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Tectonic development of Central Thailand: new evidences from airborne geophysical data

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Abstract: The N-S oriented central floodplain of Thailand is situated between the NE-SW-trending strike-slip Uttaradit Fault Zone (UTFZ) to the north, the northern shoreline of the Gulf of Thailand to the south, and irregular paths of normal faults to the east and west. Major structures of the area include the NW-SE-trending sinistral strike-slip Mae Ping and Three Pagoda Fault Zones (MPFZ and TPFZ) located to the west and a N-S-oriented Central Volcanic Belt (CVB) located to the east of the plain. Tertiary basins located within the Central Plain have geometries indicating that they were formed due to the reversed movement from sinistral to dextral of the major NW-SE-trending strike-slip fault zones during Late Oligocene-Early Miocene times.

Geophysical data interpretation results (magnetic, gamma-radiometric, digital terrain data and regional gravity data) show the N-S-trending CVB, outline the known major fault zones, discover the Chao Phraya Fault Zone (CPFZ) and other subsurface lineaments and magnetic bodies within the Central Plain, as well as suggest a new fault path for the TPFZ.

The findings indicate that the tectonic evolution of the Central Plain was controlled by the movement along the CVB, which may represent an ancient suture zone, and strike-slip faults bounding small sub-continental blocks. These movements include: extension (oblique) along the old sutures and volcanic arcs, reversed sinistral-to-dextral movement on the NW-SE-trending MPFZ, TPFZ and CPFZ, and reversed dextral-to-sinistral UTFZ. Indochina's southeast extrusion tectonic setting associated with the collision of the Indian and Eurasian plates may have reactivated these lithospheric weak zones and caused the opening of the Central Plain and the Gulf of Thailand since Late Oligocene time.

INTRODUCTION

The N-S-trending Chao Phraya Floodplain of Thailand is a significance source of on-shore petroleum. The floodplain is situated between the NE-SW-trending strike-slip Uttaradit Fault Zone (UTFZ) to the north, the northern shoreline of the Gulf of Thailand to the south, and irregular paths of normal faults to the east and west (Fig. 1). Major structures of the area include the NW-SE-trending sinistral strike-slip Mae Ping and Three Pagoda Fault Zones (MPFZ and TPFZ) located to the west and a N-S-oriented Central Volcanic Belt (CVB) located to the east of the plain, i.e., along the longitude 101°E in Figure 1. Tertiary basins located within the Central Plain have geometries indicating that they were formed due to the reversed movement from sinistral to dextral of the major NW-SE-trending strike-slip fault zones during Late Oligocene-Early Miocene times.

The present day location of geological units on the northern and southern sides of the major NW-SE-trending MPFZ (DMR, 1987) and the study of shear fabrics in mylonitic rocks taken from the fault zone (Lacassin *et al.*, 1993) indicate that the fault movement is sinistral or left lateral. On the other hand, recent earthquake evidences (Le Dain *et al.*, 1984) indicates that the fault shows dextral or right lateral strike-slip motion. Paleomagnetic analyses of Cenonzoic rocks in Thailand indicate a clockwise rotation without any significant paleolatitude displacement (Barr and MacDonald, 1981; Bunopas, 1981; Maranate and Vella, 1986), implying that such a clockwise rotation is a result of inter blocks' rotation by dextral shear process. The opposite conclusion may indicate a reversal of the sense of fault motion (Tapponnier *et al.*, 1982; Polachan and Sattayarak, 1989; Polachan *et al.*, 1991).

This paper presents a combined airborne magnetic and gamma-ray radiometric qualitative

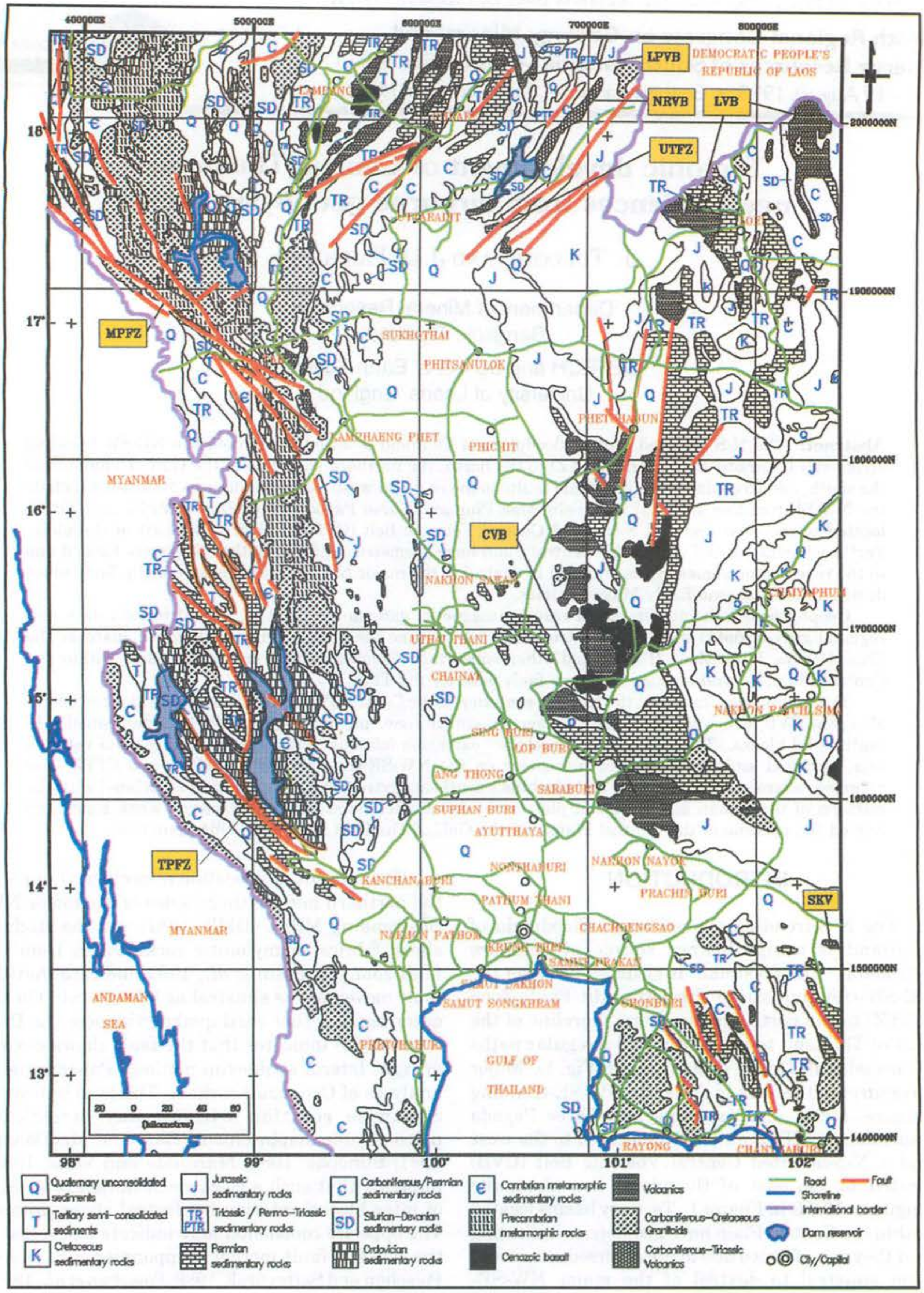

Figure 1. A geological sketch-map of Central Thailand modified after DMR (1987). MPFZ = Mae Ping Fault Zone; TPFZ = Three-Pagoda Fault Zone; UTFZ = Uttaradit Fault Zone; LPVB = Lampang-Phrae Volcanic Belt; NRVB = Nan River Volcanic Belt; LVB = Loei Volcanic Belt; CVB = Central Volcanic Belt; SKV = Sa Kaeo Volcanic.

interpretation aimed at studying the geological structure and its relation to the development of the Cenozoic Chao Phraya Floodplain as the result of the Indian-Eurasian collision tectonic.

GEOLOGY OF THE STUDY AREA

The study area covers the major parts of the country except the central and eastern parts of the Khorat Plateau and the Peninsula. The area exhibits different physiography, which are: the mountainous terrains in the north, west, northeast and east; the central alluvial floodplain of the Chao Phraya River in the centre; and the Khorat Plateau in the east (Fig. 1). The geology of Central Thailand has been studied by Suensilpong *et al.* (1978), Chonglakmani *et al.* (1983), Dheeradilok (1987), Dheeradilok *et al.* (1992) and Bunopas (1992) as part of national studies.

Stratigraphy

The area contains rocks of different ages ranging from Precambrian (?) to Quaternary (Fig. 1). The Precambrian metamorphic rocks, referred to as the Lan Sang Gneiss Complex (Bunopas, 1992), comprise gneisses, schist and calcsilicates of amphibolite facies (Fig. 1).

The Lower Paleozoic (Cambrian to Ordovician) rocks have been subjected to low grade dynamo-metamorphism (Baum *et al.*, 1970; Bunjitradulya, 1978) and have locally transformed into quartzite, phyllite, schist and recrystalised limestone. These rocks are in fault contact with the inferred Precambrian gneiss. The Middle Paleozoic (Silurian-Devonian) sedimentary rocks, which are shales and carbonates, crops out over the west and the east of the western mountainous area; north of the Chao Phraya Floodplain; the northeast (Changwat Loei); and the south of the study area. According to Bunopas (1983), the Silurian-Devonian rocks can be differentiated into several facies belts from west to east including: back-arc basin; volcanic arc and fore-arc facies. The Upper Paleozoic (Carboniferous and Permian) rocks conformably overlain the middle Paleozoic rocks. The Carboniferous rocks in the Sukhothai Fold Belt (Bunopas, 1983) comprise rocks of various lithology and thickness from west to east in the west, north and the southeast Thailand (Bunopas, 1983; quoted by Sukontapongpow, 1997). At places marine shelf sedimentation continued in the west and flysch type sediments in the east, but with local unconformities. In the middle part of the fold belt pronounced unconformities on the Silurian-Devonian rocks are overlain by thick volcanic agglomerates and possibly marine red beds underlying Permian Limestone.

The Mesozoic sequences in Central Thailand include rocks of two depositional types: marine and continental facies. The former comprises the Triassic and Jurassic sediments and conformably or disconformably overlie the Permo-Triassic volcanic formation, Permian or older strata. The latter includes the Khorat Group representing rocks of continental facies of Late Triassic to Cretaceous age.

The Cenozoic rocks are mainly fresh-water shale sandstone in fault bounded intermontane basins in west, central and north Thailand and often contain lignite and oil shale. The Quaternary unit comprises fluviatile, coastal, eolian, lateritic, volcanic and lacustrine unconsolidated sediments (Dheeradilok, 1987). The unit covers most of the Central Plain, intermontane basins in the north and the eastern parts of the study area. Economic mineral deposits include tin and its associated heavy minerals which usually occur as placer deposits along the contacts of the tin-bearing granite located to the west of the study area.

Igneous rocks

Thai granites have been an interesting topic for researchers who have worked in this region for many decades (e.g., Brown *et al.*, 1951; Aranyakanon, 1961; Pitakpaivan, 1969; Burton and Bignell, 1969; Baum *et al.*, 1970; Garson *et al.*, 1975; Pitfield, 1988; Charusiri, 1989). There are three N-S-oriented granitic belts in the study area: Eastern, Central and Western (Nakapadungrat and Putthapiban, 1992).

1. The *Eastern Belt granites* lie to the west of the Khorat Plateau occurring geographically as two separate belts: Loei-Phetchabun-Nakhon Nayok; and Tak-Uthai Thani-Chanthaburi ones. These granites comprise batholiths of zoned and unzoned plutons of I-type affinity and Triassic age. The granites are closely related with volcanic and sub-volcanic equivalents and intrude Lower Paleozoic sediments. Mineralization associated with the Eastern Belt granites includes base metal, gold, molybdenum, antimony, barite, feldspar and tungsten.
2. The *Central Belt granites* consist of migmatitic granite (inferred Precambrian metamorphic rock), foliated granite, megacrystic biotite granite and alkaline complexes. These granitic rocks extend from the northwest of the study area, Lampang, Tak, Uthai Thani, Chonburi, Rayong to the east peninsula. The granites are of S-type affinities (Chappell and White, 1974) and derived from continent-continent or continent-magmatic arc collision during the Triassic (200–240 Ma) (Mitchell, 1977; Beckinsale *et al.*, 1979). Researchers regard

the migmatitic granite as Precambrian metamorphic rock based on field evidences. The ages of these granites: a U-Pb age of 207–213 Ma for zircon from the migmatitic granite (Macdonald *et al.*, 1991) and an $^{40}Ar/^{39}Ar$ age of 180–220 Ma (Charusiri, 1989) suggests that it was derived from a Late Triassic-Early Jurassic granite pluton. A U-Pb monazite age suggests that high grade metamorphism occurred in the Late Cretaceous (72 ± 1 Ma) (Macdonald *et al.*, 1991). Mineralization within the Central Belt is dominated by tin, tungsten and fluorite deposits.

3. The granites of the *Western Belt* occur over the westernmost and southwesternmost parts of the study area, along the Thai-Myanmar border. It comprises a large batholith of S-type and small I-type plutons. This group of granite is a major source of tin mineralization in Peninsular Thailand, i.e., Ranong-Phuket tinfield.

Volcanic rocks

Volcanic rocks are widely distributed in the area, in general, as indicated in a number of geological maps, e.g., Charaljavanaphet (1951), Baum *et al.* (1970), Piyasin (1972, 1975), Nakornsri (1976), Hinthong *et al.* (1985) and Charoenpravat *et al.* (1987). A number of petrographic and geochemical studies of the volcanic rocks are available, e.g., Barr and Macdonald (1978), Bunsue (1986) and Intasopa and Dunn (1990). Focused studies on late Cenozoic volcanic include Barr and Macdonald (1978, 1981), Vichit *et al.* (1978), Jungyusuk and Sirinawin (1981), Yaemniyom (1982) and Intasopa (1993). Volcanic rocks of the area are important in term of their associated mineralization (Jungyusuk and Khositanont, 1992). The rocks also act as a key to both the ancient and latest tectonic development of Thailand.

Volcanic rocks range in ages from Middle Paleozoic to Late Cenozoic (Bunopas, 1981). The major volcanic rocks can be separated based on their distribution, tectonic setting and ages into the Chiang Mai belt, the Lampang belt and the Nan River Belt, the Loei-Phetchabun Belt (Barr and Macdonald, 1991) and a Late Cenozoic volcanic suite.

1. The Lampang-Phrae Volcanic Belts (LPVB), located in the northern part of the study area, includes pre Cenozoic volcanics exposed from southeast of Tak extending to Lampang, Phrae, Nan and Chiang Khong. Volcanics mapped east and southeast of Tak comprise rhyolite with flow bands, porphyritic rhyolite, aphanitic andesite, fine to coarse grained tuff and fine grained agglomerate and are stratigraphically dated to be Late Triassic-early Jurassic. In Lampang-Phrae area, the rocks include Late Permian-Early Triassic andesites, rhyolites and tuff. These rocks are intruded by shallow intrusive of diorite, granodiorite and granite of Triassic age (Jungyusuk and Khositanont, 1992). According to Bunopas (1981) these rocks are Late Permian to Early Triassic ages and indicate the presence of Triassic volcanic arc between Lampang and Phrae.
2. The Nan River Volcanic Belt (NRVB) has long been regarded as representing the Paleo-Tethys destroyed by continent-continent collision between Shan-Thai (Sinoburmalaya) and Indochina. The volcanic belt represents Paleozoic-early Mesozoic volcanic suites extending northeastward from Uttaradit along the Nan River for approximately 100 km. The belt consists of ophiolitic mafic and ultramafic rocks produced by pre-Permian sea-floor spreading in a back-arc or inter-arc setting (Barr and Macdonald, 1987). Both Thanasuthipitak (1978) and Bunopas (1981) believed that the ultramafic rocks probably mark a zone of westward subduction of oceanic crust. Sa Kaeo Ultramafics are ultramafic bodies occurring at a few localities in the southeastern parts of the study area. The rocks are mostly serpentinite. The Sa Kaeo ultramafics are believed to be the extension of the ophiolite belt found in Uttaradit (Bunopas, 1981). Hada *et al.* (1994, quoted by Metcalfe, 1996) have shown that the Sa Kaeo suture comprises a western chert-clastic belt and an eastern serpentinite melange belt. The former appears to form a stack of imbricate thrust slices and is dated as Middle Triassic by radiolarians. The serpentinite melange belt includes a wide variety of rock packages including rocks of oceanic, island arc and continental affinities of various ages. Structures indicate east-directed accretionary thrusting and hence westward directed subduction. The suture zone rocks are overlain unconformably by Jurassic redbeds and post-Triassic basaltic lavas which disconformably overly the suture are interplate continental basalts (Panjasawatwong and Yaowanoiyothin, 1993). Metcalfe (1996) suggested a Permo-Triassic age for this suture.
3. The Loei-Phetchabun (-Lop Buri-Ko Chang) Volcanic Belt is located to the east of the study area. These scattered volcanic outcrops along the western margin of the Khorat Plateau, referred to as the Central Thailand Volcanic Belt (Intasopa and Dunn, 1990), extend from Loei in the northeast, through Phetchabun, Lop Buri, Nakhon Nayok-Prachin Buri and Chanthaburi in the southeast. These rocks are of mafic to felsic compositions. DMR's (1987)

geological map considered the volcanic rocks in the Central Belt to be of Permo-Triassic age. Intasopa (1993) later suggested the Loei volcanic rocks (rhyolite and tholeiites) to be of Late Devonian time. Volcanic rocks in Phetchabun areas comprise basalt, rhyolite, andesite and tuff of Permo-Triassic ages (Jungyusuk, 1985; Intasopa, 1993). Volcanics in the Lop Buri area comprise rhyolite, trachyandesite and andesite. The $^{40}Ar/^{39}Ar$ geochronological ages of samples from this area show that they are much younger than those of Loei and Phetchabun areas.

4. The late Cenozoic basalts occur in the north, as small isolated outcrops; in the west of the Khorat Plateau, adjacent to other volcanics in the Lop Buri area; and in the southeastern part. Ages of these basaltic rocks range from the Late Miocene to Holocene. The $^{40}Ar/^{39}Ar$ ages of volcanics in the Lop Buri area suggest a distinct periodicity of magmatic activity which may be related to changing patterns of tectonic activity. The volcanism in the area may have involved at least four tectonic events: Early Eocene (55–50 Ma), Late Oligocene to Early Miocene (23–19 Ma), Middle Miocene (18–14 Ma) and Late Miocene (9 Ma) (Intasopa, 1993). Furthermore, basalts in other parts of the area yield younger K/Ar ages, e.g., 5.64 ± 0.28 Ma (Denchai, SW of Phrae), 3.14 ± 0.17 Ma (Bo Phloi, Kanchanaburi) and 0.8 ± 0.3 and 0.6 ± 0.2 Ma (Mae Tha, SE of Lampang (Barr and Macdonald, 1981).

TECTONIC SETTING

The development of Cenozoic basins in SE Asia is attributed to the collision of the Indian Craton with Eurasia that commenced 40–50 Ma ago (Tapponnier *et al.*, 1982). The increase in the obliquity of subduction of the Indian Plate to the west of Southeast Asia was caused by the indentation of India into Asia, which effected a clockwise rotation of Southeast Asia. The event resulted in movement along major strike-slip faults and the associated development of pull-apart basins in Thailand and adjacent areas (Polachan and Sattayarak, 1989; Polachan *et al.*, 1991). According to the model of Tapponnier *et al.* (1982), who based their analysis in part on plasticine modelling, the NW-trending major faults of South China and Southeast Asia should be left-lateral and the NE-trending faults right-lateral in sense. In fact, focal mechanism solutions and offsets of some young geological features in the region indicate that the reverse is true. Tapponnier *et al.* (1986) have proposed an explanation which involves a recent reversal of motion on these faults to explain the paradox.

The Central Plain and its surroundings exhibit major faults, which have been active in Tertiary time. These faults include the NW-SE-trending Mae Ping (MPFZ) and Three-Pagoda Fault Zones (TPFZ) and the NE-SW-trending Uttaradit Fault Zone (UTFZ) located in the western and the northern parts of the study area, respectively. The UTFZ extends southwest from the Nan River Volcanic Belt and meets the MPFZ near Changwat Tak area. These fault zones are inferred to have been active since Oligocene time. Their orientations can be related to the strain ellipsoid of a dextral simple shear model with N-S compression and E-W extension, as is suggested by several researchers (Wilcox *et al.*, 1973; Harding, 1974). According to the dextral simple shear strain ellipsoid model, the NW-SE-trending MPFZ and TPFZ are the principal right-lateral strike-slip faults whereas the NE-SW-trending UTFZ is a conjugate left-lateral strike-slip fault (Polachan and Sattayarak, 1989). On the basis of geological observations and geochronological data, Charusiri (1989) suggested that the major NW-trending faults were active between 77–46 Ma and probably controlled the distribution of the Sn-W mineralization in the western part of the study area. Several researchers have suggested that the Central Plain have occurred along a reactivated ancient suture zone (Uttaradit-Nan and Sa Kaeo) and accreted volcanic arcs (Central Volcanic Belt) (Intasopa, 1993; Lee and Lawver, 1995). Recently, Lacassin *et al.* (1997) have proposed that left-lateral movement might have occurred along the NW-SE-trending TPFZ and MPFZ between 40–33 Ma and 37–30 Ma, respectively. The movement along these faults has changed to dextral since around 20 Ma. The N-S trending Chao Phraya Basin development occurred as a result of movement along these faults during Cenozoic time.

AIRBORNE GEOPHYSICAL SURVEYS AND DATA

The Royal Thai Department of Mineral Resources (DMR), with the assistance of the Canadian International Development Agency (CIDA), has carried out airborne magnetic and radiometric surveys covering nearly the entire country during 1984 and 1989. The surveys were flown by Kenting Earth Sciences International Limited (KESIL), a Canadian contractor. Survey flight-line spacings are: 1 km for the aeromagnetic surveys; and 1, 2 and 5 km, depending on different types of terrain, for the radiometric surveys. The flight-line directions are N-S and E-W for magnetic and radiometric surveys, respectively. The aeromagnetic data were originally compiled with secular correction to the year 1980. DMR had prepared nationwide aeromagnetic, radiometric and elevation grids during 1992 and 1994 (Hatch *et al.*, 1994). The aeromagnetic data of different elevations were draped to the same 300 m elevation. Aeromagnetic and radiometric grids used in this study were extracted from the nationwide grids with a 500 m grid cell size.

AIRBORNE GEOPHYSICAL DATA ENHANCEMENT AND INTERPRETATION

Magnetic data enhancement products used in this study include: reduction to the pole (REDP) and equator (REDE); horizontal and vertical derivatives; and analytic signal grids. Radiometric total count and ternary maps, which represent potassium, equivalent uranium and equivalent thorium, are the main types of radiometric maps used. The shaded relief maps of magnetic derivatives and radiometric grids are the most suitable form of map presentation for interpreting structural elements.

The magnetic data interpretation was carried out with the awareness of limitation on nature of data collected, i.e., E-W flight direction and the REDP enhancement of data at low magnetic latitudes. Testing of the REDP enhancement technique (Grant and Dodds, 1972) used in this study gives acceptable result, i.e., anomaly's shape and location, compared to other enhancement method, e.g., REDE and analytic signal.

Data interpretation process includes three main steps, which are:

1. outlining the boundary of the Chao Phraya Basin using geological and digital terrain grid;
2. differentiation of surface sediments over the basin using radiometric data.
3. delineation of lineaments and different geophysical units using the combined radiometric and magnetic data.

The combined used of aeromagnetic and radiometric data has enabled a comprehensive regional mapping of the fault structures and geology. This was possible by eliminating the effects of stream/river radiometric responses by overlaying a digital model of the river system of Thailand.

Aeromagnetic total field data (Fig. 2) and its enhanced products, analytic signal grid (Fig. 3); clearly reveal the main volcanic belts which are the Lampang-Phrae (A, Fig. 2); the Nan River (B, Fig. 2); the Central (C, Fig. 2) and Loei Volcanic Belts located to the NE of the area. These volcanic belts give relatively short wavelength magnetic anomalies while exposed sedimentary sequences and granitoid basement located to the western part of the area show broad magnetic anomalies. The magnetic data also highlight the major structures, i.e., the Three-Pagoda Fault Zone (TPFZ) and the Mae Ping Fault Zone (MPFZ). The magnetic data clearly demonstrate that the TPFZ runs from approximately 98°30'E and 15°00'N passes Changwat Kanchanaburi, Pathum Thani, Samut Sakhon and continues to the Eastern Coastal part. This fault path was previously traced to the NW coast of the Gulf of Thailand by other researchers based on surface information. This evidence may indicate that the Three-Pagoda fault plane dips to the NNE direction. The data also reveal a possible subsurface NW-trending fault zone within the Central Plain, i.e., at approximately 15°N and 100°E. This fault is referred to as the Chao Phraya Fault Zone (CPFZ) due to its location.

A total count shaded colour grid overlain with major and minor rivers (Fig. 4) of the Central Plain area reveal much of the surface geological information. The map reveals much more information over the exposed basement area than the basin area. High to very high radioactive and low magnetic responses (Figs. 2 and 3) indicate granite and inferred Precambrian gneisses in the exposed basement area located to the western mountainous part and the Eastern coast. Low to very low radioactivity associated with high magnetization characteristic over the eastern part of the area indicates intermediate to (ultra?) mafic volcanics and sedimentary rocks. There are three major lineaments related to the radiometric data, NW-, NE- and, approximately, N-S-trending. The NW-trending ones occur over the MPFZ, TPFZ and over the western mountain range. The NE-trending lineaments occur over the Uttaradit (Nan River) Volcanic Belt in the northern part of the area. The almost N-S-trending lineament occurs in the western part of the area. The data show that there are several sedimentary units in the area based on their difference in radioactive contents and the depositional process. Most of the sediments were transported from the western mountain except in the northernmost part of the basin where sediments were washed from the N, NW and W. These relatively high radioactive sediments occurring as a series of fans located along the western rim of the Central Plain indicate its granitoid sources from the western mountainous area. One of these fans (D, Fig. 4) was cross-cut by the Mae Ping River along the major NW-trending MPFZ's fault path implying the late development of this fault zone. The shifting of the high radioactive marker on both side of the fan may indicate the latest movement of the fault zone is dextral.

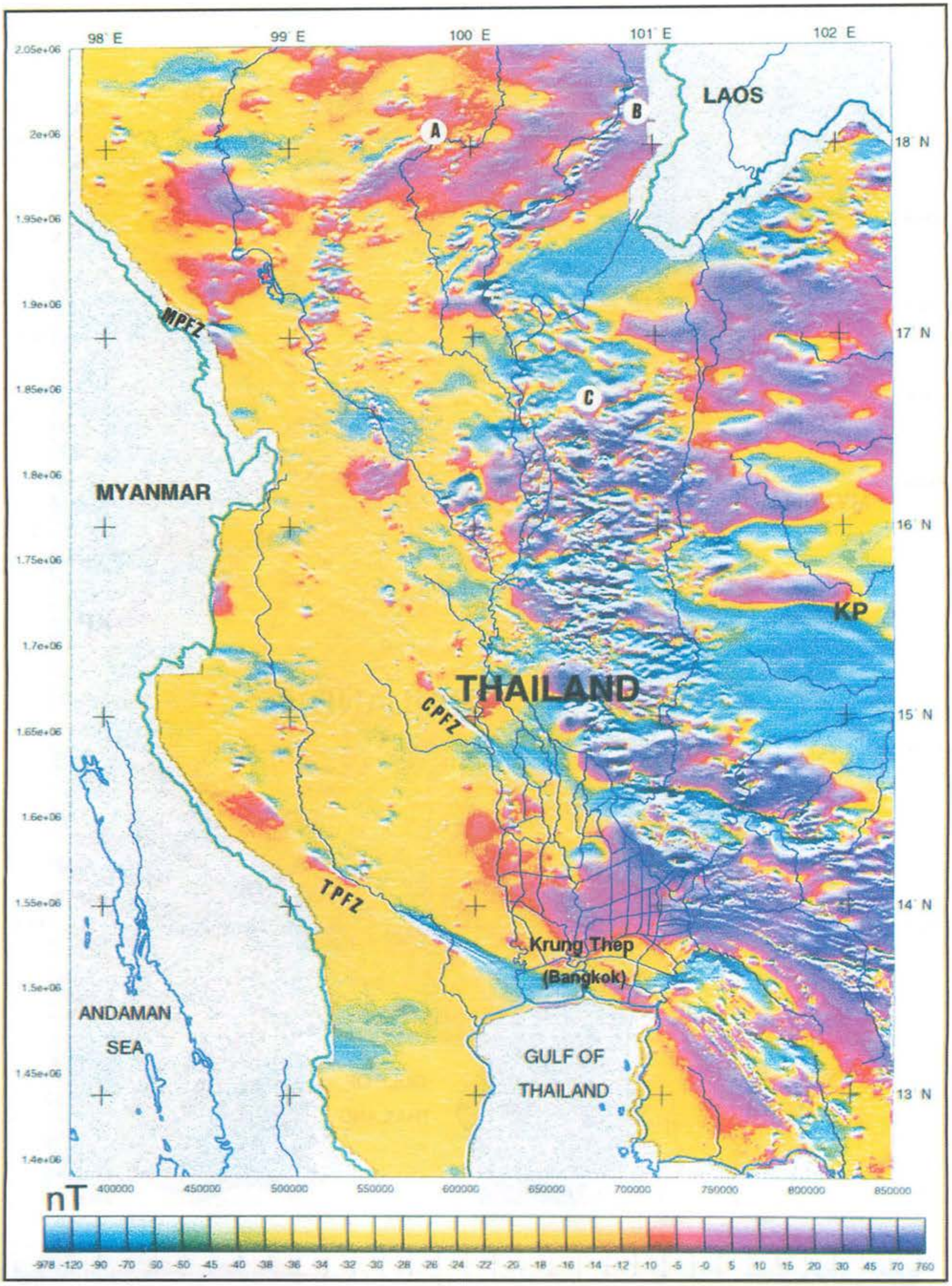

Figure 2. A magnetic total field map of the Central Plain. The map shows relatively strong relief, short wavelength anomalies over the main volcanic belts, i.e., A: Lampang-Phrae Volcanic Belt; B: Nan River Volcanic Belt; and C: Phetchabun-Lob Buri (Central) Volcanic Belt. Negative anomalies highlight the Mae Ping (MPFZ); Chao Phraya (CPFZ); and Three-Pagoda (TPFZ) Fault Zones. Khorat Plateau (KP) exhibits broad magnetic anomaly.

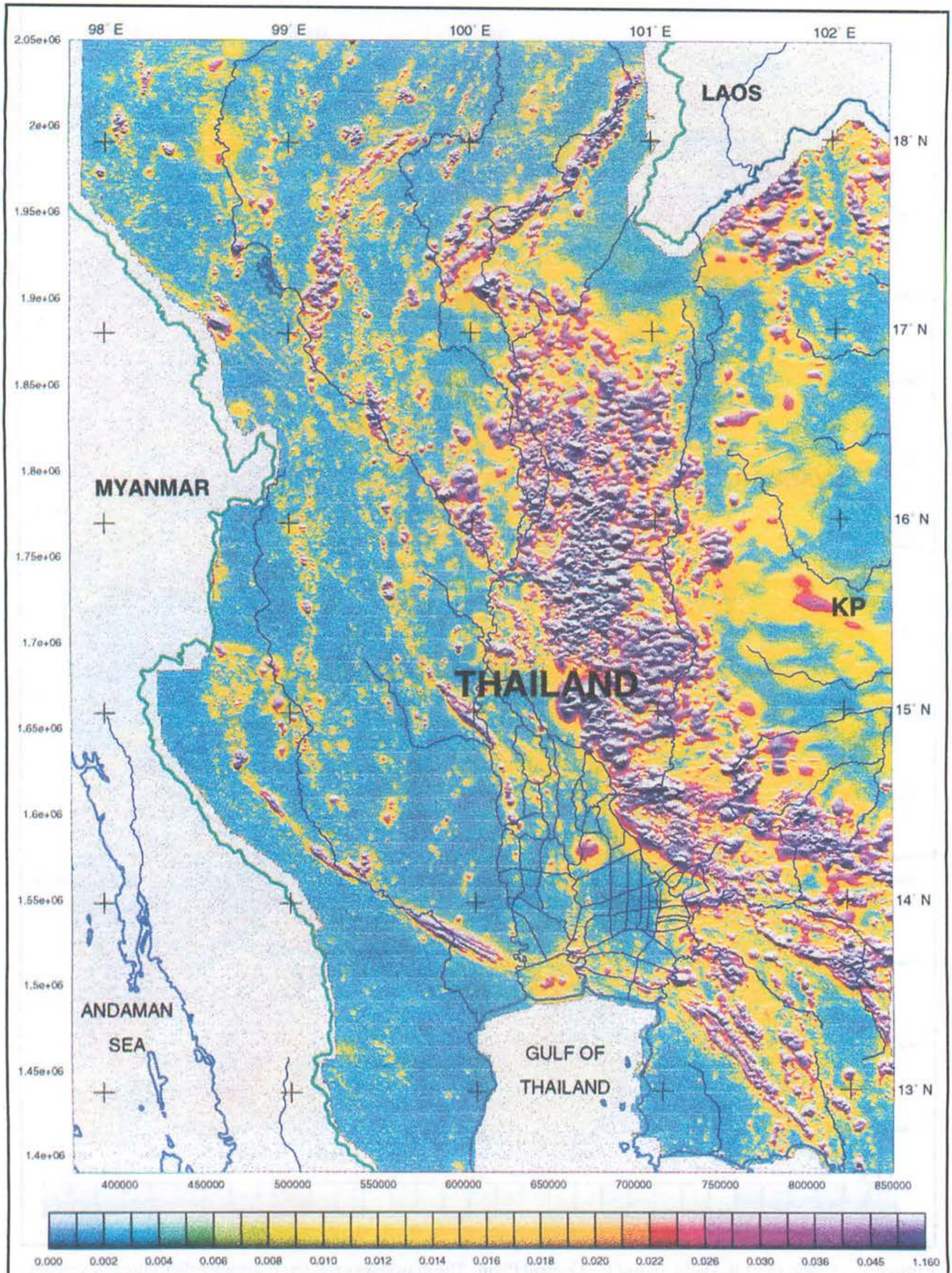

Figure 3. A full analytic signal magnetic map of the Chao Phraya Central Plain area with major rivers overlain. The map shows improved images of the major volcanic belts and the major faults of the area. KP = Khorat Plateau.

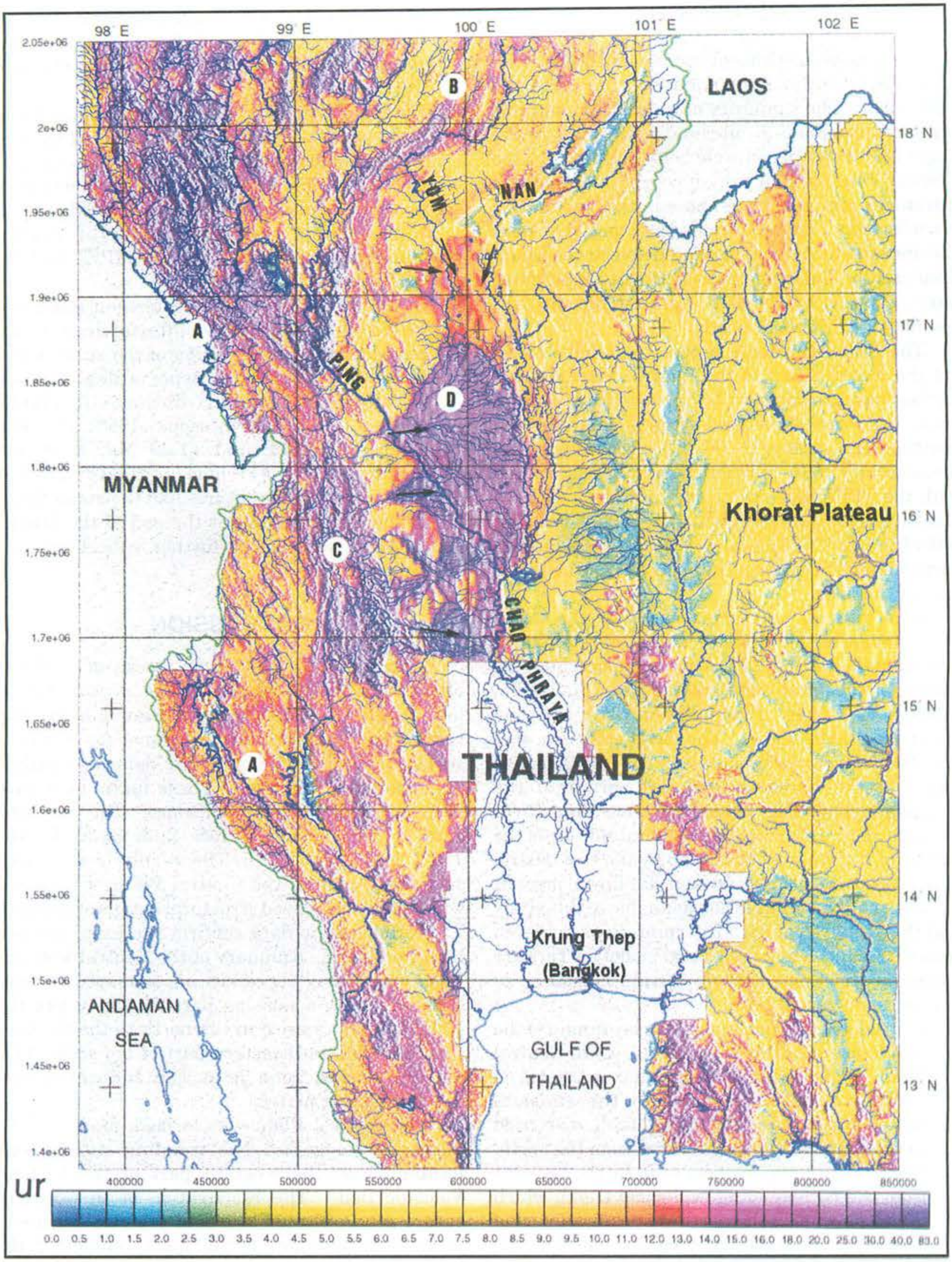

Figure 4. A total count (TC) radiometric map of the Central Plain area with rivers overlain. Mae Nam Ping, Wamg, Yom, Nan and Chao Phraya are major rivers in the Central Plain. The data show NW-SE-trending lineament over the major fault zones (A); NE-SW-trending one over the Lampang Volcanics (B); and the almost N-S-trending over the western mountain (C). Arrows indicate flow direction of relatively high radioactive sediments (D), which were washed over from the west.

DISCUSSION

The geophysical interpretation map of the study area (Fig. 5) outlines the major volcanic belts and fault zones. The similarity of magnetic signatures representing mafic to ultramafic volcanics in the major N-S-trending volcanic belts implies that the Central Volcanic Belt may have rocks of mafic to ultramafic composition as those in the Nan and Sa Kaeo Sutures. These volcanic belts may represent the ancient suture zone joining between the Shan-Thai and the Indochina sub-continents, which was later cross-cut by the left-lateral strike-slip NE-trending UTFZ in the north.

The E-W-extensional process may have cross-cut the western part of the Central Volcanic Belt leaving several parts to be present in the basin area, e.g., the structural high located to the southeastern parts of the MPFZ. According to the discontinuity of the magnetic anomalies associated with the TPFZ, the extensional process may have also separated the TPFZ, which path runs from the NW of the Gulf of Thailand, through the southern part of Bangkok (Krung Thep), to the southeastern part of the area.

It is difficult to confirm whether the latest development of the MPFZ is a dextral or sinistral movement based on the above evidence and the nature of the fault cross-cutting the alluvial fan (along the Mae Ping River, SW of the Kamphaengphet Fan). The best evidence of a possible dextral movement along the MPFZ maybe found at the northwesternmost corner of the Kamphaengphet Fan where the Mae Ping River meets the fan. This small right-lateral shifting of the outline of the fan may be caused by the real dextral movement or the result of present-day fluvial process.

Using all the information available to this study and the geophysical data interpretations achieved from this study, a new structural model for Tertiary basins in the Central Plain during Oligocene to Recent is suggested here.

1. Late Oligocene time marks the beginning of the development of the Cenozoic basins in Central Plain as the result of the major extrusion of Indochina. This resulted in the sinistral movement of the UTFZ as the fault zone tried to accommodate such extrusion from the north. The evidence may be best seen by the bending from the N-S-trending geological trend, which is still obvious in the northwesternmost part of Thailand, to the NE-SW-trending one, e.g., the Lampang and Nan River Volcanic Belts. The bending of these geological trends may gradually increase through time throughout the development of the Central Plain. The event initiated the reactivation of the western boundary of the N-S-trending Central Volcanic Belt and other volcanic belts in the area. This resulted in the beginning of the E-W extension in the Central Plain.
2. During Early Miocene time, the main basin development occurred. Rifts bounded by N-S-striking oblique-slip normal faults developed in the Central Plain (Polachan *et al.*, 1991), with further extension along the western edge of the N-S-trending suture zone and the dextral (oblique) movement along the MPFZ and the CPFZ in the Central Plain.
3. In Middle Miocene time, extension continued with a widespread alluvial/fluvial depositional period and the reactivation of the sutures and the major faults. The presence of alkali-basaltic volcanism in Lop Buri during late Middle Miocene (13.6 Ma, Intasopa, 1993; 11.6 Ma, Charusiri, 1989; and 11.29 Ma, Barr and Macdonald, 1981) may indicate another reactivation of the sutures and the major faults in the Central Plain at the end of the Middle Miocene resulting in further subsidence and faulting.

CONCLUSION

Magnetic data can reveal rocks of mafic to ultramafic compositions at various depths even at low magnetic latitudes whereas gamma-ray radiometric data are very effective for mapping surface geology. The magnetic data also outline major faults of the area. These faults may have been intruded by mafic volcanics. The magnetic data help us to outline new fault paths for the TPFZ and the CPFZ. The result is a revised subsurface map of the Central Plain of Thailand which shows improved structural details of the area.

Aeromagnetic data confirm the existence and better define the boundary of the Central Volcanic Belt, which may represent ancient suture zones (Paleo-Tethys), a missing part that may join the Nan-Uttaradit suture in the north to the Sa Kaeo suture in the southeastern part of the area. This ancient suture zone joins the Indochina and Sinoburmalaya plates.

The Central Plain was formed, more or less, along the suggested N-S-trending suture zone located along the western part of the Central Volcanic Belt. The reactivation of this ancient suture zone, volcanic arcs and pre-existing major strike-slip (oblique) faults have controlled the Cenozoic basin development in Central Thailand. The reactivation of the suture and fault zones may have caused by the southeast extrusion of the Indochina block caused by the Indian-Eurasian collision.

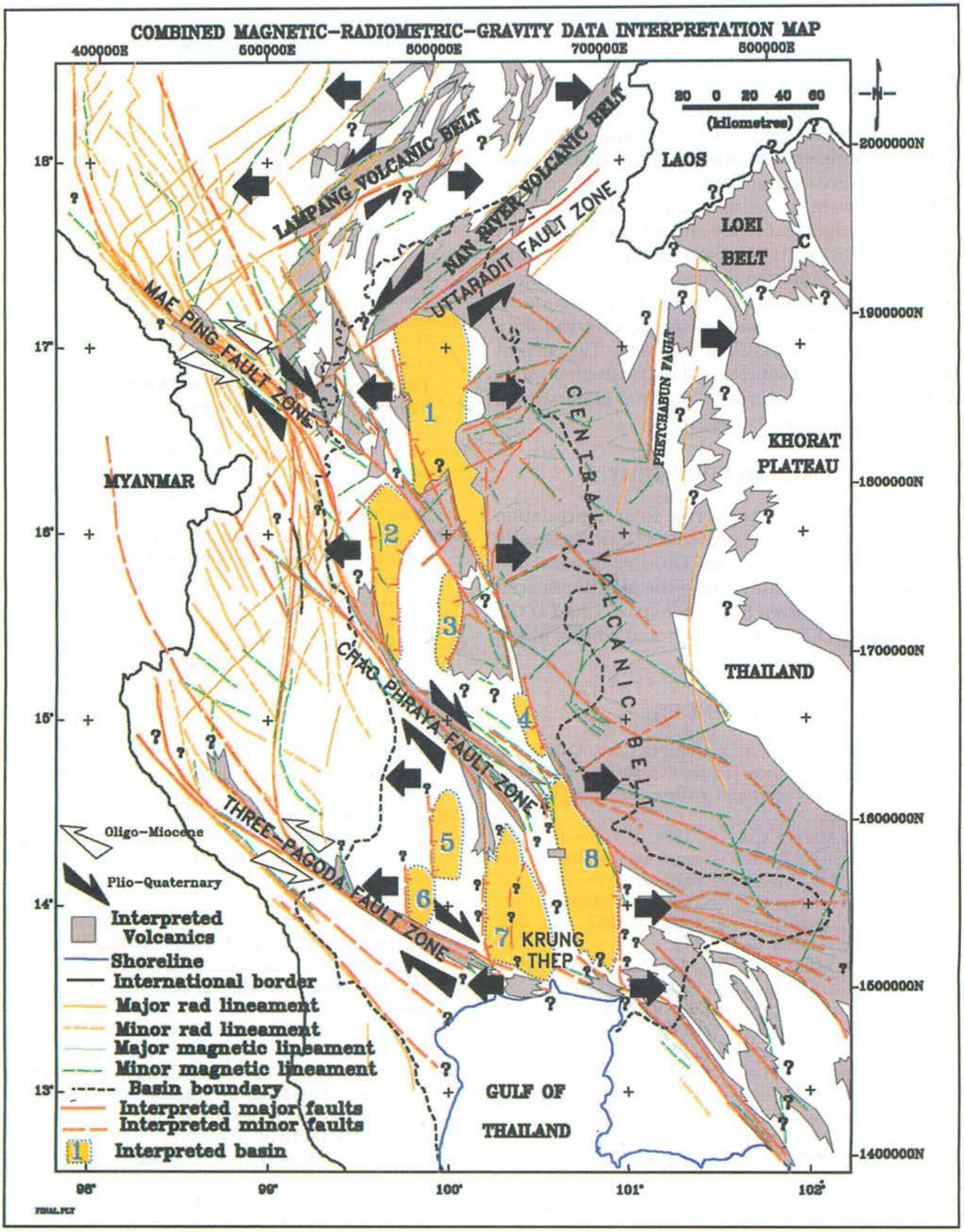

Figure 5. A sketched structural map of the Central Plain area. This new model shows realistic fault paths, which, when used in accordance with the information on volcanic belts, can provide a new explanation on how Cenozoic basins in the area developed. Pair black arrows indicate an E-W-extension along the near-N-S-oriented Chao Phraya Floodplain. Basins in the area are: 1 = Phitsanulok; 2 = Phetchabun; 3 = Lad Yao; 4 = Sing Buri; 5 = Ayutthaya; 6 = Suphan Buri; 7 = Kamphaengphet; 8 = Thon Buri; 9 = Sakhon; and 10 = Paknam. White and black arrows associated with major fault zones indicate timing of the fault movements as Oligo-Miocene and Plio-Quaternary, respectively (Lacassin *et al.*, 1997).

RECOMMENDATIONS

Further detailed study of volcanic rocks in Central Thailand on the basis of geophysical data will be very useful in differentiate volcanic rock of the area. Considering the volcanic's different physical characteristics, orientation and distribution should improve the knowledge of how each group of these rocks were formed and under which condition. As well, geochemical study should also carried out to find out whether these volcanics represent oceanic rocks or not. Additional geochronological data of these volcanics are also vital to the future study. Further study also includes the geophysical data interpretation of the Gulf of Thailand. The current possible types and sources of data for further study include: aeromagnetic data, regional gravity data, seismic and well information.

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