Chinese Science Bulletin

Springer

Developing the plate tectonics from oceanic subduction to continental collision

ZHENG YongFei[1†], YE Kai[2] & ZHANG LiFei[3]

[1] CAS Key Laboratory of Crust-Mantle Materials and Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China;
[2] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China;
[3] MOE Key Laboratory of Orogenic Belt and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China

The studies of continental deep subduction and ultrahigh-pressure metamorphism have not only promoted the development of solid earth science in China, but also provided an excellent opportunity to advance the plate tectonics theory. In view of the nature of subducted crust, two types of subduction and collision have been respectively recognized in nature. On one hand, the crustal subduction occurs due to underflow of either oceanic crust (Pacific type) or continental crust (Alpine type). On the other hand, the continental collision proceeds by arc-continent collision (Himalaya-Tibet type) or continent-continent collision (Dabie-Sulu type). The key issues in the future study of continental dynamics are the chemical changes and differential exhumation in continental deep subduction zones, and the temporal-spatial transition from oceanic subduction to continental subduction.

crustal subduction, continental collision, ultrahigh-pressure metamorphism, continental dynamics

One of the most provocative findings in the earth sciences during the past three decades is the recognition and confirmation of coesite and diamond in metamorphic supracrustal rocks from more than twenty continental subduction/collision zones[1,2]. Such metamorphic minerals as coesite and diamond have been viewed as index minerals for the process that host mineral assemblages underwent ultrahigh-pressure (UHP) metamorphism at continental lithospheric mantle depths in excess of at least 80 km[3]. The findings of UHP metamorphic rocks in continental subduction/collision zones have brought a revolution of plate tectonics, because no subduction of the low-density continental crust to mantle depths was expected in the traditional model of plate tectonics[4,5]. However, in view of the increasing numbers of occurrences of UHP terranes, it is probably useful to ask what is special for their formation? Is deep subduction of supracrustal rocks actually a common condition during continental subduction/collision? Or is only the tectonic regime required for their exhumation unusual?

These new findings are exciting to earth scientists and thus their implications are far-reaching to continental dynamics. The range of metamorphic pressures at crustal depths has been dramatically expanded to mantle depths, numerically from >80 km[6,7] to >120 km[8,9], possibly into mantle depths of 200 to 350 km[10,11]. Special tectonic processes are expected to exhume the UHP rocks from the mantle depths to the crustal levels. The isotope geochronology and geochemistry of UHP rocks present wonders that have given us new insights into deep earth processes[12−14]. Although the interpretation of the subduction and exhumation processes has been a

Received June 17, 2009; accepted June 18, 2009
doi: 10.1007/s11434-009-0464-0
†Corresponding author (email: yfzheng@ustc.edu.cn)
Supported by the Chinese Academy of Sciences (Grant No. kzcx2-yw-131) and Ministry of Science and Technology of China (Grant No. 2009CB825000)

Citation: Zheng Y F, Ye K, Zhang L F. Developing the plate tectonics from oceanic subduction to continental collision. Chinese Sci Bull, 2009, 54: 2549−2555, doi: 10.1007/s11434-009-0464-0

challenge to earth scientists, it brings us new insights into geodynamic processes in collision zones. It also enables us to decipher the origin of heterogeneity in the upper mantle, and the nature and diversity of mantle-derived magmas. On one hand, these new discoveries and scientific insights are rooted in the study of mineralogy and petrology[15,16]. On the other hand, prominent progresses have been also made by dynamic interpretations of isotope geochronological and geochemical data on UHP metamorphic rocks[13,14].

At the very beginning, a group of Chinese scientists were involved in the revolution of plate tectonics since the finding of coesite and diamond in terrigenous UHP rocks. They have made seminal contributions in the past two decades to understanding of geodynamic processes from the subduction of oceanic crust to the collision of continental crust. The Chinese Continental Scientific Drilling (CCSD) project has been accomplished between 2001—2005 at Donghai in the Sulu UHP terrane, providing an advantageous and rare chance for collecting UHP rock samples continuously from its main hole (MH) as deep as 5158 m. A great deal of studies have demonstrated that continental and oceanic crust was subducted to continental lithospheric mantle depths, resulting in the formation of UHP metamorphic rocks. This not only provides us with an opportunity to develop the traditional theory of plate tectonics, but also is a challenge to the study of solid earth science. It has been realized recently that sufficient attention must be paid to processes of the subduction and exhumation of continental and oceanic crust, focusing not only on intracrustal detachment decoupling and differential exhumation but also on intraslab fluid flow and chemical changes. Although there are significant differences in the tectonic setting of forming and outcropping the UHP metamorphic rocks between different orogens, both fluid action and crustal exhumation in deep subduction zones are the key subject of various studies in the near future. Such studies are expected to answer the following questions: (1) How were the UHP metamorphic rocks exhumed from mantle depths to shallow crust? (2) How did the dehydration and melting of HP/UHP metamorphic minerals in deep subduction zones dictate the formation and evolution of metamorphic fluids/melts? (3) What are the differences in fluid flow and chemical differentiation during the subduction and exhumation of continental and oceanic crust? (4) How did the fluid/melt action in deep subduction zones influence the differentiation of elements and isotopes as well as their metasomatism to contacting slabs?

The Ministry of Science and Technology of China has lunched a new national basic research program of China (973) entitled “Chemical changes and differential exhumation of deeply subducted continental crust” since 2009 to further decipher the mystery of continental subduction zones. Both continental and oceanic subduction zones have been taken into account with the aim to provide insights into fluid action and crustal exhumation in collisional orogens. Thus, chemical differentiation and detachment decoupling in deep subduction zones have been the major point in doing so. An integration of geological and geochemical studies has being devoted to both continental- and oceanic-type UHP metamorphic terranes that discontinuously crop out along about 5000 km length of orogens from east to west in central China. The results have being used to see through the protolith nature and tectonic affinity of deeply subducted crust, to reconstruct the structure and composition of typical UHP metamorphic zones, to decipher the difference and transition between the subduction and exhumation of oceanic and continental crust, and to provide insights into the fluid action and geodynamic effects of deep subduction zones. In order to find multiply lines of observational evidence of fundamental operators for deep subduction and exhumation of continental crust, the project is focused on the following key issues: (1) the differential exhumation of multi-slabs and triggering mechanism; (2) the nature of deeply subducted crust and its effects on fluid action and element transport; (3) the influence of deeply subducted crust on the adjacent lithosphere and upper mantle; and (4) the temporal-spatial transformation and dynamic linkage from oceanic subduction to continental collision.

This thematic issue brings three papers together to summarize updated results of tectonic, petrological, geochronological and geochemical studies involving issues from oceanic subduction to continental collision in China[17−19]. Along with a thematic issue for UHP metamorphism and crustal deep subduction in 2008[20−22] and sporadic papers published in 2008 and 2009[23−28], great progress has been made by Chinese earth scientists to the geodynamics of both oceanic and continental subduction zones. This set of twelve papers not only provides overviews on well-studied UHP metamorphic terranes from Dabie-Sulu to Western Tianshan to Tibet in China, but also covers a variety of specific topics and methods used in understanding and interpreting rocks from UHP terranes. Thus, it can serve as an introduction to the study of HP and UHP metamorphic rocks in both the continental subduction zones of eastern China and the oceanic subduction zones of western China. Furthermore, it may throw light on the geodynamics of crustal deep subduction and continental collision in general. Therefore, it is valuable to any scientist with an interest in the origin and evolution of the continental lithospheric crust and mantle and will appeal especially to those doing research in tectonics, geodynamics, and petrology of continental subduction zones.

Shortly after the recognition of plate-tectonics, the famous Wilson cycle was proposed to describe the creation and demise of ocean basins in the following four stages: (1) rifting of a continent; (2) continental drift, sea-floor spreading and formation of ocean basins; (3) subduction of oceanic lithosphere and progressive closure of ocean basins; and (4) continent-continent collision and final closure of an ocean basin. After a half of century efforts in developing the plate tectonics theory, it has been realized that the formation and evolution of continental crust can be outlined in the following six stages: (1) subduction of oceanic crust, island arc magmatism and growth of juvenile crust; (2) arc-arc collision and formation of continental nuclei; (3) arc-continent collision, crustal reworking and continental accretion; (4) continent-(arc)-continent collision, continental subduction and supercontinental assembly; (5) rifting of the orogenic continental lithosphere and supercontinental breakup; and (6) continental drift, seafloor spreading and renewed subduction. A change in plate convergence rate or plate motion direction may lead to differences in the nature and extent of crustal reworking (metamorphism and magmatism) between oceanic and continental subduction zones. The juvenile crust can commonly grow from island arc magmatism during subduction of the oceanic plate beneath the oceanic plate, but there is only reworking of continental lithosphere during subduction of the oceanic plate beneath the continental plate. In addition, the juvenile arc crust is not part of the continental crust until it is accreted to the continental margin.

With the development of plate tectonics, significant differences have been recognized in subduction-zone metamorphism, which shows contrasting geological occurrences, mineral assemblages, and physicochemical conditions of peak metamorphism. These are categorized into Pacific and Alpine types of subduction zones in view of the nature of subducted crust[29]. The Pacific type in oceanic subduction zones is mainly characterized by the occurrence of low-T/HP blueschist- and eclogite-facies metamorphic rocks in association with ophiolites, whereas the Alpine type in continental subduction zones is principally characterized by the occurrence of mid-T/UHP eclogite-facies metamorphic rocks. Plates subduct at relatively low geothermal gradients and carry mafic and felsic lithologies to depths of 30—120 km or more, producing HP Pacific type and UHP Alpine type metamorphic terranes, respectively. Typically, the Pacific-type subduction is associated with underflow of thousands of kms of oceanic lithosphere, resulting in syn-subduction magmatism as arc volcanics and thus growth of juvenile mafic crust above basaltic crust-capped oceanic plates. In contrast, the Alpine type subduction involves the possible closure of backarc basins, arc-continent and continent-arc-continent collision, finally leading to subduction of continental crust without syn-subduction magmatism and juvenile crustal growth above granitic crust-capped continental plates. Thus, the Alpine-type collision reworks preexisting terranes, resulting in reworking of preexisting crust rather than growth of juvenile crust.

Although the two types of plate convergence can be distinguished from tectonic observations, there are a number of transitions between them. Thus, continental collision zones are further classified into two types also in view of the nature of subducted crust. One is the Himalaya-Tibet type that starts from the Alpine type arc-continent collision with contemporaneous metamorphism and magmatism (Figure 1(a)). Ultimately, it evolves into continent-arc-continent collision orogens (Figure 1(b)), with or without HP to UHP metamorphism. This leads to broad intercontinental orogens with reworking of juvenile crust[30,31]. The other is the Dabie-Sulu type in which the subduction of one granitic crust-capped continental plate beneath the other continental plate to bring about UHP metamorphism during continent-continent collision (Figure 2(a)), with no juvenile arc between the collided continents. This results in narrow intercontinental orogens and reworking of relatively ancient crust[13]. Because of the buoyancy of felsic continental crust at continental lithospheric mantle depths, exhumation of deeply subducted continental crust is hypothesized to follow slab breakoff that occurs

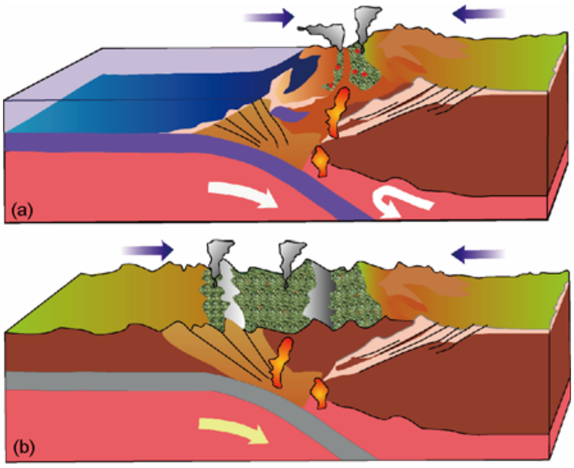

Figure 1 Schematic diagram for the Himalaya-Tibet type of continental collision orogens. (a) The Alpine-type arc-continent collision with contemporaneous metamorphism and magmatism; (b) continent-arc-continent collision with HP to UHP metamorphism.

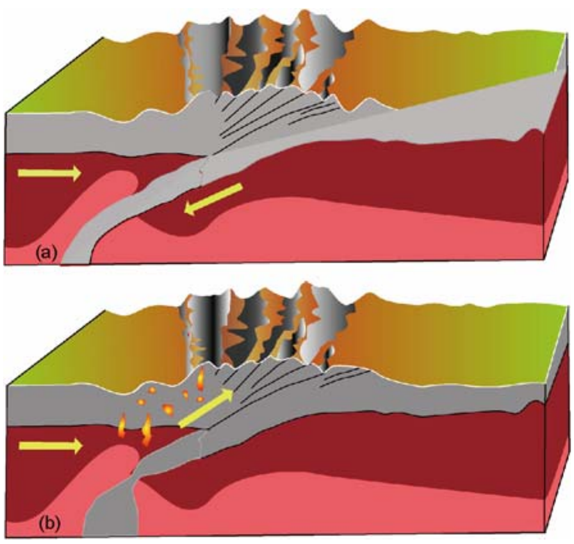

Figure 2 Schematic diagram for the Dabie-Sulu type of continental collision orogens. (a) The continent-continent collision due to subduction of granitic crust-capped continental plate beneath the other continental plate, with no juvenile arc between them; (b) exhumation of deeply subducted continental crust due to slab breakoff at the transition between the continental and oceanic lithospheres.

at the transition zone between the continental and oceanic lithospheres (Figure 2(b)), commonly accompanied by syn-exhumation dehydration melting.

The exhumation processes of UHP metamorphic terranes can be divided into two stages: (1) the syn-collisional extension phase, in which slices of low-T/UHP metamorphic rocks preferentially travel upward along subducting channels either by buoyancy-driven upward flow or by tectonic extrusion, and (2) the post-collisional extension phase, which is related to stretching of the orogenic continental lithosphere and exhumation of metamorphic core complexes upon tectonic collapse. Nevertheless, there is a significant difference in the exhumation rate of UHP terranes between the two types of collision. Fast exhumation (>20 mm/yr) commonly took place in the Himalaya-Tibet type, whereas slow exhumation (<10 mm/yr) generally occurred in the Dabie-Sulu type[13]. Although there are abundant occurrences of post-collisional magmatic rocks in the two types of collision orogens, their magmatic sources differ from each other in radiogenic isotope compositions. While remelting of juvenile crust is evident in the Himalaya-Tibet type, anatexis of relatively ancient crust prevails in the Dabie-Sulu type. In either case, granitic rocks are only really abundant in the orogens of thick continental crust. Nevertheless, primary sites of net continental crustal growth during plate convergence are arc-continent collision zones developed from the Pacific type subduction, rather than continent-continent collision zones evolved from the Alpine type subduction.

Several lines of prominent advance in the chemical geodynamics of continental collision and UHP metamorphism have been made from both surface outcropped and subsurface CCSD-MH core samples in the Dabie-Sulu orogenic belt[12–16,21,32–34]. This has been greatly benefited from the creative studies of modern petrology that integrates the traditional petrology with analyses of in-situ geochemistry. This principally involves combined applications of various advanced techniques that link the optical observations of BSE, SEM, TEM and so on to the in-situ analyses of EMP, LA-RAMAN, LA-ICPMS, LA-MC-ICPMS, SIMS and so on, with spatial resolution on variable scales from a few to hundreds micrometers. The progress in zirconology has been a typical example of resolving the geochronology of metamorphic rocks[35–37]. It combines the external morphology and internal structure of zircons with their microdomain trace elements, U-Th-Pb and Lu-Hf isotopes. This enables us to identify and distinguish the different origins of zircons on the microscale of tens of micrometers. Thus, many of the problems that cannot be solved by the conventional methods have been resolved by the new methodology. For instance, the origin of metamorphic zircons is a key to interpretation of their U-Pb ages because different types of metamorphic growth and recrystallization are responsible for different records of tectonic events during subduction-zone metamorphism. For this reason, it has to identify the metamorphic growth from aqueous fluids, hydrous melts or supercritical fluids, and the metamorphic recrystallization by solid-state transformation, replacement alteration or dissolution reprecipitation[14,38]. Therefore, microanalyses of elements and isotopes in the minerals of HP and UHP metamorphic rocks enable to decipher the quantitative relationships between the element transport and the fluid/melt action during the subduction and exhumation of crustal rocks.

Innovation of observations and interpretations from UHP metamorphic terranes has been a key to the understanding of continental subduction-zone processes. It is based on this point that the continental dynamics is developed into tectonic processes from the subduction and exhumation of continental crust to the tectonic collapse of collisional orogens[20], with an attempt to advance the intracontinental orogenesis into the plate tectonics theory. In addition, the physico-chemical controlling of geochemical reactions is evident in subduction zones[12]. While the thermodynamic difference leads to spontaneous chemical changes toward the equilibrium with the minimum free energy, the kinetic factor prevents the reactions toward the equilibrium at a limited duration. Competition between the two physico-chemical parameters determines the final status of the reactions recorded in HP/UHP mineral assemblages. As a result, metamorphic minerals in the lithology of different compositions and positions are not necessary to have the same degree of thermodynamic and kinetic responses to *P-T* changes during subduction-zone metamorphism. The principles of competition between thermodynamics and kinetics were used to account for preservation of meteoric oxygen isotope signature in UHP metamorphic minerals after their journey at mantle depths (i.e. the icecream-frying model)[12]. With respect to metamorphic geothermobarometers, resetting of element and isotope partitions between coexisting minerals is thermodynamically inevitable due to significant *P-T* changes in UHP metamorphic rocks during exhumation. Kinetically, however, either the preservation of primary equilibrium or the achievement of retrograde reequilibration depends on fluid availability and retrogression duration under the changed *P-T* conditions. Metastable occurrences of some eclogite-facies minerals (e.g., omphacite and phengite) in amphibolite-facies overprinted rocks also depend on the availability of aqueous fluid[14] and the duration of retrograde metamorphism at the different *P-T* conditions[13]. The same principle is also applicable to occurrences of dehydration melting in UHP metamorphic rocks during their exhumation in the UHP-HP regime[19,39,40].

By taking UHP metamorphic rocks and associated assemblages as the natural laboratory, earth scientists are in a position to understand continental subduction-zone metamorphism and its inherent geodynamics. As a consequence, there are basically twelve aspects of intriguing questions under consideration[20]. These are: (1) spatial distribution of the UHP metamorphic rocks, (2) timing of the UHP metamorphism, (3) timescale of the UHP metamorphism, (4) the protolith nature of deeply subducted crust, (5) subduction erosion and crustal detachment during continental collision, (6) the possible depths of continental subduction, (7) fluid activity in the continental deep-subduction zone, (8) partial melting during continental collision, (9) element mobility in continental deep-subduction zone, (10) recycling of subducted continental crust, (11) geodynamic mechanism of postcollisional magmatism, and (12) lithospheric architecture of collision orogen. Although the deep subduction of oceanic and continental crust occurs in both arc-continent and continent-continent collision orogens, the exhumation of mafic UHP rocks is probably enclosed by felsic UHP rocks due to their buoyant property. As a consequence, UHP terranes are dominated by massive felsic UHP rocks, with very sporadic occurrences of mafic UHP rocks as lenses, puddings and rarely km-scale blocks. Because of high water concentrations in their constituent minerals, however, the felsic UHP rocks are susceptible to retrograde metamorphism during the exhumation. This rarely leaves the mineralogical records of UHP metamorphism. In contrast, the mafic UHP rocks are relatively resistant to retrogression. Thus, earth scientists have paid much more attention to mafic eclogites than to felsic gneisses.

Although the above twelve aspects have been generalized from the Dabie-Sulu case study, it has many advantages in general. It provides geodynamic insights from a well-constrained geological setting, and enables the evaluation of lateral and vertical variations in the continental collision zone. The presence of different *P-T-t* paths for different metamorphic units permits us to retrieve the bulk processes of subduction and exhumation during the continental collision. It also serves as a reference frame for the comparison with other settings of continental collision elsewhere in the world. In fact, our understanding of geodynamic processes during the subduction and exhumation of continental crust has been greatly improved from the comprehensive study of various records in the Dabie-Sulu UHP metamorphic rocks. Some of the most promising research directions now lie in high integration of field observations, experimental analyses and theoretical models in given UHP terranes. As soon as the twelve aspects can be assessed both in individual cases and in general sense, the results would certainly advance our understanding of geodynamic processes from the oceanic subduction to the continental collision regardless of which continental collision zones are dealt with. This also places the reference framework to study the geodynamics of continental subduction-zone processes.

1 Chopin C. Ultrahigh-pressure metamorphism; tracing continental crust into the mantle. Earth Planet Sci Lett, 2003, 212: 1—14[doi]
2 Ernst W G, Liou J G. High- and ultrahigh-pressure metamorphism: Past results and future prospects. Am Mineral, 2008, 93: 1771—1786[doi]
3 Zheng Y-F. Mineralogical evidence for continental deep subduction. Chinese Sci Bull, 2003, 48: 952—954
4 Carswell D A, Compagnoni R. Ultra-high Pressure Metamorphism. Eur Mineral Union Notes Mineral, 2003, 5: 1—508[doi]
5 Liou J G, Tsujimori T, Zhang R Y, et al. Global UHP metamorphism and continent subduction/collision: the Himalayan model. Intern Geol Rev, 2004, 46: 1—27
6 Chopin C. Coesite and pure pyrope in high-grade blueschists of the western Alps: a first record and some consequence. Contrib Mineral Petrol, 1984, 86: 107—118[doi]
7 Smith D C. Coesite in clinopyroxene in the Caledonides and its implications for geodynamics. Nature, 1984, 310: 641—644[doi]
8 Sobolev N V, Shatsky V S. Diamond inclusions in garnets from metamorphic rocks; a new environment of diamond formation. Nature, 1990, 343: 742—746[doi]
9 Xu S T, Okay A I, Ji S Y, et al. Diamond from the Dabie Shan metamorphic rocks and its implication for tectonic setting. Science, 1992, 256: 80—82[doi]
10 Ye K, Cong B L, Ye D N. The possible subduction of continental material to depths greater than 200 km. Nature, 2000, 407: 734—736
11 Liu L, Zhang J F, Green II H W, et al. Evidence of former stishovite in metamorphosed sediments, implying subduction to >350 km. Earth Planet Sci Lett, 2007, 263: 180—191
12 Zheng Y-F, Fu B, Gong B, et al. Stable isotope geochemistry of ultrahigh pressure metamorphic rocks from the Dabie-Sulu Orogen in China: implications for geodynamics and fluid regime. Earth Sci Rev, 2003, 62: 105—161[doi]
13 Zheng Y-F, Chen R-X, Zhao Z-F. Chemical geodynamics of continental subduction-zone metamorphism: Insights from studies of the Chinese Continental Scientific Drilling (CCSD) core samples. Tectonophysics, 2009, doi:10.1016/j.tecto.2008.09.014[doi]
14 Zheng Y-F. Fluid regime in continental subduction zones: petrological insights from ultrahigh-pressure metamorphic rocks. J Geol Soc, 2009, 166: 763—782[doi]
15 Liou J G, Ernst W G, Zhang RY, et al. Ultrahigh-pressure minerals and metamorphic terranes – The view from China. J Asian Earth Sci, 2009, 35: 199—231[doi]
16 Zhang R Y, Liou J G, Ernst W G. The Dabie-Sulu continental collision zone: A comprehensive review. Gondwana Res, 2009, 16: 1—26[doi]
17 Zhang K J, Tang X C. Eclogites in the interior of the Tibetan Plateau and their geodynamic implications. Chinese Sci Bull, 2009, 54: 2556—2567
18 Wu Y B. Multistage evolution of continental collision orogen: a case study for western Dabie orogen. Chinese Sci Bull, 2009, 54: 2568—2579
19 Zeng L S, Liang F H, Asimow P, et al. Partial melting of deeply subducted continental crust and the formation of quartzo-feldspathic polyphase inclusions in the Sulu UHP eclogites. Chinese Sci Bull, 2009, 54: 2580—2594
20 Zheng Y-F. A perspective view on ultrahigh-pressure metamorphism and continental collision in the Dabie-Sulu orogenic belt. Chinese Sci Bull, 2008, 53: 3081—3104
21 Liu Y C, Li S G. Detachment within subducted continental crust and multi-slice successive exhumation of ultrahigh-pressure metamorphic rocks: Evidence from the Dabie-Sulu orogenic belt. Chinese Sci Bull, 2008, 53: 3105—3119
22 Zhang L F, Lü Z, Zhang G B, et al. The geological characteristics of oceanic-type UHP metamorphic belts and their tectonic implications: Case studies from Southwest Tianshan and North Qaidam in NW China. Chinese Sci Bull, 2008, 53: 3120—3130
23 Chen Z Y, Li Q L. Zr-in-rutile thermometry in eclogite at Jinheqiao in the Dabie orogen and its geochemical implications. Chinese Sci Bull, 2008, 53: 768—776
24 Niu H C, Zhang H X, Shan Q, et al. Discovery of super-silicic and super-titanic garnets in garnet-pyroxenite in Zhaheba and its geological significance. Chinese Sci Bull, 2008, 53: 2186—2191
25 Wei C J, Zhang Y H. Phase transition in the subducted oceanic lithosphere and generation of the subduction zone magma. Chinese Sci Bull, 2008, 53: 3603—3614
26 Zhang J X, Meng F C, Li J P, et al. Coesite in eclogite from the North Qaidam Mountains and its implications. Chinese Sci Bull, 2009, 54: 1105—1110
27 Liu L, Yang J X, Zhang J F, et al. Exsolution microstructures in ultrahigh-pressure rocks: Progress, controversies and challenges. Chinese Sci Bull, 2009, 54: 1983—1995
28 Liu Q, Jin Z M, Zhang J F. An experimental study of dehydration melting of phengite-bearing eclogite at 1.5—3.0 GPa. Chinese Sci Bull, 2009, 54: 2090—2100
29 Ernst W G. Alpine and Pacific styles of Phanerozoic mountain building: subduction-zone petrogenesis of continental crust. Terra Nova, 2005, 17: 165—188[doi]
30 Zheng Y-F, Wu Y-B, Gong B, et al. Tectonic driving of Neoproterozoic glaciations: Evidence from extreme oxygen isotope signature of meteoric water in granite. Earth Planet Sci Lett, 2007, 256:

196－210[doi]
31 Zheng Y-F, Wu R-X, Wu Y-B, et al. Rift melting of juvenile arc-derived crust: geochemical evidence from Neoproterozoic volcanic and granitic rocks in the Jiangnan Orogen, South China. Precambriam Res, 2008, 163: 351－383[doi]
32 Zhang Z M, Shen K, Sun W D, et al. Fluids in deeply subducted continental crust: petrology, mineral chemistry and fluid inclusion of UHP metamorphic veins from the Sulu orogen, eastern China. Geochim Cosmochim Acta, 2008, 72: 3200－3228[doi]
33 Xu Z Q, Yang W C, Ji S C, et al. Deep root of a continent-continent collision belt: Evidence from the Chinese Continental Scientific Drilling (CCSD) deep borehole in the Sulu ultrahigh-pressure (HP–UHP) metamorphic terrane, China. Tectonophysics, 2009, doi:10.1016/j.tecto.2009.02.029[doi]
34 Ye K, Song Y R, Chen Y et al. Multistage metamorphism of orogenic garnet-lherzolite from Zhimafang, Sulu UHP terrane, E. China: Implications for mantle wedge convection during progressive oceanic and continental subduction. Lithos, 2009, 109: 155－175[doi]
35 Wu Y-B, Zheng Y-F, Zhao Z-F et al. U-Pb, Hf and O isotope evidence for two episodes of fluid-assisted zircon growth in marble-hosted eclogites from the Dabie orogen. Geochim Cosmochim Acta, 2006, 70: 3743－3761[doi]
36 Liu D Y, Jian P, Kröner A et al. Dating of prograde metamorphic events deciphered from episodic zircon growth in rocks of the Dabie-Sulu UHP complex, China. Earth Planet Sci Lett, 2006, 250: 650－666[doi]
37 Liu F L, Gerdes A, Zeng L S, et al. SHRIMP U-Pb dating, trace element and Lu-Hf isotope system of coesite-bearing zircon from amphibolite in SW Sulu UHP terrane, eastern China. Geochim Cosmochim Acta, 2008, 72: 2973－3000[doi]
38 Xia Q-X, Zheng Y-F, Yuan H L et al. Lu-Hf and U-Th-Pb isotope distinction between metamorphic growth and recrystallization of zircon from eclogite-facies metagranite in the Dabie orogen. Lithos, 2009, doi:10.1016/j.lithos.2009.04.015[doi]
39 Xia Q-X, Zheng Y-F, Zhou L G. Dehydration and melting during continental collision: constraints from element and isotope geochemistry of low-T/UHP granitic gneiss in the Dabie orogen. Chem Geol, 2008, 247: 36－65[doi]
40 Zhao Z-F, Zheng Y-F, Chen R-X et al. Element mobility in mafic and felsic ultrahigh-pressure metamorphic rocks during continental collision. Geochim Cosmochim Acta, 2007, 71: 5244－5266[doi]