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REACTIVATED INTRAPLATE TECTONICS IN EAST CHINA DURING THE MESOZOIC: NEW CONSTRAINTS FROM ^{40}AR/^{39}AR DATING

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ABSTRACT

China is an amalgamated continent formed by welding of numerous continental blocks, subdivided by several orogenic belts at different stages of development. The Caledonian orogeny produced a series of the Tianshan, Qilian, Qinling, Tongbai-Dabie and Huanan orogenic belts, which were sutures of the welded blocks. From late Permian to Triassic, accretion of Siberia, Qiantang, Songpan-Ganzi and Indochina with the existing China (North China, Yangtze, Huanan, Cathaysia, Junggar, and Tarim blocks) assailing from both north and south, was accompanied by intense intraplate deformation which particularly rejuvenated the ancient orogenic belts.

Several new lines of paleontologic, petrologic and geochronologic data from the Tongbai-Dabie and Huanan orogenic belts markedly contradicts with the previous interpretation of an early Triassic interplate compressional orogeny. The systematic ^{40}Ar/^{39}Ar dating of samples collected from these belts consistently yields three composite ages representing Caledonian (~435-300 Ma), Indosinian (~245-200Ma), and Yanshanian (~160-90 Ma) times. We believe that the first age represents the Caledonian interplate collision and mountain exhumation and the others Indosinian and Yanshanian reactivated intraplate mountain exhumation. The Indosinian orogeny seems to be a major tectonic event in China causing intraplate deformation dominated by ductile shearing in the ancient orogenic belts and thin-skinned folds and thrusts surrounding in their environments. Especially, the cause of the successive accretions assailing from both north and south induced the Huanan Block to be subducted underneath the north China Block and its subsequent swift uplift during early Mesozoic. There occurred

a great amount of crustal shortening and exhumation distributed among these ancient orogenic belts.

INTRODUCTION

Asia is a composite of a number of continental blocks. Individual blocks include Siberia, Kazakhstan, Junggar, Tarim, North China, Yangtze, Jiangnan, Cathaysia, Songpan-Ganzi, Qiantang, Lhasa, Indochina and India Blocks, that have been successively accreted and welded together since the Mesoproterozoic (McElhinny *et al.*, 1981). The amalgamated blocks, which form the east Asia, are separated by several orogenic belts that are at different stages of development (Fig. 1). Many previous studies have used geochronology to gain a better understanding of these stages of mountain welding in China (e.s., Mattauer *et al.*, 1985; Liou *et al.*, 1989; Ames *et al.*, 1993). Unfortunately, individual orogenic belts in China often yield confliction dates that have complicated interpretations regarding the timing of collision. Timing of collision, for example of the Tongbai-Dabie and Huanan orogenic belts, has been debated as being related to Caledonian, Indosinian, or Yanshanian deformation by many geologists in the past decade (e.s., Hsu, 1988; Rodgers, 1989; Ames *et al.*, 1993; Zhai *et al.*, 1998).

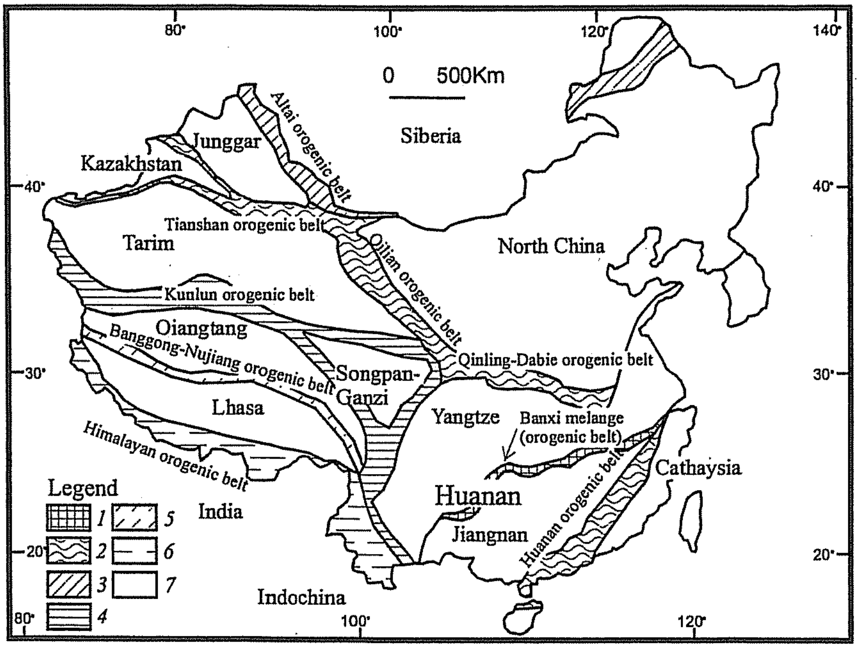

Figure 1. *1.*Mesoproterozoic orogenic belt, *2.*mid-Paleozoic (Caledonian) orogenic belt, *3.*late Permian (Hercynian) orogenic belt, *4.*early Mesozoic (Indosinian) orogenic belt, *5.*early Jurassic orogenic belt, *6.*Cenozoic orogenic belt, *7.*continental block. Map showing continental blocks and orogenic belts in China, modified after Hsu *et al.*(1988), Wang and Mo(1995).

In the past few years, abundant morphological evidence for Neogene reactivated deformation was documented in the Tianshan, Qilian and Qinling Mountains (Peltzer *et al.*, 1985; Cunningham *et al.*, 1996). These mountain ranges formed initially in response to Caledonian deformation (Mattauer *et al.*, 1985; Hendrix *et al.*, 1992). In other words, the Neogene reactivation of the "older" mountains is being induced by the India-Asia collision (Molnar and Tapponnier, 1975). Reactivation of "older" orogenic belts is also important for understanding mountain exhumation (Hendrix *et al.*, 1994; Sobel and Dumitru, 1997; Yin *et al.*, 1998). Episodic reactivation of west China is thought to be related to accretion of the Songpan-Ganzi, Qiantang, Lhasa and India Blocks onto the south Asia continent since the Permian (Carroll *et al.*, 1990; Hendrix *et al.*, 1992). A better understanding of the geology of west China, the reactivated intraplate deformation was frequently concentrated in the "older" orogenic belts of central China, particularly in response to the India-Asia collision. We have used idea as an analog for reevaluating and reinterpreting similar tectonics in the Paleozoic-Mesozoic of east China.

Isotopic dating of metamorphic rocks is a well-established and powerful technique for delineating exhumation histories of orogenic belts. In this study, we review and present new ^{40}Ar/^{39}Ar dates from the Huanan, Banxi and Tongbai-Dabie orogenic belts, that better delineate the timing of mountain exhumation in east China. Especially, the purpose of this paper will discuss episodes of exhumation in the pre-Mesozoic orogenic belts. In addition, paleontologic and sedimentologic results have gained a better constraint of paleogeography in east China.

HUANAN OROGENIC BELT

The Huanan Block defined in this study comprises three smaller blocks divided into the Yangtze, Jiangnan and Cathaysia Blocks by the Banxi (Jiangshan-Shaoxing suture) and Zhenghe-Dapu sutures (Fig. 2). They are different with regard to the characteristic of neodymium-depleted mantle model ages which seems to indicate that they were distinct tectonic blocks before the Mesoproterozoic period (Chen and Jahn, 1998). Although the timing of accretion of the Banxi melange (or Banxi orogenic belt) has been discussed by many geologists, the geological evidence now, however, shows clearly that the Banxi melange is a Mesoproterozoic suture (Rowley *et al.*, 1989; Gupta, 1989; Rodgers, 1989; Li, 1994; Shu and Charvet, 1996). After suturing, deposition of the Sinian-Silurian sedimentary cover of the Yangtze-Jiangnan Block occurred. The Yangtze-Jiangnan and Cathaysia Blocks were welded together by the Zhenghe-Dapu suture during the Silurian (Wang *et al.*, 1988; Wang *et al.*, 1992; Yang *et al.*, 1995). Accretion occurred coevally within the Caledonian metamorphic belt along the Zhenghe-Dapu suture which is called the Huanan orogenic belt in this paper or the Huanan metamorphic complex by Hsu *et al.* (1990). Thus, construction of the south China block is a result of accretion of continental fragments such as the Huanan Block (Fig. 2). The stratigraphic relations in southeast China display two fining-upward depositional sequences, a late Devonian-early Triassic sequence and a late Triassic-Cretaceous sequence. These sequences record two compressional orogenic events and two extensional events from the middle Paleozoic to Mesozoic. The pre-Devonian sequence was covered by a late Devonian molasse with an angular unconformity (Mo and Ye, 1980; Zhen, 1984; Zhou and Zou, 1996) representing the Caledonian Orogeny due to collision of the Yangtze-Jiangnan with Cathaysia Block. Following the collision, this area subsided to form a broad northeast-trending extensional basin, which is

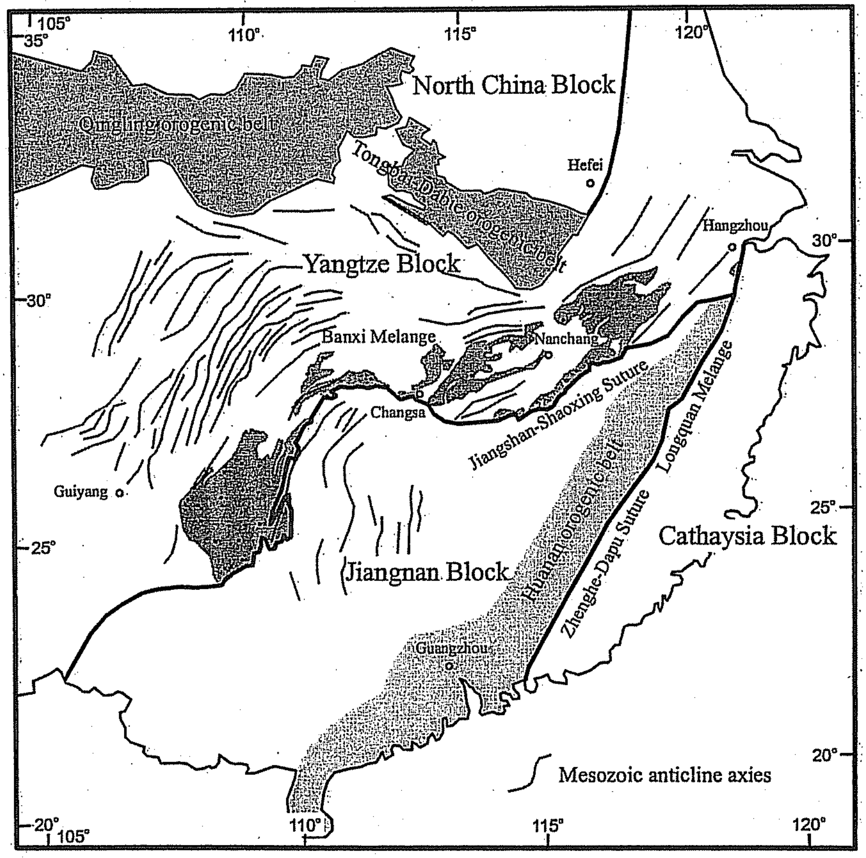

Figure 2. Tectonic units of east China, modified after geologic map of China. The Huanan Block comprises three blocks, the Yangtze, Jiangnan and Cathaysia Blocks which are separated by the Jiangshan-Shaoxing and Zhenghe-Dapu sutures. The Mesozoic thin-skinned fold and thrust systems occur along the ancient orogenic belts. The W-E trending structures of the upper Yangtze region are approximately paralleled to the Qinling-Dabie orogenic belt. The NE trending structures of the lower Yangtze region are paralleled to the Banxi orogenic belt.

interpreted as a product of post-orogenic extension. The 5,000 m of late Devonian-early Triassic littoral deposits in the Huanan orogenic belt implies active subsidence during the entire depositional period. Next, widespread deformation of the Indosinian Orogeny occurred in east China along the ancient orogenic belts. The late Paleozoic-early Triassic sequence was covered by a late Triassic molass with an angular unconformity representing the Indosinian Orogeny (Zhou *et al.*, 1995). The depositional sequence in south China extensively recorded two major orogenic events that occurred in the middle Paleozoic and early Mesozoic.

The widespread late Paleozoic-Mesozoic alluvial, deltaic, offshore and carbonate deposits, except in southernmost China, represent a continental platform environment (Ma, 1996). According to our interpretation of the depositional framework outlined above, we advocate that it is not the Tethys Ocean but instead a wide epeiric sea that existed in south China during the late Paleozoic-early Mesozoic. In addition, late Paleozoic-early Mesozoic ophiolitic rocks have never been found in south China. Actually, the authigenic Indosinian suture (Song-Ma suture) was situated between the Indochina and Huanan Blocks, which exposed in the Indochina and western Yunnan (Sengor and Hsu, 1984).

South China has undergone several stages of deformation including thin-skinned fold-thrust and ductile shear deformation during the middle Paleozoic and early Mesozoic (Wang, 1983; Wan and Zhu, 1991). Early Mesozoic deformation was most intensive in south China. The Banxi and Huanan orogenic belts were, of course, also influenced and overprinted by early Mesozoic deformation. Within these orogenic belts, several Mesoproterozoic-early Paleozoic formations are thrust onto late Paleozoic and early Mesozoic strata (Tao, 1987). Hsu *et al.* (1988) documented a series of fold and thrust structures, like the Lantien, Loping, Xishan and Lushan nappes, that formed during the Indosinian Orogeny. Nappes and windows are common in the fold and thrust belts of south China, especially where reactivation has occurred along incompetent zones of the pre-Mesozoic orogenic belts such as the southern Qinling, Banxi and Huanan orogenic belts. The reactivated deformation were commonly produced mylonitic structure at a deep level in the ancient orogenic belts and then underwent much older or high-graded metamorphic terrane elevated.

Geochronological dating for relevant metamorphic rocks is necessary to elucidate the exhumation history of the orogenic belt. Therefore the systematic $^{40}Ar/^{39}Ar$ dating in this paper is essential for understanding the reactivated exhumation history. These samples were mainly collected from the basement of the Proterozoic rocks of Huanan orogenic belt. The new ages of the Huanan orogenic belt here fall into three ranges, namely, the Caledonian (~418-340 Ma), Indosinian (~232-200 Ma) and Yanshanian (~140-135 Ma) times (Fig. 3). The Proterozoic gneiss and schist obtained from the Huanan orogenic belt give the Caledonian ages of 417.6±3.5 Ma (FJ05), 367.3±3.1 Ma (FJ04), 366.7±1.2 Ma (FJ09) and 339.6±1.7 Ma (FJ01; Figs. 3 and 4). These ages (~418-340 Ma) are interpreted as regarding the Caledonian orogenic event in the belt. These ages are interpreted as the product of tectonically induced metamorphism and basement exhumation during the late Silurian-late Devonian which produced a regional late Devonian angular unconformity. The unconformity is widely distributed over southeast China and overlain by extensive late Devonian-early Carboniferous molasses.

Four mica samples extracted from Proterozoic gneiss yielded dates of 228.1 ± 3.8 Ma (FJ10), 232.3 ± 3.8 Ma (FJ07), 208.0 ± 6.0 Ma (FJ08) and 199.9 ± 5.8 Ma (FJ05; Figs. 3 and 4). Two hornblende samples collected from gneiss within a mylonitic zone have ages of 230.2 ± 3.7 Ma (FJ02) and 209.4 ± 3.4 Ma (FJ03; Figs. 3 and 4). These dates are interpreted as recording the Indosinian event which is responsible for inducing ductile shearing and basement exhumation during the early Mesozoic. Mylonitic rocks in the ancient orogenic belts of China often have Indosinian age range (Chang and Lo, 1994; Xu *et al.*, 1992). The ductile shearing associated with Indosinian intraplate deformation overprinted any isotopic signature of earlier deformational event within the ancient orogenic belts. Indosinian deformation (~232-200 Ma) also produced a widespread middle Triassic unconformity in southeast China.

Four K-feldspar samples collected from the Proterozoic gneiss and pre-Caledonian granite have ages of 146.5 ± 4.3 Ma (FJ05), 139.1 ± 0.8 Ma (FJ06), 172.8 ± 2.9 Ma (FJ10), and 133.4

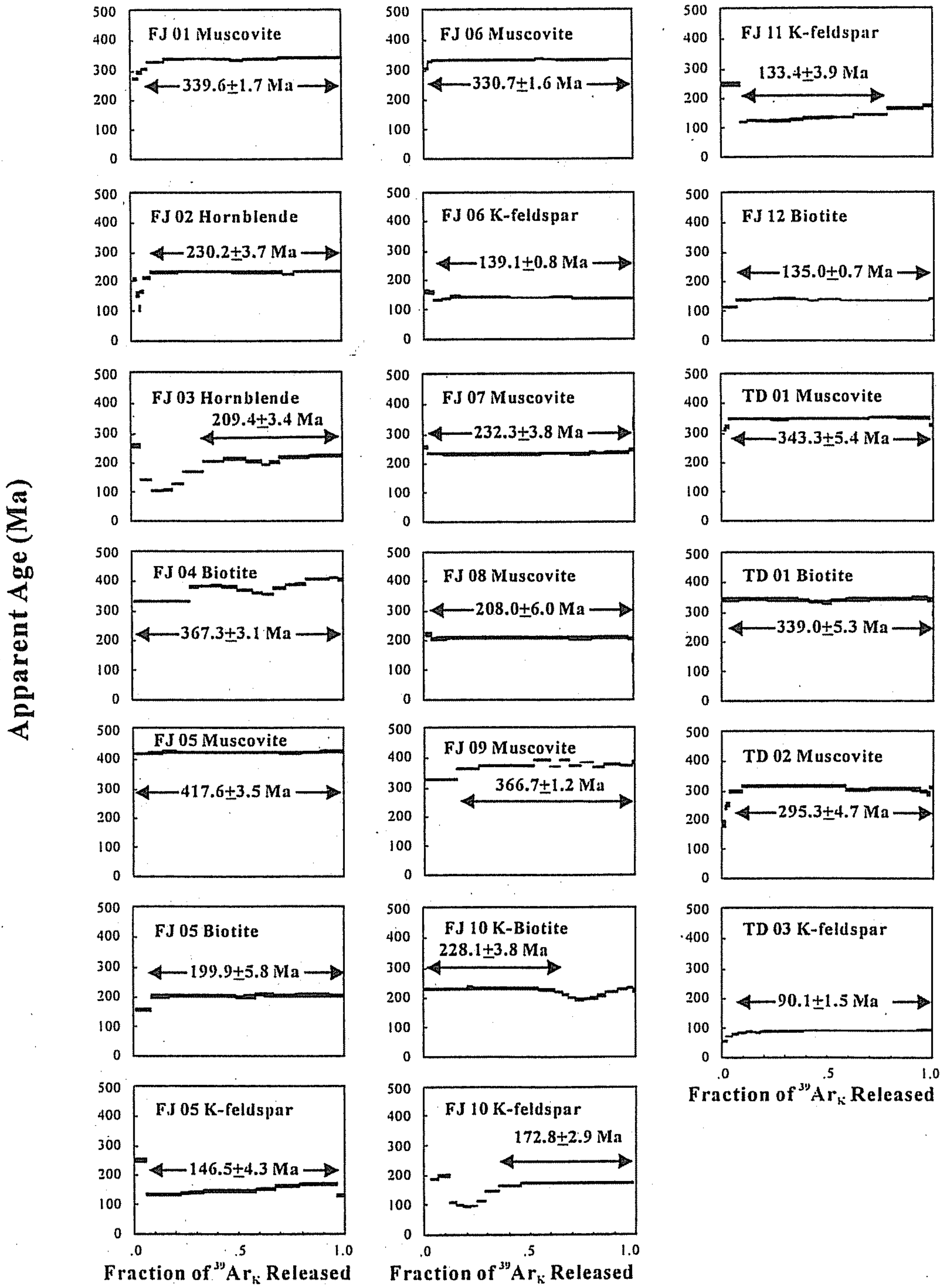

Figure 3. Age spectra for analysed minerals. Location of samples shown in Fig. 4 and 5.

± 3.9 Ma (FJ11; Figs. 3 and 4), which are also interpreted as exhumation ages from the Yanshanian stage. Sample FJ05, for example, was extracted from a Proterozoic gneiss which had been thrust over Permian and Jurassic strata. Dates from muscovite, biotite and K-feldspar have ages of 417.6 ± 3.5 Ma, 199.9 ± 5.8 Ma and 137.5 ± 4.1 Ma (FJ05), respectively. Among these of 417.6 ± 3.5 Ma is interpreted as exhumation of Huanan orogenic belt associated with accretion of the Cathaysia and Yangtze-Jiangnan Blocks. Thus, the ages of 199.9±5.8 Ma and 146.5±4.3 Ma may be the product of intermittent reactivation relating to Mesozoic detachment faulting.

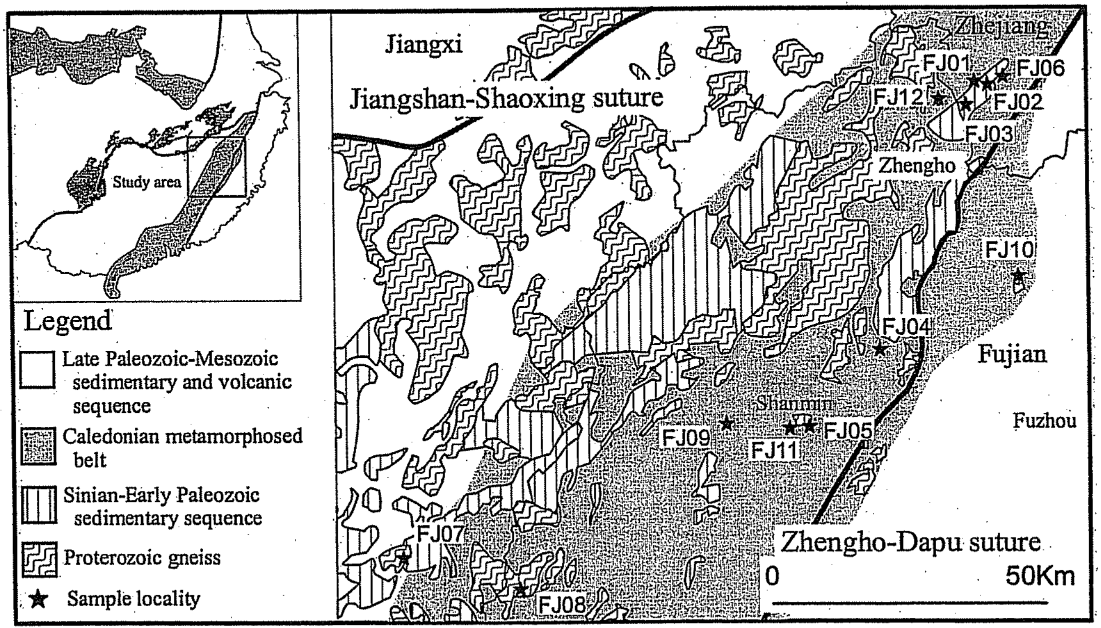

Figure 4. Geological map of the Huanan metamorphic complex in southeast China.

In addition, the geochronological studies of the Mesoproterozoic Banxi orogenic belt have reported four general age ranges which are 1,100 - 900 Ma, 430 - 360 Ma, 225 - 200 Ma and 160 - 130 Ma (Table 1; Shu *et al.*, 1991; Xu *et al.*, 1992; Li, 1994; Chang and Lo, 1994; Charvet *et al.*, 1996). The 1,100 - 900 Ma ages for ophiolitic blocks denote the formation age of the Banxi Ocean formed in the Mesoproterozoic (Chang and Lo, 1994; Chang, 1996; Shu and Charvet, 1996; Charvet *et al.*, 1996) and collided in the late Proterozoic (~800 Ma; Zhou and Zou, 1996). The other age's compositions are represented as recording three stages of reactivated deformation in the Banxi orogenic belt. Obviously, several episodes of tectonics including the Caledonian, Indosinian and Yanshanian orogenies exhumed this area. In fact, the majority of Chinese geologists have been inclined to look the Indosinian Orogeny as an intraplate deformation for the past several decades (Zhang *et al.*, 1989; Zhao, 1994).

Table 1. Summary of isotopic dating on igneous and metamorphic rocks from the Tongbai, Dabie, Qinling, Banxi, Pingtan-Dongshan orogenic belts.

Ages (Ma)	Isotopic dating method	Minerals/rock types	Orogenic belt	Reference
470±20Ma, 470±14Ma, 435±14Ma	$^{207}Pb/^{206}Pb$	Granulite, xenolith, gneiss	Tongbai	Kröner et al., 1993
375-400Ma	K-Ar	Magmatic arc	Tongbai	Kröner et al., 1993
399 Ma	$^{40}Ar/^{39}Ar$	Metavolcanics	Tongbai	Hao, 1988
401Ma	$^{40}Ar/^{39}Ar$	Metavolcanics	Tongbai	Jin et al., 1997
435±2Ma, 433±2Ma, 407±2Ma, 404±5Ma, 317±1Ma, 304±14Ma, 130±1Ma	$^{40}Ar/^{39}Ar$	Metavolcanics (amphibole)	Tongbai	Zai et al., 1998
240±2Ma, 236±3 Ma, 246±8Ma, 243±2Ma	Rb-Sr, Sm-Nd, $^{40}Ar/^{39}Ar$	Eclogite	Dabie	Okay et al., 1993
200-180 Ma	$^{40}Ar/^{39}Ar$	Eclogite, amphibolite	Dabie	Dong et al., 1996; Hacker et al., 1995
135-120 Ma	$^{40}Ar/^{39}Ar$	Pluton, metamorphic rocks (hornblende, biotite)	Dabie	Dong et al., 1996; Hacker et al., 1995
208±2Ma, 212±11Ma	U-Pb	Eclogite(zircon)	Dabie	Ames et al., 1993
241-190 Ma (10samples), 157-100Ma (19samples)	$^{40}Ar/^{39}Ar$	Gneiss(amphibole, phengite, biotite) Gneiss(biotite, feldspar)	Dabie	Liou et al., 1999
402±17Ma	Sm-Nd	ophiolite	Qinling	Zhang et al., 1989
447±16Ma, 219Ma	Rb-Sr	Ophiolite, mylonite	Qinling	Zhang et al., 1989
211±8Ma	U-Pb	granite	Qinling	Zhang et al., 1989
1000-930Ma	Sm-Nd, U-Pb	ophiolite	Banxi	Shu et al., 1991; Li et al., 1994
901±19Ma	$^{40}Ar/^{39}Ar$	Blueschist (amphibole)	Banxi	Xu et al., 1992
428±1Ma,	$^{40}Ar/^{39}Ar$	Mylonitic rocks (phengite)	Banxi	Xu et al., 1992
390Ma	K/Ar	Mylonitic rocks (biotite)	Banxi	Shu et al., 1992
371±4Ma, 427±3Ma, 428±12Ma	$^{40}Ar/^{39}Ar$, U-Pb, Sm-Nd	granodiorite	Banxi	Li, 1994
425±6Ma, 394±2Ma; 391±2Ma, 386±8Ma; 357±2Ma, 352±2Ma; 318±1Ma	$^{40}Ar/^{39}Ar$	Gneiss, mylonitic rocks (amphibole, muscovite, biotite)	Banxi	Chang and Lo, 1994
231±1Ma~211±1Ma	$^{40}Ar/^{39}Ar$	Mylonitic gneiss, schist (biotite, feldspar)	Banxi	Chang and Lo, 1994
157±1Ma	$^{40}Ar/^{39}Ar$	Gneiss (feldspar)	Banxi	Chang and Lo, 1994
132-85Ma (33 samples)	$^{40}Ar/^{39}Ar$	Gneiss (amphibole, biotite, muscovite, feldspar)	Pingtan-Dongshan	Yang et al., 1997, 1998

TONGBAI-DABIE OROGENIC BELT

Geochronological ages from metamorphic rocks within orogenic belts are often interpreted as representing the initiation of orogenic processes such as collision and exhumation events. Geochronological ages thought to represent timing of collision and mountain exhumation of the Huanan and North China Blocks give both Silurian-Devonian (Caledonian) and early Triassic (Indosinian) ages. Due to these conflicting age results, previous studies have developed two contrasting models for the timing of Huanan-North China collision. Understandably, the two different models with very different collisional ages have resulted in considerable debate. The Qinling-Dabie Mountains of central China mark an orogenic belt that formed between the Huanan and North China Blocks. The age of the Qinling orogenic belt is poorly understood with various tectonic models having it form at either the beginning of Silurian or the end of its Permian (Mattauer *et al.*, 1985; Gao *et al.*, 1995; Xue *et al.*, 1996; Zhang *et al.*, 1997). The Dabie orogenic belt has been interpreted as forming during middle Paleozoic collision (Mattauer *et al.*, 1985; Zhai *et al.*, 1998) or early Mesozoic (Wang *et al.*, 1992; Ames *et al.*, 1993; Okay and Sengor, 1993; Nie *et al.*, 1994).

Geologically, the Tongbai-Dabie orogenic belt is characterized by intense polyphase deformation and metamorphism, and can be divided into the medium P/T (Qinling and Erlangping Groups) and the high P/T metamorphic terranes (ultrahigh-pressure metamorphic rocks, UHP terrane) which are separated by the Xiaotian-Motzitan fault (Fig.5). Gneiss, mica schist, marble and metavolcanic rocks of the Qinling and Erlangping Groups in the northern

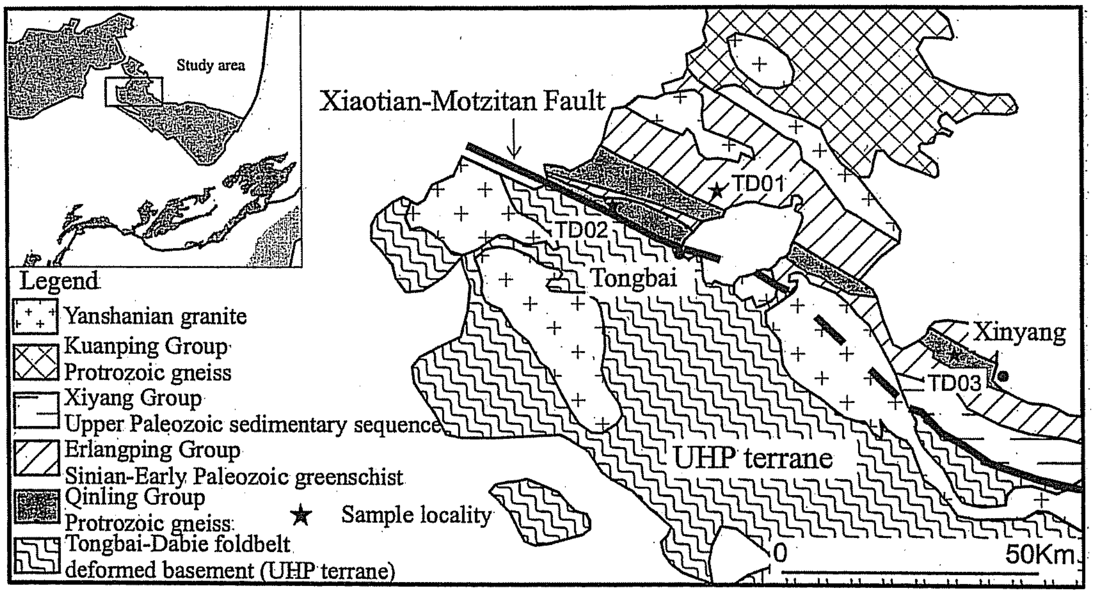

Figure 5. Geological map of the western Tongbai-Dabie foldbelt.

Tongbai Mountain have undergone greenschist-facies to amphibolite-facies metamorphism. The estimated peak metamorphic temperature is close to the hornblende and muscovite closure temperature of 500°C. Geochronological data from previous studies of the Qinling and Erlangping Groups have K-Ar ages of 435-130 Ma and Pb-Pb zircon ages of ca. 435 Ma (Liu and Hao, 1989; Kroner *et al.*, 1993; Zhai *et al.*, 1998). In our study, one muscovite and biotite (TD01, Fig.5) separated from mica schist of the Erlangping Group in Tongbai area have been determined by $^{40}Ar/^{39}Ar$ dating which displays date 343.3±5.4 Ma and 339.0±5.3 Ma(Fig.3), respectively. Meanwhile, a muscovite (TD02) collected from Proterozoic gneiss of the Qinling Group yields an age of 295.3±4.7 Ma (Fig.3). $^{40}Ar/^{39}Ar$ ages measured by us here indicate that cooling to 400°C was achieved by 343-295 Ma in the medium P/T metamorphic terrane. Previous studies have presented U-Pb zircon and Rb-Sr whole rock-phengite isochron ages, collected from the UHP terrane, that range from 240 Ma to 210 Ma. These dates have been interpreted as representing the timing of collision between the Yangtze and North China Blocks (Wang *et al.*, 1992; Ames *et al.*, 1993, 1996; Okay and Sengor, 1993; Nie *et al.*, 1994). A comparison of our new dates with previous published dates indicates that the medium and high P/T metamorphic terranes of the Tongbai-Dabie orogenic belt have very different exhumation histories.

According to the "closure temperatures" concept of Dodson (1973), when a mineral's closure temperature is lower than the peak metamorphic temperature, any dates from this mineral should be considered as representing the timing that the mineral cooled through the closure temperature rather than the actual time of peak metamorphism. On the other hand, if the mineral's closure temperature is close to the peak metamorphic temperature, then radiometric dates from that mineral can be interpreted as an approximation of the time of initial collision and exhumation. Therefore, the meaning of U-Pb zircon age collected from the UHP terrane may represent the time when this terrane went through the 650-700°C isotherm during early Mesozoic and not the time of peak metamorphism. Unfortunately, Ames *et al.* (1993, 1996) interpreted their dates as the approximate time of peak metamorphism and collision. The peak metamorphic of the UHP terrane in the Dabie Mountain, however, is at ~830-750°C (Zhang *et al.*, 1996) which is a higher temperature than the closure temperature for the U-Pb system in zircon. The U-Pb zircon age from their study, therefore, may not be represent the time of the peak metamorphism in the Tongbai-Dabie orogenic belt. In addition, the zircon may have also grown during the exhumation process, which again could be misleading in trying to determine the age of peak metamorphism (Roberts and Finger, 1997). We argue that the U-Pb zircon dates of Ames *et al.* (1993, 1996) are a record of the timing of exhumation, because the peak metamorphic temperature of the UHP terrane is higher than the closure temperature of zircon. The interpretation of Ames *et al.* (1993) is only valid if the peak metamorphic temperature of the UHP terrane was near the closure temperature of zircon.

Another important point is that the medium P/T metamorphic and UHP terranes of the Tongbai-Dabie orogenic belt are different terranes separated by the Xiaotian-Motzitan fault (Fig.5). The radiometric ages obtained from each individual metamorphic terrane are interpreted as representing the exhumation history of the Tongbai-Dabie orogenic belt. Dates for amphibole and mica collected from mica schist in the medium P/T metamorphic terrane show ages about 435 - 295 Ma (Table 1; Jin *et al.*, 1997; Zhai *et al.*, 1998). Their dating results are older than the age range extracted from the UHP terrane based on previous studies (Wang *et al.*, 1992; Ames *et al.*, 1993, 1996; Okay and Sengor, 1993; Nie *et al.*, 1994). Our $^{40}Ar/^{39}Ar$ dates for mica and feldspar, which mineral's closure temperature is lower than the peak metamorphic temperature (~500°C) of the medium P/T metamorphic terrane, collected from schist. Therefore the meaning of ^{40}Ar/^{39}Ar ages just represent the time when this terrane was exhumed since early Paleozoic. We interpret the older date (~435 Ma; Zhai *et al.*, 1998) in the medium P/T metamorphic terrane as suggesting initial collision and exhumation ages for the Tongbai-Dabie orogenic belt associated with the collision of the Huanan and North China Blocks. Following the Silurian-Devonian tectonic event, the UHP terrane was rapidly exhumed along the Xiaotian-Motzitan fault during the early Mesozoic. Although, U-Pb zircon ages in the UHP terrane may approximate the timing of peak metamorphism, they probably do not represent the age of initial collision. Instead, we interpret the ages to be related to the exhumation of UHP terrane that occurred at the beginning of early Mesozoic. Our ^{40}Ar/^{39}Ar dates from the medium P/T metamorphic terrane are consistent with our interpretation that the Tongbai-Dabie orogenic belt was deformed and exhumed during the Devonian. Hence we suggest that the early Mesozoic exhumation of the UHP terrane merely represent a reactivated intraplate deformation.

The northern Tongbai-Dabie Mountains expose a 7-10 km thick late Devonian early Carboniferous molasse sequence (Li *et al.*, 1997; Liu and Hao, 1989) which is composed mainly of quartzite, schist, slate, granite, limestone and sandstone detritus. The molasse was derived from sedimentary and low-grade metamorphic cover rocks that represent the initial development of the Tongbai-Dabie orogenic belt. In this sequence, *Heliolites cf. anhuiensis* (coral) was discovered in a limestone clast of the molasse, which was thought to be restricted to early Paleozoic deposits of the Yangtze Block (Lu *et al.*, 1987). An in situ *Protomonocarina* fossil was also found in the molasse, which was also thought to be restricted to the North China (Lu *et al.*, 1987). These discovered fossils are important because they show that the molasse contain in situ North China type fauna mixed with reworked Yangtze type coral from the Huanan Block. Obviously, the molasse was derived from a middle Paleozoic exhumed orogenic belt, and then deposited in a foreland basin along the southern margin of the North China Block. The significance of the reworked Yangtze type fossil is that the orogenic belt has been a part of the Huanan Block. Many paleontologists have also documented vertebrate (*Sinolepis, Remigolepis*) and flora fossils from the Lower Carboniferous strata that were originally distributed in both the Huanan and North China Blocks (Burret *et al.*, 1990; Pan *et al.*, 1996; Li *et al.*, 1997). Collectively these findings suggest an evidently close relation between the North China and Huanan Blocks since the late Devonian.

The evolution of the Tongbai-Dabie orogenic belt as it relates to the timing of collision between the Huanan and North China Blocks is still debated. Geographically the Tongbai-Dabie and Qinling orogenic belts are located at the boundary between the Huanan and North China Blocks. The previous (Table 1) and our geochronologic dates (343 - 295 Ma) from the medium P/T metamorphic terrane of the Tongbai-Dabie orogenic belt indicate that it may have formed in response to collision (~435 Ma) and mountain exhumation (<435 - 295 Ma). Vase quantities of late Devonian - early Carboniferous molasse, derived from a nearby Caledonian orogenic belt of the Huanan Block, was deposited on the southern edge of North China Block. In the southern Qinling Mountain, the Upper Paleozoic sedimentary sequence represents a shallow marine environment which was deposited in an intraplate remnant basin on the northern edge of the Yangtze Block (Liu *et al.*, 1989; Xue *et al.*, 1996). It is important to evaluate paleogeographic links between the Huanan and north China Blocks. We propose that most of the available data indicate that the accretion of the Huanan and North China Blocks began in the Silurian. The early Paleozoic event represented the subduction of the paleo-Qinling Ocean and interplate collision of the Yangtze - North China Blocks. The early Mesozoic event represented the intraplate collision and reactivated mountain exhumation between the two blocks.

DISCUSSION AND CONCLUSION

The Huanan, Tarim, Kazakhstan, Junggar and North China Blocks were accreted to the Central China supercontinent forming the Tianshan, Qilian, Qinling and Tongbai-Dabie orogenic belts during the Caledonian Orogeny. After the late Paleozoic, the Siberia, Indochina, Songpan-Ganzi, Qiantang, Lhasa and India Blocks successively accreted and amalgamated with the supercontinent. The successive accretions may be analogous to a "chain of traffic-accidents" in that progressive deformation takes plate at the junction between cars. Subsequent deformation within the supercontinent continued to be concentrated along these ancient orogenic belts between blocks. Butler *et al.* (1997) suggest that pre-existing heterogeneities in the continental lithosphere, such as fault zones, are thought to influence markedly its response to subsequent deformation. It is generally considered that ancient orogenic belts within amalgamated continents should be important lineament structures that penetrate through the lithosphere. The Caledonian orogenic belt, for example, may represent a major lithospheric discontinuity in China. Reactivated intraplate deformation would be expected to utilize the existing early Paleozoic fracture zones of the Caledonian orogenic belts as the amalgamated supercontinent deformed and exhumed, that was especially significant during the Indosinian Orogeny.

Mesozoic thin-skinned fold-thrust and ductile deformations in China were regularly concentrated along the ancient orogenic belts or deep fracture zones. Several orogenic belts which contain evidence of Indosinian deformation surround the Yangtze Block. A Mesozoic east-west trending thin-skinned fold and thrust system of the upper Yangtze region parallels the Qinling-Dabie orogenic belts. These Mesozoic structures appear to have inherited the preexisting trend of the previous subduction zone between the Huanan and North China Blocks. Likewise, Mesozoic thin-skinned deformation and ductile shearing of the Lower Yangtze region have also been well documented surrounding the Banxi orogenic belt (Fig.2). Recurrent fold and thrust deformation has been frequently concentrated along these ancient plate boundaries. Thus the early Mesozoic compressive event overprinting the Proterozoic and early Paleozoic structures is well documented on the Banxi and Huanan orogenic belt (Wan and Zhu, 1991). The early Mesozoic deformation is interpreted to be the product of intraplate reactivation. The cause of reactivated deformation makes Hsu *et al.*'s (1988) misunderstanding that a Mesozoic collision-type orogeny formed by the accretion of Yangtze and Cathaysia Blocks. In fact, the majority of the Chinese geologists favored the Indosinian Orogeny with an intraplate deformation in the past several decades (Liu and Hao, 1989; Zhao *et al.*, 1994).

Reactivated intraplate deformation produced complicated deformation, multistage metamorphism and episodic deformation. The intraplate deformation restricted in the pre-Mesozoic orogenic belts which have been shortened and thickened, and this may contribute to the exhumation of metamorphic rocks. Therefore, these ancient orogenic belts of east China show overprinting by Indosinian deformation. Unfortunately, geochronologic results are often embarrassing, making some conflicting interpretations about the timing of collision. Isotopic dates, commonly, make it possible to determine the timing of collision and exhumation of an orogenic belt. The previous and our isotopic dates from the pre-Indosinian orogenic belts of east China yield three distinct age ranges: Caledonian (~435-300 Ma), Indosinian (~245-200 Ma) and Yanshanian (~160-90 Ma) times. These isotopic dates for amphibole, mica and feldspar collected from metamorphic rocks, which mineral's closure temperature is generally lower than the peak metamorphic temperature of the metamorphic terrane. Therefore the meaning of ages just represent the time when the orogenic belt was exhumed. For this reason, we interpret these age ranges to represent three specific periods of exhumation. Reactivated deformation has occurred along incompetent zones of the pre-Mesozoic orogenic belts, that was commonly produced mylonitic structure at a deep level in the ancient orogenic belts and then underwent much older or high-graded metamorphic rocks elevated. The ductile shearing deformation overprinted any isotopic signature of earlier deformational event, that recorded the Indosinian event which is responsible for inducing ductile shearing and basement exhumation. In the previous and this studies, the early-Mesozoic and late-Mesozoic isotopic-dates for amphibole and mica commonly collected from the mylonitic rocks (Chang and Lo, 1994; Xu *et al.*, 1992; this study). Especially, many previous studies have used geochronology to gain an early Mesozoic age range within the pre-Mesozoic orogenic belts, such as the Tianshan (Cai *et al.*, 1996), Qilian (Lo, 1998), Qinling (Mattauer *et al.*, 1985) orogenic belts. Furthermore, the early-Mesozoic and late-Mesozoic age ranges also reinterpreted by us as representing reactivated intraplate tectonics events in the pre-Mesozoic orogenic belts. Reactivated intraplate deformation of east China since the early Mesozoic is consistent with the tectonic processes of west China that are related to accretion onto the south Asia continent of the Songpan-Ganzi, Qiantang, Lhasa and India Blocks since the Permian. Continued continental accretions lead to episodic intraplate deformation as the amalgamated continent of China since early Paleozoic.

Recent paleomagnetic studies of China have improved paleogeographic reconstructions of Asia since the Paleozoic. The results of paleomagnetic data are frequently used for tectonic reconstruction of the Huanan and North China Blocks (Lin *et al.*, 1985; Zhao and Coe, 1987; Zhao *et al.*, 1994). The late Paleozoic - early Mesozoic paleopoles of these two blocks, however, are quite different. Unfortunately, paleogeographic data and paleomagnetic analysis of west China shows that the Tarim Block successively shifted relative to the Siberia Block after the end of the Permian collision (Bai *et al.*, 1987). These studies report ~1,000 - 2,500 km of Cenozoic shortening in west Asia. Other studies have suggested that the collision between India and Asia produced the intraplate deformation between the Tibet and Siberia Blocks (Lin *et al.*, 1985; Chen *et al.*, 1993). Molnar and Tapponnier (1975) suggested that crustal shortening and extrusion tectonics appear to the characteristic of intraplate tectonics in the Asian during the Cenozoic. By analogy with this, similar tectonic processes might have also occurred in east China during the late Paleozoic-Mesozoic. The Huanan and North China Blocks accreted during the Silurian, but there were continued relative movements between then following accretions. We suggest that considerable crustal shortening and subduction has been distributed between the North China and Huanan Blocks. Specifically, the collision of the Siberia and Indochina Blocks with the Central China supercontinent during the late Permian - Triassic appears to be caused by widespread reactivated intraplate deformation in east China. By the above mechanism, we believe that the diversity of paleopoles for these blocks from late Paleozoic to early Mesozoic can be accounted for.

Timing for the accretion of the Huanan and North China Blocks may be unclear with some paleomagnetic and geochronologic results suggesting that these blocks welded during the late Permian - Triassic. The distribution of late Paleozoic littoral and subaerial deposits among these blocks, however, indicates that previous paleogeographic reconstructions may need to be reevaluated. Several new lines of paleontologic, petrologic and geochronologic data from the Qinling and Tongbai-Dabie orogenic belts markedly contradicts with the above interpretation of an early Triassic interplate collision. The northern Tongbai-Dabie Mountains expose a 7-10 km thick late Devonian - early Carboniferous molasse sequence which is composed mainly of quartzite, schist, slate, granite, limestone and sandstone detritus. Sedimentary detritus derived from low metamorphism terrane that is an important geological constraint on mountain exhumation. It appeared that the orogenic belt is still eroding and exhuming during late Devonian - early Carboniferous. New $^{40}Ar/^{39}Ar$ dates from the medium P/T terrane have very distinct age ranges suggesting that exhumation of the Tongbai-Dabie orogenic belt must have occurred in at least three stages. We believe that the first-stage exhumation was due to the Silurian interplate accretion and mountain exhumation, and the second one was brought about by an intraplate mountain exhumation induced by successive accretions by the Siberia, Qiangtang, Songpan-Ganzi and Indochina Blocks assailing from both north and south. Accretion of those blocks is interpreted as the tectonic processes responsible for early Mesozoic exhumation documented for the Caledonian orogenic belts. It causes that the Huanan Block was subducted to the North China Block in the late Permian and was subsequently exhumed during the early Mesozoic.

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