Advances in Solid Earth Sciences

Edited by
Pang Zhonghe, Zhang Jindong and Sun Jianhong

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Preface

Population explosion, depletion of natural resources and the deterioration of environment are threatening the existence and sustainable development of mankind. Subsequently, more and more attentions are being paid to the issues of maintaining a harmonious development of human beings and the nature. Scientists of the world are devoting themselves to studying and solving the principal problems involved in these issues and providing better knowledge on the sustainable development of the human society, through the implementation of individual and multilateral research projects.

Geosciences are facing chances as well as challenges. Their development needs to be inspired by the improvement of the infiltration and amalgamation of the different branches. Systematic concepts and global view are needed in geoscience studies. This requires geoscientists to inspect the spheres (the atmosphere, the hydrosphere, the biosphere and the lithosphere) of the earth not only independently but also integratedly in order to understand the nature of each of them, the interactions among them and the behavior of the planet earth as a whole system. Geoscience studies need a dynamic insight, i.e., not only the phenomena should be described but also the driving force for their evolution revealed. Furthermore, novel methods and new techniques should be applied for the acquisition of new and more reliable data. The development of geosciences will help human beings in maintaining the natural resources supply, protecting and improving the living environment, and abating or diminishing natural hazards.

With emphasis on problems in energy and mineral resources, environmental issues related to continental and oceanic geology, the 30th International Geological Congress to be held in Beijing in August of 1996 reflects the expectation of society for geosciences and the trends in the development of the sciences themselves. It will provide a unique opportunity for the exchange of ideas and experience between geoscientists from home and abroad and for our foreign colleagues to understand the geology of China.

Chinese Academy of Sciences has more than ten institutions engaged in scientific research of geology, geophysics, geochemistry, paleontology and oceanic geology, with several thousands of scientists and engineers as well as ample facilities and equipment for carrying out analysis, experiments and observations. In recent years, a number of programs have been implemented in the field of solid earth sciences on continental dynamics, mineral and energy resources, oil and gas geology and environmental geology. The projects include: ultrahigh-pressure metamorphism in Dabie Mountains, tectonic evolution of lithosphere of the different areas including the Qinghai-Xizang Plateau, Karakorum-Kunlun Mountains, western Yunnan and western Sichuan, Qinling and northern Xinjiang of China, metallogenesis of super-large scaled ore deposits, low temperature geochemistry, past environmental changes and Quaternary geology, geological and geochemical study of oil and gas, geological and geophysical surveys on the East China Sea, the South China Sea, and the Yellow Sea. These projects have made substantial progress.

Chinese Academy of Sciences, in close collaboration with the State Science and Techology Commission and the National Natural Science Foundation of China, has sponsored the publication of a series of monographs entitled *Solid Earth Sciences Research in China*, to be published before the 30th IGC. Like other monographs, this selection of papers is also designated to foster the perception by scientists from other countries of some of the latest work of the scientists – especially the younger scientists of Chinese Academy of Sciences in the above fields.

Many institutions helped us in the preparation of this selection. Many scientists spent a great deal of time to help organize and contact authors. Our greatest debt of gratitude goes to Wang Qingchen, Geng Ansong, Zhu Rixiang, Xu Juntao, Wang Xingli, Zhou Di, Zheng Yongfei and Lin Ge.

Thanks are also due to the following scientists who kindly reviewed and ensured the quality of both the academic contents and the language of the manuscripts: Bai Zhenghua, Chen Duofu, Chen Haihong, Chen Xu, Chu Xuelei, Fan Shanfa, Guo Sujie, Han Xuemin, Han Jiamao, Hou Wei, Hu Aiqin, Jiang Nayan, Liao Weihua, Lu Jialan, Pang Zhonghe, Qiu Huaning, Shen Chengde, Teng Jiwen, Wang Jiyang, Wang Miaoyue, Wang Shijie, Wang Weiming, Wang Yurong, Wang Zhongcheng, Xu Juntao, Yin Binchuan, Zhang Buoyou, Zhang Qian, Zhou Di, Zhu Binquan, Zhang Guoxin, Zhu Huicheng, Zhu Rixiang, Zhuang Hanping.

We want to thank Chen Haihong, Wang Zhongcheng, Wu Yasheng for their assistance in the editorial work of this book.

Qin Dahe
Director
Bureau for Resources
and Environmental Sciences
Chinese Academy of Sciences

18 May 1996, Beijing

Contents

Squeeze-up of the Dabie UHP Rocks: an Extrusive Exhumation Model*

Wang Qingchen
(*Laboratory of Lithosphere Tectonic Evolution, Institute of Geology, Chinese Academy of Sciences, Beijing 100029, China*)

Abstract: Exhumation of ultrahigh-pressure (UHP) rocks might have resulted from tectonic and/or erosional removal of, or upwards extrusion through, the overburden. A squeeze-up model of exhumation is suggested for the Dabie UHP rocks. The invoked extrusion mechanisms are corner-flow in the first stage and upward extrusion in the second stage. This model is supported by lower density of UHP rocks, pressure gap between UHP-rock-bearing unit and non-UHP unit on top, contrast in exhumation rate, and shear sense in the orogenic belt.
Key words: UHP rocks, squeeze-up, exhumation, Dabie Mountains

1. Introduction

It has been recognized that buoyant supracrustal rocks could be dragged down to mantle depth and then exhumed to shallow crust in an orogenic process. Such an important geodynamic process of great dimension has launched a new challenge to conventional geodynamics ideas since the discovery of coesite in metamorphic sedimentary rocks from West Alps (Chopin, 1984). While it is accepted that ultrahigh-pressure (UHP) metamorphic rocks could be formed when supracrustal materials subducted down to mantle depth, it remains unclear how those UHP rocks were exhumed from mantle depth. So far, a number of models have been proposed to explain the exhumation mechanism (Platt, 1993). Besides the European West Alps, the Chinese Dabie orogenic belt has provided a natural laboratory to study UHP rocks. Large dimension and good exposure of UHP rocks in the Dabie orogenic belt, Central China, have attracted a worldwide attention. International studies on their petrology, mineralogy, geochemistry, isochronology have made great progress. However, as in the case of West Alps, there still exist hot debates on how the Dabie UHP rocks were exhumed. This is the focus to be discussed in the present paper.

2. Tectonic Background of the Dabie UHP Rocks

The Dabie UHP rocks occur in the eastern section of the Qinling-Dabie Mountains, which is a collision-type orogenic belt. The Dabie Mountains could be divided into five tectonopetrological units, i.e., North Huaiyang Backarc Flysch (NHBF), North Dabie Arc Complex (NDAC), South Dabie Collision Complex (SDCC), Susong Metamorphic Complex (SUMC), and Foreland Belt (Cong and Wang, 1995; Liou et al., 1995). All of the UHP rocks are developed in the SDCC (Fig. 1).

Field observations have revealed that the SDCC is bounded in the north by the Shuihou-Wuhe fault. It is a flat-lying shear zone extending northwestward with a gentle dip towards

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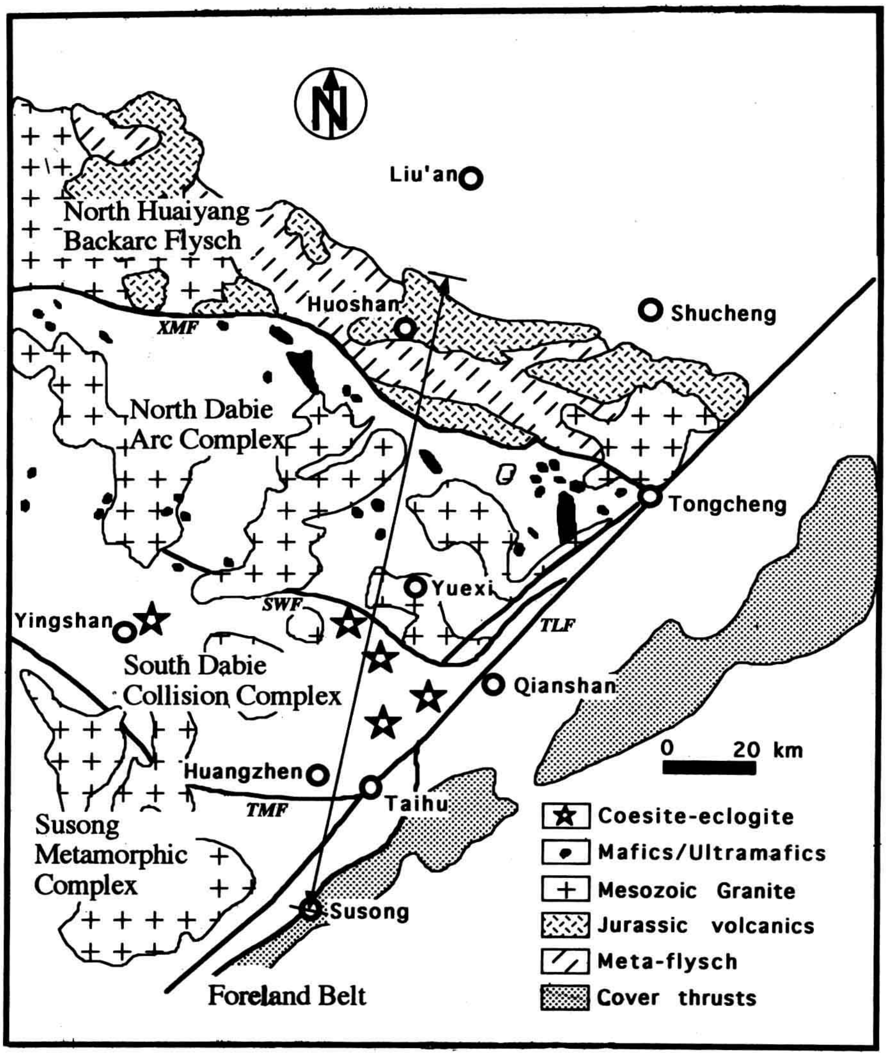

Fig. 1 Petrotectonic units of the Dabie orogenic belt

the northeast. Top-to-the-north shear sense is displayed by S-C structure, grain rotation, shear bands of feldspar and quartz, and *c*-axes fabrics of quartz(Wang et al., 1995). On the further north, the NDAC contacts the NHBF with the Xiaotian-Mozitan fault, that is a sinistral strike-slip ductile shear zone with a normal fault component.

The SDCC is bounded in the south by the Mamiao-Taihu fault. The shear sense determined by the S-C structure and rotation of feldspar crystals is top-to-the-north. SUMC is located on the south of SDCC and bounded in the south by the Xiangfan-Guangji fault. In spite of poor exposure of the fault, its southward overthrusting is evidenced by south vergence of folds developed in sedimentary cover of the Foreland belt.

3. Pressure Gaps and Exhumation Rates

Although the peak metamorphic *P-T* of coesite and diamond-bearing eclogites have been estimated as 2.8 – 4.0 GPa 740 – 900℃ (Liou et al., 1995; Wang et al., 1995; Xu, S., et

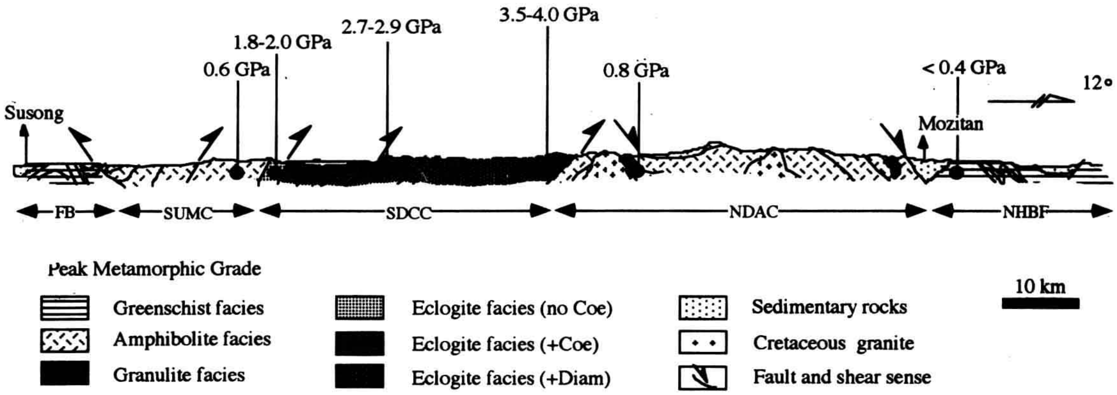

Fig. 2 Metamorphic pressure gap between adjecent units and shear sense along faults in the Dabie orogenic belt. The profile is marked in Fig. 1. Numbers above the profile are peak metamorphic pressures.
FB: Foreland Belt; SUMC: Susong Metamorphic Complex; SDCC: South Dabie Collision Complex; NDAC: North Dabie Arc Complex; NHBF: North Huaiyang Backarc Flysch

al., 1992), not all rocks in the Dabie orogenic belt have experienced UHP metamorphism For examples "cold eclogite" in the SDCC experienced only high pressure metamorphism of

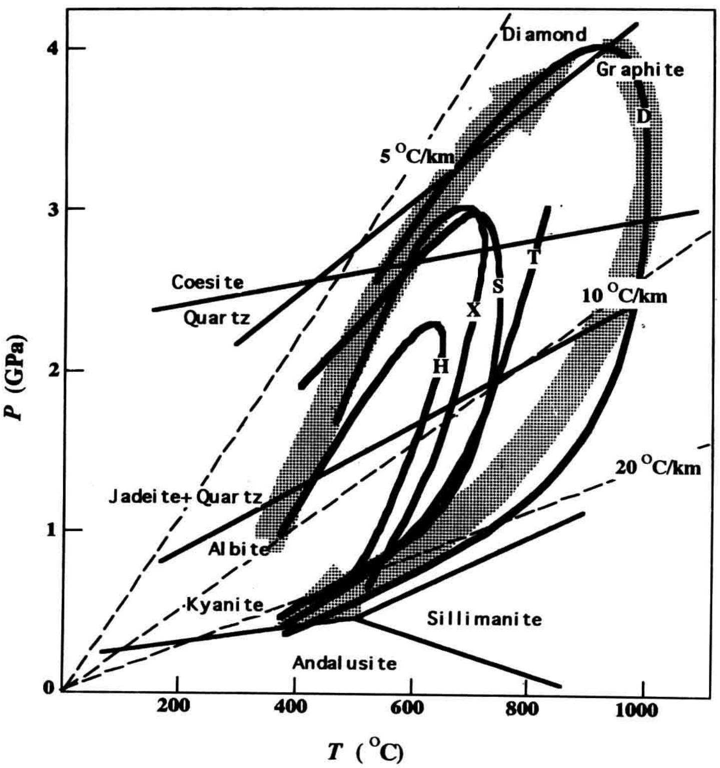

Fig. 3 *P-T* paths of the diamond-bearing eclogite in Changpu (D), coesite-bearing eclogite in Taihu (T), Shuanghe (S) and Xinxian (X), as well as "cold" eclogite without coesite in Huangzhen (H), from the Dabie Mountains

$P = 1.8 - 2.4$ GPa and $T = 650$℃ (Okey, 1993), and granulite in the North Dabie Arc Complex of $P = 11$ GPa and $T = 800$℃ (Liou et al., 1995). Large gap in metamorphic pressure across the boundary between adjacent units could be recognized (Fig. 2). However, although pressure gap has been recognized between the "cold eclogite" subunit and coesite-bearing eclogite subunit, their contact remains a puzzle due to poor exposure.

Multiple stages of metemorphism and deformation have been recognized in the Dabie UHP rocks(Liou et al. 1995; Wang and Cong, 1995). U-Pb, Sm-Nd, Rb-Sr, and $^{40}Ar/^{39}Ar$ methods have also been conducted to elucidate the time of the UHP, HP, and retrograde metamorphic events(Li et al., 1993; Hacker and Wang, 1995; Ge, N. et al., 1995; Xiao et al., 1995). With these data of petrology, structural geology, and geochronology, *P-T* paths of the Dabie UHP rocks could be constructed (Fig. 3), and average exhumation rate could be estimated (Fig. 4).

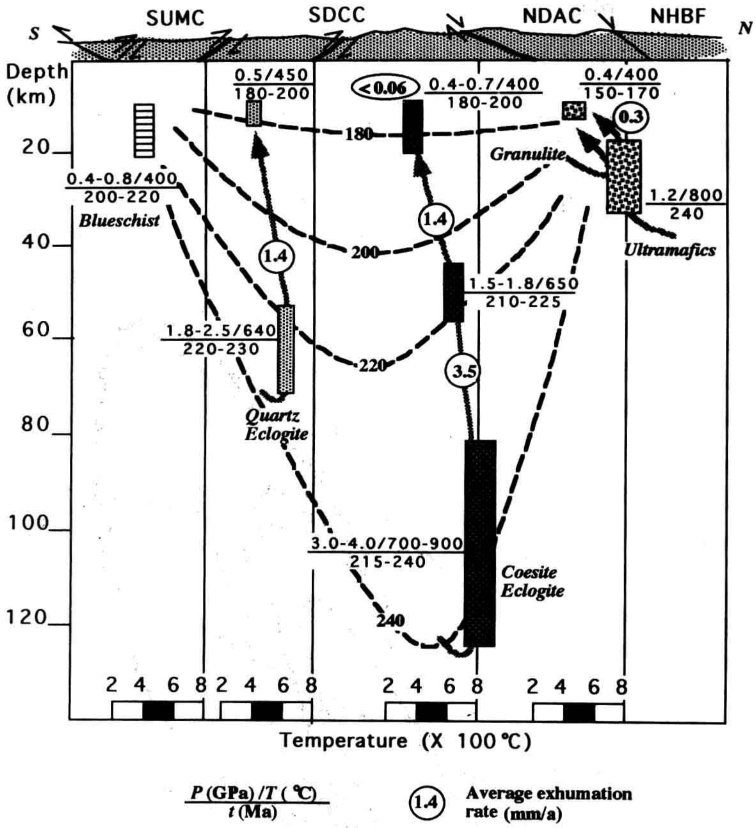

Fig. 4 Exhumation rates in the Dabie orogenic belt
The abbreviations are the same as those in Fig. 2

The above estimations have provided some constraints to the exhumation of UHP rocks. Firstly, all of the Dabie UHP rocks have isothermal decrease pressure path (Fig. 3). This implies that the exhumation was accompanied by an increases in geothermal gradient, from 9℃/km to more than 20℃/km. Secondly, three stages could be divided according to the variation of the exhumation rates. The first stage is between 240 Ma to 220 Ma, with an average exhumation rate of about 3.5 mm/a; the second stage is 220 − 180 Ma, with an average rate of 1.4 mm/a; and the third stage is after 180 Ma, exhumation rate less than 1 mm/a (Fig. 4). The change of the exhumation rates implies that the exhumation mechanism might have been changed. Thirdly, the Dabie UHP rocks were fast exhumed from mantle depth up to middle crust during the first two periods. After then, the whole Dabie Mountains were uplifted slowly (< 1 mm/a) and exposed to erosion.

4. A Squeeze-up Model

At least four models have been proposed to explain exhumation of the Dabie UHP rocks. These models include Triassic thrusting and erosion (Okey and Sengor, 1992), Triassic unroofing by erosion (Yin and Nie, 1993), Triassic wedge extrusion and Cretaceous doming (Maruyama et al., 1994), and Triassic vertical extrusion (Hacker et al., 1995). Disagreements are mainly resulted from unclear points, such as the tectonic setting of UHP rocks, the architecture of the Dabie orogenic belt, the feature of top boundary, as well as the exhumation time and rate, of the Dabie UHP rocks. With constraints of the above mentioned new data, the author suggests a two-stage extrusion model.

The proposed two-stage extrusion invokes the cornor flow and buoyancy force as mechanism in the first stage (240 – 220 Ma). The corner-flow mechanism is supported by the low geothermal gradient (6 – 9℃/km). Such a low geothermal gradient so far has been observed only in subduction zone. This implies that when some UHP rocks were transported upwards in a subduction zone, other UHP rocks were being formed. This is evidenced also by the melange feature and ecogite-facies deformation developed in the UHP rocks (Wang and Cong, 1996). The role played by buoyancy force is evidenced by the fact that no mantle rocks were associated with the Dabie UHP rocks, which have an average bulk composition equal to intermediate rocks with density < 3.0.

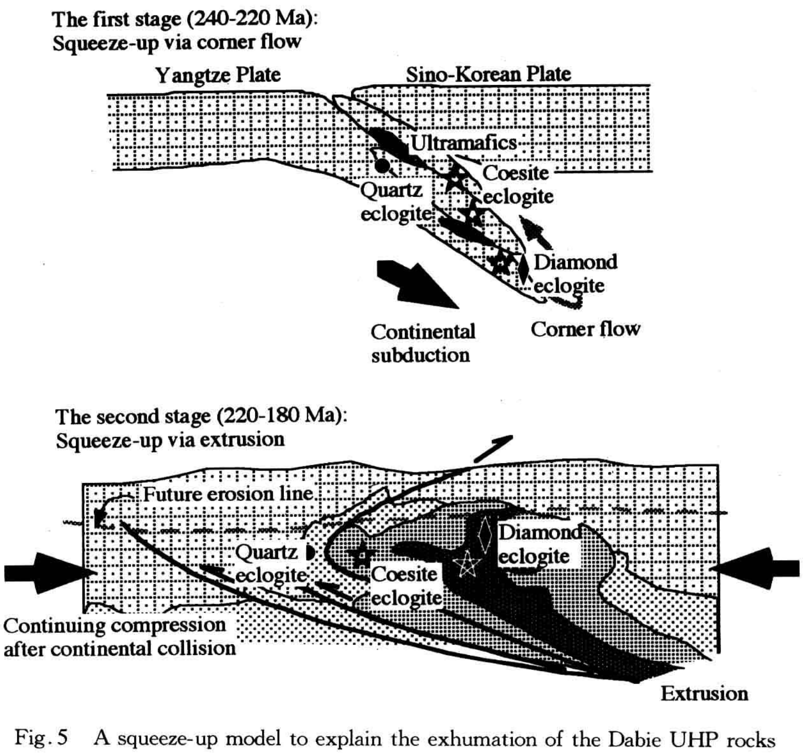

Fig. 5 A squeeze-up model to explain the exhumation of the Dabie UHP rocks

The upward extrusion is the suggested exhumation mechanism in the second stage (220 – 180 Ma). The stage is characterized by increase in geothermal gradient (from 10℃/km to 20℃/km) and the deformation of UHP rocks in the *P-T* condition of amphibolite facies, as implies that the UHP rocks had been emplaced up to depth of about 10 – 15km by 180Ma and the major structures of the Dabie orogenic belt, including foliations, shear zones, as well as pressure gaps, were finalized. The possibility of such a upward extrusion has been demonstrated experimentally by Merle and Guillier (Merle and Guillier, 1989). The prerequistite of their scale-model is horizontal compression and ductile flow in a higher geothermal gradient (Fig. 5).

The proposed model could be called as a squeezing-up model because the compression is suggested being important in both stages. When the UHP rocks were squeezed up, they would have a tectonic contact with their neighbor units. The shear sense should record the extrusive path of the UHP rocks as what is shown in Fig. 5.

5. Concluding Remarks

Based on petrological, structural, and geochronological data provided recently, a squeeze-up model is suggested to explain the exhumation of the Dabie UHP rocks. Such exhumation process could be divided into two stages. The first stage (240 – 220 Ma) is characterized by fast exhumation (3.5 mm/a) and low geothermal gradient (6 – 9℃/km), while the second stage (220 – 180 Ma) by slow exhumation rate (about 1.4 mm/a) and increased geothermal gradient (20℃/km). The Dabie UHP rocks were exhumed from depth of more than 100km to about 50km in the first stage, then to about 10 – 15km in the second. The proposed model could also explain the strutures including foliations, shear sense, and pressure gaps in the Dabie orogenic belt.

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Orogenic Processes of the Qinling*

Meng Qingren
(*Institute of Geophysics, Chinese Academy of Sciences, Beijing 100101, China*)
Zhang Guowei, Yu Zaiping, Mei Zhichao
(*Department of Geology, Northwest University, Xi'an 710069, China*)

Abstract: The Qinling has proved to have experienced a complicated evolutionary history and is characterized by its protracted orogenic processes. Subduction-collision at Shangdan suture zone was coeval with the rifting in the south of South Qinling. Collisional processes at Shangdan zone can be evidently divided into three phases and each phase is distinguished in terms of degrees of deformation, metamorphism and magmatism as well as development of different types of basins. Extensional regime was persistent from the early Paleozoic to middle Triassic in the south of South Qinling. Intensive deformation occurred and resulted in regional metamorphism and granitic magmatism throughout the Qinling in the late Triassic. Tectonic development of the Qinling is well correlated with the paleo-Tethyan evolution, indicating their genetic linkage.

Key words: Qinling, orogenic process, subduction/collision, rifting, paleo-Tethys

1. Introduction

Sedimentation and basin development are closely related to tectonic processes and can thus directly record the details of orogenic processes. It is of great importance to reconstruct the depositional systems and types of sedimentary basins in different areas in order to understand their temporal and spatial relationships because it can help to reveal the initiation, evolution and transformation of diverse tectonics within orogens.

The Qinling is located between North China block and Yangtze block (Fig. 1), and has proved to have experienced a complicated evolutionary history. The tectonic complexity is manifested as follows: the subduction was coeval with the rifting and uplift in northern and southern parts of South Qinling, respectively; initial collision occurred between North Qinling and South Qinling at Shangdan suture zone during the period from the late Devonian to Carboniferous. Some remnant basins developed within the suture zone and there also occurred small-scale foreland basins in the front. the Shangdan zone, however, was not affected by strong deformation, metamorphism, and magmatism during this period. Eastern segment of South Qinling is characterized by occurrence of platform carbonates, shelf siliciclastics and deepwater turbidites from the Permian to middle Triassic, and sedimentation of this sort indicates that the Qinling was not influenced by intense orogeny after the Carboniferous; the southern zone of South Qinling was not affected by compressive tectonism but was in the state of uplift and extension instead throughout the Paleozoic to early Triassic; from the Permian to middle Triassic, the establishment of shallow-water Carbonate platforms and deepwater turbidite systems in South Qinling was basically coeval with the event of widespread marine transgression, occurrence of continental flood basalt, and initiation of oceanic floor in both northern and southwestern parts of Yangtze block. Collision-related granite magmatism, strong deformation and regional metamorphism took place along Shangdan zone during the middle to late Triassic, and the same was true in Mianlue zone to the south of South Qin-

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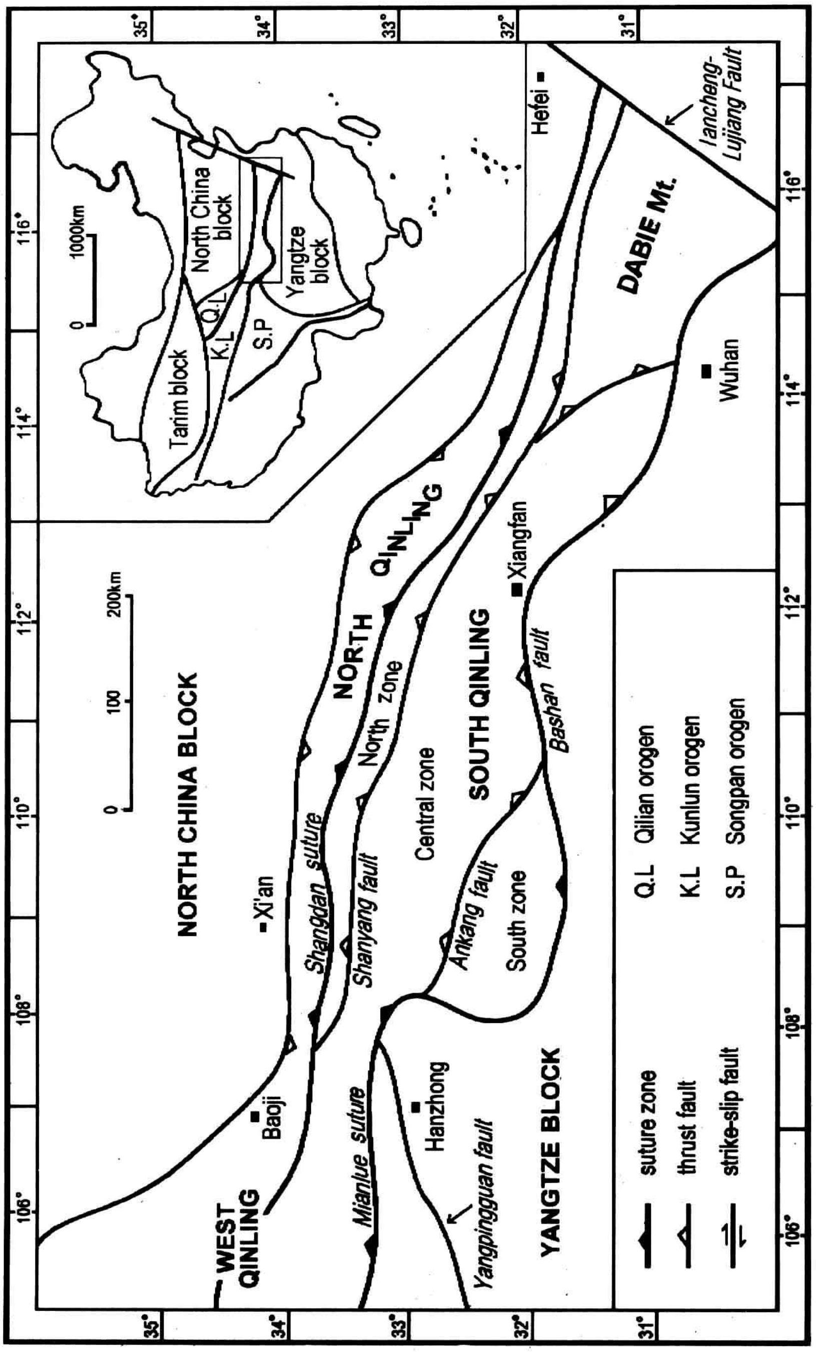

Fig.1 Simplified diagram showing tectonic locality and divisions of the Qinling