MESOZOIC COLLISION-EXTRUSION TECTONICS IN EASTERN ASIA¹

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Abstract : The eastern part of the Asian continent was intensively deformed in the early Cretaceous time. Deformation has been interpreted to be related to subduction tectonics along the eastern continental margin. We propose an alternative tectonic framework of collision-extrusion tectonics resulting from collision of the Indosinian block with the Eurasian continent. This event controlled the Jurassic to Cretaceous tectonic history in eastern Asia and evolution of the subduction zone along the eastern margin of the continent.

Key word : Collision, Extrusion tectonics, Eastern Asia, China block

Introduction

The Asian continent is interpreted to consist of a tectonic collage formed through successive collision of micro-continents during the Paleozoic-Mesozoic time (*e. g.* Zhang *et al.*, 1984 ; Sengor, 1984 ; Taira *et al.*, 1983, Maruyama and Sakai, 1986). Timing of closure of ocean regions between the continents and subsequent collisional have been inferred from geology in and around the collision sutures. For example, the South China Block (Yantze Block) collided against the North China block (Sino-Korea Block) in the late Triassic time (Sengor, 1984, Taira *et al.*, 1983). This timing is supported by paleomagnetic results (Lin, 1985 ; Zhao & Coe, 1987). In the Asian continent, the main orogenic event of Triassic time is named the "Indosinian Orogeny" and the major orogenic event of Jurassic to Cretaceous is called the "Yenshan Orogeny" (Compilation Group, 1975). The geological map of China has been organized on the concept of these cycles (Academia Sinica, 1976). The Indosinian Orogeny is interpreted to result from the collision between the Sino-Korea and Yantze micro-continents. The Yenshan orogeny, however, includes a variety of geologic events ; for example, not only collision but also extensive volcanism in the eastern Asia and strike-slip faulting along the eastern continental margin, that has been considered to result from the subduction of an oceanic plate.

We analyzed the Jurassic to Cretaceous tectonic events of the "Yenshan Orogeny" in eastern

¹ This paper is submitted to *Tectonophysics* in 1989.

Asia and concluded that most of the Yenshanian tectonic events did not result from subduction of an oceanic plate along the eastern continental margin, but from collision and related extrusion tectonics. Our alternative interpretation may be a key to understanding the tectonic events at the subduction zone along the western Pacific margin, because present models (*e. g.* Engebretson *et al.*, 1985) are based on a stable Eurasian plate.

Deformation of the northern China block

The eastern part of Asia can be divided into a North and a South China block. The boundary between the two blocks is the Qinling suture zone. The North China block is composed of Precambrian crystalline basement rocks and a cover of Proterozoic to Mesozoic sedimentary and volcanic rocks (Zhang *et al.*, 1984) that were deformed by several orogenic events. The most intensive post-Proterozoic event is the "Yenshan Orogeny" of Jurassic to Cretaceous age. Yenshanian deformation in the North China block is characterized by three different styles in three different areas.

NNE-trending strike-slip fault system- The general features of the Mesozoic deformation in eastern Asia are described in the tectonic map of China (Cui & Zhao, 1985). On this map, many NNE-trending faults parallel the continental margin, the most famous of which is the Tanlu Fault (Figs. 1 and 2), a sinistral strike-slip fault active during the Late Jurassic to early Cretaceous time (Xu, 1982). The parallel arrangement of sinistral strike-slip faults to the continental margin has led to an interpretation that the strike-slip movement is a result of oblique subduction (*e. g.* Taira *et al.*, 1983; Jolivet *et al.*, 1988). Modern examples of oblique subduction zones; such as the Sunda arc (Fitch, 1972, Page *et al.*, 1979), Southwest Japan (Okada, 1970), northern New Zealand (Walcott, 1978), and Kuril arc (Kimura, 1986), show that strike-slip faults in overriding plate are limited to forearc regions; i.e., between the volcanic front and the trench. The Mesozoic strike-slip faults in eastern Asia, however, deformed a region more than 1000km away from the volcanic front (Fig. 1). Such anomalous development of strike-slip faults is not consistent with active oblique subduction zones. Another tectonic interpretation, therefore, should be applied to the Mesozoic strike-slip faults in eastern Asia. Previously, the strike-slip faults in eastern Asia were considered to be continuous along the entire continental margin. Recently, however, it has been revealed that their displacement is diminished near the boundary between the northern and southern China blocks (in the Qinling suture zone; Fig. 3; Xu, 1982). The Tanlu Fault with a displacement of several hundred kilometers (Xu, 1982) branches and its displacement becomes smaller at the eastern margin of the Qinling suture zone near Nanjing and Wuhan (Xu, 1982). Faults parallel to the continental margin further south in the South China Block are not strike-slip faults but reverse or thrust faults (Hsu *et al.*, 1988). This change in stress regime also suggests that the strike-slip faults are not related to the oblique subduction of an oceanic plate along the eastern continental margin of Asia.

Fig. 1 Major Mesozoic structures in eastern Asia (Cui et al., 1985). The location of the trench along the eastern margin of the continent is positioned from the reconstruction of the Japanese Islands before opening of the Japan Sea.

Yenshan thrust zone- The mountains north of Beijing are composed of Precambrian basement rocks, Paleozoic to Jurassic folded and metamorphosed strata, and Mesozoic intrusive rocks (Geological Map of Beijing Area, 1987). They are repeated by thrust faults along the Yenshan Thrust Zone (Fig. 2). The time of deformation is early Cretaceous; Jurassic volcanoclastic sediments are highly deformed and metamorphosed, but Late Cretaceous sedimentary rocks are undeformed. The general ENE strike of thrusts is oblique to the sinistral strike-slip faults discussed above. The eastern margin of the thrust zone merges with the Tanlu Fault north of Bohai Bay (Fig. 2). The western margin of the zone changes its trend to NNE and continues into the Shanxi fold

Fig. 2 Deformational features of the northern China Block. The area B surrounded by the dotted line shows the area, where the "Yenshan" alkalic effusives are present.

zone.

Shanxi fold zone- The eastern half of Shanxi Province is a hilly area (Taihan Mountains) composed of Precambrian basement covered by Paleozoic, Triassic and Jurassic folded strata. Fold axes form an echelon pattern (Fig. 2), which indicates a left-lateral movement along a NNE trend for the eastern margin of the fold zone. The early Cretaceous time of folding is determined from the

Fig. 3 Tectonic feature at the southern end of the Tanlu Fault (modified from Xu, 1982). Displacement along the Tanlu Fault is several hundred kilometers (A), whereas at the southern end of the fault it branches and its displacement diminishes (Fig. B).

Fig. 4 Simplified model showing the deformation of the northern China Block. T : Tanlu Fault System, Y : Yen-shan thrust zone, S : Shanxi Fold Zone. Intra-continent deformation zone (T-Y-S) was formed by sinistral strike-slip movement between the Blocks A and B (B' and B'').

folded Jurassic strata unconformably overlain by unfolded Cretaceous (Fig. 2).

Intracontinent deformation zone The Tanlu left-lateral strike-slip fault system, the Yenshan thrust zone, and the Shanxi fold zone appear to be contemporaneous and show different deformational styles, but appear to be related with each other. The different styles of deformation in each area can be modeled as intra-continental deformation as shown in Fig. 4. Blocks A and B (B' and B'') represent the areas to the west and east of the intra-continental deformation zone, respectively. When the block B moved to the north relative to the block A, three different deformation modes are developed. As the Yenshan Thrust zone blocked the northward movement of the block B, a new left-lateral strike-slip fault was formed to the south of an older segment of the Tanlu fault and separated the blocks B' and B'' (Fig. 4-2). Although the en echelon Shanxi fold zone indicates a NNE trending left-lateral strike-slip movement, a strike-slip fault is not recognized. This difference suggests an earlier cessation of strike-slip movement in the Shanxi Fold Zone, while movement continued on the Tanlu Fault.

Deformation of south China block

It has been interpreted that South China Block (Yantze Block) collided with North China Block in late Triassic time (Sengor, 1984; Taira *et al.*, 1983). A paleogeographic map, based on facies analysis also shows the late Triassic closure of an open sea between the northern and southern blocks (Wuhan Geological Institute, 1986). Recently, Hsu *et al.* (1988) proposed that the Yantze Block can be divided into two sub-blocks, that we tentatively call Yantze I and Yantze II (Fig. 5). They are interpreted to have collided in late Triassic time. The pervasive deformation in the region may be partly related to this collision. However, the deformation occurred more recently in Jurassic to Cretaceous time as mentioned later. Figure 6 shows the profile of Sichuan basin in the Yantze I Block. The profile clearly shows that the Yantze I block was underthrust to the west during Jurassic to Cretaceous time because thick sedimentary deposits of Jurassic to Cretaceous age accumulated in the Sichuan basin, and their westernmost parts were involved in the deformation. The eastern half of the Yantze I block shows intensive folding of the Paleozoic to Jurassic sedimentary rocks (Fig. 5a). The folds are associated with strike-slip faults. The southern half of the triangular Yantze I Block contains folds with NS-trending fold axes and NE-trending right-lateral strike-slip faults (Fig. 5a), that are near the boundary between the Yantze I and II blocks. In contrast to the southern half of the Yantze I Block, the northern half contains NNW- to NW-trending fold axes with WNW-trending sinistral strike-slip faults (Fig. 5a), that lie along the southern margin of the Qinling suture zone. This deformational pattern suggests that the Yantze I blocks moved eastward relative to the North China Block and Yantze II block. The time of this movement is inferred to be Cretaceous because Cretaceous faults related to formation of a sedimentary basin was developed along the boundary zone between the Yantze I and II blocks (Fig. 5a). Precambrian basement rocks crop out in the

Fig. 5 Tectonics feature of the South China Block. a : Major faults (solid line) and fold axes (dotted line) and distribution of Triassic (T), Jurassic (J) and Cretaceous (K) sedimentary rocks. b : Distribution of granitic rocks. YI and YII show the Yantze I and Yantze II blocks, respectively.

Fig. 6 Geologic profile of the Sichuan Basin (simplified from Feng, 1985). T : Triassic, J ; Jurassic, K ; Cretaceous sedimentary rocks.

Quinling suture zone, along the southern margin of North China Block, and along the western margin of the Yantze II block near the strike-slip faults that separate Yantze I and II (Fig. 5a). These outcrops suggest uplift resulting from a small magnitude of underthrusting of the Yantze I block against surrounding blocks (Jia *et al.*, 1988) (Fig. 7). Consequently, the Yantze I block appears to have been intensively deformed during Cretaceous time ; its western margin was underthrust to the west and its eastern tip was folded due to shortening and partly underthrust. The strike-slip faults

Fig. 7 Cartoon showing the underthrusting of the Yantze I Block beneath the Yantze II block and the western continental mass.

between the Yantze I and II Blocks indicates a relatively eastward movement of the Yantze I block as described above. These relationships show that deformation within the continent continued after the late Triassic contact between the North and South China Blocks.

Collision related magmatism in and around the South China block

In and around the Yantze I Block, collision related magmatism with intrusion of S-type granites occurred (Takahashi, 1983). In the western part of the Yantze I block, "Indosinian" granitic rocks intruded during Triassic time. High K "Yenshan" granitic rocks intruded the Quinling suture zone in Jurassic to Cretaceous time. These high K granites were injected just after the collision between the South China and North China blocks during Late Triassic time. This magmatism is interpreted to be collision related magmatism by Takahashi (1983). During Jurassic to Cretaceous time voluminous volcanic rocks were erupted within the Yantze II block. Most of these volcanic rocks were related to continental margin magmatism caused by subduction of an oceanic plate, whereas some of them may have been related to collision between the Yantze I and II blocks (Hsu *et al.*, 1988). This magmatism during Jurassic to Cretaceous time around the Yantze I block is consistent with the deformational events in the block and suggests that the collision among the blocks continued after the late Triassic collision.

Collision-Extrusion Tectonics in eastern Asia During the Jurassic to Cretaceous time

The best example of continental collision is the present Indian- Eurasian collision, which started at about 50 Ma and has continued to the present (Tapponier and Molnar, 1976). The collision caused extensive deformation within the Asian continent, such as, large scale strike-slip, convergent and extensional tectonics (Tapponier *et al.*, 1982). This example of collisional tectonics shows deformation does not cease at the time of contact between continental blocks, but continues for a long time following initial contact. The pervasive deformation is characterized by extrusion of continental fragments that escape toward a free boundary continental margin (Tapponier and Molnar 1976; Tapponier *et al.*, 1982). The Mesozoic tectonic events in eastern Asia also suggests that collision related events continued after the late Triassic contact of the continental blocks.

The early Cretaceous deformation of the North China Block is characterized by pervasive strike-slip movement due to northward movement of eastern half of the block. At that time, South China Block was also deformed. The movement in the North China Block appears to have been contemporaneous with the deformation of the South China Block. The North China and South China blocks moved northward and eastward, respectively (Fig. 8). The early Cretaceous intracontinental deformation in the two blocks can be related to be collision-extrusion related deformation.

As mentioned above, two factors are important for the development of extrusion tectonics; continued convergence following collision and a free boundary for the escape of continental fragment. The first factor does not seem to prevail in the collision between the Yantze I and North China

blocks or between the Yantze I and II themselves, because after the collision, a new subduction zone was formed along the south eastern margin of the Yantze II block (*e. g.* Maruyama and Sakai, 1986). This means continued convergence by the Yantze II block is unlikely. As mentioned before, the Yantze I block moved eastward and underthrust westward at the same time. This relation suggests that the deformational forces are not generated from the southeast but from the west. The Indosina block is now located south of the South China Block, but, it was located more to the northwest before the opening of the South China Sea (Tapponier *et al.*, 1982). To obtain a Jurassic configuration, we have moved the Indosina block more than 1000km along the Red River fault which is the boundary between South China and Indosina blocks. Thus Indosina block appears to have been situated originally to the west of the Yantze I block. The Indosina Block is another micro-continent that collided against the Eurasian continent. Zhang *et al.* (1984) pointed out that accretionary complexes and subduction related magmatism along the Red River Fault mark the Jurassic to Early Cretaceous collision of the Yantze block and a western micro-continent. This continent is interpreted to be the Indosina block mentioned above. The pervasive deformation of the Yantze I and the North China block can be attributed to the collision of the Indosina Block with the Eurasian continent.

The second factor for the extrusion tectonics is a free boundary. The eastern margin of South China Block was a subduction zone toward which continental fragments could escape. The northern margin of North China block is now occupied by the Siberia continental block, which is considered as core of the Eurasian Continent. During the Jurassic to Cretaceous time, however, there was an

Fig. 8 The early Cretaceous collision-extrusion tectonics in eastern Asia caused by collision of Indosina block against Asia. M. S. : Mongolian suture zone, T. F. Tanlu Fault, Q. S. : Quinling suture zone, N : North China Block, YI : Yantze I Block, Y II : Yantze II Block, I : Indochina block.

oceanic region between the Siberian continent and North China block (Klimetz, 1983; Takahashi, 1985; Taira *et al.*, 1983; Maruyama and Sakai, 1986). The closing of this oceanic region during early Cretaceous time is inferred from the extinction of magmatism related to subduction (Takahashi, 1985). Thus, the northern margin of North China Block was also a free boundary at that time and changed to a collision zone in late Cretaceous time as a result of extrusion of the North China block.

Consequently, pervasive deformation of eastern Asia during Jurassic to the early Cretaceous time can be attributed not to subduction related tectonics along its eastern continental margin but to extrusion tectonics caused by the collision of the Indosina Block along its southern margin (Fig. 8).

Are there other collision-extrusion related events observed? The most interesting feature is the alkalic magmatism (Ishihara *et al.*, 1986) in the eastern part of Qinling suture zone (Fig. 5b). One possible mechanism for this magmatism is extension and continental break up in this region caused by relatively extensional movement between North and South China Blocks during extrusion (Fig. 8). Xu (1982) has also pointed out that extensional tectonics took place around the southern margin of the Tanlu Fault. This extension was probably related to the same time as alkalic magmatism.

Difference of subduction mode along the eastern continental margin

Up to now, the relative motion between the Eurasian continent and oceanic plates in Jurassic to Cretaceous time has been derived by assuming a stable Eurasian continent by Engebretson *et al.*, (1985) and Maruyama and Seno (1987). However within Eurasia there was relative movement between the North China Block and South China blocks as discussed above. Therefore, relative movement between the continental plate and the subducted oceanic plates along the eastern margin of the South China Block should be different from that of North China Block. The Japanese Islands are now situated to the east of the North China block, whereas they were close to the continent before the Tertiary opening of the Japan sea (Otofuji *et al.*, 1985). The Japanese Islands are mainly composed of Jurassic to Cretaceous accretionary complexes and arc-related igneous rocks which were displaced due to left-lateral strike-slip movement along the continental margin during Late Cretaceous time (Taira *et al.*, 1983). The early Cretaceous Japanese Islands, therefore, should have been situated to the southwest to their present positions, although their exact positions are unknown (Fig. 9). In the Latest Jurassic to Early Cretaceous accretionary complexes in northeast Japan and Hokkaido, ophiolitic complexes are dominant, whereas those in southwest Japan are mostly composed of terrigenous sedimentary complexes (Kimura and Okamura, 1988). Thus, the evolutionary history of the southern half of Japan is very different from northern Japan and Sakhalin (Maruyama and Seno, 1987; Kimura and Okamura, 1988). Reconstruction of the Japanese Islands before opening of the Japan Sea indicates they were rather straight along the continental margin (*e. g.*, Niitsuma *et al.*, 1986). If Eurasia was a stable continent at that time, relative movement between the Eurasian continent and subducted oceanic plates (Farallon and Izanagi Plates in the latest Jurassic to early Cretaceous time), should not have been drastically different along the continental margin (Engebretson *et al.*,

Fig. 9 Tectonic mode along the eastern margin of the Eurasian continent. The subduction mode depends on the tectonic setting of the overriding continental plates.

1985; Maruyama and Seno, 1987). Therefore, the difference in the characteristics of the accretionary complexes in northern and southwest Japan is not explicable by the "one piece of the Eurasian continent model" by Engebretson *et al.* (1985). Our "mobilized Eurasian model" can explain the difference, if southwest and northeast Japan were located in front of the South and North China blocks, respectively. In early Cretaceous time before Tertiary opening of the Japan sea, the subduction mode would have been different along the two blocks. The South China Block (Yantze) advanced toward the east, whereas the North China Block (Sino-Korea) moved northward (Fig. 9). If the locations are as shown in Fig. 9, compressional and neutral tectonic regimes were likely in the southwest and northeast Japan subduction zones, respectively (Fig. 9). Extensional tectonics seems to have occurred between the North and South China Blocks as mentioned above. Modern examples of extensional arcs such as Mariana and Mexico off Guatemala contains forearc ophiolitic complexes (e. g. Ogawa and Naka, 1984; Auboin *et al.*, 1985). These differences can be attributed to differences of the movement in the overriding plate.

Acknowledgement

We have received considerable help from various people in accomplishing the present study. We would like to thank Wei Qing-yun and Zhu Xiao-yuan of Institute of Geophysics, Academia Sinica. Thanks are due to H. Tsunakawa, T. Tosha, and H. Uchimura for constructive discussion. B. C. Burchfiel review our paper very kindly and gave us useful suggestions, which we also appreciate very much.

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