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QUATERNARY TECTONICS OF THE RED RIVER FAULT ZONE IN VIETNAM – A MORPHOTECTONIC APPROACH

Czwartorzędowa tektonika strefy uskoku Rzeki Czerwonej w Wietnamie – podejście morfotektoniczne

Witold ZUCHIEWICZ[1] & Nguyen Quoc CUONG[2]

[1]Akademia Górniczo-Hutnicza, Wydział Geologii, Geofizyki i Ochrony Środowiska
Katedra Analiz Środowiskowych, Kartografii i Geologii Gospodarczej;
al. Mickiewicza 30, 30-059 Kraków;
e-mail: witoldzuchiewicz@geol.agh.edu.pl

[2]Department of Geochronology, Institute of Geological Sciences,
Vietnamese Academy of Sciences & Technology;
84 Pho Chua Lang, Dong Da, Ha Noi, Vietnam;
e-mail: cuongnqdc@gmail.com

Treść: Rozmiary czwartorzędowego, prawoskrętnego przemieszczenia sieci drenażu w wietnamskim segmencie strefy uskoku Rzeki Czerwonej wyniosły 0.4÷5.3 km, śr. 1.1÷2 km, a odpowiadające im prędkości uskokowania zmieniały się od 0.43÷1.1 mm/rok dla poszczególnych segmentów uskoku do 5.5÷7.8 mm/rok dla przemieszczenia skumulowanego. Zuskokowane terasy rzeczne i stożki napływowe zostały uformowane głównie w późnym plejstocenie i holocenie, z wyjątkiem teras najwyższych (40÷50 m), wieku środkowoplejstoceńskiego.

Słowa kluczowe: morfotektonika, czwartorzędowa tektonika, strefa uskoku Rzeki Czerwonej, Wietnam

Key words: morphotectonics, Quaternary tectonics, Red River Fault Zone, Vietnam

INTRODUCTION

The Red River Fault Zone (RRFZ) is a major tectonic feature separating South China from Indochina. This zone, extending more than 900 km between eastern Tibet and the South China Sea, is the most conspicuous geologic and geomorphic discontinuity in Southeast Asia (Figs 1, 2). Farther to the NE, the RRFZ is paralleled by the Chay River and Lo River faults of comparable orientation and sense of slip.

Tapponnier *et al.* (1986) presented a model, according to which the RRFZ was formed during Oligocene times as a sinistral shear zone which was later transformed into a dextral one. These authors presented the first field evidence for the pre-Late Miocene sinistral shift along the RRFZ, whereas pieces of evidence for subsequent dextral movement along the RRFZ

were provided by Allen *et al.* (1984). The model of Tapponnier *et al.* (1986) was largely confirmed by the results of subsequent studies (e.g. Leloup *et al.* 1995, 2001, and references therein). According to these results, the RRFZ was a sinistral lithospheric discontinuity since at least 34 until 17 Ma. The timing of the sinistral slip overlaps with seafloor spreading (30.5÷17 Ma) in the South China Sea (Briais *et al.* 1993). The amount of sinistral offset along the RRFZ has been estimated at 330±60 km (Lacassin *et al.* 1993) to 500÷700 km (Leloup *et al.* 1995). According to Jolivet *et al.* (2001), the RRFZ is rooted in an horizontal shear zone at the brittle/ductile transition separating the upper and middle crust from the lower crust, and the sinistral strike-slip motion was first transpressional (?40÷25 Ma), and then transtensional, leading to fast exhumation from 24 to 17 Ma. Wang *et al.* (1998) maintain that the sinistral shearing took place between 27 and 17 Ma.

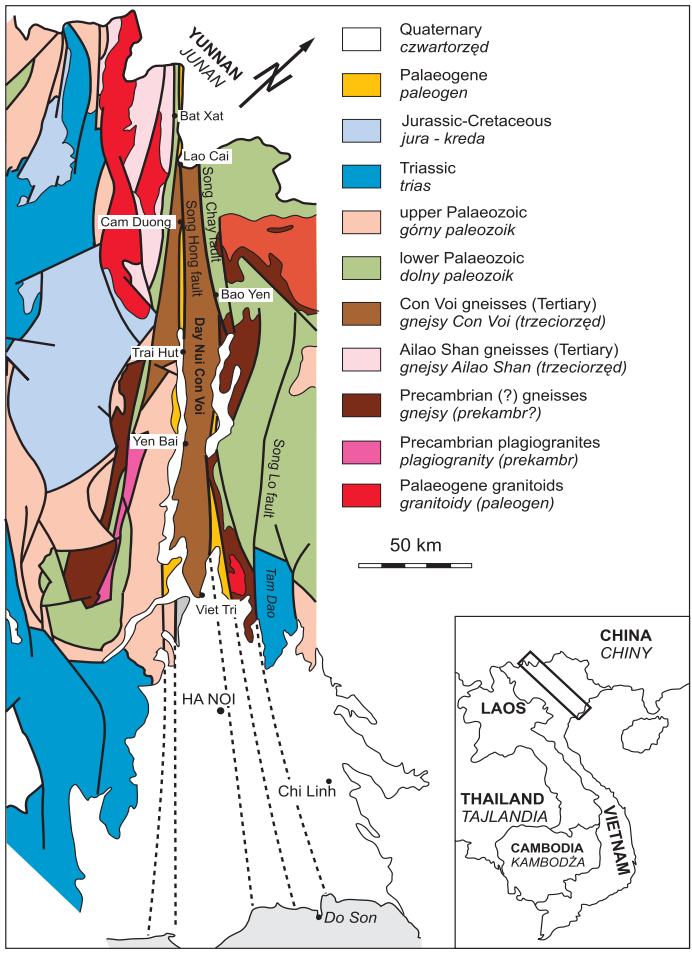

Fig. 1. Geological sketch-map of the Red River Fault Zone (based on Tien *et al.* 1991; modified)

Fig. 1. Szkic geologiczny strefy uskoku Rzeki Czerwonej (według Tien *et al.* 1991; zmienione)

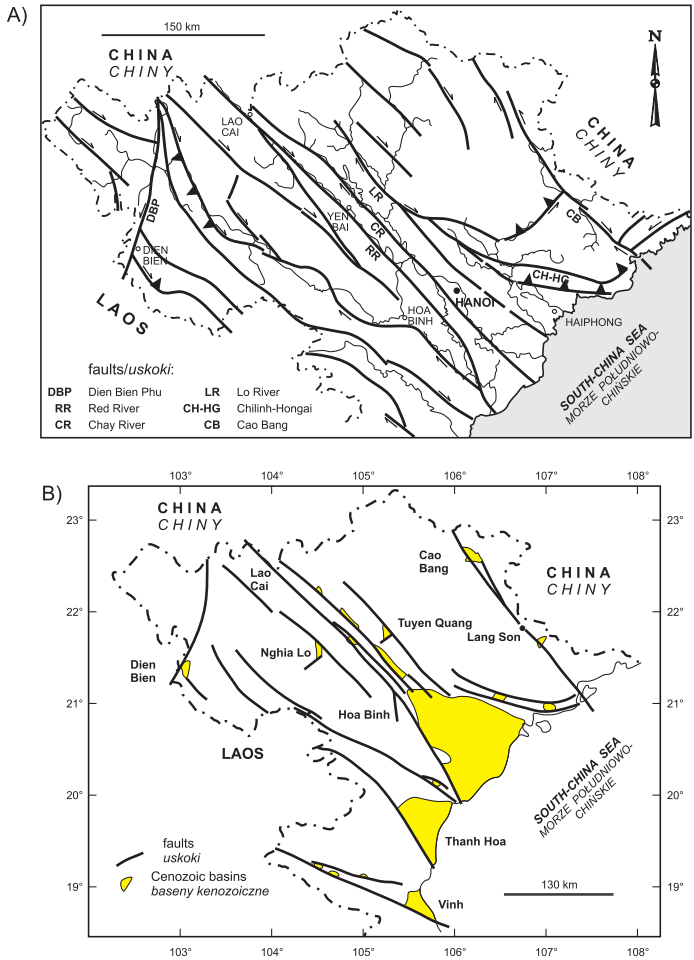

Fig. 2. Pattern of Late Cenozoic faults in Northern Vietnam (A) and related sedimentary basins (B), based on Zuchiewicz & Cuong (2006) and Nielsen *et al.* (1999); modified

Fig. 2. Uskoki późnokenozoiczne północnego Wietnamu (A) i związane z nimi baseny osadowe (B); według Zuchiewicza i Cuonga (2006) oraz Nielsena *et al.* (1999); zmienione

The amount of dextral offset initiated at the end of the Miocene has been variably reconstructed at 20÷57 km (Allen *et al.* 1984), 37 km (Tuc & Yem 2001), 40 km (Schoenbohm *et al.* 2005, 2006) or even 200÷250 km (Leloup *et al.* 1995). The size of individual dextral offset of Quaternary valleys within the RRFZ has been calculated, depending on their size, as: 9 m to 6 km, and even 25 km (Allen *et al.* 1984, Weldon *et al.* 1994, Replumaz *et al.* 2001, Schoenbohm *et al.* 2006) to 57 km (Leloup *et al.* 1995, Wang *et al.* 1998) in Yunnan; and 70 m to 17 km (Tuc & Yem 2001), 200÷1200 m (Trinh *et al.* 1993, Trinh 1995), 0.3÷2 km (Lacassin *et al.* 1994) or up to 2 km (Cuong & Zuchiewicz 2001) in Vietnam. The corresponding rates of Quaternary dextral slip range, therefore, between 1 and 9 mm/yr (Allen *et al.* 1984) or 1 and

4 mm/yr (Weldon *et al.* 1994), whereas geodetically measured rates of recent motions do not exceed 4 mm/yr (Cong & Feigl 1999) or 2 mm/yr (To *et al.* 2001). Recently, Schoenbohm *et al.* (2005, 2006) have concluded about continuous dextral, 5 mm/yr, long-term slip rate.

RESULTS OF MORPHOTECTONIC STUDIES

Topolineaments interpreted from remote sensing and cartographic data were plotted for different Red River Fault segments between Chinese-Vietnamese boundary in the NW and Phu Tho area in the SE. These topolineaments are linear features of different length, well visible in the topography. Most of them probably represent faults, since they either displace or deflect river courses. Drainage deflection/offset values were measured for both right- and left-hand tributaries of the Red River on different fault strands. Measurement resolution did not exceed 50 m.

In the NW portion of the RRFZ, close to Chinese-Vietnamese border, the amount of dextral offset and deflection ranges between 420 and 2850 m. Farther SE, the respective values are from 430 to 2140 m, diminishing downstream to 700÷800 m. Farther downstream dextral offsets become longer again, falling into interval between 500÷750 m and even 5300 m. Near Yen Bai, right-lateral river offsets are between 700÷900 m and 1350÷2250 m, then vary between 950 and 1600 m, increasing to 13 720 m near Phu Tho, where the Red River forms a peculiar meander loop.

The obtained figures range from 420 and 550 m to 13720 and 2250 m for the right- and left-hand tributaries, respectively. The respective averages are 2033 and 1140 m, being characterized by relatively high standard deviation values (2419 and 464 m). The number of deflected/offset segments amounts to 29 and 32, respectively. These segments are relatively short and probably represent either separate or two to three (?) combined episodes of displacement. The only exception is a segment, where cumulative effect of several deformational episodes resulted in nearly 13.7 km-long dextral offset of a large meander of the Red River (Fig. 3).

It would be difficult at this moment to speculate about total dextral displacement along the Vietnamese portion of the Red River Fault Zone. The calculated discrete values are associated with different RRFZ strands, running both NE and SW of the river course, and sometimes overlapping one another. The minimum estimates of individual offset/deflection values range from 1.1 to 2 km; their cumulative effect along the Vietnamese segment of the Red River Fault probably not exceeding 14÷15 km, while total cumulative length of the displaced drainage along the 230 km-long segment studied is between 59 and 36.5 km for the right- and left-hand tributaries, respectively. It cannot be excluded that some deflections of the river mouths may represent "false deflection", due to local lithologic variations and/or presence of subsidiary but inactive fault branches.

Field studies conducted in the Red River valley between Trai Hut in the NW and Yen Bai in the SE enabled for identification of three cut-and-fill (2÷3, 4÷6, 8 m) and four to five strath (11÷13, 15÷16, 20, 30, 40÷50 m) terraces. The thickness of gravel covers usually attains 2÷3 m, rarely 5÷7 m. Overbank sediments are thickest within the 8÷9 m terrace. According to preliminary age estimations of Tam (2005), terraces 2÷3 and 4÷5 m were formed in the Holocene, i.e. 2 and 5÷6 ka, whereas those rising 10÷15, 20÷25, and 40÷50 m should be referred to time intervals of 15÷20 (?), 50÷70 (?) and 100÷120 (?) ka, respectively, all of them representing the last glacial stage. Our dating of slope sediments (silts and loamy sands) overlying the

30÷34 and 20 m terraces gives maximum possible OSL ages ranging from 36 to 7 ka, and do not provide hints as to more precise age estimations of the fluvial series. Another possible option is that the uppermost, 40÷50 m high, terrace was shaped during the Eemian or the penultimate glacial stage, or even earlier. Further detailed studies are necessary to constrain the age of fluvial deposition.

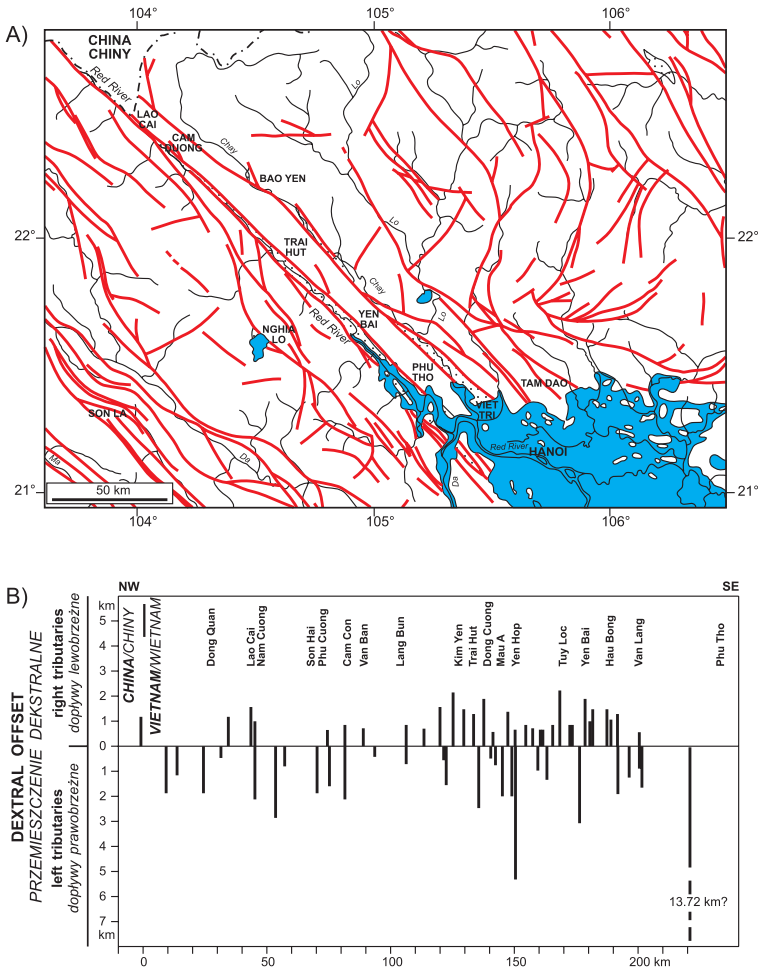

Fig. 3. The Red River Fault Zone in Northern Vietnam and related Oligocene-Miocene (stippled) and Quaternary (blue) sedimentary basins (A); (based on Tri *et al.* 1973 and Zuchiewicz & Cuong 2006; modified), and discrete values of dextral offset of this zone along the Red River course, interpreted from drainage offset and deflection (B)

Fig. 3. Strefa uskokowa Rzeki Czerwonej w północnym Wietnamie i związane z nią oligoceńsko-mioceńskie (pola zakropkowane) oraz czwartorzędowe (pola niebieskie) baseny osadowe (A); (według Tri *et al.* 1973 oraz Zuchiewicza i Cuonga 2006; zmienione). Dolny diagram (B) obrazuje rozmiary prawoskrętnego przemieszczenia wzdłuż wymienionej strefy, interpretowane na podstawie przemieszczenia i defleksji sieci drenażu

The above terrace steps, and particularly those occupying most of the valley bottom and overlain by/interlayered with the material of alluvial fans (i.e. higher than 11 m), are at places dextrally displaced. In the Trai Hut area, the amount of displacement is difficult to constrain, except that it exceeds 50÷150 m, judging from offset of tributary river mouths. Farther SE, the amount of offset on the left river bank attains 675 m, then increases to 750÷700 m. In the Yen Bai area, in turn, right-lateral offset of the SW strand of RRFZ amounts to 3050 m; that on the NE strand attaining first 1900 m and then, farther downstream, 950 and 1500 m. These figures provide very rough estimation of the Late Pleistocene and – possibly – also Holocene offset of young alluvium.

FINAL REMARKS

The minimum estimate of right-lateral offset of tributary valleys along different strands of the RRFZ ranged between some 400 and 5.3 km, averaging at 1.1÷2 km. The cumulative effect of these discrete displacements near Phu Tho amounts to ca. 14 km. Trying to calculate rates of slip for the Quaternary time, we obtain values ranging between 0.43÷1.1 mm/yr for individual displaced segments and 5.5÷7.8 mm/yr for the inferred cumulative displacement. Rates of Holocene dextral slip along the Chay River Fault, paralleling the RRFZ on the north, do not exceed 3 mm/yr (Pho *et al.* 1999), while those recorded on the RRFZ by repeated GPS campaigns average at 2 mm/yr (To *et al.* 2001). Schoenbohm *et al.*'s (2005. 2006) studies in Yunnan point to continuous, long-term slip rate of 5 mm/yr during the past 8 million years in the Chinese segment of the RRFZ.

Judging from fault behaviour in post-Miocene times and the lack of strong seismicity (216 events between 1277 and 1992 AD of average magnuitude 3.5; cf. Cuong & Zuchiewicz, 2001) in historical times leads us to conclude that the axis of maximum horizontal compression associated with dextral slip of the RRFZ was aligned NNW-SSE to N-S, and the fault motion resulted mainly from aseismic creep. The last conclusion stems from the fact that seismically fractured pebbles are confined solely to the Oligocene-Neogene strata, and are absent from Quaternary alluvium.

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