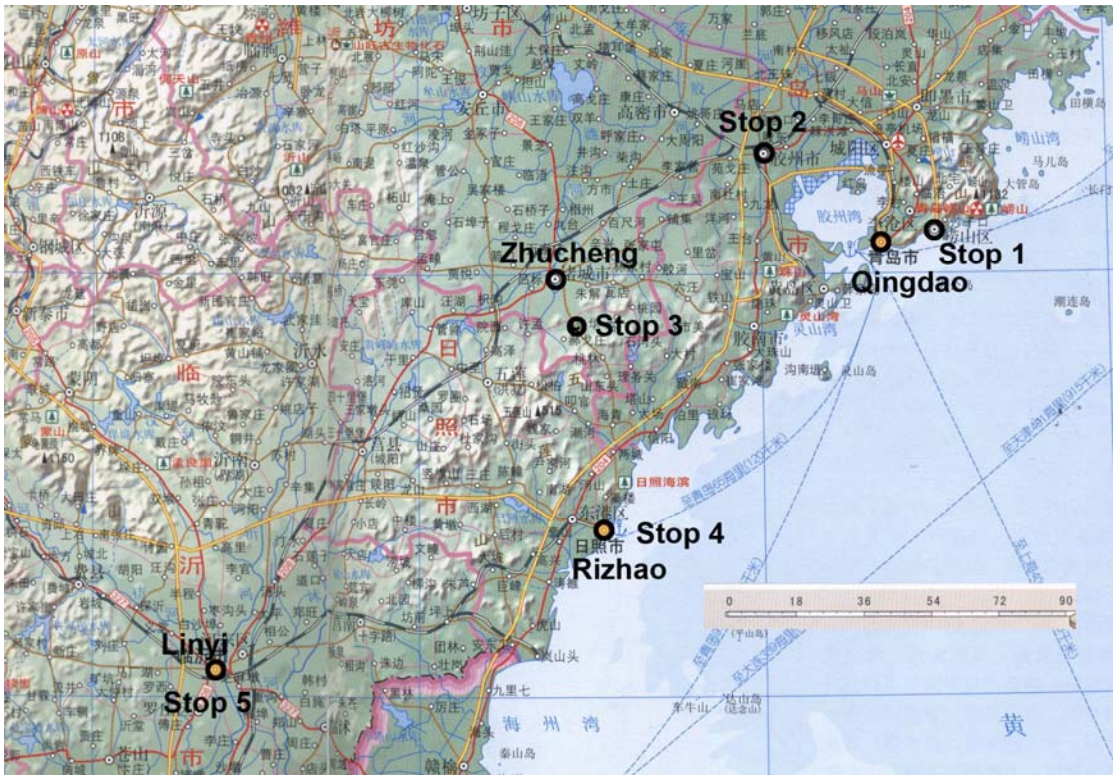
The Origin, Evolution and Present State of Subcontinental Lithosphere

—IUGS-SECE (Commission on Solid Earth Composition & Evolution) Conference at Peking Univeristy, June 25-30, 2005

Field Excursion

(Mesozoic volcanics and Sulu UHP belt in Qingdao–Rizhao–Linyi, Shandong Province, June 28~30, 2005)



Leaders: Kai Ye, Hong-Fu Zhang
Shang-guo Su, Shu-Guang Song

Trip Schedule

June 27, 20:13—Beijing to Qingdao by night train

June 28, 07:33—Arriving in Qingdao and Breakfast

June 28: Stop 1—UHP rocks in Yangkou, Qingdao.

Stop 2—volcanic rocks with mantle xenoliths in Daxizhuang area, Jiaozhou

Stop 3—UHP rocks in Taohan, Zhucheng

June 29: Stop 4—UHP rocks in Suoluoshu-Hujialin, Rizhao

Stop 5—volcanic rocks with mantle xenoliths in Fangcheng area, Linyi

June 29, 16:30—supper in Linyi

June 29, 18:39—Linyi to Beijing by night train

June 30, 05:11—Arriving in Beijing

Part 1: Ultrahigh-pressure (UHP) metamorphic rocks in Sulu area

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Geological Setting:

The Sulu UHP terrane and its western extension into the Dabieshan and Hong'an UHP terranes in eastern China, mark the Triassic subduction/collision zone between the Sino-Korean and Yangtze cratons (Fig.1).

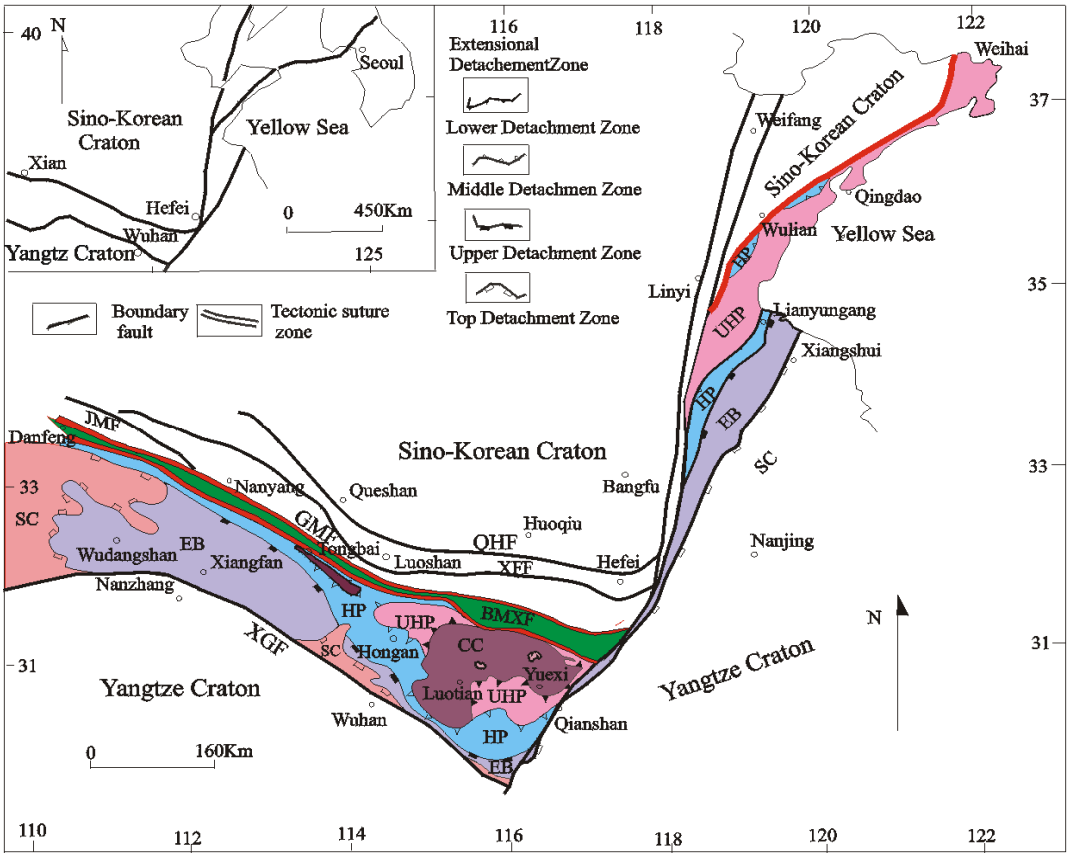

Fig.1 Simplified geological map showing Dabieshan-Sulu UHP terrane in eastern China.

The Sulu UHP metamorphic terrane is bounded by the Wulian-Qingdao and Mishan Faults in the north, Jiashan-Xiangshui and Wendeng-Rongcheng Faults in the south (Fig. 2). The Dabieshan-Sulu UHP terranes consist mainly of two sets of

lithologies. One set is metamorphic sedimentary sequences composed of intercalated marble, jadeite-quartzite, kyanite-quartzite, dark biotite-epidote-rich paragneisses, abundant boudinaged eclogite occur in this rock sequence. Another set of lithologies is composed of tonalitic-trondhjemitic-granitic orthogneisses; rare eclogite and ultramafic rocks occur as isolated lenses in the orthogneisses.

Coesite and its quartz pseudomorph are commonly recognized in UHP eclogite and jadeite-quartzite (see review of Enrst & Liou, 1999). However, the voluminous regional gneissic country rocks show extensive amphibolite-facies metamorphism, no index UHP minerals are found by traditional optical methods. Recently, minute coesite inclusions were commonly identified by Raman Microspectroscopy in zircons from various gneissic rocks from the Sulu and Dabieshan UHP terrane (Ye *et al*. 2000; 2001; Liu *et al*., 2001), and thus proved that most lithologies in the Dabieshan-Sulu UHP terrane witnessed the Triassic subduction to mantle depths greater than 80 km and later exhumation to the earth's surface, as a coherent continental slab.

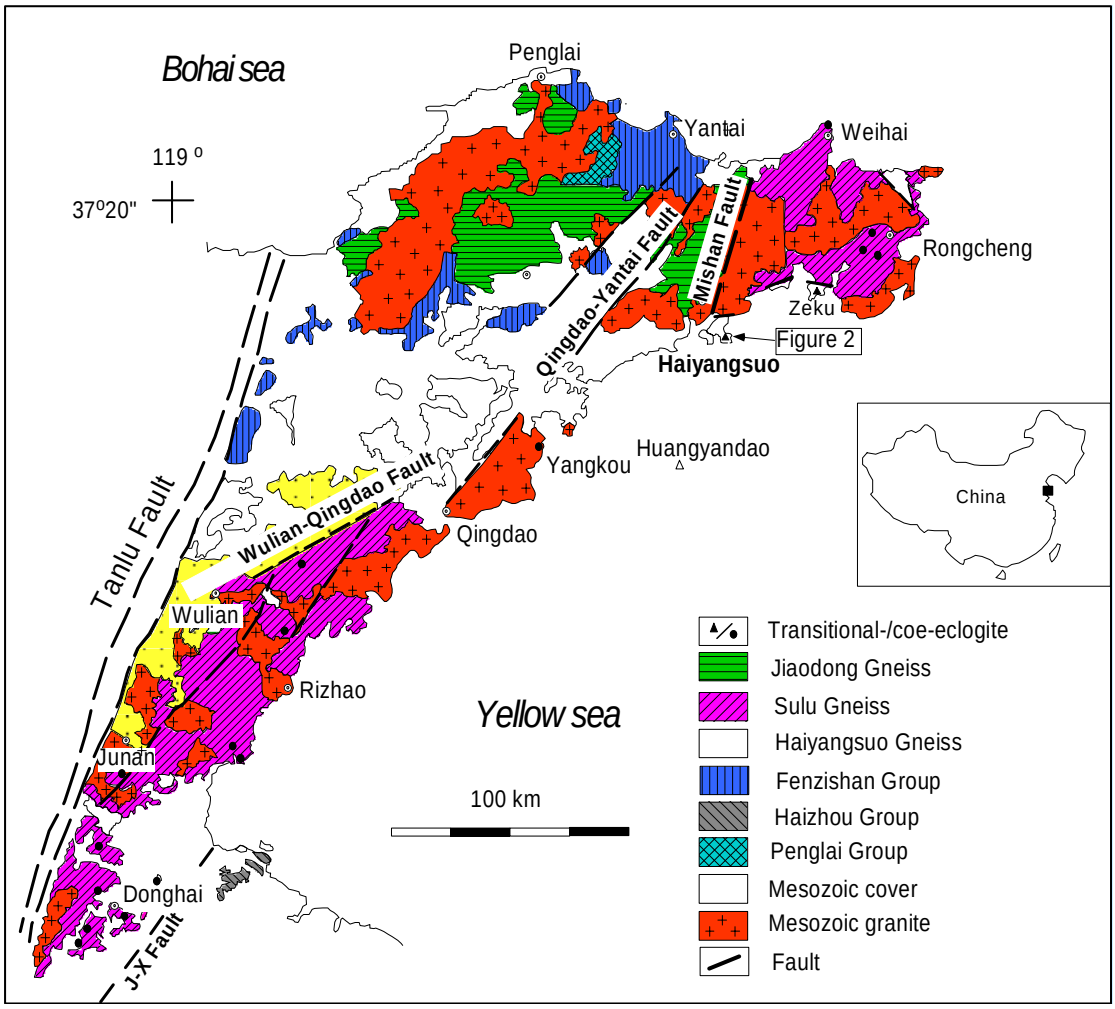

Fig.2 Simplified geological map showing the Sulu UHP terrane in eastern China.

The igneous zircons from the orthogneisses and eclogites have preserved their

magmatic zoning and give middle Neoproterozoic U-Pb age between 700 and 800 Ma, which are correlated with the rifting accompanying the breakup of Rodinia supercontinent. Triassic ages of 245 to 210 Ma were determined by Sm-Nd and U-Pb isotope techniques for eclogite and metagranitoids, which have been interpreted as the timing of the UHP metamorphism (See review by Zheng et al., 2004).

The southern part (Donghai region) and the northern part (Taohang, Rongcheng, and regions) of the Sulu UHP terrane show different decompressional metamorphisms. The eclogites from Donghai region in the southern Sulu are similar to those in the Dabieshan UHP terrane. They are lack of granulite-facies overprint, but show various extents of amphibolite-facies retrogression. Detailed petrological studies confirmed that the exhumation of the UHP eclogites from Donghai and Dabieshan are accompanied by significant cooling (Zhang *et al*., 1995a; 1995b). However, coesite-eclogite from Taohang region in the northwestern Sulu, show transitional eclogite-facies overprint before amphibolite retrogression (Yao *et al*., 2000), the coesite-eclogites from Weihai and Rongcheng regions in the northeastern Sulu commonly suffered granulite-facies overprint predated the pervasive later amphibolitic retrogression (Wang *et al*., 1993; Banno *et al*., 2000; Nakamura & Hirajima, 2000). The granulite-overprinted eclogites from northern Sulu ascended without significant cooling, but followed a near adiabatic *P-T* path (Wang *et al*., 1993; Banno *et al*., 2000; Nakamura & Hirajima, 2000). The country gneiss in the northern Sulu (Weihai, Rongcheng and Taohang regions) commonly show incipient migmatization structure, which is defined by alternating compositional layers of melanosome to mesosome biotite-rich gneiss and leucosome granitic gneiss in the mm to cm scale.

Detailed Description of the locations we will visit:

We will visit ultramafic bodies in Suoluoshu-Hujialin region southwest to Rizhao city, eclogite in granitic gneiss at Taohang viliiage south to in Zhucheng city and an unique UHP meta-igneous complex located at Yangkou beach eastern to Qingdao.

(1) Yangkou, Qingdao (Stop 1):

An UHP meta-igneous unit (100 m × 100 m) surrounded by amphibolite-facies regional orthogneiss outcrops along the nice beach at Yangkou near Qingdao (Fig. 3).

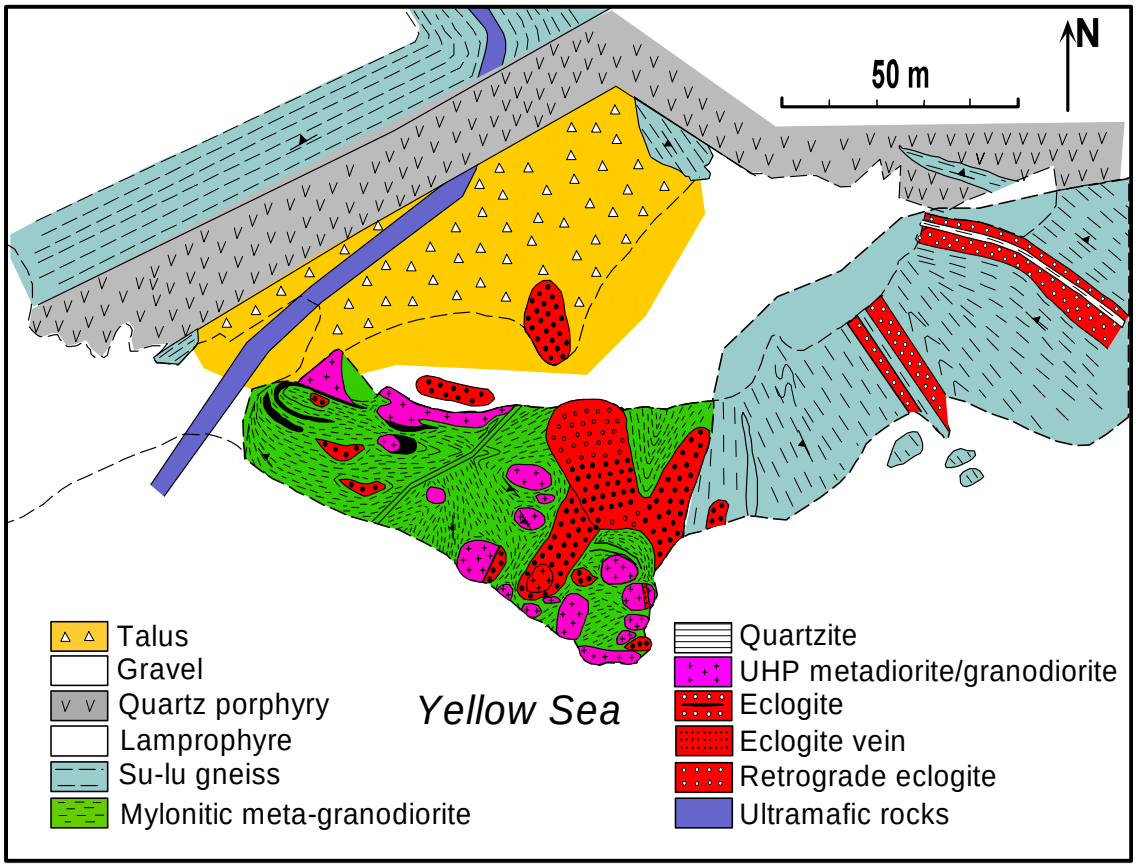

Fig. 3 Geological map of Yangkou meta-igneous complex.

The meta-igneous unit is mainly composed of UHP metagranitoid, metagabrro, coarse- and fine-grained eclogite and associated ultramafic rocks. UHP overprint of the igneous unit is controlled by degree of UHP shearing deformation and fluid availability during UHP metamorphism（Hirajima et al., 1993; Zhang & Liu, 1997）. The coarse-grained and weakly sheared metagranitoid and metagabrro partly preserve a gabbroic mineral and texture, whereas the metagbbro along UHP shear zones and near the boundary to the country gneiss has been solely transformed to fine-grained eclogite, coesite occurs both as an inclusion phase in garnet and omphacite and as an interstitial matrix phase (Liou & Zhang, 1996; Ye et al., 1996).

The garnet-peridotite contains nodules of coase-grained eclogite (Yoshida et al., 2004). High concentrations of clinopyroxene, rutile and apatite exsolutions are observed in porphyroclastic garnet within the eclogites (Ye et al., 2000), which are interpreted as resulting from the decomposition of the parental majoritic garnet formed at depths greater than 200 km.

(2) Taohang Region, Zhucheng (Stop 3):

Taohang is a small village located in the northwestern margin of the Sulu UHP

terrane. It is about 5 km south of the Wulian–Qingdao major fault. Abundant eclogites sporadically occur as lenticular bodies or discontinuous layers in the country orthogneisses. Coesite inclusions are identified in zircon from the country granitic gneiss (Ye et al., 2000).

Most eclogites from Taohang show a banded structure, which is defined by the intercalation of mm to cm scale compositional bands rich respectively in garnet + quartz, garnet + omphacite and zoisite + Kyanite. The bulk composition of the eclogite varies significantly, while their mineral assemblages are essentially identical (Grt + Omp + Coe/Qtz + Rut + Ky ± Zo ± white mica). Three types of eclogites can be distinguished based on their mineral proportions. (1) Normal eclogite is mainly composed of garnet (30-60 %) and omphacite (20-50 %), with minor quartz (2-5 %), kyanite (1-5 %), zoisite (0-3 %), white mica (<1 %) and rutile (1-2 %). (2) Garnet-quartz-rich eclogite is characterized by high proportion of garnet (60-90 %), quartz (5-20 %) and omphacite (5-15 %), with small amount of zoisite (2-3 %), kyanite (2-5 %), white mica (< 1 %) and rutile (1-2 %). (3) Zoisite-kyanite-rich eclogite contains abundant zoisite (20-30 %), kyanite (20-25 %), quartz (5-15 %) and white mica (>3 %); other phases are garnet, omphacite and rutile.

Textures associated with phengite dehydration melting happened at 17-18 kbar and 780-820℃are identified in eclogites from Taohang. Isolated fine-grained veinlet of kyanite + albite + quartz in the matrix of peak minerals documents the restite phases. Polycrystalline composite inclusions of quartz + K-feldspar ± calcite ± magnetite in peak minerals are interpreted as mixture of recrystallized melt and previously existed coesite/pseudomorph inclusions. Microfractures caused by the positive volume changes due to water-undersaturated melting reactions are identified in the restite omphacite, which might have served as melt extraction pathway.

(3) Suoluoshu-Hujialin, Rizhao (Stop 4):

Several seriously serpentinized ultramafic bodies outcrop in granitic gneisses at Suoluoshu-Hujialin region, about 20 km southwest of Rizhao City (Fig. 3). The ultramafic rocks is mainly composed of serpentinized Grt-harzburgite, Grt-wehrlite, Dunite and Garnet-clinopyroxenite. Most of the peridotites are seriously serpentinized, it is very hard to collect samples with earlier minerals. A large garnet-clinopyroxenite lens occurs in serpentinite at Hujialin. The Hujialin garnet-clinopyroxenite contains two generations of mineral assemblages: earlier porphyroclastic garnet and clinopyroxene and later matrix fine-grained garnet, clinopyroxene, ilmanite and amphibole. Some clinopyroxene porphyroclast contain abundant garnet and ilmenite lammellae or rods (Hiramatsu & Hirajima,1995; Zhang and Liou, 2003; Zhang et al., 2004). Contrasting opinions exist on the interpretation of garnet and ilmenite

lammellae or rods in coarse clinopyroxene: decomposition product of earlier high-temperature low-pressure high-Ti-Al clinopyroxene due to subduction (Hiramatsu and Hirajima, 1995) and decompressional products (pseudomorph) of earlier majoritic garnet (Zhang and Liou, 2003).

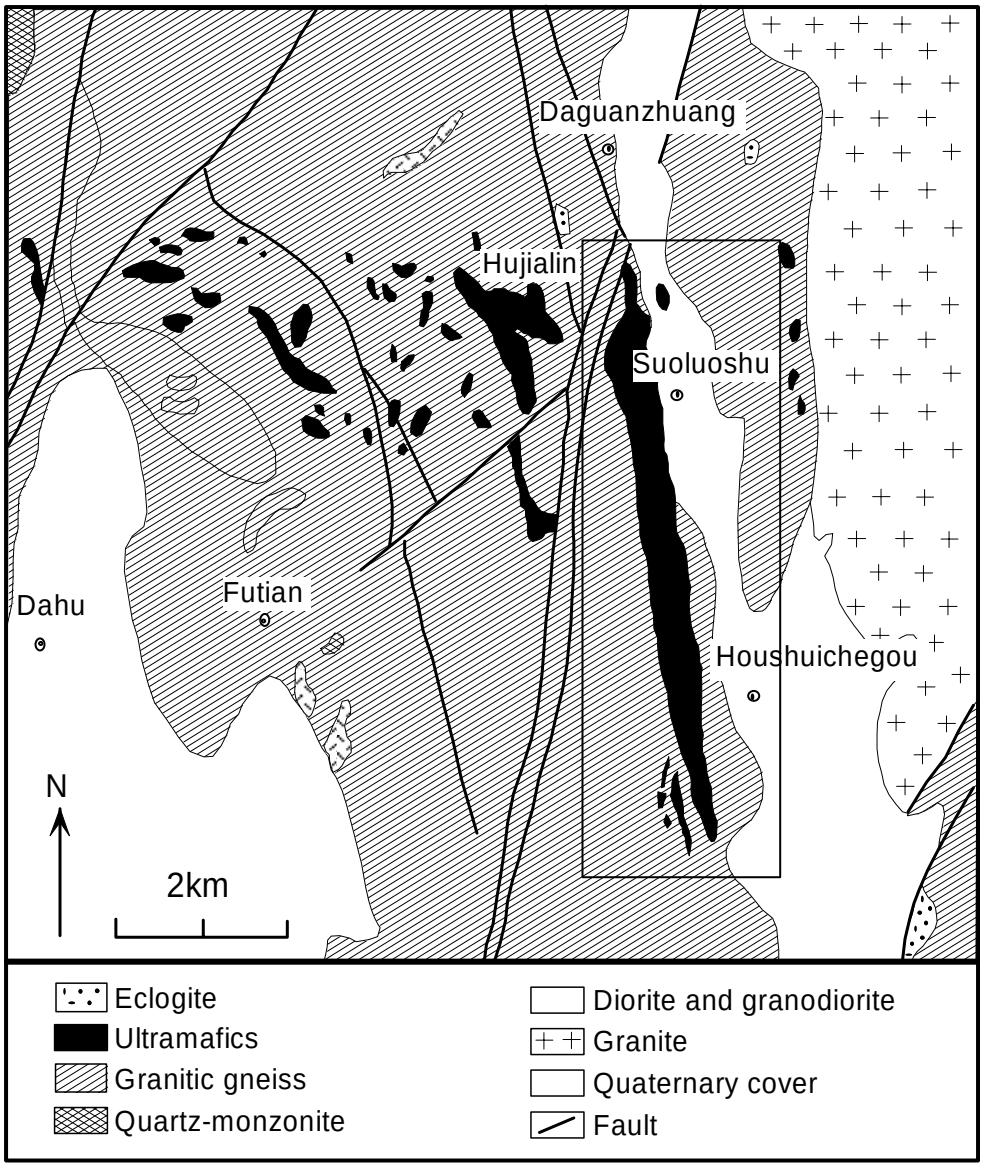

Fig. 3 Geological Sketch map of the Hujialin mafic - ultramafic complex

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Part 2: Xenolith-bearing basalts in Shandong Province

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(1) 73.5 Ma Xenolith-bearing Basalts in Daxizhuang, Jiaozhou (Stop 2)

Host Daxizhuang basalts, erupted at 73.5 Ma (whole rock Ar-Ar age), are distributed within the Cretaceous Jiaolai basin (Fig. 1), where is adjacent to the north of the surface boundary fault (Wulian-Yantai fault) between the North China Craton and the Sulu terrane. The basalts stratigraphically belong to the Late Cretaceous Wangshi Group and are dark, with porphyritic texture and massive structure, and can be classified as alkaline basalts with more than 6% normative nepheline. Olivine occurs as phenocryst (8~15%) and plagioclase and pyroxene as matrix. The basalts have high in LREE and LILE without HFSE depletion. They are low in $\varepsilon Nd_{(t)}$ +7.5~+7.6 and considered to have been derived from asthenosphere.

Daxizhuang basalts also contain abundant spinel-facies peridotitic xenoliths. The xenoliths are irregular, 3~10 cm in size and are dominantly composed of granular olivine (60-70%), orthopyroxene (15~20%) and clinopyroxene (10~15%) with minor spinel, thus they are named as spinel lherzolites. The deformation texture ubiquitously occurs in olivine and opx.

(2) Mesozoic xenolith-bearing basalts in Fangcheng area, Linyi (Stop 5)

Mesozoic Fangcheng basaltic volcanism occurs as a central-type volcano. Borehole investigation indicates that the thickness of the basaltic lava is about 100

meters. These rocks are tectonically located in the Pingyi Basin, a small fault-bounded basin in southwestern Shandong Province, 70 km west of the giant Tan-Lu wrench fault (Fig. 1) and stratigraphically belong to the lower and middle parts of the Early Cretaceous Qingshan Formation. The basalts are dark, with porphyritic texture and massive structure, and consist of 5-15% phenocrysts of clinopyroxene, olivine and minor orthopyroxene. Microgranular matrix is made up of olivine, clinopyroxene, orthopyroxene, plagioclase, and magnetite. Picrite, only reported from a borehole, has texture and mineralogy similar to the basalts, but with higher percentage of olivine phenocryst, up to 15% brown glass in the matrix, and without plagioclase. The andesite, limited to the top of the volcanic sequence, is generally considered to be a representative of another volcanic eruption cycle (LSGB, 1981) based on the contact relationship with the underlying basalts. This andesite has micro-porphyritic texture and the phenocryst (40%) is characterized by the presence of amphibole and absence of olivine. The dominant phenocrysts, pyroxene and plagioclase, are generally in the range of 0.5-2 mm with the maximum up to 1 cm size. The basalt and andesite in this study give 124.9 ± 1.8 Ma and 116.2 ± 1.7 Ma K-Ar ages, receptively, which are interpreted to be the eruption age.

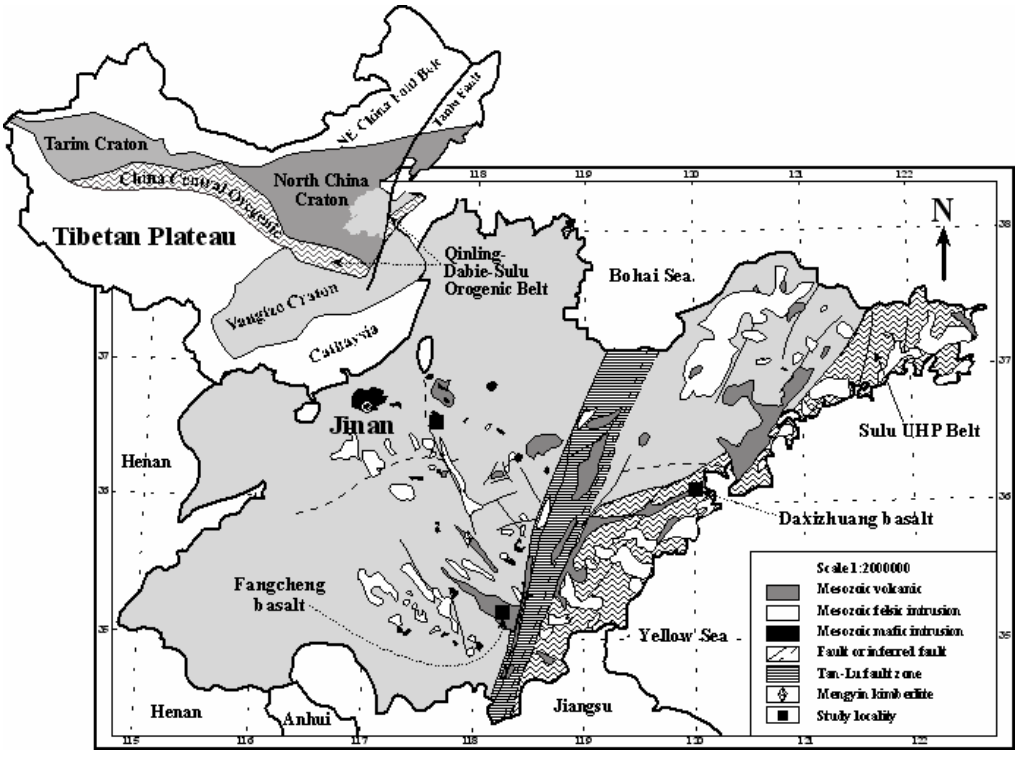

Fig. 1 Simplified geological map showing major tectonic units in eastern China and the locations of Paleozoic diamondiferous kimberlite fields and Mesozoic volcanic rocks on the North China Craton.

Fangcheng basalts contain large amounts of spinel-facies ultramafic xenoliths, which are dominantly in the range of 1~8 cm and consist of clinopyroxenes with minor olivine, spinel, and feldspar. Thus these xenoliths can be petrographically classified as olivine clinopyroxenites. Clinopyroxene, the major constituent mineral (85~90%), occurs as large crystal (2~6mm) and contains high Cr_2O_3 (0.5~0.9%) and Mg# value (Mg/(Mg+Fe) = 0.85~0.89), consistent in major composition with Cr-diopside of mantle occurrence in spinel-facies pyroxenites from Cenozoic basalts on the NCC. However, these xenoliths are highly enriched in LREE, LILE and Sr-Nd isotopes and depleted in HFSE and Pb isotope, in contrast remarkably with clinopyroxenes from Cenozoic basalts. Olivine, spinel, and occasionally feldspar occurs as small interstitial grains among clinopyroxenes.

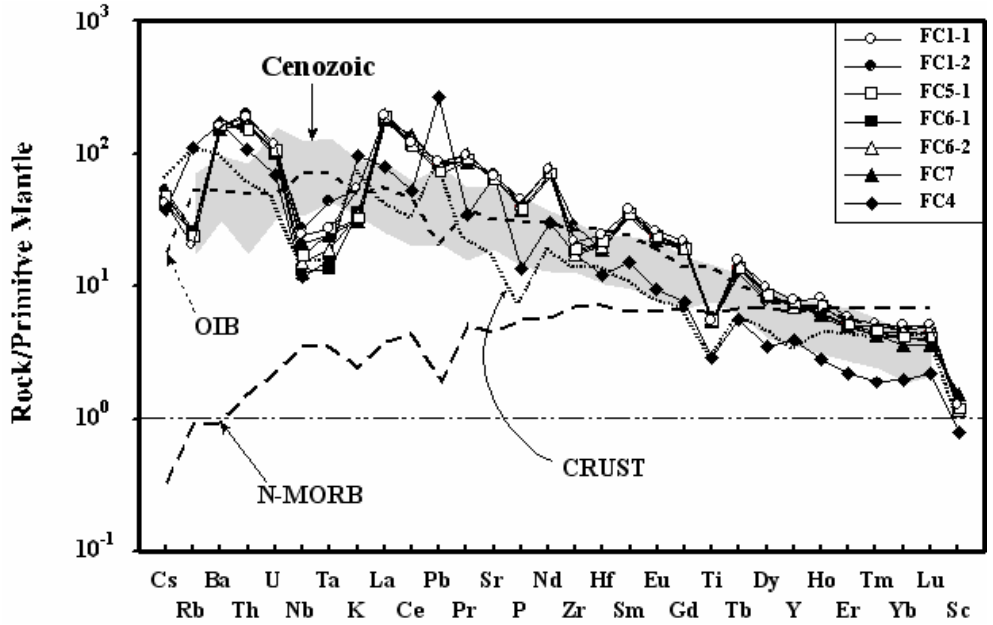

Fig. 2. Primitive mantle-normalized trace element diagrams for Fangcheng volcanic rocks. The shadow field shows the predominant trace element range of Cenozoic on-craton basalts. The long and short dash lines represent the N-MORB and OIB basalt respectively. The dotted line is the average crust of the NCC.

Fangcheng basalts include alkali basalt and olivine tholeiite, both are characterized by high Mg (Mg# = 65-72), Si, Ca and low K+Na, Ti, P. They are extremely enriched in LREE ($(La/Yb)_N$ = 39.3-49.3) and LILE (Ce, Rb, Ba, U, Th) and depleted in HFSE (Nb, Ta, Zr, Hf, Ti) with slightly negative Pb anomaly (Fig. 2). Correspondingly, these basalts are exceedingly high in ε_{Sr} (74.0 ~ 81.5) and low in ε_{Nd} (-13.1 ~ -14.2) (Fig. 3) and $^{206}Pb/^{204}Pb$ (<17.8). Since crustal contamination during the magma ascending is insignificant, the Fangcheng basalts could reflect the nature of its mantle source. The isotopic data of these basalts cannot be explained by

mixing of typical mantle components, but can be accounted for by interaction of an old lithospheric mantle with the lower/middle crust. Therefore we consider that these basalts originated from the Mesozoic lithospheric mantle, which evolved from its Paleozoic counterpart through extensive interaction with a crust-derived melt. We propose that this melt was generated from the melting of the subducted lower crust of the Yangtze Craton. This peculiar Mesozoic lithospheric mantle somehow was in turn replaced later by the hot and thin Cenozoic lithospheric mantle.

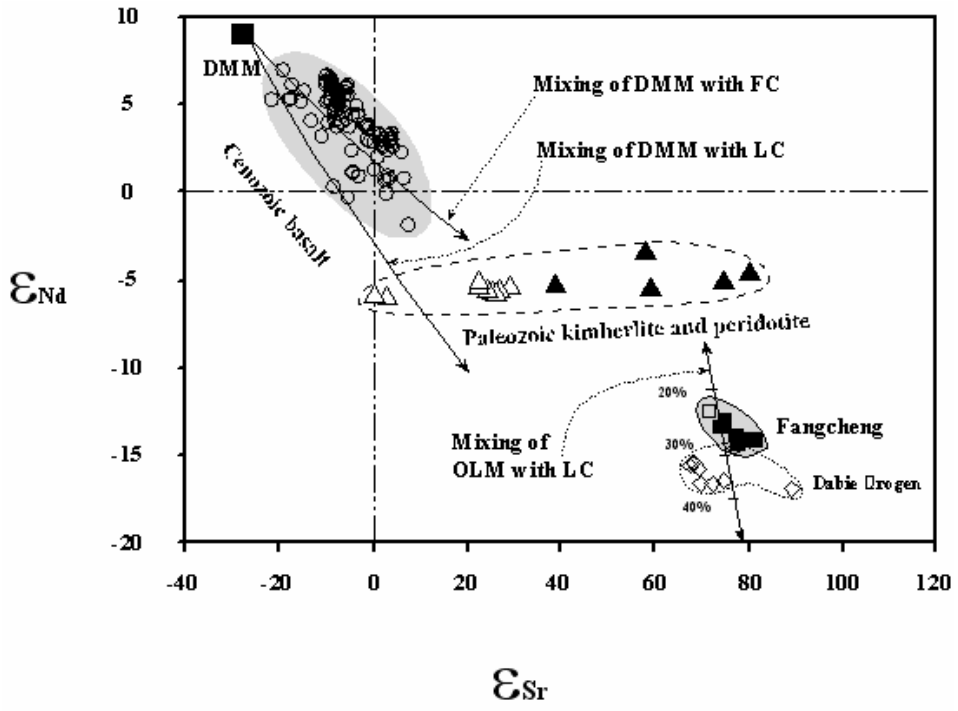

Fig.3. ε_{Sr} versus ε_{Nd} diagram for Fangcheng volcanic rocks, compared with Cenozoic on-craton basalts, Paleozoic Mengyin kimberlites and mantle peridotites, and syenites from Dabie Orogen. Initial Sr and Nd isotopic composition for Mengyin kimberlites (open triangle) and mantle peridotites (filled triangle) were recalculated to 125 Ma. Mixing of old lithospheric mantle (OLM) with lower crust (LC) can generate Fangcheng basalts. Mixing of depleted MORB mantle (DMM) with LC or Mesozoic lithospheric mantle as represented by Fangcheng basalts can produce Cenozoic basalts.

Peridotite-melt interaction:

Early Cretaceous Fangcheng basalts contain olivine and clinopyroxene xenocrysts (Fig. 4) with clear compositional zonations, which provide evidence for important mantle-melt reactions. These zoned olivines are fine-grained (200~900 μm) and the core of the relatively larger grains have compositions (such as Mg#=88~92) (Fig. 5) similar to those of olivines from the mantle peridotitic xenoliths entrained in Cenozoic basalts from the North China Craton and their rims (Mg#=76~83) are

compositionally close to those of the olivine phenocrysts from the host basalts. These compositional features as well as textural characteristics such as rounded and embayed crystal shape, well-developed cracks and grain sizes demonstrate that these olivines are mantle xenocrysts disaggregated from the lithospheric peridotites. The zoned texture was formed through rapid reaction between olivine and host melt. This may suggests that mantle-melt reaction was once very significance in the Mesozoic lithospheric mantle beneath the southeastern portion of the North China craton, which we consider to be responsible for the replacement of lithospheric mantle from the Paleozoic refractory (high-Mg) peridotitic mantle to the late Mesozoic fertile (low-Mg) and enriched mantle with the loss of more than 120 km Archaean lithospheric keel in the region.

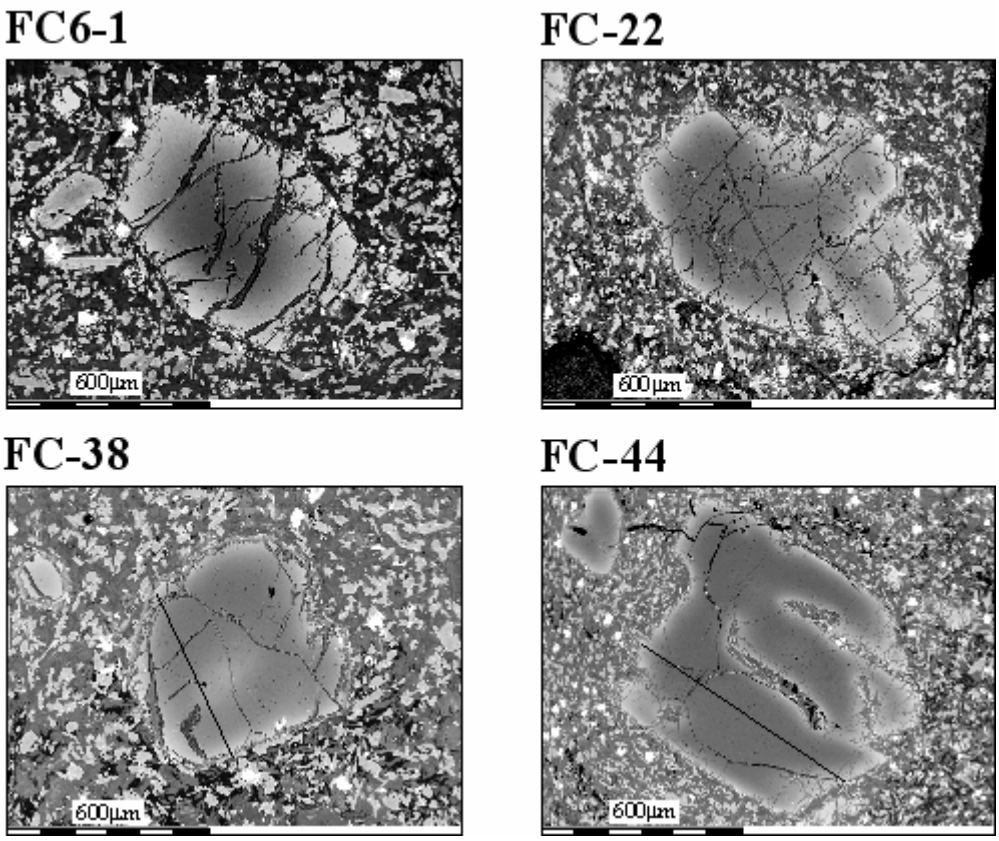

Fig. 4 Olivine xenocrysts from Fangcheng basalts.

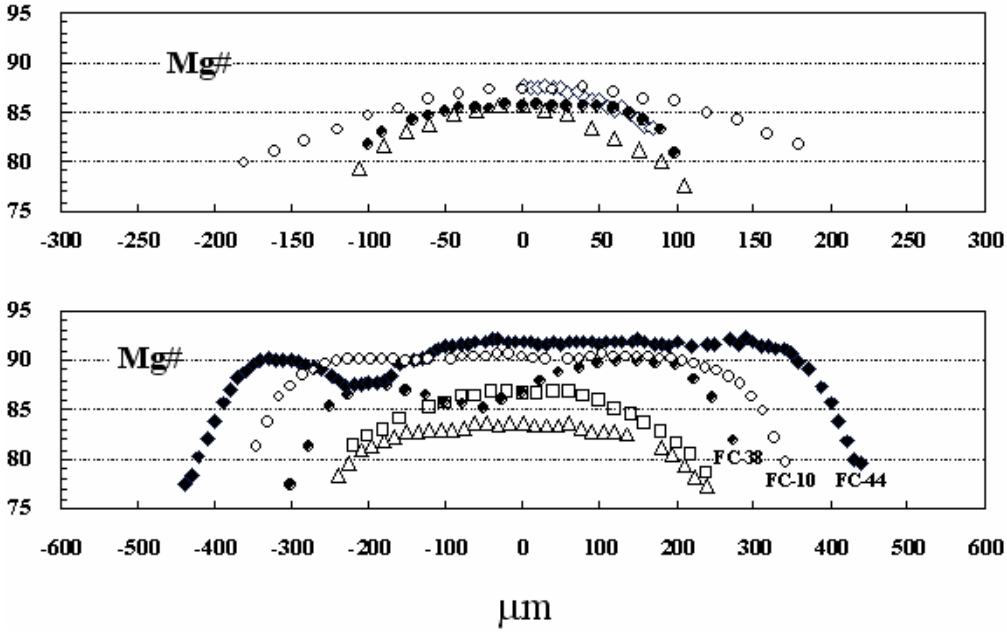

Fig. 5 Composition traverse cross olivine xenocrysts.

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