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The Boundary Between Sino-Korea Craton and Yangtze Craton and Its Extension to the Korean Peninsula

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ABSTRACT: The Dabie-Sulu ultra-high pressure metamorphic (UHPM) zone is commonly suggested to be a collisional belt between the Sino-Korea craton (North China craton) and Yangtze craton (Zhai and Cong, 1996). Two important questions in formulating the tectonic evolution of the northeast Asia are: (1) the boundary between the UHPM zone and the Sino-Korea craton in the Shandong peninsula and (2) the extension of this Chinese UHPM zone into the Korean peninsula. There have been different opinions on the boundary between UHPM zone and the Sino-Korea craton in the Shandong peninsula. For example, the boundary has been suggested to be the Tan-Lu fault (Bai *et al.*, 1993; Wang and Cong, 1996), or Wulian-Rongcheng fault (Cao *et al.*, 1990). Our recent study finds out new evidences, indicating that the possible boundary is the Kunyushan granitoid complex zone, which occurs along the Wulian-Muping fault. Our new evidences are: (1) the basic rocks west to the Kunyushan granitoid zone are high-pressure granulites rather than eclogites (Zhai, 1996) with their Sm-Nd isotopic ages of 1750 Ma and 2788 Ma, representing their retrograde metamorphic and petrogenetic ages, respectively (Li *et al.*, 1997b); (2) the orthogneisses west to the Kunyushan granitoid zone yield 2600-2900 Ma zircon ages and 1600-2020 Ma Rb-Sr and chemical U-Th-total Pb ages, with no younger data (Enami *et al.*, 1993; Ishizaka *et al.*, 1994), having a typical characteristic for the early Precambrian rocks in the Sino-Korea craton; (3) the orthogneisses east to the Kunyushan granitoid zone have 110-320 Ma isotopic ages with a peak value of 180-230 Ma, showing a typical characteristic of metamorphic rocks in the UHPM zone; (4) the Kunyushan granitoid zone consists of numerous granitic bodies, stocks and veins, which have 1900-2000 Ma, 610-710 Ma and 124-180 Ma istotopic ages indicating a long and complicated evolution history of this granitoid zone. There are many lenses and enclosures of metamorphic rocks from the Sino-Korea craton and Sulu UHPM belt in the Kunyushan granitoid zone. Zhai *et al.* (1998) have defined the Kunyushan granitoid zone as the Jiaodong Boundary complex zone. Some geologists suggested that the UHPM zone extend eastward to the Korea peninsula (Yin and Nie, 1993; Wang and Cong, 1996) and possibly to the Imjingang belt (Chang, 1994; Ree *et al.*, 1996). Unfortunately, there has not been a conclusive evidence indicating that UHPM rocks occur in the Korea peninsula. In this regard, it becomes more important to compare metamorphic rocks in the Shandong peninsula with those in northern and southern Korea peninsula.

Key word: ultra-high pressure metamorphic (UHPM) zone, collisional belt, Sino-Korea craton, Yangtze craton, Kunyushan granitoid zone

INTRODUCTION

Since 1989, ultrahigh pressure metamorphic (UHPM) rocks of the coesite-eclogite facies from the Sulu (eastern Shandong-northern Jiangsu) region and Dabieshan (Dabie Mountains) have been extensively studied. The UHPM rocks include not only eclogite and ultramafic rock, but also marble, jadeitic quartzite and schist. Studies on these UHPM rocks indicate that the metamorphosed supracrustal rocks were subducted to a depth of more than 100 km, which is a key to understanding the crustal evolution in northeast Asia. It is generally accepted that the Qinling-Dabieshan orogenic belt separates the Sino-Korea craton and Yangtze craton and that the belt is a continent-continent collisional belt (Wang *et al.*, 1989; Okay *et al.*, 1989; Liou *et al.*, 1994; Zhang *et al.*, 1994; Wang and Cong, 1996). The Sulu zone is a part of the Qinling-Dabieshan belt and separated 60 km north by the Tan-Lu fault (Zhai and Cong, 1996). The UHPM terrain is closely related to the Yangtze craton in geochemistry, and can be classified into the Yangtze geochemical province (Zhang *et al.*, 1995). Zhai and Cong (1996) explained that the UHPM terrain represents a root complex of continent-continent collisional zone, and its main material was from the Yangtze craton during the northward subduction of the Yangtze craton under the Sino-Korea craton. Two outstanding questions at present in establishing the tectonic history of northeast Asia are the boundary between the UHPM zone and the Sino-Korea craton in the Shandong peninsula, and the extension of the collisional belt to the Korean peninsula across the Yellow Sea. In this paper, we present new evidences indicating that the boundary between the UHPM zone and the Sino-Korea craton in the Shandong peninsula is the Kunyushan granitoid complex. We also discuss problems with extending the collisional belt to the Korean peninsula.

THE BOUNDARY BETWEEN SINO-KOREA CRATON AND YANGTZE CRATON IN THE SHANDONG PENINSULA

The boundary between the UHPM terrain and Yangtze craton is clearly defined. The UHPM rocks contact with the Susong Group by the Hualiangting fault and the Donghai Group by the Lianyungang fault in Anhui and Jiangsu provinces, respectively, which are called the southern mobilized-cover-sedimentary complex on the Yangtze continental margin (Zhai *et al.*, 1995). However, the boundary between UHPM terrain and Sino-Korea craton is controversial. Traditionally, all metamorphic rocks in the Shandong peninsula have been termed as the Jiaodong Group or Jiaonan Group of Archaean. With the recent discovery of UHPM rocks, Cao (1990) suggested that the boundary between UHPM terrain and the Sino-Korea craton in the Shandong peninsula is the Wulian-Rongcheng fault. On the other hand, Bai *et al.* (1993) and Wang and Cong (1996) suggested the boundary to be the Tan-Lu fault. We have found new evidences implying that a rock complex rather than a single fault zone occupies the boundary. The rock complex is the Kunyushan granitoid complex, which occurs along the Wulian-Muping fault. Our new suggestion is based on metamorphic, lithologic and isotopic evidences which are explained in detail below.

First, eclogites and other UHPM rocks are extensively distributed in areas east to the Kunyushan granitoid zone, including Rongcheng, Weihai, Junan and Zhucheng. The eclogites were commonly retrograded to granulite facies or amphibolite facies rocks. Coesites are common in retrograded eclogites, indicating that these rocks of the eclogite facies were buried in

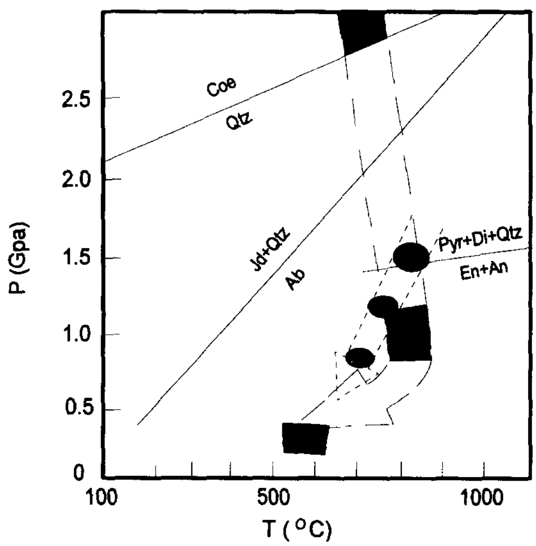

Fig. 1. P-T-t path diagram of UHPM rocks and high-pressure granulites. broken line arrow : UHPM rocks, dashed line arrow : high－pressure granulites.

mantle depth of more than 100 km. Their UHPM and retrograde mineral assemblages imply a clockwise P-T-t path (Cong *et al.*, 1996). Sm-Nd mineral isochron ages for various eclogites in the Sulu region and Dabieshan fall within a range of 204-240 Ma and zircon ages within 228±2 Ma (Li *et al.*, 1997a), suggesting the peak metamorphism of eclogites in the Sulu region and Dabieshan occurred during the Middle-late Triassic. The exhumation process, estimated from P-T-t paths (Fig. 1), shows a multiple exhumation stages, with a high exhumation rate (3.3-3.6 mm/a) in the Middle-late Triassic, a lower rate (0.7-1.1 mm/a) in the Early Jurassic and a very low rate (0.15 mm/a) in the Middle Jurassic to Early Cretaceous (Wang and Cong, 1996).

Secondly, the basic metamorphic rocks commonly occur in Laixi and Qixia west to the Kunyushan granitoid zone. Bai *et al.* (1993) suggested that these basic metamorphic rocks are eclogites since the basic rocks commonly have metamorphic reaction textures and contain garnets and pyroxenes. Our detailed study shows that these rocks are high-pressure granulites rather than eclogites (Zhai, 1997). Omphacite and other typical high-pressure minerals of eclogite facies have never been found in these rocks. All clinopyroxenes, occuring as matrix phase and inclusion mineral in garnet, are disposide-augite containing only 2-6 mol% jadeite component. Three metamorphic mineral assemblages representing three main metamorphic episodes have been identified. Initial assemblage of clinopyroxene+plagioclase+garnet is only preserved in garnet. Garnets commonly have a symplectitic corona texture, which formed by graphic intergrowths of orthopyroxene+clinopyroxene+plagioclase± brown hornblende. Matrix clinopyroxenes were sometimes broken down and became fine-grained intergrowths of orthopyroxene+clinopyroxene±plagioclase. Orthopyroxene+clinopyroxene+plagioclase±hornblende is the second mineral assemblage. Mineral compositions were obtained using CAMEBAX SX51 electron microprobe at the Institute of Geology, Academia Sinica. The result is shown in Table 1. The metamorphic temperature and pressure of the second mineral assemblage are 770-820℃ and 1.0-1.1 GPa, respectively. The third mineral assemblage is hornblende+plagioclase, which partially or wholly replace pyroxenes. The three mineral assemblages indicate that the basic granulites have a decompressional P-T-t path (Fig. 1). The mineral Sm-Nd isochron is 1750 Ma (Fig. 2), and Nd isotopic model age of whole rock is 2788 Ma (Table 2), representing their retrograde metamorphic age and petrogenetic age, respectively (Li *et al.*, 1997b). Note that these data are consistent with those of high-pressure basic granulites in northwestern Hebei, of the North China craton (Guo *et al.*, 1996). The age of 1800 Ma represents the most important metamorphic episode in the North China craton. According to characteristics of petrology and geochronology, the basic metamorphic rocks west to the Kunyushan granitoid zone should belong to the early Precambrian rock association of the North China craton. Although basic granulites west to the Kunyushan granitoid zone and eclogites east to the Kunyushan granitoid zone exhibit a clockwise P-T-t path, their metamorphic conditions a very different and show different metamorphic history.

Thirdly, the Shandong peninsula is occupied predominantly by quartz-feldspathic orthogneisses. Eclogites, granulites and other metamorphic supracrustal rocks occur as lenses and slabs in orthogneisses. All gneisses have been traditionally believed to belong to the same Archaean association, the Jiaodong gneisses or Jiaonan gneisses. Our study (Enami *et al.*, 1993; Ishizaka *et al.*, 1994; Zhai and Cong, 1996) revealed that the orthogneisses on both sides of the Kunyushan granitoid zone have significant differences. In order to distinguish the two gneisses, Zhai and Cong (1996) called orthogneisses west to the Kunyushan granitoid zone the Laiyan gneisses and those east to the Kunyushan granitoid zone the Jiaodongnan

Table 1. Representative analyses for minerals in basic granulites

	96 ml01		96 ml06					96 ml08		
	Cpx	Opx	Gt (core)	Gt (rim)	Cpx (in Gt)	Cpx (in reaction rim)	Cpx (big)	1-Gt	1-Cpx	2-Cpx (host)
SiO_2	51.284	50.163	37.931	37.609	49.264	50.796	50.022	37.341	49.824	50.149
TiO_2	0.081	0.058	0.065	0.089	0.386	0.3270	0.296		0.218	0.08
Al_2O_3	0.903	0.694	21.610	20.971	5.305	2.123	3.002	20.850	1.469	1.060
Cr_2O_3		0.083	0.056	0.030	0.027	0.032	0.050		0.040	0.072
Fe_2O_3	0.870	1.087	0.647	0.838	2.557	2.103	2.106	0.722	1.916	3.052
MgO	10.712	14.525	5.221	4.393	11.163	12.132	11.817	2.812	9.207	10.169
CaO	21.770	0.592	10.768	8.272	21.340	22.435	21.087	8.288	20.977	21.737
MnO	0.289	0.712	0.517	1.026	0.041	0.125	0.183	2.328	0.516	0.482
FeO	12.841	32.659	24.422	26.593	8.975	8.693	10.023	27.416	14.471	12.311
NiO		0.009	0.025	0.144			0.002		0.121	0.005
Na_2O	0.276	0.000		0.012	0.639	0.385	0.378		0.285	0.272
K_2O		0.000			0.013	0.021	0.013	0.008	0.020	
P_2O_5			0.019	0.051				0.032		
H_2O										
Total	99.026	100.580	101.282	100.027	99.712	99.173	98.979	99.797	99.063	99.386
O	6	6	12	12	6	6	6	12	6	6
Si	1.975	1.965	5.866	5.932	1.858	1.927	1.907	5.959	1.942	1.938
Ti	0.002	0.002	0.008	0.011	0.011	0.009	0.009		0.006	0.002
Al	0.041	0.032	3.939	3.898	0.236	0.095	0.135	3.921	0.068	0.048
Cr		0.003	0.007	0.004	0.001	0.001	0.002		0.001	0.002
Fe^{3+}	0.025	0.032	0.075	0.100	0.073	0.060	0.060	0.087	0.056	0.089
Mg	0.615	0.848	1.203	1.033	0.628	0.686	0.672	0.669	0.535	0.586
Ca	0.898	0.025	1.784	1.398	0.862	0.912	0.862	1.417	0.876	0.900
Mn	0.009	0.024	0.068	0.137	0.001	0.004	0.006	0.315	0.017	0.016
Fe^{2+}	0.414	1.070	3.158	3.508	0.283	0.276	0.320	3.659	0.472	0.398
Ni		0.001	0.003	0.018			0.000		0.004	0.000
Na	0.021			0.004	0.047	0.028	0.028		0.022	0.020
K					0.001	0.001	0.001	0.002	0.001	
P			0.003	0.007				0.004		
Total	4	4	16.113	16.048	4	4	4	16.032	4	4

	96 ml08		96 ml09		96 ml12				96 ml14	
	2-Opx (son)	2-Opx (small crystal)	Gt	Cpx	Gt (core)	Cpx (in gt)	1-Gt (rim)	Cpx (host)	Gt (host)	Cpx
SiO_2	49.056	49.675	37.228	49.644	37.945	49.082	36.969	50.555	37.478	49.665
TiO_2	0.069	0.103	0.101	0.251	0.099	0.100	0.065	0.058	0.063	0.258
Al_2O_3	0.609	0.650	20.309	1.659	21.188	4.741	20.584	1.574	21.055	3.060
Cr_2O_3	0.066	0.016			0.087	0.032	0.030	0.032	0.030	0.027
Fe_2O_3	0.355	0.955	1.135	2.389	0.426	2.464	0.753	2.349	0.600	2.618
MgO	12.149	13.323	2.174	8.540	3.649	10.362	3.414	11.158	4.029	11.575
CaO	0.617	0.618	8.259	21.106	12.562	22.540	7.319	21.222	8.556	21.639
MnO	1.118	1.029	1.352	0.369	1.243	0.130	2.862	0.499	1.644	0.213

Table 1. Continued.

	96 ml08		96 ml09		96 ml12				96 ml14	
	2-Opx (son)	2-Opx (small crystal)	Gt	Cpx	Gt (core)	Cpx (in gt)	1-Gt (rim)	Cpx (host)	Gt (host)	Cpx
FeO	34.997	33.805	28.946	15.503	21.988	9.333	26.696	11.158	26.171	9.615
NiO		0.005			0.021	0.007	0.061		0.097	
Na_2O	0.032	0.002		0.313	0.001	0.418		0.381		0.305
K_2O						0.009				0.007
P_2O_5					0.002				0.0017	
H_2O										
Total	99.067	100.201	99.524	99.774	99.211	99.217	98.751	98.985	99.724	98.981
0	6	6	12	6	12	6	12	6	12	6
Si	1.978	1.968	5.986	1.931	5.974	1.871	5.953	1.942	5.936	1.897
Ti	0.002	0.003	0.012	0.007	0.012	0.003	0.008	0.002	0.008	0.007
Al	0.029	0.030	3.852	0.076	3.932	0.213	3.907	0.071	3.931	0.048
Cr	0.002	0.001			0.011	0.001	0.004	0.001	0.004	0.138
Fe^{3+}	0.011	0.029	0.137	0.070	0.050	0.071	0.091	0.068	0.072	0.001
Mg	0.730	0.787	0.521	0.495	0.856	0.589	0.819	0.639	0.951	0.075
Ca	0.027	0.026	1.423	0.880	2.119	0.920	1.263	0.874	1.452	0.659
Mn	0.038	0.035	0.184	0.012	0.166	0.004	0.390	0.016	0.221	0.886
Fe^{2+}	0.180	1.120	3.892	0.504	2.895	0.297	3.592	0.359	3.467	0.007
Ni		0.000			0.003	0.000	0.008		0.012	0.307
Na	0.003	0.002		0.024	0.000	0.031		0.028		
K						0.000				0.023
P					0.000				0.000	0.000
Total	4	4	16.007	4	16.0178	4	16.0381	4	16.0529	4

	96 ml21		96 ml24			96 qx17		96 wd19	
	Gt	Cpx	Gt	Cpxl	Cpx (reaction rim)	Gt	Cpx	Gt	Cpx
SiO_2	37.859	47.728	37.841	50.833	49.719	37.798	51.816	37.512	51.646
TiO_2		0.174		0.295	0.481	0.142	0.195	0.034	0.057
Al_2O_3	20.670	6.435	20.949	1.775	2.505	21.009	0.918	21.075	1.085
Cr_2O_3		0.046	0.174	0.059	0.032		0.005	0.009	0.037
Fe_2O_3	1.641	2.817	0.635	1.126	1.312	0.630	0.509	0.670	1.150
MgO	1.252	9.193	1.984	10.828	10.047	3.485	11.806	4.820	12.210
CaO	23.636	23.455	13.880	23.208	22.690	11.077	22.216	6.741	22.020
MnO	3.522	0.725	2.831	0.335	0.360	0.894	0.328	0.766	0.125
FeO	10.470	8.288	21.281	10.991	11.662	24.648	10.971	27.172	10.519
NiO					0.006	0.063	0.030		
Na_2O		0.382	0.011	0.148	0.181	0.021	0.266		0.257
K_2O					0.013		0.022		
P_2O_5			0.039			0.024			
K_2O									
Total	99.050	99.244	99.625	99.597	99.006	99.879	99.080	99.798	99.104
0	12	6	12	6	6	12	6	12	6

Table 1. Continued.

	Gt	Cpx	Gt	Cpxl	Cpx (reaction rim)	Gt	Cpx	Gt	Cpx
Si	5.937	1.823	5.985	1.940	1.917	5.953	1.977	5.934	1.967
Ti		0.005		0.009	0.014	0.017	0.006	0.004	0.002
Al	3.820	0.290	3.905	0.080	0.114	3.917	0.041	3.929	0.049
Cr		0.001	0.022	0.002	0.001		0.000	0.001	0.001
Fe^{3+}	0.194	0.081	0.076	0.032	0.038	0.075	0.015	0.080	0.033
Mg	0.293	0.523	0.468	0.616	0.577	0.818	0.671	1.137	0.693
Ca	3.971	0.960	2.352	0.949	0.937	1.869	0.908	1.143	0.898
Mn	0.468	0.024	0.379	0.011	0.012	0.119	0.011	0.103	0.004
Fe^{2+}	1.373	0.265	2.815	0.351	0.376	3.247	0.350	3.727	0.335
Ni					0.000	0.008	0.001		
Na		0.028	0.003	0.011	0.014	0.007	0.020		0.019
K					0.001		0.001		
P			0.005			0.003			
Total	16.056	4	16.008	4	4	16.0326	4	16.057	4

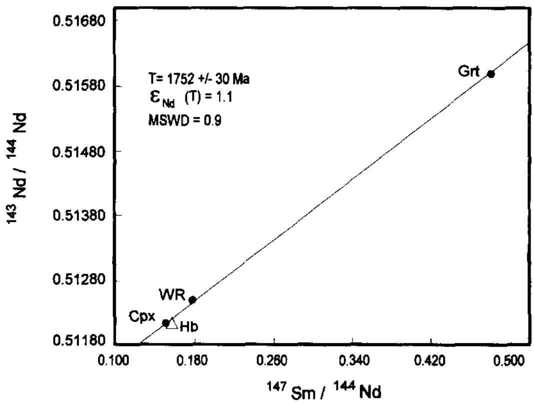

Fig. 2. Sm-Nd isochron of basic high-pressure granulite from Laixi

gneisses. Their main differences are as follows: (1) The Laiyan gneisses are high in Na, belonging to a tonalitic-trondhjemitic-granodioritic (TTG) grey gneiss series. They have high Na/K ratios and Al_2O_3 ranging from 12 to 16%. They show an enrichment in incompatible elements of large-ion lithophile(LIL) elements, depletion of high-field-strength(HFS) elements and obvious Nb negative anomalies. On the contrary, the Jiaodongnan gneisses belong to a calc-alkaline granitic series, with only a minor amount of gneisses having trondhjemitic characteristics; (2) The two gneisses have different isotopic ages (Fig. 3). Rb-Sr and chemical Th-U-total Pb isochron methods (CHIME) were applied to determine the age of gneiss samples that were collected from both sides of the Kunyushan granitoid zone. The two gneiss terrains are clearly distinguished. The Laiyan gneisses yield a middle Proterozoic whole rock Rb-Sr isochron age (1808±71 Ma) and middle

Table 2. Sm-Nd isotopic data of the high-pressure basic granulite

Sample No.	Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T(CHUR) (Ma)
ML06-1	Garnet	1.30	1.63	0.4807	0.515962÷24	1778
ML06-2	Clinopyroxene	3.89	15.6	0.1505	0.512142÷7	1640
ML06-3	Amphibole	2.36	9.12	0.1562	0.512090÷13	2064
ML06-4	whole rock	2.46	8.37	0.1776	0.512489÷10	1206

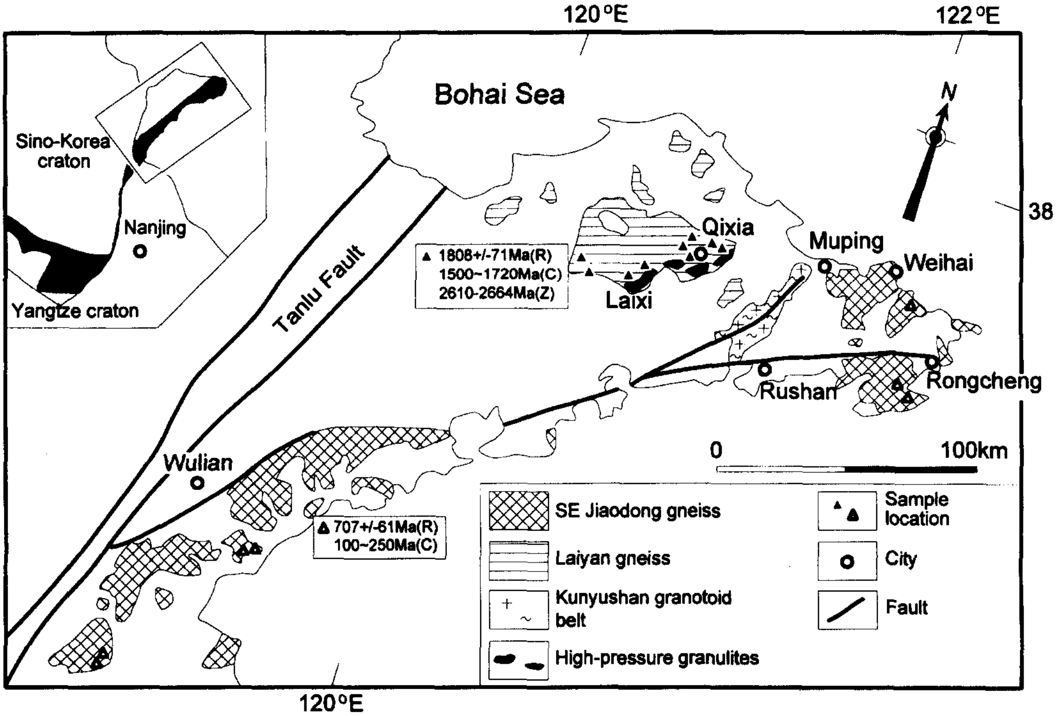

Fig. 3. A compilation map of radiometric data for the Laiyan gneisses and Jiaodongnan gneisses (after Enami, *et al.*, 1993; Ishizaka, *et al.*, 1994; Li, *et al.*, 1997). (R) Rb-Sr isochron age; (C) CHIME age; (Z) Zircon age

to late Proterozoic biotite ages (1312 and 729 Ma). Their CHIME ages are 1500-1720 Ma. These ages represent the important metamorphic events in the Sino-Korea craton. The zircon ages of the Laiyan gneisses from Qixia area are 2610-2664 Ma and 1858 Ma. However, the Jiaodongnan gneisses are composed of younger orthogneisses. Their Rb-Sr whole rock isochron age is 707±61 Ma and biotite ages are 172-222 Ma. Their CHIME ages are 100-250 Ma. These data are similar to those of eclogites in the Sulu zone (Li *et al.*, 1997), showing that the gneisses formed in middle-late Proterozoic and were metamorphosed in Mesozoic; (3) The Laiyan gneisses and granulite lenses have Nd, Sr and Pb isotopic characteristics of the North China craton. On the other hand, the Jiaodongnan gneisses and eclogite lenses have Nd, Sr and Pb isotopic characteristics closely related to Yangtze craton (Zhang *et al.*, 1995; Lu *et al.*, 1995; Li *et al.*, 1994). Therefore, they belong to the North China geochemical province and Yangtze geochemical province, respectively.

Lastly, the Kunyushan granitoid zone consists of numerous granitic bodies, stocks and veins. Its isotopic ages are classified into three ranges, which are 1900-2000 Ma, 619-710 Ma and 124-180 Ma. These ages are interpreted respectively as residual age of source material, formation age of the granite and remelting age of the granite (Yu, 1989; Xu *et al.*, 1997). There are many lenses and enclosures of metamorphic rocks in the granitoid zone. Our detailed study reveals that lenses and enclosures are from the Sino-Korea craton (Precambrian basement) and Sulu UHPM belt. In some places, different metamorphic lens and granitic gneiss contact each other by a ductile shear zone. Zhai *et al.* (1998) defined the Kunyushan granitoid zone as a Boundary complex zone.

In summary, we suggest based on the above evidences that the possible boundary is the

Kunyushan granitoid complex zone, occurring along the Wulian-Muping fault.

Discussion

Another important question is the eastward extension of the Sulu UHPM to the Korean peninsula, which has been discussed in some publications. We visited both North Korea and South Korea in 1997 in order to compare geology in the Korean peninsula and Shandong peninsula. Our evidence is still too poor to answer this question, but we review some data on the Korea geology and discuss problems below.

1) The Korean peninsula consists of several amalgamated continental blocks, which are Pyongnam-Nangrim, Kyonggi and Ryongnam blocks from north to south, divided by two orogenic belts: the Imjingang belt and the Ogcheon belt. The ages of these three blocks are known to be Archaean to Proterozoic (Kim *et al.*, 1997). Some geologists suggested that the boundary between the Sino-Korea and Yangtze cratons extends eastward to the Korean peninsula (Hsü *et al.*, 1990; Yin and Nie, 1993; Liu, 1993; Ernst and Liou, 1995; Chang, 1995; Ree *et al.*, 1996; Cho, M. *et al.*, 1996; Lee *et al.*, 1997). The possible boundaries are the Imjingang belt and/or Ogcheon belt. Two main opinions are as follows: (1) The northern edge of the Yangtze craton was rectangular. It moved eastward as a wedge form and collided to the smooth southern edge of the Korean peninsula, the two boundaries becoming the Imjingang belt and Ogcheon belt (Indentation model). As a result, the middle part (the Kyonggi block) belongs to the Yangtze craton, the northern and southern parts (the Pyongnam-Nangrim and Ryongnam blocks) belong to the Sino-Korea craton (Cluzel *et al.*, 1991; Yin and Nie, 1993). Some other supporting evidences of stratigraphy, structural geology and palaeomagnetic data have been reported (Kim *et al.*, 1997); (2) The Dabieshan-Sulu suture extends to the Imjingang belt between northern and southern Korea. This collisional belt extends farther eastward to become an active continental margin along the southern margin of late Paleozoic Hida belt in Japan, whereas the Ogcheon belt is related to the south China aulacogen of early Paleozoic (Chang, 1994).

2) There are some evidences against the Imjingang belt and/or Ogcheon belt as the collisional belt. (1) The Precambrian basement rocks in the Pyongnam-Nangrim (for example in Nampho) and the Kyonggi blocks seem to be equivalent (Choe, 1996; Na, 1988). The rapakivi-gabbro plutons with 1800-1900 Ma age in the Pyongnam-Nangrim block are equivalent to Proterozoic rapakivi-gabbro-anorthosite plutons in Chengde (Damiao)-Beijing in the Sino-Korea craton. The metamorphic rock association in southern part of the Pyongnam-Nangrim block and northern part of the Kyonggi block is similar to the Fenzishan Group in the Shandong peninsula, which are mainly composed of a series of metamorphosed Al-rich sediments of amphibolite facies or partially granulite facies with migmatization, occurring as a typical biotite-sillimanite-garnet gneiss and biotite-garnet-cordierite-K-feldspar gneiss. Their isotopic ages are about 1700-2200 Ma and 2400-2600 Ma (Choe, 1996). (2) The Paleozoic strata are mainly distributed in the Pyongnam basin north to the Imjingang belt and the Taebaegsan basin of the Ogcheon belt. The Cambrian-Ordovician strata (Hwangju System and Carboniferous-Triassic System) are equivalent in the Pyongnam basin and Taebaegsan basin (Yong *et al.*, 1996). The Cambrian-Ordovician strata are overlain by the Carboniferous-Triassic strata with an unconformity. According to paleontological and stratigraphical studies, these sedimentary successions and characteristics show no difference from the Paleozoic strata in northern China (Qian, 1997, personal communication; Choe, 1997; Woo *et al.*, 1997). (3) The medium and low-pressure metamorphic rocks of the Ogcheon belt have experienced a polycylic P-T evolution characterized by crustal thickening during the Middle Paleozoic time and regional

retrograde metamorphism in the Triassic, suggesting that the UHPM collisional zone in east-central China does not pass through the Ogcheon belt (Min and Cho, 1998).

3) With regard to this argument, the key point is that there has not been a conclusive evidence of UHPM rocks in the Korean peninsula. However, Ree *et al.* (1996) reported high-pressure garnet amphibolite (Yeoncheon) in western Imjingang belt. Its metamorphic condition was estimated as 8-11 kbar and 630-740℃. Cho, M. *et al.* (1996) and Lee *et al.* (1997) reported the Hwacheon granulite complex, which include high-pressure pelitic and mafic granulites. Relict kyanite commonly occurs in sillimanite and coexists with staurolite or K-feldspar, indicating that high-pressure assemblage is significantly replaced by sillimanite-bearing lower pressure assemblage. Although there is no evidence for the eclogite facies metamorphism, all of these results suggest that the high-pressure granulite-amphibolite facies metamorphism corresponding to the collisional event between the Sino-Korea and Yangtze cratons was prevalent not only in the Imjingang belt but also in the northern Kyonggi massif.

4) The above-mentioned data provide some clues for deciphering tectonic evolution of central Korean peninsula, but a problem arises from these data : If the Imjingang belt is the eastward extension of the Sulu zone and the Hwachon complex is a reactivated Proterozoic crystalline basement (Lee *et al.*, 1997), the Hwachon complex that is located in the northern margin of the Kyonggi massif should belong to the Yangtze craton. However, the Hwachon granulite complex is similar to the granulite complex in the Sino-Korea craton on its rock association, metamorphism and metamorphic history. First, high-pressure mafic granulites (including garnet amphibolites) and pelitic granulites are extensively distributed in the eastern part of the Sino-Korea craton (Shandong peninsula), for example, Mincun in Anqiu Country, Yukeding and Malianzhuang in Laixi Country, Shengmushu in Qixia Country (Qian, 1996; Li *et al.*, 1997). Almost all high-pressure granulite facies rocks in the Sino-Korea have a clockwise P-T path from high pressure to middle-lower pressure. Their metamorphic mineral reactions are nearly the same as those described by Ree *et al.* (1996), Cho, M. *et al.* (1996) and Lee *et al.* (1997). For example, kyanite is replaced by sillimanite in pelitic granulite. Moreover, the Sm-Nd mineral-whole rock isochron ages of the high-pressure granulites in the Sino-Korea craton range from about 1750-1900 Ma, which represent the most important metamorphic episode of the Sino-Korea peninsula (Zhang *et al.*, 1995; Zhai, 1997). The high-pressure granulite in the Hwachon complex also has 1742-1897 Ma Sm-Nd isochron ages (Lee *et al.*, 1997). These results seem to support that the Hwachon complex belongs to the Sino-Korean craton rather than the Yangtze craton, because the metamorphic rocks in the Yangtze craton do not have above geochronological and petrological characteristics. If the Hwachon complex is not equivalent to the Yangtze craton, it is difficult to define that the Imjingang belt is the extending part of the Sulu zone.

5) However, another evidence seems to support the opposite opinion. A batch of Permo-Triassic isotopic data were yielded from samples in central Korean peninsula, including the CHIME monazite age of 245±3 Ma from the sillimanice-garnet gneiss (Cho, D.L. *et al.*, 1996) and $^{40}Ar/^{39}Ar$ age of hornblende (226±8 Ma) from the garnet amphibolite (Lee *et al.*, 1997) in the Hwacheon complex and a mineral-whole rock Sm-Nd isochron of 249±31 Ma from garnet amphibolite in the Yeoncheon complex (Ree *et al.*, 1996). These results indicate that the Permo-Triassic regional metamorphic event in the Kyonggi massif and Imjingang belt is significant. In other words, the collisional event between the Sino-Korea and Yangtze cratons is possibly related to the geotectonic evolution of the central Korean peninsula and Imjingang belt.

Above informations, though some of which are contradictory, prompt us to put more attention to metamorphism and metamorphic history of the Imjingang belt and to comparative study of the basement metamorphic rocks on both sides of the Imjingang belt.

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중·한 및 양쯔 육괴 경계와 한반도로의 연장가능성

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요 약: 다비-술루 초고압 변성대(UHPM)는 중·한육괴와 양쯔육괴의 충돌경계부로 알려져 있으나 (Zhai and Cong, 1996) 북동 아시아의 조구조 진화에서 2가지 문제점이 제기되었다; (1) 산동반도에서 UHPM와 중·한육괴의 경계부 (2) 중국에서 UHPM가 한반도로의 연장가능성. UHPM와 중·한육괴의 경계에 대해 많은 이견이 있으며 경계부로 탄루(Tanru) 단층(Bai *et al.*, 1993; Wang and Cong, 1996) 또는 우리안·룽칭 단층(Cao *et al.*, 1990)이 제안된 바 있다. 저자들의 최근 연구의 새로운 증거에 의하면 가능한 경계부는 울리안 머핑 단층대를 따라서 분포하는 군류산 화강암질암 복합체일 수 있다. 새로운 증거란 (1) 군유산 화강암질암 복합체 서부의 염기성암류는 에클로자이트라기보다 고압 그래뉼라이트에 해당하며 (Zhai, 1996) Sm-Nd 동위원소 연령에서 후퇴변성작용 시기는 1750 Ma이며 암석연령은 2600~2900 Ma, Rb-Sr, U-Th-Pb 연령은 1600~2020 Ma이며 이보다 더 신기의 암석은 발견되지 않으며(Enami *et al.*, 1993; Ishizaka *et al.*, 1994) 중·한 육괴의 선캠브리아기 초기 암석 특징과 일치한다. (3) 군유산 화강암질암대 동쪽의 정편마암의 연령은 110~320 Ma이며 그 중 180~230 Ma 의 분포가 가장 많아서 UHPM의 특징을 이룬다. (4) 군유산 화강암질암대는 동위원소연령으로 1900~2000 Ma의 많은 화강암체, 610~710 Ma의 암주, 124~180 Ma의 맥등으로 구성되며 복잡하고 오랜 화강암질암대의 진화과정을 보인다. 군유산 화강암질암대에는 중·한육괴와 술루 UHPM 대에서 유래된 많은 변성암류의 렌즈와 포유물이 분포한다. Zhai외 (1998)는 군유산 화강암질암대를 지아오동 경계대로 정의 하였다. 일부는 UHPM 대가 동쪽으로 한반도까지 연상됨을 제안하였고(Yin and Nic, 1993; Wang and Cong, 1996), 임진강대가 제안된 바 있으나 (Chang, 1994; Ree *et al.*, 1996) 한반도에서 UHPM 암석의 결정적인 증거는 없다. 이런점에서 산동반도의 변성암을 한반도 북부와 남부의 변성암과 비교하는 것이 보다 중요하다 하겠다.

주요어: 초고압 변성대, 중·한육괴, 양쯔육괴, 충돌경계부, 군유산 화강암질암대