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THE ANCIENT TETHYS IN THAILAND AS INDICATED BY NATIONWIDE AIRBORNE GEOPHYSICAL DATA

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ABSTRACT

Ophiolitic volcanic rocks in Thailand crop out in the Mae Chan and Nan River volcanic belts in the north, the Sa Kaeo volcanic area in the east, the Loei volcanic belt in the northeast, and the northern extension of the Raub-Bentong volcanic belt at the Thai-Malaysia border in the southern part of the country. These volcanic belts comprise rocks of mafic to ultramafic composition and are parts of the ancient Tethys sea. Most researchers based their hypothesis on the distribution of volcanic rocks in central Thailand to join between the Nan River and the Sa Kaeo volcanic belts. The relationship among these volcanic belts in different locations at the ground surface is still unclear. Nationwide airborne geophysical data, especially aeromagnetic data, have revealed a possible distribution pattern of the mafic to ultramafic volcanic rocks along the Chiang Khong, Nan River, central volcanic, Sa Kaeo, and Raub-Bentong volcanic belts. Magnetic anomalies imply that the central volcanic belt, which extends between the Nan River and the Sa Kaeo volcanic areas, may represent a missing part of the ancient Tethys sea. These data also show that the Chiang Mai, Mae Chaem, and Loei volcanic areas possibly represent different parts of the ancient Tethys sea. The geological evidence, including field data in the Mae Chan-Chiang Khong and Loei areas and the overlying Permian carbonate build-ups and successive sequences of Late Paleozoic deep water clastic, chert, and volcaniclastic rocks, seems to reasonably support this hypothesis. However, the connection between the main central volcanic belt and the Raub-Bentong volcanic belt in the southernmost part of the country is still unclear due to the lack of geophysical data in the Gulf of Thailand.

INTRODUCTION

Suture zones in Thailand are some of the most important geological features for gold and base-metal exploration and for the study of the ancient Tethys sea. The Tethys sea was probably destroyed by the collision between the Shan-Thai and Indochina sub-continents (Figure 1). A suture zone normally comprises certain rock types, including ultramafic and ultrabasic rocks, such as tholeiites. These ultramafic and ultrabasic rocks are possibly overlain by abyssal or bathyal strata, such as ribbon chert, red pelagic limestone, metalliferous deposits, volcanic breccias, and pyroclastic deposits. Surface geological evidence confirms that several areas exhibit ultramafic rocks, including the Chiang Khong volcanic belt (Sukvattananunt and others, 1989) in the northernmost part of the country, the

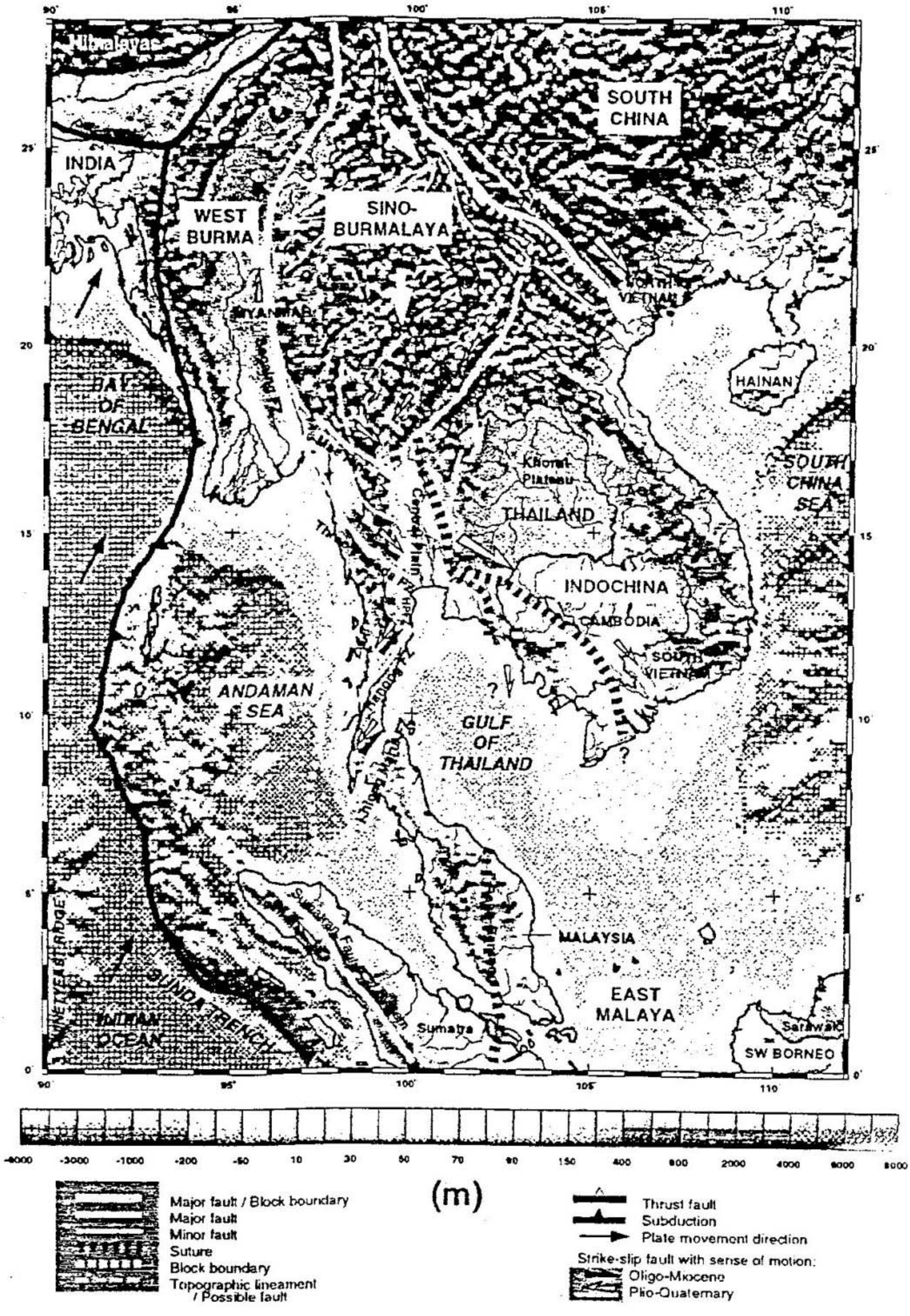

Figure 1 Sketched geotectonic map of Southeast Asia, with bathymetric-topographic grid, major rivers, and international borders overlain, showing the continental blocks/fragments and major sutures of Southeast Asia (sketched and modified after Metcalfe, 1990, 1996; Peltzer and Tapponnier, 1988).

Nan-Uttaradit volcanic belt, the Loei volcanic area (Intasopa and Dunn, 1990) in the northeast, the Sa Kaeo volcanic area in the east, and the northern part of the Raub-Bentong volcanic belt in the southernmost part of the country along the Thai-Malaysia border. Although the surface distribution of these ultramafic volcanic rocks is limited, researchers always refer to the Nan River volcanic belt, the Sa Kaeo volcanic area (Hada and others, 1991; Metcalfe, 1996), and the Raub-Bentong volcanic belt as major suture zones in the country. However, the current available geological evidence is still insufficient to accurately outline all the suture zones in the country.

Thailand's residual magnetic total field map (Department of Mineral Resources, 1989a) and radioactivity maps, including total count, TC, in ur, potassium, K, in percent, equivalent uranium, eU, in parts per million, and equivalent thorium, eTh, in parts per million (Department of Mineral Resources, 1989b), at scales of 1:1,000,000 clearly show both surface and subsurface geological information. Aeromagneitc data are an effective tool for mapping both surface and subsurface geological rock units and structures (Tulyatid and Fairhead, 1996; Jaques and others, 1997), specially so for mafic to ultramafic rocks. Processing and enhancement of aeromagnetic data help to define both surface and subsurface lithological units and geological structures.

This paper presents a combined magnetic-gamma ray radiometric qualitative interpretation to the study of major volcanic belts and their related structures. The majority of these volcanic belts are believed to represent ancient suture zones that joined a number of sub-continents, such as Shan-Thai and Indochina. Surface evidence from various locations helped to outline known sutures and to suggest several new sutures in the country. The results of geophysical data interpretation helped to improve the knowledge of the closing of the Tethys sea.

GEOLOGY

The geology of central Thailand has been studied by Suensilpong and others (1978), Chonglakmanee and others (1983), Dheeradilok and others (1992), and Bunopas (1992). The area contains rocks of ages that range from Precambrian (?) to Quaternary (Figure 1).

Stratigraphy

The Precambrian metamorphic rocks, referred to as the Lan Sang Gneiss Complex (Bunopas, 1992) is made up of gneiss, schist, and calcsilicate of amphibolite facies (Figure 1).

The Lower Paleozoic, Cambrian and Ordovician, rocks have been subjected to low grade dynamo-metamorphism (Bunjitradulya, 1978; Baum and others, 1970) and have been locally transformed into quartzite, phyllite, schist, and recrystalised limestone. These rocks are in fault contact with the inferred Precambrian gneiss. The Middle Paleozoic, Silurian and Devonian, sedimentary rocks, which are shale and carbonate sequences, crop out in the west and east parts of the western mountainous area, in the north part of the Chao Phraya River floodplain, in the northeast in Loei Province, and in the southern part of the study area. According to Bunopas (1983), the Silurian and Devonian rocks can be divided into several facies belts from west to east. These are back-arc basin, volcanic arc, and fore-arc facies. The Upper Paleozoic, Carboniferous and Permian, rocks conformably overlie the Middle Paleozoic rocks. The Carboniferous rocks in the Sukhothai fold belt (Bunopas, 1983) comprise rocks of various lithologies and thicknesses in west, north, and southeast Thailand (Bunopas, 1983; Sukontapongpow, 1997). At places marine shelf sedimentation continued in the west and flysch type sediments were deposited 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. However, the occurrence of Paleozoic and Early Mesozoic radiolaria implies the paleogeography of Thailand as being deep sea water (Sashida and others, 1993; Sashida and Nakornsri, 1997).

The Mesozoic sequences in central Thailand include rocks of two depositional facies, marine and continental. The marine facies makes up the Triassic and Jurassic sequences. These rocks conformably or disconformably overlie the Permian-Triassic volcanic formation and Permian or older strata. The continental facies includes the Khorat Group of Late Triassic to Cretaceous age.

Cenozoic rocks are mainly freshwater shale and sandstone in fault bounded intermontane basins in west, central, and north Thailand. These basins 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 and the intermontane basins in the north and eastern parts of the 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 in the western and southern parts of the country.

Igneous Rocks

Thai granites have been an interesting topic for researchers for many decades (Brown and others, 1951; Aranyakanon, 1961; Pitakpaivan, 1969; Burton and Bignell, 1969; Baum and others, 1970; Garson and others, 1975; Pitfield, 1988; Charusiri, 1989). There are three north-south oriented granitic belts in the study area --- eastern, central ,and western (Nakapadungrat and Putthapiban, 1992).

The eastern granite belt occurs to the west of the Khorat Plateau as two separate belts, the Loei-Phetchabun-Nakhon Nayok and Tak-Uthai Thani-Chanthaburi belts. These granite belts comprise Triassic batholiths of zoned and unzoned I-type plutons. They are closely related to volcanic and sub-volcanic equivalents and intrude Lower Paleozoic sedimentary rocks.

The central belt granite consists of migmatitic granite, foliated granite, megacrystic biotite granite, and alkaline complexes. These granitic rocks extend from the north, Lampang, Tak, Uthai Thani, Chonburi, and Rayong, to the east and south of the peninsula. These granite bodies have S-type affinities (Chappell and White, 1974) and were derived from continent-continent or continent-magmatic arc collision during the Triassic, about 200-240 million years ago (Mitchell, 1977; Beckinsale and others, 1979). The migmatitic granite has been regarded as Precambrian metamorphic rock based on field evidence. The migmatic granite has been dated as having an U-Pb age of 207-213 million years (Macdonald and others, 1991) and an $^{40}Ar/^{39}Ar$ age of 180-220 million years (Charusiri, 1989). These dates suggest the granite is a Late Triassic-Early Jurassic pluton. Another younger U-Pb date of 72, + or − 1, million years suggests that high grade metamorphism occurred in the Late Cretaceous (Macdonald and others, 1991).

The western granite belt occurs in the western and southwestern parts of the study area, along the Thai-Myanmar border. It comprises a large S-type batholith and small I-type plutons.

Volcanic Rocks

Volcanic rocks are widely distributed in the area. They have been mapped by Charaljavanaphet (1969), Baum and others (1970), Piyasin (1972,1975), Nakornsri (1976), Hinthong and others (1985), and Charoenpravat and others (1987). Petrographic and geochemical studies of the volcanic rocks were made by Barr and Macdonald (1978), Bunsue (1986), and Intasopa and Dunn (1990). Focused studies on late Cenozoic volcanic rocks include Barr and Macdonald (1978,1981), Vichit and others (1978), Sirinawin (1981), Yaemniyom (1982), Jungyusuk and Sirinawin (1981), and Intasopa (1993). Volcanic rocks of the area are important in terms of their associated mineralization (Jungyusuk and Khositanont, 1992). These rocks also act as a key to both the ancient and latest tectonic development of Thailand.

Volcanic rocks range in age from Middle Paleozoic to Late Cenozoic (Bunopas, 1981). The major volcanic rocks can be separated into five belts based on their distribution, tectonic setting, and age (Figure 2). These are the Chiang Mai-Chiang Rai belt, the Tak-Lampang-Phrae-Chiang Khong belt, the Nan River belt, the Loei belt, and the Phetchabun-Lop Buri-Sa Kaeo-Ko Chang belt.

The Chiang Mai-Chiang Rai volcanic belt consists of discontinuous thin bands of pre-Cenozoic volcanic rocks that trend northeast-southwest and crop out from northeast of Chiang Mai to west and north of Chiang Rai. These volcanic rocks are mainly tuff and agglomerate, locally basalt flows, gabbro, and olivine- and pyroxene-rich mafic cumulates. Chemically they are tholeiitic (Macdonald and Barr, 1978). These volcanic rocks are believed to be the product of back-arc spreading and are of Late Permian-Early Triassic age (Bunopas, 1981). The volcanic rocks of the Chiang Mai-Chiang Rai volcanic belt may have formed in an extensional continental setting, possibly a back-arc setting related to westward subduction along the Nan River volcanic belt that occurs to the east (Macdonald and Barr, 1978; Barr and others, 1990). Mafic rocks in the Chiang Rai area may have formed in a subduction environment. These rocks are associated with a chert-clastic sequence, the Fang Chert, which contains Early Devonian graptolites, Carboniferous conodonts, and Early Devonian, Carboniferous, and Early to Middle Permian radiolarian faunas. This evidence led Wu and others (1995), Metcalfe (1996), and Charusiri and others (1999) to view the Chiang Mai-Chiang Rai volcanic belt as a southward extension of the Changning-Menglian suture that bounds the western rim of the Simao terrane. The Simao terrane is the disrupted part, or parts, of the Qamdo-Simao block, which is regarded as an extension of the Indochina terrane.

The Tak-Lampang-Phrae-Chiang Khong volcanic belt, located in the northern part of the study area, includes pre-Cenozoic volcanic rocks exposed from southeast of Tak northward to Lampang, Phrae, Nan, and Chiang Khong. The rocks east and southeast of Tak are rhyolite with flow bands, porphyritic rhyolite, aphanitic andesite, fine- to coarse-grained tuff, and agglomerate. They are dated as Late Triassic-Early Jurassic. In the Lampang-Phrae area, the rocks include Late Permian-Early Triassic andesite, rhyolite, and tuff. These rocks are intruded by shallow intrusives of Triassic diorite, granodiorite, and granite (Jungyusuk and Khositanont, 1992). According to Bunopas (1981) these volcanic rocks are Late Permian to Early Triassic and they indicate the presence of a Triassic volcanic arc between Lampang and Phrae. Field data confirm the existence of serpentinite in the Chiang Khong area.

The Nan River volcanic belt has long been regarded as representing the Paleo-Tethys that was destroyed by continent-continent collision between Shan-Thai and Indochina. This volcanic belt represents Paleozoic-Early Mesozoic volcanic suites that extend northeastward

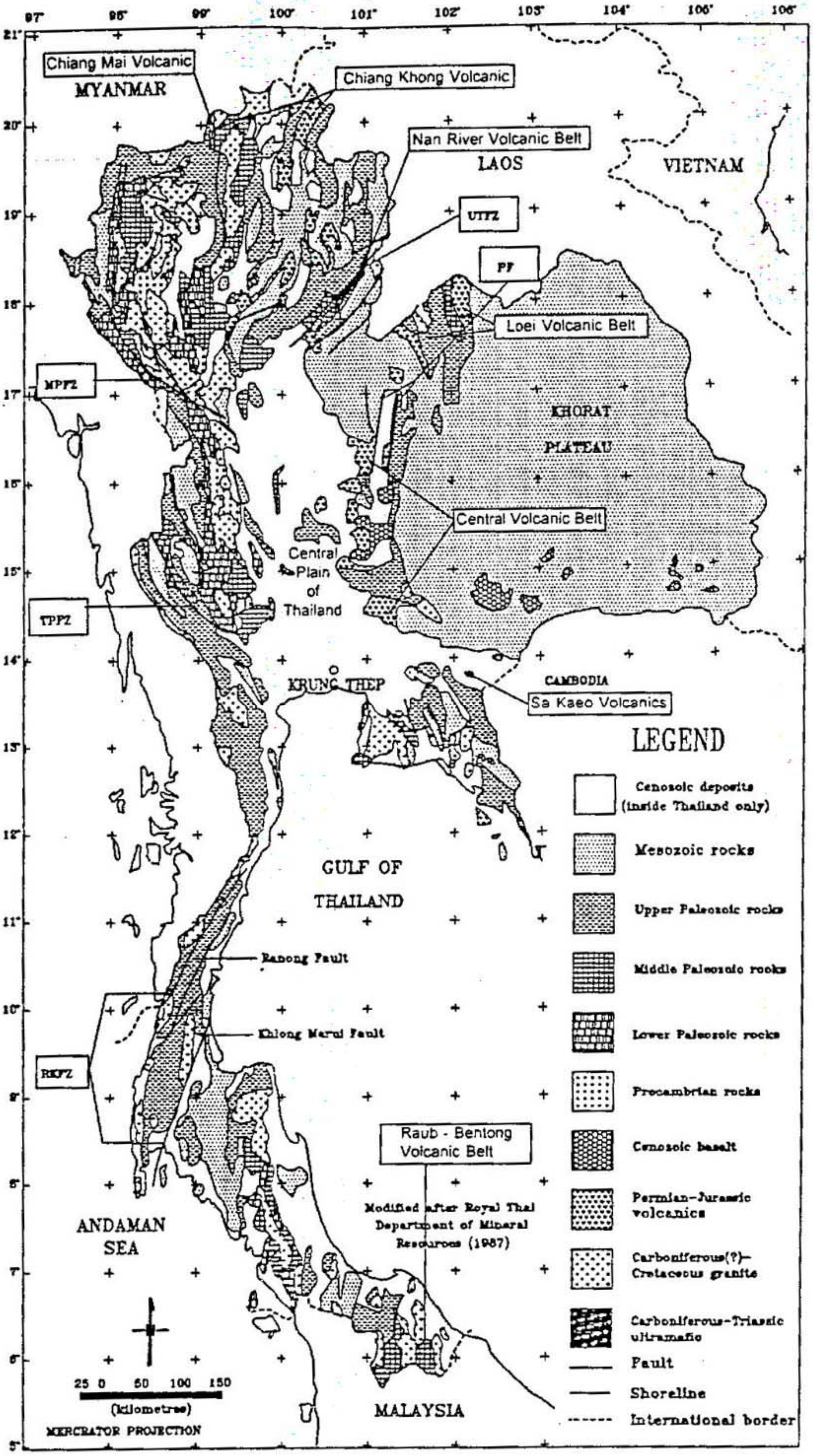

Figure 2 Simplified geological map of Thailand (modified after Suensilpong and others, 1978; Chonglakmani, 1983; Department of Mineral Resources, 1987). Major fault zones in the area are MPFZ=Mae Ping fault zone, TPFZ=Three Pagoda fault zone, and RKFZ=Ranong-Khlong Marui fault zone.

from Uttaradit along the Nan River for approximately 100 kilometers. The belt consists of ophiolitic, mafic, and ultramafic rocks that resulted from 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 marked a zone of westward subduction of oceanic crust.

The Loei volcanic belt is located in the northeast of the country. Intasopa (1993) suggested that the Loei volcanic rocks are Permian-Triassic rhyolite in the west and Late Devonian tholeiites in the east. The eastern sequence likely represents the ancient Paleo-Tethys that was destroyed by the collision between Indosinia and Cathaysia during Devonian to Carboniferous times (Gatinsky, 1986).

The scattered volcanic outcrops along the western margin of the Khorat Plateau make up the Phetchabun-Lop Buri-Sa Kaeo-Ko Chang volcanic belt. This belt has been called the central volcanic belt (Intasopa and Dunn, 1990) and it extends from Loei in the northeast, southward to Phetchabun, Lop Buri, Nakhon Nayok, Prachin Buri, and Chantaburi in the southeast. These rocks have mafic to felsic compositions. Past mapping has shown the volcanic rocks in this central belt to be Permian-Triassic in age (Department of Mineral Resources, 1987). Volcanic rocks in the Phetchabun area comprise Permian-Triassic basalt, rhyolite, andesite, and tuff (Jungyusuk, 1985; Intasopa, 1993). Rocks in the Lop Buri area are rhyolite, trachyandesite, and andesite. The $^{40}Ar/^{39}Ar$ geochronological ages of samples from this area show that they are much younger than those in the Loei and Phetchabun areas. The Sa Kaeo ultramafic bodies occur at a few localities in the southeastern parts of this volcanic belt, very near sheared and deformed beds. These rocks are mostly serpentinite and are believed to be the extension of the ophiolite belt that occurs in Uttaradit (Bunopas, 1981). Hada and others (1994) have shown that the Sa Kaeo suture comprises a western chert-clastic belt and an eastern serpentinite melange belt. The western belt appears to form a stack of imbricate thrust slices and is dated as Middle Triassic by radiolarians. The serpentinite melange belt is composed of a wide variety of rock units, including rocks of oceanic, island arc, and continental affinities of various ages. Structures indicate east-directed accretionary thrusting and, hence, westward-directed subduction. Rocks of the suture zone are overlain unconformably by Jurassic red beds and post-Triassic basaltic lavas. The basalt disconformably overlies the suture and is interplate continental basalt (Panjasawatwong and Yaowanoiyothin, 1993). Metcalfe (1996) suggested a Permian-Triassic age for this suture.

Late Cenozoic basalt occurs in the north as small isolated outcrops, to the west of the Khorat Plateau adjacent to other volcanic rocks in the Lop Buri area, and in the southeastern part. These basaltic rocks range in age from the Late Miocene to Holocene (Intasopa, 1993; Barr and Macdonald, 1981).

AIRBORNE GEOPHYSICAL SURVEYS AND DATA ENHANCEMENT

This study involved the application of the nationwide airborne geophysical data to the study of the major volcanic belts of Thailand and the implication of these volcanic belts to the study of the ancient Tethys sea.

The Royal Thai Department of Mineral Resources, with the assistance of the Canadian International Development Agency, has carried out airborne magnetic and gamma ray radiometric surveys covering nearly the entire country during 1984 and 1989. The surveys were flown by Kenting Earth Sciences International Limited, a Canadian contractor. Survey flight-line spacing was 1 kilometer for the aeromagnetic survey and 1, 2, and 5 kilometers, depending on different types of topography, for the radiometric survey. The flight line directions were north-south for the magnetic survey and east-west for the radiometric survey. The aeromagnetic data were originally compiled with secular correction to the year 1980. The Department of Mineral Resources had prepared nationwide aeromagnetic, radiometric, and elevation grids during 1992 and 1994 (Hatch and others, 1994). The aeromagnetic data of different elevations were draped to the same 300-meter elevation. Aeromagnetic and radiometric grids used in this study were extracted from the nationwide grids with a 500-meter grid cell size.

Magnetic data enhancement products used in this study included reduction to the pole (Grant and Dodds, 1972) and reduction to the equator, horizontal and vertical derivatives, and analytic signal grids (MacLeod and others, 1993). Radiometric total count and ternary maps, which represent potassium, effective uranium, and effective thorium, were the main radiometric maps used. Shaded relief maps of magnetic derivatives and radiometric grids are the most suitable map presentation for interpreting structural elements. Data interpretation was carried out with an awareness of the limitations of the data collected --- east-west flight direction and the reduction to the pole enhancement of data at low magnetic latitudes. Testing of the reduction to the pole enhancement technique used in this study gave acceptable results concerning anomaly shape and location compared to other enhancement methods, such as reduction to the equator and analytic signal.

AIRBORNE GEOPHYSICAL DATA INTERPRETATION

The combined use of aeromagnetic data (Figures 3 and 4) and radiometric data (Figure 5) has enabled a comprehensive national mapping of geology and fault structures. High to very high radioactive and low magnetic responses indicate granite and inferred Precambrian gneiss in the exposed basement areas located in the western part of the country. Low to very low radioactivity associated with high magnetization characteristics over the central part of the area indicates mafic volcanic and sedimentary rocks. Aeromagnetic data clearly indicate the presence of subsurface volcanic rocks within the basin along major strike-slip faults.

Aeromagnetic total field data and their enhanced products, such as an analytic signal grid, clearly reveal the main volcanic belts of the country (Figures 3 and 4). These volcanic belts are the Chiang Mai-Chiang Rai, Chiang Khong, Lampang-Phrae, Nan River, central or Phetchabun-Sa Kaeo, and Loei belts. The magnetic responses over these volcanic belts are relatively short wavelength anomalies. Exposed sedimentary sequences and granite basement located in the western part of the area have broad magnetic anomalies.

The aeromagnetic data also clearly outlines major structures (Figure 4), such as the Three Pagoda, Mae Ping, Ranong, and Uttaradit fault zones. Traditionally, the southern part of the Three Pagoda zone's fault path runs through the Gulf of Thailand, almost parallel to the east coast of of the peninsula. Magnetic data indicate that the Three Pagoda zone's fault path runs through the southern part of Krung Thep and that its plane dips to the north northeast. However, these data poorly outline the Khlong Marui fault located in the Thai peninsula. This poor result is possibly because the area is located near the magnetic equator.

The gamma ray radiometric data of Thailand reveal much more surface geological information over the exposed basement area than in the basin area (Figure 5). High to very high radioactive and low magnetic responses indicate granite and inferred Precambrian gneiss in the exposed basement area located in the western mountainous region and in the eastern coast area. Radiometric data also clearly outline Carboniferous-Permian sedimentary rocks and Permian limestone. The Permian limestone has relatively high effective uranium content compared to other sedimentary rocks. The Carboniferous-Permian sedimentary

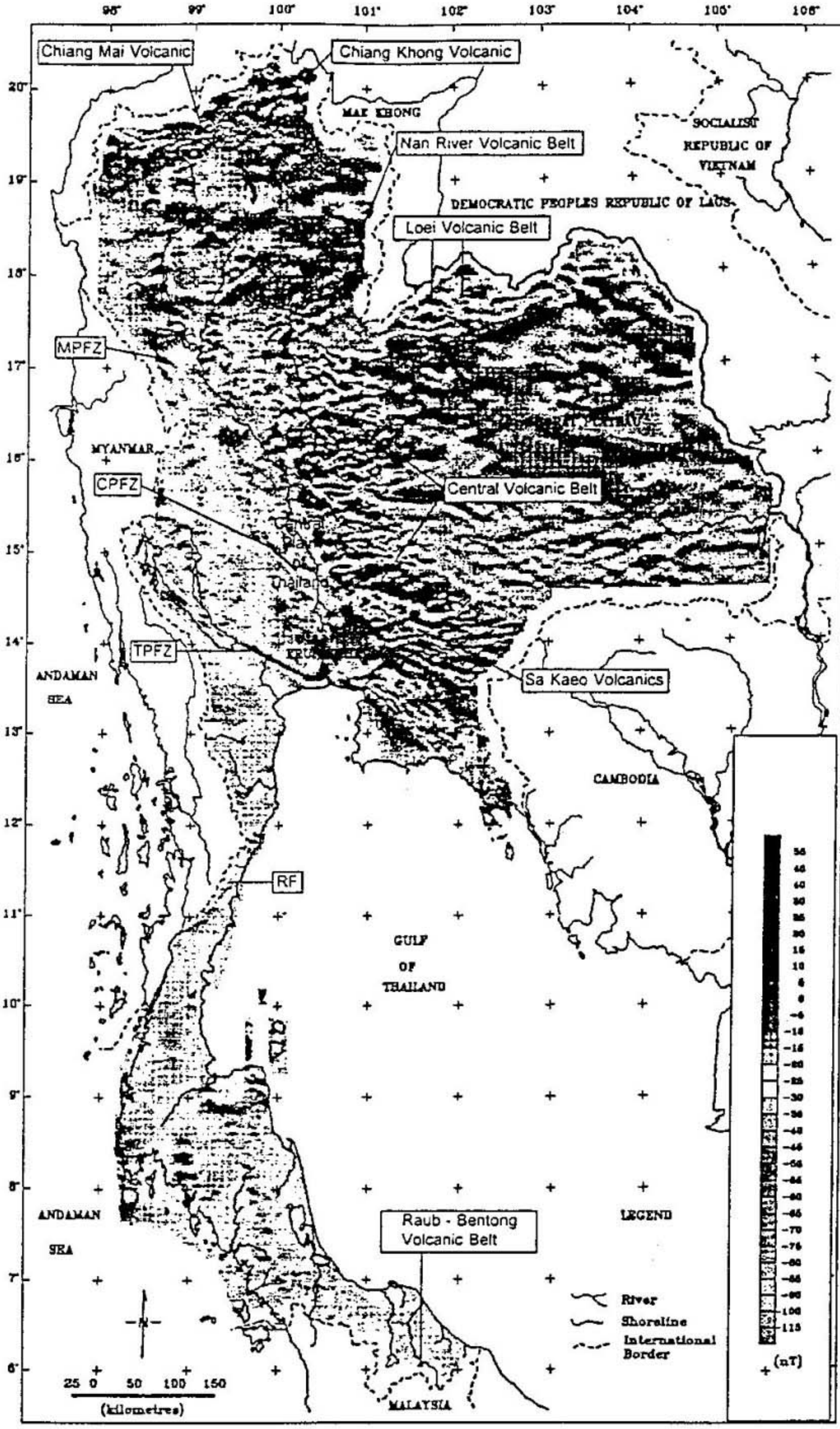

Figure 3 Residual magnetic total field image of Thailand.

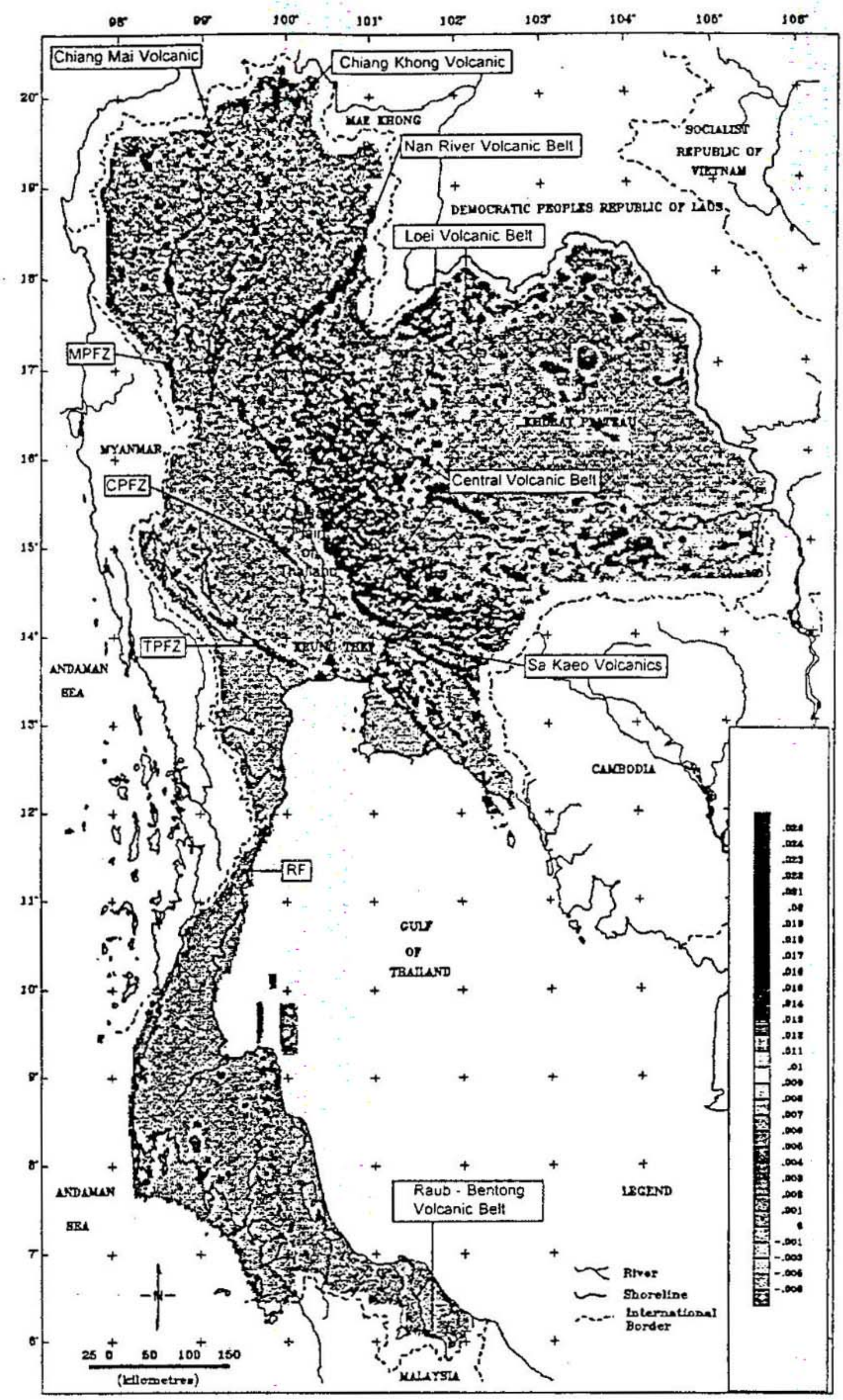

Figure 4 Pole-reduced first order derivative residual magnetic total field map ofThailand.

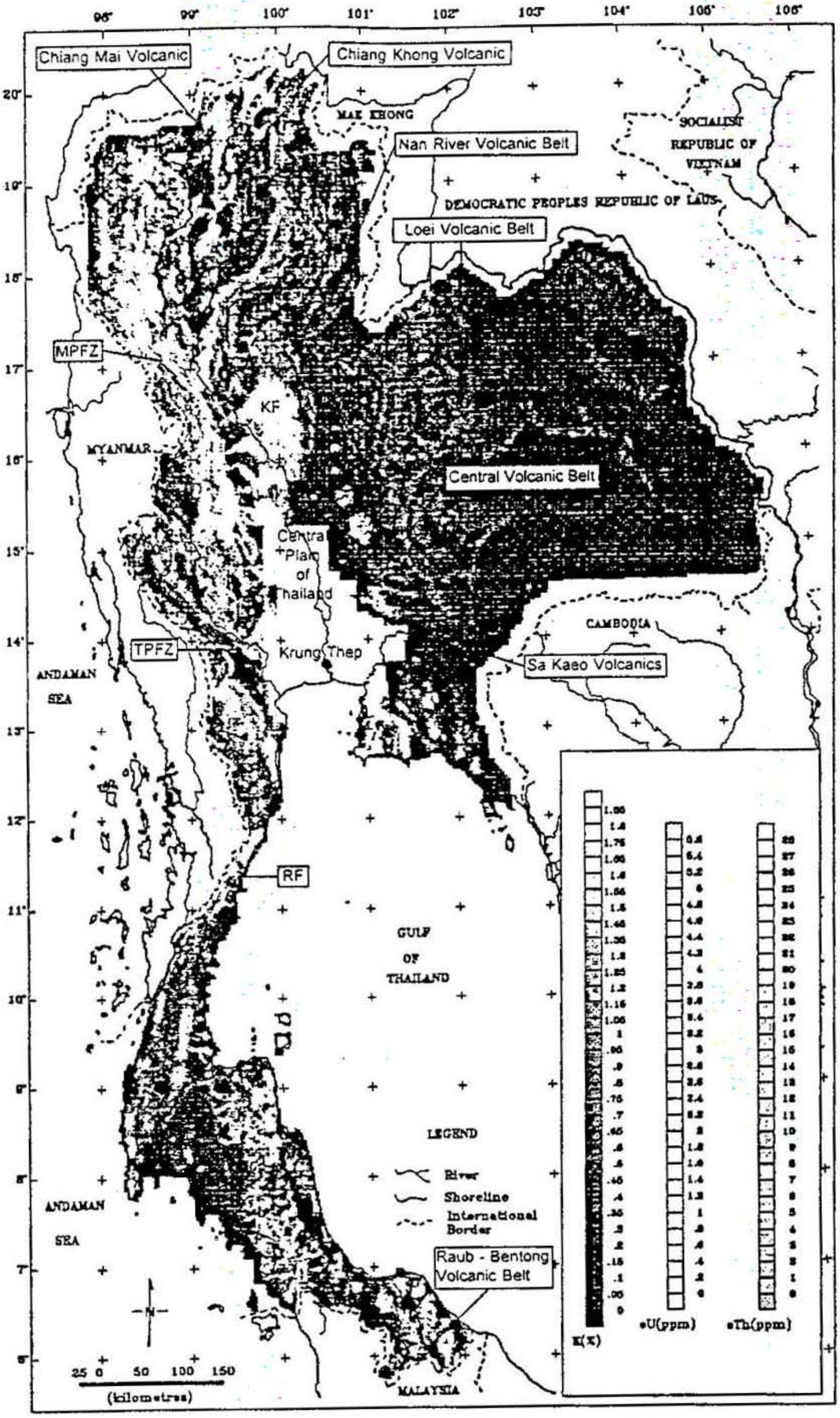

Figure 5 Magnetic analytic signal image of Thailand.

rocks have moderate potassium and effective thorium content. However, the use of radiometric data to classify these sedimentary rocks for studying the ancient Tethys is beyond the scope of this paper. The low to very low radioactivity associated with high magnetization that is characteristic of the central part of the country, such as along the western edge of the Khorat Plateau, indicates intermediate to mafic, and possibly ultramafic, volcanic rocks and sedimentary rocks.

There are three major lineaments related to the radiometric data. These lineaments trend northwest-southeast, northeast-southwest, and north-south. The northwest-southeast trends occur over the Mae Ping fault zone and the Three Pagoda fault zone in the western mountain range. The northeast-southwest trends occur over the Nan River volcanic belt in the north and the Ranong fault in the south. The north-south trends occur in the western part of the country. These data also outline a series of sedimentary units in the Central Plain based on differences in radioactive content and the depositional process. Most sediments were transported from the western mountains except in the northernmost part of the basin where sediments were washed from the north, northwest, and west. These data are very important for the study of the post-Mesozoic tectonics of Thailand and east Asia (Tulyatid and Fairhead, 1998).

DISCUSSION

The geophysical interpretation map of the country (Figure 6) outlines the major volcanic belts, fault zones, and suggested sutures along some of the volcanic belts. Ground evidence includes the finding of mafic to ultramafic rocks in the Chiang Mai, Chiang Khong (Tulyatid and others, 1999), Nan River, Lop Buri-Sa Kaeo (Intasopa, 1993), Loei, and Raub-Bentong volcanic belts. The similarity of magnetic signatures may represent mafic to ultramafic volcanic rocks in these major volcanic belts. The Nan River, central or Petchabun and Lop Buri, and Sa Kaeo volcanic belts, which possibly extend to the southeast into Cambodia, may represent the largest branch of the ancient Tethys sea in Thailand. This main suture joined the Shan-Thai and the Indochina sub-continents during Late Paleozoic and Early Mesozoic times. In addition, the Chiang Mai suture (Charusiri and others, 1998) may actually represent the same suture as the Chiang Khong suture (Figure 6). The Chiang Khong and Loei volcanic belts may also represent other branches of suture zones based on magnetic signatures and field evidence. However, magnetic data show no clear connection between the Chiang Khong and either the Phrae or Nan River volcanic belts or between the Loei and Petchabun volcanic belts. In addition, it is clear from Figures 2 and 6 that some high magnetic anomalies referred to volcanic belts are also recognized in areas dominated by Upper Paleozoic carbonate rock sequences, such as the east central Saraburi, northeast Loei, and northern Chiang Mai areas. Because of the regional extent of such magnetic anomalies, they may indicate the existence of remnant ocean floor basins beneath limestone terranes. Such areas have high potential for mineralization because volcanic rocks and limestone are high potential rock types that can be both sources and hosts for mineralization. These limestone terranes may have occurred on the Paleo-Tethyan ocean floor and represent isolated platform limestone facies. Field evidence in north central Thailand, the Phichit-Petchabun-Loei areas, indicates that limestone overlies volcanic and volcanic tuff sequences.

The central suture zone was possibly cross-cut by reversed movement on pre-existing faults during Miocene to Pliocene time (Lacassin and others, 1997). Faults that could have had reversed movement were the left-lateral northeast-southwest strike-slip

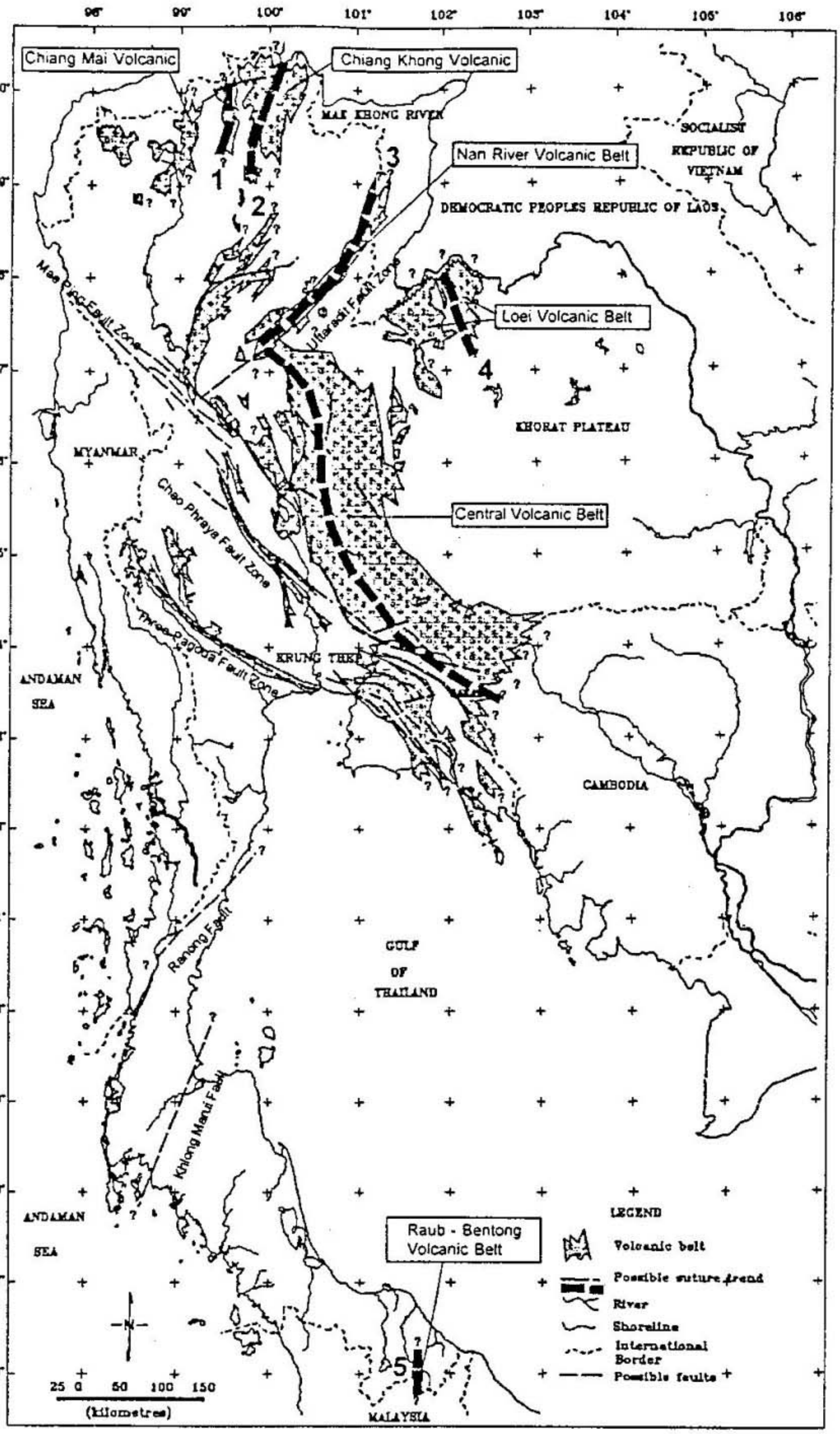

Figure 6 Sketched tectonic interpretation map of Thailand. The results of this study, in accordance with other geological evidence, suggest that there are four sutures in Thailand: (1) Chiang Mai (Charusiri and others, 1998); (2) Mae Chan, (3) Nan River-Central Thailand (-Sa Kaeo); (4) Loei and (5) the north extension of the Raub-Bentong sutures. These sutures may indicate different branches of the ancient Tethys Sea during Late Paleozoic - Early Mesozoic times.

Uttaradit fault zone in the north, the right-lateral northwest-southeast strike-slip Three Pagoda fault zone, and/or the Chao Phraya fault zone (Tulyatid and Fairhead, 1998). The suture zones in the country, specially along the western edge of the central volcanic belt, were reactivated causing the extension of the Phitsanulok and the Chao Phraya basins. The Indian-Eurasian collision during Cenozoic time may be the cause of the reversed movement of these faults and the reactivation of the ancient suture zone. On the basis of this Cenozoic tectonic model, the Nan River volcanic belt might have almost been connected to the Tak-Lampang volcanic belt before the Cenozoic opening of the Central Plain and the Gulf of Thailand, as indicated by magnetic data.

CONCLUSIONS AND RECOMMENDATION

1. Aeromagnetic data successfully helped to outline the distribution of possible ancient suture zones in Thailand.

2. Different branches of ancient sutures representing Late Paleozoic-Early Mesozoic Tethys seas include: (1) Chiang Mai, (2) Mae Chan, (3) Nan River-Phetchabun-Lop Buri-Sa Kaeo, or central volcanic belt, (4) Loei, and (5) Raub-Bentong. The geological evidence, including overlying Permian carbonate build-ups and successive Late Paleozoic deep water clastic, chert, and volcaniclastic sequences, seems to support this hypothesis.

3. Radiometric data successfully helped to outline the surface distribution of sedimentary rock units formed in the ancient Tethys sea, such as Carboniferous strata and Permian limestone.

4. The connection among the suggested sutures is still unclear. On the basis of aeromagnetic data, there may be some connection between the Nan River volcanic belt and the Mae Chan volcanic belt.

5. The connection between the main central volcanic belt and the Raub-Bentong volcanic belt in the southernmost part of the country is not likely valid since the central volcanic belt curves to the southeast and extends into Cambodia.

6. This study also showed that there may have been different branches of the Tethys sea. Therefore, the other possibility is that the Ruab-Bentong volcanic belt may not connect to the central volcanic belt of Thailand.

7. Some problems remain to be solved. Does the main suture in central Thailand connect to the Raub-Bentong suture? Are there any connections among different sutures, such as the Chiang Mai, Mae Chan, Nan River, and Loei sutures? For the first problem, future work should include the collection and interpretation of geophysical data in the Gulf of Thailand. The second problem requires both better data resolution and knowledge of structural geology concerning the gaps among the suggested sutures.

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