Mesozoic tectonics in the Eastern Block of the North China Craton: Implications for subduction of the Pacific Plate beneath the Eurasian Plate

Sanzhong Li[a*] Timothy M. Kusky[a, b] Guochun Zhao[c] Wu Fuyuan[d] Jiangzhong Liu[e] Min Sun[c] and Wang Lu[a]

[a]*Department of Marine Geology, Ocean University of China, 266003, Qingdao, China*
[b]*Department of Earth and Atmospheric Sciences, St Louis University, 3507 Laclede Avenue, St Louis, MO 63103, USA*
[c]*Department of Earth Sciences, The University of Hong Kong , Hong Kong, China*
[d] *Institute of Geology and Geophysics , Chinese Academy of Sciences , Beijing, 100029, China*
[e]*National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, China*

[*]Address for corresponding author: No. 5, Yushan Road, Qingdao, Shandong Province, China
Department of Marine Geology, Ocean University of China, 266003, Qingdao, China
Tel: 86-532-82031971(office)
E-Mail: Sanzhong@mail.ouc.edu.cn

Abstract

The Jiao-Liao massif is an important part of the Eastern Block of the North China Craton located on the hanging wall of the north-dipping Dabie-Sulu suture zone. Several important tectonic models for the tectonic evolution of the eastern Asia rely on critical information from the Jiao-Liao massif. This paper combines new SHRIMP U-Pb zircon ages of the Dandong Granite in the southern Liaoning Province, China, with extensive field data in the eastern North China Craton, including the Bohai Bay Basin. Combined with other recent SHRIMP dating, we use this information to summarize the Mesozoic tectonic reactivation and evolutionary processes of the Jiao-Liao massif of the Eastern Block of the North China Craton.

In this study we identify a ~160 Ma episode of partial melting of Paleoproterozoic plutons in the Jiao-Liao massif. CL and BSE imagery reveal circa 167-157 Ma magmatic euhedral single zircons and magmatic zircon rims surrounding ca. 2100 Ma cores in the Dandong Granites near the Liaonan Neoarchaean terrane. This partial melting is most likely derived from in-situ remelting of ancient lower continental material, mostly North China Craton. The Dandong plutons are aligned in a NE direction and are extensively deformed by subhorizontal ductile thrust-related shearing and subsequent NNE-trending folding. Here, we show that for the Dandong area, the first deformation occurred between 195 and 193 Ma, based on K-Ar and $^{40}Ar/^{39}Ar$ ages of muscovites from the E-W trending shear zones on the Liaodong Peninsula. Based on the field relationships between the plutons and structural fabrics, a range from 153 to 145 Ma is defined as the duration of the second deformation in the Dandong Granites. The NNE strike-slip faulting, i.e. the third deformation, is constrained between 135 Ma to 95 Ma. This deduced result is most similar to a range from the $^{40}Ar/^{39}Ar$ age of 128-132 Ma of initial sinistral strike-slip faulting of the Tan-Lu fault in the Anhui province to a biotite cooling age of 100 ± 2.3 Ma of the Yilan-Yitong segment of the Tan-Lu fault in the Jilin province. These faults are transtensive and controlled the formation of pull-apart basins. However, during the third deformation, some metamorphic core complexes in eastern China formed in the overlapping area between the large-scale sinistral faults.

Our SHRIMP data also indicate that the Liaodong basement and Early Mesozoic magmatism are exactly similar to the Jiaodong basement and Mesozoic magmatism. Therefore, the Early Mesozoic evolution in the Liaodong area, similar to that in the Jiaodong area, is also related closely to the Sulu Orogen in the Early Mesozoic and to the Pacific subduction in the entire Mesozoic.

1. Introduction

The North China Craton has had a long tectonic history with major tectonothermal events in the early Archean, late Archean, NeoProterozoic, Mesozoic, and Cenozoic (see review by Kusky et al., this volume; Zhai, ----; Zhao et al., 1999, 2000, 2001a, 2001b, 2002; Kusky and Li, 2003). The Jiao-Liao massif (Fig. 1) is an important part of the Eastern Block of the North China Craton located on the hanging wall of the north-dipping Dabie-Sulu suture zone (Li, 1994; Yang et al., 2002). Many researchers have attempted to determine whether or not the stable Precambrian block has experienced intensive reworking during collision of the North and South China cratons and formation of the Dabie-Sulu orogen.. Although several important tectonic models about tectonic evolution of northeast Asia have been proposed in the last decade, and some are closely related to the Jiao-Liao massif (Yin and Nie, 1993; 1996; Faure et al., 2001; Yang et al., 2002), none

systematically describe the responses of the stable Precambrian Eastern Block of the North China Craton to Mesozoic tectonic processes. Yin and Nie (1993) suggested an indentation model and that the north boundary of the Sulu orogen is the Wulian-Yantai fault, north of which (typically in the hanging wall of the Liaonan detachment fault), Triassic thrust faults and folds are extensively developed. However, more recently Faure et al. (2001) proposed a thin-skinned extensional model in which the north boundary of the Sulu orogen is moved to the Bohai strait or further to the north, and the Jiaobei massif, i.e. the southern Jiao-Liao massif, is an equivalent of the basement of South China Plate. On the contrary, Hong (1989) and Yang et al. (2002) proposed a thin-skinned thrust tectonic model. These debates lead us to discuss the Mesozoic tectonics of the Eastern Block of the North China Craton. The geological responses of tectonics and magmatism in the Liaodong Peninsula to the Early Mesozoic collision between the North China Plate and the South China Plate, and the subduction of the Pacific Plate beneath the Eurasian Plate, have to-date received very little attention in this region. Thus, we concentrate our discussion on Mesozoic tectonics in the Liaodong peninsula.

An important reason to choose this research area is that there are widespread Triassic to Cretaceous granitoids and multiphase, well-preserved Mesozoic deformation events including thrusting, extension, and strike-slip faulting, such as along the Tan-Lu fault system. Another reason is that this area is a link between the Mesozoic Pacific tectonic domain, the Paleozoic-Mesozoic Central Asia tectonic domain, and the Paleozoic-Mesozoic Qinling-Dabie tectonic domain. The third reason is it is a key site for understanding the UHPM processes or to justify the pre-existing models that were proposed by geologists and based mainly on UHP-HP geology and/or Paleomagnetic data, geochronology, and isotopic geochemistry. The fourth reason is that the Hefei Basin covers the hanging wall of the Dabie Orogen, whereas the Jiao-Liao massif preserves excellent outcrops of the hanging wall of the Sulu Orogen and is a prime site to study the response to Mesozoic orogeny.

This paper uses our results of SHRIMP U-Pb zircon dating of Mesozoic tectonic processes in the Southern Liaoning Province, China. The structural analysis together with our extensive field data in the eastern North China Craton, our work in the oilfields of the Bohai Bay Basin and recent other SHRIMP dating (Luo et al., 1999; 2001; Miao et al., 1997; 1998; Wang et al., 1998), allow us to establish Mesozoic tectonic evolutionary processes of the Eastern Block of the North China Craton.

2. Regional geological setting

The Jiao-Liao massif is located in the northeast part (Zhang et al., 1988; Li et al., 1998) of the Eastern Block in the North China Craton (Fig. 1, Zhao et al., 1999; 2002). It is bounded by the Central Asia tectonic belt to the north (Fig.1), and the Sulu Triassic Orogen and the Gyeonggi Archaean Massif to the south (Li et al., 2001a; 2001b). It composed the Paleoproterozoic rocks in the central, the Paleo- to Neo-Archaean basement in the north (Song et al., 1996) and the south, and widely outcropping Mesozoic granitoids and Sinian, Paleozoic and Mesozoic strata (Fig. 1).

In the range of the Paleoproterozoic rocks of the Liaodong peninsula, north of the study area (Fig. 2), some Paleoproterozoic granitoids from 2400 to 2100 Ma are widely scattered (Chen et al., 2001; Li et al., 1997a, Li and Yang, 1997b; Lu et al., 2004). The Paleoproterozoic Liaohe Group is mainly composed of meta-volcanosedimentary rocks, inhomogeneously metamorphosed by

widespread lower greenschist-upper amphibolite facies and local granulite facies (Li et al., 1998). The structural fabric of the Paleoproterozoic terrane composed of those rocks is generally E-W striking.

Some deformed Sinian to Paleozoic strata are mainly distributed north and southwest of the Paleoproterozoic terrane. Mesozoic granitoids crop out with a NE trend and crosscut the Paleoproterozoic rock series and the folds in the Sinian to Paleozoic strata. In the field, many NE-NNE-trending brittle faults offset the Mesozoic plutons and controlled some Early Cretaceous pull-apart basins widely seen in the Liaodong Peninsula, Korean Peninsula and Jiaodong Peninsula. Lower Cretaceous strata filled in the pull-apart basins, consisting mainly of andesite, dacite and rhyolite of 127 Ma to 95 Ma in the lower section (SBGMR, 1991), and the coal series in the upper section.

No Triassic plutons are reported from the Jiaodong Peninsula. However, many Triassic plutons have been discovered in the Liaodong Peninsula and the southern Jilin Province. For example, the Xiangmo tonalite pluton in the Tonghua of Jilin Province is 229.8 Ma (Chen, 1994). The Dongqin and Yangmulin, Renao, Liangbin and Dahuanggou plutons in the southern Jilin Province has U-Pb ages of 206.7 Ma and 230.7 Ma, Rb-Sr ages of 239.9 Ma, 234.7 Ma and 242 Ma, respectively (Sui, 1995). The Tongjiapu tonalite in the Xiuyan County of Liaoning Province has a biotite K-Ar age of 215.3 Ma. A large pluton of alkaline granite of U-Pb ages of 237 to 223 Ma was discovered in the Saima Town of Liaoning Province (Fig. 2; Chen, 1994). In the southern Liaodong Peninsula, the Shuangta pluton has a Rb-Sr age of 224 Ma and the part of the Yinmawanshan pluton recorded a Rb-Sr age of 198 ±19 Ma (Yu et al., 2002). Both plutons were deformed by an intensive and subhorizontal ductile shearing event that did not affect the Zhaofang pluton (a Rb-Sr age of 140 Ma) or the Guangminshan pluton (a U-Pb age of 139.2 Ma) (Yu et al., 2002). The Xiaoheishan pluton was emplaced at about 180 Ma ago (Wu Fuyuan, unpublished data). The granites in the Liaonan area are mainly middle Mesozoic, especially latest Early Cretaceous (Chen, 1994), including the Gudaoling（LA-ICPMS 122±2 Ma）, Yinmawanshan （LA-ICPMS 122±6 Ma）, Qianshan（LA-ICPMS 126±2 Ma）, and Zhaotun (gneiss, LA-ICPMS 128±5Ma）, etc. (Wu et al., 2005), some of which, however, were previously regarded as Triassic plutons.

Therefore, some geologists believed that a gap of plutonism ranges from ca. 160 to ca.100 Ma in Korea (Kim, 1996; Chough et al., 2000) and from ca. 180 to ca.140 Ma in the eastern North China Craton. However, in the Jiaodong Peninsula, the emplacement age of the Linglong granite based on SHRIMP U-Pb dating has recently been shown to range from 150 to 160 Ma (Miao et al., 1998; Luo et al., 1999) and that of the Guojiadian pluton from156 Ma and 164 Ma (Chen, 1994). In the eastern Yanshan Orogen, i.e., west of the study area, the Yiwulushan granite is also dated at 164±9.5 Ma(U-Pb SHRIMP of single zircon), with some inherited zircons yielding ages of 1991± 16Ma (Luo et al., 1999). These plutons are intensely deformed.

In the Liaodong Peninsula, four Mesozoic stages of regional deformation are identified based on the cross-cutting relationships in the field. The first deformation is characterized by NWW or E-W trending thrust faults and folds in the west (Chen, 1998) and north of the study area (Fig.2)

and the area near Bohai Bay. In the Triassic plutons, some ductile shear zones are preserved (Chen et al., 1999; Yu et al., 2002). The second deformation is characterized by NNE trending, subhorizontal ductile shear zones and folds in the lower and middle Jurassic and the 150-160 Ma plutons. Then, the second deformation zone affects the 120-130 Ma granites (Fig. 3). At Shuiyuandi Town of the southern Liaodong Peninsula, some sheath folds (Fig. 6) related to this thrusting event, with strong mineral lineations (see A in Fig. 2) and quartz C-axes (see B, C, D and E in Fig. 2) indicate top-to-the-northwest motion. The third deformation is characterized by NNE trending sinistral strike-slip and transtensive faults, metamorphic core complexes (Liu et al., 2005; Fig.1), and rifting responsible for the related Cretaceous pull-apart basins from the Apation Age （about 125 Ma to 112 Ma） of Early Cretaceous to Late Cretaceous. The fourth Mesozoic deformation is characterized by open E-W trending folds in the Liaodong Peninsula (Hong, 1989). From Late Cretaceous to Early Tertiary, E-W trending thrusting and folding developed intensively in Korea (Kim, 1996) and weakly in the Jiaodong and Liaodong Peninsulas. These deformation movements are based on several disconformities without precise dating.

3. Zircon U-Pb geochronology and Timing of Deformation of The Dandong Granites

In this section we use SHRIMP U-Pb zircon data for mica monzogranitic gneiss in the Dandong Granites of the Liaodong Peninsula to provide constraints on some of the tectonic questions posed above. The significance of the results are discussed in the following section.

3.1 SHRIMP results of the Dandong Granite

Samples LJ023 and LJ030 are mica monzogranitic gneiss, collected from Jianzhan Village of Hushan Town, about 15 km north of Dandong City and Dongjiapu Village, about 20 km southeast of Xiuyan County, respectively (Fig.2). They have a coarse granular texture and mylonitic, gneissic structure. The SHRIMP data of samples LJ023 have been published by Li et al. (2004). Here we provide data of sample LJ030 for testing the dating result of the Dandong Granite (Table 1).

Zircons from sample LJ023 are euhedral, elongate prismatic, semi-transparent to transparent. Length/width ratio of most zircons is up to 10:1, but be mainly 5:1. Maximum and minimum zircon sizes are about 0.4×0.05 mm^2 and about 0.1×0.05 mm^2 in sample LJ023, respectively. CL and BSE images reveal that zircon is characterized by well-developed oscillatory zoning, and the zoned core is often truncated by the zoned rim (Fig. 3).

SHRIMP analytical results of zircon in sample LJ023 show that only one zircon grain (spot 30.1) on the concordia line gives a $^{207}Pb/^{206}Pb$ age of 686 ± 19Ma, the geological significance of which remains unknown. Seven concordant points on the zoned cores of different zircon grains yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 2105 ± 21Ma (Li et al., 2004), interpreted as the crystallization age of major inherited zircons. All SHRIMP data in the oscillatory zoned rims and zoned cores give a younger age of 157.4 ± 5.7 Ma (Li et al., 2004). This age is interpreted to represent the crystallization age of this pluton and an intensive, crustal reworking event in this area including the Liaonan Archaean complex reworked in the Mesozoic. This interpretation is supported by the CL images of the rims reflecting the magmatic zircon in spite of typical Th/U

ratios. Therefore the ages are emplacement ages for the granite. The reworked crust is mainly composed of Paleoproterozoic plutons, revealed by the peak in the population of inherited cores of Paleoproterozoic zircons.

Zircons within sample LJ030 are complicated. Four morphological types of zircon within sample LJ030 are recognized in this study. Maximum zircon size is about 0.5×0.125 mm^2 and minimum zircon size is about 0.075×0.025 mm^2 in sample LJ030.

SHRIMP data in the type (Ⅰ) zircons of this sample are scattered from 638 Ma to 127 Ma (Table 2). Especially 638±20Ma, 465.6±8.7Ma, 206.2±3.8Ma and 166.9±3.0 Ma are on or near the concordia line (Fig. 4). Real geological significances of these ages remain unknown now. However, the last two are probably related to the regional crustal reworking of this area including the Mesozoic reworking of the Archean Liaonan complex (Yin and Nie, 1996). It is noted that spot 23.2 as the rim of type (Ⅳ) gives the same age of magmatic zircon as that of type (Ⅰ) (Fig.3). This leads us to strongly suggest that the last two zircon ages represented magmatic events or remelting of the crust respectively. The others are perhaps affected by later disturbance of the intensive Late Yanshanian tectonism and subsequent lead loss.

Two grains of type (Ⅲ) zircons on the concordia line give a $^{207}Pb/^{206}Pb$ age of 2167±11 Ma to 2174±11Ma, the geological significance of which is regarded as the crystallization age of previous Paleoproterozoic plutons because their Th/U ratios and those of type (Ⅰ) fall into two distinct age groups (Table 1).

Nine concordant points on the zoned cores of different type (Ⅱ) zircon grains yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1863±15 Ma, interpreted as another magmatic event reflected by inherited zircons of this pluton (Table 1, Fig. 4).

Type (Ⅳ) zircons in this sample are only found in the core of type (Ⅰ) and they had a zoning style evidently different from peripheral zones of zircon under CL and BSE images. By SHRIMP dating, their ages are respectively 2534±45 Ma in the spot 23.1 and 2440.2±5.1 Ma in the spot 27.1. They are interpreted as thenages of different inherited zircons from Archean and Paleoproterozoic basement (Table 1).

3.2 Precise timing of deformation of the Dandong Granite

Wang et al. (2000a and 2000b) identifys the precise timing of the first deformation event to be between 195 to 193 Ma (Jurassic) using K-Ar and $^{40}Ar/^{39}Ar$ ages of muscovites in the E-W trending shear zones of Liaodong Peninsula. The earliest deformation event is Early Mesozoic (Triassic) in the Yanshan Orogen (Chen, 1998).

Further studies integrating observations of plutonic and deformation features with geochronology should be completed in the granitoids around Dandong City, especially about the Sanguliu (LA-ICPMS, 125±3 Ma) and Wulongbei plutons (LA-ICPMS, 125±4 Ma) (Wu et al., 2005) (Fig. 5). The new zircon ages of these plutons range from 125-131 Ma (Wu et al., 2005). In this paper we have dated (SHRIMP) two plutons north and south of the Sanguliu and Wulongbei plutons previously-identified as Paleoproterozoic as Mesozoic, recognizing widespread granites of the Dandong suite, , yielding interesting Mesozoic ages of 157 to 158 Ma. Wu Fuyuan also obtained circa 165 Ma age of emplacement for the so-called Pre-Sinian, deformed granites near the Wulong Gold mine (Wu et al., 2005).

In the Dandong area, the circa 157-158 Ma Dandong plutons are reworked intensively into orthogneisses by subhorizontal ductile thrust-related shearing and subsequent NE trending folding.

After these deformations, the Sanguliu and Wulongbei plutons crosscut the solid-state foliation and the folds in the Dandong orthogneisses. Thus, we deduce that the second deformation time of the Dandong granites, is loosely defined between after 157 Ma and before 130 Ma. The Linglong pluton and Guojialing pluton in the Jiaodong peninsula are also involved in this episode of deformation, and have yielded a muscovite $^{40}Ar/^{39}Ar$ age of 134.26 ± 0.34 Ma in the Zhaoyuan-Pingdu shear zone (Lin et al.,2000). The Zhaoyuan-Pingdu shear zone crosscuts the earlier foliation in the Linglong and Guojialing plutons, so we conclude that the precise timing of the second deformation is between 153 Ma to 145 Ma. To the west of this area, this deformation is compared with the Chengde-Xinlong thrust dated at 161-148 Ma and the Sihetang nappe of 143 Ma (from Davis et al., 1996; Ratschbacher et al., 2000).

From the Dongjiagou shear zone in the Dalian area (Fig. 2), Yin and Nie (1996) obtained muscovite $^{40}Ar/^{39}Ar$ ages ranging from 153.1±1.9 Ma to 144.6±1.1 Ma. However, some $^{40}Ar/^{39}Ar$ ages of deformation in the Dongjiagou shear zone and the Liaonan Archaean basement are 109-114 Ma, from biotite, K-feldspar and muscovite (and less hornblende) obtained recently by Wu Fuyuan (unpublished data). These ages are identical to some ages from 112.9+0.4 Ma to 110.4+0.4 Ma (Yin and Nie, 1996) in the western detachment fault of the Liaonan metamorphic core complex. Garnet-bearing granites were emplaced along the Dongjiagou shear zone at about 120 Ma, and most of these contain circa 1900 Ma inherited zircons (Wu Fuyuan, unpublished data). This relationship is similar to that of the Guojialing pluton in the Jiaodong Peninsula (Luo et al., 1999).

Based on the field relationship between the plutons and deformation foliations mentioned above, a range from 153 to 145 Ma is most possible to the duration of the second deformation event

The ages of the Yinmawanshan, Qingshan, and Zhaotun plutons fall between 120-130 Ma (zircon U-Pb), being indistinguishable within age errors (Wu et al., 2005). According to the ages and the field investigation, the outer part of the Yinmawanshan pluton crystallized during deformation, whereas the inner part is post-deformational. The circa 120-145 Ma marginal deformation in the plutons is different from the second penetrative deformation in the Dandong plutons. Therefore, it is a later deformation controlled by the sinistral strike-slip faulting and later extension, combined with emplacement-related structure. The sinistral strike-slip faults controlled and sometimes crosscut the 120-130 Ma plutons, and controlled the Early Cretaceous basins with ages between 127 Ma to 95 Ma. So the NNE strike-slip faulting, i.e. the third deformation, is constrained in a range from 135 Ma to 95 Ma. This result is the same as the range from the $^{40}Ar/^{39}Ar$ age of 128-132 Ma of initial sinistral strike-slip faulting of the Tan-Lu fault in the Anhui Province to a biotite cooling age of 100±2.3 Ma of the Yilan-Yitong segment of the Tan-Lu fault in the Jilin Province (Zhu et al., 2001). These faults are transtensive.

Several metamorphic core complexes in eastern China formed in the overlapping areas between large-scale sinistral strike-slip faults uring the third deformation (Fig. 1). For example, the Yunmeng Shan metamorphic core complex formed at 128-119 Ma (Davis et al., 1996; Darby et al., submitted). The Yiwulushan metamorphic core complex formed at 126-124 Ma (based on SHRIMP; Ma et al., 1999; 2000; Luo et al., 2001). The Wugongshan core complex formed at 145-123 Ma using biotite $^{40}Ar/^{39}Ar$ method (Faure et al., 1996). The Xingzi core complex formed at 127±2 Ma using U-Pb single zircon (Li et al., 2001). The North Orthogneiss Unit in the eastern Dabie Orogen formed at 140-120 Ma using $^{40}Ar/^{39}Ar$ method (Ratschbacher et al., 2000). The last

ductile deformation age of the Dongjiagou shear zone is 114-109 Ma from the geochronological constraint on the hornblende, muscovite and biotite in the shear zones (Wu Fuyuan, unpublished data). It can be regarded as the formation age of the Liaonan metamorphic core complex (Yin and Nie, 1996).

4. Discussion and tectonic implication

4.1 Relation between the Sulu orogen and the Jiao-Liao massif

Many workers have debated whether or not rocks of the North China Craton, resting on the hangingwall of the Dabie-Sulu orogen, were significantly re-worked by convergent and collisional processes in the Triassic. We report some important discoveries using SHRIMP U-Pb dating showing that there are many Indosinian inherited zircons from 200 to 250 Ma in the circa 150-160 Ma Linglong granite from the Jiaodong Peninsula (Miao et al., 1997; 1998; Luo et al., 1999). This event recorded in the inherited Triassic magmatic zircons is the same as that in the Dabie-Sulu orogen (Miao et al., 1998). This suggests that the Linglong granite originated from crustal felsic rocks and some inherited zircons came from the granites related to the collision between the North and South China Plates (Miao et al., 1997; Wang et al., 1998; Luo et al., 1999). The Linglong, Luanjiahe and Guojialing suites were derived from this early Mesozoic basement between 165 and 125 Ma, and were probably emplaced as post-collisional granitoids (Wang et al., 1998). 3446±2Ma ～ 3114±4Ma ages of inherited zircons in the Linglong granite and many Paleoproterozoic inherited zircons in the Guojialing pluton (Luo et al., 1999) were also discovered. This indicates that the crust in the Jiaodong Peninsula is as old as the Anshan Archean basement in the Liaodong Peninsula, and the crust belongs to the North China Craton (Song et al., 1996) rather than the Yangtze Craton as recently proposed by Faure et al. (2001).

To the north, there are fewer inherited Triassic magmatic zircons from samples LJ030 and LJ023 than from those in the Linglong granite. There are three possibilities for the origin of two spots of inherited zircons of 640 and 690 Ma from the samples LJ030 (Table 1) and Lj023 (Data in Li et al., 2004) in the Liaodong peninsula. . The first is that they come from the Yangtze Craton or the Sulu Orogen. However, Hacker et al. (2000) pointed out the effects of the Dabie-Sulu orogen did not reach that far. The 1000 to 800 Ma Jinning event (Li, 1999) is an important marker to distinguish the North China Craton and the Yangtze Craton. Therefore, the first possibility is excluded here. The second possibility is closely associated with 680~650 Ma rifting event (Qiao, 2001) recorded in the diabase sills of 585-723 Ma (K-Ar method, Pan et al. 2000) in the Eastern Block. Chen et al. (2002) reported some zircon U-Pb ages of magmatism and metamorphism of 658 to 540 Ma from the Huadian area. Therefore, the third possibility is that the two inherited magmatic zircons came from the Huadian area of the Jilin province, on the north margin of the Eastern Block. The last two models are very different from the characteristics of the Yangtze Craton and possible to fit the situation of the studied area. Although their precise geological implication is still unknown, our data imply that the Liaodong basement and Mesozoic magmatism are mostly similar to the Jiaodong basement and Mesozoic magmatism. Although the Mesozoic evolution of the Liaodong area is similar to that of the Jiaodong area, it is also related closely to the Sulu Orogen, but the Jiao-Liao massif is not a part of the Yangtze Craton. Some Paleoproterozoic inherited zircons in sample LJ023 and Lj030 reflected that the remelting is in-situ. Therefore, the second possibility best-matches the geological data.

4.2 Setting of remelting of continental crust and tectonic regime transition of the eastern China

Even though the timing of Mesozoic deformation in the eastern North China Craton not well constrained, the N-S shortening is generally regarded to be responsible for a series of E-W trending fold and thrust belts in the Early Mesozoic, especially the Late Triassic (Yin and Nie, 1996; Chen et al., 1999; Chen, 1998; Yang et al., 2002). NNE trending Basin-and-Range-style extensional tectonic features are commonly considered to have formed in the Late Mesozoic. However, it is uncertain how and when the transition from compression to extension occurred.

Research of the transition of tectonic regime has been mainly focused on the Yinshan-Yanshan Orogen (Zhao et al., 1994). Strong east-west striking folds and thrusts that formed from Early-Mid Triassic to Jurassic, and locally the Cretaceous, characterize both the south and north margins of the North China craton, especially the Yinshan-Yanshan orogen (Davis et al., 1998; 2001 and 2002) and the Qinling Orogen (Zhang et al., 1996; Meng et al., 2000). The time of this thrusting in the Yunmeng Shan, east of the Yinshan-Yanshan Orogen, is defined at 142-143 Ma (Davis et al., 1996) possibly related to final east-to-west closure of the Mongol-Okhotsk Ocean (Ziegler et al., 1996; Yin and Nie, 1996; Halim et al., 1998) or the formation of the Solonker suture (Xiao et al., 2003). The Early Cretaceous in the north part of the Sichuan Basin is involved in the foreland deformation of the Qinling Orogen related to the collision between the North and South China cratons (Meng et al., 2000; Zhang, 1996). According to Paleomagnetic data, the Siberia craton, the North and South China cratons were unified at ca. 130 Ma (Gilder et al., 1997) or from 130 to 110 Ma (Nozaka and Liu, 2002). According to this S-N-directed collision model of three continental blocks, we should find more E-W trending structures of ~130 Ma.

However, in eastern China, many NE-NNE trending thrusts and folds are reported to have formed from Late Jurassic to Early Cretaceous. Here, in conjunction with Mesozoic magmatism and deformation in the Dabie orogen, the Western Shandong block, the Yinshan-Yanshan orogen, and those in the Jiao-Liao massif, many of the same events reflect the same dynamics and processes of the compression/extension transition in north and northeastern China. The NE or NNE trending faults and folds from northwest to southeast in the North China craton include the top up to the SSE of the Sihetang fold nappe in the Yunmeng Shan of Beijing (Davis et al., 1996), the top up to the NNW of the Chengde thrust in Hebei province, the top up to the NW of thrusts between Luanping City and Jiangchang City of the western Liaoning province, the top up to the NW or W of the Liaonan thrusts and folds in the southern Liaoning province, the Candong thrust and the Lankao-Liaocheng thrust (buried by the Tertiary strata of the Bohai Basin), the Wujing thrust and the NE-trending open folds in the western Shandong province, the top up to the NW or W of Xuhuai thin-skinned thrusts, and so on (Fig. 1). This N-S compressive geodynamic setting could not cause the NE-NNE trending structural features. What geodynamic forces led to this change from the E-W trending deformation to the NE-NNE trending deformation?

Engebretson et al.（1985）proposed that the subduction directions of the Paleo-Pacific Plate along the margin of the eastern Eurasia changed during this interval-for example, NW directed convergencefrom 180-145 Ma, NNW from 145-85 Ma and west after 85 Ma. However, the related deformation, magmatism and metamorphism in the North China area are less understood, and must be analyzed in the context of possibly related to these changing subduction dynamics. We

here assess the structural and geochronological evidence and consider whether or not the the NNE-NE trending deformation features are related to NW-NNW-directed subduction of the Paleo-Pacific plate during 180-145 Ma or 145-85 Ma.

In this study we identify a ~160 Ma remelting of Paleoproterozoic plutons in the Jiao-Liao massif. In sample LJ023 and sample LJ030 near the Liaonan Neoarchaean terrane and sample LJ037 in the north margin of the Paleoproterozoic terrane, some magmatic, euhedral single zircons and magmatic zircon rims around ca. 2100 Ma cores are recognized, and the remelting event is constrained between 167-157 Ma. However, this remeling event was not previously recognized in N-NE China. But in SE China, Du (1998) briefly mentioned this magmatic event of 165~137 Ma. What induced the remelting of the crust from northeastern China to southeastern China? That this remelted belt parallels the Pacific subduction zone is obviously not a consequence of intracontinental subduction (Zhang et al., 1996) in the Qinling-Dabie Orogen.

Four geodynamic models may resolve the Early Cretaceous remelting of the East Block of the North China craton. This remelting is most likely derived from remelting of ancient lower continental crust, mostly North China crust, lower crustal contamination of the Yangtze crust (Zhang et al., 2002), or subducted slabs of the Paleo-Pacific Plate (Engebreston et al., 1985), or a deep lithospheric wedge contaminated by crustal slabs related to the Mongol-Okhotsk ocean and/or the Paleo-Pacific ocean (Zhou et al., 2001). However, Gao et al. (1999), Hacker et al. (2000) and Rastchbacher et al. (2000) proposed that the subducted Dabie slab was delaminated at about 190 Ma and did not affect areas farther away than 20 kilometers north of the Dabie Orogen due to the steep angle of subduction. So the probability of the second model (Zhang et al., 2002) is less. The first model is also not acceptable because the geochemistry of Early Cretaceous calc-alkaline basalts and mafic dikes derived from enriched lithospheric mantle differs considerably from the Paleozoic and Cenozoic lithosphere of the Jiaodong Peninsula and the Western Shandong Block (Li, 2000; Zhou et al., 2001). Therefore, the setting of Early Cretaceous remelting in the Jiaodong Peninsula and the Western Shandong Block (Yang et al., 2005) is most possible to be like that of Early Cretaceous magmatism in SE China, which occurred in a dominantly extensional environment from 140 to 90 Ma (Li, 2000). That is to say, the last two models are most reasonable. Ratschbacher et al. (2000) deduced that the change from transcurrent to head-on convergent Pacific subduction in the Late Jurassic and the resultant magmatism with its onset at ~145 Ma in eastern China may have caused the reheating of the Hong'an Block, thus facilitating crustal extension which is defined to be about 130-110 Ma in the Jiao-Liao Massif.

Although the four models mentioned above were not based on analysis of the remelting at circa 160 Ma, the Late Jurassic tectonic setting of compression related to the Paleo-Pacific subduction was obviously different from the Early Cretaceous extension. The belt of ~160 Ma plutons is aligned in the NE direction perpendicular to the Paleo-Pacific subduction direction, extends into the Central Asian Tectonic Zone to the north and the Yangtze Craton to the south, and shows evidence for NNE-trending thrusting. Thus, we deduce that this partial melting event is correlated to NW-directed subduction of the Paleo-Pacific Plate at 180-145 Ma (Engebretson et al., 1985; Du, 1998). Although far to west of the West Block of the North China Craton, the N-S trend of the Western Ordos fold-thrust belt may also suggest a link with Paleo-Pacific subduction along the eastern margin of Asia (Darby and Ritts, 2002). But it is more likely a synthetic effect of eastward extrusion (Liu, 1998) resulting from the N-S compression between the north and south margins of the North China Craton (Zhang et al., 1996; Davis et al., 1996) and synchronous block

faulting resulting from subduction of the Paleo-Pacific plate. Because both the Yinshan-Yanshan orogen north of the North China craton and the Qingling-Dabie orogen south of the North China Craton are synchronous with contraction from Early and Middle Jurassic to Late Jurassic, two E-W-striking strike-slip faults in the north and south margins of the North China Craton, respectively, cut across the fold-thrust belts.

On the other hand, the time of the collapse of the East China plateau in North China is also from 150 to 120 Ma, loosely constrained by the ages of the widespread adakites (Zhang et al., 2001; 2002; Davis, 2003). Plateau collapse probably accompamied the change in tectonic regime from compression to extension (Shao et al., 2001). Along the Taishan, Lushan and Yishan mountains in the western Shandong Province, the Western Shandong block was intruded by abundant intermediate to mafic plutons with K - Ar ages of 110 - 130 Ma (SBGMR, 1991) resulting in formation of NW-trending domino-type fault-bounded basins. The gabbro and pyroxenite formed from 130 to 115 Ma (based on $^{40}Ar/^{39}Ar$ ages, Lin et al., 1996) resulting from the reheating of the Western Shandong Block. In the Dabie orogen, the North Orthogneiss Unit suite was dated using the $^{40}Ar/^{39}Ar$ method on hornblende and biotite, yielding ages from 130 to 120 Ma (Ratschbacher et al., 2000).

However, Li (2000) proposed that the 140-100 Ma peak stage of coeval, intensive volcanism and magmatism may have been generated in response to Izanagi Plate subduction in southeastern China. Maruyama et al. (1997) suggested that the Paleo-Pacific Plate subducted at a fast velocity (greater than 200 mm/a) at a low angle during 145-85 Ma. Because the Eastern Eurasian continental margin extended from south to north at that time, NW-directed subduction of the Paleo-Pacific Plate means oblique subduction during 145-85 Ma. This oblique subduction process led the East Asian continental margin to be sheared intensively, with strain partitioned into zones of contractional strain and zones of strike-slip shearing (Maruyama et al., 1989). In this case, large-scale left-lateral faults formed and developed along the weak zone of the island arc and aided upward emplacement of magma and the formation of metamorphic core complexes. However, to the south of the study area, this change from compression to extension in the southeastern China is about 120-100 Ma, later than that in the northeastern China. This event resulted in thinning of crust and lithosphere, upwelling of athenosphere, and basaltic magma underplating in southeastern China (Liu et al, 1990; Xu et al., 1999; Shu et al., 2000b). In a similar scanario, Kusky et al (2003) and Bradley et al (2003) relate diachronous changes along the Pacific rim in Alaska to passage of a triple junction, and subduction of different plates before and after triple junction migration, with different convergence vectors before and after ridge subduction.

In summary, we propose in this study that a remelting event at circa160 Ma and a compressive deformation event fromt 153-145 Ma marked a change from Triassic compression to Early Cretaceous extension in the Liaodong Peninsula, and across North China. This remelting event is well correlated to NW-directed subduction of Paleo-Pacific Plate.

4.3 Implication for subduction of the Pacific Plate beneath the Eurasian Plate

The E-W trending deformation of 200-190 Ma in North China, especially in the Liaodong Peninsula (Chen et al., 1999; Wang et al., 2000a and 2000b), matches the collision of the North and South China Plates and 210-180 Ma subduction of the Farallon Plate interpreted by

Maruyama et al. (1997) based on geology and paleomagnetic data.

Mesozoic magmatism, especially from 145 to 90 Ma, related to the Pacific subduction is studied more in southeast China (e. g. Li, 2000), than northeast China (e. g. Lin et al., 1998), and the north margin of the North China Craton (e. g. Zhou et al., 2001). However, there is little understanding about the relation between subduction of the Pacific and Izanagi plates and Mesozoic magmatism among the above-mentioned three areas. Ratschbacher et al. (2000) summarized data from some Chinese metamorphic core complexes from Mongolia to southeastern China. They concluded that the tectonic setting of Early Cretaceous (especially 147 to 110 Ma) deformation is extension in eastern and northeastern China. Wang et al. (2002) proposed that two stages of volcanism occurred during this time. This is regarded to result from Pacific backarc extension, the S-N compression between the Mongol-Okhotsk and Bangong-Sanjiang Sutures and the related eastward tectonic escape of the North China Plate and the South China Plate. However, all the metamorphic core complexes mentioned above are aligned in a NNE direction parallel to the Pacific subduction zone. Thus, the mid-Cretaceous tectonic setting is dominated by Pacific subduction (Ratschbacher et al., 2000). Cretaceous magmatism in SE China also occurred in a dominant extensional environment, especially in continental back-arc and post-collision extension settings from 140 to 90 Ma according to A-type granitic and within-plate basaltic geochemistry (Li, 2000). Therefore, we suggest that the transition from compression to lithospheric extension occured over arange in age from 180 Ma to 145 Ma. The transition time was previously suggested to be between 120-90 Ma by Maruyama et al. (1997).

The remelting in the Jiao-Liao massif suggests that the monzogranites underwent intensive Mesozoic reworking. At 180-120 Ma, the continental margin in east China belonged to an Andean-type continental margin (Li, 2000; Li et al., 2001). Furthermore, our data and others of Li (2000) and Li et al. (2001) define that the time of NNE trending compressional deformation that is closely related to the Pacific subduction is from 160 to 145 Ma, supporting an extension time mainly from 145 to 100 Ma. During this time, east China was affected by coexisting wrench faulting, voluminous volcanism and extensional basin formation. During 100-90 Ma, another intense compressive deformation occurred along the continental margin of the western Pacific, especially in southwestern Japan, South Korea, southeastern China and Taiwan, and the western Philippines. This is suggested to be related to accretion and collision between the terranes on the oceanic plate and the continental margin of the Eurasian Plate（Charvet et al., 1985, 1999; Ichikawa et al., 1990). This process developed ophiolite mélanges, high-pressure blueschists, paried metamorphic belts, collision-type granites and ductile shear zones along the suture zone (Charvet et al., 1990; Shu et al., 2000b).

Acknowledgements

This study was funded by a China NSFC grant 40472098 and 40002015, KZCX1—07 of Chinese Academy of Science and Hong Kong RGC grant HKU7090/01P, and also supported by US NSF grant EAR-02-07886 awarded to T. Kusky. We thank other partners such as Master Hao Defeng, Dr. Luo Yan and Dr. Xia Xiaoping in the fieldworks. Prof. Michael Brown, Prof. Maruyama, Dr. Wang Tao and Prof. Moonsup Cho are thanked for sending some important papers. SHRIMP dating was supervised by Dr. Wan Yusheng, Dr. Song Biao and Prof. Liu Dunyi at the Beijing SHRIMP Center. They are also appreciated.

References

Bradley, D.C., Kusky, T.M., Haeussler, P., Rowley, D.C., Goldfarb, R., and Nelson, S., 2003, Geologic signature of early ridge subduction in the accretionary wedge, forearc basin, and magmatic arc of south-central Alaska, *in* Sisson, V.B., Roeske, S., and Pavlis, T.L.(eds.), Geology of a Transpressional Orogen Developed During a Ridge - Trench Interaction Along the North Pacific Margin, **Geological Society of America Special Paper 371**, pp. 19-50.

Charvet, J., Cluzel, D., Faure, M., et al., 1999. Some tectonic aspects of the pre-Jurassic accretionary evolution of East Asia. In: Metcalfe I, Ren J, Charvet, J, Hada, S,(Eds) , Gondwana dispersion and Asian accretion, A. A. Balkema/Rotterdam/brookfield, pp. 37-65.

Charvet, J., Faure, M., Caridrioit, M., et al., 1985. Some tectonic and tectonogenetic aspects of SW Japan: an Alpine-type orogen in an island-arc position. In: Nasu N et al (eds), Formation of Active Ocean Margin. Terra Scientific Pub. Co.,Tokyo, pp. 791-817.

Charvet, J., Faure, M., Xu, J. W., et al., 1990. La zone tectonique de Changle-Nanao,Chine du sud-est. C R Acad Sci Paris, t310, 2, 1271-1278.

Chen A., 1998. Geometric and kinematic evolution of basement-cored structures: intraplate orogenesis within the Yanshan Ogrogen, north China. Tectonophysics 292, 17-42.

Chen, R. D., Li, X. D., Yang, Y. J., Zhang, L. H., Shan, X. D., Zhang, F. S., 1999. Bedding decollement structure of the Early Indosinian Orogenic cycle in the south of Liaodong peninsula. Liaoning Geology 16(3), 161-169.

Chen, S. L., Huan, Y. Q., Bing, Z. B., 2001. Characteristics of Palaeoproterozoic intrusive rocks and continental dynamic evolution of tectono-magmatism in the eastern Liaoning. Liaoning Geology 18, 43-50 (in Chinese with English Abstract).

Chen, Y. J., Peng, Y. J., Lu, X. P., Liu, Y. W., 2002. Proterozoic tectonic slices along the northern margin of North China Plate. Journal of Jilin university (Earth Sciences Edition) 32(2), 134-139.

Chen, Y. Q., 1994. The outline of Regional Geology of China. Geological Publishing House, Beijing, China, pp. 1-474 (in Chinese with Eaglisn abstract).

Chough, S. K., Kwon, S.-T., Ree, J.-H., Choi, D. K., 2000. Tectonic and sedimentary evolution of the Korean peninsula: a review and new view. Earth-Science Reviews 52, 175-235.

Darby, B. J., Ritts, B. D., 2002. Mesozoic contractional deformation in the middle of the Asian tectonic collage: the intraplate Western Ordos fold-thrust belt, China. Earth and Planetary Science Letters 205, 13 –24.

Darby, B.J., Davis, G.A., Zhang, X.H., Wu, F.Y., Wilde, S., and Yang, J.H., The newly discovered Waziyu metamorphic core complex, Yiwulu Shan, Western Liaoning Province, North China, to be submitted to Earth Science Frontiers

Davis, G.A., 2003. The Yanshan Belt of North China: tectonics, adakitic magmatism, and crustal evolution. Earth Science Frontiers 10(4), 373-384.

Davis, G. A., Darby, B. J., Zheng, Y. D., Spell, T. L., 2002. Geometric and temporal evolution of an extensional detachment fault, Hohhot metamorphic core complex, Inner Mongolia, China. Geology 30(11), 1003-1006.

Davis, G. A., Wang, C., Zheng, Y., Zhang, J., Zhang, Ch., Gehrels, G. E., 1998. The enigmatic Yinshan fold-and-thrust belt of northern China: new views on its intraplate continental styles, Geology 26, 43-46.

Davis, G. A., Zheng, Y., Wang, C., Darby, B. J., Zhang, C., and Gehrels, G. E., 2001. Mesozoic tectonic evolution of the Yanshan fold and thrust belt, with emphasis on Hebei and Liaoning provinces, northern China. In: Hendrix, M.S., and Davis, G.A., eds., Paleozoic and Mesozoic tectonic evolution of central and eastern Asia: From continental assembly to intracontinental deformation. Geological Society of America Memoir 194, pp. 171-197.

Davis, G.A., Qian, X., Zheng, Y., Yu, H., Wang, C., Tong, H-M., Gehrels, G.E., Shafiquallah, M., and Fryxell, J.E., 1996. Mesozoic deformation and plutonism in the Yunmeng Shan: A Chinese metamorphic core complex north of Beijing, China, In: Yin, A., and Harrison, T.M., eds., The tectonic evolution of Asia.

Cambridge University Press, Cambridge, pp. 253–280.

Du G. Y.. Analysis of Granite Isotopic Geological Data and Periods of Magma- tectonic Action in Mesozoic in South China. Journal of East China Geological Institute, 1998, 21(2): 116-122 (in Chinese with Eaglisn abstract).

Engebretson, D. C., Cox, A. and Gordon, R. G., 1985. Relative motions between oceanic and continental plates in the Pacific basin. Geol. Soc. Am. Spec. Paper，pp. 1-59.

Faure, M., Lin, W., Breton, N. L., 2001. Where is the North China-South China block boundary in eastern China? Geology 29(2), 119-122.

Faure, M., Sun, Y., Shu, L. S., Monie, P., and Charvet, J., 1996. Extensional tectonics within a subduction-type orogen. The case study of the Wugongshan dome (Jiangxi Province, Southeastern China). Tectonophysics 263, 77-106.

Gao, S., Zhang, B. R., Jin, Z. M., Kern, H., 1999. Delamination of the lower crust of the Qinling-Dabie Orogenic Belt. Science in China 29(6), 532-541(in Chinese).

Gilder, S. A., and Courtillot, V., 1997. Timing of the North-South China collision from new middle to late Mesozoic paleomagnetic data from the North China Block. Journal of Geophysics Research 102, 17713-17727.

Hacker, B. R., Ratschbacher, L., Webb, L., McWilliams, M. O., Ireland, T., Calvert, A., Dong, S. W., Wenk, H. R., 2000. Exhumation of ultrahigh-pressure continental crust in east central China: late Triassic-early Jurassic tectonic unroofing. Journal of Geophysical Research 105(B6), 13339-13364.

Halim, N., Kravchinsky, V., Gilderm S., Cognem J. P., Alexyutinm M., Sorokinm A., Courtillotm V., Chenm Y., A 1998. Palaeomagnetic study from the Mongol-Okhotsk region: rotated Early Cretaceous volcanics and remagnetized Mesozoic sediments. Earth and Planetary Science Letters 159 (3-4), 133-145.

Hong, Z. M., 1989. Research progresses and implication of upper Precambrian in the Liaonan area. Liaoning Geology (1), 87-94 (in Chinese with Eaglisn abstract).

Ichikawa, K., Mizutani, S., Hara, I., et al., 1990. Pre-Cretaceous terrances of Japan. Publication of IGCP 224: Pre-Jurassic evolution of Eastern Asia. Osaka，pp. 1-413.

Kim, J. H., 1996. Mesozoic tectonics in Korea. Journal of Southeast Asian Earth Sciences 13(3-5), 251-265.

Kusky, T. M., Li, J. H., 2003. Paleoproterozoic tectonic evolution of the North China Craton. Journal of Asian Earth Sciences 22, 383-397.

Kusky, T.M., Bradley, D.C., Donley, D.T., Rowley, D., and Haeussler, P., 2003, Controls on intrusion of near-trench magmas of the Sanak-Baranof belt, Alaska, during Paleogene ridge subduction, and consequences for forearc evolution, *in* Sisson, V.B., Roeske, S., and Pavlis, T.L.(eds.), Geology of a Transpressional Orogen Developed During a Ridge - Trench Interaction Along the North Pacific Margin, Geological Society of America Special Paper 371, pp. 269-292.

Li, S. Z., Han, Z. Z., Liu, Y. J., Yang, Z. S., 2001a. Constrains of Geology and Geochemistry on Palaeoproterozoic Pre-orogenic deep processes in the Jiao-Liao Massif. Scientia Geological Sinica 36, 189-195.(in Chinese with English Abstract).

Li, S. Z., Han, Z. Z., Liu, Y. J., Yang, Z. S., Ma, R., 2001b. Continental Dynamics and Regional Metamorphism in the Liaohe Group. Geological Review 47, 9-18 (in Chinese with English Abstract).

Li, S. Z., Liu, Y. J., Yang, Z. S., Ma, R., 1998. Relations between deformation and metamorphic recystallization in metaperlite of Liaohe Group. Acta Petrologica Sinica 14(3), 352-366 (in Chinese with Eaglisn abstract)

Li, S. Z., Yang, Z. S., 1997b. Types and Genesis of Palaeoproterozoic Granites in the Jiao-Liao Massif. Northwest Geology 43(6), 21-27 (in Chinese with English Abstract).

Li, S. Z., Yang, Z. S., Liu, Y. J., Liu, J. L., 1997a. Emplacement Model of Palaeoproterozoic Early-Granite in the Jiao-Liao-Ji Area and Its Relation to Layered Gravitational Sliding Structure. Acta Petrologica Sinica 13, 189-202 (in Chinese with English Abstract).

Li, S. Z., Zhao, G. C., Sun, M., Wu, F. Y., Liu, J. Z., Hao, D. F., Han, Z. Z., Luo, Y., 2004. Mesozoic, not Paleoproterozoic SHRIMP U-Pb zircon ages of two Liaoji Granites, eastern block, North China craton. International Geology Review 46(2), 162-176.

Li, X. H., 1999. U-Pb zircon ages of granites from northern Guangxi and their tectonic significance. Geochimica 28(1), 1-9.

Li, X. H., 2000. Cretaceous magmatism and lithospheric extension in Southeast China. Journal of Asian Earth Sciences (18), 293-305.

Li, X. W., Zhou, X. M., Li, X. H., Xie, G. G., Li, J. H., 2001. Zircon U-Pb dating of pegmatite from Xingzimetamorphic core complex of Lushan Mountain and its geological implication. Earth Sciences 26(5), 491-495(in Chinese with Eaglisn abstract).

Li, Z.X., 1994. Collision between the North and South China Blocks - a crustal-detachment model for suturing in the region east of the Tanlu fault. Geology 22 (8), 739-742.

Lin, J. Q., Tang, D. J., Jin, Y., 1996. $^{40}Ar/^{39}Ar$ ages of Mesozoic igneous activities in western Shandong Province. Acta Petrologica et Minerologica 15(3), 213-222 (in Chinese with Eaglisn abstract).

Lin, Q., Ge, W. C., Sun, D. Y., Wu, F. Y., Chong, K. W., Kyung, D. M., Myung, S. J., Moon, W., Chi, S. K., Sung, H. Y., 1998. Tectonic significance of Mesozoic volcanic rocks in northeastern China. Scientia Geologica Sinica 33(2), 129-138 (in Chinese with Eaglish abstract).

Lin, W. W., Zhao, Y. M., Xu, J., 2000. Active properties of Zhaoyuan-Pingdu shear zone. Regional Geology of China, 19(1), 43-50 (in Chinese with Eaglisn abstract).

Liu, C. S., Zhu, J. G., Shen, W. Z., and Xu, S. J., 1990. Classification and meterial source of continental crust transformation series granitoids in South China. Acta Geological Sinica 3(3), 287-298 (in Chinese with Eaglisn abstract).

Liu, J. L., Liu, Y. J., Chen, H., Sha, D. M., and Wang, H. C., 1997. The inner zone of the Liaoji Paleorift: its early structural styles and structural evolution. Journal of Asian Earth Sciences 15(1), 19-31.

Liu, J.L., Davis, G.A., Lin, Z.Y., Wu, F.Y., 2005. the Liaonan metamorphic core complex, southeastern Liaoning Province, North China: a likely contributor to Cretaceous rotation of eastern Liaoning, Korea and contiguous areas. Tectonophysics 407: 65– 80.

Liu, S., 1998. The coupling mechanism of basin and orogen in the western Ordos basin and adjacent regions of China. J. Asian Earth Sci. 16, 369-383.

Lu, Y. F., 1997. Genesis characteristics of Mesozoic granitoid in south Liaoning (Zhuanghe-Dandong) and its relation with gold deposits. Liaoning Geology (4), 292-302 (in Chinese with Eaglisn abstract).

Lu, X.P., Wu, F.Y., Lin, J.Q., Sun, D.Y., Zhang, Y.B., Guo, C.L., 2004. Geochronological successions of the Early Precambrian granitic magmatism in Southern Liaodong peninsula and its constraints on tectonic evolution of the North China Craton. Scientia Geologica Sinica 39(3):123-138.

Luo, Z. K., Guang, K., Miao, L. C., Huang, J. Z., 1999. Ages and implication of inherited zircons in the granites of Zhaoyuan areas. Shandong Geology 3, 112-123 (in Chinese with Eaglisn abstract).

Luo, Z. K., Miao, L. C., Guan, K., Qiu, Y. S., Qiu, Y. M., McNoughlon, N. J., Groves, D. I., 2001. SHRIMP U-Pb zircon age of magmatic rock of Paishanlou Gold Mine district, Fuxi, Liaoning province, China. Geochemica 30(5), 483-490 (in Chinese with Eaglisn abstract).

Ma, Y. S., Cui, S. Q., Wu, G. G., Wu, Z. H., Zhu, D. G., Li, X., Feng, X. Y., 2000. Uplift history of the Yiwulushan Mountain in the west Liaoning Province. Acta Geoscienctia Sinica 21(3), 245-253.

Ma, Y. S., Cui, S. Q., Wu, G. G., Wu, Z. H., Zhu, D. G., Li, X., Feng, X. Y., 1999. The structural feature of metamorphic core complex in the Yiwulushan Mountains, the Western Liaoning Province. Acta Geosientia Sinica 20(4), 385-391.

Maruyama, S., Suzuki, Y., Kimura, G., and Terabayashi, M., 1997. Paleogeographic maps of the Japanese islands: plate tectonic synthesis from 750 Ma to the present. The Island Arc 6(1), 121-142.

Maruyama, S., Liou, J.G., Seno, T., 1989. Mesozoic and Cenozoic evolution of Asia. In: Ben-Avraham, Z.(ed.), The Evolution of the Pacific Ocean Margins, Oxford University Press, pp75－99.

Meng, Q. R., Zhang, G. W., 2000. Geologic framework and tectonic evolution of the Qinling orogen, central China. Tectonophysics 323 (3-4), 183-196.

Miao, L. C., Luo, Z. K., Guan, K. and Huang, J. Z., 1998. The Implication of the SHRIMP U- Pb Age in Zircon to the Petrogenesis of the Linglong Granite, East Shangdong Province. Acta Petrologica Sinica 14(2), 198-206 (in Chinese with Eaglisn abstract).

Miao, L. C., Luo, Z. K., Guan, K., and Huang, J. Z., 1997. Zircon Sensitive High Resolution Ion Microprobe(SHRIMP)study of granitoid intrusions in Zhaoye Gold Belt of Shandong Province and its implication. Science in China (Series D) 40(4), 361-369 (in Chinese).

Niu, S. Y., 1994. The Fuping and Zanghuang Uplifts in the Taihangshan Mountain are Mesozoic metamorphic core complexes. Geological Science and Technology Information 13(2), 10-12.

Nozaka, T., Liu, Y., 2002. Petrology of the Hegenshan ophiolite and its implication for the tectonic evolution of northern China. Earth and Planetary Science Letters 202, 89-104.

Pan, G. Q., Kong, Q. Y., Wu, J. Q., Liu, J. R., Zhang, Q. L., Zeng, J. H., Liu, D. Z., 2000. Geochemical feature of Neoproterozoic diabase sill in Xuzhou-Suzhoou area. Geological Journal of China Universities 6(1), 53-63 (in Chinese).

Qiao, X. F., 2002. Intraplate seismic belt and basin framework of Sino-Korean plate in Proterozoic. Earth Science Frontiers, 9(3), 141-149.

Ratschbacher, L., Hacker, B. R., Webb, L. E., McWilliam, M., Ireland, T., Dong, S., Calvert, A., Chateigner, D., Wenk, H. R., 2000. Exhumation of the ultrahigh-pressure continental crust in east central China: Cretaceous and Cenozoic unroofing and the Tan-Lu fault. Journal of Geophysical Research 105(B6), 13303-13338.

SBGMR (Shandong Bureau of Geology and Mineral Resources), 1991. Regional Geology of Shandong Province. Geological Publishing House, Beijing, China, pp. 1-526. In Chinese with English abstract.

Shao, J. A., Zhang, L. Q., Jia, W. and Wang, P. Y., 2001. Harkin metamorphic core complex in Inner Mongolia and its upwelling mechanism. Acta Petrologica Sinica 17(2), 283- 290.

Shu, L S., Wang, D. Z., Shen, W. Z., 2000a. Nd-Sr isotopic compositions of granitic rocks of Mesozoic metamorphic core complex in the Wugongshan area, Jiangxi Province. J. of Nanjing University (Natural Sciences) 36(3), 306-311(in Chinese).

Shu, L. S., Sun, Y., Wang, D. Z., 1998. Mesozoic extensional tectonics in the Wugongshan area, South China. Science in China (Series D) 41(6), 601-608 (in Chinese).

Shu, L. S., Yu, J. H., Wang, D. Z.. 2000b. Late Mesozoic granitic magmatism and metamorphism-ductile deformation in the Changle-Nanao fault zone, Fujian Province. Geological Journal of China Universities 6(3), 368-378 (in Chinese with English abstract).

Shu, L. W., An, J. Y.. 1994. Nappe structure in the coal basin of Wafangdian and prospecting of coal. Coal Technology of Northeast China (4), 52-57 (in Chinese with Eaglisn abstract).

Song, B., Nutman, A. P., Liu, D. Y., and Wu, J. S., 1996. 3800 to 2500 Ma crustal evolution in Anshan Area of Liaoning Province, northeastern China. Precambrian Research 78: 79-94.

Song, H. L., 1996. Characteristics of Fangshan metamorphic core complex, Beijing and a disscusion on its origin. Geosciences 10(2), 149-158.

Sui, Z. M., 1995. The genesis of Mesozoic granites in Jilin province and their tectonic setting. Jilin Geology, 14 (1), 15-22 (in Chinese with Eaglisn abstract).

Wang, L.G., Qiu, Y.M., McNaughton, N.J., Groves, D.I., Luo, Z.K., Huang, J.Z.,. Miao, L.C, Liu, Y.K., 1998. Constraints on crustal evolution and gold metallogeny in the Northwestern Jiaodong peninsula, China, from SHRIMP U–Pb zircon studies of granitoids. Ore Geology Reviews 13, 275-291.

Wang, Y. J., Fan, W. M., Guo, F., 2002. K-Ar dating of late Mesozoic volcanism and geochemistry of volcanic gravels in the North Huaiyang Belt, Dabie orogen: Constraints on the stratigraphic framework and exhumation of the northern Dabie orthogneiss complex. Chinese Science Bulletin. 47 (20), 1688-1695.

Wang, Z. X., Tang, Z. M., Yang, Z. Z., Yang, X. B., 2000b. Redetermination of the Meso-Cenozoic structural framework of Dalian area. Regional Geology of China 19(2), 120-126 (in Chinese with Eaglisn abstract).

Wang, Z.X., Tang, Z. M., Yang, Z. Z., Yang, X. B., 2000a. Ductile tectonic deformation of Mesozoic time in the Dalian area. Seismology and Geology 22(4), 379-386 (in Chinese with Eaglisn abstract).

Wu，F.Y., Lin, J.Q., Wilde, S.A., Zhang, X.O., Yang, J.H., 2005. Nature and significance of the Early Cretaceous giant igneous event in eastern China. Earth and Planetary Science Letters 233, 103-119.

Xiao, W.J., Windley, B.F., Hao, J., and Zhai, M.G., 2003. Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the central Asian orogenic belt. *Tectonics*, 22(6), 1069, doi: 10.1029/2002TC001484.

Xu, J. W., Zhou, G., Tong, W. X., Cui, K. R., Liu, Q., 1987. Formation and evolution of the Tancheng-Lujiang wrench fault system: a major shear system to the northwest of the Pacific Ocean. Tectonophysics 134, 273-310.

Xu, X. S., Zhou, X. M., Wang, D. Z., 1999. Crust-mantle interaction and the genesis of granite: A case study of coastal area of southeastern China. Geological Journal of China Universities 5(3), 241-250 (in Chinese).

Yan, S. X., 1994. The history of Meso-Neozoic crustal extension in western Shandong as viewed from a sedimentary Paleotectonic analysis of the basin. Regional Geology of China (1), 46-51.

Yang ,W. C., 2002. Geophysical profiling across the Sulu ultra-high-pressure metamorphic belt, eastern China. Tectonophysics (354), 277- 288.

Yang, J.H., Wu, F.Y., Chung, S.L., Wilde, S.A., Chu, M.F., Lo, C.H., Song, B., 2005. Petrogenesis of Early Cretaceous intrusions in the Sulu ultrahigh-pressure orogenic belt, east China and their relationship to lithospheric thinning. Chemical Geology 222, 200-231.

Yang, J. Z., Shen, Y. C., Liu, T. B., 2000. Gold mineralization association with Queshan metamorphic core complex. Geology and Geochemistry 28(1), 15-19.

Yang, T. N., Peng, Y., Wang, Z. X., Yang, Z. Z., and Wang, G. Z., 2002. Nearly S-N compressional deformation of sedimentary cover in the Lushun-Dalian area: intraplate deformation of overlying plate on continental deep-subduction of the Sulu area. Geological Bulletin of China 21(6), 308-314 (in Chinese with Eaglisn abstract).

Yang, Z. Z., Meng, Q. C., Tong, J., Han, X. P., 1996. The Liaonan metamorphic core complex. Liaoning Geology (4), 241-250.

Yin, A., and Nie, S. R., 1993. An indentation model for the north and south China collision and the development of the Tan-Lu and Honam fault systems, Eastern Asia. Tectonics 194, 131-151.

Yin, A., and Nie, S. R., 1996. A Phanerozoic palinspastic reconstruction of Chinaand its neighboring regions, in The Tectonic Evolution of Asia, edited by A. Yin and T. M. Harrison, Cambridge Univ. Press, New York, pp. 442-285.

Yin, G. S., Xie, G. G., 1996. Extensional structure and the Xingzi metamorphic core complex in the Lushan area, Jiangxi. Regional Geology of China (1), 17-26.

Yu, H. F., Dong, W. D., He, Z. Q., Hao, Y. L., 2002. Tectonic feature and continental dynamic background of the Jiaheshan ductile shear zone in the Zhuanghe area, southern Liaoning. Geological Bulletin of China 21(7), 392-396 (in Chinese with Eaglisn abstract).

Xiao, W.J.,, Windley, B.F., Hao, J., and Zhai, M.G., 2003, Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the central Asian orogenic belt, Tectonics 22, p. 1069.

Zhang Q. S., Yang, Z. S., 1988. Early crust and mineral deposits of Liaodong peninsula, China. Geological Publishing House, Beijing, pp. 218-450 (in Chinese with English Abstract).

Zhang, G. W., Meng, Q. R., Yu, Z. P., Sun, Y., Zhou, D. W., Guo, A. L., 1996. Orogenesis and dynamics of the Qinling orogen. Science in China (Series D) 30(3), 225-234 .

Zhang, H. F., Sun, M., 2002. Geochemistry of Mesozoic basalts and mafic dikes, southeastern North China craton, and tectonic implications. International Geology Review 44(4), 370-382.

Zhang, K. J., 1997. North and south China collision along the eastern and southern North China margins. Tectonophysics 270, 145-156.

Zhang, Q., Qian, Q., Wang, E. Q., Wang, Y., Zhao, T. P., Hao, J., Guo, G. J., 2001. An east China Plateau in the Mid-Late Yanshanian period: implication from adakites. Chinese Journal of Geology 36(2), 248-255 (in Chinese with English Abstract).

Zhang, Q., Wang, Y., Liu, W., Wang, Y. L., 2002. Adakite: its characteristics and implications. 21(7), 431-435 (in Chinese with Eaglisn abstract).

Zhao, G. C., 2001a. Palaeoproterozoic assembly of the North China Craton, Geological Magzine 138, 89-91.

Zhao, G. C., Cawood, P. A., Simon, A. W., Sun, M., Lu, L. Z., 2000. Metamorphism of basement rocks in the central zone of the North China Craton: implication for Palaeoproterozoic tectonic evolution. Precambrian Research 103, 55-88.

Zhao, G. C., Simon, A. W., Cawood, P. A., and Sun, M., 2002. SHRIMP U-Pb zircon ages of the Fuping Complex: implications for late Achean to Paleoproterozoic accretion and assembly of the North China Craton. American Journal of Science 302, 191-226.

Zhao, G. C., Wilde, S. A., Cawood, P. A., Lu, L. Z., 1999. Tectonothermal history of the basement rocks in the western zone of the North China Craton and its tectonic implications. Tectonophysics 310, 37-53.

Zhao, G. C., Wilde, S. A., Cawood, P. A., Sun, M., 2001b. Archean blocks and their boundaries in the North China Craton: lithological, geochemical, structural and P-T path constrains and tectonic evolution. Precambrian Research 107, 45-73.

Zhao, Y., Yang, Z. Y., Ma, X. H., 1994. Geotectonic transition from Paleo-Asian system and Paleo-Tethyan system to Paleo-Pacific active continental margin in eastern China. Acta Geoscientia Sinica 29(2): 105-118(in Chinese with Eaglisn abstract).

Zhou, X. H., Zhang, C. H., Yang, J. H., Chen, W. J., Sun, M., 2001. Sr-Nd-Pb isotope mapping of Late Mesozoic volcanic rocks across northern margin of North China Craton and implications of geodynamic processes. Geochimica 30(1), 10-23 (in Chinese with English abstract).

Zhu, G., Song, C. Z., Wang, D. X., Liu, G. S., Xu, J. W., 2001. Tectonic implication and $^{40}Ar/^{39}Ar$ geochronology of strike-slipping of Tanlu fault belt. Science in China, Series D 31(3), 250-256 (in Chinese).

Ziegler, P. A., van Wees, J. D., Cloetingh, S., 1998. Mechanical controls on collision-related compressional intraplate deformation. Tectonophysics 300 (1-4), 103-129.

Figures

Fig. 1. Tectonic division of Eastern China showing Mesozoic thrust faults and folds, and metamorphic core complexes. NCC-the North China Craton, WB-the Western Block, EB-the Eastern Block, TNCO-the Trans-North China Orogen, QL-DB-SL-the Qinling-Dabie-Sulu Orogen; SCC-the South China Craton; TC-the Tarim Craton. 1-the Yiwulushan metamorphic core complex (Ma et al., 1999 and 2000), 2-the Yumeng Shan metamorphic core complex (Davis et al., 1996), 3-the Fangshan metamorphic core complex (Song, 1996), 4-the Taihanshan metamorphic core

complex (Niu, 1994), 5-the Liaonan metamorphic core complex (the site of this study area, Yang et al., 1996; Chen et al., 1999), 6-the Queshan metamorphic core complex (Yang et al., 2000), 7-the Western Shandong extensional tectonics (Yan, 1994), 8-the North Orthogneiss Unit of the Dabie Orogen (Ratschbacher et al., 2000), 9-the Xingzi metamorphic core complex (Yin and Xie, 1996), 10-the Wugongshan metamorphic core complex (Shu et al., 2000a; Faure et al., 1996). BJ-Beijing, TCh-Tangcheng, SH-Shanghai, PR-Pyeongrang, SE-Seoul.

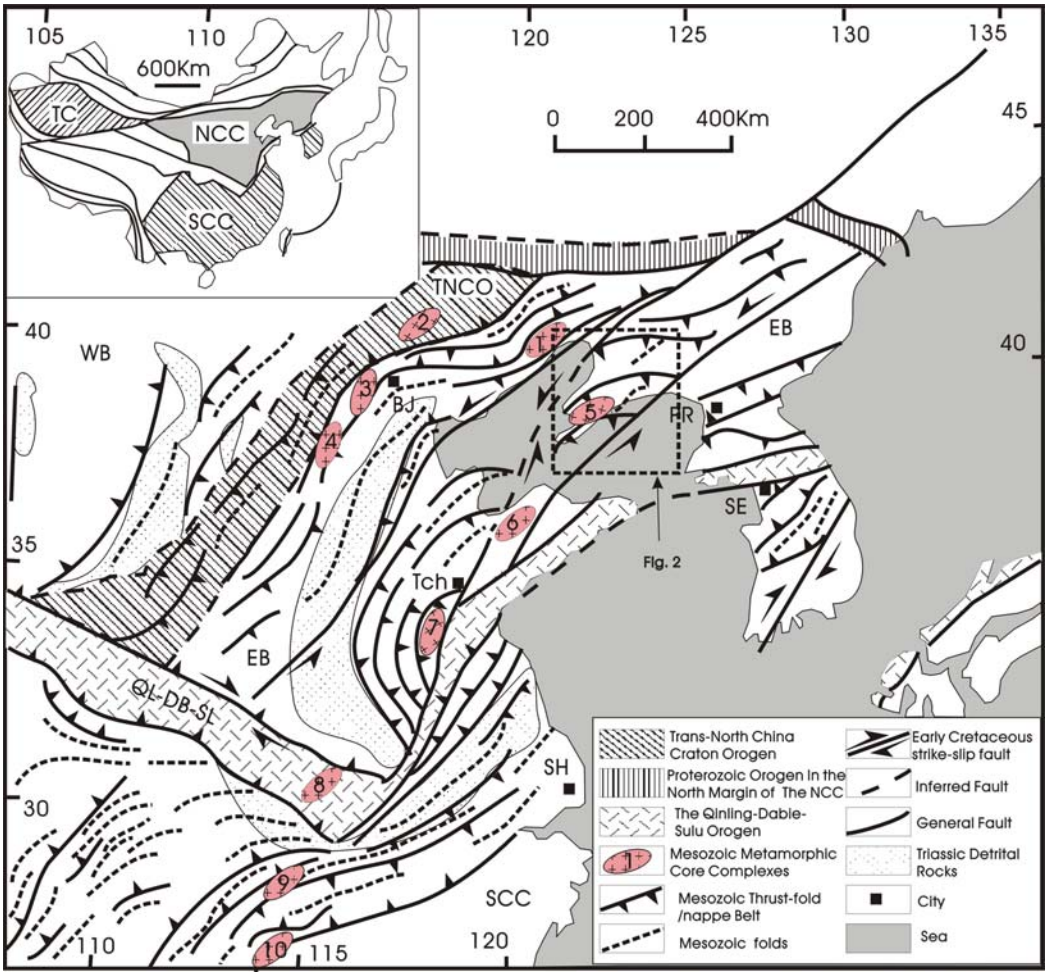
Fig. 2. Tectonic framework of Liaodong peninsula showing the sampling sites. A-stereo of 69 Yanshanian lineations in the lower hemisphere; B, C, D, E-quartz C-axes preferred senses sampled from the upper of the Archaean basement, their locations are marked in the map by the equivalent characters. Their contour intervals are 2%~4%~8%~16% of 200 grains in sample B, 4%~6%~12% of 160 grains in sample C, 2%~4%~6%~8% of 170 grains in sample D and 8%~16% of 200 grains in sample E.

Fig. 3. Representative selection of CL zircon images from the Dandong granites (taken by Zhao GC in Mainz University).

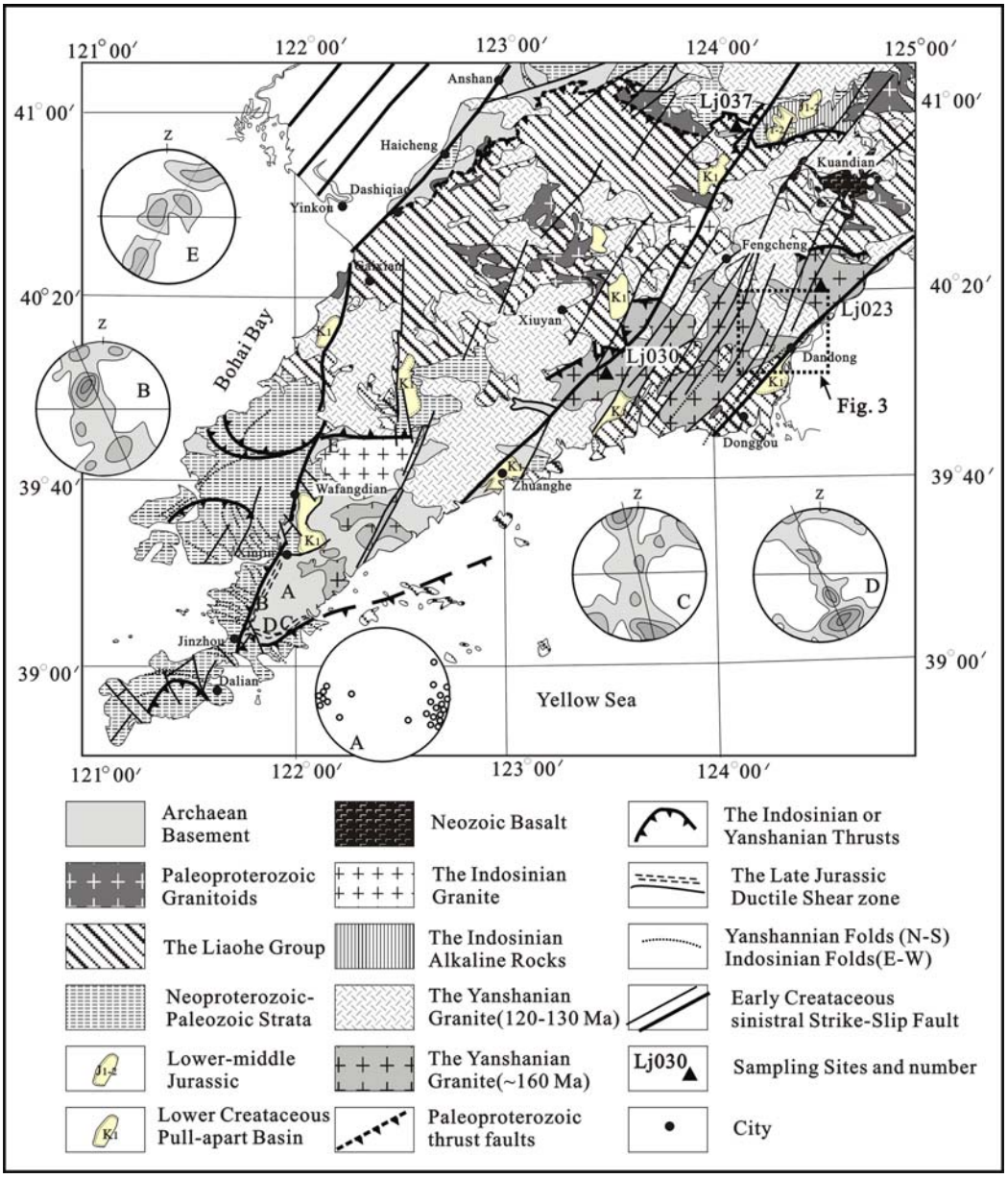
Fig. 4. Concordia plots of SHRIM U-Pb zircon analytical results for mica monzogranitic gneisses of samples LJ030

Fig. 5. Structural map showing the Sanguliu and Wulongbei plutons crosscutting the second deformation fabrics in the Dandong area.

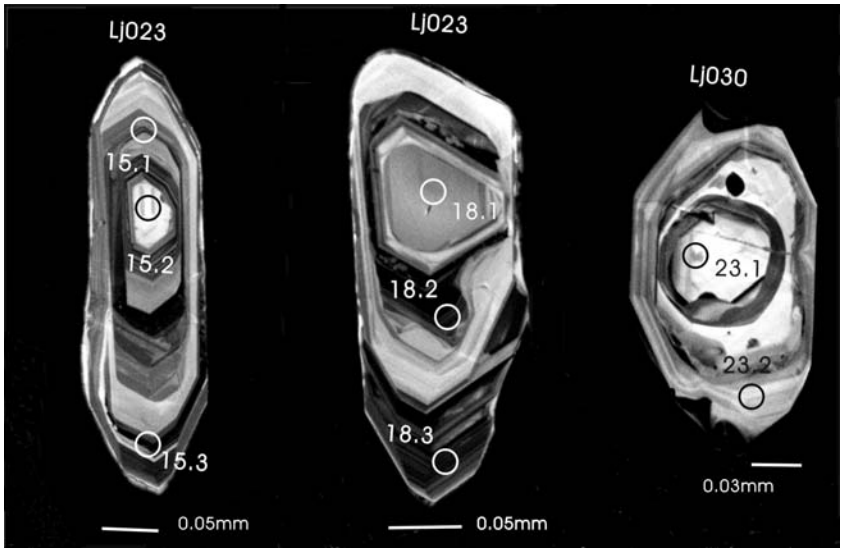
Fig. 6. Sheath folds at the Shuiyuandi, Liaodong peninsula (lens toward east, the sense of the sheath fold is toward west, the scale mark of coin is about 2 centimeters in diameter).



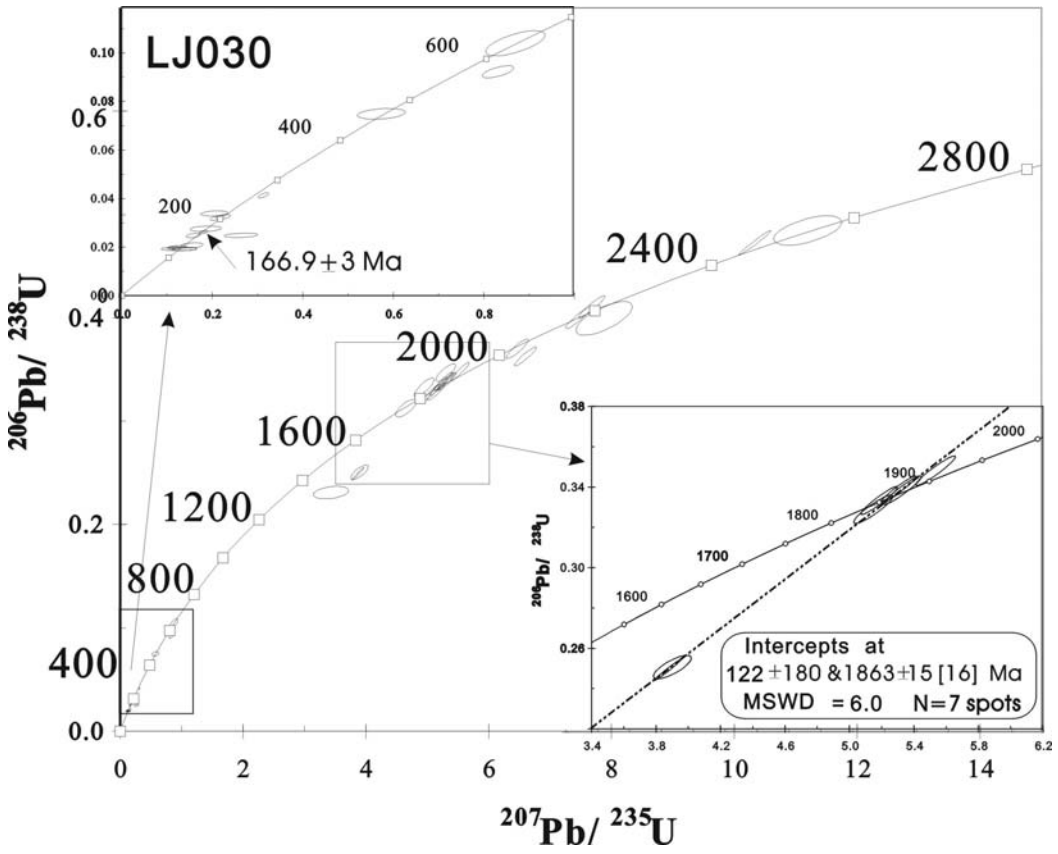
Sanzhong Li et al., Fig. 1



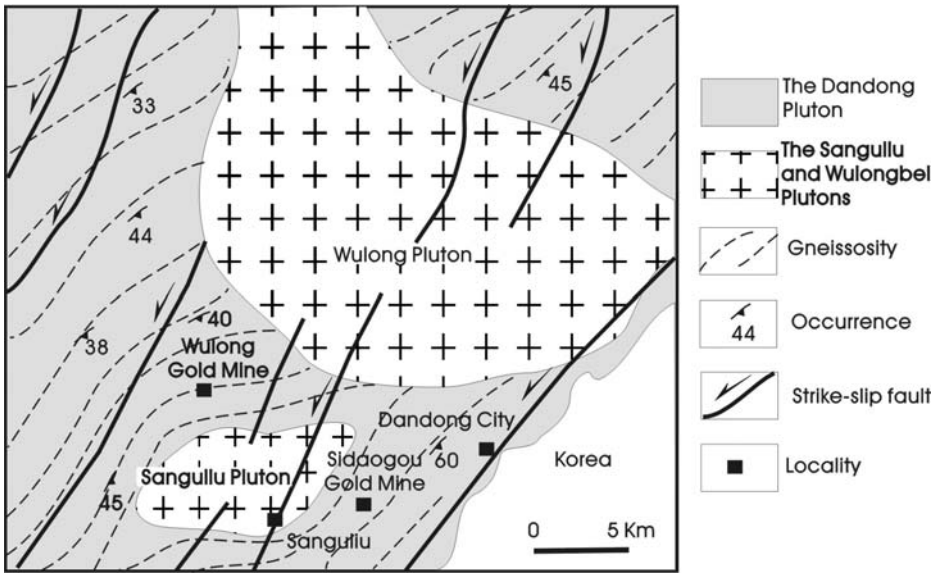
Sanzhong Li et al., Fig. 2



Sanzhong Li et al., Fig. 3



Sanzhong Li et al., Fig. 4



Sanzhong Li et al., Fig. 5



Sanzhong Li et al., Fig. 6

Table 1 SHRIMP U-Pb isotopic analyses for zircons of Dandong Granite Sample LJ030

	Spot location[+]	Texture[++]	$\%_c$ ^{206}Pb	U ppm	Th ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$ ppm	$^{206}Pb/^{238}U$ Age		$^{207}Pb/^{206}Pb$ Age		$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%
.	R	1,O	1.31	246	41	0.17	5.94	175.2	± 4.6	144	±280	0.0489	±12	0.186	±12	0.02755	±2
.	C	1,O	0.16	627	51	0.08	14.2	166.9	± 3.0	189	± 69	0.0499	±2.9	0.1803	±3.5	0.02622	±1
.	C	2,U	--	475	250	0.54	136	1854	±27	1845	± 10	0.11281	±0.55	5.184	±1.8	0.3333	±1
.	C	3,O	--	360	580	1.66	124	2167	±50	2265	± 47	0.1431	±2.7	7.88	±3.8	0.400	±2
!	R	1,O	1.78	2123	161	0.08	36.7	125.0	± 2.2	-203	±200	0.0424	±7.9	0.1145	±8.1	0.01959	±1
.	C	2,O	--	375	72	0.20	81.0	1442	±24	1846	± 28	0.1129	±1.6	3.901	±2.4	0.2507	±1
.	C	1,O	1.05	955	224	0.24	26.2	202.0	± 3.4	50	± 72	0.0470	±3.0	0.2064	±3.5	0.03184	±1
.	C	1,O	1.10	236	99	0.43	3.92	122.9	± 2.8	290	±300	0.0521	±13	0.138	±13	0.01925	±2
.	C	2,U	--	462	229	0.51	138	1925	±28	1885	± 10	0.11532	±0.56	5.535	±1.8	0.3481	±1
.	C	2,U	--	466	221	0.49	135	1879	±28	1867	± 10	0.11421	±0.58	5.329	±1.8	0.3384	±1
1	C	2,U	--	436	242	0.57	123	1826	±27	1837	± 12	0.11227	±0.64	5.070	±1.8	0.3275	±1
1	C	2,U	0.14	333	130	0.40	94.4	1834	±28	1856	± 15	0.11349	±0.81	5.148	±1.9	0.3290	±1
1	C	2,U	--	888	526	0.61	258	1879	±28	1857.2	±8.6	0.11356	±0.48	5.298	±1.8	0.3384	±1
1	C	3,U	--	312	229	0.76	107	2170	±32	2167	± 11	0.13521	±0.64	7.46	±1.8	0.4002	±1
1	C	2,U	--	3101	751	0.25	664	1434	±21	1843.1	±5.0	0.11268	±0.27	3.872	±1.7	0.2492	±1
1	C	3,O	--	291	174	0.62	103	2218	±32	2172	± 11	0.13560	±0.63	7.68	±1.8	0.4106	±1
1	R	1,O	0.97	561	115	0.21	12.0	157.4	± 3.7	13	±150	0.0463	±6.1	0.158	±6.5	0.02471	±2
2	R	3,O	0.11	417	118	0.29	132	2029	±30	2053	± 14	0.1267	±0.80	6.46	±1.9	0.3699	±1
1	C	2,O	0.45	892	146	0.17	31.6	260.9	± 4.5	410	± 39	0.05494	±1.8	0.3128	±2.5	0.04130	±1
1	C	1,O	2.38	174	100	0.60	5.15	214.4	± 4.4	-113	±240	0.0440	±9.7	0.205	±9.9	0.03381	±2
1	C	2,O	2.45	158	77	0.50	3.33	158.1	± 3.9	1120	±180	0.0770	±9.0	0.263	±9.3	0.02483	±2
1	C	2,U	0.01	578	288	0.52	168	1880	±27	1843	± 12	0.11267	±0.64	5.261	±1.8	0.3387	±1
1	R	2,O	2.57	376	270	0.74	29.8	568.7	± 9.7	786	± 44	0.0654	±2.1	0.831	±2.8	0.0922	±1
1	R	2,A	6.42	206	97	0.49	13.4	465.6	± 8.7	434	±130	0.0555	±5.8	0.573	±6.1	0.0749	±1
1	C	4,X	0.01	170	93	0.57	70.7	2547	±41	2534	± 45	0.1676	±2.7	11.20	±3.3	0.4846	±1
2	R	2,O	3.80	174	24	0.14	3.17	132.1	± 4.4	382	±230	0.0543	±10	0.155	±11	0.02070	±3
1	C	1,O	1.25	336	211	0.65	9.41	206.2	± 3.8	195	±100	0.0500	±4.3	0.224	±4.7	0.03251	±1
1	R	1,O	1.20	359	172	0.50	6.26	127.4	± 2.6	-75	±260	0.0447	±11	0.123	±11	0.01995	±2
1	C	2,O	0.04	770	65	0.09	153	1340	±21	1762	± 95	0.1078	±5.2	3.43	±5.5	0.2310	±1
1	C	4,U,X?	0.01	890	496	0.58	361	2495	±34	2440.2	±5.1	0.15855	±0.30	10.33	±1.7	0.4726	±1
1	C	2,U	--	2094	594	0.29	624	1921	±28	1812	± 22	0.1108	±1.2	5.30	±2.0	0.3471	±1
1	R	2,U	0.10	170	45	0.27	48.6	1852	±29	1764	± 22	0.1079	±1.2	4.95	±2.2	0.3328	±1
1	R	2,U	0.74	246	103	0.43	66.2	1754	±28	1764	± 30	0.1079	±1.6	4.65	±2.4	0.3128	±1
1	R-C	2,O	2.16	280	210	0.78	25.1	638	±20	627	± 81	0.0607	±3.7	0.870	±5.0	0.1040	±3
1	C	2,A	4.07	154	192	1.29	2.61	123.0	± 3.2	86	±490	0.0477	±21	0.127	±21	0.01926	±2
1	R	3,U	--	682	325	0.49	213	1994	±29	2124	± 11	0.13191	±0.63	6.59	±1.8	0.3626	±1

Note: 1—Type (Ⅰ), 2—Type (Ⅱ), 3—Type (Ⅲ), 4—Type(Ⅳ). U— Extremely low luminescent, weakly-zoned zircon; X—Xenocrystic core