Unconformity of red sandstones in north Vietnam: field evidence for Indosinian orogeny in northern Indochina?

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ABSTRACT

We re-examine several unconformity sites in northwestern Vietnam where the Indosinian orogenesis has been defined. Field observations in the Black-River (Song Da) region, near Son La, demonstrate that red sandtones and conglomerates, reportedly of Cretaceous age, occur unconformably above schistosed epimetamorphic middle-Triassic sediments. A mesozoic unconformity thus really exists in this region, though the age of deformation is poorly contrained (upper Triassic to upper Cretaceous). In most places, however, the unconformity is strongly deformed, folded Triassic limestones are often thrusted onto the Cretaceous rocks. This implies that Tertiary deformations probably due to the India–Asia collision have been strong in the northern part of the Indochina block.

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Northern Vietnam, 'locus typicus' of Indosinian orogenesis

North and east of the Himalayas, the Asian crust has been structured by several collisional events (e.g. Allègre *et al*., 1984; Sengör and Hsü, 1984; Hutchinson, 1989). Amongst these events, the Indosinian or Cimmeride orogeny is thought to have affected a large region from northeastern Tibet to mainland SE Asia, in the middle Triassic (Deprat, 1914b; Fromaget, 1941; Sengör and Hsü, 1984; Hutchinson, 1989). This concept of large collisional deformations of Triassic age comes from the pioneering work of Deprat (1914a, 1914b), who suggested that the Black-River region of northern Vietnam was a major edifice of refolded thrust nappes affecting the Palaeozoic and Triassic rocks. Together with the possible existence of discordances within the Triassic series (Fromaget, 1941; Fromaget, 1952), the main argument for a Triassic age of nappe emplacement, is the existence of red conglomerates, sandstones and pelites reported to be syntectonic and to lie unconformably on deformed Triassic sediments. Hence, the concept of Indosinian orogenesis has been extended to the whole Indochina peninsula, southwestern China and eastern Tibet (Fromaget, 1941; Sengör and Hsü, 1984).

In the Yunnan province of China, it was thus quite surprising to find very little evidence for such Triassic compressional deformations along the Red River Fault zone, and on both sides of it (Tapponnier *et al*., 1990). There, most of the visible deformations are clearly of Cenozoic age (Schärer *et al*., 1990; Schärer *et al*., 1994; Leloup *et al*., 1995). In central Yunnan and Sichuan basins, there is no clear angular unconformity within the Triassic to Cretaceous series and the Triassic rocks are generally folded or sheared together with the Jurassic–Cretaceous red beds (Tapponnier *et al*., 1990; Leloup *et al*., 1995). In north-west Vietnam, 'locus typicus' of Indosinian orogenesis, there is no published, clear factual description of such angular unconformity. These observations have led us to question the real significance and importance of this orogenesis (Tapponnier *et al*., 1996).

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The Indosinian unconformity in the Black-River region

In northern and central Vietnam, the clearest descriptions of tectonic structures are those of Deprat (e.g. Deprat, 1914a, 1914b, 1914c). His detailed and factual cross-sections proved to be highly reliable in the field, a conclusion we failed to reach for the interpretative sections and descriptions of Fromaget (1941). In central Vietnam, Deprat clearly describes the post-Hercynian unconformity of lower Triassic polygenic conglomerates deposited onto gneisses (Deprat, 1914c). In his studies of the black river region, comparable field evidence for a syn-Triassic, post-compressional unconformity is less clear. Deprat's detailed geological sections of the Song Da region, south of the so-called Black-River nappes, show the reportedly unconformable red-bed series pinched in synclines, and folded like the Triassic limestones (Deprat, 1914a, 1914b). As no detailed field description of this hypothetical unconformity has been published since Deprat, we attempt here to reinvestigate the structure of some of these red bed basins.

Geological setting of the Song Da region

Along the Red River Fault Zone (RRFZ) in NW Vietnam, left-lateral shear has occurred mainly in the high-grade mylonitic core of the Dai Nui Con Voi (Leloup *et al*., 1995, 1997). South and north of this core, several strike-slip faults and shear zones also account for significant left-lateral motion (Fig. 1). About 100 km south-west of the RRFZ, the Song Da (Black river) has entrenched a deep valley in folded Palaeozoic and Triassic sediments. Upper Palaeozoic lower–middle Triassic sedimentation is considered to have occurred in a subsident basin, the 'Song Da rift', together with basaltic volcanism and intrusions of upper Permian to early Triassic age (Hutchinson, 1989). For Sengör and Hsü (1984), this zone would correspond to the major indosinian suture zone. The rocks of the Song Da region have been affected by an intense N–S to NE–SW shortening and most of the structures, including thrusts, shear zones and tight folds, are presently steep. Where present, lineations and shear criteria attest to nearly vertical stretching and upthrust movements on such steep structures.

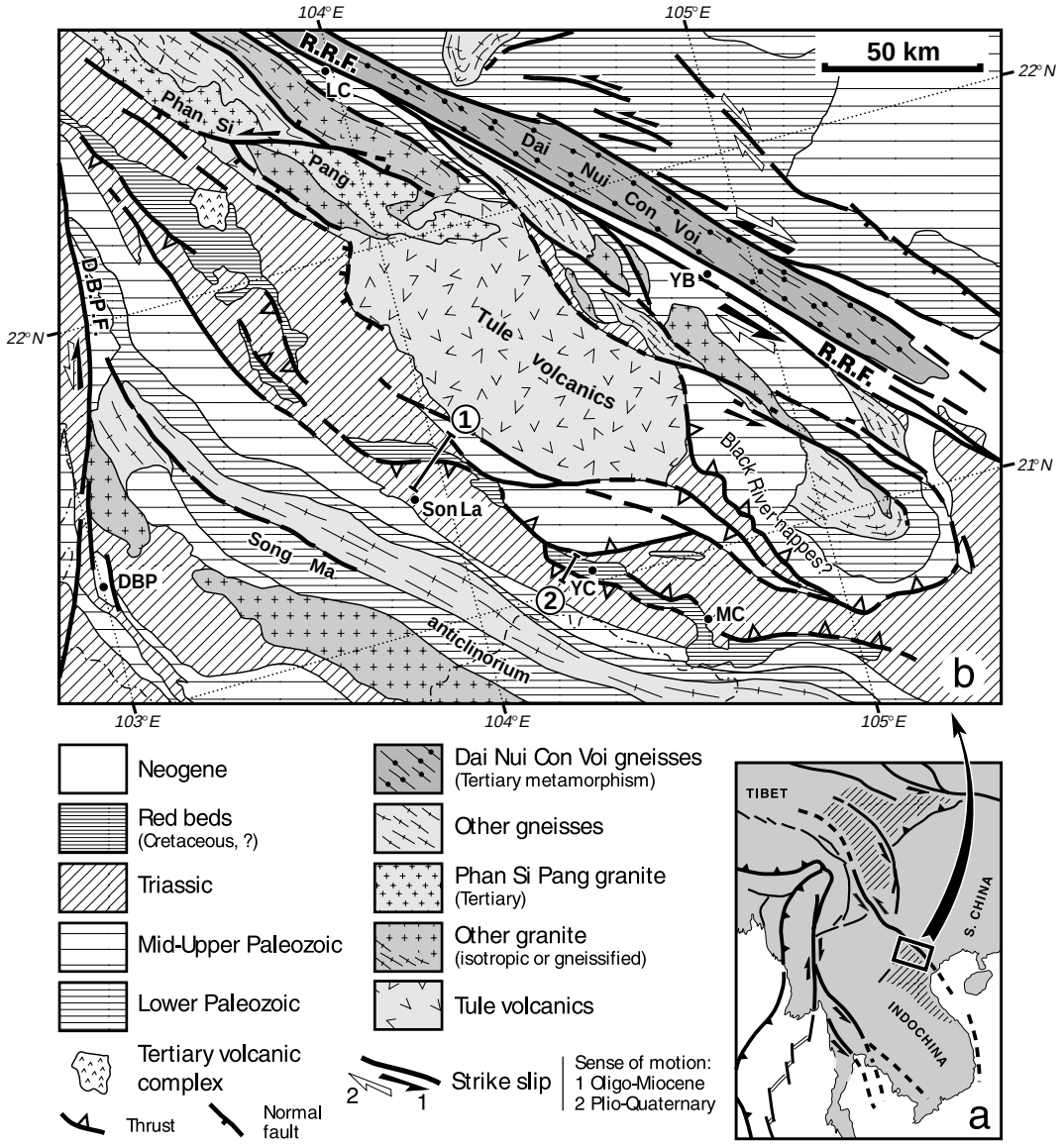

Fig. 1 Location and tectonic sketch of north-western Vietnam and adjacent regions. (a) Location of NW Vietnam in tectonic framework of continental SE Asia. Arrows show finite sense of displacement along Cenozoic strike-slip faults. Hatched areas correspond to inferred Triassic fold and thrust belts strongly affected by subsequent Tertiary deformations. (b) Tectonic sketch map of Song Da (Black-River) region showing Son La–Moc Chau red bed basins and location of geological sections of Fig. 2 (circled numbers) (after General Department of Mines and Geology of the Socialist Republic of Vietnam 1988; General Geological Department of the Democratic Republic of Vietnam 1973). The Red River Fault (R.R.F.) and Dai Nui Con Voi metamorphic core mark the Cenozoic transform boundary between South China and Indochina blocks (Leloup *et al.*, 1995). DBP, Dien Bien Phu; LC, Lao Cai; MC, Moc Chau; YB, Yen Bai; YC, Yen Chau, D.B.P.F., Dien Bien Phu Foult.

South of the Song Da valley, in the Son La and Moc Chau region, a discontinuous stripe of red beds (Fig. 1b), reportedly of Cretaceous age, is mapped discordantly on the folded Triassic series (General Department of Mines and Geology of the Socialist Republic of Vietnam, 1988; Nguyen Xuan Bao *et al.* 1978; Bui Phu My *et al.* 1978; Nguyen Vinh *et al.*, 1978; Trang Danh Tuyet *et al.* 1978). Geological maps and satellite images suggest that this stripe is cut or bounded by strike-slip faults and thrusts (Fig. 1b). We report here detailed observations along two key sections: North of Son La (section 1, Fig. 2a) and across the Yen Chau basin (section 2, Fig. 2c), which allow us to assess in the field the relationships between the red beds and the Triassic rocks.

The basal unconformity of the red bed series north of Son La

The first section (Fig. 2a), from the Song Da River to Son La, shows red conglomerates and sandstones, mapped as Cretaceous, outcropping in a small basin within the Triassic series. Towards the SW, the middle-Triassic limestones (Anisian according to De-

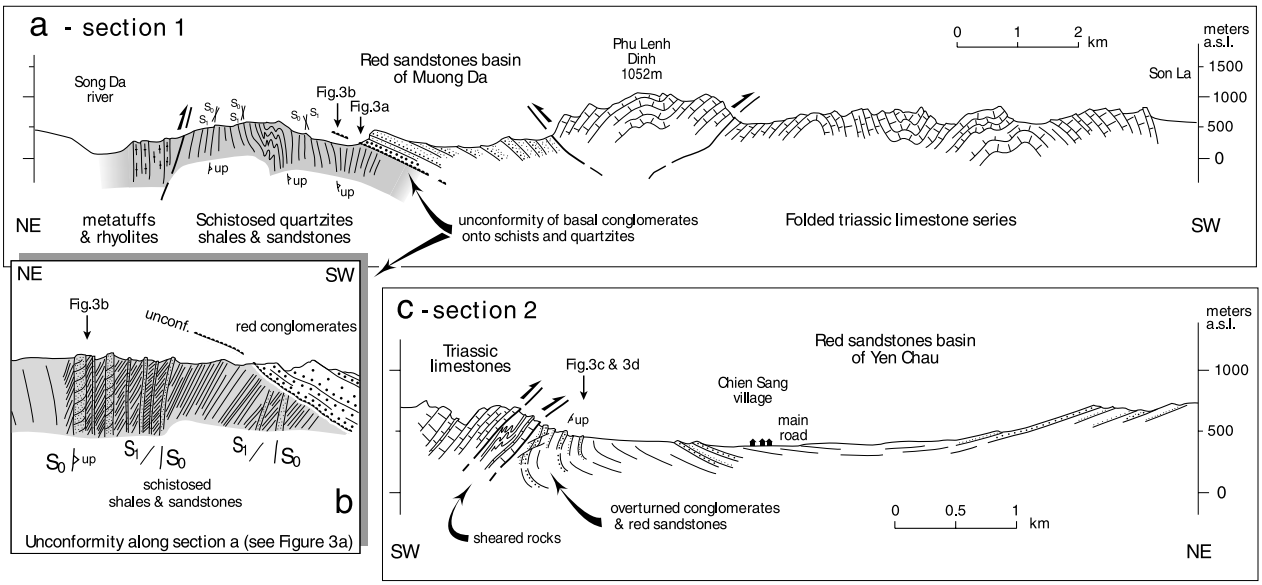

Fig. 2 Geological sections across red bed basins of Song Da region. (a) Section along unpaved road from Son La to Song Da river (section 1, Fig. 1b); NE to the left. (b) Detail of unconformity of conglomerates onto schistosed sandstones and shales (outcrop of Fig. 3a). (c) Section of southern border and middle part of Yen Chau basin (section 2, Fig. 1b), NE to the right. Main road from Son La to Moc Chau is in middle of section.

prat, 1914c; Nguyen Vinh, 1978; Trang Danh Tuyet, 1978) are tightly folded in a series of anticlines and synclines whose axes trend NW–SE to WNW–ESE. These limestones probably overthrust the red bed basin of Muong Da (Fig. 2a), though contact between the two units has not been observed directly in the field. The red sandstones and conglomerates of this basin dip 15–30° SW on average. Towards the NE, they overlie unconformably a series of schists, sandstones and quartzites, of Triassic age. On a single outcrop along the road (UTM coordinates 48Q VJ 001 691) one can observe the red conglomeratic beds, dipping 20–30° SSW, lying directly on top of schistose, steeply dipping sandstones and schists (Figs 2b and 3a).

Up to the Song Da valley, the rest of the section shows a nearly vertical flyschoid series with shale, schist, grey and yellowish sandstone and quartzite, reportedly of Ladinian age (Nguyen Vinh, 1978; Trang Danh Tuyet, 1978). These rocks are epimetamorphic and affected by fracture or slaty cleavages (Fig. 3b). The bedding planes trend N120–130°E and dip steeply to the NE or SW, while the cleavage generally dips to the NE (Fig. 3b). The constant bedding (S0)–cleavage (S1) relationships, together with polarity criteria (graded bedding, shape of refracted cleavage, load and flute casts) suggest that this nearly vertical series is roughly monoclinal (Fig. 2a). The northernmost part of the section, near the Song Da valley, shows mylonitic metatuffs and rhyolites, with a N110°E-trending schistosity dipping to the NE or nearly vertical. These rocks are probably thrust southwestward onto the flyschoid series.

Evidence for shortening of the red bed series

The second section crosses the southern border of the Yen Chau red-bed basin, ≈ 50 km SE of Son La (Fig. 2c). Hills of middle-Triassic limestones, dipping to the SW, bound the basin to the south. These limestones are thrust towards the north onto the red conglomerate, sandstone and pelitic series. A 250-m thick zone of sheared limestone, pelite and sandstone marks the thrust contact and shows intense boudinage, microfolding and small reverse shear-zones (Fig. 2c). Overturned to nearly vertical thick beds of red conglomerate, also cut by reverse faults and shear zones, outcrop just below this sheared zone (Fig. 3c, d). These conglomerates bear mainly limestone and sandstone pebbles, with a few quartz pebbles. We have not found pebbles of plutonic or metamorphic rocks. Towards the north and upward, the series become less conglomeratic and grades into fine-grained sandstones and pelites that form the middle part of the basin. South of the village of Chien Sang the sandstones dip ≈ 20° NE while they dip gently to the SSW north of the road from Son La to Moc Chau (Fig. 2c). We have not reached the northern border of the basin along this section. Nevertheless, between Yen Chau and Moc Chau, the morphology of the Yen Chau basin on satellite images and in the field implies that thrusts may also follow this northern border (Fig. 1b). The Yen Chau red-bed basin thus appears to be a pinched syncline bounded on both sides by reverse faults.

Discussion

The detailed field observations we report here definitively demonstrate that the red bed series of the Black-River region have been deposited on previously deformed Triassic rocks. That the sandstones and schists located below the unconformity are steep and schistose strongly supports the idea that the red-beds are not onlapping onto a block-faulted region, as in central Yunnan (Leloup *et al.*, 1995), but instead postdate a compressional tectonic event. Note however, that the underlying rocks are only epimeta-

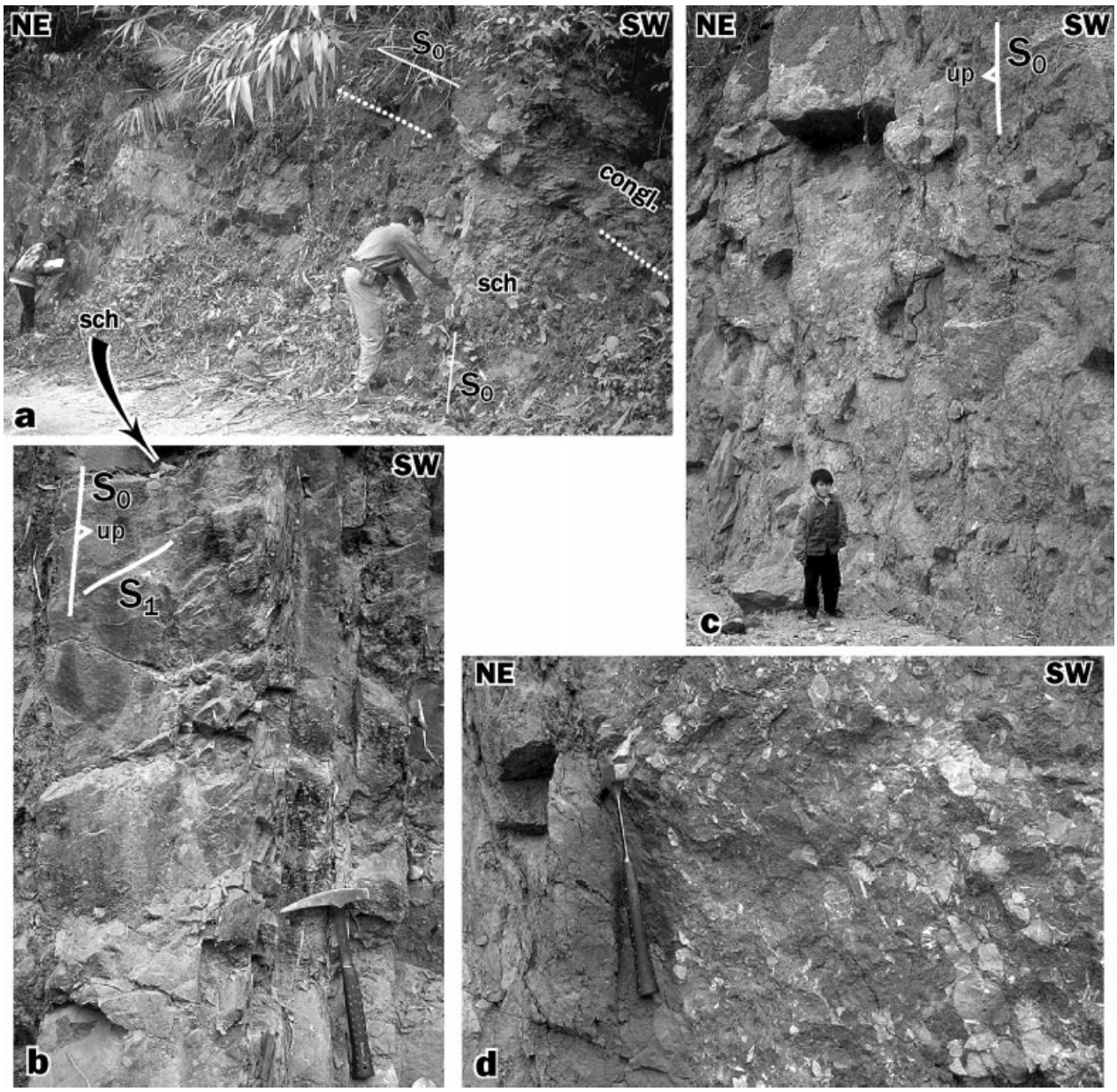

Fig. 3 (a) View of red bed unconformity along Son La-Song Da section (Fig. 2a, b). The dotted white line outlines the base of conglomeratic beds (congl.) above nearly vertical to overturned schists and sandstones (sch.); S_0 is bedding. (b) Detail of schistosed sandstones (left part of Figs 2b and 3a). Spaced fracture cleavage in coarse sandstone beds (left) grades into penetrative slaty cleavage in schists (middle). Curved shape of cleavage, due to refraction more important in coarser parts of sandstone beds (left), outlines gradded bedding and is used as polarity criteria. (c) Nearly vertical red conglomerates at southern border of Yen Chau basin (Fig. 2c). (d) Detailed view of conglomeratic beds of Fig. 3(c). Pebbles, rounded to angular, are mostly sandstone and limestone. Hammer handle outlines bedding.

morphic and that the red conglomerate is not a polygenic molasse bearing a lot of metamorphic and plutonic pebbles. This could imply that, in the Black-River region, the pre-unconformity compressional event has not brought to the surface deep metamorphic units, such as those typically found in internal parts of a mountain belt.

From available data, it is difficult to assign a unequivocal age to this compressional event. During the first half of the century, the red beds were considered to be upper Triassic to lower Liassic. It was the so-called 'terrain rouge' inferred to be 'infralias' and syntectonic by Deprat (1914a, 1914b), then by Fromaget (1941). A Cretaceous age is now ascribed to these red-beds, that could perhaps be as young as upper Cretaceous to lower Cenozoic (General department of mines and geology of the socialist republic of Vietnam 1988; General Geological Department of the Democratic Republic of Vietnam, 1973; Phan Cu Tien *et al.*, 1989). Indeed, they reportedly 'contain Cenozoic remains

and a freshwater Bivalvia (Unio sf. grabaui) of Late Cretaceous' (Phan Cu Tien *et al.*, 1989; p.56). The possible ages for the deformation of the underlying Triassic rocks thus range between the middle–upper Triassic and probably the uppermost Cretaceous. In any case, the unconformable red beds cannot be younger than the volcanic and hypovolcanic complex that overprint the unconformity south of the Phan Si Pang range (Fig. 1). One Ar–Ar radiometric result (Sun Li Chung *et al.* 1997) on phlogopite-rich lavas (cocites) suggests an age of about 30 Myr for this complex. Triassic ages of metamorphism and deformation have been obtained from the Song Ma anticlinorium ($\approx$ 30 km south of Son La, Fig. 1b) and farther south in central Vietnam (Maluski *et al.*, 1995; Lepvrier *et al.*, 1997; Maluski *et al.*, 1997). This supports the hypothesis of an Indosinian (upper Triassic) deformation in the black river region. We cannot exclude, however, the existence of a Jurassic or Cretaceous event also suggested by some radiochronological results in the region (Maluski *et al.*, 1997). At most, this deformation could even be related to the onset of the India–Asia collision, as it is inferred in Tibet for the deformation of the Takena series below the unconformable Linzizong formation (Tapponnier *et al.*, 1986).

It is clear, however, that the basal unconformity, and the red-beds themselves are involved in the fold and thrust edifice of the Black-River region. This implies that post-Cretaceous shortening, likely an effect of the India–Asia collision, has been strong in the northern part of the Indochina block. In the folded Triassic limestones, the proportion of shortening that was acquired before and after red-bed deposition remains unclear. Note, however, that the orientation of fold axes in the limestones and the post red-bed thrusts have the same direction, and have linked geometries at places, implying that they could be due to the same Tertiary tectonic event.

At the scale of mainland SE Asia (Fig. 1a), the probably Triassic, Black River tectonic belt could tentatively be correlated with the Songpan-Garze fold and thrust belt of eastern Tibet, western Sichuan and northern Yunnan (Mattauer *et al.*, 1992; She Fa Chen *et al.*, 1995). In the Songpan-Garze belt and in the western Sichuan basin, the occurrence of Indosinian shortening is attested to by an upper Triassic unconformity (She Fa Chen *et al.*, 1995) and of Jurassic granites cross-cutting folded Triassic rocks (Calassou, 1994). In this belt, which is also strongly affected by Tertiary shortening (Calassou, 1994; Lacassin *et al.*, 1996), the other major reported unconformities are of Cenozoic age (She Fa Chen *et al.*, 1995). In this hypothesis, the southern part of the Songpan Garze belt would have been cut and displaced 400–700 km towards the south by Tertiary sinistral motion along the Red River Fault zone.

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