



Pre-Cenozoic tectonic deformation phases in the Muong Xen area, Nghe An province

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ABSTRACT

The Ca River fault zone, located in the North-Central Vietnam, is one of the most complicated deformation zones with very low grade metamorphism but high intense folding. Investigations of deformation conducted in the Muong Xen area, northwest of the Ca River fault zone, show that, the Ca River fault zone had undergone at least three deformation phases before the Cenozoics. The first (oldest) deformation phase is characterized by recumbent, reverse folds and overthrust faults in NW-SE direction. The second deformation phase is characterized by large scale Z-shaped folds that deformed older structures. Those structures are covered by a pre-Late Triassic angular unconformity. The third deformation phase refolds previously formed structures and shows similar characteristics of folding as the first phase. These structures were subsequently deformed by Cenozoic tectonics.

Keywords: Ca River fault zone; Pre-Cenozoic deformation; Recumbent folds; Z-shaped folds; Pre-Late Triassic angular unconformity.

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1. Introduction

The Ca River fault zone is located in Nghe An, Ha Tinh provinces, and partly in northern Quang Binh province. Geologically, the fault zone is limited by route 48 faults in the north and Rao Nay fault to the south. Up to date, a number of studies on structural tectonics in this area have been conducted (Nguyen, 1987; Phan, 1995; Bui et al., 1996; 2001; 2002; 2005; 2008; Lepvrier et al., 1997; 2003; 2008; Cao et al., 1998; 2002; 2003; 2008; Nguyen, 1998; 2009; Ngo, 1999; Le et al., 2000; Le, 2003; Nguyen and Dao, 2004; Phan, 2005). Regardless of having different views, most of the authors showed that the Ca River fault

zone experienced various tectonic activities in three major periods, including Indosinian (Permian - Triassic), Yanshan tectonic movements (Jurassic - Cretaceous) and Himalayan tectonic movements (Cenozoic).

However, the nature and character of tectonic deformations as well as their effecting level on the regional structure plan, especially the deformation phases occurred before the Cenozoic remain unclear. Geological mapped folds and faults of this area are not clearly depicted.

In this research, pre-Cenozoic deformation characteristics will be presented for the Ca River fault zone based on field observations and geological mapping conducted in the Muong Xen area, Nghe An, northwest of the Ca River fault zone (Figure 1).

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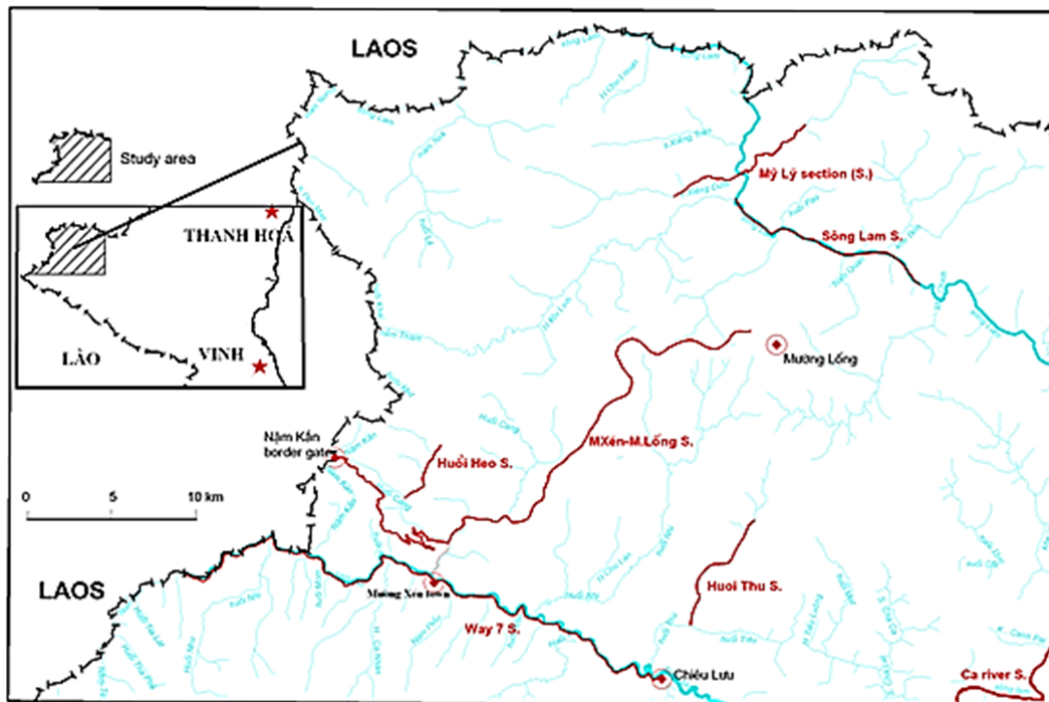


Figure 1. Study area and location of observed cross sections (red lines)

2. Geological setting of the Muong Xen area

2.1. Stratigraphy and magmatics

According to the geological map at 1:50,000 scale of Muong Xen sheet group (Nguyen et al., 2005), the geological formations in the Muong Xen area are distributed along two sides of the Ca River fault zone, including mainly stratigraphic and magmatic formations of Late Ordovician to Late Triassic ages.

Stratigraphically, the study area expose of Early-Middle Paleozoic terrigenous formations of the Ca River Formation (O_3 - S_{sc}) and Huoi Nhi Formation (S_3 - D_1hn); Early Devonian - Early Carboniferous terrigenous carbonate formations of Huoi Loi Formation (D_{1-2hl}), Nam Kan (D_2g - D_3fnk) and Khanh Thanh Formations (D_3 - C_1kt); Carboniferous - Permian carbonate - siliceous formations of La Khe Formation (C_1lk) and Muong Long Formation (C_1 - Pml); Middle Triassic sedimentary - rhyolite eruption formations including Dong Trau Formation

(T_2adt) and coarse debris sediments of Dong Do Formation (T_3n-rdd).

The igneous formation includes Phia Bioc granitoidic complex (γP_3 - T_1pb), a member of the regional Late Permian - Early Triassic magmatic series.

2.2. Structural - tectonic features

The sedimentary rocks of different ages exposed along the Ca River fault are strongly deformed with complex folding systems. However, the grade of accompanied metamorphism is inconsistently low, corresponding to the lowest of greenschist facies, although greenschist facies rocks can be occasionally found along Song Ca fault zone.

On the current plan, the Ca River deformed-faulted zone contains a series of WNW-ESE faults and their branches. The Ca River fault is linear - formed, extending from Vietnam - Laos border running through Muong Xen town and along the Nam Mo River, almost matching the Ca River flow and National Road No 7. The traces of the fault

segments can be observed over 40 km. Muong Xen - Binh Chuan fault is a branch of the Ca River fault. This fault starts from Muong Xen, extending about 45 km in the sub-latitude direction to the Ban Ve hydropower. These are the two most important faults in the Ca River fault zone.

3. Research methodology

Survey roadmap and data collecting folding and faulting characteristics at several cross sections include: along the Ca River, from Cua Rao to Kim Da; My Ly segment of the Lam River; National Route No. 7, from Chieu Luu to the Nam Kan border gate; routes from Muong Xen town to Muong Long; and cross sections at Huoi Thu and Huoi Heo streams.

Analyzing, interpreting, and synthesizing survey documents to distinguish the tectonic deformation phases were processed as follows: division of deformation phases with time, and expected ages of deformation phases on the basis of field data on the properties of the folding system, the kinematics and character of faults, the relationship between the folding system and different faults, combination of geological relationships observed in the area.

Structural tectonic mapping representing geological structures, tectonic deformation phases, folds and faults in the study area.

Microscopic analysis of structural petrographic samples was done at the Department of Geology, VNU Hanoi University of Science. Ar/Ar analysis for deformation age was conducted at the University of Montpellier II, France.

4. Results

The study of deformation in the Muong Xen area reveals that at least three deformation phases occurred in the Ca River fault zone before the Cenozoic.

4.1. The first deformation phase

Field survey at the cross sections in Late Ordovician - Middle Permian geological

formations, including Ca River, Huoi Nhi, Huoi Loi, Nam Kan, Khanh Thanh, La Khe, and Bac Son Formations show that the earliest deformation phase in the area is characterized by recumbent to isoclinal folds having horizontal-to-inclined axial plane accompanied by reverse and overthrust faults, with direction from NW-SE to sub-parallel. These folds are commonly characterized by NW-SE orientation, two limbs of the folds making narrow or sub-parallel angles observed at outcrops and cross-sections with sizes from a few dozen centimeters to tens of meters (Figure 2-5).



Figure 2. The recumbent folds (phase 1) with axis surface $235 \angle 15$ (NW-SE), axial line (ϕ_1): $70 < 16$, in sandstone alternating with siltstone, shale of the Song Ca Formation at Huoi Thu cross section (MX.2651). Photo: Nguyen Van Vuong

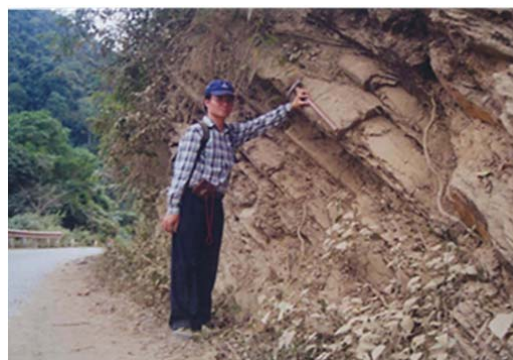
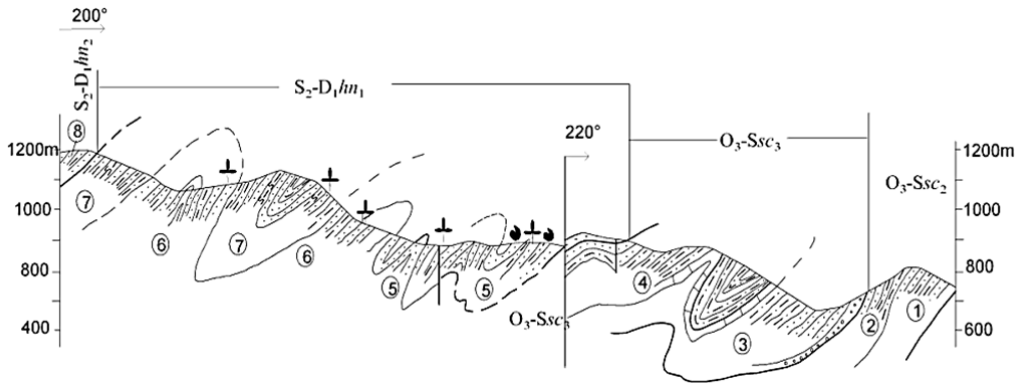


Figure 3. Complex M-shape fold (phase 1): axial line $270 < 30$ (Point MX.376 + 300m) at Ban Lan cross section, South-Eastern Muong Xen town (about 3 km). Photo: Nguyen Ba Minh



←**Figure 4.** Recumbent folds of phase 1 with horizontal axial plane and NW-SE axial line, found in sandstone alternating with shale exposed at the right bank of Song Ca, Song Ca Formation, near Ban Ve hydropower (MX.165). Photo: Nguyen Ba Minh

Along with the folding systems, there are thrust and overthrust faults of NW-SE direction having relatively gentle slipping slope. These faults were formed by progressive folding as a result of compressive deformation (Figure 6). The overthrust faults was observed at different scales from outcrops to microscopic thin sections (Figure 7).



Legend using for sections in article

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20

1. Pebble stone, 2. Gravel stone, 3. Sandstone, 4. Sand-siltstone, 5. Siltstone, 6. Clay shale, 7. Coal-clay shale, 8. Carboniferous bering sandstone, 9. Carboniferous bering siltstone, 10. Carboniferous bering clayshale,
11. Limestone, 12. Dolomite, 13. Silicerous limestone, 14. Banded limestone, 15. Lime-breccia, 16. Silicerous-silt-shale, 17. -Silicerous shale, 18. Sericite-silt shale, 19. Felspar-mica-quartz schist, 20. Sericite quartz schist.

● a ▲ b ● c ♥ d Fossils: a. Animal, b. Plant, c. Foraminifes, d. Spore

① Member No. in setion 340 ∠ 70 Bedding layer

Figure 5. Huoi Nhi - Huoi Thu cross section (northeastern Muong Xen town), found NW-SE folds (phase 1) in sediments of Song Ca and Huoi Nhi Formations

The Ca River major fault is characterized by dextral motion. The right lateral kinematic indicator have been consistently observed along the fault zone. Those indicators cover

wide range from sleeply plunging fold axes (Figure 8, 9) to very reliable indicators like S/C and rotaion of porphyroblast/porphyroclast (Figure 10, 11).

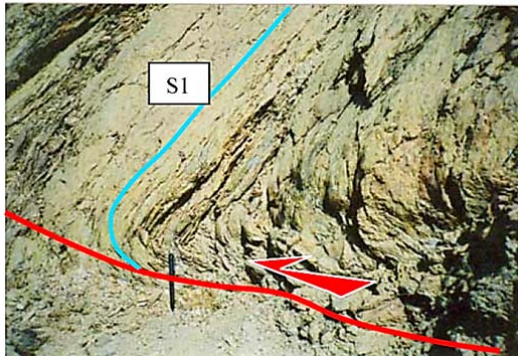


Figure 6. Schistosity plane and overthrust fault developed in the axial zone of the NW-SE folding structure, found in Huoi Nhi claystone, siltstone, in northern Muong Xen town (3 km) (MX.1853). Photo: Nguyen Van Vuong

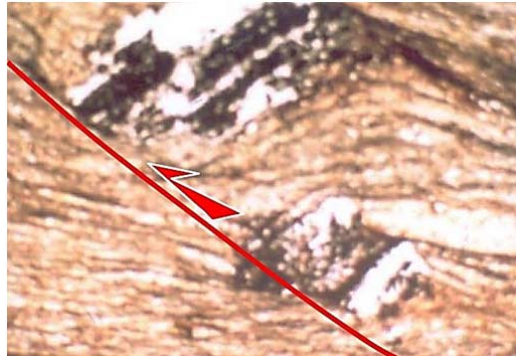


Figure 7. Micro overthrust and dextral motion observed in thin section. Samples collected at the Song Ca, about 1 km from north Ban Ve, Tuong Duong, Nghe An (MX.163). Photo: Vu Van Tich



Figure 8. The steep axial fold showed the nature of right strike-slip of Song Ca fault. Observations found in the sand-siltstone of Song Ca Formation, on National Highway No 7, southeast Muong Xen town, about 3 km (MX.376). Photo: Nguyen Ba Minh



Figure 9. The steep axial fold linked to the right strike-slip of Song Ca fault. Observations found in rhyolite extrusive of Dong Trau Formation (South Tuong Duong town, 3 km). Photo: Nguyen Van Vuong



Figure 10. Structure of C/S (observed on the earth surface) indicates dextral motion of the Muong Xen - Ban Ve fault (F_9) in shale - sericite of Song Ca Formation in the survey point MX.581 (Ban Coi, right bank of Lam river). Photo: Nguyen Ba Minh



Figure 11. Signs of right sliding movement directed of Song Ca fault in the first deformation phase, observed in pressed sandstone of Huoi Nhi Formation (2 km from north Canh Trap). Photo: Nguyen Van Vuong

4.2. Second deformation phase

Evidence of plastic - brittle deformation of the second phase was recognized at the same cross-sections as for the first phase. The structures formed in this phase consist of folds and NE-SW overthrust faults.

At some outcrops and cross-sections, the relationship of folding structures between the first and second phase, in which, folds formed

in the first deformation phase were folded by the second phase, forming typical Z-shaped structure (Figure 12, 13). Folded structure formed in the second deformation phase changed those of the first phase into the regional Z-shaped plan. Although being deformed by the later phase, the structures formed in the second phase are clearly recognized at some parts of the current geology (Figure 14).

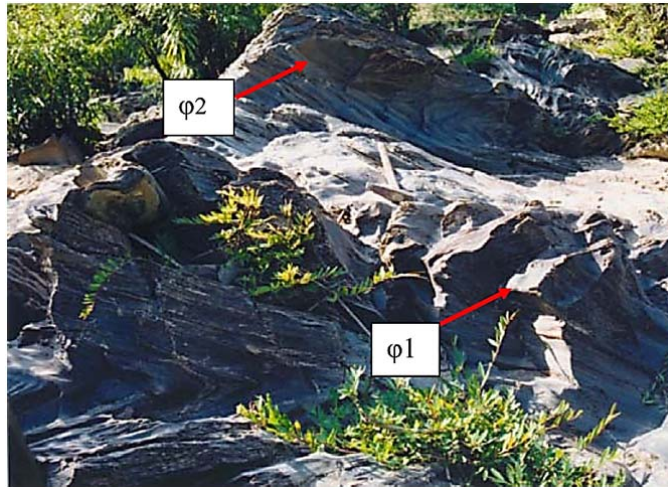


Figure 12. Interference of two first folding phases (NW-SE) and the second folding phase (NE-SW). Fold axis of the first phase (ϕ_1) is folded by the second phase (ϕ_2). Observation point at the left bank of Song Ca, 1 km from north Ban Ve in shales of Song Ca Formation (MX.162). Photo: Nguyen Van Vuong

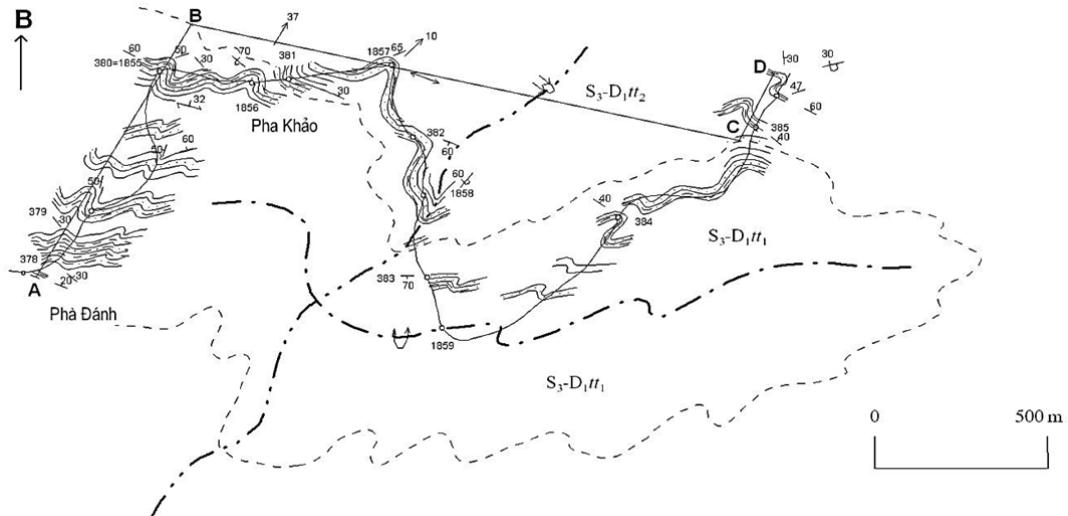


Figure 13. Muong Xen - Muong Long section plan (through Pha Khao mountain village). Found folds of the phase 1, NW-SE direction (bold dotted line with a dot), are folded by the phase 2, NE-SW (bold dotted line with two dots)

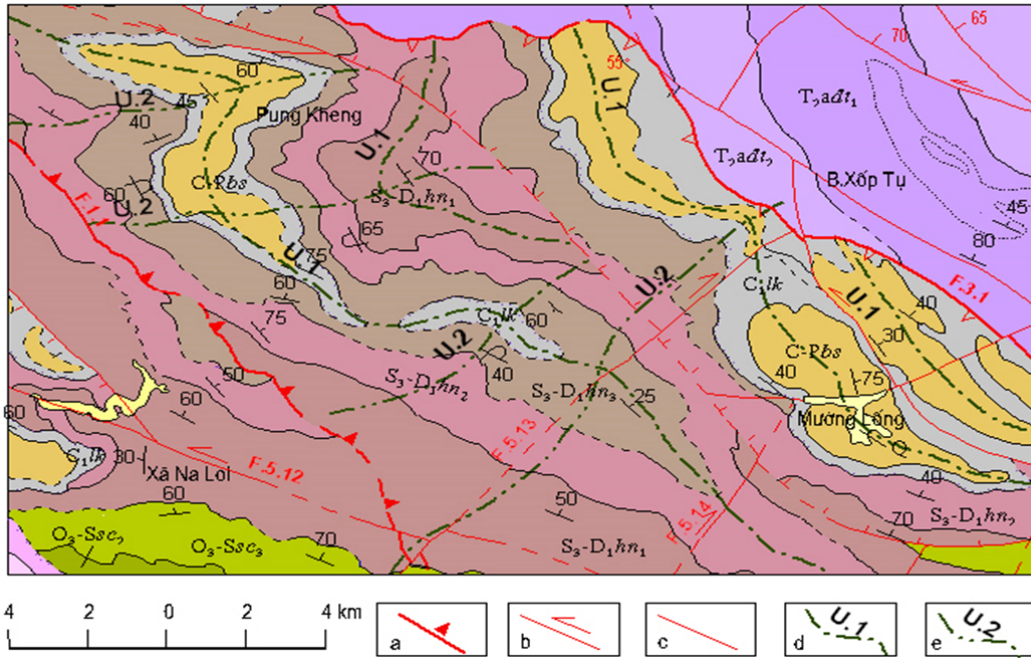


Figure 14. The regional geological map of Muong Long, northwest Nghe An. Found folded structures and overthrust faults of phase 1 and phase 2 in this region (a: overthrust fault, Phase 1: filling red triangle, phase 2: empty triangle; b: slip fault; c: unknown fault; d, e: phase 1 and phase 2 axis)

Activities of the second distortion phase also distort reverse and overthrust faults of the first deformation phase. Some overthrust faults created by the second distortion phase inherit the faults of the first distortion phase but transformed from NW-SE to NE-SW direction, these activities created overthrust faults bent on the plan with NE-SW direction (Figure 14).

4.3. The third deformation phase

The third deformation phase in the area formed folds and overthrust faults of NW-SE direction, coinciding with the trend of deformed structure in the first phase. They distorted the Ordovician to late Triassic geological formations and altered previously formed structures (Figure 15, 16).

Reverse and overthrust faults formed in the third phase are NW-SE or sub-parallel oriented. These faults constitute overthrust zones cutting through many geological formations of different ages, or sometimes developed

along geological boundaries and altered the surface of these boundaries.

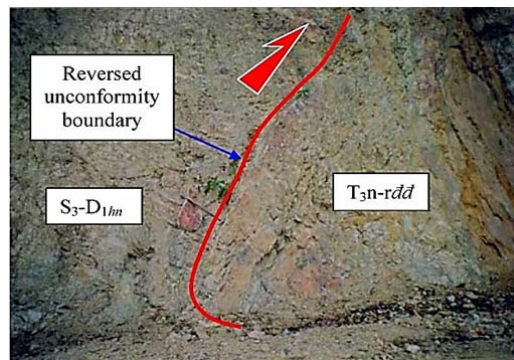


Figure 15. Dong Do Formation is covered with unconformity on folded structures of the two early deformation phases in Huoi Nhi Formation. This unconformity boundary is to be turned into overthrust fault (Pieng Hom - Huoi Thu overthrust fault) by activity of later distortion phase. Observation points at Pha Danh commune, near 15 km from north Muong Xen town (MX.1862). Photo: Nguyen Ba Minh

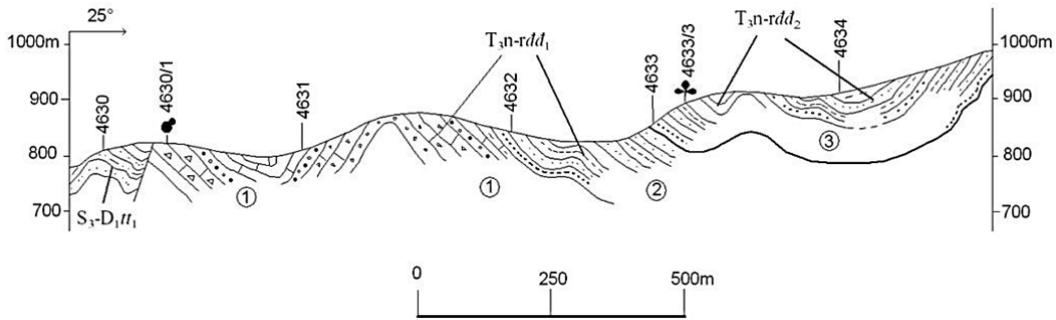


Figure 16. Huoi Heo cross section, northwestern Muong Xen town, about 12 km. Deformed activity of the phase 3 folded sediments of Dong Do Formation (T_{3n-rdd}) (NW-SE)

An overthrust zone developed along the boundary between La Khe and Dong Trau Formations is observed in the My Ly area (Figure 17). This evidence confirms the occurrence of these faults after Late Triassic (after the formation of Dong Do coal-bearing sedimentary Formation). Ar/Ar age of a granite from Muong Xen block (MX.219) show a thermal tectonic age at 114 ± 4.9 Ma, corresponding to late Early Cretaceous Figure 18.



Figure 17. Overthrust zone (slip surface 235 \angle 55) developed along the unconformity boundary between Dong Trau and La Khe Formations. Observation point in My Ly area (Northeastern Muong Long commune, about 5 km). Sliding grooves formed along the fault, in the bottom gravel-breccia of the Dong Trau Formation (MX.579 + 200m). Photo: Nguyen Ba Minh

Tectonic activities having occurred in the three deformation phases established a geological structural plan with complex systems consisted of multiple fold and overthrust fault systems in the region (Figure 19). The structures were then deformed by subsequent brittle deformation activities in the Cenozoic (Figure 20, 21).

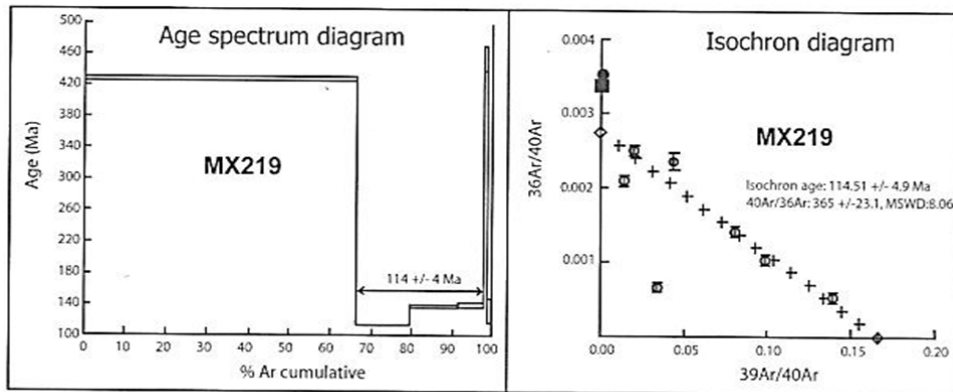


Figure 18. A diagram determines isotopic age (114 ± 4.9 Ma) in biotite of granites in Muong Xen block, Ky Son, Nghe An (sample MX.219).

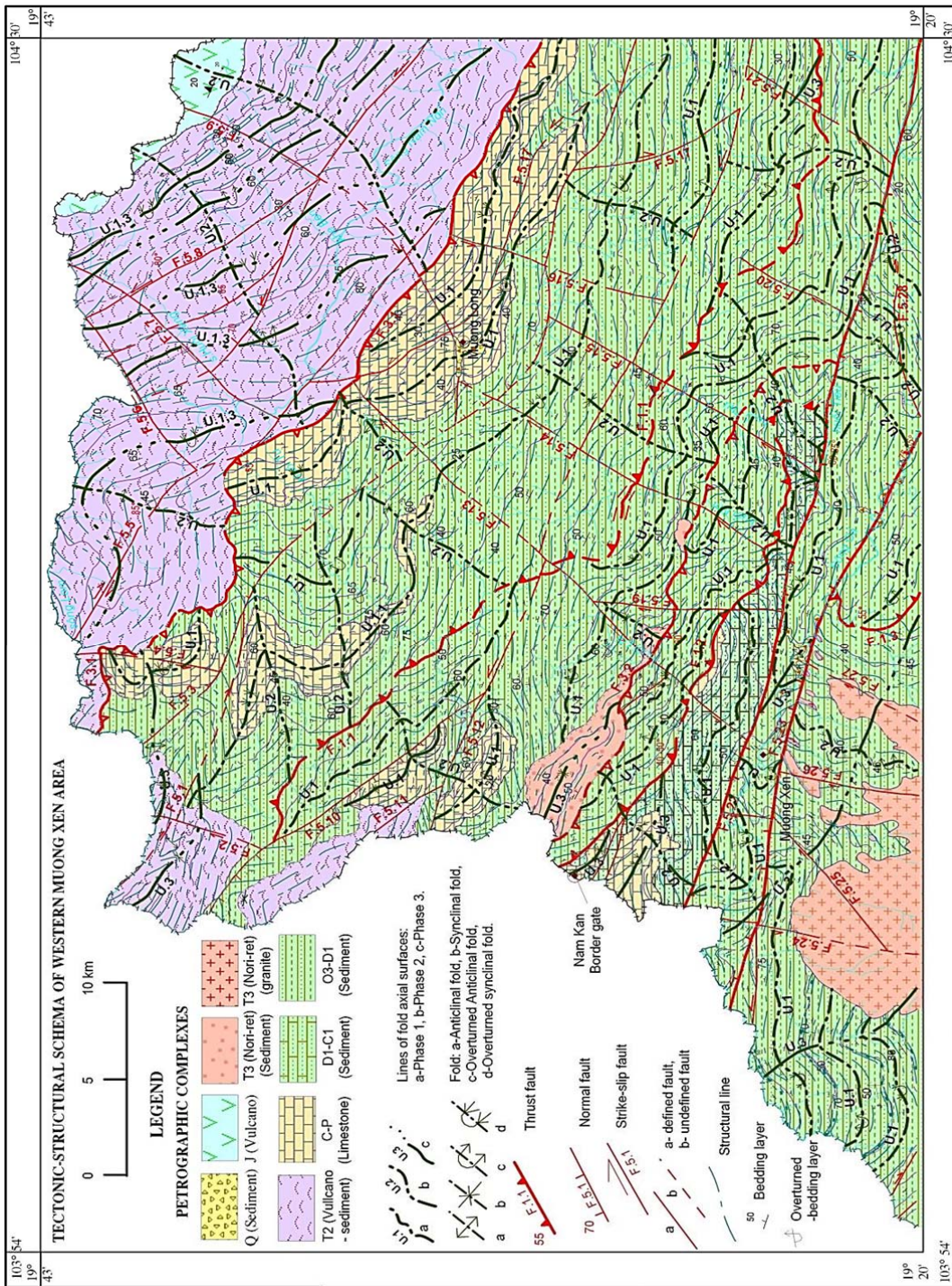


Figure 19. Tectonic structural schema of Muong Xen region, western Nghe An, expression of folding and faulting systems of different phases of Song Ca fault zone



Figure 20. Right strike-slip fault with subparallel direction, activated in Cenozoic and cut through pressed sandstones and siltstones, The Song Ca Formation. Viewpoint at Canh village, western Muong Xen town, about 3km (CT.5). Photo: Nguyen Ba Minh



Figure 21. Normal fault, NW-SE direction, activated in the Cenozoic and cut through sandstone of Dong Do Formation (T_{3n-rdd}). Viewpoint (MX.4630) in Phu Sang (Ky Son, Nghe An). Photo: Nguyen Van Vuong

5. Discussion

5.1. Interrelationship among deformation phases

The study results acquired from the Muong Xen area, Ca River fault zone, showed that there were at least three deformation phases having occurred before the Cenozoic. The earliest phase was dominated by compression accompanied by right strike-slip motion on the major faults, in elastic - brittle state, forming folded structures having tilted to horizontal axial planes accompanied by reverse and overthrust faults of NW-SE to sub-parallel direction. The second deformation phase also occurred in compression condition of elastic - brittle state, forming NE-SW structures or altering those formed in the first phase to make Z-shaped structures. The third deformation phase also occurred under compression environment, of elastic - brittle state, forming NW-SE oriented structures, coinciding with the trend of first phase, while altered the previous structures.

5.2. Age of the deformation phases

The ages of two early deformation phases in the study area are recorded to start by Late Permian and ended before Late Triassic

(Norian), corresponding to an active period of the Indosinian tectonic activities. Evidence includes geological relationships and absolute ages as follows: (1) the activities of the two deformation phases constitute folded structures and overthrust faults in geological formations from Late Ordovician to Middle Permian (including the Ca River, Huoi Nhi, Huoi Loi, Nam Kan, Khanh Thanh, La Khe, and Bac Son Formations); (2) the folded structures of the two deformation phases in the region are overlain angularly and unconformably by Dong Do late Triassic continental sedimentary formation ($T_{3n-r dd}$) as mentioned above; (3) a deformation age was acquired from a mylonitized sandstone sample in the Ca River Formation by Ar/Ar, and from samples collected in the Keo Nua village, near Cau Treo border gate, Ha Tinh yielded ages ranging from 260 to 245 Ma (Nguyen, 1998).

Age of the third deformation phase was estimated about Jurassic - Cretaceous, corresponding to a period of Yanshan tectonic movements according to the following series of evidence: (1) the activities of third phase altered folded structures formed in two previous phases, while simultaneously affecting Late Late Triassic sediments of Dong Do Formation ($T_{3n-r dd}$); (2) the Ar/Ar age on

granites of the Muong Xen block recorded thermal tectonic events at 114 ± 4.9 Ma, e.g. by late Early Cretaceous; (3) the structures formed in this phase were deformed and displaced by brittle deformation activities in the Cenozoic.

6. Conclusions

Based on the geological mapping and structural field observations, the following conclusions could be drawn:

Before the Cenozoic, the Ca River fault zone was affected by at least 2 tectonic movement periods, including the Indosinian (Permian - Triassic) and Yanshan (Jurassic - Cretaceous) expressed by three deformation phases. The first two phases belonged to the Indosinian tectonic movement, while the third phase belonged to the Yanshan tectonic movement.

The three pre-Cenozoic deformation phases formed the regional structural geological plan of the Ca River fault zone. Folded structures formed in the first two deformation phases are characterized by NW-SE direction and Z-shaped form. They were deformed and displaced by brittle deformation in the Cenozoic, but the main structural features are still preserved.

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