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Research Article

Missing ophiolitic rocks along the Mae Yuam Fault as the Gondwana–Tethys divide in north-west Thailand

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Abstract Thailand comprises two continental blocks: Sibumasu and Indochina. The clastic rocks of the Triassic Mae Sariang Group are distributed in the Mae Hong Son–Mae Sariang area, north-west Thailand, which corresponds to the central part of Sibumasu. The clastic rocks yield abundant detrital chromian spinels, indicating a source of ultramafic/mafic rocks. The chemistry of the detrital chromian spinels suggests that they were derived from three different rock types: ocean-floor peridotite, chromitite and intraplate basalt, and that ophiolitic rocks were exposed in the area, where there are no outcrops of them at present. Exposition of an ophiolitic complex denotes a suture zone or other tectonic boundary. The discovery of chromian spinels suggests that the Gondwana–Tethys divide is located along the Mae Yuam Fault zone. Both paleontological and tectonic aspects support this conclusion.

Key words: detrital chromian spinel, mafic rock, Sibumasu, suture zone, ultramafic rock.

INTRODUCTION

It has been well established on the basis of Bunopas' model (1981) that Thailand comprises a complex assembly of two allochthonous microcontinents (or terranes); namely, Sibumasu and Indochina (e.g. Metcalfe 1984, 1988). These two microcontinents were completely allochthonous to Asia and were amalgamated along the Nan suture (or Nan River suture; Barr & Macdonald 1987) (Fig. 1). Both of the microcontinents were rifted from the northern margin of Gondwana at different times, and drifted northward across Paleo-Tethys (e.g. Metcalfe 1996). They collided and then were amalgamated to proto-Asia. However, the timing of rifting and collision of the Cimmerian continent, including Sibumasu, to proto-Asia, and the position of the boundary between these two microcontinents are still controversial.

Faunal characteristics suggest that the eastern limit of Sibumasu corresponds to the Mae Yuam (called 'Mae Sariang' by some researchers) Fault zone running in the north–south direction near the Thailand–Myanmar border (Ueno & Igo 1997). Its southern extension in western and central Thailand is, however, still debated. No exposures of ultramafic or other ophiolitic rocks are known along the Mae Yuam Fault zone. Detrital chromian spinels in ancient sediments indicate that ophiolitic rocks were exposed near their depositional sites (e.g. Hisada & Arai 1993).

We have discovered chromian spinel-bearing sediments around the Mae Yuam Fault zone, north-west Thailand. We examined the petrological and tectonic aspects of the detrital chromian spinels to provide a new interpretation of the Gondwana–Tethys divide.

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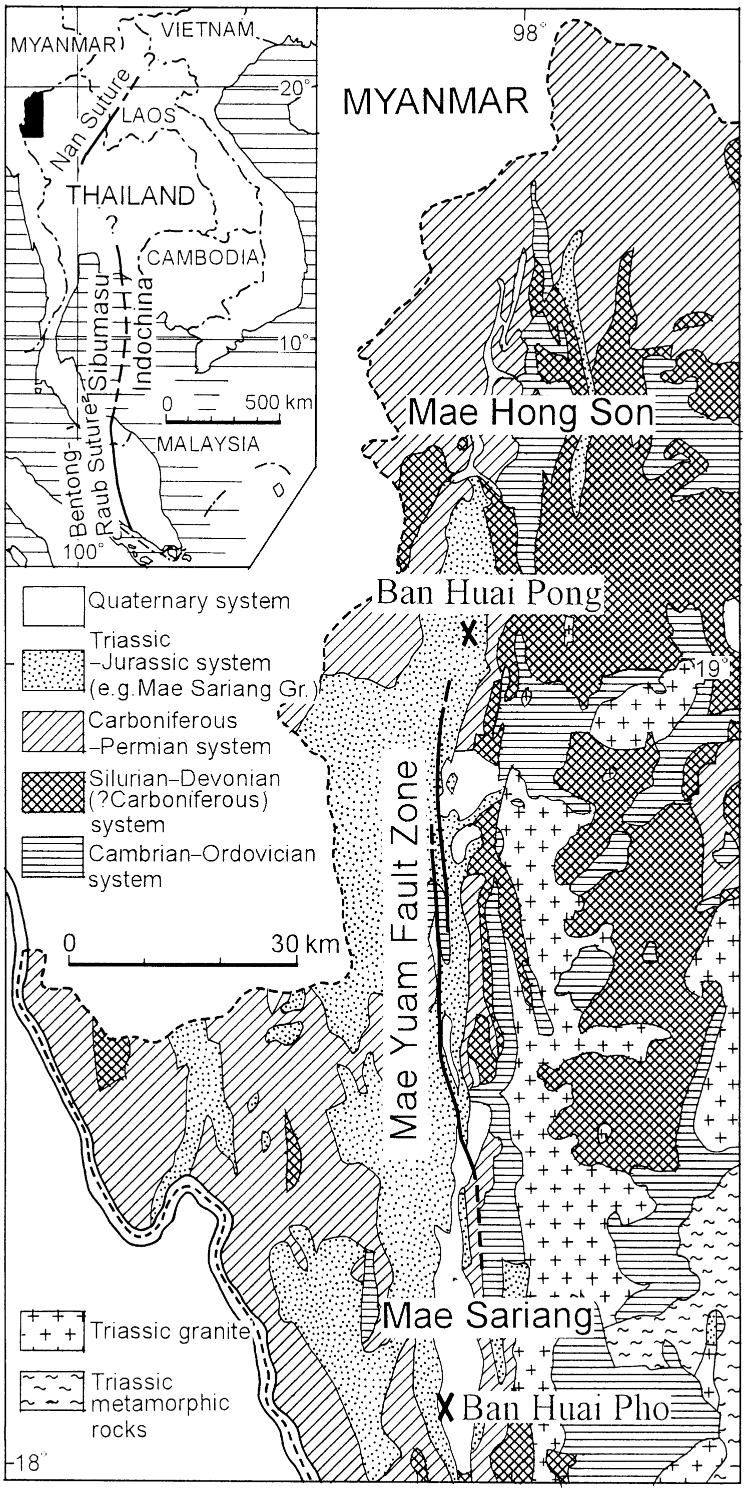

Fig. 1 Geological map of the Mae Hong Son–Mae Sariang area (adapted from Department of Mineral Resources (1999)). The trace lines of the Mae Sariang–Mae Hong Son Fault (Mae Yuam Fault zone) are based on Raksakulwong and Bunopas (unpubl. data, 1985).

GEOLOGY OF SAMPLING LOCALITIES

The Mae Hong Son–Mae Sariang area is located in the north-western corner of Thailand (Fig. 1). According to Bunopas (1981), Paleozoic and Mesozoic sedimentary rocks comprise the Hod Limestone, Mae Hong Son Formation and Mae Sariang Group, in ascending order. The Hod Limestone and Mae Hong Son Formation are early to late Ordovician and late Silurian to Late Devonian, respectively. The Triassic Mae Sariang Group (Bunopas 1981), composed of sandstone, shale and limestone with subordinate bedded chert, is widely distributed in the Mae Hong Son–Mae Sariang area (Fig. 1). Calcareous shale of this group yields *Daonella* and *Halobia* of Carnian age (e.g. Baum *et al.* 1970). In some places, the Triassic clastic rocks contain oriented pebbles of metamorphic rocks and flute casts, which suggest a transport direction parallel to the strike of mountain belt (Tofke *et al.* 1993). Recently, Kamata *et al.* (2002) reported that bedded chert intercalated in the Mae Sariang Group yields Spathian to Carnian radiolarians. Thick Cenozoic sediments cover the Mae Sariang Group (Fig. 1).

The Mae Hong Son–Mae Sariang area is topographically characterized by a north–south trending valley of the Mae Nam Yuam (River). This valley is generally interpreted as marking a trace of a strike-slip fault of Tertiary age (Baum *et al.* 1970). The Mae Yuam Fault zone has been recognized as the boundary between the Western Thai and Inthanon zones, both of which comprise the Shan-Thai (or Sibumasu) terrane (Barr & Macdonald 1991). This fault zone corresponds to the Yuam Fault system (Mae Sariang–Mae Hong Son Fault), considered to be a young fracture by Baum *et al.* (1970). This fault zone also marks the eastern end of the distribution of the Mae Sariang Group. According to the Chiang Mai geological map of 1 : 250 000 scale (Baum *et al.* 1981), metamorphics and Paleozoic strata occur extensively on the eastern side and Paleozoic and Mesozoic strata occur on the western side of the fault zone (Fig. 1).

We studied the Mae Sariang Group along two sections exposed at Ban Huai Pong and Ban Huai Pho. In the Ban Huai Pong section near Mae Hong Son, the following occur in ascending order: bedded shale with chert, bedded chert, bedded shale with chert, shale and sandstone. The sandstone is massive, but partly bedded, micaceous, and fine to medium grained (Fig. 2). The bedded chert, of which individual beds are approximately 50 mm thick, is black in color, and changes to bedded shale with an increase of mud content. Marl is in fault contact with the bedded shale with chert and yields Halobininoides. In the Ban Huai Pho section near Mae Sariang, the following occur in ascending order: shale with bedded limestone, bedded chert, bedded limestone, sandstone and shale (Fig. 3). It is unknown whether the bedded limestone is conformable with or exotic to the clastic rocks, because of poor exposure. The sandstone is characteristically micaceous and massive. Medium-grained sandstones, which are suitable for detrital spinel inspection and analysis, were collected from the two sections.

SIGNIFICANCE OF DETRITAL CHROMIAN SPINELS

Deposition of serpentine sandstone is a tectonic landmark (Arai *et al.* 1983). Okada (1964) found a classic example from postorogenic sediments

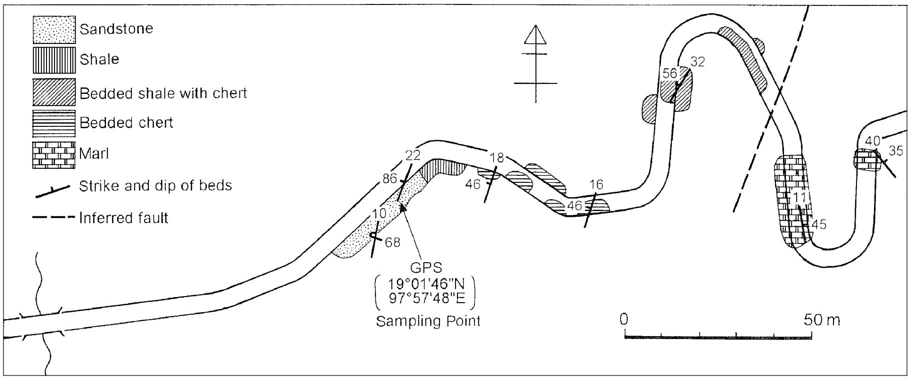

Fig. 2 Sampling point at Ban Huai Pong.

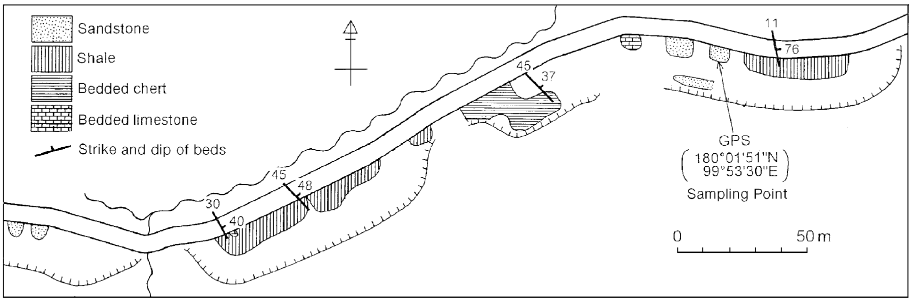

Fig. 3 Sampling point at Ban Huai Pho.

derived a short distance from the axial part of an orogenic belt. Serpentine sand, however, is not suitable as a tracer, due to its mechanical weakness. Chromian spinel is very stable and resistant under sedimentary conditions (Pettijohn *et al.* 1987), and is a good tracer compared to serpentine particles (Arai & Hisada 1991). A chemical database of chromian spinels in ultramafic and mafic rocks (e.g. Dick & Bullen 1984; Arai 1992a) facilitates precise linkage of detrital grains to their source rocks (Arai & Hisada 1991; Hisada & Arai 1993). Chromian spinels in volcanic rocks are a potential discriminant of magma chemistry (Arai 1992a). Chromian spinel chemistry also plays an important role in classifying mantle-derived peridotites in terms of their origin and tectonic setting (Dick & Bullen 1984; Arai 1994). Detrital chromian spinel derived from peridotitic rocks is an excellent indicator of both the lithology and the equilibrium temperature of the source rocks, even though it is usually only present in small amounts (Arai & Okada 1991).

We consider that the chemical characteristics of detrital chromian spinels are a powerful tool for determining their provenance, despite the conclusion of Power *et al.* (2000) that detrital spinel chemistry is not useful. Power *et al.* (2000) claim the low reliability of Mg# (Mg/(Mg + Fe^{2+}) atomic ratio) – Cr# (Cr/(Cr + Al) atomic ratio) and Cr-Al-Fe^{3+} diagrams of spinel, which are commonly used for discrimination of spinel derivation. They particularly refer to the incomplete nature for distinction of the layered intrusion field on the diagrams. We use these diagrams for discrimination of spinel derivation with care regarding the alteration effect.

The occurrence of detrital chromian spinels was recently reported from the Permian Nam Maholan Formation, Loei area (Sugiyama *et al.* 2000), and the Permian Nam Duk Formation, Phetchabun area (Chutakositkanon *et al.* 2001), in Thailand.

THIN SECTION PREPARATION

We collected medium-grained sandstone samples for spinel study from Ban Huai Pong and Ban Huai Pho in the Mae Hong Son–Mae Sariang area. Sampling locations are shown in Figures 2 and 3. Some chromian spinel grains were detected in thin sections under the microscope from Ban Huai Pho, but not in sections from Ban Huai Pong. We found a total of 50 chromian spinel grains from 30 thin sections from Ban Huai Pho. We carried out heavy liquid treatment for obtaining detrital chromian spinel grains from sandstone samples from both localities, following the procedure of Sugiyama *et al.* (2000). As a result, we obtained many detrital chromian spinel grains from Ban Huai Pho and Ban Huai Pong sandstone samples, whose weights were approximately 200 and 500 g, respectively.

MICROSCOPIC OBSERVATION OF DETRITAL CHROMIAN SPINELS

We observed 118 chromian spinel grains obtained from the Mae Sariang Group under the microscope. We found 44 grains in sandstone thin sections and 39 in heavy mineral concentrates from Ban Huai Pho, while 35 grains were obtained from heavy mineral concentrates from Ban Huai Pong. The grains were commonly angular to subangular, and some of them were subeuhedral (Fig. 4). The color of the spinel grains was commonly red–brown, yellow–brown or black.

The diameter was slightly different between spinels in sandstone thin sections and in heavy mineral concentrates, ranging from 20 to 150 μm (average: 67), and from 40 to 100 μm (average: 52), respectively. The smaller diameter of chromian spinels in heavy mineral concentrates is probably due to the crushing effect of processing the sandstone samples.

CHEMISTRY OF CHROMIAN SPINELS: DISTINCTION OF THREE GROUPS

Chromian spinels were analyzed with a microprobe (JXA8621 Super Microprobe; JEOL, Tokyo, Japan) at the Chemical Analysis Center, University of Tsukuba, Japan. Selected analyses are listed in Table 1. Cationic ratios were calculated assuming spinel stoichiometry. All Ti was assumed to form the ulvöspinel molecule, Fe_2TiO_4, on calculation. The compositions were obtained from nearly the center of each spinel grain. Chemical zoning was not detected. As the chromian spinels from Ban Huai Pho and Ban Huai Pong were quite similar in chemistry to each other, they are dealt with collectively below.

Content of TiO_2 reached 4.6 wt%, mostly ranging from 0 to 3.0 wt% (Fig. 5). In terms of the Cr# to TiO_2 relationship, the detrital chromian spinels could be divided into three groups: low Ti, high Ti, and high Cr, although the boundaries were arbitrary. Both Cr# and Mg# varied greatly, from 0.33 to 0.78 and from 0.02 to 0.77, respectively (Fig. 6).

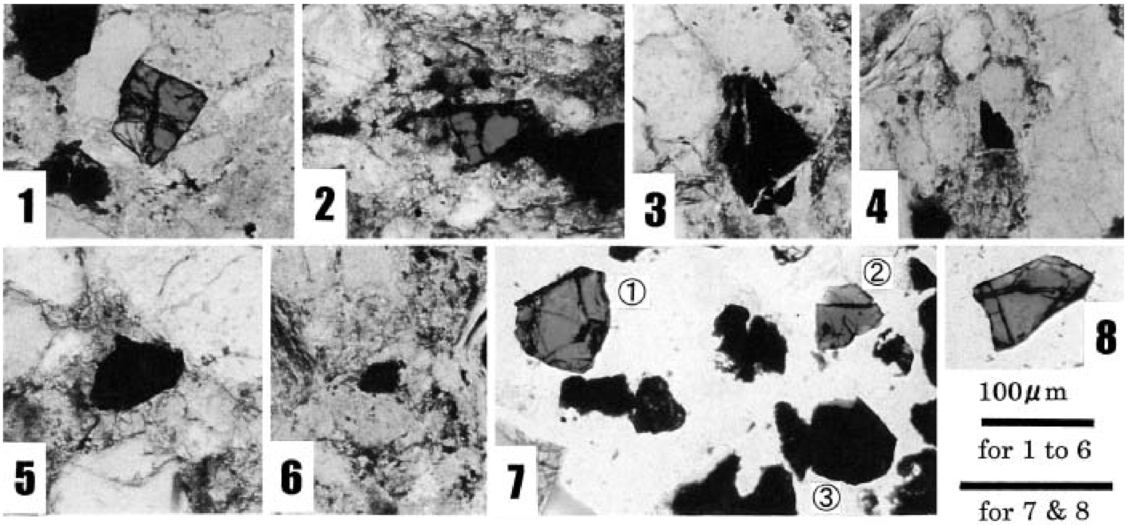

Fig. 4 Photomicrographs of detrital chromian spinels. (1,2,7,8) Low-Ti group; (3,4) high-Ti group; and (5,6) high-Cr group. 1, MSR 1-9-2; 2, MSR 2-2-2; 3, MSR 1-6-3; 4, MSR 2-7-5; 5, MSR 2-2-3; 6, MSR 2-12-3; 7 (i) MSR 1-3-17(1)H, (ii) MSR 1-3-17(3)H, (iii) MSR 1-3-17(4)H; and 8, MHS 10–2H. MHS, Ban Huai Pong spinels; MSR, Ban Huai Pho spinels.

Table 1 Selected microprobe analyses of detrital chromian spinels

	MSR 1-9-2	MSR 2-2-2	MSR 1-6-3	MSR 2-7-5	MSR 2-2-3	MSR 2-12-3	MSR 1-3-17(1) H	MSR 1-3-17(3) H	MSR 1-3-17(4) H	MHS 10-2H
SiO_2	0.00	0.03	0.14	0.03	0.12	0.17	0.03	0.39	0.04	0.03
Al_2O_3	34.74	29.43	16.35	14.95	12.09	12.02	26.64	26.06	26.46	30.24
TiO_2	0.01	0.26	3.48	4.23	0.18	0.24	0.07	0.54	0.55	0.02
Cr_2O_3	32.93	36.90	32.56	30.81	51.98	56.47	40.81	37.12	36.42	38.77
FeO*	15.42	18.31	33.02	35.71	21.97	16.45	15.77	18.41	20.08	13.76
NiO	0.12	0.18	0.24	0.27	0.00	0.10	0.07	0.10	0.18	0.08
MnO	0.25	0.32	0.28	0.27	0.28	0.24	0.27	0.33	0.34	0.12
MgO	15.35	13.47	11.30	11.67	10.96	12.87	12.89	12.17	13.00	15.90
CaO	0.02	0.00	0.02	0.01	0.00	0.19	0.03	0.07	0.02	0.04
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.02	0.00
K_2O	0.02	0.00	0.05	0.03	0.03	0.01	0.00	0.01	0.01	0.00
Total	98.86	98.90	97.44	97.98	97.62	98.76	96.58	95.31	97.12	98.96
Mg#	0.67	0.61	0.60	0.63	0.54	0.63	0.60	0.59	0.61	0.70
Cr#	0.39	0.46	0.57	0.58	0.74	0.76	0.51	0.49	0.48	0.46
Cr3#	0.38	0.44	0.46	0.44	0.68	0.73	0.50	0.47	0.45	0.45
Al3#	0.60	0.53	0.34	0.32	0.24	0.23	0.49	0.50	0.49	0.53
Fe3#	0.02	0.03	0.20	0.24	0.08	0.04	0.01	0.03	0.06	0.02

FeO*, total iron as FeO; Mg#, Mg/(Mg + Fe^{2+}) atomic ratio; Cr#, Cr/(Cr + Al) atomic ratio ; Cr3#, Al3# and Fe3#, atomic fractions of Cr, Al and Fe^{3+}, respectively, for trivalent cations (Cr + Al + Fe^{3+}). Ratios of Fe^{2+} and Fe^{3+} were calculated assuming spinel stoichiometry.

Fe^{3+}# (Fe^{3+}/(Al + Cr + Fe^{3+}) atomic ratio) was mostly less than 0.2 (Fig. 7). It is noteworthy that the high-Ti group was characterized by higher Fe^{3+}# (Fig. 7).

DISCUSSION OF SOURCE ROCKS FOR THREE GROUPS OF DETRITAL CHROMIAN SPINELS

Subeuhedral shapes of high-Ti group spinels, combined with relatively high Ti and Fe^{3+} contents (Fig. 7), suggest a volcanic origin. The high-Ti group spinels were also relatively high in both Cr# and Mg# (Fig. 6), indicating either a high equilibrium temperature (e.g. volcanic rocks) or a high concentration of chromian spinel (i.e. chromitite) (Arai 1992b). That finding, combined with their relatively high Fe^{3+} ratio (Fig. 7), suggests that the high-Ti spinels were most probably derived from volcanic rocks (Arai 1992a). Their high TiO_2 contents at a given Fe^{3+} ratio suggests an intraplate magma origin (Fig. 8; Arai 1992a). Their high Cr#

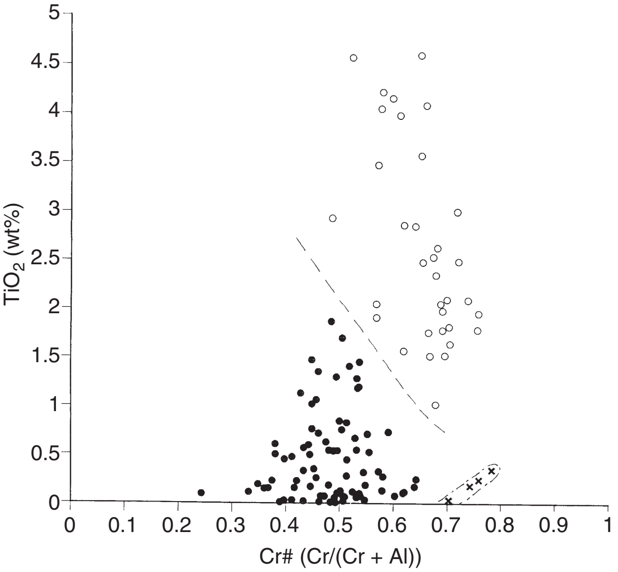

Fig. 5 Relationships between Cr# and TiO_2 wt% of detrital chromian spinels. ○, High Ti; ●, low Ti; ×, high Cr.

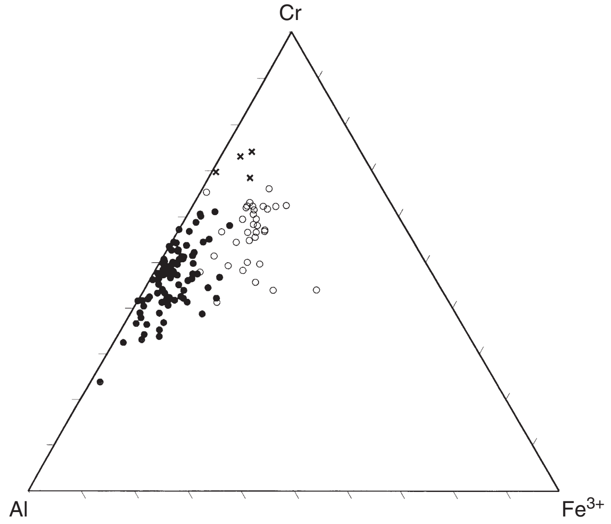

Fig. 7 Cr-Al-Fe^{3+} atomic ratios of detrital chromian spinels. ○, High Ti; ●, low Ti; ×, high Cr.

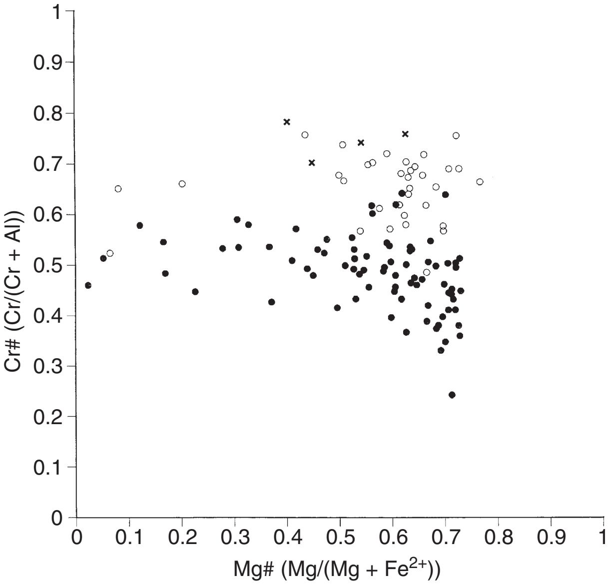

Fig. 6 Relationships between Mg# and Cr# of detrital chromian spinels. ○, High Ti; ●, low Ti; ×, high Cr.

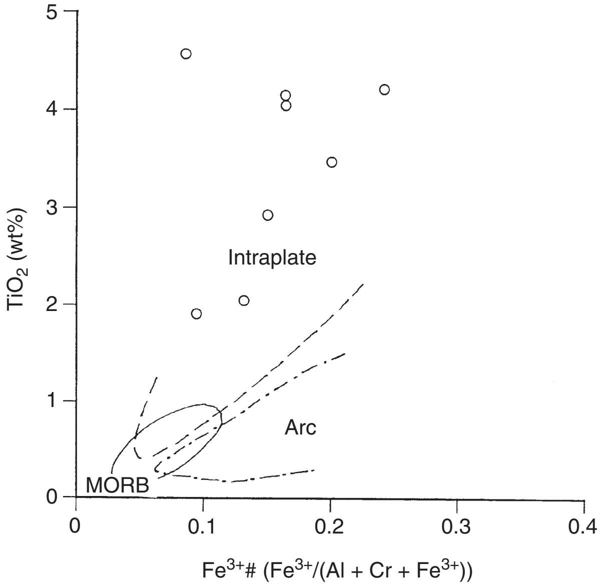

Fig. 8 Relationships between $Fe^{3+}/(Fe^{3+} + Al + Cr)$ atomic ratio and TiO_2 wt%. The discrimination boundaries of spinel compositions of mid-oceanic ridge basalts (MORB), arc magma and intraplate magmas are after Arai (1992a).

in particular indicates tholeiitic parentage (Arai 1992a).

The low-Ti group spinels have a peridotitic derivation. They are very similar in composition to spinels in most common ophiolitic peridotites (Dick & Bullen 1984; Arai 1992b). They were most probably derived from ocean-floor peridotites, because the upper limit of their Cr# was approximately 0.6, which is consistent with the Cr# limit for spinels in oceanic peridotites (e.g. Dick & Bullen 1984; Arai 1994). The compositional range for the low-Ti group spinels is, however, also included in the range for spinels in subarc peridotites (e.g. Arai 1994), and therefore, the possibility of derivation from subarc peridotites cannot be excluded.

The high-Cr spinels, characterized by high Cr# and Mg# and low Ti and Fe^{3+}, indicate a derivation from chromitite. The relatively coarse and noneuhedral grains support this conclusion.

MAE YUAM FAULT ZONE AS THE GONDWANA–TETHYS DIVIDE

The Mae Hong Son–Mae Sariang area has been located within Sibumasu. Bunopas and Vella (1978) regarded the north–south trending valley of the Mae Nam Yuam as the western part of Sibumasu. Hahn *et al.* (1986) also interpreted this region to be a part of the Shan-Thai paraplatform. However, the Nan–Uttaradit suture to the east has also been considered to be a suture zone, represented by remnants of paleo-oceanic sediments and arc igneous rocks, between the Sibumasu and Indochina continental blocks (Bunopas 1981), although the timing of collision and the position of the boundary are still controversial (e.g. Tan 1996; Chonglakmani 1999; Ueno 1999).

As stated above, the Mae Sariang Group yields detrital chromian spinels, derived from ocean floor peridotite, intraplate basalt and chromitite. Their source rocks correspond to a suite of ophiolitic rocks. Such rocks, however, are not exposed along the Mae Yuam Fault zone. This suggests that the ophiolitic rocks have been eroded out. If the proto-Mae Yuam Fault zone was accompanied by ophiolitic rocks, the Gondwana–Tethys divide is not the Nan–Uttaradit suture, but the Mae Yuam Fault zone. This opinion is supported by fusulinoidean biostratigraphy and paleobiogeography (Ueno 1999).

Recently, Ueno (1999) subdivided mainland Thailand into four tectonic terranes, which are, from west to east: the Sibumasu block, the Inthanon zone, the Sukhothai zone and the Indochina block. The Inthanon zone has been regarded to be a part of Shan-Thai derived from Gondwana (Bunopas 1981; Hada *et al.* 1997; Metcalfe 1998). Ueno (1999), however, proposed that the Inthanon zone is composed of pelagic-oceanic sedimentary rocks representing Paleo-Tethys remnants, and Ueno and Igo (1997) in particular noted the occurrence of Tethyan foraminiferal fauna from Chiang Dao in northern Thailand. Therefore, the Mae Yuam Fault zone between the Sibumasu and Inthanon zones is considered to be the Gondwana–Tethys divide. Because the Bentong–Raub suture in peninsular Malaysia (Fig. 1) is characterized by the presence of ophiolitic rocks, including serpentinite (peridotite), the discovery of detrital chromian spinels proves that the proto-Mae Yuam Fault zone accompanied by ophiolitic rocks is probably an extension of the Bentong–Raub suture.

PALEOGEOGRAPHIC SIGNIFICANCE OF THE MAE SARIANG GROUP

Recently, four main Triassic sedimentary facies have been distinguished in Thailand: continental facies, continental platform facies, marine intra-arc facies and deep marine facies (Chonglakmani 1999). The Mae Sariang Group is characterized by bedded chert intercalated with terrigenous clastic rocks, and is included in the deep marine facies. Sashida *et al.* (1999, 2000) discussed the Middle Triassic sedimentary facies in mainland Thailand and north-western peninsular Malaysia. They distinguished a subparallel arrangement of three rock units, shallow to slope limestones, clastic and chert sequences, from west to east. The three sequences extend southward from Mae Sariang and Kanchanaburi, through southern peninsular Thailand to north-western peninsular Malaysia. This lithological transition reflects a change from shallow to deep marine environments in the Paleo-Tethys (Sashida *et al.* 1995, 1999). These studies suggest that the Mae Sariang Group was deposited in rather deep sea to the east of Sibumasu during the Middle Triassic. In contrast, Barber and Crow (2003) envisaged that the whole area from Sumatra to peninsular Malaysia was subjected to east–west extension with the formation of several north–south graben structures after the collision event (Late Permian to Early Triassic), and they inferred that carbonates were deposited on the horst blocks, while bedded cherts and thin shales were accumulated in the graben. Turbiditic sands and shales, stemming from the eastern part of peninsular Malaysia, were deposited in the graben.

Tofke *et al.* (1993) proposed that the region of Mae Sariang was a terrane in which the pre-orogenic to syn-orogenic sedimentation was predominant. Furthermore, they insisted that the region between Chiang Mai and the Shan boundary fault in Myanmar was not a single coherent craton (Shan–Thai craton or Sibumasu), but that it was dissected at Mae Sariang by a highly mobile zone affected by compressional deformation during the Triassic Period. If we accept the interpretation of successive pre-orogenic to syn-orogenic sedimentation in the Mae Sariang Group, the occurrence of detrital chromian spinels from sandstone interbedded with chert is unexpected. Our findings of detrital chromian spinel leads to the presence of an uplifted suture concurrent with deposition of eroded materials, including spinels, on a remnant frontal ocean basin. Graham *et al.*

(1975) have already envisaged this phenomenon, illustrating progressive incorporation of synorogenic flysch within an orogenic suture. This progressive incorporation could be the main tectonic process in the Gondwana–Tethys divide. More recently, Metcalfe (2000) concluded that the Middle to Late Triassic sediments of the Bentong–Raub suture zone in peninsular Malaysia were deposited on top of an accretionary complex in a foredeep basin following the collision of Sibumasu and Indochina. In the Mae Hong Son–Mae Sariang area, the stratigraphy of the Mae Sariang Group is somewhat unsettled. However, the detrital chromian spinels were provided from ophiolitic rocks incorporated in the accretionary complex.

CONCLUSIONS

We propose a new location for the Gondwana–Tethys divide in Thailand, based on the occurrence of detrital chromian spinels, which were provided from ocean floor peridotite, chromitite and intraplate basalt. This boundary now corresponds to the Mae Yuam Fault zone. This interpretation is also supported by paleontological evidence, such as the occurrence of Tethyan fauna. However, the Mae Yuam Fault zone is not accompanied with ultramafic rocks at present, and its displacement remains unresolved. To definitively confirm the Gondwana–Tethys divide, there is a need to understand the stratigraphy and the paleogeography of the Inthanon zone.

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