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Tectonically-controlled sedimentation of Cenozoic deposits from selected basins along the Vietnamese segment of the Red River Fault Zone

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ABSTRACT:

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Small, narrow sedimentary basins occur along the main faults in the Vietnamese segment of the Red River Fault Zone (RRFZ), which is the major discontinuity separating the South China and Indochina microplates. The sedimentary basins of the RRFZ are grouped into three main sections: along the Red River Valley, the Chay River Valley and the Lo River Valley. The sedimentary basins are filled with thick series of Palaeogene and Neogene clastic deposits that differ in type and origin. In the lower part of the basin fill, coarse-grained deposits predominate. In the upper part, different types of sandstones, siltstones and brown coal occur. There are no sediments of Late Pliocene age. Quaternary deposits are represented by sands and gravels. Biostratigraphical data are very poor, therefore only lithostratigraphical subdivision is applied. Thus, it is possible that deposits from adjacent basins associated with the RRFZ represent strata of different ages.

The investigations were focused on the Lo River Basin (associated with the Chay River fault), Yen Bai Basin (associated with the Red River fault) and Co Tiet Basin (associated with the southwesternmost branch of the Red River fault). Thirteen sedimentary facies were recognised in deposits filling the investigated basins. The facies were grouped into five facies associations representing five distinct depositional environments. These comprise alluvial fan, gravel-dominated fluvial channel, sand-dominated fluvial channel, alluvial plain and lacustrine environments. In addition, the basin fills show features characteristic of strike-slip basins.

Key words: Alluvial system, Braided river, Tectonic-sedimentation, Provenance, Red River Fault Zone, Vietnam.

INTRODUCTION

Several sedimentary basins are associated with the main faults in the Vietnamese segment of the Red River Fault Zone (RRFZ) (Text-fig. 1). The basins are filled with Eocene-Pliocene continental clastic deposits (YEM 1985). The origin of the basins is probably related to the activity of the RRFZ (BAT 2000; LELOUP & *al*. 2001), which is a major strike-slip fault zone separating the South China and Indochina microplates (Text-fig. 1B). Therefore, the depositional pattern of these basins should depend on the development of the RRFZ.

A number of studies have documented depositional patterns within basins delimited by transcurrent faults

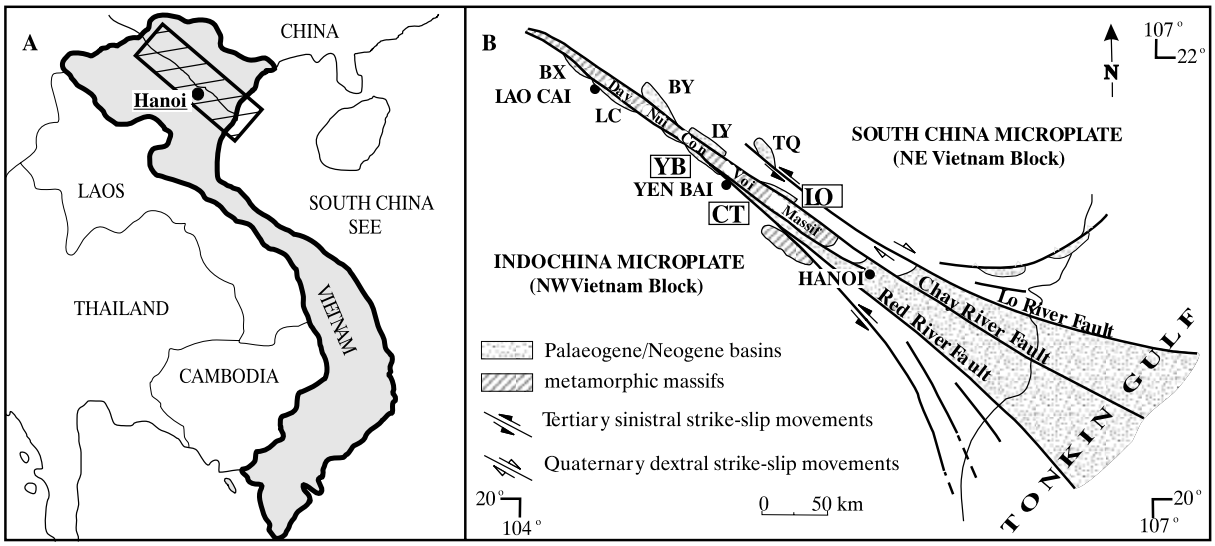

Fig. 1. Location of the study area in northwestern Vietnam (A) and its tectonic pattern with the sedimentary basins along the RRFZ (in box - localities of investigated basins): **BX** – Bat Xat, **LC** – Lao Cai, **BY** – Bao Yen, **LY** – Luc Yen, **YB** – Yen Bay, **TQ** – Tuyen Quang, **CT** – Co Tiet, and **LO** – Lo River (B)

(see e.g. CROWELL & LINK 1982; MCLAUGHLIN & NILSEN 1982; HEMPTON & DUNNE 1984; STEEL 1988; DOOLEY & MCCLAY 1997; RYANG & CHOUGH 1999). However, it is important to realise that tectonic activity in a transcurrent fault setting may create different structural styles along different segments of the fault, resulting in the formation of different types of basins (NILSEN & SYLVESTER 1995), such as fault-bend basins, pull-apart basins, transrotational basins and transpressional basins.

The paper presents the results of the sedimentological analysis of various sedimentary facies deposited in the study basins. The investigations were conducted in the northwestern part of Vietnam by a Polish-Vietnamese group of geologists and were focused on the basin fills (WYSOCKA & *al*. 2001; COUNG & *al*. 2002; WYSOCKA & ŚWIERCZEWSKA 2003).

TECTONIC AND GEOLOGICAL SETTING

In Vietnam the RRFZ is about 300 kilometres long. It trends NW-SE and is covered by Cenozoic sediments of the Hanoi Trough (Text-fig. 1B). The Chay River (Song Chay) and the Red River (Song Hong) faults are major faults of the RRFZ, which bound the Day Nui Con Voi massif from the NE and SW, respectively. The prominent Lo River (Song Lo) fault occurs to the NE of the RRFZ (Text-fig. 1B), running subparallel to it.

The RRFZ is the main structural element of southeastern Asia and can be followed from Tibet to the South China Sea for over 1000 kilometres. Left-lateral shearing along the RRFZ is dated as Oligocene and Miocene. At that time, this narrow zone acted like a continental transform plate boundary (LELOUP & *al*. 1995). Estimates of left-lateral offsets of geological features along the shear zone calculated by TAPPONNIER & *al.* (1990) range between 300 and 700 kilometres. However, the offset for the RRFZ in the area of the Tonkin Gulf probably does not exceed a few tens of kilometres (RANGIN & *al*. 1995). New $^{40}Ar/^{39}Ar$ data from the south-eastern exposure of the Day Nui Con Voi metamorphic massif in Vietnam suggest that the exhumation of the metamorphic massif along the RRFZ began at ~27 Ma B.P. and lasted until ~22 Ma (WANG 2000). Moreover, the initiation time of both denudation in the Day Nui Con Voi massif and subsidence was about 28 Ma (Late Oligocene). The rapid cooling of the massif from 350°C to below 150°C occurred between 25 and 22 Ma (LELOUP & *al*. 2001). At present, this zone corresponds to right-lateral movements, which started about 5.5 Ma ago (e.g. ALLEN & *al*. 1984; LELOUP & *al*. 1995; TAPPONNIER & *al*. 1990). The right-lateral offset ranges between 5.5 and 30 kilometres (ALLEN & *al*. 1984). New data from the Lo River Fault (one of the branches of the RRFZ in Vietnam) point to Quaternary dextral slip rates between 1 and 2 mm × a^{-1} (CUONG & *al*. 2001; CUONG & ZUCHIEWICZ 2001).

Several Palaeogene/Neogene sedimentary basins occur in the area between the Lo River and Chay River Faults, close to both faults, as well as along the Red River Fault (Text-fig. 1B). The sedimentary basins from

Era	Period	Epoch	Stage	In Central Part of the Red River Trough	Along the Red River Valley	Along the Lo River Valley
CENOZOIC	QUARTERNARY	HOLOCENE		**THAI BINH:** sand, silt, clayey mud	**Flooded zone**: unconsolidated sand, silt, clay	
		HOLOCENE / PLEISTOCENE		**HAI HUNG:** sandy silt and sandy clay		
		PLEISTOCENE		**VINH PHUC:** sand and silty sand	**Lower Terrace** — conglomerate with gravel, poor consolidated sand	
				HAI DUONG: coarse sand and gravel	**Higher Terrace**	
	NEOGENE	PLIOCENE	N_2	**VINH BAO:** fine sandstone with intercalations of thin bedded claystone and siltstone (vb)		
		MIOCENE	N_1^3	**TIEN HUNG:** coarse and medium-grained sandstone with gravel, intercalated by siltstone, claystone and brown coal (th)	**SONG HONG 4 (sh4):** thin bedded sandstone, siltstone	**SONG LO 3 (sl3):** conglomerate, gravel, sandstone, siltstone
			N_1^2	**PHU CU:** - Upper: claystone, siltstone intercalated by sandstone and brown coal with flora - Lower: thin bedded coarse sandstone with glauconite and marine fauna (pc)	**SONG HONG 3 (sh3):** - Upper: fine sandstone, siltstone, claystone with brown coal - Lower: conglomerate, gravel, silty sandstone	**SONG LO 2 (sl2):** - Upper: fine sediments, thin bedded coal, marly claystone with siderite - Lower: conglomerate, gravel
			N_1^1	**PHONG CHAU:** - Upper: intercalations of sandstone, siltstone and claystone with glauconite, siderite, pyrite - Lower: sandstones with thin clayey siltstone intercalations (pch)		
				THUY ANH: coarse and medium-grained sandstone with intercalations of conglomerate, gravel and siltstone (ta)	**SONG HONG 2 (sh2):** - Upper: coarse sandstone, coaly claystone, flora - Lower: conglomerate, breccia	**SONG LO 1 (sl1):** conglomerate, polymictic conglomerate, gravelite
	PALAEOGENE	OLIGOCENE	P_3	**DINH CAO:** claystones, conglomerates, siltstones with intercalations of breccias (dc)	**SONG HONG 1 (sh1):** olistostrome-formed conglomerate, breccia, gravelite	
		EOC.	P_2	**PHU TIEN:** claystones, conglomerates, breccia, with intercalations of olistostrome-formed sandstone, siltstone, argilite (pt)		

Fig. 2. Stratigraphical scheme of the Cenozoic deposits in the sedimentary basins developed along the Red River Fault Zone in Vietnam (modified after YEM 1985)

the RRFZ are grouped into three main sections: in the central part of the Red River trough, along the Red River Valley and along the Lo River Valley (Text-fig. 2) (YEM 1985). The basins are filled with clastic deposits, differing in type and origin. In the lower part of the sections, coarse-grained deposits with blocks of olistostrome-type predominate. In the upper part, different types of sandstones, siltstones and other fine deposits occur, sometimes with brown coal intercalations. Unfortunately, in the sections along the Red River Valley and along the Lo River Valley there are no good biostratigraphical markers, therefore the stratigraphy is based on the lithology.

The basins studied are located in sections along the Red River Valley and the Lo River Valley. Infilling of these basins (Text-fig. 2) started from coarse deposits of conglomerate-type, followed by fine sediments such as sandstones and marly claystones with fine-bedded coal intercalations and occasionally with siderite. Conglomerates, sandstones and siltstones terminate the Miocene sequence. There are no sediments of Late Pliocene age. Sands and gravels represent Quaternary deposits.

MATERIAL

The present research was carried out along the banks of the Lo River and the Red River, and was the first sedimentological investigation of basins from the Vietnamese segment of the RRFZ. In Vietnamese literature, the basins located north to the Day Nui Con Voi Massif are called (from north to south): Bao Yen, Luc Yen, Tuyen Quang and Lo River (Text-fig. 1B). The basins located south to the Day Nui Con Voi Massif are called (from north to south): Bat Xat, Lao Cai, Yen Bay and Co Tiet (Text-fig. 1B). Detailed lithological sections were constructed for the Lo River, Yen Bai and Co Tiet basins. The investigations were focused mainly on the Lo River basin fills (WYSOCKA & ŚWIERCZEWSKA 2003).

FACIES ASSOCIATIONS

Thirteen sedimentary facies (based on MIALL 1977, 1978) were recognised in the Lo River, Yen Bai and Co Tiet basin fills (Tab. 1). The facies were grouped into five facies associations (based on NICHOLS 1999) representing five distinct depositional environments. These comprise: alluvial fan (Facies Association I), gravel-dominated fluvial channel (Facies Association II), sand-dominated fluvial channel (Facies Association III), alluvial plain (Facies Association IV) and lacustrine (Facies Association V) environments.

Facies Association I – alluvial fan

This facies association is represented by decimetre- to several metres thick, sand- and mud-supported disorganised pebble- to cobble-size, occasionally boulder (Text-fig. 3D) breccia and conglomerate beds (facies Gb, Gh, Gms and Sm; Table 1) (Text-figs 3A, B). Most of the beds are massive (Text-figs 3D, E), sometimes with recognisable top and bottom surfaces. Locally, normal grading is discernible. The conglomerate beds are tabular, or broadly lenticular in shape. In some cases, the contact with the underlying or overlying deposits of the other facies association is sharp and of an erosive character (Text-fig. 3E).

The thick matrix-supported and disorganised conglomerate bodies indicate deposition by high-concentration flows or debris-flows (e.g. NEMEC & STEEL 1984; NEMEC & POSTMA 1993). The occurrence of these conglomerate bodies within and/or overlapping the coarse-sand deposits of facies association II suggests deposition in an alluvial-fan setting associated with active fault scarps.

Facies Association II – gravel-dominated fluvial channel

This facies association is composed predominantly of sand- and clast-supported, poorly to well sorted, subrounded to well-rounded pebble to cobble conglomerates (Text-fig. 3C), and poorly sorted pebbly sandstones (facies Gt, Glg, Sm; Tab. 1). Facies Glg is represented by centimetre- to decimetre-thick crudely bedded clast-supported cobble conglomerates. They have erosive bases and show a rapid upward-fining trend in the topmost part of the beds. This facies can be interpreted as the basal gravel lag of a barform (e.g. ZIELIŃSKI 1997; VINCENT 2001), particularly because it was observed below the trough cross-stratified (facies Gt) and/or massive pebbly sandstones (facies Sm). Massive or poorly stratified reddish siltstones, commonly alternating with sandy siltstones (Text-fig. 5A), commonly occur above facies Gt and Sm.

Facies association II is composed of repetitive fining-upward cycles, usually more than 2 metres thick. Such features indicate deposition of barforms by bedload transport with variable fluid flow and sediment discharge. These features are characteristic of gravel-dominated fluvial channels. In some cases, siltstones occur at the top of some cycles, pointing to relatively low energy of processes and sedimentation rates.

Table 1. Lithofacies identified in the study [lithofacies code based on MIALL (1977, 1978 and 1996)]

Lithofacies	Description	Interpretation
Sand- and mud-supported disorganised breccias (Gb)	Decimetre thick; poorly defined, discontinuous beds; pebble- to cobble-size and angular to subrounded clasts; sand to mud matrix.	Deposition from debris and/or high-concentration flow.
Massive or amalgamated bodies of conglomerates (Gh)	Up to several metres thick; highly amalgamated; cobble-size and sub-rounded to well-rounded clasts; clast- to sand-supported; undefined base and top.	Deposition from high-concentration flow.
Sand- and mud-supported disorganised conglomerates (Gms)	Up to two metres thick; highly amalgamated; pebble- to cobble-size and sub-rounded to well-rounded clasts; fining-upwards trend; sand- to mud matrix; may be erosively based.	Deposition from high-concentration flow.
Crudely bedded conglomerates (Glg)	Decimetre thick; cobble-size and sub-rounded to well-rounded clasts; clast supported; rapid finning-upwards at top; erosively based.	Lag deposits; size segregation due to winnowing at erosive surfaces or during barform migration.
Planar and trough cross-stratified sand-supported conglomerates (Gt)	Up to several metres thick; highly amalgamated; low angle trough cross-stratified; pebble-size and sub-rounded to well-rounded clasts; gravel patches with partly open-work fabric common; very coarse to coarse sand matrix.	Bedload transport; downstream migration of sinuous-crested barforms.
Massive or amalgamated beds of sandstones (Sm)	Up to several metres thick; poorly defined beds; poorly sorted; isolated pebbly sandstones lenticles and layers; occasionally normally graded; often developed above the Gt or Glg lithofacies as part of a fining upwards trend.	Upper plane bed flow.
Planar and trough cross-stratified sandstones (Sp/St)	Variable thickness of sets (up to 1 m); poorly to well sorted; medium to coarse grained; low angle bounding surfaces; occasionally coalified flora fragments, muddy intraclasts occur.	Downstream migration of ripple and dune scale sinuous- (St) or straight-crested (Sp) barforms, in same cases falling to low stage gravelly barform modifications.
Ripple cross-laminated sandstones (Sr)	Thin sets (up to 10 cm); well sorted; fine-grained; asymmetrical ripples.	Downstream migration of ripple scale barforms
Convolute-laminated sandstones (Sc) with normal grading (Sng)	Horizontally stratified fine sandstones; common normal grading; occasionally beds with disturbed lamination of convolute or slump type.	Deposition from a current gradually decreasing in velocity. Occasionally liquefication of sediment.
Reddish siltstones (Fr)	Generally thick (a few metres); massive or poorly stratified; commonly alternated with sandy siltstones; occasionally pedogenic (?) structures.	Deposition of fine grains on alluvial plain; oxidising conditions during and after deposition.
Grey siltstones with clayey and coal interbeds (Fg/C)	Up to 50 cm; stratified; coal layers up to 5 cm.	Deposition of fine grains and organic matter on alluvial plain.
Orange claystones (Fm)	Generally thick (a few metres); massive; alternated with coal beds.	At this state of study – unclear.
Coal beds (C)	Up to 1 metre thick; massive; without visible flora fragments.	Phytogenic accumulation.

Facies Association III – sand-dominated fluvial channel

This facies association is composed of poorly- to well-sorted, medium- to coarse-grained, occasionally fine-grained sandstones (facies St, Sp, Sr and Gt, Sm; Tab. 1). Facies St and Sp are represented by centimetre- to decimetre-thick sets (Text-fig. 4B) building metre-thick cosets (Text-fig. 4A). Coalified flora fragments and muddy intraclasts are commonly dispersed within the fine-grained sandstones. Occasionally, in the Lo River and Yen Bai basins, synsedimentary folds also occur between the undisturbed sandstone strata (Text-fig. 4F). The alternation of sandy facies St/Sp/Sr with coarse sediment admixtures indicates deposition by bedload transport in sand-

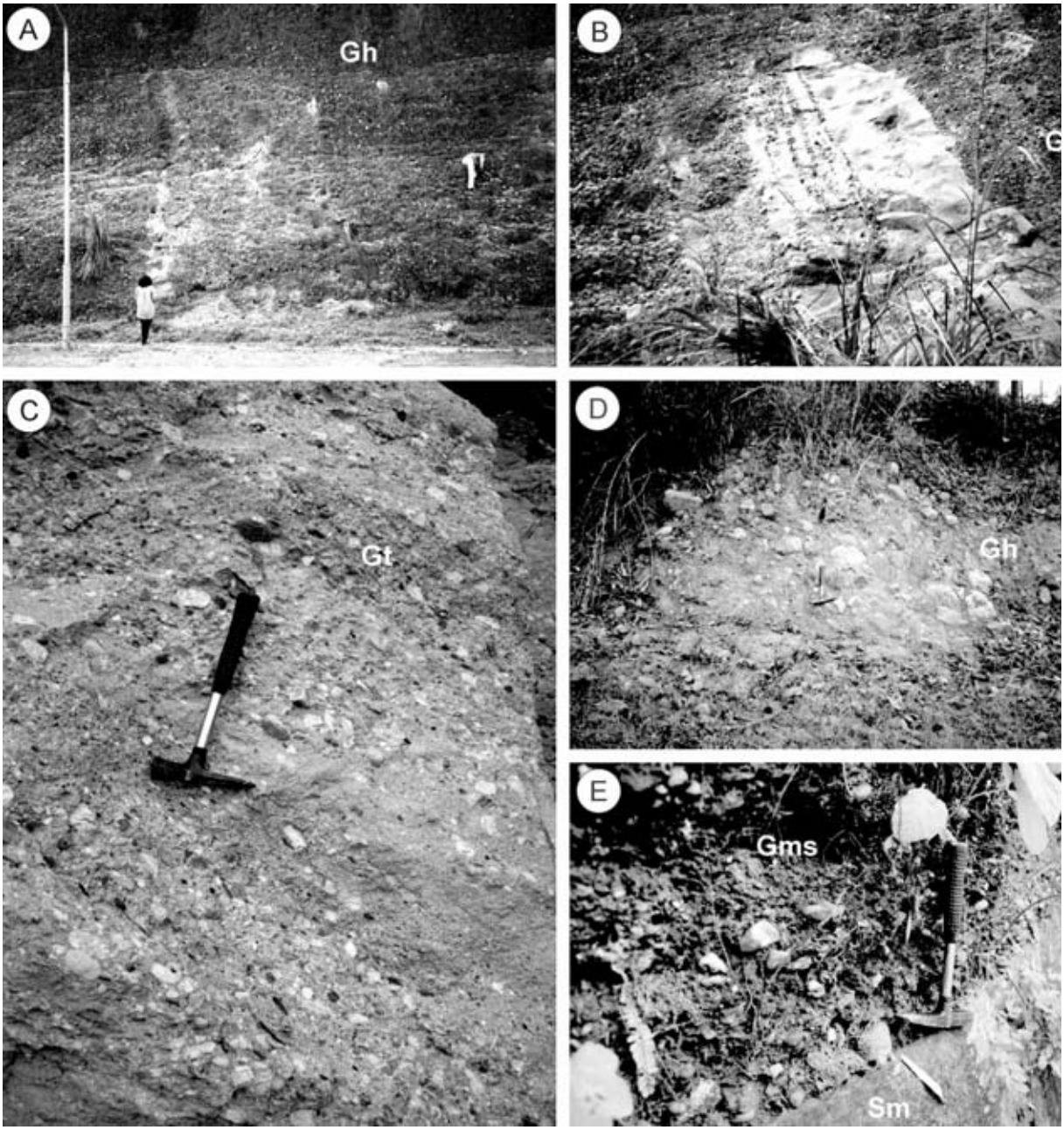

Fig. 3. Gravel-dominated lithofacies. Hammer is 30 cm long. (A) General view of the conglomerate body; Yen Bai basin, Co Phuc section. (B) Massive conglomerate body with amalgamated sandstone lens; Yen Bai basin, Co Phuc section. (C) Horizontal alternating stratified conglomerates and sandstones; Lo River basin, Xom Dom section. (D) Cobble-size massive conglomerates; Co Tiet basin, Phong Chau section. (E) Sharp contact between sand-supported disorganised conglomerate and massive sandstone; Lo River basin, Xom Dom section

dominated fluvial channels. Migration of sinuous- and straight-crested barform dunes covered with ripples (Text-fig. 4E) was the chief sedimentary process, pointing to a continuous, highly variable sediment discharge.

Facies association IV – alluvial plain

This facies association is dominated by reddish siltstones (facies Fr; Tab. 1; Text-fig. 5A) and grey silt-

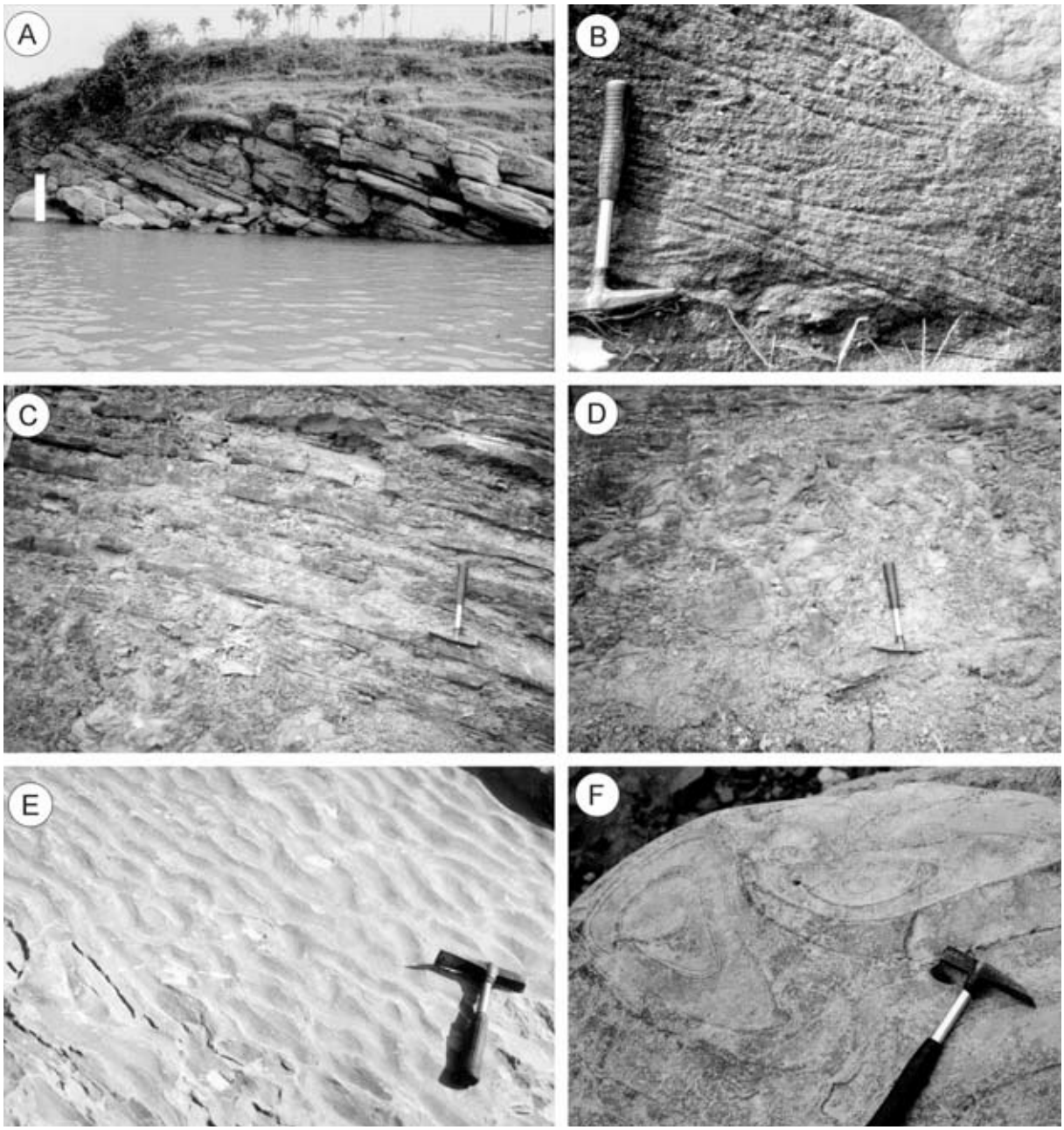

Fig. 4. Sand-dominated lithofacies. (A) General view of the planar and trough cross-stratified sandstones; Lo River basin, Tri Quan section. The scale bar is ca. 1 m. (B) Set of coarse-grained planar and trough cross-stratified sandstones, Lo River basin, Bach Luu section. Hammer is 30 cm long. (C) Horizontally stratified fine- to very fine-grained sandstones, normal grading with siltstone interbeds; Yen Bai basin, Co Phuc section. Hammer is 30 cm long. (D) Deformations within horizontally stratified fine- to very fine-grained sandstones with siltstone interbeds, Yen Bai basin, Co Phuc section. Hammer is 30 cm long. (E) Surface of fine-grained sandstones covered by straight-crested small current ripples; Lo River basin, Bach Luu section. Hammer is 30 cm long. (F) The top view of a sandstone bed with synsedimentary folds (the surface intersects the folds); Lo River basin, Tam Son section. Hammer is 30 cm long

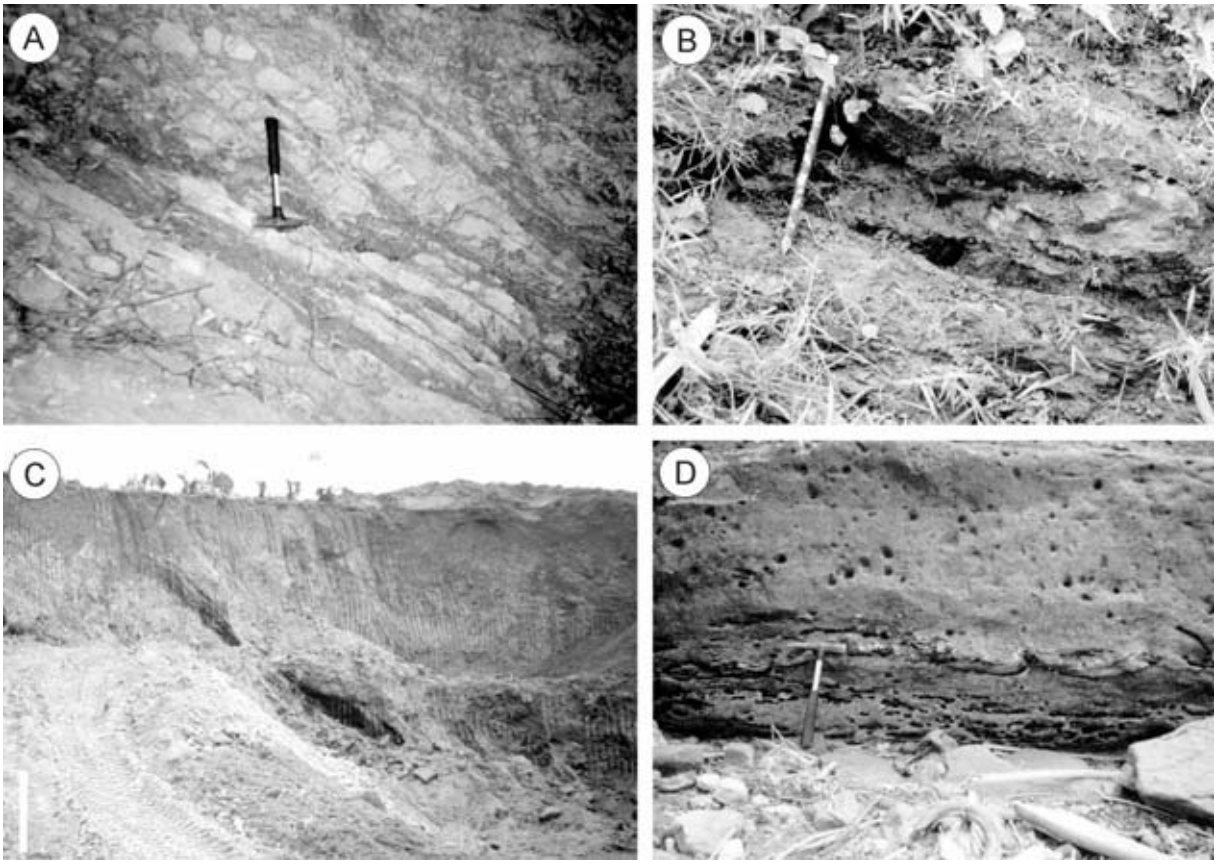

Fig. 5. Silt- and mud-dominated lithofacies. (A) Thin-bedded sandy siltstones; Lo River Basin, Xom Dom section. Hammer is 30 cm long. (B) Coal lens within grey siltstones; Lo River Basin, Xom Dom section. Pencil is 17 cm long. (C) Massive coal beds within orange claystones; Yen Bai basin, Co Phuc section. Scale bar is ca. 2 m. (D) Mud curls and flakes from fine-grained sandstones; Lo River basin, Tam Son section. Hammer is 30 cm long

stones (facies Fg; Tab. 1). The latter contain clayey and coal lenses and layers (facies Fg/C; Tab. 1; Text-fig. 5B), and in some cases also clayey intraclasts such as mud curls and flakes (Text-fig. 5D). The reddish siltstones commonly contain fine-grained sandstone interbeds and calcareous nodules of probably pedogenic origin. As a rule, the reddish siltstones terminate the fining-upward successions of facies association II from the Lo River Basin.

The thick reddish siltstones capping the fining-upward successions indicate deposition during the lowest velocity flow. The red colour of these siltstones may suggest oxidising conditions during or after deposition. Pedogenic structures are indicative of occasional subaerial exposure. Coal and clayey lenses (Text-fig. 5B) within the grey siltstones point to high organic influx and to deposition in standing bodies of water. The development of reddish and grey siltstone facies is indicative of deposition within an alluvial plain.

Facies association V – lacustrine

This facies association is poorly documented at present, because neither freshwater faunas nor pollen grains were found in the samples collected. Facies association V, which is probably of lacustrine origin, was found only in the Yen Bai basin. It is dominated by horizontally stratified, fine- to very fine-grained, normally graded sandstones with siltstone interbeds (facies Sng; Tab. 1; Text-fig. 4C). Centimetre-thick, normally graded sandstone layers may be interpreted as formed by low-density turbidity currents. Synsedimentary soft-sediment deformations (Text-fig. 4D) within the sandstone layers can be interpreted as an effect of liquefaction or sliding. Orange massive claystones with thick coal beds (facies Fm and C; Tab. 1; Text-fig. 5C) were also noted in the Yen Bai basin. They point to an intensive rate of phytogenic accumulation associated with high water-table and low clastic sediment input.

BASIN CHARACTERISTICS

Lo River basin

The Lo River basin is the best-studied basin from the Vietnamese segment of the RRFZ (COUNG & *al*. 2002; WYSOCKA & ŚWIERCZEWSKA 2003). It trends NW-SE and is about 40 kilometres long and up to 5 kilometres wide (Text-fig. 6A). The basin is filled with over 6000 m of clastic deposits (Text-fig. 6B), which dip at ca. 20° S and range in age from probably he Late Oligocene/Early Miocene (YEM 1995) up to the Late Miocene (NHAN & DANH 1975). The present-day Lo River Basin is triangular in shape: the Chay River Fault constitutes the southern margin (Text-fig. 6A), while the northern border is formed by a normal fault, running obliquely to the master Chay River Fault. The high-grade metamorphic Day Nui Con Voi massif occurs southwest of the basin. It is built of garnet-biotite-sillimanite gneiss and garnet-biotite gneiss, with subordinate two-mica schists with garnet, amphibolite, migmatite and marble (TRI 1973; NAM & *al*. 1998). Northeast of the basin, the Upper Proterozoic-Lower Palaeozoic low-grade metamorphic and sedimentary rocks of the Viet Bac fold zone form the area between the Lo River and Chay River faults. Several small granitoid intrusions also crop out in this area. The rhyolitic Tam Dao Massif of Triassic age occurs in the NE limb of the Lo River Fault (Text-fig. 6A).

Deposits from the Lo River basin equivalent to Song Lo 2 from Text-fig. 2), namely the Lo River Sequence (WYSOCKA & ŚWIECZEWSKA 2003), can be divided into three units (WYSOCKA & ŚWIECZEWSKA 2003): Vu Quang (~ 3 km thick), Tri Quan (~ 2 km thick) and Tam Son (~ 1 km thick) (Text-fig. 6B). The Vu Quang unit, comprising the Vu Quang and Xom Dom sections (Text-figs 6B, 7), is characterised by gravel-dominated fluvial channel deposits (facies associa-

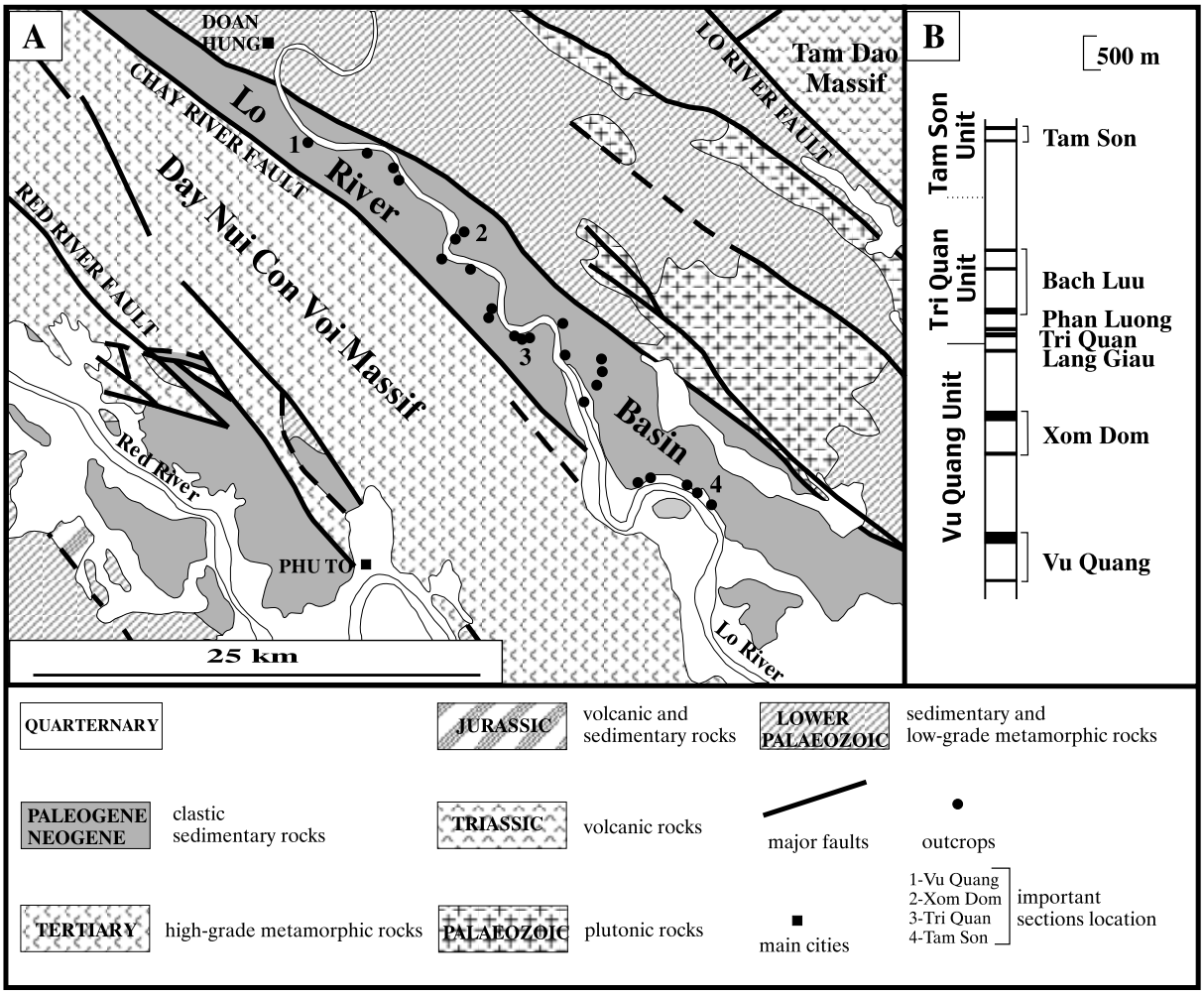

Fig. 6. Geological sketch map showing the location of the Lo River Basin (A). Summary log of the Lo River Sequence with location of studied sections (B)

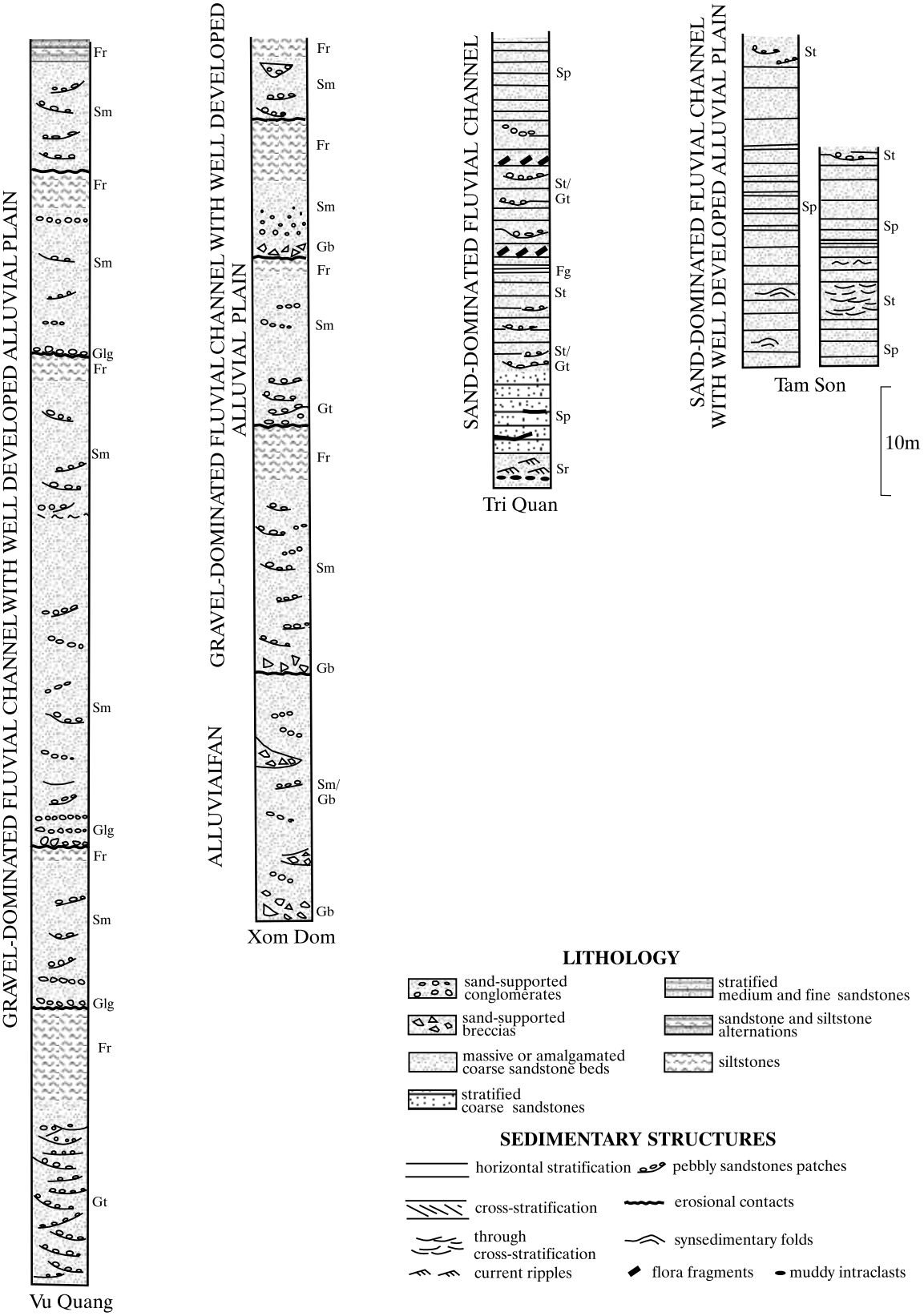

Fig. 7. Representative sections of the Lo River Sequence (for lithofacies code see Table 1)

tion II), reddish siltstones deposited in an alluvial plain environment (facies association IV) and coarse-grained sand- and mud-supported disorganised alluvial fan breccias and conglomerates (facies association I). The entire unit consists of repetitive fining-upward cycles. Depositional features of the Vu Quang unit suggest that the deposition was connected with a bedload-dominated gravel-bed braided river associated with a relatively well-developed alluvial plain. The great thickness and numerous repetitive fining-upward cycles within the Vu Quang unit (Text-fig. 7) may reflect a relatively high rate of subsidence where the aggradation rate was also relatively high. The presence of alluvial fan deposits points to a local fault-controlled syndepositional relief.

The Tri Quan unit (Text-figs 6B, 7) is characterised by sand-dominated fluvial channel deposits (facies association III) interbedded with gravel-dominated channel fills (facies association IV). The depositional features of the Tri Quan unit suggest that the deposition was connected with a bedload-dominated sand-bed river. This was a sand-dominated system, with a wide channel and flat, linguoid sandbars and sand waves covered with smaller bed-forms such as dunes and ripples.

The Tam Son unit is built of sand-dominated fluvial channel deposits (facies association III) and of alluvial plain deposits (facies association IV). Abundant synsedimentary fold deformations occur within the sandy layers. This unit was deposited by a sand-dominated river system characterised probably by a broad river plain with very shallow channels. There are no features indicative of syndepositional relief, however abundant synsedimentary fold deformations may point to seismic activity.

Palaeoflow directions and lateral fining of the facies indicate that the alluvial system developed generally from the north-west. In all three depositional units consistent N-S palaeocurrent directions are observed (Wysocka & Świerczewska 2003). Moreover, the downstream changes in clast size and sedimentary facies document the transition from a coarse-grained proximal braided river system, through a distal braided river system, to a distal braidplain system. Furthermore, the intraformational folds point to a syndepositional tectonic activity.

Yen Bai basin

Preliminary investigations were also carried out south of the Con Voi Massif, in the Yen Bai and Co Tiet sedimentary basins. The NW – SE trending Yen Bai basin (Text-fig. 1B) is about 40 km long and up to 3 km wide. The basin is directly bordered by the Red River fault, limited to the north by the high-grade metamor-

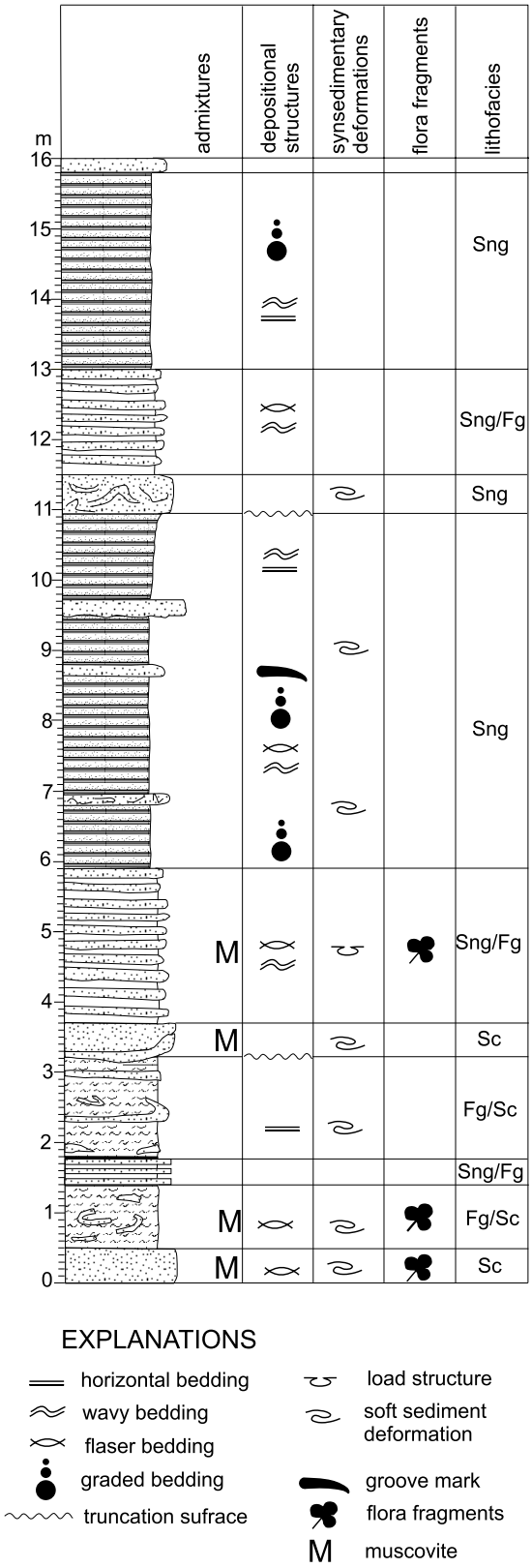

Fig. 8. Co Phuc section from the Yen Bai basin (for litthological explanations see Fig. 7)

phic Con Voi Massif and to the south by Palaeozoic rocks. Over a small area occur sections representing diametrically different sedimentary environments. One of them is the Au Lau section (Text-figs 3A, B), with thick coarse clastic series composed of pebble-size conglomerates with rare sand lenses (facies association I). This conglomeratic body has a lenticular shape, borders on Palaeozoic rocks and is more or less parallel to the Red River fault. It probably represents one of the alluvial fan systems that formed the fault-flank conglomeratic wedge during deposition. Moreover, the Yen Bai basin is characterised by numerous local facies changes. The Co Phuc section (Text-fig. 8) represents a lacustrine sequence with turbidites. This section is characterised by heterolithic facies with graded bedding, convolute bedding, synsedimentary folds, tool marks and numerous floral fragments (facies association V). The Yen Bai basin can provide material for future studies on tectonic-related sedimentation.

Co Tiet basin

The NW – SE trending Co Tiet Basin (Text-fig. 1B) is about 20 kilometres long and up to 5 kilometres wide. The basin is sharply delimited by the Red River Fault, representing a branch of the RRFZ. To the north, the Co Tiet Basin is bordered by the high-grade metamorphic Con Voi Massif of Tertiary age, while to the south it is bordered by sedimentary belts of Early and Late Palaeozoic age. The basin is filled with Upper Oligocene/Lower Miocene deposits – represented chiefly by coarse-grained alluvial fan deposits (facies association I). Sporadic siltstones with coal interbeds also occur. The most characteristic section of this basin is the Phong Chau section (Text-fig. 9). The sand- and mud-supported, cobble- to pebble-sized breccia and conglomerate bodies, surrounded by cross-stratified, fine pebble-conglomerates and coarse-grained sandstones were probably deposited by a marginal alluvial fan system. The Phong Chau section is terminated by clast-supported, partly lithified gravels of Quaternary age (Text-fig. 9).

TECTONICALLY-CONTROLLED SEDIMENTATION – DISCUSSION

At present, there are several small narrow sedimentary basins located between the branches of the RRFZ. Because of recurrent stages in the structural development of the Vietnamese segment of the RRFZ, it is difficult to reconstruct the original shape and size of these basins. Based on data from the Lo River basin, it is possible to interpret the development of its depositional system (Wysocka & Świerczewska 2003). In the early stage of the Lo River basin development, the Vu Quang unit was deposited in the NW part of the area by a proximal braided river system. The great thickness and numerous repeated fluvial cycles within this unit may reflect a relatively high rate of subsidence at a place where the aggradation rate was also high. The presence of subordinate alluvial fan deposits points to a local syndepositional relief associated with fault-flank conglomeratic wedges. These features suggest that the Vu Quang unit was formed in the vicinity of a fault-controlled scarp margin. On the other hand, neither the Tri Quan nor the Tam Son units shows features indicative of significant syndepositional relief. Moreover, the changes in clast size and sedimentary facies point to the transition from a coarse-grained proximal braided river system, through a distal braided river system, to a distal braidplain system in the late stage of the Lo River basin development.

Preliminary results for the Yen Bai and Co Tiet basins suggest that these basins are also filled with thick series of coarse-grained clastic deposits containing sand- and mud-supported breccia and conglomerate bodies. There is an evidence of local syndepositional relief, such as fault-flank conglomeratic wedges. Moreover, the strata are characterised by numerous local facies changes. For example, one can distinguish turbitide-like deposits of lacustrine origin close to the deposits of alluvial fan origin.

The next unresolved problem is the Palaeogene/Neogene tectonic history of the Vietnamese segment of the RRFZ, particularly with regard to the synsedimentary and post-sedimentary tectonic evolution of areas adjacent to the basins studied. The only seismic and drilling data from the Vietnamese part of the RRFZ come from the Tonkin Gulf (Rangin & *al*. 1995; Dinh Tham 1998; Bat 2000), about 300 km SE of the study area. For this region, the data suggest four main stages of structural evolution: (I) before the 30 Ma unconformity connected with active extension during rift opening, (II) between the 30 Ma and 15.5 Ma unconformities connected with a left-lateral transtensional regime, (III) between the 15.5 Ma and 5.5 Ma unconformities connected with a left-lateral transpressional regime after cessation of sea-floor spreading within the South China Sea, and (IV) after the 5.5 Ma unconformity related to the recent right-lateral movement (after Rangin & *al*. 1995). Even though the basins studied lie at a distance of about 300 km from the Tonkin Gulf, it is probable that their structural evolution had a great deal in common with that of other parts of the Vietnamese segment of the RRFZ. A recent prelimi-

nary correlation with the stages of structural evolution of the RRFZ has been made, but only for the Lo River basin (WYSOCKA & ŚWIERCZEWSKA 2003). The relationships between the faults delimiting the basin and its position suggest that, during its formation, sinistral strike-slip movements along the RRFZ were accompanied by the separation of two blocks which formed an overstep. Thus, during sedimentation, the Lo River Basin appears to have been a typical pull-apart basin. The resultant transtensional regime might have been connected with the exhumation of the Day Nui Con Voi metamorphic massif that began ~27 Ma and lasted until ~22 Ma (WANG & *al.* 2000; LELOUP & *al*. 2001). The exhumation should probably be correlated with the second stage of structural evolution of the Tonkin Gulf area (left-lateral transtensional regime according to RANGIN & *al*. 1995).

In order to prepare a model of the development of a depositional system for the basins in the Vietnamese segment of the RRFZ, to correlate deposits from adjacent basins and to prove the offset of the source area, further investigations should comprise a wide spectrum of studies including palynological, petrographical and structural analyses.

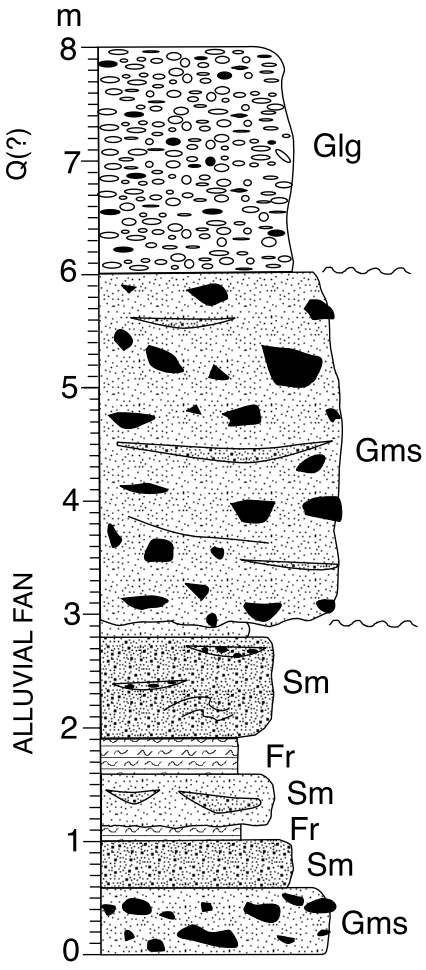

Fig. 9. Phong Chau section from the Co Tiet basin (for explanations see Fig. 7)

CONCLUSIONS

- Investigations were focused on the Lo River Basin (associated with the Chay River fault), Yen Bai Basin (associated with the Red River fault) and Co Tiet Basin (associated with the southwesternmost branch of the Red River fault), in the Vietnamese segment of RRFZ.
- The basins are filled with thick series of clastic sediments and the strata are characterised by numerous local facies changes.
- Thirteen sedimentary lithofacies were recognised within the deposits filling the basins. The facies were grouped into five facies associations representing five distinct depositional environments. These comprise alluvial fan, gravel-dominated fluvial channel, sand-dominated fluvial channel, alluvial plain and lacustrine environments.
- Basins from the Vietnamese segment of the RRFZ can be treated as a model area for further studies in tectonically-influenced basins.

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