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► **To cite this version:**

Qin Wang, Weidong Sun, Michel Faure, He Li. From the Yanshan orogeny to Late Mesozoic multi-plate convergence in East Asia. *Tectonophysics*, 2023, 856, pp.229839. 10.1016/j.tecto.2023.229839 . insu-04105816

**HAL Id: insu-04105816**

**<https://insu.hal.science/insu-04105816v1>**

Submitted on 25 May 2023

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## Preface

### From the Yanshan orogeny to Late Mesozoic multi-plate convergence in East Asia

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#### **1. Introduction**

The Yanshan orogeny was defined as significant crustal movement and magmatism of Late Jurassic age in North China in 1927 by Dr. Wenhao Wong. The following studies revealed that the Yanshan orogeny in the North China Craton (NCC) lasted from the Middle Jurassic to Cretaceous, and was coeval with widespread emplacement of granites, eruption of volcanic rocks, formation of world-class ore deposits and large sedimentary basins in East Asia. Therefore, the Yanshan orogeny was widely used as a time interval for the Late Mesozoic deformation and magmatism in East Asia. In addition, according to the contrasting deformation patterns and magmatism in the NCC and the South China Block (SCB), two episodes of the Yanshan orogeny were recognized: the Early Yanshan episode in the Middle-Late Jurassic and the Late Yanshan episode in the Cretaceous. The change of regional tectonic regimes was mainly attributed to the evolving NW-WNW-ward subduction of the Paleo-Pacific Plate beneath East Asia. It is well known that in the Late Mesozoic, the NCC experienced significant lithospheric thinning, exhumation of metamorphic core complex, magmatism and gold mineralization, whereas the SCB developed a broad (~1300-km-wide) intracontinental orogen this is for Triassic (central SCB)-Jurassic (W SCB) and Cretaceous magmatic province coeval with rift basins and polymetallic magmatic-hydrothermal ore deposits such as Au-Mo, W-Cu, U, Sn. This raised a lot of debate on subduction models of the Paleo-Pacific Plate and crustal reworking mechanisms.

In fact, from the Middle Jurassic to Cretaceous, East Asia was subject to subduction of the Paleo-Pacific Plate in the east, and subduction and closure of the Mongol-

Okhotsk Ocean in the north and the Bangong-Nujiang Ocean in southwest. Previous studies generally treated these subduction systems as independent plate boundary conditions. However, their interaction may have produced the far-field Mesozoic deformation and magmatism in East Asia. Therefore, the Late Mesozoic multi-plate convergence in East Asia is a key to understand the initiation and development of the Yanshan orogeny and deep process of metallogenic explosion.

Such multi-plate convergence process may have occurred repeatedly during the supercontinent assembly in the Earth's history. Compared with formation of the Columbia supercontinent at ~1.8 Ga, Rodinia at ~1.0 Ga and Pangea at 300–250 Ma, East Asia in the Late Mesozoic had well-constrained plate boundary conditions and exceptional exposure, make it a testing ground for various models of subduction zone process, not only along convergent boundaries but also as a far-field response in continental interiors. Therefore, knowledge about East Asia in the Late Mesozoic will throw new insights to the continental evolution and crust-mantle interaction during supercontinent assembly.

## **2. Volume overview**

This compilation of papers was initiated in 2021 because two National Key R&D Program of China were accomplished to explore deep structure and controlling mechanisms of metallogenic systems during the Mesozoic and its possible links with the Yanshan orogeny. A lot of new data were collected in the past decade through different geological, geochemical and geophysical methods. Combined with other independent studies, we could see a bigger and more complicated picture about the tectonic evolution of East Asia in the Late Mesozoic. Nineteen papers in this special issue are organized into three sections.

### ***2.1 Deformation and magmatism in North and NE China***

Late Mesozoic magmatism and metallogenesis in East Asia was closely related to subduction of the Paleo-Pacific Plate. However, the effects of the Paleo-Asian Ocean and the Mongol-Okhotsk Ocean regimes in NE China, geometry and convergence direction of the subducted Paleo-Pacific Plate and the related response in the continental margin remain unclear. This section provides new compilations, which allow us to reconstruct the fate of subducted oceanic plates.

This special issue starts with a review paper entitled “Late Mesozoic intracontinental deformation and magmatism in North and NE China in response to multi-plate convergence in NE Asia: An overview and new view” (Zhang Y Q et al.,

this volume). They establish new compilations of Mesozoic structural, petrological and geochronological data on a board region that comprises the NCC, the eastern domain of the Central Asia Orogenic belt, and the eastern margin of the NE Asia continent. They recognize three tectonic stages according to deformation patterns and the migration of magmatism in the Late Mesozoic: the extension-dominated stage with A-type granitoids and bi-modal volcanism along the northern and eastern marginal zones in 200–170 Ma, the compression-dominated stage with multi-directional intracontinental deformation and magmatism in 170–135 Ma, and the alternative extension-compression stage comprising “within-plate” magmatic flare-up in 135–120 Ma and progressive eastward magmatism migration in 120–70 Ma. The tectonic switch at 170 Ma from back-arc extensional to compressional regimes was interpreted as the result of the shallowing subduction angle of the Paleo-Pacific Plate and closure of the Mongol-Okhotsk Ocean. The trend of magmatism migration from the marginal zones to the continental interior reversed at 135 Ma, suggesting slab rollback or breakoff of the Paleo-Pacific Plate. Compared with geological records in East Asia, they link the change of tectonic stages with widespread Late Mesozoic deformation in the NCC and the surrounding thrust-folds, orogenic belts and the sinistral strike-slip Tan-Lu fault system.

Liu et al. (this volume) investigate the final closure of the Paleo-Asian Ocean and the pre- to post-collisional evolution of the southeastern Central Asian Orogenic Belt. Using a comprehensive dataset of detrital zircon U-Pb ages and Hf isotopes, they find episodic provenances changes in the Middle Permian to Middle Jurassic foreland sediments, suggesting closure of the Paleo-Asian Ocean and a ‘soft’ collision of the opposing accretionary prisms along the Solonker suture zone at ca. 270–258 Ma, and the onset of the Paleo-Pacific regime since 171 Ma. Guo et al. (this volume) find that the earliest eruption age of Middle-Late Jurassic volcanic rocks (i.e., Tiaojishan Formation) in the northern NCC and adjacent Great Xing’an Range decreases from 166 Ma in the east to 157 Ma in the west, reflecting the predominant contribution of subduction of the Paleo-Pacific Ocean. Meanwhile volcanism in the northern Great Xing’an Range was controlled by both subduction of the Paleo-Pacific Ocean and closure of the Mongol-Okhotsk Ocean.

The closure timing of the Mongol-Okhotsk Ocean is well constrained by magmatism and deformation in NE China and the northern NCC. Gao et al. (this volume) find a NE-trending A-type granite belt in 162–148 Ma along the western Xing’an Block and the northern margin of the NCC. Contemporaneous Late Jurassic A-type granites and adakitic rocks in the westernmost NE China implies orogenic

collapse and intense crustal extension after closure of the Mongol-Okhotsk Ocean. Structural analysis and  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronology yield activation of the Kaiyuan-Jiapigou shear zone in the northern margin of the NCC at 165–161 Ma, which was probably associated with the far field effect due to closure of the Mongol-Okhotsk Ocean in the Middle Jurassic (Huang et al., this volume).

Extensive magmatism in the Early Cretaceous in East Asia provides evidence for the slab rollback of the Paleo-Pacific Plate. Quan et al. (this volume) distinguish three types of Early Cretaceous granitic rocks in the northeastern NCC: the low-Mg adakitic rocks of 134–120 Ma originated from thickened lower mafic rocks, the high-Mg adakitic rocks of 126–114 Ma derived from partial melting of delaminated lower mafic rocks, and normal granitic rocks of 127–121 Ma from lower mafic crust with normal crustal thickness. The nearly coeval occurrence of these granitic rocks in the northeastern NCC suggests significant crustal extension and partial melting during the peak period of the NCC destruction. This scenario is confirmed by zircon chemistry and detailed textural analyses on the Fangshan pluton in the NCC. Zhang Z K et al. (this volume) find that four types of zircons from the Fangshan pluton recorded multi-stage magma pulsation from the lower crust to the upper crustal magma chamber between 132.5 and 128.7 Ma. An incremental growth model by mingling and mixing of various properties of residual melts can better explain the chemical and isotopic heterogeneity in the Cretaceous plutons. Zeng et al. (this volume) present an integrated study of structural analysis, anisotropy of magnetic susceptibility and gravity modelling for granite plutons, which can yield information on the regional stress field during magma emplacement or post-solidus deformation. They reveal that two Early Cretaceous granite plutons in the northern NCC experienced the weak NW-SE extension at 130–127 Ma, just prior to the large-scale intensive NW-SE extension during 127–110 Ma in the NCC.

To the west, the Yili Block in the western Central Asian Orogenic Belt forms the easternmost part of the Kazakhstan collage system. Apatite fission track thermochronology reveals different Mesozoic thermo-tectonic evolution in the northern and southern margins of the Yili Block (He et al., this volume). Cretaceous basement cooling in the northern Yili Block may reflect far-field effects of the Lhasa-Qiangtang collision along the Bangong-Nujiang suture zone, whereas Early Triassic-Middle Jurassic cooling of the southern Yili Block is attributed to the post-orogenic strike-slip motion due to the Qiangtang and Kunlun-Qaidam collision.

## ***2.2 Deformation and magmatism in South China***

The following papers indicate that subduction of the Paleo-Pacific Plate was the primary controlling factor for Late Mesozoic deformation and magmatism in South China. After continental collision between the NCC and SCB in the Late Permian to Early Triassic, the Northern Sulu Massif experienced exhumation of ultrahigh-pressure metamorphic rocks, migmatization and alkali magmatism in the Late Triassic, and felsic magmatism in the Late Jurassic. Combining structural analysis, anisotropy of magnetic susceptibility of granite plutons and gravity modelling of the Northern Sulu massif, Meng et al. (this volume) attribute the latest Triassic (~220–210 Ma) NW-SE extension to the post-collisional lithospheric delamination and Late Jurassic NE-SW weak extension to the oblique subduction of the Paleo-Pacific Plate.

Qian et al. (this volume) observe Early Cretaceous (130–125 Ma) I-type granitoids in the Liyang volcanic basin in the eastern Yangtze Block, which was derived from mixing of Proterozoic crustal components with mantle-derived magma. This suggests the extensional tectonic setting due to the slab rollback of the Paleo-Pacific Plate. About 200 km to the east, core samples from boreholes in Shanghai confirm the response of the SCB to the rollback of the Paleo-Pacific Plate (Qiu et al., this volume). Geochemical features and zircon U-Pb age and Hf isotope indicate that ~130 Ma andesite was produced by partial melting of metasomatized mantle wedge, whereas ~102 Ma granodiorites originated from partial melting of the lower crust with the addition of mantle-derived magma.

The Paleozoic Yuechengling-Miao'ershan batholith in the central SCB was split by a top-to-the-west or -NW mid-crustal detachment (i.e., the Ziyuan Detachment) during 100–85 Ma and then partially covered by a Late Cretaceous half-graben at the hanging wall (Feng et al., this volume). This deformation pattern is typical for Late Cretaceous crustal extension in South China, which is different from exhumation of deep crustal rocks in the NCC. To the south, two calderas in the Daiyunshan volcanic field along the coast of SE China reveal the crystal-melt segregation and magma recharge process at 97–94 Ma. Furthermore, Late Jurassic to Late Cretaceous volcanic-plutonic rocks from the Daiyunshan volcanic field indicate variable contribution of asthenospheric mantle-derived melts, which probably reflects a change in the subduction dip of the Paleo-Pacific Plate beneath the SCB (Liang et al., this volume).

### ***2.3 Crust-mantle structure and interaction***

How to give timing constraints on deep structures is critical for interpretation of geophysical observation and geodynamic modelling. Previous geophysical studies show that the crust-mantle structure in China has been significantly modified by

subduction of the Pacific Plate and the Philippine Sea Plate in the east, and the Indo-Asia collision in the west. This section provides the crust-mantle structure of the Central Asian Orogenic Belt and the central SCB. The former is the largest accretionary orogen and is a product of long-term evolution of the Paleo-Asian Ocean from the Late Paleozoic to Early Mesozoic. The latter has been reactivated by the Triassic intracontinental orogeny and the Jurassic-Cretaceous tectonic and magmatic events. Both areas are far away from the present-day convergent boundaries.

The closure process and subduction polarity of the Paleo-Asian Ocean along the Solonker suture zone during the Late Permian and Early Triassic are still controversial in geological records. Low resistivity anomalies in orogenic belts or ancient suture zones are often related with the subducted oceanic crust. Yi et al. (this volume) present a NW-trending magnetotelluric (MT) profile across the south-eastern Central Asian Orogenic Belt and the northern margin of the NCC to explore the multi-stage closure process of the Paleo-Asian Ocean. The lithospheric resistivity model reveals two crustal conductors with opposite dipping directions, which constrain the northern and southern boundaries of the Solonker suture zone and indicate the late-stage low-angle bidirectional subduction of the Paleo-Asian Ocean. Meanwhile, two mantle conductors with opposite dipping directions beneath the Solonker suture zone delineate the early-stage high-angle bidirectional subduction of the Paleo-Asian Ocean. Compared with previous parallel MT profiles across the Central Asian Orogenic Belt, the subduction angle becomes gentle from west to east. In addition, a conductive lower crust beneath the northern margin NCC may result from the magma underplating or crust-mantle decoupling.

Li et al. (this volume) present a 600-km-long EW-trending MT profile across the southwestern segment of the Jiangnan Orogenic Belt. A west-dipping, trans-lithosphere conductor is interpreted as relics of the Neoproterozoic subduction zone between the Yangtze and Cathaysia blocks. However, it could also be caused by partial melting of a metasomatized lithospheric mantle and reactivation of an ancient suture zone during the Cretaceous extension in the SCB. The notably thinned electrical lithosphere, as well as elevated crustal and mantle conductivity in the western Cathaysia Block are probably related with the rollback of the Paleo-Pacific Plate and subsequent upwelling of asthenosphere material along shear zones/faults.

The Mongolian Plateau in the western Central Asian Orogenic Belt experienced multiple tectonics events, and intraplate volcanism and magmatism in the Miocene and Quaternary. Wang et al. (this volume) obtain high-resolution S-wave velocity structures of the crust and upper mantle beneath the Mongolia Plateau and the Gobi Desert using

Rayleigh wave tomography. They find the strong low-velocity anomalies in the lower crust immediately beneath the Hangay Dome, and the low-velocity zones beneath the dome margins in the upper mantle. This implies that the Hangay Dome was formed by mantle upwelling into the crust from major faults. The high-velocity patches in the upper mantle beneath the southern Gobi Desert are interpreted as the fossil slabs during closure of the Paleo-Asian Ocean.

Furthermore, Wu and Huang (this volume) measured SKS splitting in the western Mongolian Plateau and used upper mantle anisotropy to trace deformation in this region. The predominant NW-SE oriented fast polarization directions are consistent with the past and present lithosphere deformation and asthenospheric flow. The rigid Siberian Craton may cause the deflection of the asthenospheric flow. Combined with the distribution of low-velocity anomalies in the upper mantle (Wang et al., this volume), small delay time in the Hangay Dome also implies the asthenospheric upwelling beneath the dome. In brief, different from the well-preserved subducted oceanic crust in the electrical structure in the eastern Central Asian Orogenic Belt, the crust-mantle structure of the Mongolian Plateau has been significantly modified by the far-field effect of the Indo-Asian collision more than 2000 km away.

The special issue ends with a paper entitled “Late Mesozoic multi-plate convergence in East Asia: Insights from 3-D global mantle flow models” (Zhang et al., this volume). They first summarize major stages of deformation, magmatism and paleogeography in the Mesozoic East Asia, and then establish global mantle convective flow models coupled with plate reconstruction motions from 200 to 90 Ma. The modelling results show the subduction-related dynamic topography of East Asia during multi-plate convergence: (1) In the Early Jurassic, the East Asian continental margin breakup occurred due to the mantle-driven dynamic topography; (2) The continuous advancing subduction of the Paleo-Pacific Plate led to the onshore dynamic uplift and orogenesis in East Asia, while the closure of the Paleo-Tethys Ocean and subduction of the Bangong-Nujiang Ocean contributed to the southward migration of the dynamic topography; (3) Since 130 Ma, slab rollback of the Paleo-Pacific Plate caused the back-arc extension and dynamic subsidence zone in East Asia; (4) The alternating compression-extension stage controlled the dynamic topography of the marginal belts. Therefore, as direct evidence of the crust-mantle interaction, mantle dynamics controlled distribution of the dynamic uplift/subsidence areas of East Asia in the Late Mesozoic.

### **3. Conclusions**



This special issue shows how multi-plate convergence in East Asia in the Late Mesozoic affected deformation, magmatism and the crust-mantle structure in convergent boundaries and far-field regions. The broad regions of deformation and magmatism highlight the importance of rheological structure and tectonic inheritance of the continental lithosphere during strain distribution and crust-mantle interaction. The new structural, petrological and geochronological datasets, as well as geophysical structures of the crust and upper mantle and dynamic modelling, improved our understanding of deep processes and mechanisms of the Mesozoic events in a global scale. We hope that this volume may stimulate more research on the relationships between tectonic evolution, metallogenic explosion and environmental change in East Asia in the Late Mesozoic, as well as comparative studies around the world.

### **Acknowledgments**

The guest editors are indebted to the editors and reviewers who have provided invaluable comments to improve the quality of the presented papers. The trust and support of editors Ling Chen, Philippe Agard and Timothy Horscroft are greatly appreciated.