b).

Northwest-Southeast Direction

Fig. 5(c) depicts two remarkably straight and continuous, northwest-trending lineaments, especially those in the central part of the area. These major lineaments presumably extend from southern Loei area to Lao PDR. A number of less obvious lineaments (10 km up to 20 km long), can be observed clearly on the image, form the second-order fractures branching to the two major faults. Many of the lineaments are distributed in the northern and southern parts of the study area.

Northeast-Southwest Direction

Fig 5(d) illustrates the northeast-trending lineaments (5-10 km long) that are shorter than the other direction and become denser than those of the other directions. These northeast-trending lineaments with an average length of 7 km are distributed throughout the study area. The major lineaments of this direction are considerably essential since they presumably involve in mineralization, which will be discussed later.

Discussion

Lineaments Related to Structural Tectonics

In an effort to relate lineaments with geological structures, we subdivide major lineaments into continuous and discontinuous patterns. It is interesting that the discontinuous pattern is well recognized only in the eastern part of the study area. The easternmost part of the discontinuous pattern conforms very well with the structural feature mapped as the thrust fault by DMR[16] (see Fig. 6b). Moreover, it is essential, with

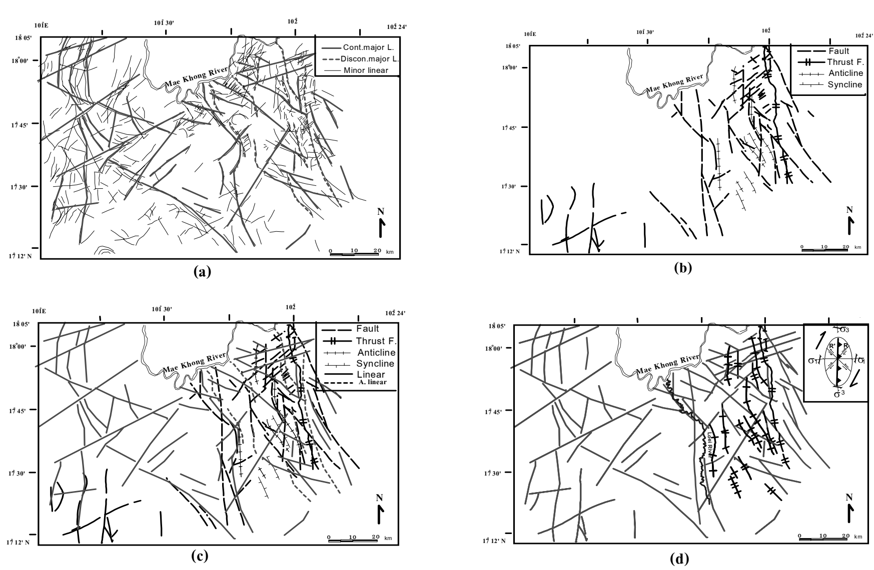

Fig 6. (a) Major and minor lineaments of the Loei study area as visualized from the enhanced Landsat data. (b) Major structural features deduced from a geological map of DMR (1992), (c) Combination of major lineaments and DMR major structural features, (d) Combined features (Fig. c) onto DMR geological map.

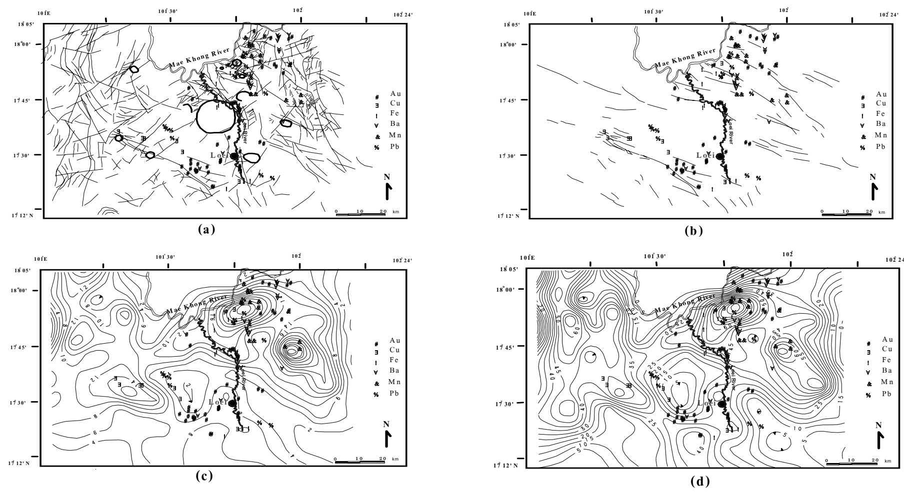

Fig 7. (a) Map showing overall interpreted lineaments and important mineral occurrences,
(b) Map showing NE trending lineaments and important mineral occurrences,
(c) A density -lineament map with important mineral occurrences,
(d) A total length -lineament map with important mineral occurrences.

the exception of the western part, that our lineament patterns correspond quite well with the structural feature mapped by DMR.[16] However, for the western part, our result on lineament analyses is useful in areas where accessibility is quite difficult and structural features are not shown at all in the DMR map. With a combination of the Landsat and geological data we can construct the new structural features of this area as shown in Fig. 6(d).

The structural map by DMR,[16] revealed that major structures in north-south direction (see Fig. 6b), from field survey provide good supporting evidence for our work, and that the north-south lineaments deduced from the Landsat image data constitutes the fault zone especially in the eastern part of the study area.

Several lineaments in the study area provide an adequate evidence of lateral displacement, and they can be considered as the strike-slip (or wrench) fault. In the northwestern part, the major north-and northwest-trending fault structures display significant displacement by the cross cutting northeast-trending strike-slip fault, suggesting that the former developed prior to the latter. In the northern part of the study area, some large northeast-trending lineaments, considered herein as faults, interrupt the north-and northwest trending ones without significant offset, and are affected subsequently by the north-trending normal faults. On the other hand, the fault patterns in the northeastern part reveal that the structures with minor movement perhaps indicate the difference in stress regimes through times. Their kinematics relationships can be described on the basis of assuming simple shear mechanisms, and using the strain ellipsoid (see Fig. 6 d). Orientation of the thrust fault and fold axes in this study area, indicate the compression force ($\sigma 1$) in the east-west direction and the extension force ($\sigma 3$) in the north-south direction. The strike-slip faults in northwest-southeast and northeast-southwest directions are the R and R', respectively.

Based on $^{40}Ar/^{39}Ar$ and Rb-Sr whole-rock isochronal geochronological data of granites in the western Thailand and eastern Myanmar,[3] northward drifting of western Burma block,[19] and perhaps from the southern hemisphere,[20] may have caused subduction of oceanic slab beneath the amalgamated mainland southeast Asia terrain during Middle to Late Cretaceous. Such the compressive tectonics may have provided enormous stress roughly in the north-south direction to the study area. The en echelon NE-trending strike-slip faults with sinistral displacement may have formed due to this tectonic stress. The NW- trending lineaments in the western part of the study area are observed to cut across the Paleozoic strata. But these lineaments seem not to extend into the Loei basin, at least from surface indication. This may indicate that the deformation along lineaments was ceased in early Cenozoic. The north-trending thrust and the northwest-trending fault, which developed earlier, may have formed due to the amalgamated terrain within mainland southeast Asia, i.e., plate interaction of Shan-Thai[14] or Sibumasu[20] to the west, Indochina[19] and intervened plates[21] to the east. Such plate interaction, particularly eastward subduction of an oceanic slab beneath Indochina where the study area is located, may have given rise to the emplacement of felsic to intermediate magmas. The intrusive bodies are clearly detected by previously described circular features in the study area. The north-trending normal fault in the central part of the study area cannot be explained using circular strain ellipsoid due to its much later development. We, therefore, consider that a major change in tectonic regime may have occurred after Cretaceous and this may correspond to the India-Asia collision[22], which may have caused the development of the possibly normal fault-bound basin of the north-trending Loei river valley.

Lineaments Related to Mineral Deposits

Fig. 7 shows the relationship between mineral occurrences of northern Loei area and lineaments. Most mineral occurrences (Au, Cu, Fe, Ba, Mn and Pb) are located in the central part of the study area. It is clear that mineral deposits, particularly Cu, Fe and Au are significantly related to circular features northwest of the Loei area as shown in Fig. 7 (a). Circular features in Thailand were earlier interpreted to represent granite intrusions producing abundant cracks.[23] Such fractures were able to serve as channel ways for hydrothermal and mineralizing fluids, as discussed by Sawkins,[24] Mitchell & Garson,[19] and Hutchison.[25] Fig. 7 (b) displays the minerals occurrences related to the northeast-southwest short lineaments, which generally are branches of long northwest-trending lineaments, especially at the lineament intersection. We also count numbers of lineaments and measure their total length within each square-grid area of 10*10 km using the MapInfo and GEOSOFT programs and present them as density and total-length lineament maps as shown in Figs. 7(c) and 7(d), respectively. It can be assumed that, most of mineral occurrences are concentrated in areas where lineaments denote both high density and continuous total length.

On the bases of these relationships, it appears that the northeast-trending lineaments may serve to control ore mineralization. For further exploration we should select targets along this direction starting at prominent intersection, and attention should be focused in areas with high density and total length of lineaments, such as an area to the northwest corner of the map (e.g., further to Laos and nearby area).

Conclusions

Digital image enhancement processing is a useful tool to help analyzing space-borne image data. Interpretation of images is a qualitative technique and should be tested against other data such as the airborne geophysical data, air-photo data and ground-truth field checks.

Combination of major lineaments from enhanced Landsat data and structures from this and previous geological maps can delineate new structural features of the area. Based upon our lineament analysis, the suitable area for further mineral exploration can be selected.

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