RESEARCH ARTICLES

Tectonic blocks and suture zones of eastern Thailand: evidence from enhanced airborne geophysical analysis

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ABSTRACT

Airborne geophysical data were used to analyze the complex structures of eastern Thailand. For visual interpretation, the magnetic data were enhanced by the analytical signal, and we used reduction to the pole (RTP) and vertical derivative (VD) grid methods, while the radiometric data were enhanced by false-colored composites and rectification. The main regional structure of this area trends roughly in northwest-southeast direction, with sinistral faulting movements. These are the result of compression tectonics (σ_1 in an east-west direction) that generated strike-slip movement during the pre Indian-Asian collision. These faults are cross-cut by the northeast-southwest-running sinistral fault and the northwest-southeast dextral fault, which occurred following the Indian-Asian collision, from the transpession sinistral shear in the northwest-southeast direction. Three distinct geophysical domains are discernible; the Northern, Central and Southern Domains. These three domains correspond very well with the established geotectonic units, as the Northern Domain with the Indochina block, the Central Domain with the Nakhonthai block, the Upper Southern Sub-domain with the Lampang-Chaing Rai block, and the Lower Southern Sub-domain with the Shan Thai block. The Indochina block is a single unit with moderate radiometric intensities and a high magnetic signature. The direction of the east-west lineament pattern is underlain by Mesozoic non-marine sedimentary rock, with mafic igneous bodies beneath this. The Nakhonthai block has a strong magnetic signature and a very weak radiometric intensity, with Late Paleozoic-Early Mesozoic volcanic rock and mélange zones that are largely covered by Cenozoic sediments. The boundaries of this block are the southern extension of the Mae Ping Faults and are oriented in the northwest-southeast direction. The Lampang-Chaing Rai and Shan Thai blocks, with very weak to moderate magnetic signatures and moderate to very strong radiometric intensities are dominated by marine clastic and igneous rocks or a northwest-southeast trending deformation zone of inferred Precambrian complexes, respectively. It is suggested that these tectonic plates collided against one another in a west-east direction.

1. Introduction

It is widely accepted that the eastern Thailand region has complex geology and structures [Hada 1990]. This region is characterized by the Sra Kaeo Suture Zone [Bunopas and Vella 1978], which was earlier interpreted as the site of a significant collision zone between the Shan-Thai (or Sibumasu) and Indochina blocks [Bunopas and Vella 1978, Hada et al. 1997, Metcalfe 1999] (Figure 1A). Followed the results of new geological, geochemical and geochronological data from Charusiri et al. [2002], new suture zones (or tectonic lines) have been proposed in Thailand (Figure 1B). These suture zones in Thailand have occurred as branch sutures, which consist of the Loei, Nan, Sra Keao and Chiang Mai Sutures Zones [Charusiri et al. 2002], and they represent the tectonic lines that border the Shanthai, Indochina, and other intervening blocks [Charusiri et al. 2002]. Two new blocks have been clearly defined in northern Thailand: the Nakhonthai and Lampang-Chiang Rai blocks [Charusiri et al. 2002]. This has significantly changed the geological components and the tectonomagnetic and metallogenic models of Thailand and mainland southeastern Asia. However, in eastern Thailand, they are much less defined. Moreover, an Early Mesozoic accretionary complex developed in the Sra Kaeo-Chanthaburi area [Hada et al. 1997, Chutakositkanon et al. 2003] and it has also been interpreted as having formed as a result of the accretion of oceanic and terrigenous materials that were mixed along the western margin of the Indochina block during Late Paleozoic to Early Mesozoic times [e.g., Metcalfe 1999, Charusiri et al. 2002]. After two micro-plate collisions and accretions in the Early Mesozoic times, the Paleo-Tethyan Ocean was closed completely, thus creating geo-suture zones [Bunopas 1991, Charusiri et al. 2002]. Therefore, several minerals that have been deposited along these sutures can result in magmatism between the plate boundaries, such as gold, gem, chromite, magnesite, stibnite and fluorite ores [e.g., Suwanasing 1969, Hinthong 1995]. However, these sutures are not clearly defined, particularly for their locations. Additionally, the northwest-to-southeast trending Mae Ping Fault (MPF) extends from

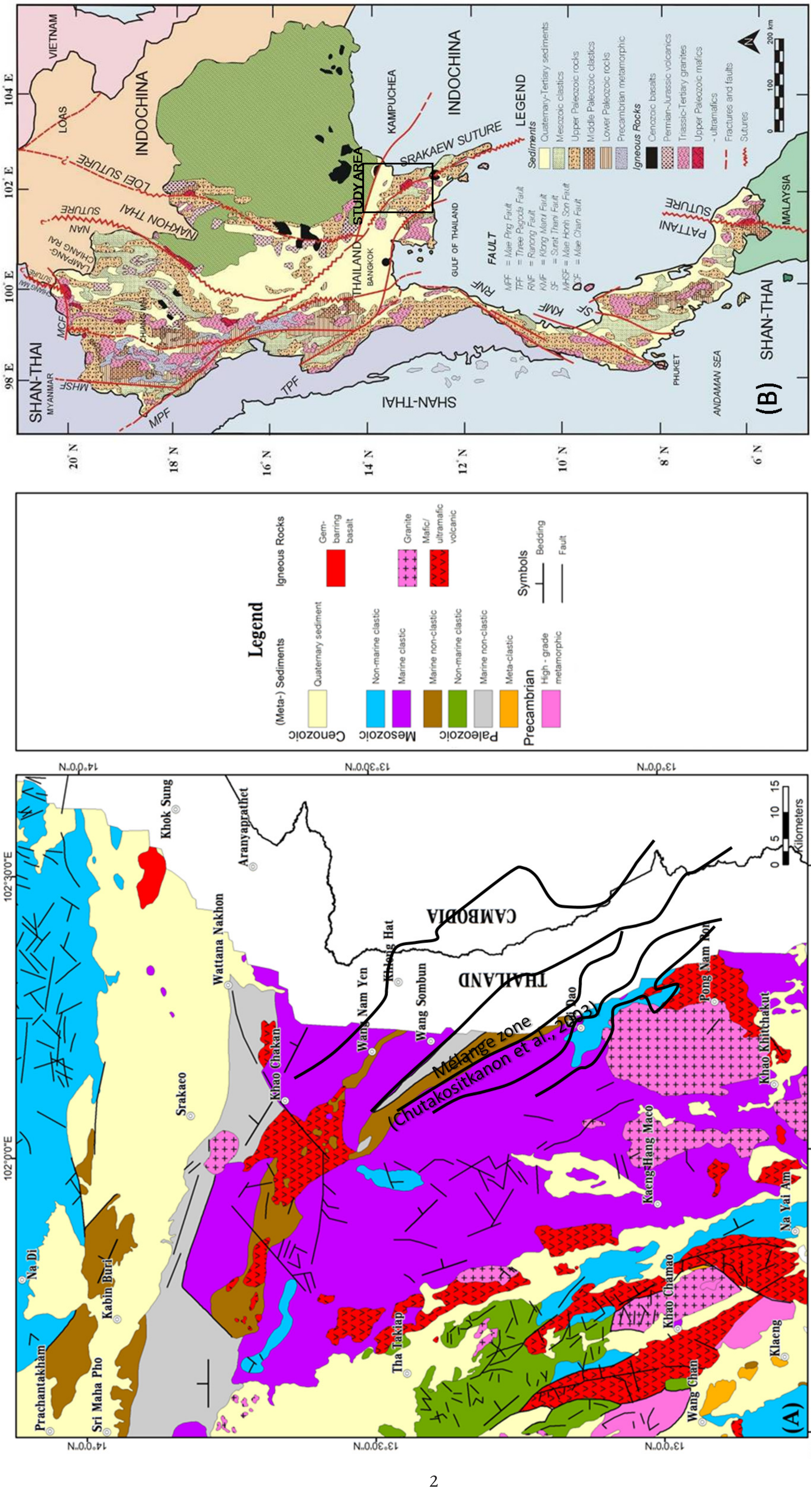

Figure 1. (A) Simplified regional geology covering the study region in eastern Thailand for the airborne geophysical investigate (data from Salyapongse [1992a, 1992b, 1997], Charusiri et al. [1992], Sangsomphong et al. [2008] and this study). (B) Simplified tectonic map of Thailand based on the results of the airborne geophysical and geological investigations, showing the major sutures and two micro-plates (Nakhon Thai and Lampang-Chiang Rai) between the Shan Thai and Indochina terranes (modified after Charusiri et al. [2002], Tulyatid and Charusiri [1999]).

western Thailand to pass through central and eastern Thailand, as seen from airborne geophysical data [Tulyatid and Charusiri 1999]. Furthermore, the prominent curvilinear topographic depressions in eastern Thailand for the MPF are also visible on satellite images [Ridd 2012].

The neo-tectonics in Thailand and mainland southeastern Asia are therefore the result of the collision between the Indian and Eurasian plates in the Middle Cenozoic times [Bunopas and Vella 1983, Hinthong 1991, Charusiri et al. 1997, Fenton et al. 1997]. Thus, present-day seismicity has occurred along the MPF zone (MPFZ) several times. The MPFZ is classified as a seismic hazard zone, which makes it of particular interest to study this fault zone since an earthquake might take place there at any time [Hinthong 1995, 1997]. Consequently, there is the necessity to understand the tectonic settings along the MPFZ, where the exposure is very poor due to the dense vegetation.

No studies have been carried out using airborne geophysical data to interpret the tectonic features and settings in eastern Thailand, although, a few studies have been reported regarding other surveys. For example, data of high-resolution airborne magnetic surveys were used to interpret the Sestri-Voltaggio line in Italy, defining it as a major tectonic boundary [Gambetta et al. 2007], and the high-angle structures in the New Guinea islands as vertical tectonic movements of crustal blocks [David Lindley 2006]. To understand the geological structures at the regional scale, airborne geophysical data are required, as the interpretation of such geophysical data can help to improve our knowledge and to detect the presence of contrasting tectonic units (or blocks) [Tulyatid and Charusiri 1999]. Thus, airborne geophysical data can help to define both the surface and subsurface geological information for eastern Thailand, which are the best geophysical data for this regional scale for the interpretation of the tectonic features. Both magnetic and radiometric data were obtained from the Department of Airborne Geophysical Data Interpretation Selection, Mineral Resources Development Project, eastern Thailand, based on Charusiri et al. [2002] and Tulyatid and Charusiri [1999]. These data consist almost entirely of high magnetic anomalies, as compared with the other adjacent regions.

The objective of the present study was to characterize the geophysical domains of eastern Thailand and to relate these to the tectonic setting. Although the occurrence of the Sa Kaeo Suture has been documented in several studies over the past two decades [Bunopas 1981, Bunopas and Vella 1992, Hada et al. 1997, Metcalfe 1999, Charusiri et al. 2002], the exact boundary locations and the orientation of this suture are still not clear. This is probably mainly due to the poorly defined geology, the difficulty in accessibility, and the scarcity of its exposure, as reported by Chutakositkanon et al. [2003]. Subsequently, Khaowiset et al. [2007] attempted to delineate the suture boundary using remote-sensing and field data in the Sra Kaeo area; however, they failed to locate the exact boundary of the Sra Kaeo Suture, and indeed, their area of interest was also too small to achieve this. Moreover, the tectonic blocks or plates on both sides of the suture have been poorly described [Bunopas 1981]. Therefore, the present study was aimed at using enhanced airborne magnetic and radiometric data to delineate the tectonic blocks and related sutures of the eastern Thailand region.

2. Regional setting

Eastern Thailand comprises several kinds of rock, which range from the Pre-Cambrian to Cenozoic ages (Figure 1A). Based on studies of Bunopas [1981] and Hada [1990], eastern Thailand consists of two major continental plates: namely Shan Thai in the west, and Indochina in the east. These tectonic plates were approached and intervened by two major oceanic plates in Early Mesozoic times, the Nakhonthai and the Lampang-Chiang Rai tectonic blocks [Charusiri et al. 2002], which might have resulted in more than one suture zone (Figure 1B). In eastern Thailand, the suture zone (or tectonic line) is known as the Sra Kaeo Suture Zone [Bunopas and Vella 1978], and it is dominated by mixtures of various deformed and thrust rock, representing a so-called Thung Kabin mélange zone [Hada et al. 1997, Chutakositkanon et al. 2003] (Figure 1B).

Within the Shan-Thai terrane of eastern Thailand, the inferred Precambrian amphibolite facies (Figure 1A) was formed as the oldest crystalline basement rock [Salyapongse 1992a]. The younger rock sequences are then possibly from the Early Paleozoic metaclastic-marine nonclastic and Middle Paleozoic marine rocks that would have been unconformably overlain by the inferred Precambrian rock [Salyapongse 1992b]. The Middle Paleozoic marine metaclastic sediments appear to be transitional to the Late Paleozoic marine nonclastic units [Bunopas and Vella 1983].

The Indochina terrane of the study region in eastern Thailand is an elongated block with a NNW-SSE trend, which deviates to an almost east-west direction in the north. The oldest rock of the Indochina terrane are the Middle Paleozoic deformed sequences of the older arc setting [Salyapongse et al. 1997]. The Late Paleozoic to Early Mesozoic igneous rock in the area is composed of felsic-intermediate plutonic rock, basaltic breccia and hyaloclastite, and rhyolitic to andesitic volcanics. The Middle-to-Late Mesozoic red beds of the Khorat Group became extensive and are limited to the southeast and north regions [Salyapongse et al. 1997]. The so-called Sra Kaeo Suture Zone was completely covered by active flood plains with dense vegetative cover, and partly by the Early Mesozoic marine clastic unit [Hada et al. 1997]. This has led to difficulties in the geological mapping. The suture is concealed by Cenozoic in-fill sediments along the remnant basin between the two plates. After the compressive tectonic setting, the younger Middle-to-Late Mesozoic red beds (Khorat

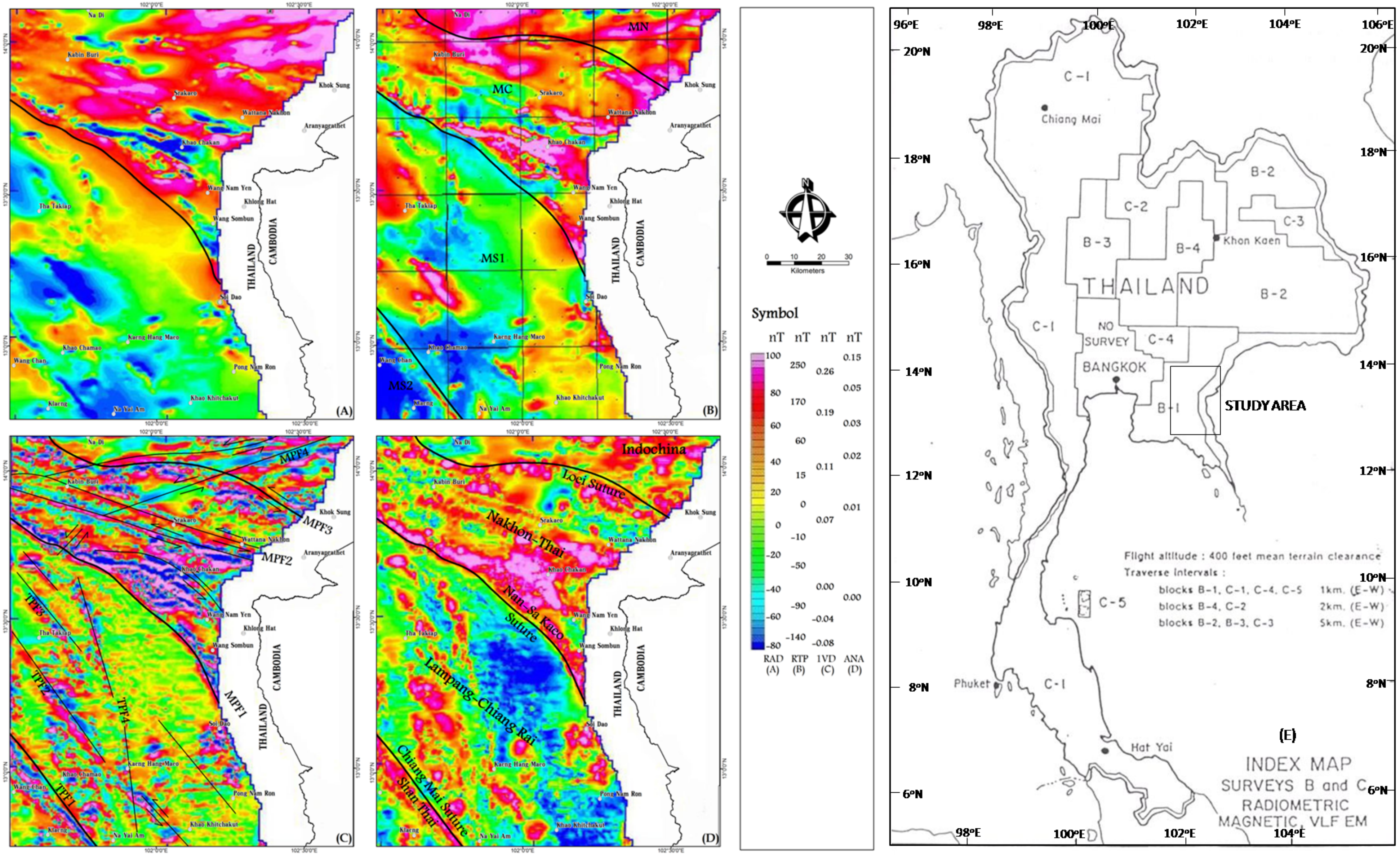

Figure 2. Enhanced aeromagnetic maps of the study region in eastern Thailand showing the residual magnetic field (A, RAD), the reduction to the pole (B, RTP), the first vertical derivative (C, 1VD), the analytical signal (D, ANA) (all units are in nT), and the Index map of Thailand showing airborne survey B-1 in the study area (E), with survey line spacing of 1 km, and the survey in the east-west direction with a 50 m data sampling interval, by Kenting Earth Science International, Ltd. [1987].

Group), the Middle Mesozoic I-type-granites, and the Cenozoic basalts with gem deposits completed the geologic succession [Salyapongse 1992b] (Figure 1A).

3. Materials and methods

The airborne surveying, digital compilation, automatic profiling, and map production were carried out by Kenting International Earth Science Ltd. [1987]. Data acquisition took place from February 1985 to March 1987. We reprocessed the digital data using the Geosoft program at the Geophysical Data Interpretation Section, under the Mineral Resources Development Project. The dataset included both enhanced radiometric and magnetic data, which were used for the visual interpretation (Figure 2E).

In the present study, the enhanced maps were processed and are presented in the form of false-colored composite maps (Figure 2). For the residual magnetic field data, the analysis included reduction to the pole (RTP), vertical derivative and analytical signal grids (Figure 2B-D). The RTP method is the process of converting the magnetic field from magnetic latitude to the field at the magnetic pole, where the inducing field is transformed to the vertical, and anomalies are directly over their sources [Milligan and Gunn 1997]. The vertical derivative technique is used for locating the edges of magnetic source bodies after a transformation in the frequency domain that converts magnetic anomalies by multiplying the amplitude spectra of the field [Milligan and Gunn 1997]. The analytical signals of a magnetic anomaly are a combination of the vertical and horizontal magnetic derivatives that are symmetrical and occur directly over the edges of wide bodies and the center of narrow bodies [MacLeod et al. 1993]. For air-borne radiometric data, false-colored composites and rectification were used for enhancement. The radiometric total count, which represents potassium (K), and the effective uranium (U) and effective thorium (Th) contents (Figure 3) were used for visual interpretation.

After several enhancement processes, we found that derivative maps and radiometric grids are the most suitable maps for the interpretation of the structural elements in this study. Each technique helps to display the edges of magnetized bodies and lateral contrasts in magnetization, which are mainly caused by lithological and structural changes in the buried basement. These provide help with the magmatism and structural evolution in the various terranes for the recovery of previously unmapped tectonic features. Data interpretation was carried out with an awareness of the limitations of the data collected in the east-west flight direction and the RTP enhancement of data at low magnetic latitudes (14° of magnetic inclination). Testing of the RTP enhancement technique used in this study yielded acceptable results concerning the shapes and locations of anomalies, compared to the analytical signal-enhancement method.

We also revised the geological maps compiled from the 1:250,000 scale geological maps of Salyapongse [1992a, b] and Sangsomphong et al. [2008], in conjunction with our field reconnaissance survey. The new geological map was then compared with the interpreted geophysical map. Several studies on tectonic evolution were consulted to redefine the tectonic elements from the geophysical results (Figure 1A) [Bunopas and Vella 1978, Bunopas 1981, Bunopas and Vella 1983, Hada 1990, Bunopas 1991, Charusiri et al. 1992, Charusiri et al. 1997, Metcalfe 1999, Charusiri et al. 2002, Chutakositkanon et al. 2003].

4. Results and interpretation

The residual magnetic map shows regionally high magnetic intensities in the northern part of the study area, and low to moderate intensities in the southern part. The magnetic intensity levels ranged from −100 nT to 100 nT, with a base level of 5 nT. Local variations in the field intensity always exceeded 50 nT in the northern and central parts, and diminished rather abruptly to less than 50 nT in the southern part. This intensity map clearly shows three regional magnetic zones that roughly trend in a northwest-southeast direction. From the north, there is the high magnetic zone that is clearly visible on the enhanced map. The most prominent low magnetic intensity zone is in the central part, from the Tha Takiap district (see Figure 2A), and continues southeastwards to the Cambodia–Thailand border. Within this zone, there are a series of the elongated and relatively higher magnetic intensities that trend in a northwest-southeast direction. Additionally, the boundary between the central and southern zones is displayed by a fairly sharp magnetic contrast. To the north, this zone shows higher magnetic intensities that trend in an east-west direction (Figure 2A). Therefore, a qualitative interpretation can be applied by examining the magnetic maps and looking for similar magnetic signature zones (Figure 2B-D). It is also quite clear, as shown in the interpretative maps in Figure 2C, D, that the boundary between the south of Sra Kaeo and the north of Tha Takiap is distinctly sharp.

Both the RTP and the analytical signal digitally enhanced maps show similar magnetic features, and these enhancements lead to the more outstanding magnetic boundaries. The RTP map shows high anomalies oriented as a northwest-southeast trend, with a total length of about 100 km. The central edge of this anomaly is marked by a sharp magnetic gradient in a northwest-southeast trend, extending from the south of Kabinburi to the south of Sra Keao (Figure 2B). The analytical signal image shows the marked narrow zone between the central and southern parts better than those of the previously described images. It should also be emphasized that the boundary contrast within the individual zones is quite clear (Figure 2D). The first vertical-derivative map reveals a significant magnetic pattern better than those of the other maps, such as linear structures. Applica-

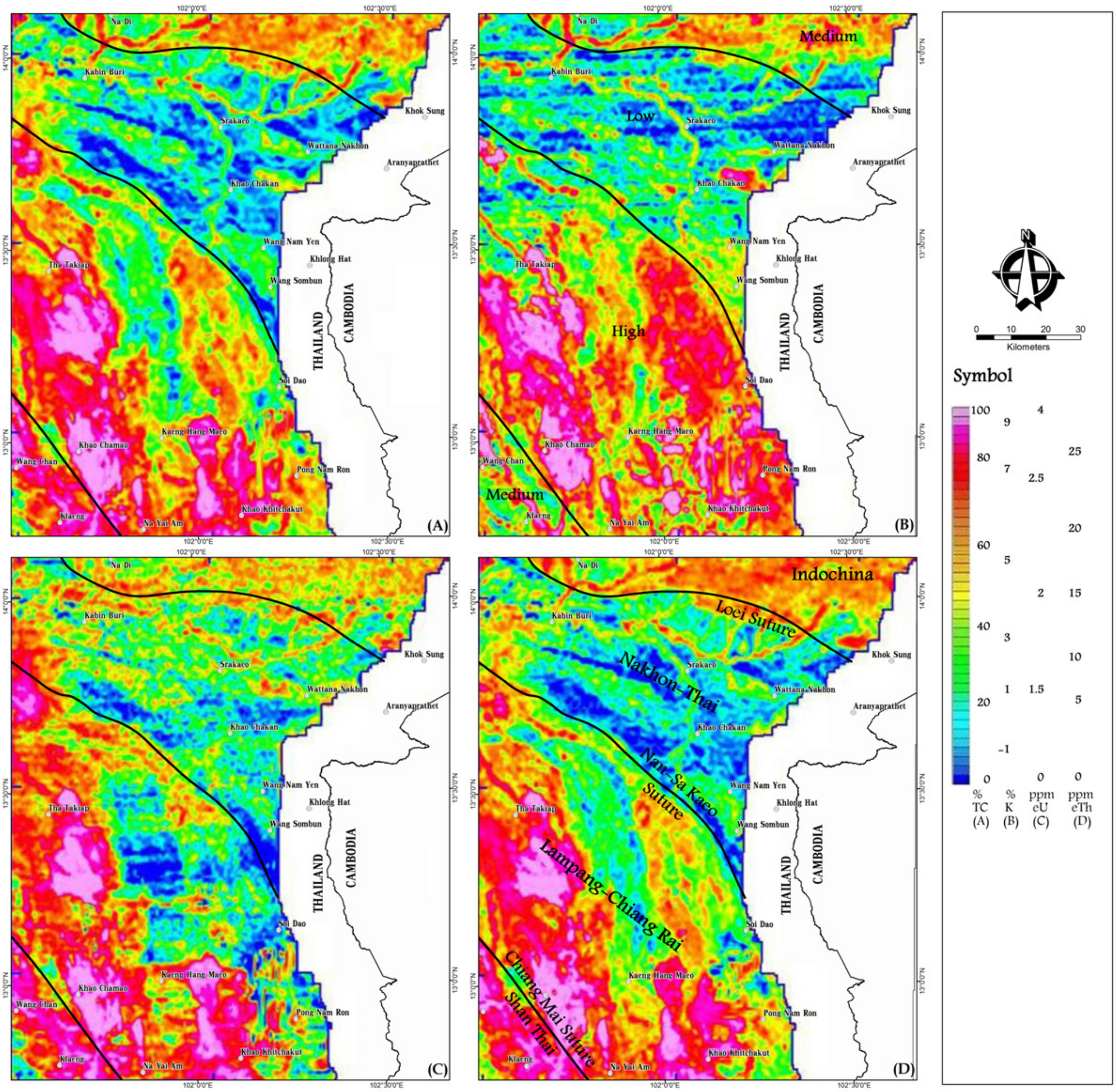

Figure 3. Enhanced radiometric maps of the study region in eastern Thailand showing the total counts of potassium, uranium and thorium contents (A, TC, in %), the potassium content (B, K, in %), the equivalent uranium contents (C, eU, in ppm), and the equivalent thorium contents (D, eTh, in ppm).

tion of the first vertical-derivative maps shows well-defined lineaments, particularly those trending in the northwest-southeast direction. These long and continuous lineaments in this direction appear to cross-cut the three regional magnetic zones mentioned earlier (Figure 2C). Additionally, some lineaments from the residual magnetic, RTP, and first vertical-derivative maps show an informative displacement (of 0.5 km), such as those to the southwest of Sra Keao. The results shown in these residual magnetic, RTP, and first vertical-derivative maps clearly indicate the northwest trending lineaments with the sinistral sense of movement.

With respect to the radiometric maps (Figure 3), the areas that show a low radioactive content are located in the central part of the study area, while those with moderately high radioactive levels and with high to very high radioactive levels are located in the northern and southern parts, respectively. Most of the maps from each type of radiometric information reflect the contrast in the surface geology and structures. Based on radiometric intensities, structural styles and geological features, the three radiometric domains conform well to those of the magnetic domains (see Figure 2).

From the enhanced image maps, we created a new interpretation map using our data integration and interpretation (Figure 4A). The study area is divided into three magnetic domains, the Northern, Central and Southern Domains, which are based on the magnetic intensities/ textures, structural styles, and geological features. The boundaries of the individual domains clearly coincide with the abrupt changes in the average magnetic intensities, and anomaly variabilities and orientations. Each domain has been further

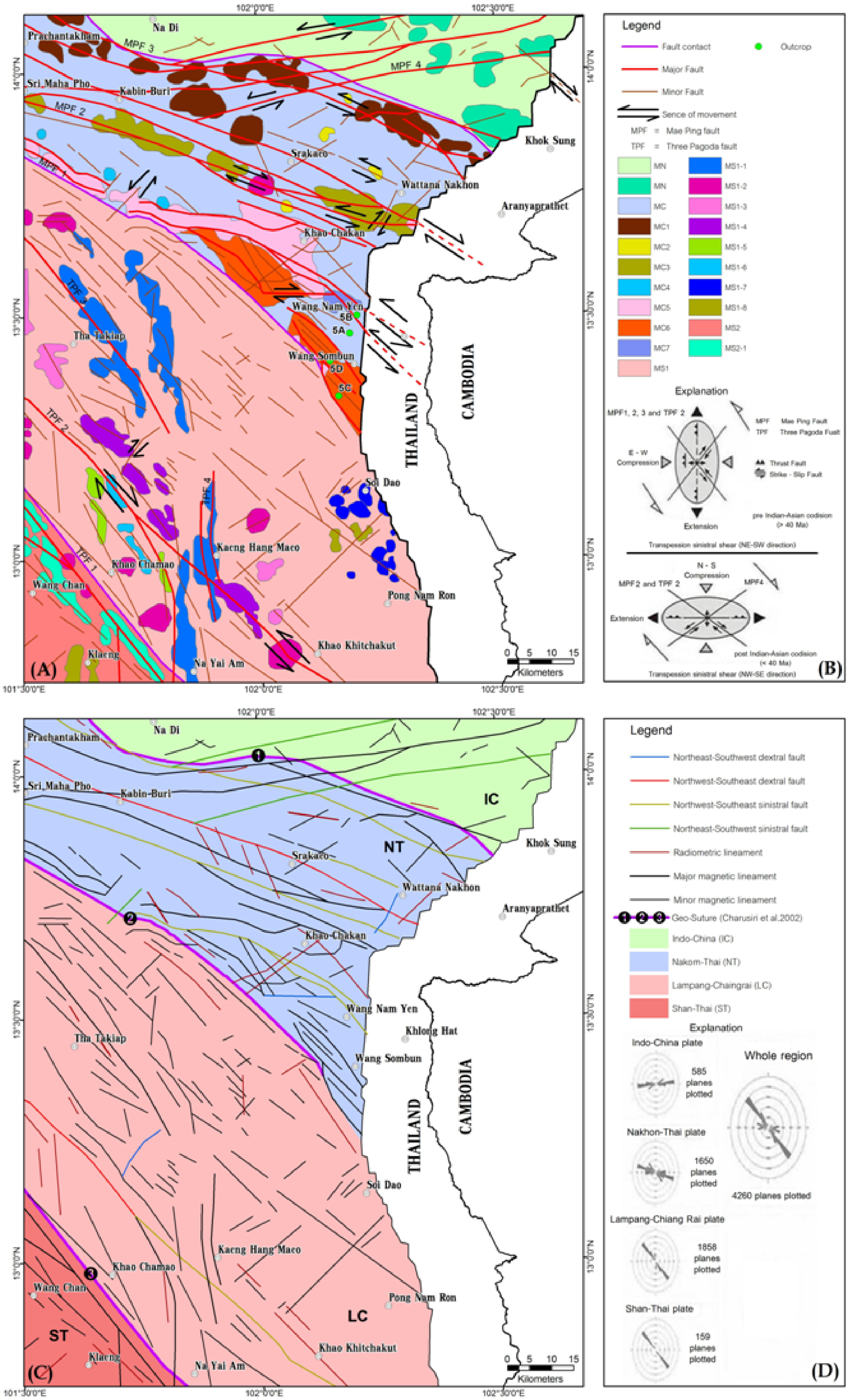

Figure 4. (A) Magnetic interpretation maps of the studied region in eastern Thailand showing the contrasting tectonic units, from the north to the south: the Indo-china (MN), Nakhon-Thai (MC), Lampang-Chiang Rai (MS1) and Shan-Thai (MS2) plates corresponding to the magnetic domains. (B) Strain ellipsoids showing the east-west compression and development of MPF1, MPF3 and TPF2 during the pre Indian-Asian collision in (A) and the transpression sinistral shear in a northwest-southeast direction with the development of MPF2, MPF4 and TPF2 during the post Indian-Asian collision in (B). (C) Structural map (based on data of A and B), and (D) Rose diagrams showing the major lineament patterns of the Indo-china (MN), Nakhon-Thai (MC), Lampang-Chiang Rai (MS1) and Shan-Thai (MS2) tectonic plates.

divided into sub-domains and units on the basis of the local detailed magnetization, interpreted subsurface geology, structures, lineament patterns, and magnetic features. The characteristics of the individual sub-domains are described by a comparison of the interpretation with the proposed geological features (Figure 4A).

4.1. Northern geophysical domain

The Northern Domain is essentially composed of moderately magnetized material, which is interpreted as being igneous bodies beneath the Mesozoic sedimentary rock. This domain consists of a high magnetization, short-to-moderate wave length, circular feature and a coherent pattern, which are considered to be mafic igneous rocks. These are not controlled by the regional northwest-southeast trending fault, which possibly suggests volcanic vents and intrusive bodies. The radiometric data show a moderate level of the three major radiometric elements, K, U and Th. This anomaly indicates sedimentary rock with a high K-feldspar content, equivalent to the continental Mesozoic sedimentary rock (Khorat Group) (Figures 1A, 2, 3).

4.2. Central geophysical domain

The Central Domain shows elongated highly magnetic signatures with clear trends in an almost northwest-southeast direction. It is chiefly composed of the high magnetic intensities of mafic/ ultramafic igneous rock. Our regional reconnaissance survey revealed that the very high magnetic intensity units in the southeastern part correspond to the exposed mafic and ultramafic volcanic blocks of the mélange zone. The radiometric data show low K, U and Th contents. This anomaly is considered a hydrothermal alteration of host rock. Some parts to the east of the Central Domain show high K content, which is considered to be potassic alteration in the Late Paleozoic-Early Mesozoic volcanic rock (see Figures 1A, 2, 3).

4.3. Southern geophysical domain

The Southern Domain is largely composed of low-to-moderate magnetic intensity features. This domain can be divided into two sub-domains, the Upper Southern Sub-domain and the Lower Southern Sub-domain, according to the north-south magnetic pattern in the Upper Southern Sub-domain, as well as the distribution of circular magnetic bodies and northwest-southeast structural styles in the Lower Southern Sub-domain. The Upper Southern Sub-domain has northwest-southeast magnetic signatures that are cross-cut by the north-south trending and low-to-moderate magnetic zone that corresponds to the Late Paleozoic-Early Mesozoic volcanic rock and Early Mesozoic granites. This sub-domain consists of an incoherent high magnetic intensity with a north-south trend, which is equivalent to the volcanic belt with rhyolitic to andesitic associations. This sub-domain is associated with major faults (Figure 2C, Three Pagoda Fault 3 [TPF3]) that run parallel to a regional structure. The Lower Southern Sub-domain is chiefly composed of low-to-moderate magnetic intensities that correspond to the (inferred Precambrian) metamorphic rock. This clearly defined lineament trend is illustrated by the curved lineament patterns interpreted as representing the northwest-southeast trend. The Southern Domain is composed largely of moderate-to-high radiometric contents. The high anomaly in the Upper Southern Sub-domain defines Early Mesozoic granites and Late Paleozoic-Early Mesozoic volcanic rock. The eastern part shows low-to-moderate levels of K and Th, and a low U content, which can be related to the marine Early Mesozoic clastic rock. The low radiometric contents indicate the volcanic clastics of Early Mesozoic rock. The Lower Southern Sub-domain shows high radiometric intensities that correspond to the inferred Precambrian metamorphic rock and Cenozoic sediments (see Figures 1B, 2, 3).

4.4. Structural interpretations

Major lineaments of various patterns and styles were drawn using visual interpretation following the image manipulation. Geological lineaments (fractures and faults) were superimposed afterwards as a separate layer. Comparisons with the geological lineaments show that many of the magnetic anomaly trends coincide with exposed geological fault contacts and faults (Figure 4C).

The Northern Domain is characterized by a 120-km-long, east-west-trending fault (Figure 4D). This domain is not controlled by the major northwest-southeast trending fault. From the residual magnetic, RTP and first vertical-derivative maps, a northeast-southwest trending fault with a sinistral movement of about 3 km was found in the north of the Sra Kaeo district.

The Central Domain is characterized by a rather irregular pattern of magnetic anomalies that contain long segments with a predominant northwest-southeast linear trend (Figure 4D) and a length of about 100 km. This belt is separated by sharp northwest-southeast lineaments, conforming to the regional structures. The magnetic data also show a strike-slip fault with sinistral and dextral movement motion running in a northwest-southeast direction. From the residual magnetic, RTP and first vertical-derivative maps, the sinistral fault shows a displacement of about 1 km in the south of the Sra Kaeo district, while to the north of the Sra Kaeo district, the fault shows a sinistral offset of about 2.5 km. The northwest-southeast dextral fault cross-cuts through the Quaternary sediment, which can be seen from both the magnetic and radiometric maps. The northwest-southeast sinistral faults of MPF1 are cross-cut by the northeast-southwest sinistral faults.

The Southern Domain comprises sets of northwest-southeast and north-south trending faults (Figure 4C), with a length of 90 km. From the residual magnetic, RTP and first vertical-derivative maps we found a northwest-southeast fault with a sinistral movement of about 1 km in the south of the Kaeng Hang Maeo district. To the south of Thatakiab, there is a northeast-southwest orientated fault with a dextral movement of about 3 km. The boundary between the Central Domain and Southern Domain is marked by a northwest-southeast sinistral fault, as indicated by the offsets in the north-south axial plane of the fold axis. In the geological map, the thrust faults demarcate the boundary between the marine non-clastic rock and the volcanic rock of the late Paleozoic ages. Our airborne magnetic results also show contrasting signatures between the Upper Southern Sub-domain and the Lower Southern Sub-domain of the northwest-southeast fault boundary, which is a boundary between the inferred Precambrian metamorphic rock and the Middle Palaeozoic non-marine clastic rock.

Tectonic boundaries separate regions or geological blocks that show different structures and deformation styles. Faulting, which follows the main deformation stage, was recognized as an abrupt termination of one deformation style with respect to the adjacent one. Figure 4C shows the faults from the interpretation of airborne magnetic and radiometric maps. MPF3 represents the boundaries between the Northern and Central Domains, and MPF1 separates the Central Domain and the Southern Domain. TPF1 separates the boundary between the Upper and Lower Southern Sub-domains.

5. Discussion

5.1. Lineaments related to tectonic features

Comparisons between the airborne geophysical lineaments and the tectonic features proposed by Charusiri et al. [2002] and with the subsequent studies by Chutakositkanon et al. [2003] and Ridd [2012], have revealed that the major lineaments of the Northern and Central Domains correspond well with the MPFZ, while the Southern Domain is bound to the east by a fault that conforms well with TPF, which is believed to extend from western Thailand to the east (Figure 1B).

The MPF can be divided into four branches: MPF1, MPF2, MPF3 and MPF4. MPF1 is the boundary between the Central Domain and the Southern Domains, as a northwest-southeast fault with sinistral movement. MPF3 divides the Northern Domain from the Central Domain, as a northwest-southeast sinistral fault. MPF2 is a northwest-southeast sinistral fault. MPF4 is a northeast-southwest sinistral fault, and it cuts through the Northern Domain and a northwest-southeast sinistral fault (MPF3).

The TPF also consists of four branches: TPF1, TPF2, TPF3 and TPF4 (Figure 4A). TPF1 is the boundary between the Upper and Lower Southern Sub-domains, which is associated with the inferred Precambrian metamorphic rock. TPF2 shows both sinistral and dextral fault offsets. TPF4 trends in the north-south direction and cross-cuts through TPF2 and TPF3 (Figure 4A), and is associated with Late Paleozoic-Early Mesozoic volcanic rock in the Upper Southern Sub-domain. The occurrence of these faults can be explained using the strain ellipsoid proposed by Charusiri et al. [2002]. We suggest that MPF1, MPF2, MPF3 and TPF2 were formed as a result of compression tectonics with σ_1 in the east-west direction, and generated strike-slip movement during the pre Indian-Asian collision. MPF4 occurred later, from the transpression sinistral shear in the northwest-south direction following the Indian-Asian collision (Figure 4B).

5.2. Geophysical responses related to tectonic setting, blocks and sutures

The airborne magnetic interpretation maps of the eastern Thailand region (Figure 4A, C) show four major contrasting geophysical domains with faults and sutures along the geophysical boundaries. To correlate the magnetic anomalies with the rock units, the Northern Domain is characterized by spot magnetic patterns in east-west-running structures of igneous bodies beneath the Indochina terrane [Charusiri et al. 2002]. It is very interesting that this zone is not shown in the geological map. The contact boundary between the Northern and Central Domains is derived from the magnetic pattern (and major structure) of each domain, and reveals a sharp contact between the magnetic boundaries. We therefore interpret this as the fault boundary (MPF3) of the Khorat Group sedimentary rock. Based on Charusiri et al. [2002], the fault corresponds with the so-called Loei Suture Zone. The geophysical domains were also used to help the interpretation of the Sra Kaeo–Chanthaburi Suture (or Nan-Sa Kaeo Suture) [Charusiri et al. 2002]. Data from field investigations (Figure 5), which include the existence of the pillow lava (the present study) and the accretionary complex [Chutakositkanon et al. 2003], suggest that the Nan-Sra Kaeo Suture represents the eastern margin of the Nakhonthai block in the Central Domain. The similar magnetic signature observed in the Central Domain represents the northwest-southeast sinistral fault (MPF1) and the presence of the mafic to ultramafic volcanic block in the mélange zone of the northwest-southeast trending accretionary complex. This major fault continues on to Tonle Sap Lake in Cambodia. Our field data and that of Salyapongse et al. [1997] support the occurrence of Permo-Triassic volcanic rock, and this might indicate a volcanic arc after the collision between the Nakhonthai block and the Indochina terrane (Figure 6) during the late Paleozoic to Early Mesozoic times [Hada et al. 1997, Charusiri et al. 2002].

Our analysis shows that the Southern Domain is divided into two sub-domains, the Upper and Lower Southern Sub-domains. The boundary of the Lower Southern Sub-domain is divided by TPF1 and inferred Precambrian metamorphic

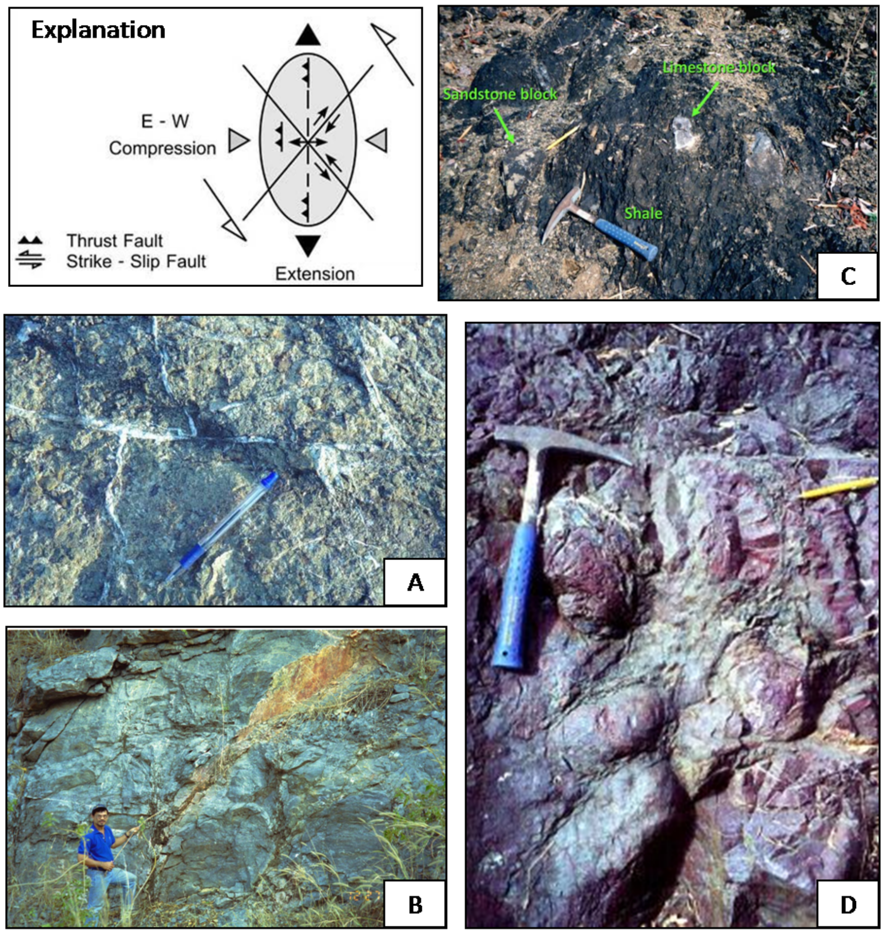

Figure 5. Evidence from the field survey results: (A) An ellipsoid-showing fault orientation and sense of movement interpreted from the outcrop, which is a fault plane oriented in the norteast-southwest direction, 5 km south of Wang Nam Yen district, Sra Kaeo, indicating a dextral strike-slip sense of movement (top of pen points to the north). (B) A road-cut exposure of thick-bedded Late-Paleozoic limestone, 2 km south of Wang Nam Yen district, Sra Kaeo, showing the northwest-southeast reverse fault. (C) Exposure of the mélange zone, containing sandstone and limestone blocks set in a shale matrix, 10 km south of Wang Sombun district, Sra Kaeo [Chutakositkanon et al. 2003]. (D) A road-cut exposure of pillow lava basalt, 5 km west of Wang Sombun district, Sra Kaeo.

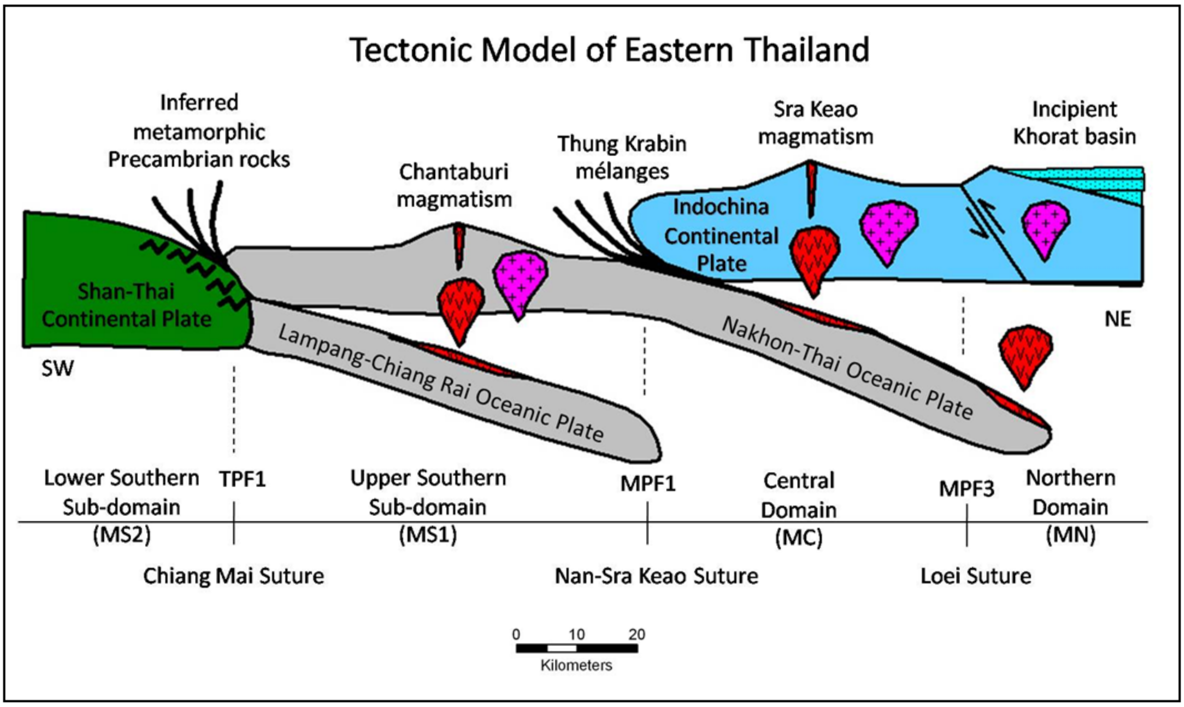

Figure 6. Schematic tectonic model of eastern Thailand showing tectonic blocks, sutures, and settings during the Early Mesozoic times, based on the interpretation of geophysical, geological results from the current (see Figure 4) and previous studies.

rock. The Upper Southern Sub-domain shows a low-to-moderate magnetic intensity, but with a high radiometric intensity, due to the occurrence of a large Early Mesozoic granite body and Late Paleozoic-Early Mesozoic volcanic rock that is covered by the Early Mesozoic marine clastic. Based on Charusiri et al. [2002], the Late Paleozoic-Early Mesozoic volcanic rock and Early Mesozoic granites are of I-type magma and they were formed in response to subduction of the Lampang-Chiang Rai oceanic plate beneath the Nakhonthai oceanic plate (Figure 6). For the Lower Southern Sub-domain, MS2-1 corresponds to the inferred metamorphic Precambrian rock (Figures 1B, 4A) that belongs to Shan Thai terrane. As a result, the boundaries of the sutures are better defined and better delineated than the tectonic map proposed earlier by Charusiri et al. [2002]. However, the contrasting geophysical domains found in the present study can clearly explain the tectonic units or blocks proposed by Charusiri et al. [2002]. We, therefore, infer that the Northern Domain is equivalent to the Indochina terrane (Figure 4C, D, MN), the Central Domain to the Nakhonthai plate (Figure 4C, D, MC), the Upper Southern Sub-domain to the Lampang-Chiangrai plate (Figure 4C, D, MS1), and the Lower Southern Sub-domain to the Shan Thai terrane (Figure 4C, D, MS2; see also Figure 1A). Based on the airborne geophysical interpretation, the Indochina terrane, Nakhonthai plate, Lampang-Chiang Rai plate and Shan Thai terrane were tectonically compressed and the east-dipping subduction might have developed from southwestwards to northeastwards in eastern Thailand (Figure 6).

6. Conclusions

Based on the results of the airborne geophysical interpretation, part of eastern Thailand is essentially characterized by intricate geology and complex mega-structures. Four microtectonic plates are newly and clearly defined in terms of their locations and orientations, namely the Indochina, Nakhonthai, Lampang-Chiang Rai and Shan Thai blocks. Moreover, our results help to unravel the geological incidents in the past, and they are very useful for further investigations into the paleotectonic and neotectonic settings.

According to our lineament investigation, by comparing the geophysical data with other available geological data in the past, new lineaments which had never been described before have been recognized. These lineaments are mainly covered by Cenozoic sediments, and so they are not visible in the field. There is newly discovered branching or subsidiary faults trending in the northwest-southeast direction that can be traced following the major MPF and TPF of western Thailand. These newly defined faults show both sinistral and dextral senses of movement. The northwest-southeast dextral fault passes through Cenozoic basins, which provides sound evidence that the study region is still active.

Our interpretation using enhancement data improves upon the previous geologically mapped data where the rock is poorly exposed. As a result, a more detailed and comprehensive understanding of the geological/ tectonic data is provided. The resulting tectonic map can be applied not only for mineral exploration, but also for seismological analysis.

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