Available online at www.sciencedirect.com
ScienceDirect
C. R. Geoscience 340 (2008) 166–179
COMPTES RENDUS GEOSCIENCE
http://france.elsevier.com/direct/CRAS2A/

Tectonics

Parallel Tethyan sutures in mainland Southeast Asia: New insights for Palaeo-Tethys closure and implications for the Indosinian orogeny

Masatoshi Sone [a,1,*], Ian Metcalfe [b]

[a] *Graduate School of Science and Technology, Niigata University, Niigata 950-2101, Japan*
[b] *School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia*

Received 18 June 2007; accepted after revision 10 September 2007
Available online 3 December 2007

Written on invitation of the Editorial Board

Abstract

Two contrasting parallel tectonic sutures can be recognised through the Yunnan–Thailand region of mainland Southeast Asia; they are sutures of the Devonian–Triassic Palaeo-Tethys Ocean and a Permian back-arc basin. The Changning–Menglian and Inthanon suture zones are regarded as the Palaeo-Tethys Suture Zone. The Jinghong–Nan–Sra Kaeo suture is regarded as a closed back-arc basin. The Sukhothai Zone is no longer treated as a part of the Sibumasu Terrane, but is defined as the core part of the Permian island-arc system developed on the western margin of the Indochina Terrane. Two tectonic events are interpreted from the parallel sutures; a Late Permian collapse of the back-arc basin and a mid-Triassic collision of Sibumasu to the Sukhothai Arc of Indochina (= closure of the Palaeo-Tethys). The Early–early Middle Triassic thermotectonism of Vietnam as linked to the Indosinian orogeny by some authors is incompatible with the suggested timing of Sibumasu collision, but instead it is temporally closer to the back-arc compression of western Indochina. ***To cite this article: M. Sone, I. Metcalfe, C. R. Geoscience 340 (2007).***

Résumé

Zones de suture parallèles en Asie du Sud-Est : un nouvel éclairage sur la fermeture de la Paléotéthys et implications pour l'orogenèse indosinienne. Deux sutures parallèles peuvent être distinguées dans la région du Yunnan et en Thaïlande, en Asie du Sud-Est ; elles correspondent à la suture de la Paléotéthys ouverte du Dévonien au Trias et à la suture d'un bassin arrière-arc d'âge Permien. La suture de Jinghong–Nan-Sra Kaeo est considérée comme le reste d'un bassin arrière-arc. La zone de Sukhothai ne peut être désormais considérée comme faisant partie du bloc Sibumasu, mais comme la partie centrale d'un arc insulaire d'âge Permien, développé à la marge du bloc continental indochinois. Deux événements tectoniques se rapportent à ces deux sutures : un effondrement, au Permien supérieur, du bassin arrière-are et une collision, au Trias moyen, de Sibumasu avec l'arc de Sukhothai, à la marge de l'Indochine (fermeture de la Paléo-Téthys). L'événement thermotectonique du Trias inférieur à moyen au Vietnam, qui se rapporte à l'orogenèse indosinienne, est incompatible avec l'âge suggéré de la collision de Sibumasu, mais est chronologiquement plus proche de celui de la compression ayant affecté le

* Corresponding author.
E-mail address: masatoshi.sone@gmail.com (M. Sone).
[1] Present address: Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.

1631-0713/$ – see front matter
doi:10.1016/j.crte.2007.09.008

bassin arrière-arc dans la partie occidentale de l'Indochine. ***Pour citer cet article : M. Sone, I. Metcalfe, C. R. Geoscience 340 (2007).***

Keywords: Tethys; Suture; Permian; Triassic; Thailand; Yunnan; Indochina

Mots clés : Téthys ; Suture ; Permien ; Trias ; Thaïlande ; Yunnan ; Indochine

1. Introduction

In Southeast Asia, there are two major continental masses, that is, the Indochina Terrane and the Sibumasu Terrane. Sibumasu collided with Indochina after prolonged subduction of the Devonian–Triassic Palaeo-Tethys Ocean [51]. We here recognise two sub-parallel suture zones along the belt of convergence between Sibumasu and Indochina; one wide suture zone representing an extensive accretionary complex of the Palaeo-Tethys (Changning–Menglian and Inthanon sutures), and one narrow suture zone representing a closed back-arc basin (Jinghong, Nan and Sra Kaeo sutures). These two sutures are more or less parallel to each other, with a former island arc in between, stretching from western Yunnan in the north through to Thailand. A new tectonic framework for mainland Southeast Asia is here proposed (Fig. 1).

The Nan and Sra Kaeo sutures in Thailand have traditionally been regarded as representing the Palaeo-Tethys Suture (e.g., [10,34]). However, this interpretation has been questioned by some authors [58,71,72] who have suggested an alternative site for the true Palaeo-Tethys subduction zone to the west, where pelagic cherts of Devonian–Triassic ages are distributed, and instead regarded the Nan and Sra Kaeo sutures as a closed back-arc basin. This view is supported, and is further refined in this paper.

Our new interpretation proposes the existence of an island-arc system and its back-arc basin developed along the western margin of the Indochina Terrane. The distribution patterns and emplacement periods of pre-Cretaceous S- and I-type granitoids support this proposal. Particular attention is paid to the chronostratigraphic occurrence of pelagic or deep-sea sediments in these parallel sutures in order to analyse the age ranges of the two closed seas.

2. Palaeo-Tethys Suture Zone

2.1. Changning–Menglian Suture Zone

The Changning–Menglian Suture Zone corresponds to the widely used term Changning–Menglian Belt. It is generally regarded as the main Palaeo-Tethys Suture Zone in western Yunnan (e.g., [47,75]), and, to the south, it is correlated with the Inthanon Suture Zone in Thailand (Fig. 1). This suture zone contains ophiolitic mélanges, volcanics, shallow-marine carbonates, and deep-sea sedimentary rocks (with substantial pelagic cherts).

Three major ophiolitic mélanges, the Tongchangjia, Shuanggou, and Menglian ophiolites, are known at the northern, central, and southern parts of the suture zone, respectively [83,84]. A series of tightly imbricate thrust sheets are common in mélange matrices [87]. Zhong et al. [87] pointed out that the structural vergence of the thrust sheets is generally west-dipping, appearing opposite to interpreted kinematics of the east-dipping subduction (see below), and they explained this to be a turn over owing to subsequent collisional compression. This requires to be verified.

Some basaltic volcanics range in age from Devonian to Late Permian, and are regarded as seamounts and/or oceanic islands in origin (e.g., [22]). Pure carbonate successions of the Carboniferous–Permian are closely associated with intraplate basalts, and are interpreted as limestone caps to seamounts (e.g., [35,75]).

The deep-sea sediments bear Devonian-Triassic radiolarians (e.g., [26,28,30]), and twenty-two radiolarian assemblage zones are recognised [28]. The oldest deep-sea sediment is represented by the *Eoalbaillella lilaensis* radiolarian zone (here assigned to the early Middle Devonian) of the Lalei Formation in the Menglian area [25,28]. This sediment, however, is unlikely a true pelagic deposit, because of its turbiditic sedimentary facies and clastic inclusions (Q. Feng, pers. commun., 2005). The Lalei Formation probably represents a hemi-pelagic deposit during the rifting to opening stage when Indochina was split from Gondwana in the Devonian. Unequivocal pelagic sediment of the Changing–Menglian Suture Zone commences with late Middle Devonian cherts with the *Entactinia–Entactinisphaera* radiolarian assemblage [28]. The youngest pelagic sediment is Late Anisian/Early Ladinian (Middle Triassic) chert represented by the *Triassocampe deweveri* radiolarian assemblage [28,31]. The chronostratigraphic range of pelagic sediments in

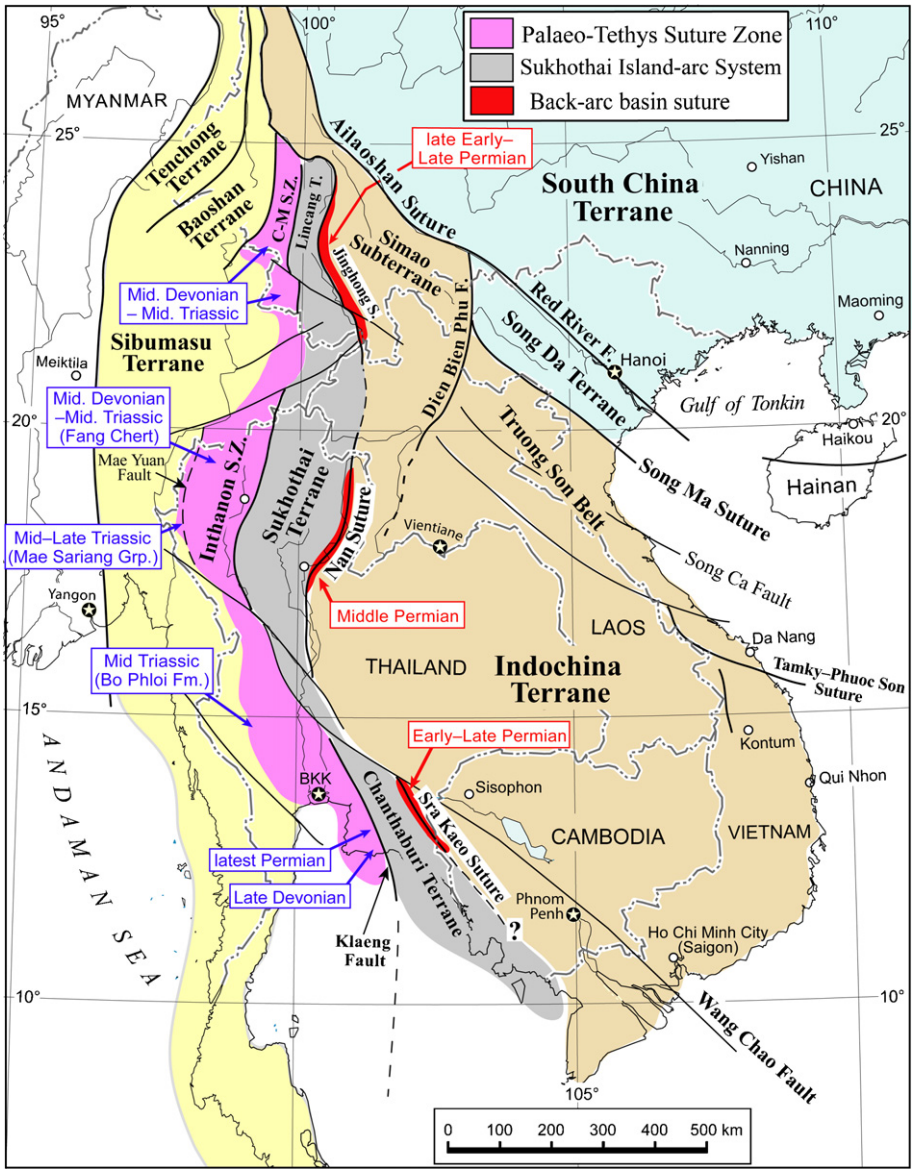

Fig. 1. Proposed tectonic subdivision of mainland Southeast Asia, showing the Palaeo-Tethys Suture Zone and back-arc sutures. The occurrence of deep-sea sediments in each local suture is indicated (for the Palaeo-Tethys Suture Zone in blue and for the back-arc basin in red). C-M S.Z. = Changning–Menglian Suture Zone.

Fig. 1. Subdivisions tectoniques de l'Asie du Sud-Est montrant les zones de suture de la Paléotéthys et des bassins arrière-arc, ainsi que la distribution des sédiments océaniques profonds dans chaque zone de suture (pour la Paléotéthys en bleu, pour le bassin arrière-arc en rouge).

the Changning–Menglian Suture Zone is therefore from Middle Devonian to late Middle Triassic.

The eastern fringe of the Changning–Menglian Suture Zone is intimately associated with paired metamorphic belts (Lancang Metamorphic Belts), which are constituted mainly of Permian–Triassic greenschists and blueschists [20,85,86]. That is, a low-*P*/*T* metamorphic belt in the east is associated with the Lincang Batholith (island arc), and an outer high-*P*/*T* metamorphic belt in the west is on the oceanward side to the Changning–Menglian Suture Zone (i.e., the Palaeo-Tethys subduction zone). Within the high-*P*/*T* belt, the metamorphic grade increases eastwards [20,85], suggesting an east-dipping subduction zone. The Lancang Metamorphic Belts of Zhang et al. [85] are regarded as representing typical paired metamorphic belts which can be developed in a subduction zone associated with an island arc (e.g., [1,54]), and this is taken as evidence of

the Permo-Triassic east-dipping subduction beneath the Lincang arc.

2.2. Inthanon Suture Zone

The Inthanon Suture Zone of Thailand is largely equivalent to the Inthanon Zone described by Barr and Macdonald [3]. It is interpreted as an extensive accretionary complex of the closed Palaeo-Tethys Ocean, following the view of Ueno and Hisada [71]. Note that the term Chiang Mai Suture used by Metcalfe [52] is essentially equivalent to part of the Inthanon Suture Zone (see [71,72]).

Various types of rocks are distributed within the Inthanon Suture Zone, including Permian basaltic volcanics, Carboniferous–Permian limestones, Devonian–Triassic radiolarian cherts, Triassic S-type granitoids, and mylonitic/migmatitic gneisses. The Permian Chiang Mai Volcanics were analysed by Barr et al. [6] and Phajuy et al. [57]. The former considered it to have been generated in a back-arc rift setting within the Shan-Thai Terrane, whereas the latter suggested an oceanic island or a seamount in an oceanic within-plate setting. The latter interpretation is here supported.

Like the Changning–Menglian Suture Zone, the Inthanon Suture Zone also contains pure carbonate successions spanning from Early Carboniferous through to Late Permian, which yield abundant micro-fossils of warm-water Tethyan type [32,73,76]. These limestones are regarded as seamount caps originally formed within the Palaeo-Tethys Ocean [52].

The deep-sea sediments of the Inthanon Suture Zone can be classified into two main units, the Fang Chert and the Mae Sariang Group. The Fang Chert consists of ribbon-bedded radiolarian cherts, and represents a typical pelagic deposit of the Palaeo-Tethys. It ranges from late Middle Devonian through to late Middle Triassic in age [11,23,61,80]. The oldest strata documented in the Fang Chert are Givetian (late Middle Devonian) [80]. The youngest horizon is the Late Anisian/Early Ladinian (Middle Triassic) represented by the *Triassocampe deweveri* radiolarian assemblage [23].

The Mae Sariang Group is distributed around westernmost Thailand, and consists of Middle–Late Triassic radiolarian cherts and turbiditic clastics, with the Carnian beds (early Late Triassic) being the youngest [12,40,69]. Facies of the Mae Sariang Group is non-pelagic, and represents deposits more proximal to the Sibumasu passive margin than the Fang Chert [40]. Tofke et al. [69] interpreted these as typical pre- to syn-orogenic successions. The Middle Triassic sequence of the Fang Chert, not the Late Triassic of the Mae Sariang Group, is here regarded as the latest pelagic deposit in the Inthanon Suture Zone.

The southern part of the Inthanon Suture Zone is not well observed due to the extensive Cenozoic fluvial cover of the Menam Delta. In East Thailand, a transcurrent fault zone is recognised to the east of Chonburi through to near Klaeng [42]. This fault zone, called the ‘‘Klaeng Fault’’ by local geologists (P. Chaodumrong, pers. commun., 2005), corresponds to the boundary between the S- and I-type granitoid belts shown by Cobbing et al. [18,19], and is here defined also as the eastern boundary of the Inthanon Suture Zone (Figs. 1, 3).

Some deep-sea sediments of Devonian to Triassic ages are sporadically recognised in the southern part of the Inthanon Suture Zone (Fig. 1). In East Thailand, pelagic radiolarian cherts of Late Devonian or Early Carboniferous age near Rayong [62] and of Latest Permian age near the Klaeng Fault [63] have been reported. To the west of Bangkok (Kanchanaburi Province), Middle Triassic radiolarian chert of the Bo Phloi Formation was reported [64].

3. Back-arc basin suture

The Nan and Sra Kaeo sutures in Thailand and the Jinghong Suture (new name) in Yunnan are here regarded as the trace of a former back-arc basin. These local sutures have traditionally been thought to represent the Palaeo-Tethys Suture (e.g., [10,34,82]). However, the limited Permian deep-sea record precludes these as representing the Devonian–Triassic Palaeo-Tethys Ocean. Permian mélanges of possible ophiolites are recognised consistently in these local sutures, as noted below. Some authors (e.g., [55]) now suggest that ophiolites can form in back-arc basin environment, supporting the current case.

3.1. Nan Suture

The Nan Suture, also called the Nan–Uttaradit Suture, forms the tectonic boundary between the Sukhothai Terrane and the Indochina Terrane (Fig. 1). It is a narrow zone of Permian ophiolites and mélange. The Pha Som Metamorphic Complex consists mainly of greenschist and minor blueschist (crossite schist) associated with Permian bedded cherts and basic/ultrabasic igneous rocks, and represents the Nan ophiolitic mélange [2,5,66,67]. Actinolite from mafic schist of the Pha Som Complex yields a K/Ar age of 269 ± 12 Ma (i.e., Middle/Late Permian), indicating its minimum metamorphic age [2].

A late Middle Permian radiolarian chert in the Nan Mine area reported by Hada et al. [34] is the only evidence of deep-sea environment in this suture. The Pha Som Complex only reveals a Permian deformational episode. Thus, available chronological evidence suggests that the Nan basin was not a major Palaeo-Tethyan ocean, but was a short-lived Permian basin. Some authors [58,71] suggested it to be of back-arc basin origin.

The Nam Pat Group is distributed in the east of the Pha Som Complex, and it contains turbiditic sandstones and volcaniclastic conglomerates of Late Triassic age [49,65]. It overlies the Pak Pat Volcanics of possible Permian–Triassic age, which then is in contact with metasediments of the Pha Som Complex [65]. Thus, an Early/Middle Triassic unconformity below the Nam Pat Group is plausible (see [49,65]), and this may suggest that the Nam Pat sediments were deposited after back-arc uplift of the Nan Suture.

A curious find is that Hada et al. [34] reported a single specimen of the Middle Triassic radiolarian *Triassocampe* sp. found in a red-chert clast reworked in the continental Khorat Group in the Nan area. Hada et al. [34] presented it as evidence of a Triassic Palaeo-Tethys ocean in the Nan Suture. However, no host Triassic cherty sequence is so far known in the Nan Suture or the Nam Pat Group. Therefore, there is doubt that the *Triassocampe* clast was derived *in situ*. The chert clast might have been transported from the Palaeo-Tethys Suture Zone in the west, where Middle Triassic cherts (e.g., the Fang Chert) are common, during post-Triassic continental sedimentation. The Triassic chert in question seems unlikely to be a genuine element of the Nan Suture.

The deformational structure of the Pha Som Metamorphic Complex shows the northwest dipping vergence, and this has been interpreted to be an accretionary prism of a west-dipping subduction zone beneath the Sukhothai Terrane [10,66,67]. This subduction was considered by those authors to have produced the Permo-Triassic arc magmatism of the Sukhothai Terrane. However, the cause of the Sukhothai Arc magmatism is now better explained by the eastwards Palaeo-Tethys subduction at the Inthanon Suture Zone [71]. Considering that the Pha Som Complex is a small accretionary prism of limited Permian age, the occurrence of the prolonged west-dipping subduction in the former Nan basin is implausible.

In addition, some authors (e.g., [4,52]) correlated the Nan Suture with the Ailaoshan Suture in China. However, the Ailaoshan Suture likely represents a longer-lived Carboniferous–Triassic ocean [78], unlike the suggested Permian basin of the Nan Suture. The Nan Suture is, therefore, more reasonably correlated with the Jinghong Suture (southern Lancangjiang Suture) outlined later.

3.2. Sra Kaeo Suture

The Sra Kaeo Suture in East Thailand is regarded as the southern extension of the Nan Suture and the boundary between the Indochina Terrane and the Chanthaburi Terrane (new name). It represents a closed back-arc basin marginal to Indochina, as suggested by Ueno and Hisada [71,72]. An ophiolitic rock assembly called the Thung Kabin Mélange is distributed in the Sra Kaeo Suture [34], and it consists of bedded cherts, limestones, serpentinites, gabbros, and pillow lavas (also pers. observation, 2002). The cherts and limestones are dated with micro-fossils to be Permian in age [34]. The radiolarians of Sakmarian to Kungurian (Early Permian) [34] and Capitanian to Wuchiapingian (late Middle to early Late Permian) [60] are gained from the cherts, suggesting a limited Permian age for the former Sra Kaeo basin, similar to that of the Nan Suture. Thus, a Permian back-arc basin is more plausible for the origin of the Sra Kaeo Suture rather than a major Palaeo-Tethys Ocean.

Middle Triassic radiolarian-bearing cherts and black shales are distributed to the South of the Sra Kaeo Suture, and they are called the Chanthaburi Chert-clastic Sequence [34,60]. Hada et al. [34] interpreted this Triassic unit to be sediment of the former Sra Kaeo basin, and proposed the extended Sra Kaeo–Chanthaburi Suture Zone to represent the Palaeo-Tethys Suture. However, there is a certain stratigraphic gap between the Permian and Middle Triassic strata (Fig. 2). This may suggest an Early Triassic unconformity due to the Late Permian uplift in the Sra Kaeo back-arc basin. Moreover, the geographic extent of the Triassic unit is clearly separable from the Permian mélange of the Sra Kaeo Suture (see [34]). The Triassic cherts/clastics may have been deposited in a separate depression from the Sra Kaeo basin. The Triassic strata are not regarded as a genuine element of the Sra Kaeo Suture.

The Sra Kaeo Suture probably extends to Cambodia. Just beyond the Thai-Cambodia border, another mélange including basalts, peridotites, and possible Late Palaeozoic pelagic cherts is exposed near Pailin [9]. It is probably equivalent to the Permian Thung Kabin Mélange of the Sra Kaeo Suture.

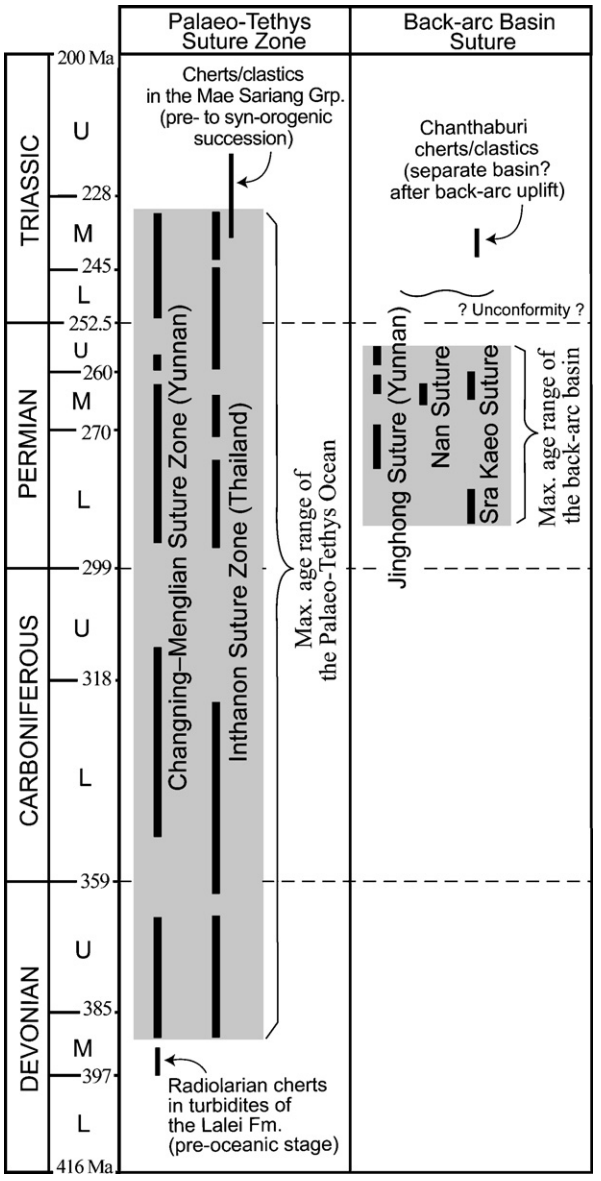

Fig. 2. Chronostratigraphic range chart of deep-sea sediments in the Palaeo-Tethys Suture Zone and the Jinghong–Nan–Sra Kaeo back-arc basin suture.

Fig. 2. Tableau montrant la distribution chronostratigraphique des sédiments océaniques profonds dans la zone de suture paléotéthysienne et dans le bassin d'arrière-arc Jinghong–Nan-Sra Kaeo.

3.3. Jinghong Suture (new name)

The Jinghong Suture is named for a minor suture between the Simao Subterrane of the Indochina Terrane and the Lincang Terrane (Fig. 1). It is after the 'Jinghong Mélange' used by Chen et al. [15], and is equivalent to that arbitrarily called the Lancangjiang Belt or the southern Lancangjiang Suture by some authors (e.g., [21,24,27,47,48]).

The so-called Lancangjiang Suture in eastern Tibet is generally accepted as the main Palaeo-Tethys Suture, and is often mistakenly correlated with the southern Lancangjiang Suture (i.e., Jinghong Suture) in Yunnan along the lengthy Lancang River (Mekong River) (e.g., [82]). However, as outlined earlier, the Palaeo-Tethys Suture in Yunnan is represented by the Changning–Menglian Suture, to which the Langcangjiang Suture in Tibet should be correlated. Hence, it is misleading to treat both Tibetan and Yunnan sections of the Lancang River together as the single Lancangjiang Suture. In order to avoid any confusion, the term Lancangjiang Suture should be restricted to Tibet. The (southern) Lancangjiang Suture in Yunnan, which is not attributable to the Palaeo-Tethys Suture, is renamed the Jinghong Suture, accordingly.

Volcanic and volcaniclastic rocks of possible Permo-Triassic ages are distributed extensively in the Jinghong Suture (e.g., [85]). Mélange-type deposits in this suture include serpentinites, basalts, and cherts (e.g., [8,27]), and these assemblages possibly represent ophiolites. The deep-sea cherts are dated by radiolarians, that is, late Early Permian cherts from the upper Longdonghe Formation [29], late Middle or earliest Late Permian red cherts of the Daxinshan Formation [27], and Early Changhsingian (Latest Permian) cherts from the Bangsha area near Jinghong [26]. The Daxinshan cherts are associated with tholeiitic basalts in the Jinghong Mélange [27]. These deep-sea sediments found are limited to the Permian, suggesting the existence of a minor short-lived basin separate to the Devono-Triassic Palaeo-Tethys closed in the Changning–Menglian Suture Zone in the west.

4. Sukhothai Arc terranes

It is proposed here that the Lincang Terrane of Yunnan, the Sukhothai Terrane and the Chanthaburi Terrane (new name) of Thailand were originally formed as parts of the same island-arc system developed along the margin of the Indochina Terrane, which was subsequently amalgamated to Indochina due to back-arc collapse and succeeded as a continental arc in the Triassic. This Permo-Triassic magmatic arc is here named "the Sukhothai Arc", with the Permian Sukhothai island-arc system. The name is after the Sukhothai tectonostratigraphic zone of Barr and Macdonald [3], to which this magmatic arc principally corresponds in Thailand. Ueno and Hisada [71,72] indicated that the Sukhothai Terrane was developed as a Permian island arc marginal to the Indochina Terrane with the opening of the Nan back-arc basin, induced by the eastward subduction of the Palaeo-Tethys in the Inthanon Suture Zone.

4.1. Sukhothai Terrane

The Sukhothai Terrane of Barr and Macdonald [3] not Barr et al. [4] is used herein. It is delineated by the Inthanon Suture Zone to the west and by the Nan Suture to the east (Fig. 1). It is dominated by folded and faulted sequences of shallow-marine sedimentary rocks and igneous rocks with I-type granitoids, mostly of Permian and Triassic ages. There is general agreement that it is a Permo-Triassic magmatic arc [4,7,10,56]. Two Middle Triassic volcanics, the Lampang and Chiang Khong suites, show chemical characteristics indicative of a continental arc [4,7,56]. This may imply that the island arc has a continental basement.

Some authors (e.g., [10,34]) have treated the Sukhothai Terrane as part of the Shan-Thai (Sibumasu) Terrane. However, Permian marine faunas of the Sukhothai Terrane (e.g., [17,74,79]) are of warm-water Tethyan type and show no linkage with Sibumasu of Gondwanan origin.

4.2. Chanthaburi Terrane (new name)

The Chanthaburi Terrane introduced here is defined as the southern extension of the Sukhothai Terrane (Fig. 1). The name is after the Chanthaburi Pluton, which constitutes the core of this magmatic arc terrane. In East Thailand, the whole area west of the Sra Kaeo Suture was previously considered to belong to the Sibumasu Terrane (e.g., [10,34,52]). However, this area is defined as largely being the Chanthaburi Terrane, a magmatic arc of Indochina. The eastern boundary of the Chanthaburi Terrane is marked by the Sra Kaeo Suture, and the western boundary with the southern Inthanon Suture Zone is drawn by the Klaeng Fault. The Cambodian portion of the Chanthaburi Terrane is not clearly definable, but, together with the Sra Kaeo Suture, it likely extends to Cambodia, as mentioned earlier.

The tectonic correlation with the Sukhothai Terrane to the north is supported chiefly by the distribution of Permian to Triassic I-type granitoids, that is, the Eastern Granitoid Province (see later discussion in §7, Granitoid Emplacement). For example, the Chanthaburi Pluton yields I-type granitoids of $^{40}Ar/^{39}Ar$ (ca. 210 Ma) age [14], suggesting the fact that magmatism of the Chanthaburi arc was active until the very Late Triassic.

4.3. Lincang Terrane

The Lincang Terrane in Yunnan is defined as the northern extension of the Sukhothai Terrane (Fig. 1). Such correlation has been suggested by some authors (e.g., [7,48,82]), although the tectonic interpretations differ from author to author. The term Lincang Terrane is used after Liu et al. [47], and a core part of the terrane is referred to the so-called Lincang Batholith. This terrane has been variously called, for example, the Lincang Arc Terrane [46] or the Lincang Massif [70].

The Lincang Batholith has been commonly interpreted to be of magmatic arc origin [e.g. 7,46,82]. Rb/Sr isotopic ages on Lincang granitoids range between 280 and 210 Ma [16], that is, from Early Permian to Late Triassic. This range closely fits with that (280–200 Ma) of the Eastern Granitoid Province of Cobbing et al. [18], supporting the current inclusion of the Lincang Terrane to the Sukhothai Arc.

5. Indochina Terrane

The Indochina Terrane is the most substantial tectonic block in Southeast Asia. Nevertheless, recent studies reveal that Indochina may be a composite terrane including micro-terranes, metamorphic complexes, possible sutures, and mylonitic fault zones [44]. The Truong Son Belt and the Kontum Massif occupy much of central Vietnam to eastern Laos. They are sites of Early Triassic ductile deformation and high-temperature metamorphism, which may have been caused by the collision between South China and Indochina [44,45,50].

The Simao block occupies a narrow triangle region in western Yunnan to northern Laos. It was interpreted by some authors [52,81] as being separated from the South China and Indochina terranes by the Ailaoshan Suture and the Nan Suture possibly connected along the Dien Bien Phu Fault. However, the Dien Bien Phu Fault does not seem to be the substantive boundary between the Simao block and the Indochina Terrane. This fault is one of the most seismically active zones in Indochina today [88]. It does not show evidence of pre-Cenozoic activity, and there is no evidence of tectonic collision along this fault zone. Correlation between the Ailaoshan suture and the Nan sutures via the Dien Bien Phu Fault is unlikely. We here suggest that the Simao block is more likely a semi-detached portion of the Indochina Terrane, here renamed ‘‘the Simao Subterrane’’ (Fig. 1).

6. Chronostratigraphic comparison between the two parallel sutures

As outlined earlier, two tectonic sutures of contrasting stratigraphic records are apparent, that is, the Palaeo-Tethys Suture Zone in the west and the back-arc

suture in the east. Chronostratigraphic ranges of deep-sea sediments recovered from these two sutures are summarised below and in Fig. 2.

Both the Changning–Menglian and Inthanon suture zones reveal similar age ranges of deep-sea environments from the early Middle Devonian through to the Late Triassic. Of them, the early Middle Devonian beds (the Lalei Formation in Yunnan) and the Late Triassic beds (the Mae Sariang Group in NW Thailand) are not assignable to proper pelagic sediments, because they show rather proximal facies to continental sources. Thus, unequivocal pelagic deposits are confined to an age range of late Middle Devonian (Givetian) to late Middle Triassic (Ladinian) (Fig. 2). This is a plausible age span of the Palaeo-Tethys Ocean that existed between the Indochina Terrane and the Sibumasu Terrane.

Facies change from early to late Middle Devonian sediments of the Changning–Menglian Suture Zone suggests that the rifting and initial spreading of the Palaeo-Tethys already started in the early Middle Devonian and its fuller oceanic stage commenced from the late Middle Devonian. The Mae Sariang Group shows typical pre- to syn-orogenic successions [69], suggesting that closure of the Palaeo-Tethys was already in progress in the Middle Triassic.

In contrast to the Palaeo-Tethys Suture Zone, a relatively minor mélange zone along the Jinghong, Nan, and Sra Kaeo local sutures yields much shorter records of deep-sea sedimentation. The Jinghong Suture reveals deep-sea environment of the late Early Permian up to Latest Permian (Early Changhsingian). The Nan Suture provides only late Middle Permian chert as deep-sea evidence. The Sra Kaeo Suture preserves deep-sea records spanning from the Sakmarian to the Wuchiapingian (Early to early Late Permian). In summary, overall deep-sea records of the Jinghong–Nan–Sra Kaeo suture are limited to the Permian, with a maximum age span from the Sakmarian to the Early Changhsingian (Fig. 2). This means that some part of the back-arc basin (e.g., Sra Kaeo) already gained a substantial depth in the Sakmarian. This further implies the probability that the initial back-arc rifting and opening already occurred in the Asselian (Earliest Permian) or even earlier. This Early Permian opening correlates well with the earliest magmatic age (280 Ma, middle Early Permian) recorded for the Sukhothai island-arc system (as in the Lincang Batholith). The Early Changhsingian marks the latest stage of deep-sea environment for the back-arc basin. Thus, it is plausible that the basin was tectonically closed before the Triassic.

From the overall chronostratigraphic ranges of deep-sea sediments in the Palaeo-Tethys Suture Zone and the Jinghong–Nan–Sra Kaeo back-arc suture, it is clear that these two former seas had contrasting age spans (Fig. 2), and should therefore be treated separately as an ocean and a marginal sea.

7. Granitoid emplacement

The tectonic feature of the parallel sutures with the island arc between fits well with the observed two granitoid provinces of contrasting geochemical characters, that is, the Main-Range Province and the Eastern Province (Fig. 3), originally recognised by Cobbing et al. [18]. These two granitoid provinces are also characterised by having distinct age ranges of their pre-Cretaceous plutonic activities.

The Main-Range Province consists mainly of S-type granitoids, whose ages range from early Late Triassic to late Early Jurassic (ca. 230–180 Ma) [14,18,41]. The petrogenesis of those S-type granitoids is explained by partial melting of the Sibumasu crust subducted beneath the Palaeo-Tethys accretionary complex [37,53]. This explains that the distribution of Main-Range granitoids overlaps the Palaeo-Tethys Suture Zone (Fig. 3). Thus, the granitoids are interpreted as orogenic and due to the collision of Sibumasu to the Sukhothai Arc. The earliest magmatic age (230 Ma) implies that the collisional orogeny (crustal thickening) started in or prior to the early Late Triassic. This appears consistent with the suggested late Middle Triassic closure of the Palaeo-Tethys.

By contrast, the granitoids of the Eastern Province are chiefly I type, and thus are regarded of magmatic arc origin [18,37,41,53]. The magmatism is considered to have been induced by the eastward subduction of the Palaeo-Tethys beneath the margin of Indochina [53,71]. These granitoids range from Early Permian to Latest Triassic in age (ca. 280–200 Ma), with occasional Cretaceous intrusions [14,18,41], the main period indicating the likely life span of the Sukhothai Arc magmatism. In summary, the collision of Sibumasu involved two plutonic episodes, that is, the initiation of Main-Range orogenic magmatism in the early Late Triassic and the cessation of the Sukhothai Arc magmatism at the end of the Triassic.

Meantime, the Eastern Province of Cobbing et al. [18] originally included the Loei-Phetchabun Volcanic Belt of the western Indochina Terrane. This volcanic belt was previously considered by Bunopas [10] to be a Permo-Triassic magmatic arc induced by the eastward subduction of the Nan–Sra Kaeo Sea. However, it is

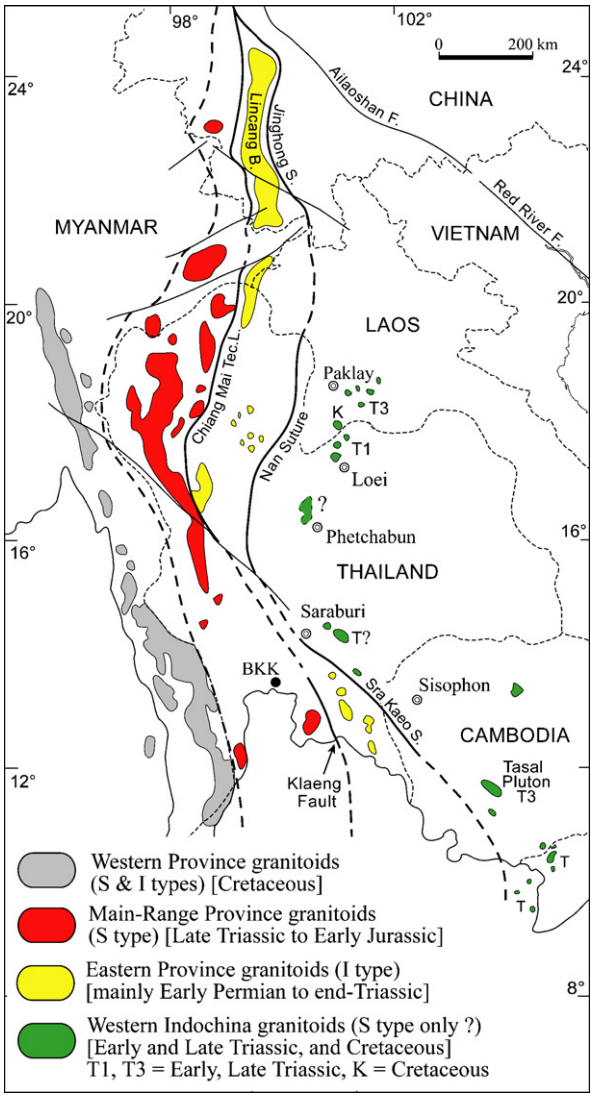

Fig. 3. Revised classification of granitoid provinces in mainland SE Asia (modified from [18]). Inferred provincial boundary indicated by dashed line.

Fig. 3. Classification révisée des provinces granitiques de l'Asie du Sud-Est (d'après [18], modifié).

here noted that there is no clear evidence of such east-dipping subduction and resultant arc magmatism. No isotopic data of Permo-Triassic I-type granitoids is available from the same volcanic belt. Moreover, some igneous rocks in this volcanic belt are now confirmed much older (Devonian) or younger (Cenozoic) [38,39].

Some granodiorites from the Paklay Volcanics in Laos, which is the northern extension of the Loei-Phetchabun Volcanic Belt, are Triassic in age [77]. Even Late Triassic and Cretaceous granites were reported from the Paklay Volcanics by Stokes [68]. In addition, granites of the Tasal Pluton in central Cambodia (Fig. 3), which may be relevant to the Loei-Phetchabun Volcanic Belt, are Late Triassic in age, and show S-type affinity [43]. Thus, so-called Permo-Triassic granitoids of the Loei-Phetchabun Volcanic Belt are supposed to be mostly Mesozoic in age. Their genesis is here interpreted to be related to the crustal thickening of western Indochina induced by back-arc compression and enhanced later by the Sibumasu collision. Therefore, subduction-induced arc magmatism for the Loei-Phetchabun Volcanic Belt is unlikely. The Eastern Province is here revised to consist only of the Sukhothai Arc granitoids delimited to the west of the Jinghong–Nan–Sra Kaeo back-arc suture and to exclude those in the Indochina Terrane (Fig. 3).

8. Tectonic evolution: brief summary

A new tectonic scenario is here proposed incorporating the two parallel sutures (Fig. 4). In the margin of Gondwana, rifting and initial spreading of the Palaeo-Tethys started by the Middle Devonian, and its fuller oceanic stage started from the late Middle Devonian (Givetian). It probably gained its greatest oceanic width during the Carboniferous.

Subduction of the Palaeo-Tethys oceanic floor beneath Indochina likely started in the Latest Carboniferous or very Early Permian. As a result, arc magmatism started along the margin of the Indochina Terrane. The Jinghong–Nan–Sra Kaeo back-arc Basin probably started to open as early as the Asselian (Earliest Permian), and the Sukhothai island-arc system emerged. The back-arc basin already gained a substantial depth by the Sakmarian (in Sra Kaeo). Back-arc opening further proceeded during the Early Permian. An extensive carbonate platform (e.g., Saraburi and Sisophon limestones in Thailand and Cambodia) developed over the western Indochina Terrane inboard of the back-arc basin from Early to late Middle Permian.

The back-arc basin started to collapse in the Middle to Late Permian, and, in the Nan back-arc basin, the short-term west-dipping subduction took place and formed the narrow Pha Som Metamorphic Complex. The entire back-arc basin was probably closed and uplifted by the end of the Permian, leaving ophiolitic mélanges in the Jinghong, Nan, and Sra Kaeo local sutures. The carbonate platform of western Indochina was uplifted in the Late Permian. Thus, the Late

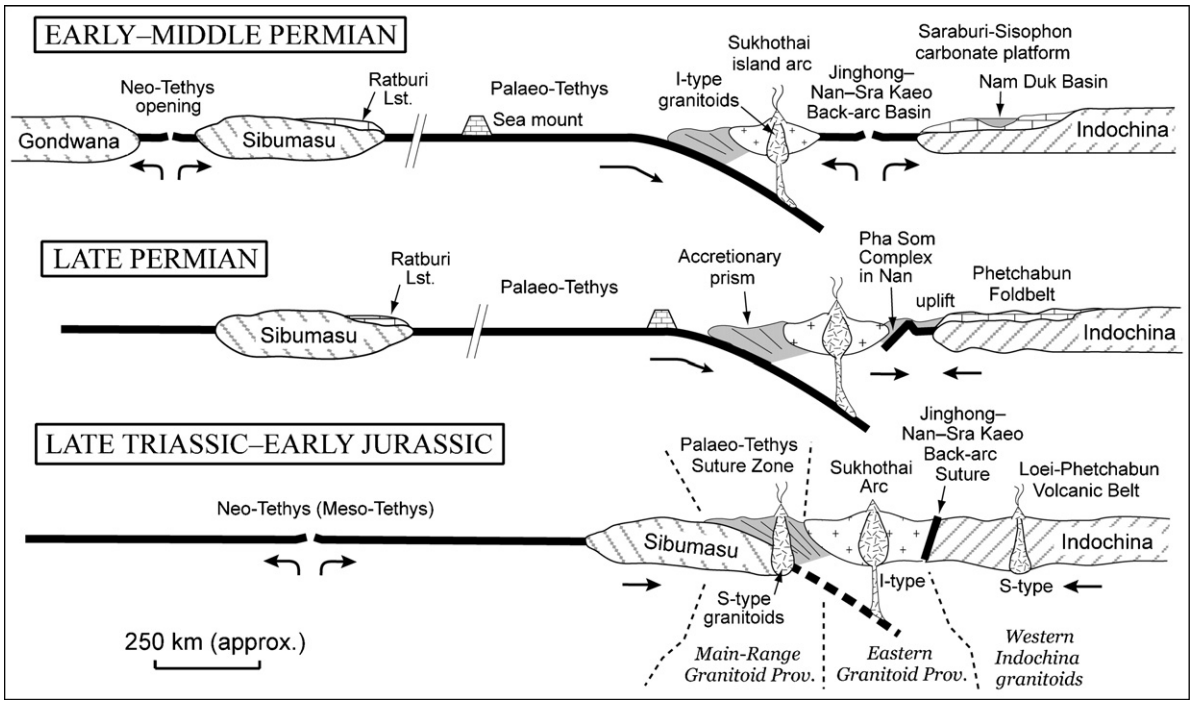

Fig. 4. Tectonic evolution of mainland SE Asia during the Permian to Early Jurassic, with respect to the formations of the Palaeo-Tethys Suture Zone and the Jinghong–Nan–Sra Kaeo back-arc Basin suture. Vertical scale arbitrarily exaggerated.

Fig. 4. Évolution tectonique de l'Asie du Sud-Est, du Permien au début du Jurassique, en considérant la formation de la suture de la Paléotéthys et celle du bassin arrière-arc Jinghong–Nan-Sra Kaeo. L'échelle verticale est exagérée.

Permian was the main phase of back-arc compression. Consequently, the Sukhothai island-arc system was amalgamated to marginal Indochina.

In the Early–Middle Triassic, the Palaeo-Tethys subduction beneath the continental Sukhothai Arc continued. Seamounts carrying Carboniferous–Permian limestone caps were accreted over the subduction zone. In the Triassic, orogenic plutonism after the back-arc collapse occurred in the western Indochina Terrane (e.g., Pak Lay to Loei areas).

By the early Late Triassic, the Sibumasu Terrane (including the Baoshan and Tenchong blocks) collided with the continental Sukhothai Arc of western Indochina. Thus, the Palaeo-Tethys Ocean was closed, forming the extensive accretionary prism of the Palaeo-Tethys Suture Zone upon the subducted part of Sibumasu. Some syn-orogenic sedimentation remained in a remnant fore-deep basin (Mae Sariang Group) during the Late Triassic. From the early Late Triassic, plutonism in the Main-Range Province started, stitching the Palaeo-Tethys Suture Zone as a consequence of collisional crustal thickening. In concert, the Sukhothai Arc ceased magmatism by the end of the Triassic, as a consequence of the termination of the Palaeo-Tethys subduction.

9. Conclusions and implications for the timing of the Indosinian orogeny

- The Sukhothai Terrane is not part of the Sibumasu (or Shan-Thai) Terrane, but forms part of a former island arc marginal to the Indochina Terrane.
- The Changning–Menglian Suture and the Inthanon Suture represent the Palaeo-Tethys Suture Zone in Yunnan and Thailand.
- The Jinghong, Nan, and Sra Kaeo sutures do not represent the Palaeo-Tethys Suture, but rather a closed Permian back-arc basin behind the Sukhothai island-arc system.
- Permo-Triassic double subduction zones in the Nan Suture suggested by Bunopas [10] are highly unlikely, and the so-called Loei-Petchabun magmatic arc is unsubstantiated.
- The Nan Suture is unlikely to correlate with the Ailaoshan Suture.
- The Jinghong–Nan–Sra Kaeo back-arc Basin closed at about the end of the Permian.
- The Palaeo-Tethys Ocean closed as Sibumasu collided with the continental Sukhothai Arc of Indochina in the late Middle Triassic–early Late Triassic (post-Anisian).

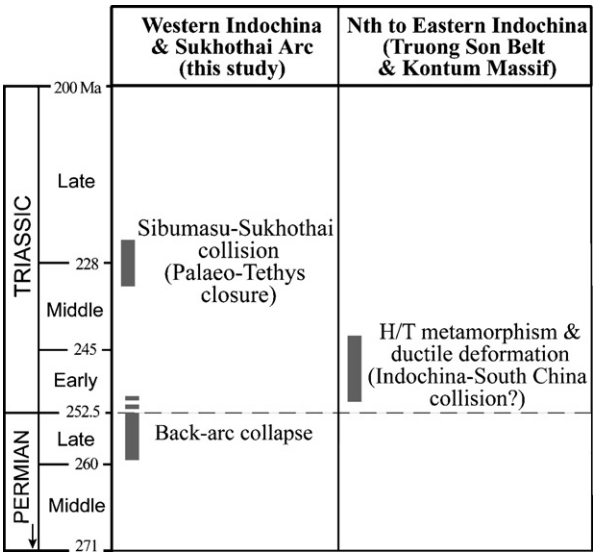

Fig. 5. Chronological comparison chart of Indosinian tectonic events between the Sukhothai Arc/western Indochina (this study) and northern to eastern Indochina (previous studies noted in text).

Fig. 5. Comparaison chronologique des événements tectoniques d'âge Indosinien dans l'Ouest indochinois (cette étude) et dans les parties nord et est de l'Indochine (études antérieures).

Are the end-Permian and mid-Triassic suturing events described in this paper (Fig. 5) related to the so-called Indosinian orogeny? Two peaks of folding episodes recognised in Indochina by Fontaine and Workman [33] have often been linked with the Indosinian orogeny, that is, Indosinian I (latest Permian–Early Triassic) and Indosinian II (Late Triassic). Helmcke and Lindenberg [36] then recognised two correlatable tectonic phases in central and northern Thailand, that is, Middle–Late Permian deformation in the Phetchabun Foldbelt and Late Triassic deformation in the Sukhothai Foldbelt. These two phases can be more or less correlated with the two suturing events recognised in this study. It is here proposed that the Late Permian deformation in the Phetchabun Foldbelt is related to the closure of the Jinghong–Nan–Sra Kaeo back-arc Basin and that the Late Triassic deformation in the Sukhothai Arc/Foldbelt is due to the collision of Sibumasu.

Further to the east, Early–early Middle Triassic thermotectonism (ca. 250–240 Ma) of the Truong Son Belt and the Kontum Massif in Vietnam was recently advocated by several authors [13,44,50,59] to correspond with the Indosinian orogeny. Some [44,50] interpreted this to be related with the South China–Indochina collision, and it seems plausible. Carter et al. [13], on the other hand, proposed that it was affected by collision of Sibumasu–Indochina. However, the present study indicates that the Sibumasu collision with Indochina must have been younger than the Vietnamese event (Fig. 5). Instead, the end-Permian collapse of the Jinghong–Nan–Sra Kaeo back-arc Basin appears temporally closer. It is still an open question as to whether the Indosinian orogeny was a result of a single or multiple collisional episodes, but we favour the latter.

Acknowledgements

H. Fontaine, P. Chaodumrong, S. Salyapongse, C. Chonglakmani, K. Malila, Q. Feng, K. Ueno, and T. Kurihara are thanked for providing valuable information and having rewarding discussion. Constructive reviews from C. Lepvrier and an anonymous referee have improved the manuscript. The bulk of the work presented here was undertaken whilst Sone was a PhD candidate at the University of New England.

References

[1] A.J. Barber, Interpretations of the tectonic environment of Southwest Japan, Proc. Geol. Assoc. 93 (1982) 131–145.
[2] S.M. Barr, A.S. Macdonald, Nan River suture zone, northern Thailand, Geology 15 (1987) 907–910.
[3] S.M. Barr, A.S. Macdonald, Toward a Late Palaeozoic–Early Mesozoic tectonic model for Thailand, J. Thai Geosci. 1 (1991) 11–22.
[4] S.M. Barr, A.S. Macdonald, P. Ounchanum, M.A. Hamilton, Age, tectonic setting and regional implications of the Chiang Khong volcanic suite, northern Thailand, J. Geol. Soc., Lond. 163 (2006) 1037–1046.
[5] S.M. Barr, A.S. Macdonald, W. Yaowanoiyothin, Y. Panjasawatwong, Occurrence of blueschist in the Nan River mafic-ultramafic belt, northern Thailand, Warta Geol. 11 (1985) 47–50.
[6] S.M. Barr, C. Tantisukrit, W. Yaowanoiyothin, A.S. Macdonald, Petrology and tectonic implications of Upper Paleozoic volcanic rocks of the Chiang Mai belt, northern Thailand, J. Southeast Asian Earth Sci. 4 (1990) 37–47.
[7] S.M. Barr, W. Yaowanoiyothin, A.S. Macdonald, G.R. Dunning, P. Ounchanum, Petrochemistry, U-Pb (zircon) age, and palaeotectonic setting of the Lampang volcanic belt, northern Thailand, J. Geol. Soc., Lond. 157 (2000) 553–563.
[8] Bureau of Geology and Mineral Resources of Yunnan, Regional Geology of the Yunnan Province, Geological Memoirs Series 21 (1) (1990) (in Chinese).
[9] M.E. Brookfield, Paleozoic and Triassic geology of Sundaland, in : M. Moullade, A.E.M. Nairn (Eds.), The Phanerozoic Geology of the World I: The Palaeozoic, B, Elsevier, Amsterdam, 1996, pp. 181–264.
[10] S. Bunopas, Paleogeographic History of western Thailand and adjacent parts of Southeast Asia: A Plate Tectonics Interpretation, Geological Survey Paper No. 5, Department of Mineral Resources Thailand, Bangkok, 1982.
[11] M. Caridroit, Permian Radiolaria from NW Thailand, in : T. Thanasuthipitak (Ed.), Proceedings of the International

Symposium on Biostratigraphy of Mainland Southeast Asia: Facies and Paleontology, Chiang Mai University, Chiang Mai, Thailand, 1993, pp. 83–96.

[12] M. Caridroit, D. Bohlke, A. Lumjuan, D. Helmcke, P. DeWever, A mixed radiolarian fauna (Permian/Triassic) from clastics of the Mae Sariang area, northwestern Thailand, in : T. Thanasuthipitak (Ed.), Proceedings of the International Symposium on Biostratigraphy of Mainland Southeast Asia: Facies and Paleontology, Chiang Mai University, Chiang Mai, Thailand, 1993, pp. 401–413.

[13] A. Carter, D. Roques, C. Bristow, P. Kinny, Understanding Mesozoic accretion in Southeast Asia: Significance of Triassic thermotectonism (Indosinian orogeny) in Vietnam, Geology 29 (2001) 211–214.

[14] P. Charusiri, B. Charusiri, A.H. Clark, E. Farrar, D. Archibald, Granite belts in Thailand: evidence from the $^{40}Ar/^{39}Ar$ geochronological and geological syntheses, J. Southeast Asian Earth Sci. 8 (1993) 127–136.

[15] H. Chen, J. Dobson, F. Heller, J. Hao, Paleomagnetic evidence for clockwise rotation of the Simao region since the Cretaceous: a consequence of India-Asia collision, Earth Planet. Sci. Lett. 134 (1995) 203–217.

[16] J. Cheng, Discussion on the age division and the reliability of isotopic age determination for granitic rock in western Yunnan, Yunnan Geol. 6 ((1987)) 101–111 (in Chinese, with English abstract).

[17] C. Chonglakmani, K. Intarawijitr, The Permian and Triassic sequences of Kiu Lom Dam area and its vicinities, northern Thailand, in : P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak, J. Tulyatid (Eds.), Proceedings of the International Symposium on Stratigraphic Correlation of Southeast Asia, Department of Mineral Resources, Bangkok, Thailand, 1994, p. 131.

[18] E.J. Cobbing, D.I.J. Mallick, E.J. Pitfield, L.H. Teoh, The granites of the Southeast Asian tin belt, J. Geol. Soc., Lond. 143 (1986) 537–550.

[19] E.J. Cobbing, P.E.J. Pitfield, D.P.F. Darbyshire, D.I.J. Mallick, The Granites of the South-East Asian Tin Belt, Overseas Memoir of the British Geological Survey No. 10, British Geological Survey, London, 1992.

[20] B. Cong, M. Zhai, Chapter 3.1 Metamorphic petrology and metamorphism in western Yunnan, in : D. Zhong (Ed.), Paleotethysides in West Yunnan and Sichuan, China, Science Press, Beijing, 2000, pp. 26–38.

[21] N. Fang, B. Liu, Q. Feng, J. Jia, Late Palaeozoic and Triassic deep-water deposits and tectonic evolution of the Palaeotethys in the Changning-Menglian and Lancangjiang belts, southwestern Yunnan, J. Southeast Asian Earth Sci. 9 (1994) 363–374.

[22] Q. Feng, Stratigraphy of volcanic rocks in the Changning-Menglian Belt in southwestern Yunnan, China, J. Asian Earth Sci. 20 (2002) 657–664.

[23] Q. Feng, C. Chonglakmani, D. Helmcke, R. Ingavat-Helmcke, B. Liu, Middle Triassic radiolarian fauna from Lamphun, northern Thailand, in : N. Mantajit (Ed.), Proceedings of the Symposium on Geology of Thailand, Department of Mineral Resources, Bangkok, 2002, pp. 108–116.

[24] Q. Feng, N. Fang, B. Liu, Regional stratigraphy study of the Changning-Menglian and southern Lancangjiang belts, in : X. Long (Ed.), Devonian to Triassic Tethys in Western Yunnan, China, China University of Geosciences Press, Wuhan, 1996, pp. 23–29.

[25] Q. Feng, B. Liu, A new Early Devonian radiolarian genus from western Yunnan, Sci. China Ser. B 36 (1993) 242–248 (in Chinese, with English abstract).

[26] Q. Feng, B. Liu, Permian radiolarians on Southwest Yunnan, Earth Sci. – J. China Univ. Geosci. 18 (1993) 553–564 (in Chinese, with English abstract).

[27] Q. Feng, S. Shen, B. Liu, D. Helmcke, X. Qian, W. Zhang, Permian radiolarians, chert and basalt from the Daxinshan Formation in Lancangjiang belt of southwestern Yunnan, China, Sci. China Ser. D: Earth Sci. 45 (2002) 63–71 (in Chinese, with English abstract).

[28] Q. Feng, M. Ye, Radiolarian stratigraphy of Devonian through Middle Triassic in southwestern Yunnan, in : X. Long (Ed.), Devonian to Triassic Tethys in Western Yunnan, China, China University of Geosciences Press, Wuhan, 1996, pp. 15–22.

[29] Q. Feng, B. Zhang, B. Liu, S. Shen, W. Zhang, S. Zhang, Radiolarian fauna from the Longdonghe Formation at the western margin of the Simao Massif and its geological significance, J. Stratigr. 24 (2000) 126–128 (in Chinese, with English abstract).

[30] Q. Feng, Z. Zhang, Early Carboniferous radiolarians from West Yunnan, Acta Micropalaeontol. Sin. 14 (1997) 79–92 (in Chinese, with English abstract).

[31] Q. Feng, Z. Zhang, M. Ye, Middle Triassic radiolarian fauna from Southwest Yunnan, China, Micropaleontology 47 (2001) 173–204.

[32] H. Fontaine, V. Suteethorn, D. Vachard, Carboniferous and Permiam limestones in the Sop Pong area: unexpected lithology and fossils, in : T. Thanasuthipitak (Ed.), Proceedings of the International Symposium on Biostratigraphy of Mainland Southeast Asia: Facies & Pleontology, Chiang Mai, (1993), pp. 319–336.

[33] H. Fontaine, D.R. Workman, Review of the geology and mineral resources of Kampuchea, Laos and Vietnam, in : P. Nutalaya (Ed.), Proceedings of the Third Regional Conference on Geology and Mineral Resources of Southeast Asia, Asian Institute of Technology, Bangkok, 1978, pp. 541–603.

[34] S. Hada, S. Bunopas, K. Ishii, S. Yoshikura, Rift-drift history and the amalgamation of Shan-Thai and Indochina/East Malaya blocks, in : I. Metcalfe, J. Ren, J. Charvet, S. Hada (Eds.), Gondwana Dispersion and Asian Accretion, A.A. Balkema, Rotterdam, 1999, pp. 67–87.

[35] F. He, B. Liu, Recognition of ancient oceanic island in Paleo-Tethys, western Yunnan, J. China Univ. Geosci. 4 (1993) 23–29.

[36] D. Helmcke, H.G. Lindenberg, New data on the 'Indosinian' Orogeny from Central Thailand, Geol. Rundsch. 72 (1983) 317–328.

[37] C.S. Hutchison, Geological Evolution of South-East Asia, Oxford University Press, Oxford, UK, 1989.

[38] S. Intasopa, T. Dunn, Petrology and Sr-Nd isotope systems of the basalts and rhyolites, Loei, Thailand, J. Southeast Asian Earth Sci. 9 (1994) 167–180.

[39] S. Intasopa, T. Dunn, R.S. Lambert, Geochemistry of Cenozoic basaltic and silicic magmas in the central Portion of the Loei-Phetchabun volcanic belt, Lop Buri, Thailand, Can. J. Earth Sci. 32 (1995) 393–409.

[40] Y. Kamata, K. Hisada, N. Nakornsri, P. Charusiri, K. Sashida, K. Ueno, Triassic radiolarian faunas from the Mae Sariang area, northern Thailand and their paleogeographic significance, J. Asian Earth Sci. 20 (2002) 491–506.

[41] R. Krähenbuhl, Magmatism, tin mineralization and tectonics of the Main Range, Malaysian Peninsula: consequences for the

plate tectonic model of Southeast Asia based on Rb–Sr, K–Ar and fission track data, Bull. Geol. Soc. Malaysia 29 (1991) 1–100.

[42] R. Lacassin, H. Maluski, P.-H. Leloup, P. Tapponnier, C. Hinthong, K. Siribhakdi, S. Chuaviroj, A. Charoenravat, Tertiary diachronic extrusion and deformation of western Indochina: structural and $^{40}Ar/^{39}Ar$ evidence from NW Thailand, J. Geophys. Res. 102 (1997) 10013–10037.

[43] M. Lasserre, J. Cheymol, J. Peetot, E. Saurin, Géologie, chimie et géochronologie du granite de Tasal (Cambodge occidental): précisions apportés par la méthode au strontium sur l'âge du massif et sur celui de son environnement, Bull. Bureau de Recherches Géologiques et Minières 4 (2) (1970) 5–13 (Section II. Géologie appliquée).

[44] C. Lepvrier, H. Maluski, V.T. Vu, A. Leyreloup, T.T. Phan, V.V. Nguyen, The Early Triassic Indosinian orogeny in Vietnam (Truong Son Belt and Kontum Massif); implications on the geodynamic evolution of Indochina, Tectonophysics 393 (2004) 87–118.

[45] C. Lepvrier, H. Maluski, N.V. Vuong, D. Roques, V. Axente, C. Rangin, Indosinian NW-trending shear zones within the Truong Son belt (Vietnam) $^{40}Ar–^{39}Ar$ Triassic ages and Cretaceous to Cenozoic overprints, Tectonophysics 283 (1997) 105–127.

[46] J. Li, Tectonic evolution of the Three-River Belt in western Yunnan, Sci. Geol. Sin. 4 (1988) 337–346 (in Chinese, with English abstract).

[47] B. Liu, Q. Feng, N. Fang, Tectonic evolution of the Palaeo-Tethys in Changning-Menglian belt and adjacent regions, western Yunnan, J. China Univ. Geosci. 2 (1991) 18–28 (in Chinese, with English abstract).

[48] B. Liu, Q. Feng, N. Fang, J. Jia, F. He, W. Yang, D. Liu, Tectono-paleogeographic framework and evolution of the Paleotethyan Archipelagos Ocean in western Yunnan, China, in : X. Long (Ed.), Devonian to Triassic Tethys in Western Yunnan, China, China University of Geosciences Press, Wuhan, 1996, pp. 1–12.

[49] S. Lüddecke, C. Chonglakmani, D. Helmke, Analysis of pebble associations from the marine Triassic of northern Thailand, J. Thai Geosci. 2 (1991) 91–101.

[50] H. Maluski, C. Lepvrier, A. Leyreloup, V.T. Vu, T.T. Phan, ^{40}Ar-^{39}Ar geochronology of the charnockites and granulites of the Kan Nack complex, Kon Tum Massif, Vietnam, J. Asian Earth Sci. 25 (2005) 653–677.

[51] I. Metcalfe, Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys, Aust. J. Earth Sci. 43 (1996) 605–623.

[52] I. Metcalfe, Permian tectonic framework and palaeogeography of SE Asia, J. Asian Earth Sci. 20 (2002) 551–566.

[53] A.H.G. Mitchell, Tectonic setting for emplacement of Southeast Asian tin granites, Bull. Geol. Soc. Malaysia 9 (1977) 123–140.

[54] A. Miyashiro, Paired and unpaired metamorphic belts, Tectonophysics 17 (1973) 241–251.

[55] C. Monnier, J. Girardeau, R.C. Maury, J. Cotten, Back-arc basin origin for the East Sulawesi ophiolite (eastern Indonesia), Geology 23 (1995) 851–854.

[56] Y. Panjasawatwong, B. Phajuy, S. Hada, Tectonic setting of the Permo-Triassic Chiang Khong volcanic rocks, northern Thailand based on petrochemical characteristics, Gondwana Res. 6 (2003) 743–755.

[57] B. Phajuy, Y. Panjasawatwong, P. Osataporn, Preliminary geochemical study of volcanic rocks in the Pang Mayao area, Phrao, Chiang Mai, northern Thailand: tectonic setting of formation, J. Asian Earth Sci. 24 (2005) 765–776.

[58] L.E. Ricou, Tethys reconstructed: plates, continental fragments and their boundaries since 260 Ma from Central America to South-eastern Asia, Geodin. Acta 7 (1994) 169–218.

[59] F. Roger, H. Maluski, A. Leyreloup, C. Lepvrier, P. Truong Thi, U-Pb dating of high temperature metamorphic episodes in the Kon Tum Massif (Vietnam), J. Asian Earth Sci. 30 (2007) 565–572.

[60] K. Sashida, S. Adachi, H. Igo, N. Nakornsri, A. Ampornmaha, Middle to Upper Permian and Middle Triassic radiolarians from eastern Thailand, Sci. Rep. Univ. Tsukuba Inst. Geosci., Sect. B: Geol. Sci. 18 (1997) 1–17.

[61] K. Sashida, H. Igo, S. Adachi, K. Ueno, Y. Kajiwara, N. Nakornsri, A. Sardsud, Late Permian to Middle Triassic radiolarian faunas from northern Thailand, J. Paleontol. 74 (2000) 789–811.

[62] K. Sashida, H. Igo, K. Hisada, N. Nakornsri, A. Ampornmaha, Occurrence of Paleozoic and Early Mesozoic Radiolaria in Thailand (preliminary report), J. Southeast Asian Earth Sci. 8 (1993) 97–108.

[63] K. Sashida, S. Salyapongse, N. Nakornsri, Latest Permian radiolarian fauna from Klaeng, eastern Thailand, Micropaleontology 46 (2000) 245–263.

[64] K. Sashida, K. Ueno, N. Nakornsri, P. Charusiri, Middle Triassic radiolarians from the Kanchanaburi area, western Thailand and its significance (preliminary report), Palaeontological Society of Japan, Annual Meeting 1998, Abstracts, 1998, p.112.

[65] S. Singharajwarapan, Provenance of sandstone in the Triassic Nam Pat Group, northern Thailand, in : B. Ratanasthien, S.L. Rieb (Eds.), Proceedings of the International Symposium on Shallow Tethys 5, Department of Geological Science, Chiang Mai University, Chiang Mai, 1999, pp. 465–480.

[66] S. Singharajwarapan, R.F. Berry, Structural analysis of the accretionary complex in Sirikit Dam area, Uttaradit, northern Thailand, J. Southeast Asian Earth Sci. 8 (1993) 233–245.

[67] S. Singharajwarapan, R.F. Berry, Tectonic implications of the Nan Suture Zone and its relationship to the Sukhothai Fold Belt, northern Thailand, J. Asian Earth Sci. 18 (2000) 663–673.

[68] R.B. Stokes, P.F.L. Smith, K. Soumphonphakdy, Timing of the Shan-Thai-Indochina collision: new evidence from the Pak Lay Foldbelt of the Lao PDR, in : R. Hall (Ed.), Tectonic Evolution of Southeast Asia, Geological Society of London, London, 1996, pp. 225–232.

[69] T. Tofke, A. Lumjuan, D. Helmcke, Triassic syn-orogenic siliciclastics from the area of Mae Sariang, (northwestern Thailand), in : T. Thanasuthipitak (Ed.), Proc. International Symposium on Biostratigraphy of Mainland Southeast Asia: Facies and Paleontology, Chiang Mai University, Chiang Mai, Thailand, 1993, pp. 391–400.

[70] K. Ueno, Gondwana/Tethys divide in East Asia: solution from Late Paleozoic foraminiferal paleobiogeography, in : B. Ratanasthien, S.L. Rieb (Eds.), Proceedings of the International Symposium on Shallow Tethys 5, Department of Geological Science, Chiang Mai University, Chiang Mai, Thailand, 1999, pp. 45–54.

[71] K. Ueno, K. Hisada, Closure of the Paleo-Tethys caused by the collision of Indochina and Sibumasu, Chikyu Monthly 21 (1999) 832–839 (in Japanese).

[72] K. Ueno, K. Hisada, The Nan-Uttaradit-Sa Kaeo Suture as a main Paleo-Tethyan suture in Thailand: Is it real? Gondwana Res. 4 (2001) 804–805.

[73] K. Ueno, H. Igo, Late Paleozoic foraminifers from the Chiang Dao area, northern Thailand, in : M. Podemski, S. Dybova-

Jachowicz, K. Ratanasthien, R. Wagner (Eds.), Proc. 13th International Congress on the Carboniferous and Permian, Warsaw, 1997, pp. 339–354.

[74] K. Ueno, S. Sakagami, Late Permian fusulinacean fauna of Doi Pha Phlung, North Thailand, Trans. Proc. Palaeontol. Soc. Jpn. New Ser. 164 (1991) 928–943.

[75] K. Ueno, Y. Wang, X. Wang, Fusulinoidean faunal succession of a Paleo-Tethyan oceanic seamount in the Changning–Menglian Belt, West Yunnan, Southwest China: An overview, The Island Arc 12 (2003) 145–161.

[76] D. Vachard, H. Fontaine, M. Caridroit, Foraminifera, algae and pseudo-algae from Carboniferous and Permian limestones of Northwest Thailand, Rev. Paleobiol. 11 (1992) 137–147.

[77] E. von Braun, C. Besang, W. Eberle, W. Harre, H. Kreuzer, H. Lenz, P. Muller, I. Wendt, Radiometric age determinations of granites in northern Thailand, Geol. Jahrb. (Reihe B Regionale Geologie Ausland) 21 (1976) 171–204.

[78] X. Wang, I. Metcalfe, P. Jian, L. He, C. Wang, The Jinshajiang-Ailaoshan Suture Zone, China: tectonostratigraphy, age and evolution, J. Asian Earth Sci. 18 (2000) 675–690.

[79] J.B. Waterhouse, A Late Permian lyttoniid fauna from Northwest Thailand, Papers of Department of Geology, University of Queensland, 10 (1983) 111–153.

[80] N. Wonganan, M. Caridroit, Middle and Upper Devonian radiolarian faunas from Chiang Dao area, Chiang Mai province, northern Thailand, Micropaleontology 51 (2005) 39–57.

[81] H. Wu, C.A. Boulter, B. Ke, D.A.V. Stow, Z. Wang, The Changning–Menglian suture zone; a segment of the major Cathaysian–Gondwana divide in Southeast Asia, Tectonophysics 242 (1995) 267–280.

[82] K. Yang, A plate reconstruction of the Eastern Tethys orogen in southwestern China, in : M.F.J. Flower, S.L. Chung, C.H. Lo, T.Y. Lee (Eds.), Mantle Dynamics and Plate Interactions in East Asia, American Geophysical Union, Washington DC, 1998, pp. 269–287.

[83] Q. Zhang, Chapter 6.1 Ophiolites, in : D. Zhong (Ed.), Paleotethysides in West Yunnan and Sichuan, China, Science Press, Beijing, 2000, pp. 112–123.

[84] Q. Zhang, D. Li, K. Zhang, Preliminary study on Tongchangjia ophiolite mélange from Yunnan Country, Yunnan Province, Acta Petrol. Sin. 1 (1985) 1–14 (in Chinese, with English abstract).

[85] R. Zhang, B. Cong, S. Maruyama, J.G. Liou, Metamorphism and tectonic evolution of the Lancang paired metamorphic belts, southwestern China, J. Metamorph. Geol. 11 (1993) 605–619.

[86] J. Zhao, D. Zhong, Y. Wang, Metamorphism of Lancang Metamorphic Belt, the western Yunnan and its relation to deformation, Acta Petrol. Sin. 10 (1994) 27–40 (in Chinese, with English abstract).

[87] D. Zhong, J. Zhao, Chapter 7.1 The Changning-Menglian tectonic belt, in : D. Zhong (Ed.), Paleotethysides in West Yunnan and Sichuan, China, Science Press, Beijing, 2000 , pp. 112–123.

[88] W. Zuchiewicz, Q.C. Nguyen, A. Bluszcz, M. Michalik, Quaternary sediments in the Dien Bien Phu fault zone, NW Vietnam: a record of young tectonic processes in the light of OSL-SAR dating results, Geomorphology 60 (2004) 269–302.