

ACTIVE FAULTING IN NORTH VIETNAM: INSIGHTS FROM MORPHOTECTONIC AND GEODETIC STUDIES ALONG THE RED RIVER AND DIEN BIEN PHU FAULT ZONES

CONTENTS

| | | |
|-------------------------------------|------|-----|
| 1. INTRODUCTION | Pag. | 147 |
| 2. MORPHOTECTONIC AND GEODETIC DATA | " | 148 |
| 3. CONCLUSIONS | " | 149 |

ABSTRACT

The Red River (RRF) and Dien Bien Phu (DBP) faults are very important strike-slip faults in SE Asia. The RRF marks the boundary between the South China and Indochina blocks which was shaped in two phases: during sinistral ductile shear active in 27-16 Ma, followed by exhumation and uplift from a depth of 20-25 km, and as dextral, predominantly brittle shear active in Plio-Quaternary times. The amount of post-Miocene dextral offset has been variously reconstructed at 20 to 57 km, whereas the size of individual offset of Quaternary valleys has been calculated as 9 m to nearly 2 km. The

* Institute of Geological Sciences, Jagiellonian University, Cracow, Poland. E-mail: witold@ing.uj.edu.pl

** Institute of Geological Sciences, Polish Academy of Sciences, Research Center in Cracow, Cracow, Poland

corresponding rates of Quaternary dextral slip range, therefore, between 1 and 9 mm/yr or 1 and 4 mm/yr, whereas geodetically measured rates of recent motions do not exceed 4 mm/yr or 2 mm/yr. Recent morphotectonic observations along the presently sinistral DBP point to a minimum offset for Holocene valleys ranging 6-150 m, that for Pleistocene valleys being 1.2 km to 9.75 km. Faults bounding narrow pull-apart basins in the southern portion of the DBP appear to reveal minimum rates of sinistral strike-slip ranging from 0.6 to 2 mm/yr in Holocene and 0.5-4 mm/yr in middle-late Pleistocene times, whereas rates of Holocene uplift have been 0.4 to 1 mm/yr. Both the RRF and DBP are conjugate faults capable of generating relatively strong earthquakes in the future.

KEY WORDS: Morphotectonics, active faulting, Red River, Dien Bien Phu faults, Vietnam

1. INTRODUCTION

The Red River (RRF) and Dien Bien Phu (DBP) faults are conjugate strike-slip faults which in Pliocene-Quaternary times have shown, respectively, right-lateral and left-lateral sense of motion (Fig. 1). The RRF marks the boundary bet-

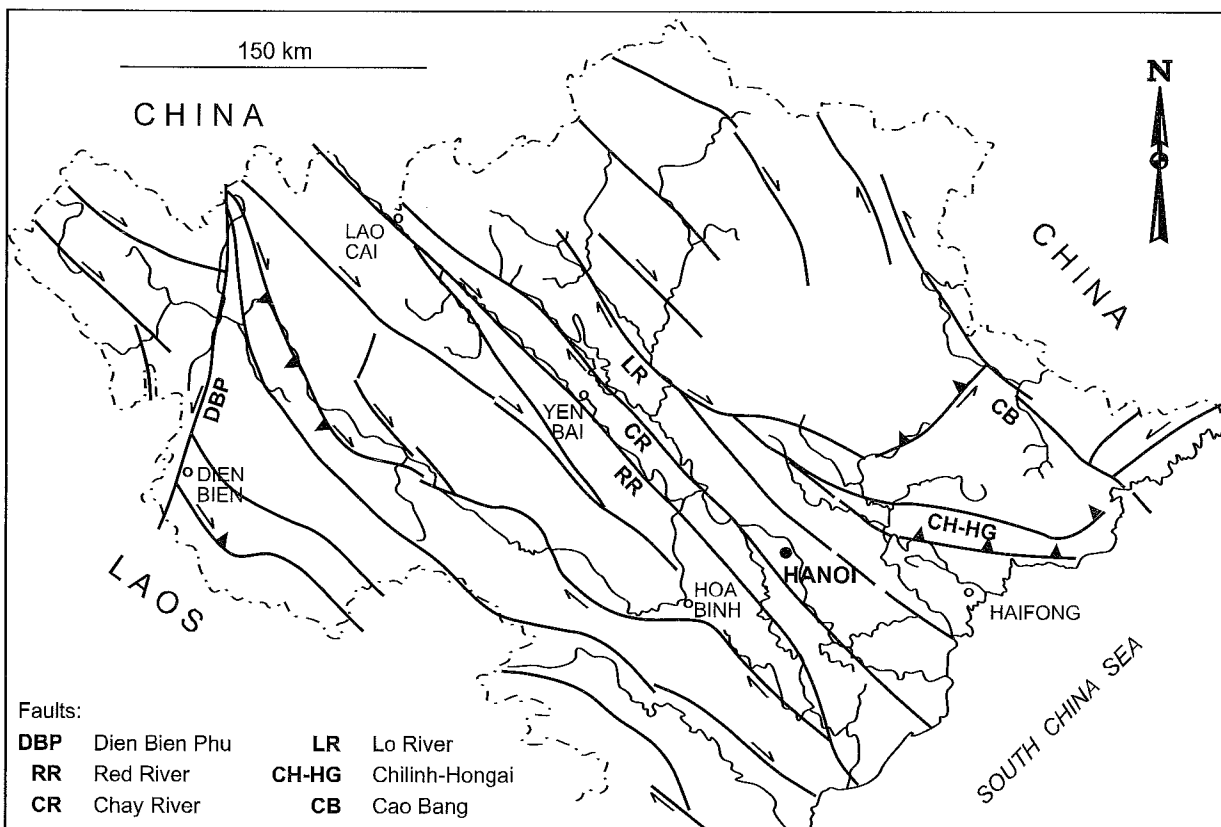


Fig. 1 - Active faults in Northern Vietnam.

ween the South China and Indochina blocks which has been shaped in two phases: during sinistral ductile shear active in 27-16 Ma, followed by exhumation and uplift from a depth of 20-25 km, and as dextral, predominantly brittle shear active in Plio-Quaternary times (LELOUP *et alii*, 1995; and references therein). This change of the sense of motion is related to collision between India and Eurasia (TAPPONNIER *et alii*, 1990). The pre-Pliocene history of the DBP is poorly known, although its recent sinistral character is obvious. Both these zones display different style of seismicity: RRF is seldom accompanied by strong earthquakes, the strongest

event recorded in historical times being 5.9, whereas DBP is the locus of frequent and relatively strong earthquakes of magnitudes 5-6 (max Ms 6.8).

2. MORPHOTECTONIC AND GEODETIC DATA

The NW-SE trending RRF fault trace is accompanied by narrow pull-apart basins and grabens filled with thick Neogene terrestrial strata and relatively thin Quaternary sediments (Fig. 2). Clasts in Neogene congl-

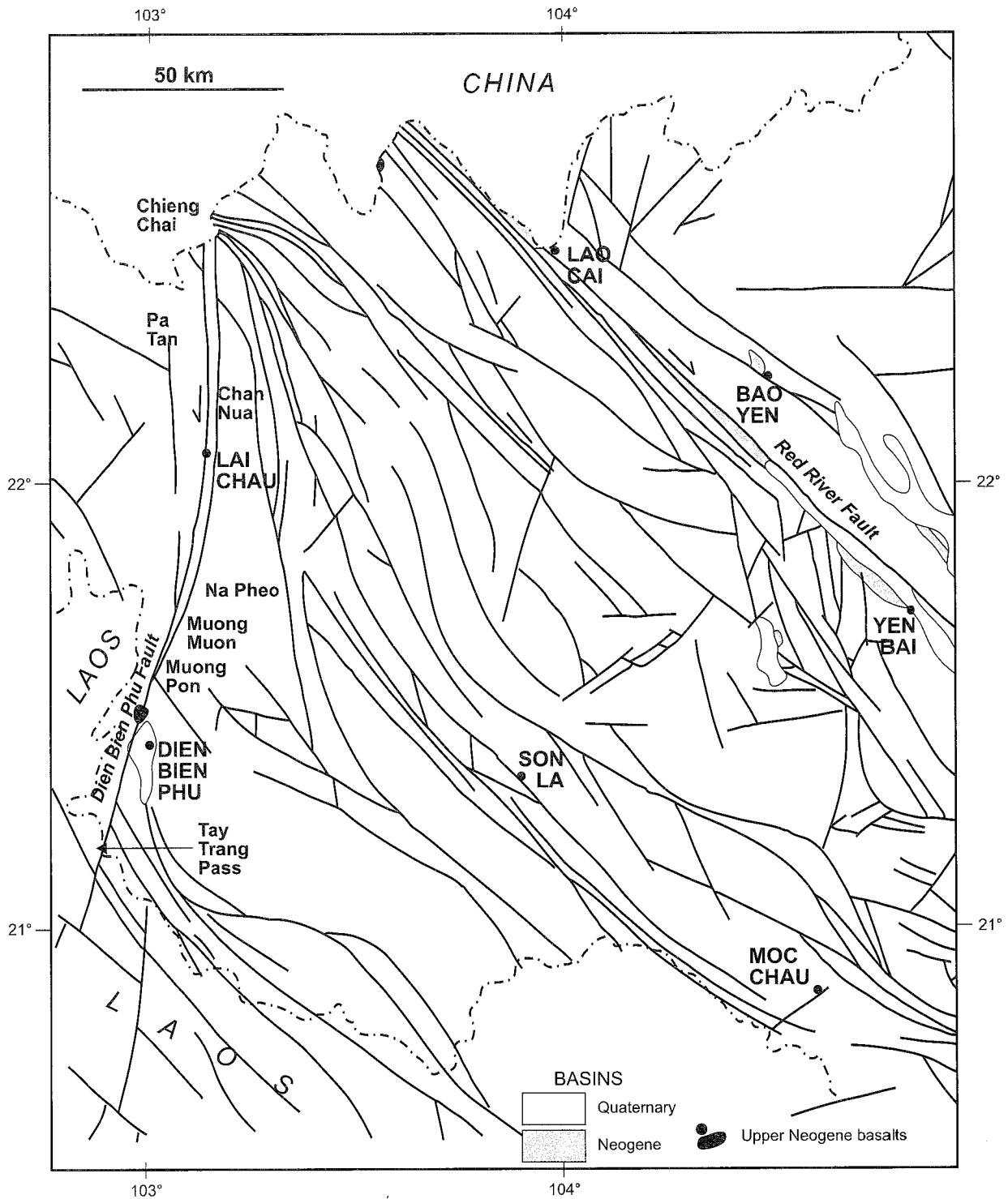


Fig. 2 - The Dien Bien Phu and Red River fault zones in Vietnam (based on TIEN *et alii*, 1991).

merates are commonly fractured, indicating at least three phases of brittle deformation, alternately extensional and compressive ones, the last of them being compatible with the dextral sense of shear. Clasts in Quaternary alluvium are, in turn, not fractured. On the other hand, the N to NNE trending DBP fault is accompanied by pull-apart basins whose size increases southwards and which are filled by Quaternary fluvial sediments, resting on Palaeozoic-Mesozoic bedrock. These sediments are frequently faulted and, at least in the Dien Bien Phu Basin, clasts composing alluvial fans are fractured parallel to the fault trace.

Indicators of recent strike-slip along the RRF and DBP fault segments in Northern Vietnam include drainage offset and deflection (9 m to some 2.0 km along RRF, and 6-50 m to nearly 10 km along DBP), beheaded streams, shutter ridges, en echelon orientated minor fault and fault-line scarps, displaced terraces and alluvial fans, rectilinear fault valleys and long, rectilinear fault scarps. Moreover, the SE and northern portions of, respectively, RRF and DBP faults, display increasing component of normal slip, as testified to by well-preserved triangular facets on fault scarps, highly elevated straths in river gorges, and overhanging valleys.

The size of individual offset of Quaternary valleys along the RRF has been calculated, depending on their size, as: 9 m to 6 km (ALLEN *et alii*, 1984), 70 m to 17 km (TUC & YEM, 2001), 200-1200 m (TRINH *et alii*, 1993; TRINH, 1995), 0.3-2 km (LACASSIN *et alii*, 1994) or up to 2 km (CUONG & ZUCHIEWICZ, 2001). The corresponding rates of Quaternary dextral slip range, therefore, between 1 and 9 mm/yr (ALLEN *et alii*, 1984) or 1 and 4 mm/yr (WELDON *et alii*, 1994), whereas geodetically (GPS) measured rates of recent motions do not exceed 4 mm/yr (CONG & FEIGL, 1999; TO *et alii*, 1999) or 2 mm/yr (TO *et alii*, 2001). The amount of post-Miocene unroofing in the RRF zone can be estimated at 800 m in the Yunnan Province (ALLEN *et alii*, 1984), to 950-1240 m, 500-1000 m, and 300 m in the upper, medial, and lower SE reaches, respectively.

Displaced terraces and alluvial fans allow us to suppose that the sinistral and sinistral-normal faults bounding narrow pull-apart basins in the Vietnamese portion of the DBP fault reveal minimum rates of left-lateral strike-slip ranging from 0.6 to 2 mm/yr in Holocene and 0.5-3.8 mm/yr in Pleistocene times, whereas rates of Holocene uplift tend to attain 1 mm/yr in the north, and 0.4-0.6 mm/yr in the south. More precise estimations, however, are difficult to obtain due to poor age control of the displaced drainage. Geodetic data, although scarce, point to some 1 mm/yr of recent uplift east of the DBP fault (cf. VIET, 2001). The amount of erosional downcutting along the fault zone changes from 900-1150 m in the northern, through 600-750 m to 1500 m in the medial, to 660-950 m in the southern portion.

Rates of Quaternary strike-slip are comparable with those of the RRF; the sense of movement being, however, opposite. The onset of fluvial incision in both fault zones is difficult to constrain; it probably coincides with the early Pliocene uplift of the Tibetan Plateau (cf., e.g., ALLEN *et alii*, 1984). Hence, maximum long-term uplift

rates along RRF and DBP can be roughly calculated as 0.06 to 0.24 mm/yr, and 0.12 to 0.29 mm/yr, respectively. The highest figures are confined to the NW portion of RRF, and the medial segment of DBP.

3. CONCLUSIONS

Morphotectonic and geodetic observations presented in this paper along the Red River (RRF) and Dien Bien Phu (DBP) faults indicate the presence of two phases of Late Cenozoic strike-slip of contrasting sense of motion. On the bases of these observations and take into account the geometry of the two fault zones, we hypothesize that the Red River and Dien Bien Phu faults are conjugate faults capable of generating relatively strong earthquakes in the future.

ACKNOWLEDGEMENTS

This study was supported through a Polish Committee for Scientific Research (KBN) grant no. 6 PO4E 026 018 (to W. Zuchiewicz) and by Galicia T. Group.

REFERENCES

- ALLEN C. R., GILLESPIE A. R., YUAN H., SIEH K. E., BUCHUN ZH. & CHENG NAN ZH. (1984) - *Red River and associated faults, Yunnan Province, China: Quaternary geology, slip rates, and seismic hazard*. Geol. Soc. Am. Bull., **95**, 686-700.
- CONG D. C. & FEIGL K. L. (1999) - *Geodetic measurement of horizontal strain across the Red River Fault near Thac Ba, Vietnam, 1963-1994*. J. Geod., **73**, 298-310.
- CUONG N. Q. & ZUCHIEWICZ W. A. (2001) - *Morphotectonic properties of the Lo River Fault near Tam Dao in North Vietnam*. Natural Hazards and Earth System Sciences, **1**, 15-22.
- LACASSIN R., TAPPONNIER P., LELOUP H. P., TRINH P. T. & YEM N. T. (1994) - *Morphotectonic evidence for active movements along the Red River fault zone*. In: Actes du Colloque Int. sur la sismotectonique et la risque sismique en Asie du Sud Est, 27 Janv.-4 Fevr. 1994, Hanoi, pp. 66-71.
- LELOUP P. H., LACASSIN R., TAPPONNIER P., SCHAEERER U., ZHONG D., LIU X., ZHANG L., JI S. & TRINH P. T. (1995) - *The Ailao Shan - Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina*. Tectonophysics, **251**, 3-84.
- TAPPONNIER P., LACASSIN R., LELOUP P. H., SCHAEERER U., ZHONG D., HAIWEI W., LIU X., JI S., ZHANG L. & ZHONG J. (1990) - *The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China*. Nature, **343**, 431-437.
- TIEN P. C. *et alii* (1991) - *Geological map of Cambodia, Laos, and Vietnam, 1:1,000,000*. The Geological Survey of Vietnam, Hanoi.
- TO T. D., YEM N. T., CONG D. C., HAI V. Q., BECKER M. H., REINHART E. & MICHEL G. W. (1999) - *GPS measu-*

- rements across the Red River fault from 1994 to 1998. 1999 AGU Fall Meeting, Crustal Deformation I - Asia and the Pacific, Poster G 51C-13.
- TO T. D., YEM N. T., FEIGL K., CONG D. C. & HAI V. Q. (2001) - *The activity of Red River Fault Zone derived from GPS data*. J. Earth Sci., **23**, 436-441, Hanoi.
- TRINH P. T. (1995) - *Influence des failles actives sur les réservoirs de Hoabinh et de la rivi re Chay (nord du Viet Nam)*. In: Dubois, J. M. M., Boussema, M. R., Boivin, F. & Lafrance, P. (Eds.), *Téledétection des ressources en eau. Actes des Journées scientifiques de Tunis 1993*. Universités Francophones, Actualité Scientifique. Aupelf, Sainte-Foy-Montréal, pp. 31-42.
- TRINH P. T., LACASSIN R., TAPPONNIER P., LELOUP P. H. & YEM N. T. (1993) - *Evidence for active strike-slip movements in Northwestern Vietnam*. Terra Abstracts, Suppl. 1 to Terra Nova, **5**, 265.
- TUC N. D. & YEM N. T. (2001) - *Amplitude and rate of slip of the Red River Zone in late Cenozoic (in Vietnamese with English abstract)*. J. Earth Sci., **23**, 344-353, Hanoi.
- VIET L. T. (2001) - *About neotectonic and geodynamic regime of Northern Vietnam in Cenozoic*. J. Earth Sci., **23**, 390-395, Hanoi.
- WELDON R., SIEH K., ZHU O., HAN Y., YANG J. & ROBINSON S. (1994) - *Slip rate and recurrence interval of earthquakes on the Hong He (Red River) fault, Yunnan, PRC*. In: *Int. Workshop on Seismotectonics and Seismic Hazard in South-East Asia*, Hanoi, pp. 244-248.