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Paleomagnetism of cretaceous continental redbed formations from Indochina and South China, their Cenozoic tectonic implications: a review

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Abstract. Available paleomagnetic data of Cretaceous redbed formations from Indochina and South China blocks are compiled and their tectonic significance is reviewed in a common reference frame of the Eurasian coeval paleopoles. The important factors that play a vital role in determining the tectonic significance of a paleomagnetic result have been taken into consideration and discussed.

Review of the Cretaceous paleomagnetic data from the South China block further confirms the conclusion of the previous researchers that the present geographic position of the South China block has been relatively stable with respect to Eurasia since Cretaceous time and shows that the paleomagnetically detected motion of a coherent lithospheric block must be based on the representative data obtained from different places across the block; so the local tectonic movements can be distinguished.

Cretaceous paleomagnetic data from the Indochina - Shan Thai block reveal complex intra-plate deformations that have been occurred due to the India - Eurasia collision. Paleomagnetically detected motions from the block-margin areas are mainly reflecting the displacement of upper crustal blocks due to folding and faulting processes, thus a rigid lithospheric block rotation and translation cannot be assumed. The paleomagnetic results from the areas located next to the south of the Red River fault suggest that the fault does not demarcate non-rotated and significantly rotated regions. Accordingly, given the difficulty in separating true lithospheric plate motions from those of superficial crustal blocks, we advocate extreme caution in interpreting the paleomagnetic record in regions such as Indochina where block interaction and strong deformation are known to have occurred.

Keywords: Paleomagnetism; Cretaceous; Indochina; South China; Tectonics.

1. Introduction

The tectonics of Southeast Asian region has attracted the attention of successive generations of geologists in the world. Many active tectonic-geodynamic evolutions have been occurring at this region, such as: the subduction of the Indo-Australian plate under the Eurasia plate along the Indonesia arc; the India-Eurasia collision and different intra-plate deformation processes. Therefore, it can consider the Southeast Asian

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region as a natural laboratory for active tectonics - geodynamics, facilitating geologists to use the region's modern tectonics as an analog for processes interpreted in the geological record. During the last two decades of the 20^{th} Century, the model of extrusion tectonics [21] has emerged as the predominant model for the tectonics of Southeast Asia.

During recent years, paleomagnetic studies on geological formations from Southeast Asian region have been increased both in quantity and quality, contributing to elucidate the tectono-geodynamic context, the paleo-geographic reconstruction of lithospheric blocks, microcontinents that were welded together to form the actual Eurasia continent (Fig. 1). However, it is not quite straightforward to interpret the paleomagnetic results of an active tectonic region such as Southeast Asia, because the primary paleomagnetic vector may be modified by subsequent tectonic effects, such as stress and temperature changes, or fluid migration, etc. Paleomagnetically detected movements may sometimes reflect local rotations related to shear zones [13, 17], they can also be caused by local deformation in thrust sheets, or in arc related deformation [14]. Therefore, coherent movements of plates, or microplates cannot be assumed. An important aspect of the interpretation of the paleomagnetic results of Southeast Asian region is therefore to understand the origin of the paleomagnetically observed movements. What is the extent in time and space of particular movement? Are there criteria we can establish to distinguish plate movements from upper crustal block movements?

The main goal of this paper is to compile the available paleomagnetic data of the Cretaceous continental redbed formations from Indochina and South China regions carried out by different researchers and to discuss their tectonic significance, especially the paleomagnetically detected movements of these formations caused by the India-Eurasia collision during the Cenozoic. The accuracy and reliability of the paleomagnetic data are not problem to be discussed but the tectonic interpretation of these data, therefore the typical factors such as: the origin of rock's magnetization (primary or secondary?), the age of the rock formation, the effects of the tectonic deformation play a vital role in determining their tectonic significance.

The relative rotation and translation of a tectonic block detected from the paleomagnetic directions of geological formations located within that block are determined by comparing the observed directions with the coeval expected directions of a reference block or continent that its Apparent Polar Wander Path (APWP) is well determined for each geological period. Besse and Courtillot [1] has derived an APWP for the Eurasia continent from 200 Ma to present with a high precision, therefore the paleomagnetic directions of the Indochina and South China blocks presented in this paper will be compared with the expected directions calculated from this APWP for certain geological period (Table 1) for discussing their tectonic significance.

2. Cretaceous paleomagnetic results of the South China Block

According to Hsu et al. [11], the South China block consists of two micro-continents that are the Yangtze Craton situated to the northwest and the Hoa Nam block to the southeast. These two micro-continents were welded together during the subduction process of the paleo-Pacific plate under the Eurasia plate in late Mesozoic time, along the Jiangnan suture zone, which consists of Middle to Upper Proterozoic low-grade metamorphic rocks. Xu et al. [22], however, suggest that the entire eastern part of the Chinese landmass was dominated by a Mesozoic sinistral shear system. Xu et al's view has been supported by the isotopic and paleomagnetic study on the Jurassic - Cretaceous intrusive rocks that are widely exposed to the southeastern part of the South China block [10].

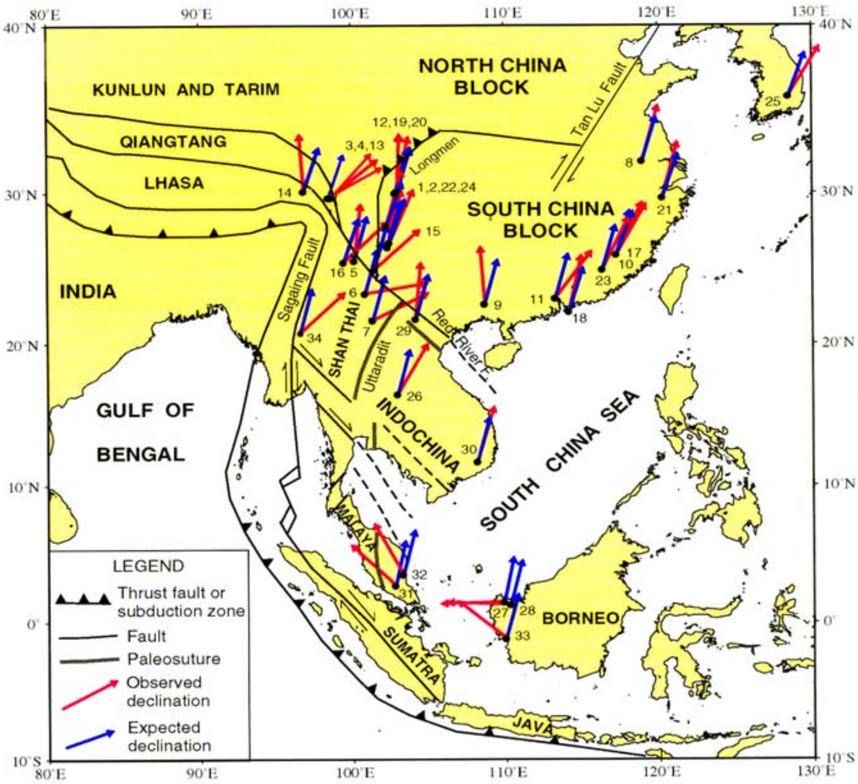

Fig. 1. Tectonic sketch of the Southeast Asia region
and the observed declinations of Cretaceous geological formations.

Table 1. Apparent Polar Wander Path for Eurasia derived by Besse and Courtillot (1991).

Age (Ma)	λ (^{0}N)	ϕ (^{0}E)	A_{95}	Age (Ma)	λ (^{0}N)	ϕ (^{0}E)	A_{95}	Note
10	84.1	149.1	2.3	110	73.3	206.5	5.1	
20	82.3	147.6	3.2	120	74.8	210.9	4.1	
30	81.0	132.8	2.7	130	75.2	205.8	5.0	
40	80.2	145.4	3.8	140	71.6	173.0	10.4	
50	77.9	149.0	4.3	150	70.0	157.8	6.7	
60	78.5	178.7	3.9	160	68.8	154.9	6.0	
70	77.2	192.4	4.1	170	63.3	120.7	3.0	
80	76.2	198.9	3.4	180	64.2	116.7	2.7	
90	76.7	200.1	3.5	190	66.7	109.0	3.9	
100	76.7	197.1	5.4	200	67.3	111.6	6.7	
Mean Eocene poles	79.8	143.1	3.3					30 Ma - 50 Ma poles
Mean K_2 poles	77.2	193.9	2.0					60 Ma - 100 Ma poles
Mean K_1 poles					74.3	198.1	6.0	110 Ma - 140 Ma poles
Mean K poles	75.9	196.0	2.5					60 Ma - 140 Ma poles
Mean J_3-K poles	75.4	186.6	3.6					60 Ma - 160 Ma poles
Mean J_3-K_1 poles					73.7	181.8	6.7	110 Ma - 160 Ma poles

Most of the geologists agree that, up to Late Jurassic, the South China block has been already accreted to the North China block along the Qinling suture belt, forming the stable Eurasia continent. During the last decades of the 20th Century, a series of paleomagnetic studies have been carried out on the Mesozoic and Cenozoic rock formations in China, which allow to construct the apparent polar wander paths (APWP) of the South China and North China blocks since Late Permian time to present. Comparison of these APWPs with the APWP of the Eurasia continent indicates that: since the Cretaceous, the South China and North China blocks have been relatively stable to the Eurasia plate [7]. The India-Eurasia collision during the Cenozoic has not significantly affected to the South China and North China blocks [4, 7].

Paleomagnetic data of the Cretaceous continental redbed formations from the South China block are listed in Table 2. The relative rotation and latitudinal translation of studied localities are illustrated in Fig. 2 and Fig. 3 respectively. Among 23 paleomagnetic studied localities, there are only 6 localities have been subjected to both relative rotation and latitudinal translation, mainly from the Late Cretaceous - Eocence continental redbed formations; from other 6 sites only relative rotation has been found and two other sites show only the latitudinal translation.

When comparing the Early Cretaceous, Late Cretaceous and Cretaceous mean paleopoles of the South China block to the corresponding paleopoles of the Eurasia, however, they show that there is neither significant rotation nor latitudinal translation of the South China block relative to the Eurasia continent. This further confirms the conclusion of other researchers mentioned above [4, 7]. The relative rotation and translation found from some study localities only reflect a local tectonic movement of the upper crustal blocks but not the motion of the whole lithospheric block. That is why, bigger degrees of rotation have been found from younger rock formations (Eocene, Late Cretaceous) while the older, underlying rock formations have been less dislocated or unaffected (Early Cretaceous).

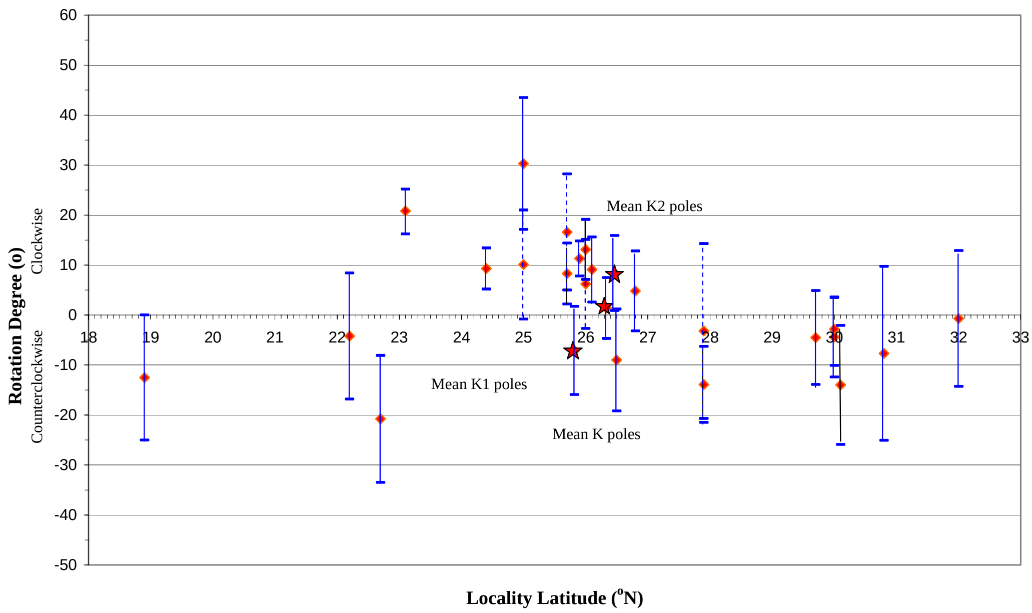

Fig. 2. Relative rotation of the South China terranes with respect to Eurasia.

Table 2. Cretaceous - Eocene paleomagnetic results of the South China block.

N	Location		Age	Observed VGP			Expected VGP		Rotation	Translation	Sign.	Ref.
	λ (⁰N)	ϕ (⁰E)		λ (⁰N)	ϕ (⁰E)	A_{95}	λ (⁰N)	ϕ (⁰E)	R ± ΔR	λ ± Δλ		
South China block												
1	25.7	101.3	E	72.3	218.4	4.5	79.8	143.1	8.3±6.1	16.3±5.6	Y/Y	[25]
2	26.1	101.7	E	70.1	224.6	4.9	79.8	143.1	9.1±6.5	19.2±5.9	Y/Y	[25]
3	25.7	102.1	K2-E	61.8	192.2	10.5	77.2	193.9	16.6±11.6	2.2±10.7	Y/N	[25]
4	25.9	101.8	K2-E	65.6	203.0	2.6	77.2	193.9	11.3±3.5	5.7±3.2	Y/Y	[25]
5	25.0	116.4	K2	67.9	186.2	9.2	77.2	193.9	10.1±10.9	-3.5±9.4	N/N	[7]
6	26.0	117.3	K2	65.1	207.2	5.0	77.2	193.9	13.1±6.0	4.8±5.4	Y/N	[10]
7	23.1	113.3	K2	56.2	211.5	3.9	77.2	193.9	20.8±4.6	9.9±4.4	Y/Y	[10]
8	24.4	112.3	K2	66.0	221.5	3.4	77.2	193.9	9.3±4.1	10.8±4.0	Y/Y	[7]
9	30.0	102.9	K2	72.8	241.1	6.6	77.2	193.9	-2.8±7.3	12.3±6.9	N/Y	[7]
10	32.0	119.0	K2	76.3	172.6	10.3	77.2	193.9	-0.7±13.6	-4.8±10.5	N/N	[7]
11	30.8	118.2	K2	83.8	200.3	14.6	77.2	193.9	-7.7±17.4	1.6±14.7	N/N	[24]
12	25.0	101.5	K	49.2	178.0	11.4	75.9	196.0	30.3±13.2	-4.2±11.6	Y/N	[7]
13	30.1	103.0	K	76.3	274.5	11.1	75.9	196.0	-14.0±11.9	11.9±11.4	Y/Y	[7]
14	22.2	114.2	J3-K	78.2	171.9	10.6	75.4	186.6	-4.2±12.6	-2.2±11.1	N/N	[2]
15	30.0	102.9	K1	74.5	229.0	4.0	74.3	198.1	-4.4±8.0	7.2±7.3	Y/N	[7]
16	18.9	109.4	K1	83.2	143.0	9.8	74.3	198.1	-12.5±12.5	-6.0±11.5	N/N	[24]
17	22.7	108.7	K1	86.5	26.4	10.0	74.3	198.1	-20.8±12.7	-1.1±11.6	Y/N	[10]
18	26.0	117.3	K1	66.9	221.4	5.4	74.3	198.1	6.2±8.9	8.9±8.1	N/Y	[7]
19	26.5	102.4	K1	81.5	220.9	7.1	74.3	198.1	-9.0±10.2	1.7±9.3	N/N	[12]
20	26.8	102.5	K1	69.0	204.6	4.3	74.3	198.1	4.8±8.0	3.5±7.4	N/N	[12]
21	27.9	102.3	K1	77.4	196.2	14.5	74.3	198.1	-3.2±17.5	-1.1±15.8	N/N	[7]
22	27.9	102.3	K1	85.2	241.7	3.5	74.3	198.1	-13.9±7.6	1.0±7.0	Y/N	[25]
23	29.7	120.3	K1	77.1	227.6	5.5	74.3	198.1	-4.5±9.4	6.6±8.1	N/N	[7]
Mean K1 poles (13-23):				80.0	216.1	5.4	74.3	198.1	-7.1 ± 8.8	2.2 ± 8.1	N/N	
Mean K2 poles (3-11):				69.2	203.6	6.6	77.2	193.9	8.4 ± 7.5	3.8 ± 6.9	Y/N	
Mean K poles (3-23):				74.2	204.9	5.0	75.9	196.0	1.4 ± 6.1	2.6 ± 5.6	N/N	

Note: Sign. = Significance (Y: Yes, N: No), Ref. = Reference, K1 = Early Cretaceous, K2 = Late Cretaceous, K = Cretaceous, J3-K = Late Jurassic - Cretaceous, K2-E = Late Cretaceous - Eocene, E= Eocene. Rotation and latitudinal translation were calculated at each study locality following Butler (1992); negative (positive) sign indicates CCW (CW) rotation and southward (northward) translation, respectively. Expected VGPs are calculated from Eurasian poles (Table 1) derived by Besse and Courtillot (1991).

We can also see that the tectonic interpretation of a whole lithospheric block based on the paleomagnetic results from several study localities, especially from active tectonic areas, can be inaccurate. It is important that the paleomagnetically detected motion of a lithospheric block must be based on the representative data obtained from different places within the block; so the local tectonic movements can be distinguished.

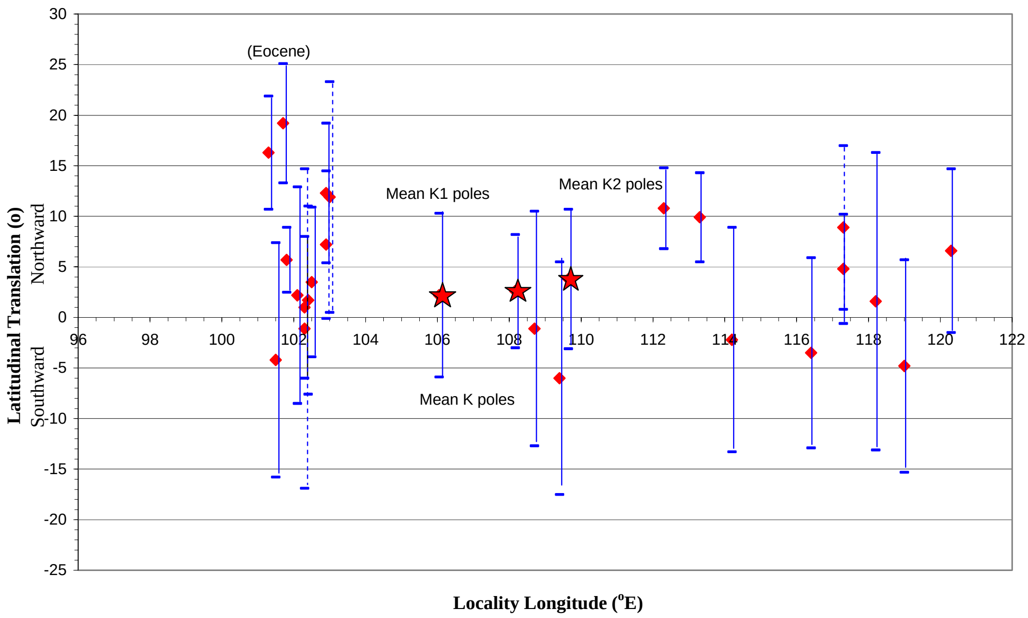

Fig. 3. Latitudinal translation of the South China terranes with respect to Eurasia.

3. Cretaceous paleomagnetic results of the Indochina - Shan Thai Block

One of the terminologies that has been often referred in the Cenozoic tectonic models of Southeast Asia region is the "Sundaland" plate. The Sundaland plate is bordered to the north by the Red River fault, to the west by the Sagaing fault in Myanmar, to the east by the Philippine subduction zone, and to the south by the Indonesia subduction zone. This plate consists of the Shan-Thai and Indochina blocks, South China Sea, Borneo, Malaya-Indonesia Islands. During the decade 90s of the 20th Century, there have been some reviews of paleomagnetic data from Southeast Asia [8, 16] for discussing the Cenozoic tectonic evolution of this region. A most common aspect from these studies is: regardless the paleomagnetic data have been compiled at different times, they always reflect the tectonic complexity of the Southeast Asian region. Contradicting rotations with various angles have been observed from the same terrane or from different terranes; from clockwise rotation of the paleomagnetic vectors on the continental part to the counterclockwise rotation of the paleomagnetic vectors on the peninsula and islands located to the southeastern part of the region (Fig. 1).

In this paper, the author will present and discuss only the Cretaceous paleomagnetic data of the Shan-Thai and Indochina blocks that have been carried out during the last 20 years in order to highlight the nature of intraplate deformation due to the impact of the India-Eurasia collision.

According to the Extrusion model, the Indochina block has been rotated about 40^0 clockwise and southward extruded about 800 - 1000 km along the sinistral Red River fault and Me Kong River fault in order to accommodate the convergence of the India -Eurasia collision. One of the paleomagnetic study carried on the Late Jurassic - Early Cretaceous sedimentary formation from the Khorat Plateau (16.5^{0}N, 103.0^{0}E), Thailand [23] has been often cited as an evidence supporting this model. Selecting five Late Jurassic - Early Cretaceous paleopoles from the South China block, the authors have determined that the Indochina block has been rotated 14.2±7.1^0 clockwise and southward extruded 11.5±6.7^0 relative to the South China block since the Cretaceous time. In this study, however, when we use the J_3-K_1 paleopole of the Eurasia continent as a reference, the Khorat Plateau has been rotated only 10.2±7.3^0 clockwise and is insignificantly southward extruded 3.4 ± 6.9^0 relative to the Eurasia (Table 3, Fig. 4 and 5). So, we can see here the importance of selection of the reference paleopole for the tectonic interpretation of a paleomagnetic result from a particular area. In order to select a representative paleopole of a tectonic block for a certain geological period, there are two critical factors that decide the accuracy, reliability of the reference paleopole, which are the age of the rock formation, and the reference paleopole must be computed from the coeval paleopoles observed from different areas within the block. Certainly, those anomalous paleopoles, which are clearly affected by the local tectonic activities should be excluded.

In Vietnam, the paleomagnetic study results of the Cretaceous extrusive, intrusive, and sedimentary rock formations from southern and northwestern Vietnam [5, 6] show that: 1) Since the Cretaceous, the southern part of Vietnam has not been significantly rotated but has been translated 6.6±6.4^0 southward relative to the Eurasia continent [5]; 2) the northwestern Vietnam (Tu Le depression) has not been significantly rotated nor latitudinal translated relative to the Eurasia continent since the Cretaceous [6].

The Cretaceous paleomagnetic results of the northwestern Vietnam are similar to the paleomagnetic data of the Late Cretaceous redbed formation from the Xiaguan locality - Yunnan, China, situated next to the Red River fault [12]. Recently, Takemoto et al. [20] has carried out a paleomagnetic study on the Yen Chau redbed formation (Song Da Terrane) and also obtain consistent results with the results of the Tu Le Depression (Table 3, Fig. 4 and 5). Thus, it can conclude that the Red River fault is not a demarcation between the South China block and the Indochina block [6, 12, 20], and there are insignificant displacements of the Indochina terranes located just to the south of the Red River fault, a basic tenet of the extrusion tectonic model.

In recent years, many paleomagnetic studies have been carried out on the Eocene-Createaceous redbed formations from the Simao terrane in Yunnan, China [3, 12, 18, 24]. In terms of geographical position, this area belongs to the Yunnan Province of China, but in terms of tectonic aspect, this area situates within the Shan Thai block near to the Eastern Syntaxis of the India-Eurasia collision belt (Fig. 1); where strong folding and faulting deformations occurred due to the impact of the India-Eurasia collision. Therefore, different paleomagnetic results have been observed on the Eocene-Cretaceous redbed outcrops from different localities in this area, reflecting the local tectonic displacements. Clockwise rotations with different angles up to 100^0 and insignificant latitudinal translations relative to the Eurasia (Table 3, Fig. 4 and 5) clearly reflect the nature of local tectonic movement of the upper crustal blocks during folding processes [14]. Furthermore, at the several localities such as Lanping, Mengla bigger clockwise rotations have been observed on the Eocence overlying redbed layers and smaller clockwise rotations of the Late Cretaceous underlying redbed layers (Fig. 4); as well as contradicting latitudinal translations of the over- and underlying redbed layers (Fig. 5) clearly indicate the complexity of local tectonic displacements. Another possible explanation might be the reliability of the rock's age; as mentioned above, it is difficult to determine precisely the age of continental redbeds because the fossils are often rarely found in the rock. Therefore, the detailed age classification of the redbed formations is difficult, in many cases it is based mostly on the stratigraphic correlation, and this can lead to a wrong or inaccurate tectonic interpretation of paleomagnetic data and sometimes making controversial conclusions, especially where has been strongly deformed like the Simao terrane.

Another paleomagnetic study on Late Jurassic - Cretaceous continental redbeds situated at the western margin of the Shan Thai block [16], near to the Sagaing right- lateral strike-slip fault (Fig. 1), shows that the study area has been rotated 29.1±5.2^0 clockwise and northward translated 7.8±4.0^0 (Table 3, Fig. 4 and 5). The observed motion of this area should also reflect the dextral displacement of the Sagaing fault, because it is a great longitudinal trending fault with a length of more than 1000 km that has been formed and being presently active during the India-Eurasia collision process. Therefore, geological formations, which situate within the fault zone certainly will be affected by the fault activity.

That is why, the paleomagnetically detected motions of the rock formations, which located within active tectonic areas (fault zone, extension zone, collision belt, interactive area between blocks or plates, etc.), are likely representative for the study area itself. It would be so subjective and ignorant if one uses the observed paleomagnetically detected rotation and translation of such area to make conclusion that these data reflect the coherent motion of the whole lithospheric block.

Table 3. Cretaceous - Eocene Paleomagnetic results of the Indochina block.

Locality	Lat (^{0}N)	Long (^{0}E)	Age	Observed VGP λ (^{0}N)	ϕ (^{0}E)	A95	Expected VGP λ (^{0}N)	ϕ (^{0}E)	Rotation R ± ΔR	Translation λ ± Δλ	Sign.	Ref.
Indochina block:												
SongDa terrane	21.7	103.9	K2	82.9	220.7	6.9	77.2	193.9	-7.0±7.6	2.7±7.1	N/N	[20]
TuLeBasin	21.7	104.2	J3-K	83.9	233.1	11.9	75.4	186.6	-10.7±13.1	5.1±12.4	N/N	[6]
Vinh locality	18.5	105.4	K	-	-	-	76.7	197.1	25.9±9.0	-13.4±10.7	Y/Y	[15]
South Vietnam	11.7	108.2	K	74.2	171.1	5.9	75.9	196.0	0.4±6.7	-6.6±6.4	N/Y	[5]
Khorat Plateau	16.5	103.0	J3-K1	63.8	175.6	1.7	73.7	181.8	10.2±7.3	-3.4±6.9	Y/N	[23]
Shan Thai block:												
Simao Terrane:												
Lanping	26.5	99.3	E	14.5	169.7	10.9	79.8	143.1	76.5±12.6	9.9±11.4	Y/N	[19]
Mengla	23.5	100.7	E	13.2	172.2	5.4	79.8	143.1	76.7±6.9	8.8±6.4	Y/Y	[3]
Yunlong	25.8	99.4	K2	54.6	171.3	4.4	77.2	193.9	26.0±5.6	-7.0±4.9	Y/Y	[18]
Xiaguan	25.6	100.2	K2	83.6	152.7	10.0	77.2	193.9	-8.2±11.7	-5.3±10.2	N/N	[12]
Jinggu	23.4	100.9	K2	18.9	170.0	8.9	77.2	193.9	65.7±10.1	-3.9±9.1	Y/N	[12]
Mengla	21.6	100.4	K2	33.7	179.3	8.2	77.2	193.9	47.2±9.0	-0.4±8.5	Y/N	[12]
Lanping	25.8	99.4	K2	69.7	167.6	6.9	77.2	193.9	8.2±8.4	-7.5±7.1	N/Y	[24]
Yongping	25.5	99.5	K1	50.9	167.3	20.6	74.3	198.1	27.5±25.7	-11.1±21.5	Y/N	[9]
Jinggu	23.5	100.7	K1	-13.9	161.3	4.3	74.3	198.1	99.2±7.9	0.6±7.4	Y/N	[3]
Shan Plateau	20.4	96.3	J3-K	46.4	190.6	3.5	75.4	186.6	29.1±5.2	7.8±4.0	Y/Y	[16]

Note: Ref. = Reference, Sign. = Significance (Y = Yes, N = No). K1 = Early Cretaceous, K2 = Late Cretaceous, K = Cretaceous, J3-K = Late Jurassic-Cretaceous, J3-K1 = Late Jurassic- Early Cretaceous, E= Eocene. Rotation and latitudinal translation were calculated at each study locality following Butler (1992); negative (positive) sign indicates CCW (CW) rotation and southward (northward) translation, respectively. Expected poles are calculated (Table 1) from Eurasian poles derived by Besse and Courtillot (1991).

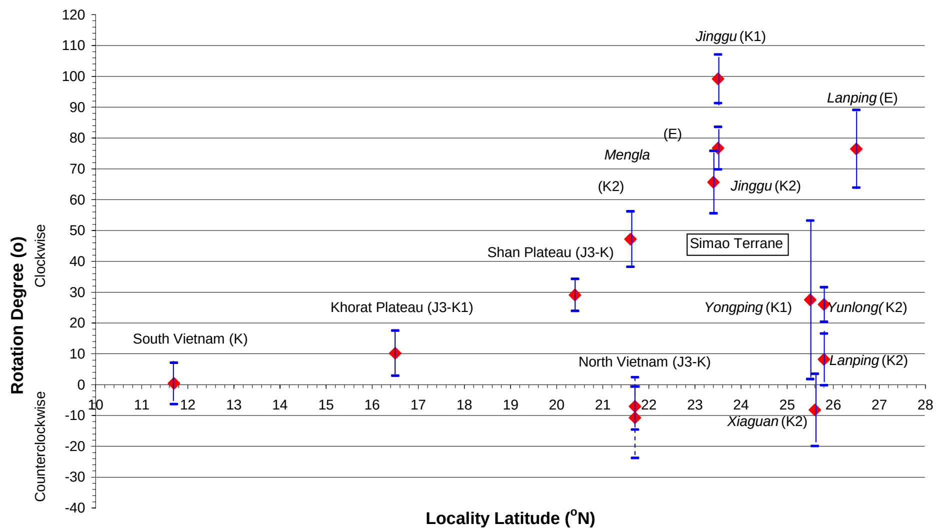

Fig. 4. Relative rotation of the Indochina - Shan Thai terranes with respect to Eurasia.

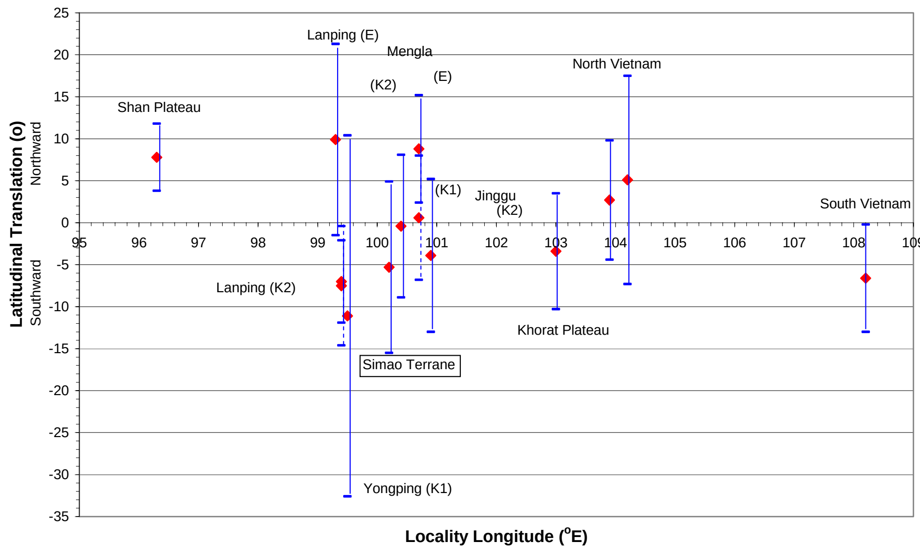

Fig. 5. Relative translation of the Indochina - Shan Thai terranes with respect to Eurasia.

4. Conclusions

The compilation and review of Cretaceous paleomagnetic data of the South China and Indochina regions lead us to conclude that:

- The present geographical position of the South China block has been relatively stable with respect to the Eurasia continent at least since the Cretaceous. The rotations and latitudinal translations, which have been recorded from some study localities reflect the local tectonic displacement of the upper crustal blocks due to active tectonic activities occurred during the Cenozoic.

- The India-Eurasia collision process has strongly deformed the Indochina - Shan Thai block, especially the areas located near to the collision belt. During the Cenozoic, Indochina and parts of Sundaland underwent complex internal deformation and did not behave as a coherent block as suggested by the extrusion model.

- The Red River fault does not demarcate the South China block and the Indochina block; the terranes that are located just to the south of this fault have not been rotated nor translated significantly relative to the Eurasia continent since the Cretaceous time. Thus, the tectonic boundary of the South China and Indochina blocks in the extrusion model, if ever exists, must be located somewhere further to the south of the Red River fault.

- The southward displacement of the southern part of Vietnam is in accordance with the extrusion model, however, no clockwise rotation has been observed from this area as well as the apparent counterclockwise rotations have been recorded from Borneo and Malaya peninsula located further to the south [8] indicating that the complex tectonic evolution of the Southeast Asian region can not be completely explained by any simple tectonic model.

- The Cretaceous - Eocene paleomagnetic results from the Simao terrane (Shan Thai block) mainly reflect the displacements of the upper crustal blocks during the folding and faulting process caused by the India-Eurasia collision.

The history of the Earth crust evolution has been a complex process, there are many problems relating to the tectonic-geodynamic mechanism that have been not elucidated yet; what is the role of the Manti flow under the continental crust relating to the plate interaction? Whether the collision, movement processes among continents, microcontinents associated with macma-orogenesis activities and intra-plate deformation have been taken place as a result of the active plate motion or they are the consequences of the Manti flow beneath? With the effort of the interdisciplinary studies of various geologist generations, these problems will be certainly clarified in future.

References

[1] J. Besse and V. Courtillot, Revised and synthetic apparent polar wander paths of the African, Eurasian, North America and Indian Plates, and true polar wander since 200 Ma, *Journal of Geophysical Research* B96 (1991) 4029.

[2] L.S. Chan, Paleomagnetism of late Mesozoic granitic intrusions in Hong Kong: Implications for Upper Cretaceous reference pole of South China, *Journal of Geophysical Research* B96 (1991) 327.

[3] H. Chen, J. Dobson, F. Heller, J. Hao, Paleomagnetic evidence for clockwise rotation of the Simao region since the Cretaceous: a consequence of India-Asia collision, *Earth and Planetary Science Letters* 134 (1995) 203.

[4] Y. Chen, V. Courtillot, J.P. Cogne, J. Besse, Z. Yang, and R.J. Enkin, The configuration of Asia prior to the collision of India: Cretaceous paleomagnetic constraints, *Journal of Geophysical Research* B98 (1993) 21927.

[5] Cung Thuong Chi and Steven L. Dorobek, Cretaceous palaeomagnetism of Indochina and surrounding regions: Cenozoic tectonic implications. In: *Aspects of the Tectonic Evolution of China edited by Malpas J., Fletcher C.J.N., Ali J.R. and Aitchison J.C., Geological Society, London, Special Publication* 226 (2004) 273.

[6] Cung Thuong Chi, Nguyen Trong Yem, Nguyen Quoc Cuong, Paleomagnetic results of Late Jurassic - Cretaceous extrusive and intrusive rocks from northwestern region of Vietnam, *Journal of Geology* No 1-2/256A (2000) 1 (in Vietnamese).

[7] R.J. Enkin, Z. Yang, Y. Chen, and V. Courtillot, Paleomagnetic constraints on the geodynamic history of the major blocks of China from the Permian to the present, *Journal of Geophysical Research* B97 (1992) 13953.

[8] M. Fuller, R. Haston, J. Lin, B. Richter, E. Schmidtke, J. Almasco, Tertiary paleomagnetism of regions around the South China Sea, *Journal of Southeast Asian Earth Sciences* 6 (1991) 161.

[9] S. Funahara, N. Nishiwaki, F. Murata, Y.-I. Otofuji, and Y.Z. Wang, Clockwise rotation of

the Red River fault inferred from paleomagnetic study of Cretaceous rocks in the Shan-Thai-Malay block of western Yunnan, China, *Earth and Planetary Science Letters* 117 (1993) 29.

[10] S.A. Gilder, J. Gill, R.S. Coe, X. Zhao, Z. Liu, G. Wang, K. Yuan, W. Liu, G. Kuang, and H. Wu, Isotopic and paleomagnetic constraints on the Mesozoic tectonic evolution of South China, *Journal of Geophysical Research* No101/B7 (1996) 16137.

[11] K.J. Hsu, S. Shuh, J. Li, H. Chen, H. Pen, and A.M.C. Sengor, Mesozoic overthrust tectonics in south China, *Geology* 16 (1988) 418.

[12] K. Huang and N.D. Opdyke, Paleomagnetic results from Cretaceous and Jurassic rocks of south and southwest Yunnan: evidence for large clockwise rotation in the Indochina and Shan-Thai-Malay terranes, *Earth and Planetary Science Letters* 117 (1993) 507.

[13] J. Jackson, and P. Molnar, Active faulting and block rotation in the western Transverse Ranges, California, *Journal of Geophysical Research* 95/B13 (1990) 22073.

[14] W.D. MacDonald, Net tectonic rotation, apparent tectonic rotation, and the structural tilt correction in paleomagnetic studies, *Journal of Geophysical Research* B85 (1980) 3659.

[15] Nguyen Thi Kim Thoa, Luu Thi Phuong Lan, Paleomagnetic study of Jurassic-Cretaceous sedimentary rocks from both sides of Red River Fault zone in Vietnam and tectonic interpretation, *Journal of Sciences of the Earth* 22 (2000) 266.

[16] B. Richter and M. Fuller, Palaeomagnetism of the Sibumasu and Indochina blocks: Implications for the extrusion tectonic model. In: *Tectonic Evolution of Southeast Asia edited by Hall R. and Blundell D., Geological Society Special Publication* 106 (1996) 203.

[17] H. Ron, R. Freund, Z. Garfunkel, and A. Nur, Block rotation by strike-slip faulting. Structural and paleomagnetic evidence, *Journal of Geophysical Research* 89 (1984) 6256.

[18] K. Sato, Y. Liu, Z. Zhu, Z. Yang, Y.-I. Otofuji, Paleomagnetic study of middle Cretaceous rocks from Yunlong, western Yunnan, China: evidence of southward displacement of Indochina, *Earth and Planetary Science Letters* 165 (1999) 1.

[19] K. Sato, Y. Liu, Z. Zhu, Z. Yang, Y.-I. Otofuji, Tertiary paleomagnetic data from northwestern Yunnan, China: further evidence for large clockwise rotation of the Indochina block and its tectonic implication, *Earth and Planetary Science Letters* 185 (2001) 185.

[20] K. Takemoto, N. Halim, Y.-I. Otofuji, Tran Van Tri, Le Van De, S. Hada, New paleomagnetic constraints on the extrusion of Indochina: Late Cretaceous results from the Song Da terrane, northern Vietnam, *Earth and Planetary Science Letters* 229 (2005) 273.

[21] P. Tapponnier, G. Peltzer, Le Dain, A.Y. Armijo, Propagating extrusion tectonics in Asia : New insights from simple experiments with plasticine, *Geology* 10 (1982) 611.

[22] J.W. Xu, Basic characteristics and tectonic evolution of the Tancheng-Lujiang fault zone. In: *The Tancheng-Lujiang Wrench Fault System, edited by J.W. Xu: 1-49*, John Wiley, New York, 1993.

[23] Z. Yang and J. Besse, Paleomagnetic study of Permian and Mesozoic sedimentary rocks from Northern Thailand supports the extrusion model for Indochina, *Earth and Planetary Science Letters* 117 (1993) 525.

[24] Z. Yang, J. Yih, Z. Sun, Y.-I. Otofuji, K. Sato, Discrepant Cretaceous paleomagnetic poles between Eastern China and Indochina: a consequence of the extrusion of Indochina, *Tectonophysics* 334 (2001) 101.

[25] S. Yoshioka, Y.Y. Liu, K. Sato, H. Inokuchi, L. Su, H. Zaman, Y.-I. Otofuji, Paleomagnetic evidence for post-Cretaceous internal deformation of the Chuan Dian fragment in the Yangtze block: a consequence of indentation of India into Asia, *Tectonophysics* 376 (2003) 61.