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Tectonics

Was the Indosinian orogeny a Triassic mountain building or a thermotectonic reactivation event?

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Abstract

The underlying cause of Indosinian thermotectonism remains unclear, in part because the term has also been adopted to explain Triassic orogenesis across southern China. This paper puts forward the case that use of the term Indosinian should be confined to Vietnam where deformation is linked to continental accretion as opposed to southern China where Triassic igneous activity, metamorphism and deformation are linked to the development of an active plate margin through north-directed subduction of the Pacific oceanic plate. A review of the regional palaeogeography, as well as palaeontological and thermochronological data, highlights the lack of evidence to support the Indosinian as a major mountain building event. There is no definitive evidence for Triassic collision between the Indochina and South China blocks. Preference is given to a plate tectonic model that explains the Indosinian as a reactivation event driven by accretion of Sibumasu block to Indochina. ***To cite this article: A. Carter, P.D. Clift, C. R. Geoscience 340 (2007).***

Résumé

L'orogenèse indosinienne : une chaîne de montagnes formée au Trias, ou une simple réactivation par un événement thermotectonique triasique d'une chaîne plus ancienne ? La cause de l'événement thermotectonique indosinien demeure obscure, en raison pour partie du fait que ce même terme a été adopté pour expliquer l'orogénèse triasique de Chine du Sud. Cet article met en avant le fait que l'usage de ce terme est restreint au Vietnam, où la déformation est liée à une accrétion continentale, alors qu'en Chine du Sud l'activité magmatique, le métamorphisme et la déformation sont associés au développement d'une marge continentale active, en rapport avec la subduction vers le nord de la plaque pacifique. Un examen de la paléogéographie régionale et des données paléontologiques et thermochronologiques met en lumière le manque d'arguments pour caractériser l'existence de la réelle construction d'une chaîne de montagnes majeure et d'une collision triasique entre Indochine et Chine du Sud. La préférence est accordée à un modèle tectonique qui explique l'événement indosinien comme une réactivation due à l'accrétion du bloc Sibumasu à l'Indochine. ***Pour citer cet article : A. Carter, P.D. Clift, C. R. Geoscience 340 (2007).***

Keywords: Indosinian; Vietnam; South China; Palaeogeography; Orogenesis; Subduction

Mots clés : Indosinien ; Vietnam ; Chine du Sud ; Paléogéographie ; Orogenèse ; Subduction

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1. Introduction

The concept of an Indosinian tectonic event originated from observations first made in Vietnam by Deprat [3] and Fromaget [10], but in recent years, it has expanded to include Triassic thermotectonism and magmatism in southern China, Thailand, and Laos. Application of the term Indosinian to Triassic magmatic, and thermotectonic events across East Asia is confusing and may not be appropriate because different mechanisms were occurring in different places at approximately the same time. How was Triassic deformation distributed across East Asia? The Triassic was clearly a period of major tectonic activity, yet not all these events need be related to the same processes. Classifying deformation as 'Indosinian' simply because deformation occurred at the same time in different places is confusing and obscures the true diversity of geodynamic processes. For example, development of an active margin with subduction of the palaeo-Pacific plate towards the northwest could explain Triassic events in the South China block, whilst the Indosinian in Vietnam might be attributed to continental accretion. It is generally acknowledged that the scale of thermotectonism in Vietnam is consistent with plate collision events but there are different viewpoints as to whether Indochina collided with South China in the Palaeozoic or Triassic.

If Indochina collided with the South China block in the Palaeozoic [9,16], an additional collision is required to explain the distinct Triassic Indosinian high-pressure-temperature ductile deformation event in Vietnam. One such model involves docking of the Sibumasu block causing reactivation of older suture zones [2]. However, most models favour collision between Indochina and South China taking place along the Ailaoshan–Song Ma/Song Da zones during the Triassic [7,21,48,58] (Fig. 1). The aim of this paper is to review how these different models sit within the constraints of regional geology, palaeogeography, thermochronology, and crustal thickness. The term Indosinian orogeny has been widely used, and it implies a mountain-building event. If this were the case, evidence should exist in the geological record, possibly in the form of residual thickened crust and significant accumulations of Triassic and younger molasse sediment that reflects denudation of a mountain belt.

2. Song Ma Zone

An outstanding controversy in relation to the Triassic assembly of East Asia is the significance of NW–SE-

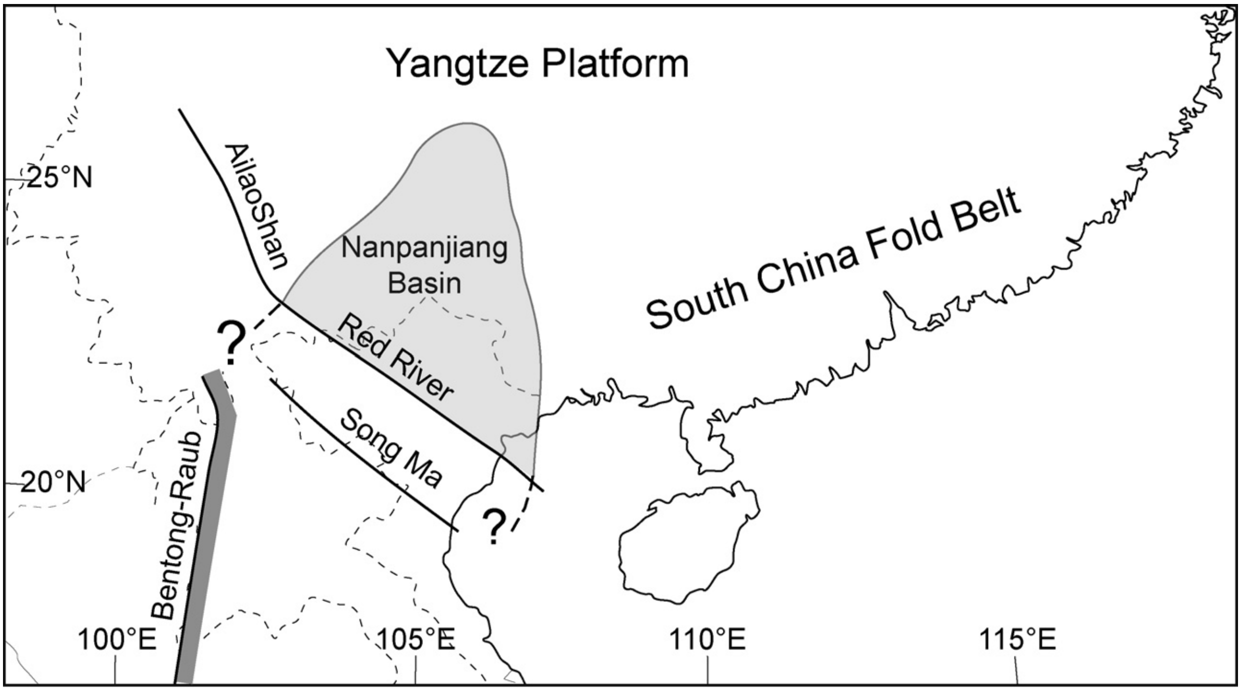

Fig. 1. Regional map with locations for Nanpanjiang Basin, Yangtze Platform Ailao–Red River Zone and Song Ma suture zone (adapted from [56]).

Fig. 1. Carte régionale avec les localisations du bassin de Nanpanjiang, de la plate-forme du Yangtze, de la zone de l'Ailao–rivière Rouge et de la zone de suture de Song Ma (adapté de [56]).

trending shear zones that dissect northern Vietnam and northeastern Laos. Debate centres on the Song Ma Zone, which is often referred to as a suture zone due to the presence of ultramafic rocks and serpentinite bodies [52], considered remnants of Palaeotethyan lithosphere. However, metamorphic overprinting and weathering make interpretation difficult. For example, the Honvang serpentinites, although not recognizable as ophiolite, contain relict chromian spinel with rare olivine inclusions. Compositions suggest that the original peridotite was spinel-bearing lherzolitic harzburgite of MORB-like affinity, consistent with an origin as a remnant palaeo-oceanic lithosphere [43]. This interpretation is strengthened by the nearby discovery of eclogites that record high pressures and low- to medium-temperatures considered diagnostic of subducted upper continental crust [29]. Whilst the growing evidence supports the Song Ma region as the site of a former Tethyan ocean basin, the chronology of oceanic closure remains debateable. Of concern is whether oceanic closure between the South China terrane and Indochina took place in the Devonian–Early Carboniferous (ca. 400–340 Ma) or much later in the Triassic (ca. 250–200 Ma). There is undeniable evidence for significant Triassic metamorphism and deformation in the Song Ma area and Vietnam in general [8 and references therein], but Tertiary deformation is also prevalent (e.g., [22,27,38,47]), and it is entirely conceivable this has overprinted and masked evidence for an earlier collision event.

Could closure have taken place earlier than the Triassic? A possible clue stems from palaeontological evidence. According to Metcalfe [38], the continental slithers (North, South China, Indochina, and Tarim blocks) that comprise present-day East Asia separated from Gondwana in the Silurian and Early Devonian, based on the observation that flora and fauna that retain Gondwana affinities until the Devonian. By contrast, the vertebrate (non-marine fish) record of Indochina has been interpreted as supporting the existence of a composite terrane comprising North-South China Indochina and Tarim that remained separate from Gondwana until the Devonian [51,57]. These studies are based on Devonian (Givetian–Frasnian age) freshwater fish faunas from terrigenous deposits in central Vietnam (Ly Hoa Formation) that record taxa (Antiarchs, Youngolepidid and Sarcopterygian remains, *Bothriolepis* sp.), which are largely unrecorded outside the Yangtze Platform (or South China Block). None of the endemic taxa has been found in the Lower Devonian of Australia, which is problematic for palaeogeographic models that require Indochina to have come from the Australian margin of Gondwana [46]. The implications of these findings are that the Song Ma zone suture event, and thus contact between Indochina and South China, occurred before the Devonian, but the time difference between the Devonian and Triassic do not rule out a later separation through ocean opening or development of a back-arc basin.

3. Triassic palaeogeography

The understanding of Triassic palaeogeography and the nature of sedimentation clearly have significance for understanding the cause of Indosinian thermotectonism. Unfortunately, much of the geology of Northeast Vietnam has been disturbed by Cenozoic deformation and erosion making this task difficult. Fortunately, a more complete sedimentary record can be found just across the border in western China. The Nanpanjiang basin has the longest marine history of any basin in China spanning the Late Proterozoic to Triassic, and once extended towards the southwest into what is now northern Vietnam. In the Permian (290–250 Ma) this area was a deep marine basin (Fig. 2) surrounded to the north and east by the shallow-marine (largely carbonate) Yangtze platform [4,25,32,56]. Until the Middle Triassic (241–227 Ma; Fig. 2) sedimentation on the Yangtze platform was dominated by shallow marine carbonates, including reefs, carbonate ramps and platforms [5,6,25]. In the basin centre, deep-water pelagic carbonates and shales were deposited in a sediment-starved environment indicative of tectonic quiescence. A marked change in sedimentation occurred in the Middle to Late Triassic with accelerated basin subsidence, drowning of the carbonate platform and deposition of siliciclastic turbidites. By the end of the Late Triassic, marine sedimentation had ended. Sedimentation was dominated by fluvial systems and a shallow marine shelf clastic environment. Whilst this change in sedimentation has often been attributed to Indosinian deformation, it is unclear if Indosinian in this context means it is related to subduction of the Pacific oceanic plate under an active south China margin or to collision between continental blocks to the southwest, i.e. between Indochina and South China.

Mesozoic sedimentation in the Nanpanjiang Basin has been interpreted as taking place in either a back arc setting [54]), back arc extensional basin [15], or foreland basin linked to collision along the Ailaoshan suture [45]. Clastic sedimentation of any note does not start to appear until the late Middle Triassic (~230 Ma). In southern China, north of the Vietnam border the clastic sedimentary sequences have been described as a

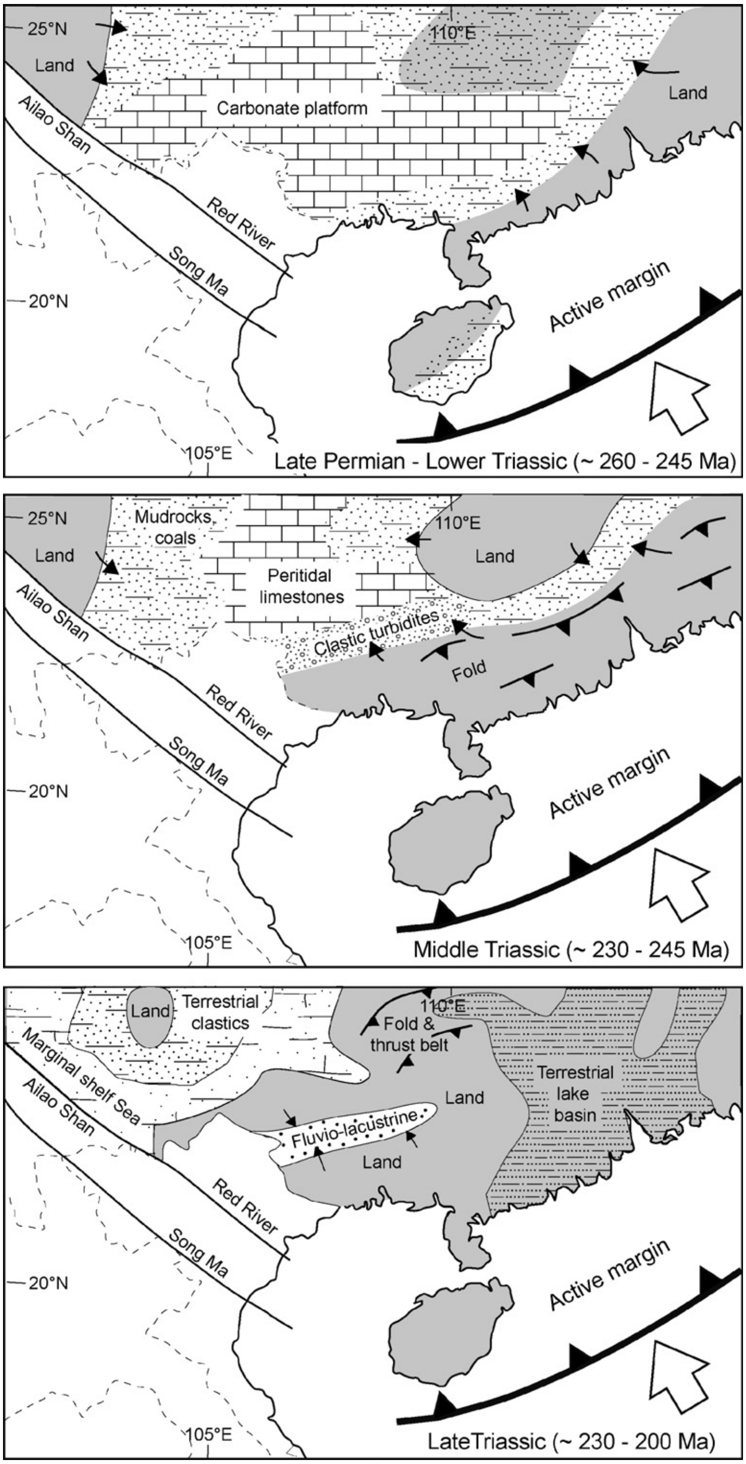

Fig. 2. Palaeogeographic reconstructions for southwestern China in the Late Permian to Lower Triassic, Middle Triassic, and Late Triassic (adapted from [5,25,56]).

Fig. 2. Reconstructions paléogéographiques de la Chine du Sud-Ouest depuis le Permien terminal jusqu'au Trias inférieur, moyen et supérieur (adapté de [5,25,56]).

classic flysch to molasse sequence typical of a foreland basin [49]. However, closer inspection reveals contrasting palaeocurrent directions that suggest they are not related packages. The earliest, so-called flysch sequences are Ladinian (∼235 Ma) with palaeocurrents indicating source areas to the east and southeast [6,15] and consistent with uplifted source areas linked to subduction of the Pacific plate. In contrast, the 'molasse' braided river deposits (up to 1500-m-thick in the Longchang area, [25,56]) are seen to rapidly thin to the east and point to an uplifted block to the west (e.g., Fig. 2). Thus in detail there is no evidence in the regions bordering northern Vietnam to support significant erosion of an uplifted region or mountain belt that would lie near the Red-River Song Ma Zone to the southwest during the Late Triassic.

4. Regional variations in crust thickness and heat flow

In many ancient orogenic belts, excess crustal roots appear to be a common feature. Little has been published on the thickness of crust in the South China-Indochina region. A synthesis [30] of early studies based on gravity [33], or sonobuoy data [50], outlined the key differences in the velocity, and structure of the lithosphere and asthenosphere in China, but gave little insight about relationships to the crust in Indochina. This gap has begun to be filled by recent studies of 3-D shear wave velocity [14,55] that include the structure of the crust and upper mantle in the South China Sea and surrounding region (to depths of ∼200 km). Broadband stations in northern Vietnam provide insight into the relationship between crust in South China and Indochina in the region of the Red River and Song Ma Zones. In a 3-D S-wave velocity study of Yunnan, evidence was found [14] for a distinct change in crustal structure between the east and west sides of the Ailaoshan–Red River Fault. This feature was also seen in the S-wave velocity structure beneath the Ailaoshan–Red River Fault [55]. Both studies found average crustal thicknesses across the fault region to be ∼36–37 km on the southwest side and ∼40–42 km on the northeast side. The evidence implies that the region to the northeast of the Red River fault in Vietnam is a continental crustal extension of the South China Platform and that the fault zone is deep rooted and cuts the crust, which lends support to the argument that the Red River–Song Ma Zone is a possible terrane boundary, at least in recent geologic times. These studies do not provide any evidence for residual thickened crust diagnostic of a Mesozoic collisional orogen. In fact, Vietnam crust is on average 5 km thinner than normal.

A complicating factor relating to Vietnamese crust is that metamorphic assemblages dated as Triassic and Tertiary suggest higher than normal heat flow [36,37]. Petrogenetic studies of metamorphic rocks associated with shear zones such as the Bu Khang Dome and Dai Ta Khan Dome [18,44] record temperatures of 900–1000 °C that combined with the presence of localised granitic magmatism are difficult to explain without invoking some form of crust thickening. One scenario recently put forward to explain the high heat flow is magmatic underplating supported by the presence of mantle-derived gabbro in the Kontum massif [44]. Plume activity in the Permian and Triassic is evident in the Emeishan province of southern China and basaltic komatiite magmas are known from the Song Da area in northern Vietnam [13]. Extension of plume activity to central Vietnam by implication requires prior collision between the Indochina and South China terranes.

5. Phanerozoic thermotectonism in Vietnam

Thermochromometric studies of basement of Vietnam generally record three main age groups. A Triassic signature attributable to the Indosinian and a Silurian signal often referred to as the Caledonian (although this has nothing in common with Caledonian orogeny of the North Atlantic region and should be given a more local name). Most recently there has been resetting of a number of both high and low temperature thermochronometers during rapid motion of the Ailaoshan–Red River Fault Zone, largely 35–16 Ma [11]. However, unlike the earlier events that are regional in nature the Cenozoic thermal overprints appear more localised, focussed close to the surface trace of the faults.

5.1. Oligocene–Miocene event

Evidence of thermal overprinting associated with Cenozoic strike-slip within the Indochina Block is not confined to the well-documented Ailaoshan–Red River Fault Zone. For example, ∼200 km south of the Ailao Shan–Red River shear zone the Bu Khang dome displays a similar structural trend and top-to-the-northeast sense of shear. A study of the Bu Khang dome highlights the scale of Cenozoic exhumation [18]. Metamorphism is marked by an early high-pressure stage (11–12 kbar) followed by progressive retrogression toward lower pressure during the top-to-the-northeast shear. $^{40}Ar/^{39}Ar$ mica dating of granite and gneiss records rapid exhumation from depths of ductile deformation (>10 km) at ~21 Ma, hence it was assumed that metamorphism was likely Cenozoic in age. However, subsequent zircon U–Pb dating [2] of a sample (VN 9709) from the study of Jolivet et al. [18] yielded an Indosinian age of 244 ± 7 Ma, with minor inherited cores between 600 Ma and 2.5 Ga.

North of the Ailaoshan–Red River Fault Zone is another extensional metamorphic dome known as the Song Chay dome. This largely orthogneiss dome records a top-to-the-north sense of shear. Zircon U–Pb dating indicates the age of the original granite protolith was ~428–424 Ma [2,26], whilst $^{40}Ar/^{39}Ar$ mica dating constrains the end of ductile deformation to the Indosinian (235–240 Ma, [36]), with only minor levels (<2–3 km) of Cenozoic exhumation evident, as constrained by apatite fission track data [36].

5.2. Triassic event

U–Pb and $^{40}Ar/^{39}Ar$ studies of Indosinian thermotectonism in Vietnam have largely centred on structures and metamorphic rocks of the Truong Son Belt and Kontum Massif where NW–SE to east–west dextral shear zones yield ages that group at ~250–240 Ma, with most younger ages attributable to subsequent exhumation [2,23,28,34,35,40–42]. Whilst zircon U–Pb dating records the timing of high-grade (amphibolite to granulite facies) metamorphism Sm–Nd, whole rock data show that the underlying crust formed during the Palaeoproterozoic and Mesoproterozoic (900–2500 Ma), i.e. the Indosinian, is a more recent overprint on old basement that involved crustal melting (e.g., charnokites through mixing of mantle-derived and crust-derived material) and lower-grade metamorphism [24]. Importantly, many of the Triassic U–Pb ages are supported by near-to-concordant argon mica ages that indicate that zircon growth was more or less accompanied by very rapid exhumation.

5.3. Silurian–Early Devonian event

Given the severity of Indosinian metamorphism our image of earlier events is noticeably less well developed. Detection of the so-called Silurian-Early Devonian 'Caledonian' overprint is mostly confined to zircon U–Pb ages but this is found across southern China and most of Vietnam. In southern China, recent zircon dating has shown that much of the exposed metamorphic basement (e.g., Yunkhai Massif) is not Proterozoic, as previously thought, but instead is formed from Silurian anatectic granites overprinted by Triassic thermotectonism [53]. Here, the 450–400-Ma event is regarded as the result of an intracontinental orogen rather than a subduction-related event [37]. Across the border in Vietnam, there is widespread evidence of a Silurian event although its precise geodynamic nature is unclear. Zircons from the Song Chay dome, (northeast of the Red River Fault Zone) yield U–Pb ages with a mean value of 424 ± 6 Ma [2], with one grain giving a Triassic age of 254 ± 4 Ma, similar to $^{40}Ar/^{39}Ar$ mica ages reported in [36]. South of the Song Ma Zone, in the Dai Loc Massif, which outcrops west of Danang, the study by Carter et al. [2] detected magmatic zircon U–Pb ages of 418 ± 8 Ma and 407 ± 11 Ma, whilst further south in the westernmost part of the Kontum massif magmatic zircons from gneisses gave an age of 444 ± 17 Ma.

5.4. Significance of overprinting events

Lack of evidence for large-scale Cenozoic exhumation north of the Ailaoshan–Red River Fault Zone led to the view that the Ailaoshan–Red River Fault Zone had cut into continental crust shaped during the Indosinian [19]. A similar line of argument can be applied to the presence of 'Caledonian'-type ages on either side of the Song Ma Zone, i.e. Indochina was already welded to part of the South China block during the Silurian.

6. Source of Triassic thermotectonism in southern China

Early research in South China tended to link thrusts, ductile shear zones, and granitoid intrusions of the South China fold belt to the Indosinian orogeny of Vietnam on the basis that most appear to be of Triassic age. Granitoids emplaced at ~251–205 Ma have been subdivided into early (~251–234 Ma) and late (~234–205 Ma) phases. Early Indosinian granitoids are typically gneissose and emplaced within a compressive regime, in contrast to the late Indosinian granites, which are massive and relatively undeformed. Some have argued that the two types represent early and late stages of collision (e.g., [60]), but, as discussed below, this can be discounted [31]. Since many of the intrusive bodies were found to have geochemical characteristics of calc-alkaline I-type granites formed in a continental arc setting, the viewpoint was formed that southern China was bordered by an active continental margin to the south at that time [17,59]. Equipped with new geochemical and themochronometric evidence researchers have begun to further refine this model, thus helping to explain the range of magmatic ages and granitoid types. The existence of a conventional active arc margin has been recently questioned [31] based on the following facts: (1) igneous rocks do not have an exclusive arc geochemistry, some are clearly intraplate alkali rocks; (2) significant areas underwent extension at the same time; (3) the magmatic province extends up to 1000 km inland; (4) the pattern of magmatism does not follow a simple coastward migration. To account for these observations, it was proposed [31] that the subducting slab, similar to the situation seen in the Cenozoic Andes [20], remained flat throughout the Triassic until slab break-off and rollback in the Jurassic. Although it can be argued that points (1) and (2) are not necessarily diagnostic of a particular setting because these features are not uncommon in many modern subduction zones, the remaining evidence does make an active margin setting for the Triassic of southern China the most appropriate environment.

7. Discussion

There are clear differences between the style and cause of Triassic deformation in southern China and Vietnam. It is our contention that although similar in timing these are separate events produced by different mechanisms. Triassic deformation (and associated magmatic activity) in southern China is a consequence of oceanic subduction along the South China margin**.** Onset of active subduction of the palaeo-Pacific plate likely began when a major change in plate velocity occurred following collision of the North and South China blocks [31]. In Southeast China, active subduction was NW–WNW directed, and this pattern was imprinted on the regional deformation trend. However, to the west, subduction and collision processes were clearly more complex and must have included a broadly northeastward-directed component between both Indochina and South China blocks, which accounts for the prevailing northeast-to-ENE structural trend seen on Hainan Island, as well as further to the east along the coast of southeastern China [31]. Crucially, this trend does not fit well with the mainly east–west-to-NW–SE trend of Indosinian structures seen in Vietnam [8]. Accordingly, it seems more appropriate to use a local Chinese name to describe Triassic deformation in South China in order to distinguish it from the Indosinian event of Vietnam.

The disparity between Triassic deformation trends in southern China and Vietnam arises because although created coevally they originated from different processes. In the literature, there has been a tendency to try to link the Lower-Middle Triassic (∼250–220 Ma) zircon U–Pb ages found in a variety of rock types covering the Qinling–Dabie Shan belt in central China, the southern Chinese margin and Vietnam. However, similarity of U–Pb ages does not necessarily mean they are all related to the same underlying plate tectonic process. Whilst Triassic magmatic zircon ages on Hainan Island record an active continental margin [20], similar aged zircons from the Dabie Shan record ultra-high pressure (UHP) metamorphic growth and rapid exhumation arising from a more complex set of local plate interactions (e.g., [12]). In the case of Triassic U–Pb ages from Vietnam and southern China, it is important to bear in mind that the zircon U–Pb ages from South China are largely from syn-orogenic calc-alkali I-type granites associated with development of an active continental margin (e.g., [31]) whilst zircon ages from Vietnam largely reflect metamorphic overprinting and exhumation (e.g., [2]).

So how different was orogenesis in South China from Indosinian thermotectonism in Vietnam? Comparison of crustal thicknesses on either side of the Red River-Song Ma Zone shows differences exist but only to the extent that Vietnamese crust south of the Red River is

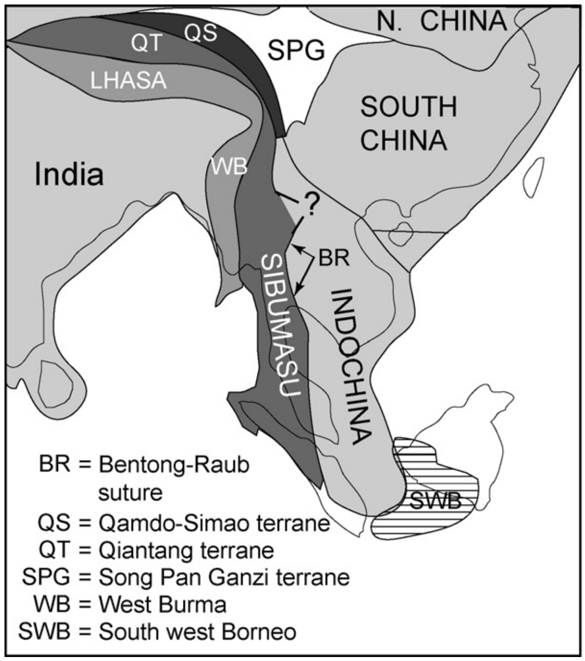

Fig. 3. Map to show the principal terrains that have amalgamated to form Southeast Asia (after [38]). Also marked is the location of the Nan–Uttardit–Raub–Bentong line that marks the eastern boundary of the Sibumasu block.

Fig. 3. Carte montrant les principaux terrains qui se sont amalgamés pour former l'Asie du Sud-Est (d'après [38]). Est également indiquée la localisation de la ligne Nan–Uttaradit–Raub–Bentong, qui marque la frontière orientale du bloc de Sibumasu.

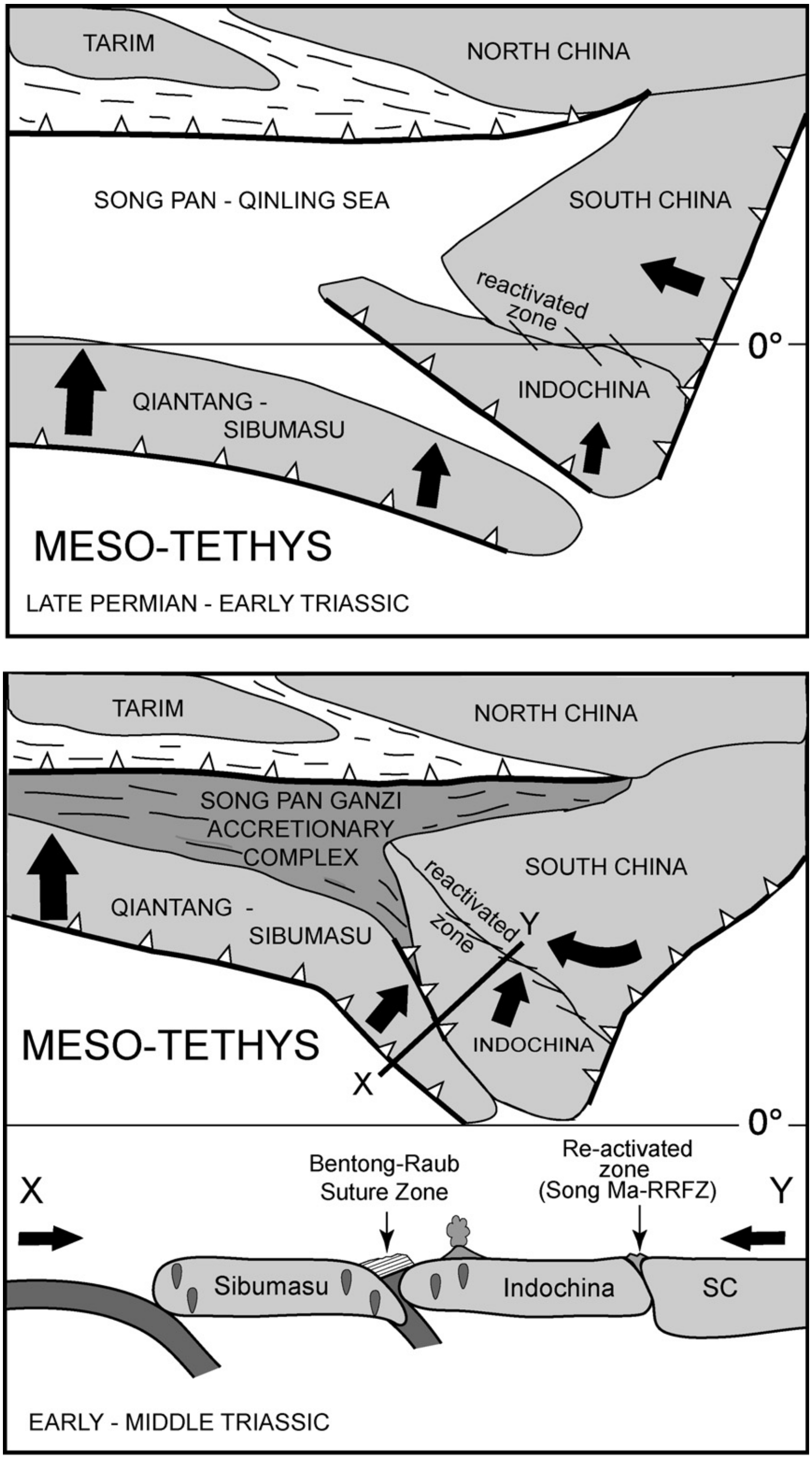

Fig. 4. Permian to Middle Triassic accretion history, adapted from [2].

Fig. 4. Histoire de l'accrétion, depuis le Permien jusqu'au Trias moyen, adaptée de [2].

thinner than that in South China. Such observations do not sit well with a model of Triassic orogenesis. Had a mountain belt once existed 250 Myr of post-orogenic decay would be expected to remove all topographic traces. This might explain the presence of thinner than normal crust in northern Vietnam but it could also signify that the Indosinian event did not involve major crust thickening. Had significant mountain building taken place in the Triassic it would take 30–70 Myr of typical orogenic erosion rates to reduce the topography to base level (based on global average values for post-orogenic decay that take into account isostatic compensation [1]). If this were the case, there must exist substantial regional deposits of Middle–Upper Triassic–Lower Jurassic clastic sediments.

Examination of regional palaeogeography (covering northern Vietnam and southwestern China) shows the Triassic was a period of relative tectonic quiescence, dominated in the Late Permian and Lower Triassic by shallow marine carbonate facies. Only in the Middle Triassic do clastic sedimentary rocks begin to appear, but the sequences are not thick and most seem to be related to topography generated by subduction along the South China margin. There is no evidence for significant clastic sediment being sourced from the southwest (Vietnam region), as predicted by the existence of an orogenic belt (Fig. 2).

If indeed the Indochina block did collide with South China in the Triassic, the site of collision is widely considered to have been the Song Ma Suture Zone given the presence there of ultramafic rocks with MORB-like affinities (i.e. remnant palaeo-oceanic lithosphere) [43]. Although evidence from these rocks supports subduction and final oceanic closure in this region, there is as yet no detailed thermochronological data that unambiguously ties this process to the Triassic. Because the region has been subjected to multiple crustal recycling events and deformational overprinting, in particular Cenozoic deformation, any dating has to be carried out with care in order to establish inheritance, timing for UHP metamorphism (presence of eclogite bodies), and subsequent decompression and retrograde metamorphism. Evidence from whole-rock Sm–Nd studies of Vietnam centred on the Kontum massif, to the South of the Song Ma Zone [24] shows clearly how much crustal recycling has taken place in that region. Rocks that record Oligocene, Triassic and Silurian high temperature events were found to contain Sm–Nd signatures diagnostic of mainly Proterozoic sources.

The evidence discussed above and outlined in the previous sections suggests that in Vietnam the Indosinian was unlikely to have been a major mountain building event, and may have not involved ocean closure between the Indochina and South China blocks. Certainly, the palaeontological evidence discussed in Section 2 supports contact between South China and Indochina prior to the Late Silurian, which fits with the regional evidence, spanning both blocks, of a Silurian thermotectonic event. If this were the case, this presents the question that, if collision between Indochina and South China did not take place in the Triassic, then what is the cause of Indosinian thermotectonism?

Carter et al. [2] put forward a model (Fig. 4) that defined the Indosinian as a reactivation event linked to collision of a Gondwana-derived continental block that comprises parts of western Yunnan, northwest and peninsula Thailand, Myanmar, and Northwest Sumatra collectively referred to as Sibumasu (Fig. 3). The rationale for this model centres on recognition of the Bentong–Raub Suture Zone (Figs. 1 and 3), located between the Sibumasu Terrane and the East Malaya–Indochina Terrane, as representing the main Palaeotethyan ocean basin that opened in the Devonian and closed in the Triassic. Tectonostratigraphic, palaeobiogeographic, and palaeomagnetic data record this closure in the Late Permian to Early Triassic with significant crust thickening and final closure taking place in the Middle Triassic [39]. It is this final collision that is considered to be the driver for regional thermotectonism and reactivation of pre-existing structures within Indochina caused by clockwise rotation of the Indochina–South China block as Sibumasu pushed northeast (Fig. 4). With rotation, there would have been accompanying changes in the regional stress field that would have evolved from oblique convergence and transpression to a transtensional environment (Fig. 4). The latter would account for the high rates of exhumation required by zircon and mica thermochronometry of the ductile shear zones.

8. Conclusions

In this paper, we emphasise a definition of the Indosinian that is confined to the style of thermotectonism seen in Vietnam. Triassic deformation in southern China has a different origin, and it should be given a different name to avoid confusion. A review of regional seismic and thermochronological evidence combined with Early Mesozoic palaeogeographic constraint do not support the Indosinian as a major mountain building event, but instead lend support to the Indosinian as a reactivation event caused by closure of Palaeotethys with accretion of the Sibumasu block (∼250–220 Ma) in the Early–Middle Triassic.

Debate will no doubt continue as to whether the Indosinian event also marks the accretion of Indochina to the South China block, because as yet there remains scant data from the Song Ma Suture Zone. Robust dating is required to unravel successive thermal overprints in order provide a date for the generation of the ultramafic rocks and serpentinite bodies considered remnants of Palaeotethyan lithosphere. Only then will we have confidence about the significance of the Indosinian event.

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