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Mesozoic superposed orogenic systems in eastern China

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A B S T R A C T

The Indosinian and Yanshanian orogenic movements are both important Mesozoic orogenies in eastern China. The resulted tectonic belts are neither products of the third stage of crustal evolution, as proposed by Chen Guoda, nor intra-continental (or intraplate) orogenic belts generated by intraplate dynamics, as argued by some scholars —rather, they are superposed orogenic belts formed on the pre-existing continental crust in eastern China due to Mesozoic Paleo-Pacific dynamic system. In the past, these orogenic belts were called the marginal Pacific epicontinental activation belts of eastern China. In the Mesozoic, under the effect of Paleo-Pacific dynamic system, the East Asia margin orogenic system formed along Northeast Russia-Sikhote Alin (Russia)–Japan-Ryukyu-Taiwan (China)-Palawan (Philippines) regions, while simultaneously the Mesozoic superposed orogenic system formed in the pre-existing continental crust in eastern China adjacent to the East Asia continental margin. The two orogenic systems, both driven by Mesozoic Paleo-Pacific dynamic system, developed synchronously to form the giant Mesozoic orogenic system in the Pacific tectonic domain in eastern Asia, radically changing the pre-Indosian tectonic framework of the area.

1. Introduction

Wong WH, Huang TK, and other early Chinese pioneering geologists in time long past proposed and defined the Indosinian and Yanshanian orogenies as well as the Indosinian orogenic cycle and the Indosinides (Indosinian orogenic belt), and the Yanshanian orogenic cycle and the Yanshanides (Yanshanian orogenic belt) in eastern China (Wong WH, 1929; Huang TK, 1945), but there has been limited acceptance that both orogenies are important orogenic events producing a large-scale Mesozoic orogenic system. This lack of acceptance could be attributed to the knowledge that orogens are thought to be formed either when a geosyncline is transformed into an orogenic belt according to geosyncline–platform theory, or formed at continental margins or between continental blocks based on plate tectonic theory, whereas most of eastern China was stable cratons before the Indosinian orogeny. Chen GD (1956, 1959) used the concept of platform activation to explain the tectonic processes that occurred in eastern China during the Mesozoic and proposed that platform activation should be the third stage of crustal evolution (Diwa, geodepression) following the geosyncline and platform stages. With the rise of plate tectonic theory, many researchers have described the tectonic belts that formed in eastern China in association with the Indosinian and Yanshanian orogenies as intracontinental or intraplate orogenic belts. In our opinion, these tectonic belts represent neither the products of platform activation nor the intracontinental (or intraplate) orogenic belts generated by intracontinental or intraplate dynamics. Instead, they are considered to be new tectonic belts developed on pre-existing continental crust under the influence of the Paleo-Pacific geodynamic system. These tectonic active belts were previously defined as the Mesozoic marginal Pacific epicontinental activation belts of East China. namely the East China Mesozoic superposed orogenic system in this paper (Ren JS et al., 1980, 1990, 1999a). Here, this paper will discuss the formation processes of the Mesozoic system more systematically.

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2. Continental tectonics of eastern China before the Indosinian Orogeny

Before the Indosinian Orogeny, the eastern China continent as a whole had been in a stable craton condition (Fig. 1). At that time, the tectonic units of eastern China trended generally east–west (relative to their present day orientations), and from north to south they were: (1) The Sayan–Erguna orogenic system and the Ural–Tianshan–Hinggan orogenic system which were transformed into the Central Asia–Mongolia post-Variscan platform after the Variscan orogeny; (2) the Sino-Korean paraplatform (a small craton); (3) the Caledonian Qinling orogenic belt (a post-Caledonian platform); (4) the Yangtze paraplatform (a small craton); (5) the Caledonian South China orogenic belt (a post-Caledonian platform that amalgamated with the South China Sea paraplatform after the Caledonian orogeny and became part of a post-Pan-African–Caledonian platform on the northern margin of Gondwana); and (6) the South China Sea paraplatform (a small craton that has largely broken up during the Cenozoic to form the South China Sea Basin with remnants preserved only in Sanya, at the southern end of Hainan Island, and on Xisha, Zhongsha, and Nansha islands) (Ren JS et al., 1999b).

The Sino-Korean paraplatform was a stable craton from the Mesoproterozoic to the Middle Triassic, apart from the Alashan–Inner Mongolia regions on the northern margin of the craton, which experienced intense tectono-magmatic activity related to the Paleo-Asian Ocean geodynamic system during the Caledonian and Variscan cycles. The Yangtze paraplatform was a stable craton from the Ediacaran to the Middle Triassic. Devonian–Middle Triassic shallow marine sedimentary rocks are present on the Caledonian folded basement of the South China orogenic belt. After the Variscan Orogeny, the East Mongolia–Hinggan region was a stable craton during the Late Permian–Middle Triassic, and a large Late Permian–Middle Triassic continental sedimentary basin formed on the Variscan basement. Devonian–Middle Triassic shallow marine sedimentary cover rocks are exposed on the Caledonian folded basement of the Qinling (or Qinling–Dabie) orogenic belt, while in West Qinling to the west of Fengxian County, the Triassic comprises sandy argillaceous turbidites. Although some researchers still argue that the ocean basins in Central Asia and Qinling did not disappear until the Triassic, forming the “Indosinian collision orogenic belt”, a large amount of data (Ren JS et al., 1991, 2019; Dong YP et al., 2013; Zhu JB et al., 2017) indicate that the ocean basin in Central Asia was closed before the Late Carboniferous or earlier and the ocean basin in the Qinling area was closed before the Devonian.

The South China Sea had been transformed into the South China Sea Basin during the Cenozoic. Marine geological and geophysical surveys of the South China Sea (including unpublished data from the Guangzhou Ocean Bureau) and palaeogeographical maps of Cambrian–Silurian and Devonian–Triassic lithofacies of China (Liu HY et al., 1955; Ren JS et al., 1964, 1980, 1990; Wang HZ et al., 1985; Liu BJ et al., 1993; Zheng HR et al., 2010) suggest that the South China Sea region was uplifted and denuded during the Paleozoic, supplying sediment to South China, and was

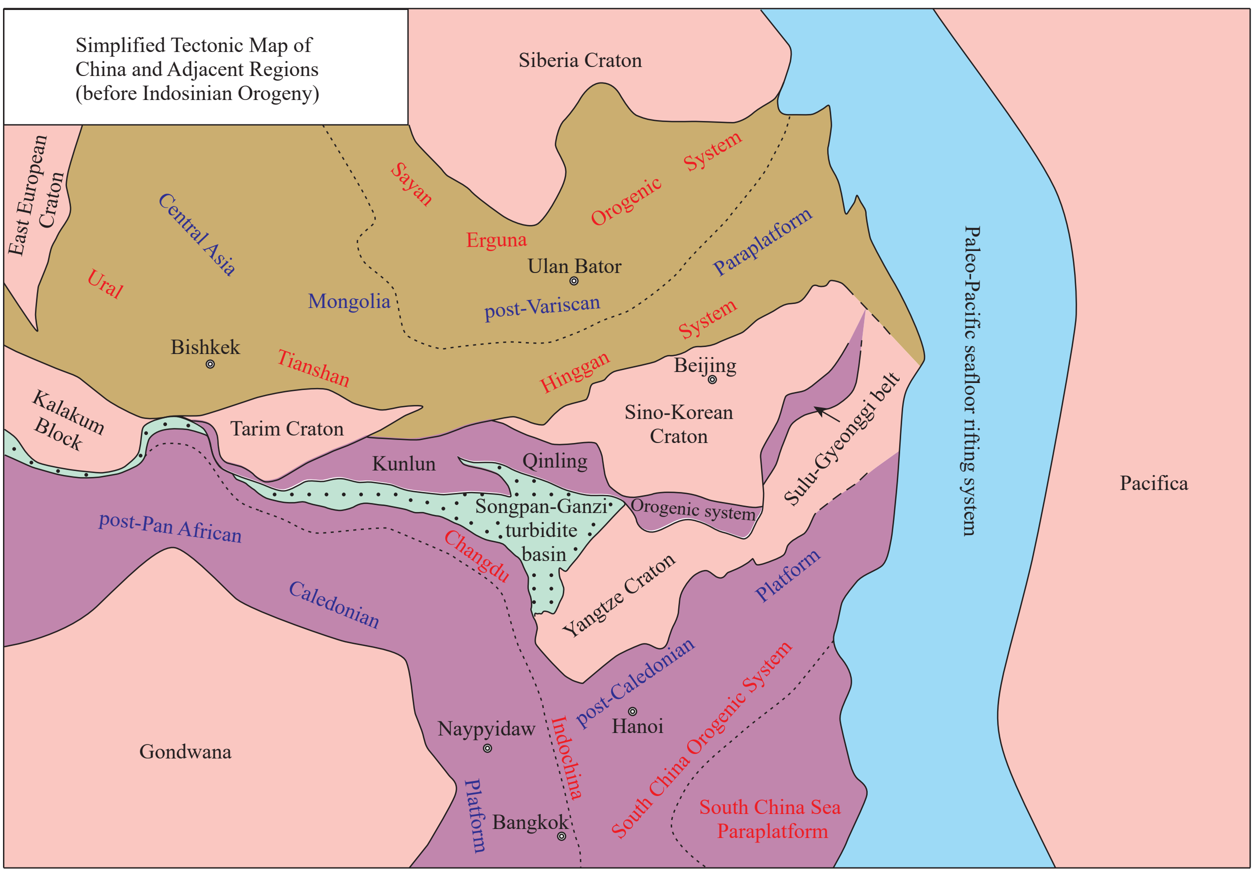

Fig. 1. Simplified tectonic map of China and adjacent regions during the period before the Indosinian Orogeny.

submerged by seawater starting in the Late Carboniferous, when shallow marine sediments were deposited, mainly carbonate rocks.

3. Mesozoic orogenies and Mesozoic superposed orogenic systems in eastern China

Wong WH (1927, 1929) demonstrated the existence of a Mesozoic orogeny in eastern China —the Yanshanian Orogeny (Fig. 2)—based primarily on geological surveys of Yanshan mountains, western Liaoning, Henan, and Shanxi in northern China (Wong WH, 1927, 1929). Subsequently, Li YY et al. (1935), Lee YY and Chu S (1934), and Huang TK and Xu KQ (1937) described the Jinzi, Nanxiang (Ningzhen), Genkou (Hunan), and Pingxiang (Jiangxi) orogenies, which are equivalent to the Indosinian orogeny in the Lower Yangtze River area and southern China, based on studies of areas including the Ningzhen Mountains, the border between Hunan and Guangdong Provinces, and Pingxiang in Jiangxi Province. Huang TK (1945) discussed the Indosinian and Yanshanian orogenic cycles and the Indosinides and Yanshanides in East China in more detail in his classic book: *On Major Tectonic Forms of China* (Huang TK, 1945). He unambiguously pointed out that the tectonic belts formed in East China by the Indosinian and the Yanshanian orogenies, different from folds in geosynclines, were “foundation folds (folding of the entire continental mass)” (Argand E, 1924), or they represented an orogenic belt superimposed on continental crust, as described in this paper.

Since the 1950s, systematic 1∶200000 to 1∶50000 scale geological mapping, numerous mineral surveys and exploration work, and ongoing scientific researches on the East China continent have further refined the understanding of Mesozoic orogenesis in eastern China and shown that the Mesozoic was the most important metallogenic period for endogenous metal deposits in eastern China (Ren JS et al., 1980, 1990, 1999a; Guo WK, 1987; Cheng YQ, 1994; Chen YC et al., 2007).

Fig. 3 clearly shows that the fold-fault systems, large granite intrusions, and volcanic rocks resulted from Mesozoic orogenesis trend generally NE-NNE and are characterized by progressively more intense folding, faulting, and magmatic activity farther eastward, although in some places the structures were controlled by pre-existing structures and have different trends (Fig. 3).

There are two Mesozoic superposed orogenic systems in eastern China: The eastern Mongolia–Hinggan and eastern China orogenic systems. The former was primarily founded on the post-Variscan eastern Mongolia–Hinggan platform, crossing the northern margin of the Sino-Korean paraplatform in the south and reaching the eastern part of the Siberian platform and the Transbaikal region in the north. The latter occupied a vast area of the eastern China continent and adjacent seas to the east of the Sichuan–Ordos basins (Fig. 4) (unpublished data from the Guangzhou Marine Geological Survey and Qindao Institute of Marine Geology).

The Mesozoic superposed orogenic systems were developed through the Indosinian and Yanshanian orogenic cycles (Table 1). The Indosinian orogenic cycle comprises three important orogenic phases. The first phase occurred at the end of the Permian, as demonstrated by 250 Ma granites in Inner Mongolia and late Permian magmatism and metamorphism in coastal areas of Zhejiang Province (Jiang Y et al., 2016). The second phase occurred from the late Middle Triassic to the early Late Triassic which is marked by an angular unconformity under the Anyuan Coal Series and equivalent strata. The third phase occurred from the end of the Late Triassic to the beginning of the Jurassic, and is recorded by an angular unconformity beneath the Jurassic Xiangshan Formation. The Indosinian Orogeny in China is equivalent to the Songrim Orogeny on the Korean Peninsula and the Akiyoshi Orogeny in Japan. This orogeny affected a vast area to the east of the Jianghan–North China Plain as well as eastern Mongolia–Hinggan in eastern Asia, forming an orogenic system on the eastern margin of the Asian continent (i.e East Asian margin orogenic system) consisting of the northeastern part of Russia, the Japanese Islands, the Ryukyu Islands, Taiwan (China), and Palawan, and an orogenic belt superimposed on the pre-existing continental crust of eastern Mongolia–Hinggan, South China, the Lower Yangtze River area, the Korean Peninsula, the Yellow Sea, the East China Sea, and the South China Sea.

The Yanshanian orogenic cycle in eastern China can be subdivided into three important orogenic phases. The first and second phases are of the early Yanshanian orogenic cycle, and the third phase represents the late Yanshanian orogenic cycle. The first phase occurred at about 165±5 Ma (Bajocian–Bathonian, middle Middle Jurassic), the upper limit of which is the angular unconformity beneath the volcanic rocks of the Tiaojishan or Lanqi formations. The second phase occurred at about 155–135 Ma (Kimmeridgian–Hauterivian, middle–late Late Jurassic to Early Cretaceous), the upper limit of which is the angular unconformity beneath the volcanic rocks of the Zhangjiakou Formation or the Yixian and Bayanhua formations. Due to the lack of Upper Jurassic to Lower Cretaceous strata in most of eastern China,

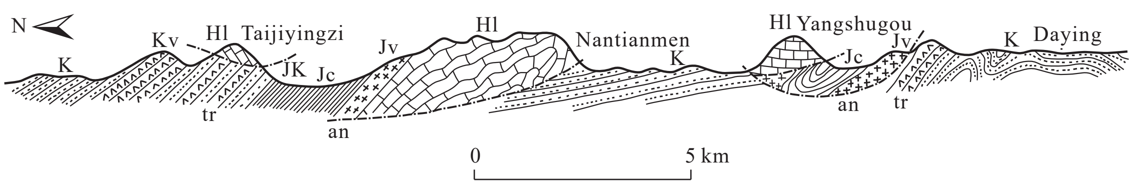

Fig. 2. Structural section of the Beipiao area (modified from Wong WH, 1927). K–Cretaceous series, Kv–Cretaceous volcanic rocks, JK–Jurassic–Cretaceous coal series, Jc–Jurassic coal series, Jv–Jurassic volcanic rocks, HI–Sinian (Ediacaran) limestones, an–andesite, tr–trachyte.

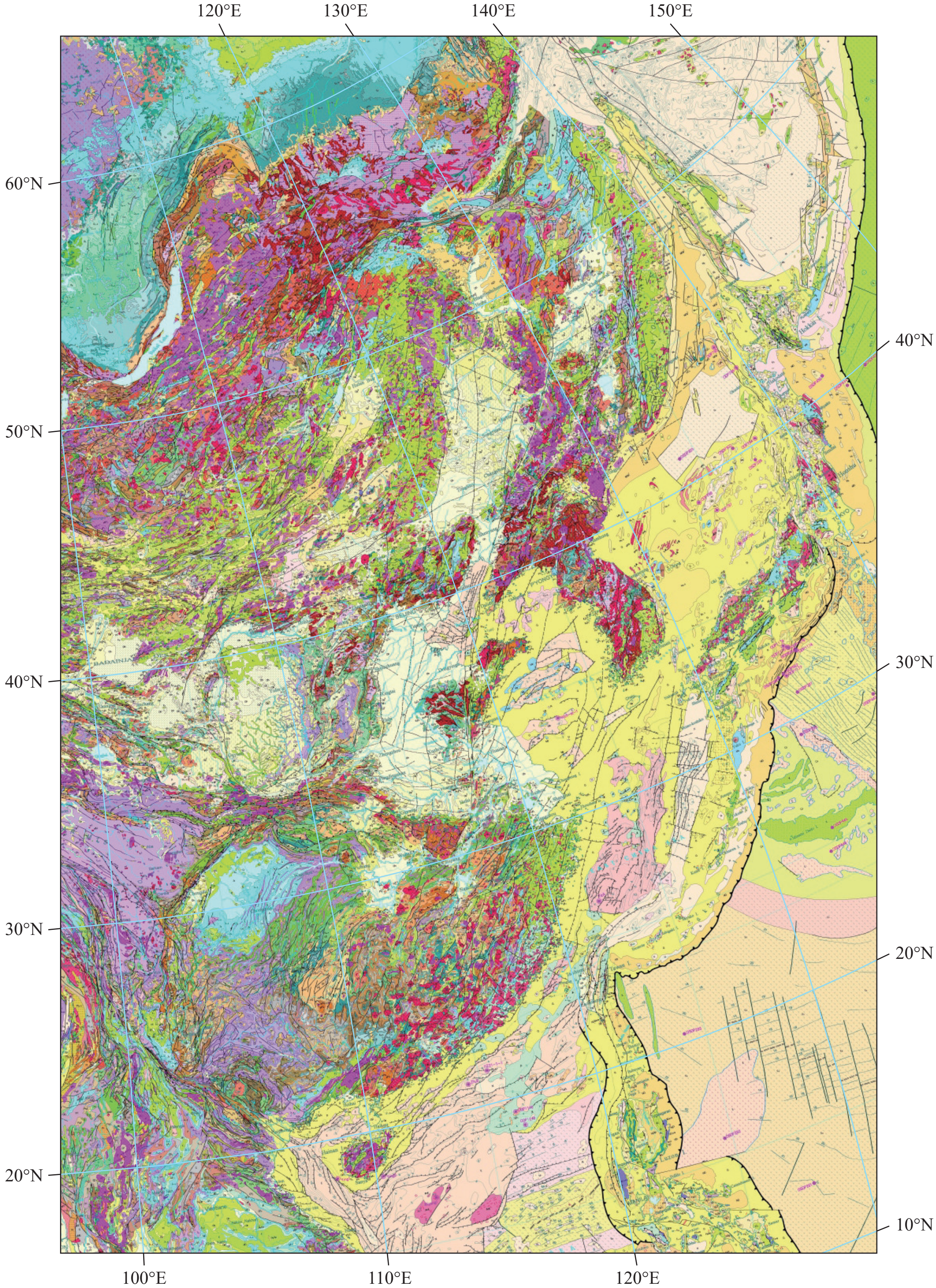

Fig. 3. Geological map of East China and adjacent regions. Modified from the 1∶5000000 International Geological Map of Asia (after Ren JS et al., 2013a, b).

Middle Jurassic (the Zhangping Formation in Fujian) and older strata are commonly unconformably overlain by volcanic rocks containing the middle–late Early Cretaceous Jehol biota in South China, the Lower Yangtze River area, and on the Shandong Peninsula. This unconformity is obviously the product of the superimposition of the first and second Yanshanian orogenies. The third phase orogenesis of the Yanshanian cycle took place at ~110±5 Ma, before the Albian or in the late Aptian (Early Cretaceous), which is marked by the angular unconformity beneath the Denglouku Formation in the Songliao Basin and Cretaceous red beds in the Hengyang Basin, but magmatism might continue until ~90 Ma. The Yanshanian orogeny is equivalent to the Daebo Orogeny on the Korean Peninsula and the Sakawa Orogeny in

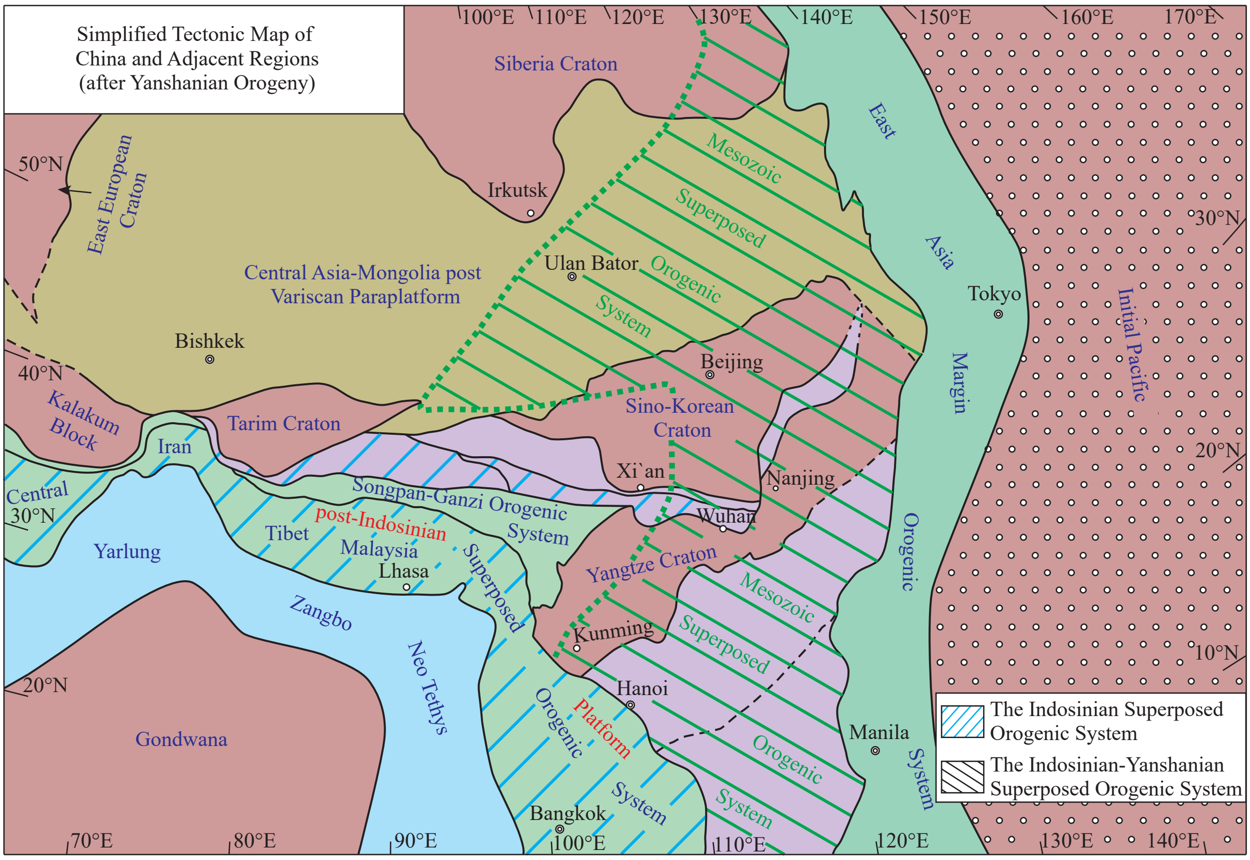

Fig. 4. Simplified tectonic map of China and adjacent regions for the period after the Yanshanian orogeny.

Table 1. Orogenic phases of the Indosinian and Yanshanian cycles.

Orogenic cycles	Phases	Strata
Yanshanian orogenic cycle	Third phase	Overlying representative strata: Albian Denglouku Formation/Dongjing Formation ~~~~~~~~~Upper limit age: 110±5 Ma Age of orogeny: late Early Cretaceous
	Second phase	Overlying representative strata: Valanginian–Hauterivian Zhangjiakou volcanic rocks ~~~~~~~~~Upper limit age: 135 Ma Age of orogeny: top–late Late Jurassic to Early Cretaceous
	First phase	Overlying representative strata: Bajocian–Bothonian Tiaojishan Formation/Lanqi Formation ~~~~~~~~~Upper limit age: 165±5 Ma Age of orogeny: top Middle Jurassic
Indosinian orogenic cycle	Third phase	Overlying representative strata: late Lower Jurassic–early Middle Jurassic Xiangshan Formation/Beipiao Formation ~~~~~~~~~Upper limit age: 190±5 Ma Age of orogeny: end of Late Triassic to Early Jurassic
	Second phase	Overlying representative strata: Norian Anyuan Coal Series/Genkou Formation ~~~~~~~~~Upper limit age: 220 Ma Age of orogeny: end of Middle Triassic to early Late Triassic
	First phase	Overlying representative strata: early Triassic strata ~~~~~~~~~Upper limit age: 250 Ma Age of orogeny: late Late Permian

Note: The first Indosinian phase occurred primarily in the Japanese islands. Most of Chinese continent records continuous Permian and Triassic sedimentation.

Japan. The Yanshanian orogenic movement was the most intense and significant Mesozoic orogeny in China and eastern Asia. It fully reactivated the continental crust in eastern Mongolia–Hinggan, the region to the east of the Sichuan–Ordos basins, and the adjacent sea areas, forming the eastern Mongolia–Hinggan and East China superposed orogenic systems. Together, these made up the largest superposed orogenic system in the world, and the intensity of tectono-magmatism increased from continent in the west to sea in the east towards the Asia continental margin (Fig. 4).

Thus, it is concluded that the Mesozoic East China superposed orogenic system was formed through the Indosinian and Yanshanian cycles. eastern Mongolia–Hinggan and the area to the east of the Jianghan–North China Plain underwent orogeneses during these cycles, resulting in intense tectono-magmatism and the formation of abundant endogenous metal deposits. In Shanxi, western Hubei, eastern Sichuan, Guizhou, and eastern Yunnan located to the east of the Sichuan–Ordos Basin, there are mainly fold–fault systems formed by the Yanshanian orogeny with scarce magmatic rocks exposed at the surface. A small volume of intermediate–felsic intrusions occur in Shanxi and other areas, but in the Upper Yangtze River area there are only low-temperature hydrothermal deposits with scarce magmatic rocks.

Geophysical and geochemical studies indicate significant changes in the composition and structure of the crust and upper mantle in eastern China and adjacent regions alongside the formation of the large Mesozoic superposed orogenic system. In the Sino-Korean Craton, the mantle changed from typical craton-type enriched mantle in the Paleozoic to highly heterogeneous orogenic-belt-type enriched mantle during the Mesozoic orogeny (Lu FX et al., 2000; Wilde SA et al., 2003; Zhou XH, 2006, 2009; Zhang HF et al., 2009). In addition, the Moho and the lower crust have been intensely altered by magmatic underplating related to the upwelling of mantle material, resulting in the transition between the crust and mantle. The trend of the mantle structures in East China has changed since the Mesozoic, from nearly east–west (parallel to the Paleozoic tectonic belt) to NE–NNE (parallel to the Mesozoic tectonic belt) (Ren JS et al., 1990, 1999b). However, the upper crust is primarily granitic and still records the Paleozoic velocity structure. In fact, the small-scale structure of the crust must have changed, yet it is not reflected by the geophysical data. This means that the crust and upper mantle in eastern China have an overpass-like architecture; i.e., the surface tectonics and mantle structure in the area trend NE–NNE, while the crust still keeps its nearly E-W trend. Based on physical properties the granitic upper crust can be divided into the Mongolia, North China, and South China blocks (roughly equivalent to the Mongolia–Hinggan belt, the Sino-Korean paraplatform, and the Yangtze–South China area, respectively) by the deep Qinling–Dabie and Tianshan–Yinshan tectonic belts, consistent with the tectonic subdivisions for the period before the Late Triassic (Ren JS et al., 1990, 1999b). The upper mantle in eastern China is divided into eastern and western belts by the Great Hinggan–Taihangshan–Wulingshan gravity gradient belt (Feng R, 1985), consistent with the tectonic subdivision of East China and adjacent areas since the Late Triassic. The superposition of the upper, middle, and lower uncoupled structural layers of the crust and upper mantle formed an overpass-like structure, which reflects the major tectonic changes that occurred in the crust and mantle in this region since the Mesozoic (Fig. 5). The fact that the mantle and the surface structure changed and the structure of the upper crust remained the same suggests that the motion of the mantle materials controls the tectonic evolution of the crust and uppermost mantle. The changes in the composition and structure of the mantle first led to changes in the lower crust and the surface structure, in turn leading to structural changes in the granitic upper crust, fundamentally transforming the tectonic properties of the region at last (Ren JS et al., 1990).

4. Geodynamic evolution of the Mesozoic superposed orogenic systems in eastern China

During the Paleozoic, the tectonics of China and adjacent areas was controlled by the Paleo-Asian Ocean geodynamic system, and the resultant tectonic belts were aligned roughly east–west (in present-day coordinates). During the Mesozoic, it was dominated by the Tethys–Paleo-Pacific geodynamic system. The Tethys geodynamic system controlled the tectonic evolution of the Tethys tectonic domain in western and southwestern China, forming the Mesozoic Songpan–Ganzi, Kunlun–Qinling and Tibet–Malaysia orogenic systems, with tectonic features that trend roughly east–west as a whole, and north–south in eastern Tibet and in western Yunnan. The Paleo-Pacific dynamic system dominated the tectonic evolution of the Pacific tectonic domain in eastern Asia, forming the Mesozoic East Asian margin orogenic system and East China superposed orogenic system, with

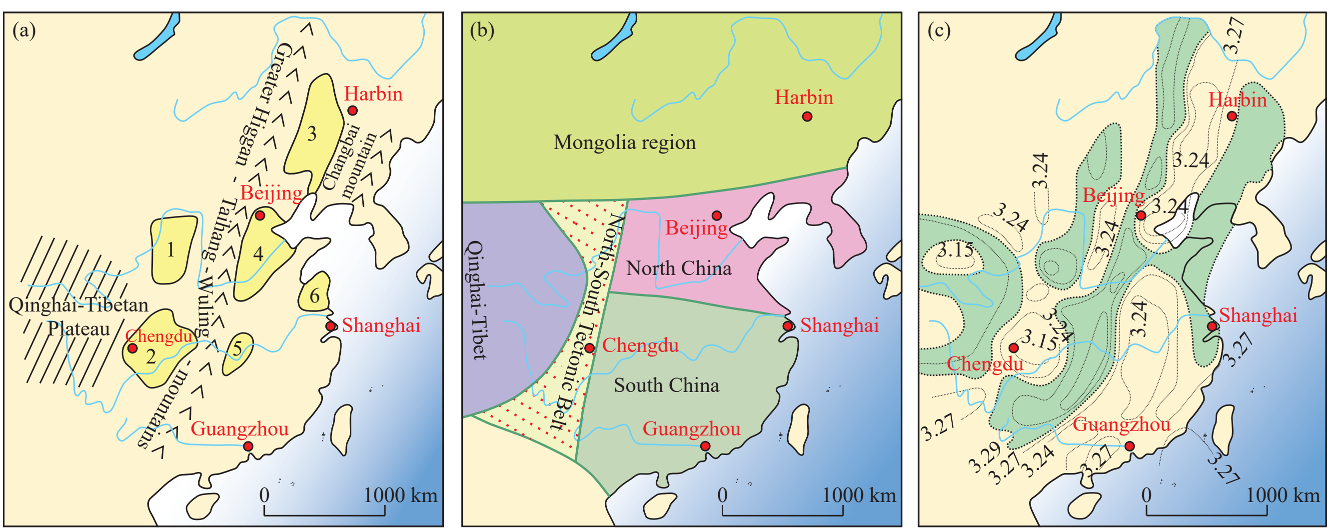

Fig. 5. Overpass-like crust–upper mantle architecture of East China and adjacent areas (after Ren JS et al., 1990, 1999a; Ren JS, 1996). (a) Surface tectonics. 1: Ordos Basin, 2: Sichuan Basin, 3: Songliao Basin, 4: Bohai Bay Basin, 5: Jianghan Basin, 6: Subei Basin. (b) Crustal structure. (c) Upper mantle structure. Dashed lines indicate contours of density in the upper mantle (after Feng R, 1985)

tectonic features that trend roughly NE–NNE (Ren JS et al., 1980, 1990, 1999a, b).

Geological, geophysical, and geochemical surveys of eastern Asia and the Pacific Ocean, as well as ocean floor drilling (OFD) and dredge sampling, have led to three main conclusions: (1) there was an ancient continent (Pacifica or West Pacifica) where the Pacific Ocean is currently located; (2) the Paleo-Pacific Ocean was not the predecessor of the present Pacific Ocean, but an ocean between the Pacifica and ancient Asian continent which has closed; and (3) the Mesozoic East Asian margin orogenic system, represented by the Japanese islands, was not formed by the subduction of the Paleo-Pacific Ocean lithosphere beneath the Asian continent, and instead was a collisional orogenic system located between the Pacifica and ancient Asian continent that formed during the closure of the Paleo-Pacific Ocean (Ren JS et al., 1990, 1999a, b, 2015, 2017).

The Paleo-Pacific can be divided into two branches based on relics of the ocean basin. The main branch, the Japanese Paleo-Pacific, separated the Pacifica from the ancient Asian continent. It stretched from the Russian Far East to Kalimantan–Java via the Japanese islands, Ryukyu islands, Taiwan, and Palawan, and was connected to the Tethys. The minor branch, the South Anuyi Ocean, was located between the ancient North American and Asian continents and extended from the South Anuyi area to the New Siberian Islands, before disappearing into the current Arctic Ocean (Ren JS et al., 1999b).

Geological data from Japan and northeastern Russia suggest that the Paleo-Pacific would be developed since the Early Carboniferous. The Visean greenstone in the tectonic belts in Japan, including the Akiyoshi, Ultra-Tamba, Mino, and Chichibu belts, may represent the remnants of oceanic crust from the Japanese Paleo-Pacific (Ichikawa K et al., 1990). The opening of the South Anuyi Ocean in northeastern Russia and large-scale rifting in Verkhoyansk also started in the Early Carboniferous (Sokolov SD et al., 2009; Petrov OV et al., 2014).

It is necessary to note that there is a statement on the existence of the Mongol–Okhotsk Ocean in the Mesozoic, as emphasized by some geologists. The present authors, in discussion with Russian researchers I Pospelov, VE. Khain and Mongolian researcher O. Tomurtoo, have come to agreement that no evidence for Mesozoic oceanic crust has been found to date.

The Paleo-Pacific was not a simple, empty ocean basin, but instead it contained a series of microcontinents, including the Ryoke (Honshu), South Kitakami, Kurosegawa, and Abukuma blocks in the Japanese Paleo-Pacific Ocean, and the Omolon and Okhotsk blocks in the South Anuyi Ocean. The microcontinental blocks and small intervening ocean basins or seafloor rift zones constitute the Paleo-Pacific seafloor rift system (Fig. 1).

The Paleo-Pacific geodynamic system experienced two cycles of development: The Indosinian and Yanshanian orogenic cycles. The Hida, Hida Gaien, Akiyoshi, Maizuru, Suo, Sangun, South Kitakami, Chichibu, and Kurosegawa belts in Japan were deeply affected by the Indosinian Orogeny. This orogeny began at the end of the Late Permian, as suggested by the angular unconformity between the Lower Triassic marine clastic rocks and the Yakuno ophiolitic mélange and flysch in the Late Permian Mazuru Group in the Mazuru Belt. In South Kitakami, there exists an unconformable relationship between the Lower Triassic and upper Permian (Ichikawa K et al., 1990). However, in China, this orogeny was not large and only affected the offshore (East China Sea) area of East China (Jiang Y et al., 2016; Cao YW et al., 2022), with no significant effect on the Chinese continent, as demonstrated by continuous sedimentation during the Permian and Triassic across most of the region. The most intense orogeny of the Indosinian cycle occurred from the late Middle Triassic to Late Triassic and resulted in the formation of the Sangun high-pressure, low-temperature metamorphic belt that yields isotopic ages of 240–220 Ma (Isozaki Y et al., 2010). Blueschists with ^{39}Ar-^{40}Ar ages of 237–225 Ma have been found in the Ryukyu Islands (Faure M et al., 1988), and garnet–chloritoid schists with a metamorphic age of 200 ± 22 Ma and metamorphosed subduction-related granite with an intrusion age of 200 ± 2 Ma was discovered in the Tananao metamorphic complex in Taiwan (Yui TF et al., 2009, 2017). Inherited zircon grains with a U–Pb age of 218 Ma crop out in Cenozoic volcanic rocks in eastern Taiwan (Shao WY et al., 2015), a granite that intruded into crystalline schists at 250 Ma was found on Mindoro island, the Philippines (Knittel U et al., 2010), and a Middle Triassic radiolarian bedded chert is unconformably overlain by an Upper Triassic sandy shale on the Calamian Islands, northern Palawan, the Philippines (Fantaine H, 1979). This suggests that the Indosinian orogenic belt in Japan extending through Ryukyu, Taiwan, Palawan, and Kalimantan connected with the Tethys Indosinian orogenic system. The Indosinian Orogeny was once thought to be related to the subduction of Paleo-Pacific lithosphere. However, all the geological units of the inner and outer belts in Japan seem to be affected by the Indosinian Orogeny and there is a sedimentary discontinuity between the Permian and Middle–Upper Triassic strata of each unit in Japan (Ichikawa K et al., 1990). Thus, the authors argue that the collision between the ancient Asian continent and microcontinental blocks in the Paleo-Pacific Ocean might have begun since the Indosinian period, which not only formed the Indosinian orogenic system extending from Japan to Palawan on the East Asian margin, but also activated pre-existing continental crust in eastern China to form the Indosinian South China–Lower Yangtze–Korean Peninsula superposed orogenic belt and affect the continental shelf in the East China Sea.

The Paleo-Pacific Ocean closed during the Yanshanian orogenic cycle. Subsequently, the collision between the ancient Asian continent and the Pacifica began during the middle Middle Jurassic and reached a peak during the Late Jurassic–earliest Cretaceous, forming the Mino–Tamba tectonic belt and the Sanbagawa high-pressure, low-temperature metamorphic belt (140–110 Ma). The Yanshanian Orogeny also had a major impact on the geological units formed by the Indosinian and older orogenies, including the Hida, Hida Gaien, Akiyoshi, Mazuru, Ultra-Tamba, and South Kitakami, Kurosegawa, and Abukuma belts, and resulted in further crustal compression and shortening. In the collisional orogeny stage that followed the closure of the Paleo-Pacific Ocean, the East China Mesozoic orogeny reached a climax and the superposed orogenic belt expanded to the eastern margin of the Sichuan-Ordos basin. The basement and cover rocks of the Shanxi region and the Upper Yangtze were folded, forming the Yanshanian superposed orogenic belt. At the same time, the crust of the Indosinian superposed orogenic belt, from South China to the lower Yangtze area and the Korean Peninsula was compressed further and subjected to thrusting and shortening, accompanied by the intrusion of voluminous granites and widespread volcanic activity.

The collision between the ancient Asian continent and the Pacifica ended during or before the Hauterivian (Early Cretaceous). Then, in the middle-to-late Early Cretaceous, the East Asia continental margin orogenic system experienced large-scale sinistral strike-slip faulting that triggered extensive volcanic activity and granitoid intrusion in East China, with the Jehol biota-bearing volcanic rocks in the Greater Hinggan Mountains, northern Hebei–western Liaoning, the Shandong Peninsula, and the southeastern coast of China came into being. This paper propose therefore that the widespread magmatic activity in East China during the middle–late Early Cretaceous was not caused by the subduction of the Paleo-Pacific plate beneath the Asian continent, but by intense interaction between the lower crust and upwelling mantle material which was driven by the large-scale shearing that followed the collision between the ancient Asian continent and the Pacifica. Most NNE-trending strike-slip faults in eastern China were also formed during the middle–late Early Cretaceous, except for those that were active earlier (e.g., the Tan–Lu and Zijinguan faults).

The evolution of the South Anuyi Ocean between the ancient Asian and Paleo-North American continents and the Mesozoic orogenic system in northeastern Russia was fundamentally the same as that of the Paleo-Pacific Ocean in Japan, and they also experienced the Indosinian and Yanshanian orogenic cycles. The most significant orogenesis in northeastern Russia also occurred during the late Middle–Late Triassic, middle Middle Jurassic, and Late Jurassic–Early Cretaceous (Sokolov SD et al., 2009; Petrov OV et al., 2014). Because the distributed orientation of the South Anuyi Ocean, a minor branch of the Paleo-Pacific Ocean, differed from that of the Japanese Paleo-Pacific (the main branch), the Verkhoyansk–Chukchi and NE–NEE-trending East Mongolia–Hinggan superposed orogenic systems were formed in northeastern Asia.

The Paleo-Pacific geodynamic system completed by a large-scale sinistral transpressional orogeny in the late Aptian–Albian period of the Yanshanian orogenic cycle, ending all the orogenic processes of the Mesozoic East Asia continental margin orogenic system and East China superposed orogenic system.

After the Yanshanian orogenic cycle, the formation of rift basins, including the Songliao, Jianghan, and Hengyang basins, suggests that East China entered a new stage of tectonic extension.

In summary, an orogenic system formed on the East Asia continental margin during the Mesozoic, governed by the Paleo-Pacific geodynamic system. Synchronously, an orogenic system was superimposed on pre-existing continental crust in East China and neighbouring continental and sea areas adjacent to the East Asia continental margin. These two orogenic systems constitute a large Mesozoic orogenic system in eastern Asia in the Pacific tectonic domain. As a result, the tectonic framework of eastern Asia before the Late Triassic was completely reorganized.

In the 1980s, the discovery of large-scale thrust faults or nappes led researchers to propose that the orogenic belt of Japan was not a Pacific-type subduction-related orogenic belt, but an Alpine-type collisional orogenic belt (Charvet J and Faure M, 1984; Charvet J et al., 1985; Charvet J, 2013). However, the researchers only recognized that the orogenic belt resulted from the collision of microcontinents (e.g., Honshu, South Kitakami, and Shimato) rather than from a more intense and significant collision between the large Pacifica and Paleo-Asia continent.

The conclusion that the Mesozoic orogenic belt in Japan is a collisional orogenic belt has been supported by Chinese and Japanese geoscienists. Jahn BM (2010) pointed out that most of the granites in southwestern Japan have high initial $^{87}Sr/^{86}Sr$ ratios (>0.707), negative $\varepsilon_{Nd}(T)$ values, Proterozoic Sm–Nd model ages (2000–700 Ma), and were sourced from recycled continental crust rather than from an subduction–accretionary complex with ocean plate stratigraphy composed primarily of mantle-derived material (Jahn BM, 2010), which is not consistent with the claim that Japan is a subduction-related orogenic belt. Archean, Paleoproterozoic, Mesoproterozoic, and Neoproterozoic inherited zircons of <3.8 Ga in age have been found in granites in the Phanerozoic orogenic belt in Japan (Isozaki Y, 2019). Paleoproterozoic granite and paragneiss have also been identified on the Oki-Dogo Island, southwest Japan (Cho DL et al., 2021). Recently, Archean–Paleoproterozoic rocks, including Archean granitic gneiss with emplacement ages of 2700–2500 Ma and a metamorphic age of 1850 Ma and Paleoproterozoic granite with an emplacement age of 1900–1825 Ma, have been reported in the 1500 × 300 m Tsuwano Complex in the Maizuru Belt of the Honshu Island, Japan (Kimura K et al., 2021). These findings show that older continental crust remains beneath the Mesozoic orogenic belt in Japan.

5. Discussion

The Chinese continent, consisting of numerous microcontinents and small cratons (Sino-Korean, Yangtze, and Tarim cratons) separated by orogenic belts, was previously located in the transitional tectonic domain between Gondwana and Proto-Laurasia[①] in the Paleozoic (Petrov O and Pubellier M, 2018). During the Paleozoic, the main body of the Chinese continent was located to the south of the Paleo-Asian Ocean and was part of Gondwana, while during the Mesozoic, it was located to the north of the Tethys and became part of Laurasia. During the Phanerozoic, the Chinese continent was successively governed by three major geodynamic systems, the Paleo-Asian Ocean, the Tethys–Paleo-Pacific, and the Indian Ocean–Pacific, thus, giving rise to the formation of three major tectonic domains, the Paleo-Asian Ocean, Tethys, and Pacific Ocean tectonic domains. The superposition and recombination of the Pacific and Tethys tectonic domains upon the Paleo-Asia Ocean domain resulted in particular development of orogenies existing on pre-existing continental crust (Ren JS et al., 1990, 1999a, 2016). During the Paleozoic, Kuruktag on the northern margin of the Tarim paraplatform and the Alashan–Inner Mongolia area on the northern margin of the Sino-Korean paraplatform underwent a tectono-magmatism transformation due to the Caledonian and Variscan orogenies, governed by the Paleo-Asian Ocean geodynamic system. As a result, they transformed tectonically from stable cratons into active superposed orogenic belts, and transferred as a member from the Tarim and Sino-Korean paraplatforms to the Paleo-Asian orogenic system. During the Mesozoic, dominated by the Paleo-Pacific geodynamic system, the intense Indosinian and Yanshanian orogenies resulted in the formation of the East China superposed orogenic system on the pre-existing continental crust, transferring East China from stable cratons to active superposed orogenic belts that became an integral part of the extremely large Mesozoic Pacific orogenic system. It considerably changed the tectonic framework of eastern China before the Late Triassic. During the Cenozoic, the tectonics of western China was driven sequentially by the Tethys and Indian Ocean geodynamic systems. The Himalayan orogenic system, Qinghai–Tibet Plateau, and activation orogenic belts (including the Kunlun, Qilian, Qinling, and Tianshan belts) were superimposed on the pre-existing continental crust, and the associated basin systems (including the Tarim, Junggar, and Qaidam basins) came into being in western China, radically changing the pre-Cenozoic tectonic framework of western China (Fig. 6).

It is worth noting that the Himalayan orogenic system, which includes the Low, High, and Tethyan Himalayas, was not constructed on the active belt of the Indian continental margin, but on the Indian platform. From the Late Cambrian or Ordovician to the Paleogene, the sediments in the Tethyan and High Himalayas were stable platform deposits. Therefore, the Main Central Thrust, Main Boundary Thrust, and related thrust–fold systems that share the main Himalayan Thrust as a detachment surface were formed in the basement and overlying strata of the Indian platform. Thus, most of the Himalayan orogenic belt is superimposed on pre-existing continental crust.

Orogenic belts superimposed on pre-existing continental crust are particularly widespread and important in China, but they are not unique to China. Most major orogenic systems globally consist of two parts: A main orogenic belt composed of sedimentary–magmatic–metamorphic complexes (the subduction–collision complex belt) and an orogenic belt superimposed on adjacent pre-existing continental crust. For example, the Sevier thrust–fold belt in the North American Cordillera is superimposed on the North American craton, the West Ural belt of the Ural orogenic system is superimposed on the eastern European craton, the Helvetia belt in the Alps is superimposed on the post-Variscan platform in Europe, and most of the Andean orogenic system in southern America is superimposed on the Brazil platform.

Generally speaking, the tectono-magmatic processes in foreland or hinterland thrust–fold belts in the footwall of thrust belts adjacent to passive continental margins have occurred at shallow tectonic levels, and mostly have involved only the crust. Typical examples include the Sevier hinterland thrust–fold belt in the North American Cordillera, the foreland thrust–fold system of the High and Low Himalayas, and the Tethyan Himalayas in the Himalayan orogenic system. The superposed orogenic belts adjacent to active continental margins and in the hanging wall of thrust belts occur at deeper tectonic levels, where the movement of mantle material often plays a greater role and intense crustal deformation occurs. For example, the Mesozoic East China superposed orogenic belt, the Gangdese tectono-magmatic belt in the Himalayan orogenic system, and the Andes orogenic system adjacent to the erosive Pacific subduction margin not only underwent intense crustal deformation, but also widespread magmatic activity.

6. Conclusions

(1) The Superposed orogenic belt is an orogenic belt that formed on the pre-existing continental crust. The tectonic belts formed by the Indosinian and Yanshanian orogenic movements in eastern China are not intracontinental or intraplate orogenic belts, rather, they are superposed orogenic systems formed under the effect of Paleo-Pacific dynamic system. It, together with the East Asia margin orogenic system formed the giant Mesozoic orogenic system in the Pacific tectonic domain in eastern Asia.

(2) The Mesozoic superposed orogenic systems in Eastern China completely changed the Paleozoic tectonic formwork and crustal and upper mantle structure, resulting in the

[①]The term “Proto-Laurasia” is coined by the author Ren JS on the basis of recent geological data about the Arctic regions (Petrov O and Shakalsroy, 2018). During the Paleozoic, the three Precambrian continents, North America (Laurentia), East Europe and Siberia were amalgamated into an united continent, namely Proto-Laurasia. At the end of the Paleozoic, the closure of the Paleo-Atlantic and Paleo-Asian oceans led to the formation of the Appalachian-Central Asia orogenic belt, and Proto-Laurasia was developed into Laurasia.

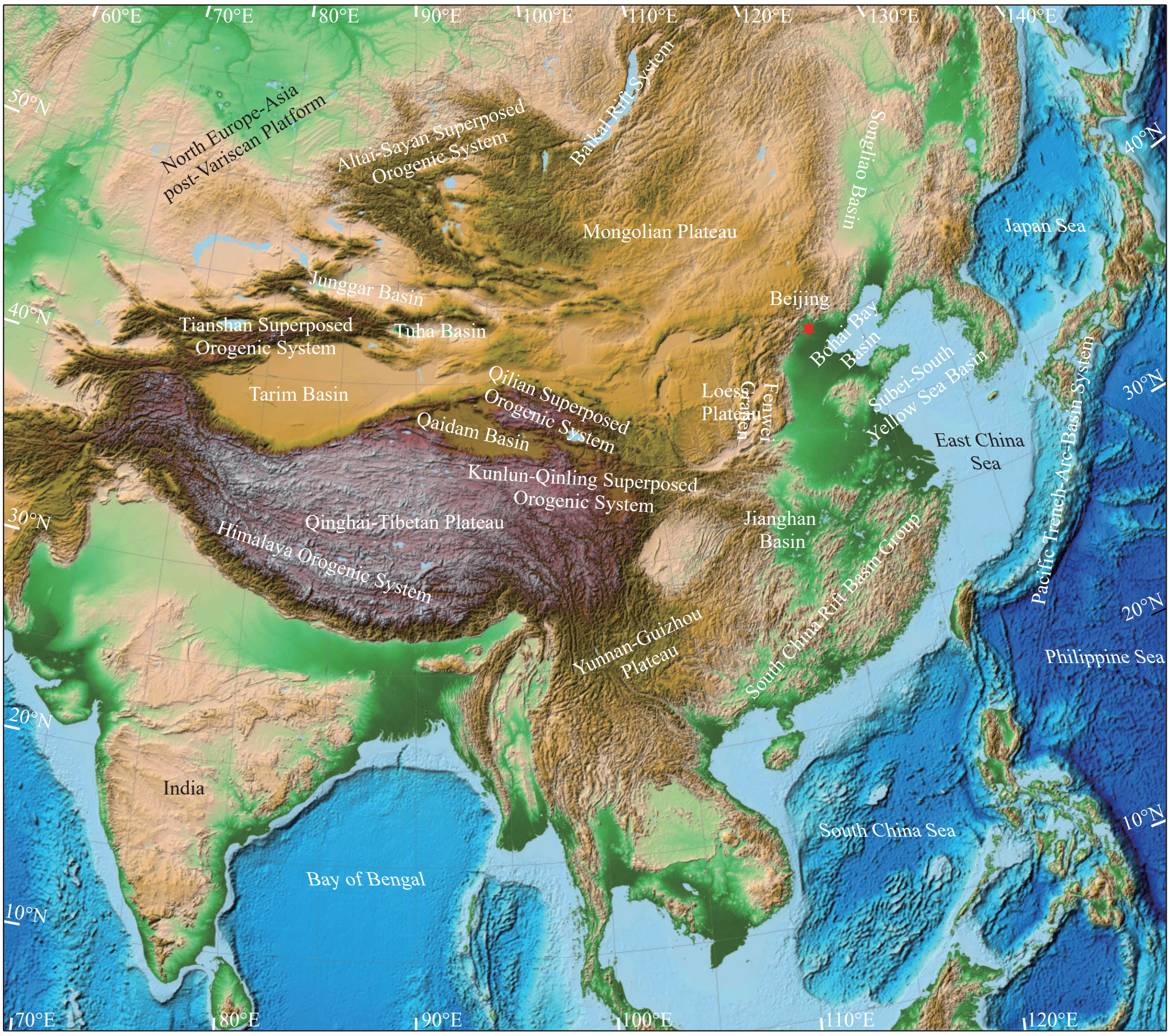

Fig. 6. Morphostructural map of China and adjacent regions for the period after the Himalayan orogeny.

formation of an overpass-like structure of the crust and upper mantle in Eastern China.

(3) Attributed to the successive effects of three major geodynamic systems of the Paleo-Asian Ocean, Tethys-Paleo-Pacific and Indian Ocean-Pacific, superposed orogenic belts are particularly widespread and important in China, but they are not unique to China. Most major orogenic systems globally consist of two parts: a main orogenic belt composed of sedimentary–magmatic–metamorphic complexes (the subduction–collision complex belt) and an orogenic belt superimposed on adjacent pre-existing continental crust.

CRediT authorship contribution statement

Ji-shun Ren conceived of the presented idea and wrote the original draft. Jian-hui Liu and Jun-bin Zhu carried out graphic and writing editing. All authors contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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